force | Fundy Ocean Research Centre for Energy

Environmental Effects Monitoring Program

Quarterly Report: January-March 2021

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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, the Offshore Energy Research Association of Nova Scotia (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 turbine deployments at FORCE's tidal demonstration site. These efforts are divided into two components: mid-field monitoring activities led by FORCE (>100 metres from a turbine), and near-field or 'turbine-specific' monitoring led by project developers (≤100 metres from a turbine) 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.

Mid-field monitoring at the FORCE site 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

In this first quarter of 2021, Sea Mammal Research Unit (SMRU) Consulting Ltd. provided their 4th year final report of harbour porpoise monitoring at the FORCE test site using C-PODs. The report describes the results of C-POD deployments #11-12 (August 2019 – September 2020), and places the results in the broader context of the overall marine mammal monitoring program implemented as part of FORCE's multiyear Environmental Effects Monitoring Program (EEMP). This ongoing monitoring program continues to show the prevalence of harbour porpoise at FORCE, with the species being detected on approximately 99% of the 1,888 calendar days since monitoring with C-PODs commenced in 2011. Harbour porpoise detections at FORCE vary 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, averages 22.6%. The report by SMRU is included here as Appendix I, and supports the findings of previous monitoring activities that harbour porpoise are prevalent at the FORCE test site. The report also reiterates that a sufficient amount of baseline data has been collected to meet the goals of the EEMP, and that future C-POD deployments could be suspended until an operational turbine is deployed at the FORCE site.

FORCE recently submitted its 2021-2023 proposed EEMP to regulators for review. The 2021-2023 EEMP is designed to prepare for effects testing with the deployment of operational turbines, 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 is working collaboratively with the OERA to advance 'The Pathway Program' to identify effective and regulator approved monitoring solutions for the tidal energy industry in Nova Scotia. Phase I of the program consisted of a 'Global Capability Assessment' that involved comprehensive literature reviews about the use of different classes of environmental monitoring technologies for monitoring tidal energy devices around the world. While this element of Phase I was completed in 2019, ongoing international engagement and knowledge exchange was fostered through a series of workshops that generated international collaborations that have assisted with other phases of the program. Phase II, 'Advancing Data Processing and Analysis', is nearly completed. Work to automate the post-processing of hydroacoustic data with DeepSense (Dalhousie University) generated a new processing tool called 'Echofilter'. Work is currently underway to develop a hydroacoustic data analysis pipeline that will generate quarterly reports to provide information on three metrics of interest to regulators: i) frequency of target detections, ii) abundance of targets detected, and iii) vertical distribution of targets in the water column. Automation of PAM data has also been completed with partners at Oregon State University that generated a harbour porpoise click detector and classification tool for application to Minas Passage called 'FindPorpoises'. The Pathway Program team is currently exploring opportunities to automate the detection, tracking and classification of targets from multibeam imaging sonars with partners in Nova Scotia, Washington state and the United Kingdom. Phase III, 'Technology Validation', is nearing completion. FORCE recently completed collaborative work with Sustainable Marine Energy Canada (SME) to assess the efficacy of upward and downward facing echosounders for monitoring fish and surface-deployed and bottom-mounted PAM instruments for monitoring harbour porpoise. The reports from that work are currently undergoing external peer-review and will be made available in the Q2 report. Sustainable Oceans Applied Research (SOAR) recently completed a performance assessment for imaging sonars (Blueview and Gemini) in both surface and bottom-mounted deployments using a series of known targets. While entrained air from turbulence made tracking targets difficult in surface deployments, both sonars were useful for target detection, although the Gemini performed better for average target detection and target tracking at greater distances (10-50 m) (Appendix II). While insufficient data was collected by the Blueview imaging sonar during the bottom-mounted tests (due to its relatively small ensonified area), the Gemini performed well for target detection, identification and tracking. Importantly, there was not significant relationship between flow speed and the ability of the Gemini to tack targets during bottom-mounted deployments. DP Energy completed a 'wet test' of their integrated monitoring platform in Halifax Harbour during fall 2020 and is preparing for deployment at the FORCE test site in spring 2021.

FORCE is also working with academic and First Nations partners 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 turbines. 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 has started planning the fish tagging component of the program required for encounter rate model validation. Ultimately, this will contribute towards understanding the risk of instream tidal power 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 first quarter of 2021. 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. Due to the ongoing risk of COVID-19 transmission, marine operations are being conducted following guidelines with respect to social distancing and the use of face masks that were developed in consultation with information provided by NS public health. This includes work in support of the 2021 EEMP and the RAP program.

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

Contents

Appendices

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
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

TISEC	Tidal In-Stream Energy Converter
SUBS	Streamlined Underwater Buoyancy System
SME	Sustainable Marine Energy (Canada)
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
VEC(s)	Valuable Ecosystem Component(s)

Introduction

This report outlines monitoring activities occurring at the Fundy Ocean Research Center for Energy test site in the Minas Passage, Bay of Fundy during January-March 2021. Specifically, this report highlights results of environmental monitoring activities conducted in the mid-field zone 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 turbine generators, four subsea power cables to connect the turbines 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 Crown Lease 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 Energy and Mines. 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.

[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. Learn more: sustainablemarine.com/news/schottel

[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, 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 turbines 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, 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 'near-field' (≤ 100 m from a turbine) and 'mid-field' or 'site-level' (> 100 m from a turbine) monitoring. As approved by regulators, individual berth holders are responsible for leading near-field monitoring in direct vicinity of their turbine(s), in recognition of the unique design and operational requirements of different turbine technologies. FORCE completes 'mid-field' monitoring activities as well as supporting integration of data analysis between these monitoring zones, where applicable.

All near-field and mid-field 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 turbine installation. In addition, FORCE and berth holders also submit an Environmental Management Plan (EMP) to regulators for review prior to turbine 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.

Turbine Deployments

Since FORCE's establishment in 2009, turbines have been installed at the FORCE site three times: once in 2009/2010, November 2016 – June 2017, and July 2018 – present. Given the limited timescales in which a tidal turbine has been present and operating at the FORCE site,

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

[6] OERA's Tidal Energy Research Portal (http://tidalportal.oera.ca/) 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

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 with the exception of 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 on a monthly basis 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 near-field 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 turbines 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. 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.[10] The project consists of submerged turbines for a total of nine megawatts – enough capacity to provide electricity to an estimated 2,500 homes.

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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 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.

Each berth holder project will be required to develop a turbine-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 turbine 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.

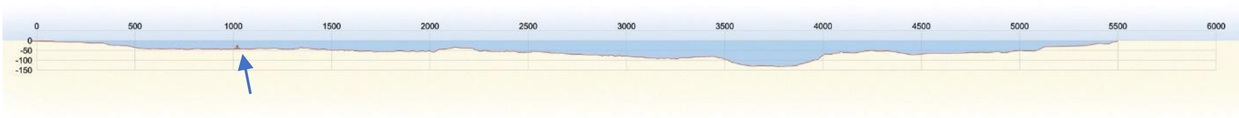

Figure 1: The scale of a single turbine (based on the dimensions of the OpenHydro turbine deployed by CSTV, indicated by the red dot and above the blue arrow) in relation to the cross-sectional area of the Minas Passage. The Passage reaches a width of ~ 5.4 km and a depth of 130 m.

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), 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[11],

[11] 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.

the Bay of Fundy Ecosystem Partnership[12], TC114[13], the Atlantic Canadian-based Ocean Supercluster[14], and OES-Environmental[15].

On February 25th, Dr. Daniel Hasselman, FORCE's science director, participated in a virtual workshop hosted by 'International Waters' – a group whose aim is to foster international collaborations among MRE test centers. Following updates from each test center, Dr. Hasselman co-moderated a session on 'Environmental Monitoring and Consenting' that centered around environmental monitoring instrumentation, data collection practices and challenges. Discussions focused on i) identifying opportunities for collaboration where MRE development is a concern for marine animals that are common to multiple test centers, ii) identifying novel monitoring technologies that may be better suited for monitoring in dynamic marine environments, and iii) identifying opportunities for combining physical oceanographic and biological data to provide a more holistic approach for understanding the risk of MRE devices to marine animals. Participants agreed that there are some marine animals (e.g., harbour porpoise) that are common to multiple test centers and of similar concern to regulators where collaborations towards developing standardized approaches to data collection, analyses and reporting are warranted. However, the transferability of monitoring results between test centers remains an issue, and participants identified the need to build trust with regulators through transparency in methodologies and interpretation of results. Recent technological advances (i.e., Passive Acoustic Monitoring array, acoustic tracking), ongoing development of standards for acquisition of monitoring data (International Electrotechnical Commission 2019), and advances in data processing and analyses for imaging sonars and echosounders were identified by participants as important advancements. Participants were intrigued by the notion of combining physical oceanographic and biological data for informing risk, and were particularly interested in the influence of hydrodynamics on the spatial distributions of marine animals.

Dr. Hasselman also participated in two collision risk workshops (fish – March 16; marine mammals – March 18) jointly hosted by OES-Environmental and ORJIP. The purpose of the workshops was to review the elements of collision risk models, including a discussion about how collision risk models have been used to date, and progress being made in the application of collision risk models for understanding the potential impacts of MRE devices on marine animals.

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 has agreed to serve 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 has advertised the special issue on Tethys and is requesting abstracts (deadline: May 26) and full manuscripts (deadline: November 26) from researchers developing cutting-edge

[12] BoFEP is a 'virtual institute' interested in the well-being of the Bay of Fundy. To learn more, see www.bofep.org.
[13] 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.
[14] 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.
[15] 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.

technologies for monitoring around marine renewable energy devices in 2021, and are aiming for publication of the special issue in 2022.

Mid-Field Monitoring Activities

FORCE has been leading 'mid-field area' or 'site-level' monitoring for a number of 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)[16] 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 results of previous monitoring activities, experience and lessons learned. This is consistent with the adaptive management approach inherent to 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.[17]

FORCE's EEMP currently focuses on the impacts of operational turbines on lobster, fish, marine mammals, and seabirds as well as the impact of turbine-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.

The following pages provide a summary of the mid-field monitoring activities conducted at the FORCE site up to the end of March 2021, including data collection, data analyses performed, initial results, and lessons learned; building on activities and analyses from previous years. Where applicable, this report also presents analyses that have integrated data collected through the near-field and mid-field monitoring programs to provide a more complete understanding of turbine-marine life interactions.

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

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

[17] 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.

area, and an assessment of the risks the tidal energy demonstration project poses to components of the ecosystem.

A comprehensive understanding of turbine-marine life interactions will not be possible until turbine-specific and site-level monitoring efforts are integrated, and additional data is collected in relation to operating turbines. 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 marine life-turbine interactions.

Table 1 outlines the objectives of the mid-field monitoring activities conducted at the FORCE demonstration site. Near-field monitoring summaries will be updated as turbines are scheduled for deployment at FORCE. At this time, and considering the scale of turbine 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 'mid-field' environmental effects monitoring activity, which consider various Valued Ecosystem Components (VECs), led by FORCE.

Mid-Field Environmental Effects Monitoring VEC	***Objectives***
Lobster	• to determine if the presence of a tidal stream energy turbine affects commercial lobster catches
Fish	• to test for indirect effects of tidal stream energy turbines 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 turbine depth in the water column
Marine Mammals	• to determine if there is permanent avoidance of the mid-field study area during turbine operations • to determine if there is a change in the distribution of a portion of the population across the mid-field study area
Marine Sound (Acoustics)	• to conduct ambient sound measurements to characterize the soundscape prior to and following deployment of the in-stream turbines
Seabirds	• to understand the occurrence and movement of bird species in the vicinity of tidal stream energy turbines • to confirm FORCE's Environmental Assessment predictions relating to the avoidance and/or attraction of birds to tidal stream energy turbines

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).[18] 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 turbine 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 turbines 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 turbine 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. Given the operational restrictions generated from the COVID-19 pandemic in 2020, this new study design is intended to be implemented in late summer 2021 in partnership with the Fishermen and Scientists Research Society (FSRS).

Fish

FORCE has been conducting mobile fish surveys since May 2016 to test the EA prediction that tidal stream turbines 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 turbines on water column fish density and fish vertical distribution; and

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

- estimate the probability of fish encountering a device based on any ‘co-occurrence’ relative to turbine 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 turbine is installed with data collected while a turbine 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 turbine 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 turbine 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 turbine 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 2021 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.

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.[19] 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'[20] 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 near-field 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 mid-field avoidance with a turbine present and operating. These findings also revealed a decrease in detections during turbine installation activities, consistent with previous findings (Joy et al. 2017), but requiring additional data during an operational turbine 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.

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

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

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 (see Appendix I) 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 turbine is deployed at the FORCE site. As a result of the damage that the SUBs package experience at the FORCE site, the C-PODs were shipped back to the manufacturer in February for refurbishment and were not available for deployment during the first quarter of 2021. They are anticipated to be returned to FORCE in April 2021.

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

Observation Program

FORCE's marine mammal observation program in 2021 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 are shared with SMRU Consulting to support validation efforts of PAM activities.

FORCE has begun using 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. Several FORCE staff including *Science Director* Dr. Daniel Hasselman, *Facility Manager* Sandra Currie, and *Ocean Technologist* Jessica Douglas 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 turbines 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 tidal turbine is improbable, but that behavioural disturbance may occur within 400 m of a turbine 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 turbine 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.

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 turbine 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). 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 turbines 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. For 2021-2023, FORCE plans to collaborate with Dr. Phil Taylor 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.

FORCE recently worked with Atlantis Watershed Consultants Ltd. to develop its 2021-2023 EEMP for the five VECs listed above. As in the past, the 2021-2023 EEMP adheres to the principles of adaptive management, and is designed to prepare for effects testing with the deployment of operational turbines. The plan evaluates existing datasets to ensure appropriate monitoring approaches are being implemented, and adopts internationally accepted standards for monitoring where possible, including feasibility assessments for new monitoring approaches that are planned to be implemented.

Near-field Monitoring Activities

While FORCE completes site-level or ‘mid-field’ monitoring activities at the FORCE site, near-field monitoring is led by individual berth holders. Like the mid-field monitoring programs, the near-field monitoring plans and reports undergo review by FORCE’s EMAC and regulators. In anticipation of a planned deployment at FORCE in late 2021, Sustainable Marine Energy Canada (SMEC) submitted a near-field EEMP plan that underwent internal review by FORCE staff. That plan is currently being modified based on FORCE’s feedback and will be reviewed by EMAC prior to submission to regulators for approval.

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 on a monthly basis that the turbine is not operational by monitoring its status during the peak tidal flow of each month. However, as a result 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 on a monthly basis from March 2019 – May 2020, but was discontinued following an amendment to this requirement. Data is also still being collected from two of the four hydrophones on the CSTV turbine.

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

Other FORCE Research Activities

The Pathway Program

The Pathway Program is a collaborative effort between FORCE and OERA to identify an effective and regulator approved monitoring solution for the tidal energy industry in Nova Scotia. The Pathway Program involves several phases, including i) Global capability Assessment, ii) Advancing Data Processing and Analytics, and iii) Technology Validation.

The first phase of this program, a Global Capability Assessment, involved a comprehensive literature review about the use of different classes of environmental monitoring technologies (i.e., PAM, imaging sonars, echosounders) for monitoring tidal energy devices around the world. Subject matter experts were commissioned to provide reports on these instrument classes, and these reports are publicly available.[21]

Phase II of the program ('Advancing data processing and analytics') involved the development of automation tools for expediting post-processing and reporting of monitoring data. To that end, the Pathway Program partnered with DeepSense (Dr. Scott Lowe) in the Computer Science Department at Dalhousie University and used machine learning methods to develop a new tool (i.e., 'Echofilter') for post-processing raw hydroacoustic data. This new tool accurately (Jaccard Index >94%) identifies the boundary between turbulence and biological targets on raw echograms and reduces the time required for manual post-processing by 45-59%. This tool is now being paired with a streamlined analysis pipeline developed by Dr. Louise McGarry that will generate standardized figures and tables for inclusion in quarterly and annual reports for regulators. Cumulatively, this work reduces the time between data collection and reporting and allows regulators to see the results of monitoring activities more quickly.

The Pathway Program also partnered with Dr. Dave Mellinger at Oregon State University to develop a harbour porpoise click detector and classifier algorithm that would be suitable for use in Minas Passage. That effort has generated a new python-based tool (i.e., 'FindPorpoises'; Figure 1) which recently underwent beta-testing and proved to be a valuable method for detecting harbour porpoise echolocation clicks in tidal channels dominated by noise contamination from flow and ambient noise. This new tool is also being paired with a streamlined analysis pipeline to generate standardized figures and tables for inclusion in quarterly and annual reports for regulators.

[21] These are available online at: https://oera.ca/research/pathway-program-towards-regulatory-certainty-instream-tidal-energy-projects

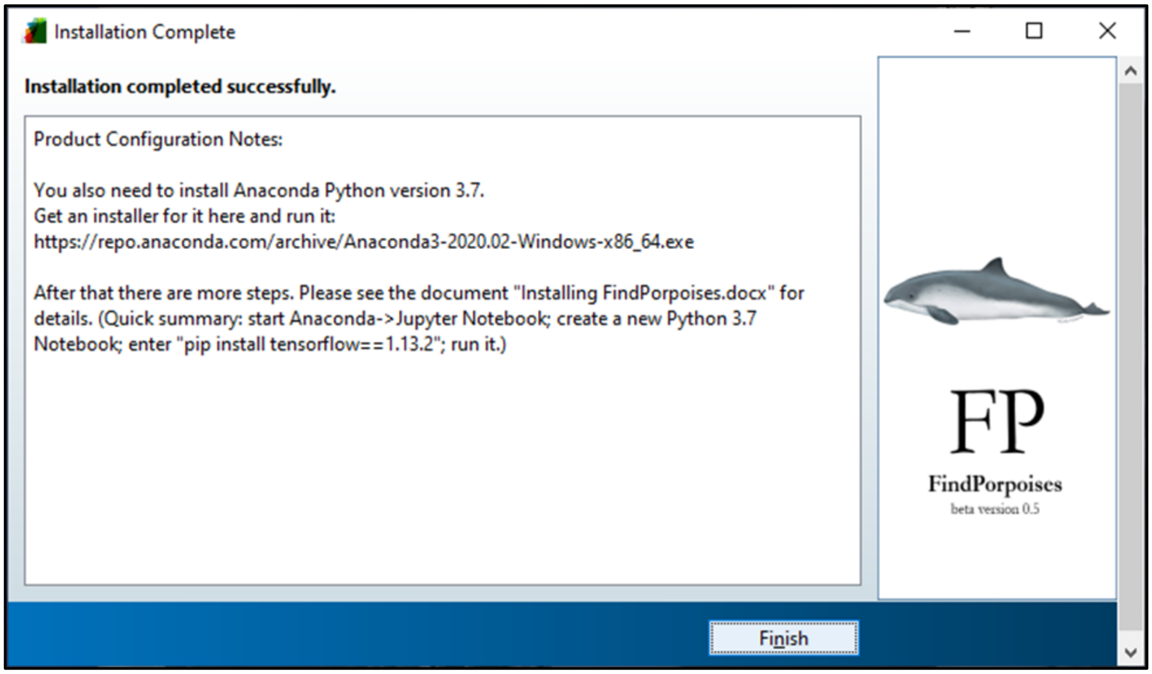

Figure 1: Screenshot from beta testing of the 'FindPorpoises' click detector and classifier tool.

FORCE is collaborating with SMEC and using the floating tidal energy platform (PLAT-I) deployed in Grand Passage, NS, to conduct four projects outlined in Phase III (Technology validation) of the Pathway Program (Figure 2). Three of these projects focus on evaluating the utility of echosounders for quantifying biological targets in high flow environments. These projects evaluate the performance of echosounders in bottom and surface deployments and using a suite of complementary technologies (optical cameras and imaging sonars) to investigate target detections. The fourth project involves an assessment of the relative performance of PAM instruments for detecting synthetic harbour porpoise clicks in high flow environments using similar bottom and surface deployments (Figure 3). The report is currently undergoing external peer review and will be made available as an appendix in the Q2 EEMP report.

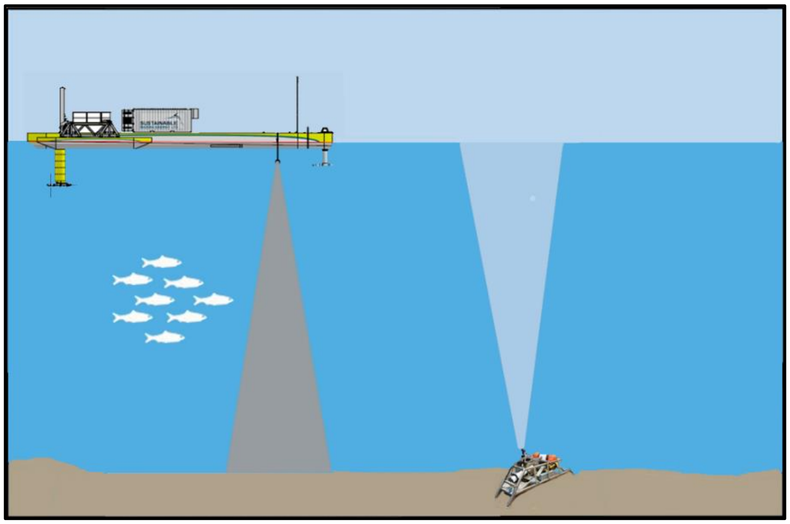

Figure 2: Schematic of the conceptual study design for an assessment of the relative performance of echosounders in bottom-deployments (FAST platform) surface deployments (PLAT-I). Shaded areas are intended for visualization purposes only, and do not accurately represent sample volumes.

Additional projects under Phase III of the Pathway Program to evaluate the performance of surface deployed and bottom-mounted multibeam imaging sonars (Gemini and Blueview) were recently completed in Grand Passage by SOAR (Sustainable Oceans Applied Research), and the reports are available online[22]. For the surface deployment (see Appendix 2), SOAR pole-mounted both imaging sonars from the side of a moored vessel and suspended a series of targets (i.e., tungsten carbide sphere, lead fishing weight, basalt rock and a V-wing glider) 2 metres below a surfboard. The targets were initially held in a fixed position but were also allowed to passively drift across the field of view to assess the ability of the imaging sonars to detect targets at increasing range. The V-wing glider was the largest target and was easiest for the Gemini and Blueview to detect, identify and track. Entrained air from turbulence, waves and the wake generated by the vessel and the pole-mount made tracking targets difficult. While both the Gemini and Blueview were useful for detecting targets, the Gemini performed better for average target detection and tracking at greater distances (10-50 m).

For the bottom-mounted assessment (see Appendix 3), SOAR integrated the Gemini and Blueview imaging sonars into an autonomous subsea platform that was deployed at 25 m depth (at low water) in Grand Passage. Three targets (i.e., lead fishing weight, basalt rock and a V-wing glider) were suspended below a vessel that passively drifted through the ensonified areas of the imaging sonars. While insufficient data was collected by the Blueview due to its small ensonified area, the Gemini performed well for target detection, identification and tracking. Moreover, there was no significant relationship between flow speed and the ability to track targets that were observed.

[22] These are available online at: https://oera.ca/research/pathway-program-towards-regulatory-certainty-instream-tidal-energy-projects

The sensors being evaluated under the Pathway Program are being integrated onto a cabled FAST platform by DP Energy (Figure 4). The integrated sensor platform underwent a successful 'wet test' in Halifax Harbour in October 2020 and is planned to be deployed at the FORCE site in spring 2021.

Figure 3: Deployment of the FAST platform in Grand Passage for an assessment of PAM instrument performance.

Figure 4: The integrated sensor platform developed by DP Energy under the Pathway Program.

Risk Assessment Program

The Risk Assessment Program (RAP) for instream tidal 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 turbine operations continues to be perceived by regulators and stakeholders as collisions between marine animals and turbines 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 turbines 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 mobile ADCP transects combined with a high-resolution radar network to create the first spatiotemporal flow atlas of the Minas Passage to understand these hydrodynamic features. 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 turbine 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 instream tidal power 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.

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 to begin quantifying hydrodynamic features (turbulence, flow etc.) of Minas passage (Figure 5). The integration of physical habitat variables with acoustic tag data has commenced, and model development for some species has begun. The number of individuals per species to be tagged for validating model predictions has been determined, and preparations for the tagging program are well underway. Discussion about the deployment of the acoustic receiver array is ongoing with project partners.

Figure 5: One of two high-resolution radars constructed near the FORCE site to be used for the RAP program.

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 is broadcasted live on the Ocean Networks Canada's (ONC; Victoria, BC) website.[23]

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.

[23] This is available online at: www.oceannetworks.ca/observatories/atlantic/bay-fundy

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 6). 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 the OERA.

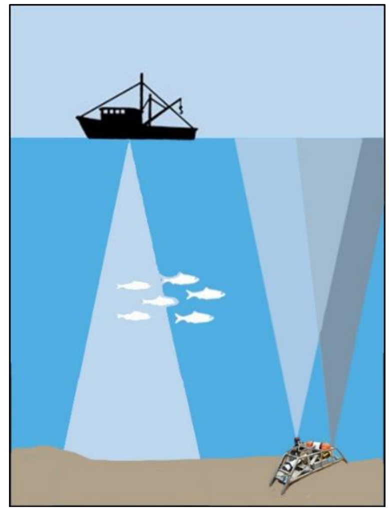

Figure 6: A representation of the data collection methods of the FORCE mid-field fish EEMP and the FAST-3 platform.

Fish Tracking

To enhance fish monitoring and to expand its data collection capacity, FORCE partnered with the Ocean Tracking Network (OTN)[24] and attached one VEMCO[25] fish tag receiver (a VR2 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 has applicability beyond tidal energy demonstration, as well as complement FORCE's hydroacoustic data collection efforts that do not allow for species identification.

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);

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

[25] 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.

- 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); and
- 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)
- Juvenile White Shark Study (Tobey Curtis)

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).[26]

[26] Information about this project, and others funded through this program, is available online at: www.oera.ca/press-release-research-investments-in-nova-scotia-in-stream-tidal-technology-research/

Discussion

The year 2021 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. FORCE recently submitted its 2021-2023 proposed EEMP to regulators for review. The 2021-2023 EEMP is designed to prepare for effects testing with the deployment of operational turbines, 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 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, and in transferring knowledge about hydroacoustics to less experienced staff.

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, and are following health guidelines to maintain social distancing and the wearing of face masks. 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 turbines 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 near- and mid-field 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-turbine 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 turbine 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 turbine(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 turbine technologies in order 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.

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Appendix I

FORCE Marine Mammal EEMP – Year 4 Final Report

Prepared for FORCE

[February 2021]

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FORCE Marine Mammal EEMP – Year 4 Final Report

February 2021

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Executive Summary

The main objectives of FORCE's marine mammal Environental Effects Monitoring Program (EEMP) are to assess long-term effects of direct and indirect stressors on harbour porpoise (*Phocoena phocoena*) by monitoring their activity and site use, with the primary objectives to assess firstly, permanent avoidance of the mid field study area during turbine installation and operation and secondly, large magnitude (~50%) change in the distribution (echolocation activity levels) of a portion of the population in the study mid-field area (see SLR Consulting Ltd. 2015).

This final report provides summary data for the eleventh and twelfth deployment of C-PODs of FORCE's ongoing multi-year EEMP, representing the deployments of the fourth year of the EEMP. Data cover the period between August 2019 through September 2020. Results include data collected from five C-PODs representing a total of 1,043 days of monitoring of the FORCE site. There was at least one porpoise detection on all survey days throughout both deployments. The median number of porpoise positive minutes for the first deployment was 11, and 17 minutes for the second deployment. Both deployments experienced equipment malfunction with E1 failing to return data in October and November 2019 and D1 failing to return any incontestable data for the second deployment. Mean lost time due to sediment noise was 19.5% for the first deployment and 23.8% for the second deployment.

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1. Introduction and EEMP Objectives

Tidal energy is an excellent potential renewable energy source. Worldwide, only a small number of in-stream tidal turbines have been deployed to date. The Fundy Ocean Research Center for Energy (FORCE) is a Canadian non-profit institute that owns and operates a facility in the Bay of Fundy, Nova Scotia (Figure 1), where grid-connected tidal energy turbines can be tested and demonstrated. It enables developers, regulators and scientists to study the performance and interaction of tidal energy turbines with the environment. The offshore test site is in the Minas Passage area of the Bay of Fundy (Figure 2).

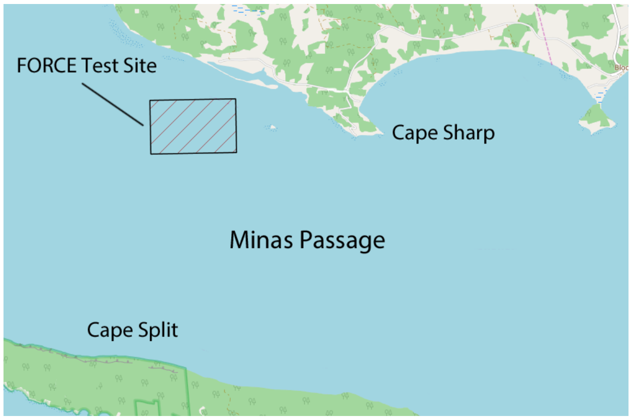

Figure 1: Regional location of FORCE test site. Figure 2: Detailed location in Minas Passage.

Harbour porpoise (*Phocoena phocoena*), the key marine mammal species in Minas Passage (Tollit et al. 2011; Wood et al. 2013; Porskamp et al. 2015), use high frequency echolocation clicks to hunt and communicate and are known to be very susceptible to pulsed noise disturbance (Tougaard et al. 2009), but few studies have focused on exposure to continuous low frequency noise sources, such as those emitted by tidal turbines.

This Year 4 Final Report describes the results of the overall Marine Mammal C-POD Monitoring Program. The program was put in place as part of FORCE's multi-year Environmental Effects Monitoring Program (EEMP) at its marine demonstration and testing facility in Minas Passage. Baseline C-POD monitoring has been ongoing since 2011 (see references above) and year 1, 2 and 3 EEMP results are documented in Joy et al. (2017, 2018) and Tollit et al. (2020).

The main objectives of the marine mammal EEMP are to assess long-term effects of direct and indirect stressors on harbour porpoise by monitoring porpoise activity and site use, with the primary objectives to assess: 1) Permanent avoidance of the mid field study area during turbine installation and operation. 2) Large magnitude (~50%) change in the distribution (echolocation activity levels) of a portion of the population in the study mid-field area (see SLR Consulting Ltd. (2015).

The location of the five C-POD monitoring sites relative to the turbine are found in Figure 3. This final report provides summary data for August 2019 to September 2020 deployment of 5 C-PODs as part of FORCE's continued EEMP.

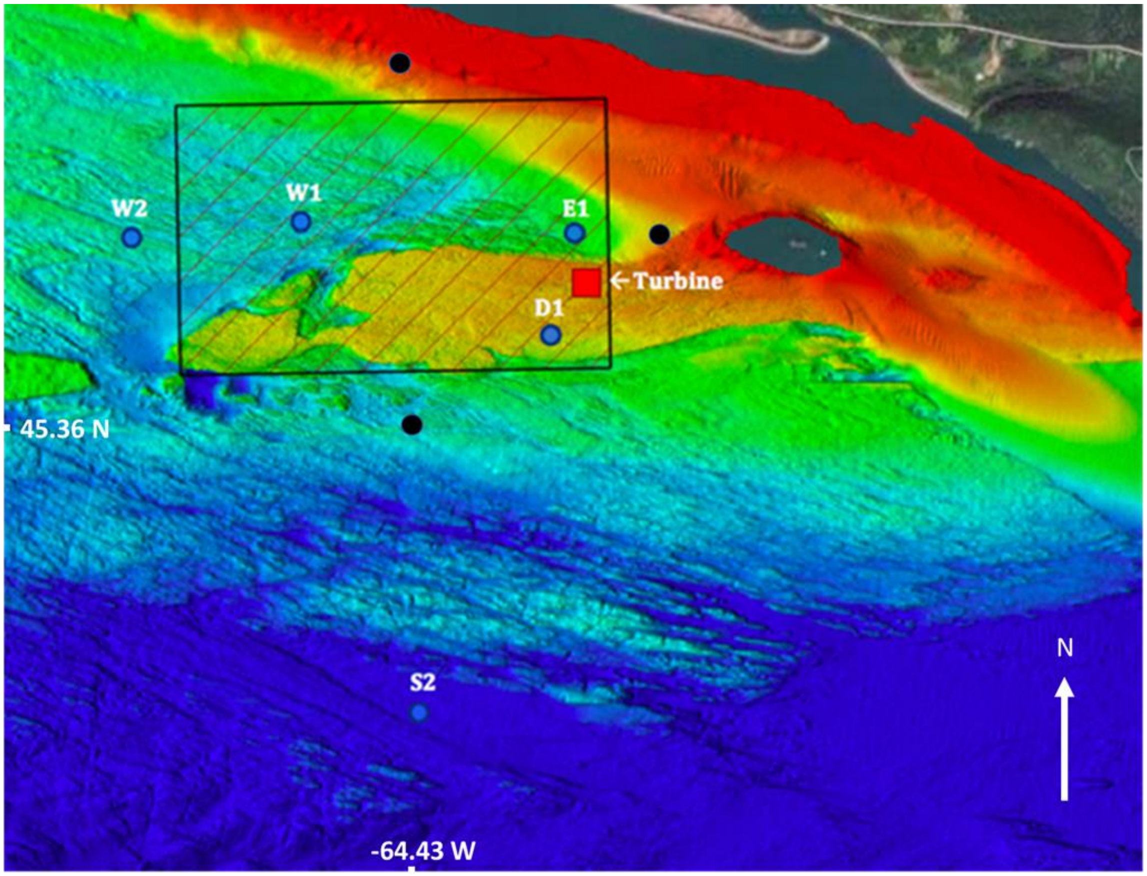

Figure 3: Locations of five monitoring C-PODs and CSTV turbine installed at Berth D. The hatched box denotes the FORCE demonstration area. Shallow water is depicted by warmer colours. C-POD locations are marked and labelled as E1 = East 1, D1 = Berth D, W1 = West1, W2 = West2 and S2 = South2. Locations of three previously used C-POD locations (N1, E2, S1; black circles) are provided.

2. Methods and Results

2.1. C-POD deployment and recovery information (conducted by FORCE field scientists)

Five C-PODS and associated moorings and buoys were deployed between June and August 2020. Each torpedo-shaped C-POD is approximately 1.21 m (4 ft.) long and approximately 40 cm (16”) in diameter. Each C-POD is assembled into a “subs package” containing the acoustic release mechanism and recovery buoy. This is connected by a 2.5 m long chain to an anchor made of several lengths of chain (Figure 4).

Deployment of the C-PODs was completed by assembling each individual mooring on board the *Nova Endeavour*. The mooring was placed in the water over the stern, the anchor then raised with the capstan via the A-frame mounted on the stern, lifted clear of the deck, and pushed forward away from the vessel and deployed using a quick release when safe to do so, allowing the C-POD and mooring to free fall to the sea bottom. Five deployment locations were selected (Table 1) and are depicted in Figure 3 above. Depths ranged from 32-70 m. These locations were similar to previous deployments varying from the last reported by ~60m.

Where possible, the same C-POD units were deployed at the same locations. The exception being units 2790 and 2793 that were deployed at locations W1 and D1 respectively for the first data period and reversed for the second (Table 2)

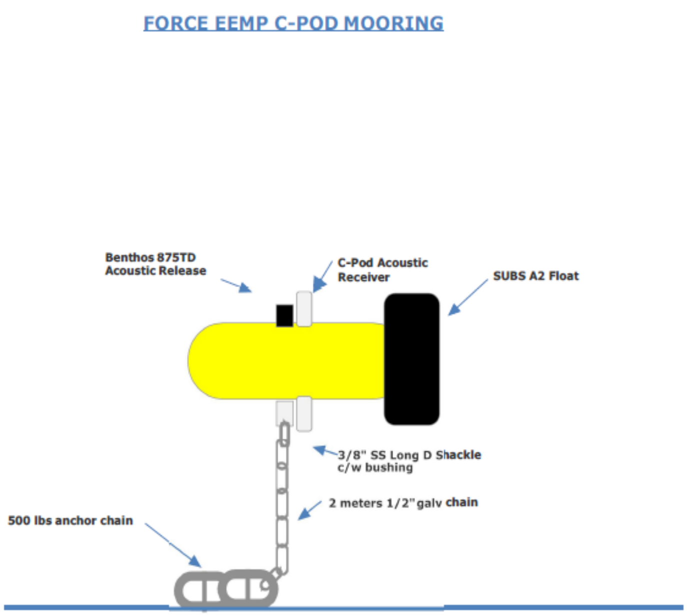

Figure 4: Diagram of FORCE C-POD mooring.

Table 1: Data summary for the two deployments during the year 4 EEMP. Gray shading for ease of use only. All dates and times are presented in UTC.

Location	Lat	Lon	Deployment Date		Retrieval Date		Data Start Date		Data Stop Date	
			Deployment 1	Deployment 2	Deployment 1	Deployment 2	Deployment 1	Deployment 2	Deployment 1	Deployment 2
W1	45' 21.973	-64' 26.074	2019-08-14	2020-06-12	2020-01-14	2020-11-06	2019-08-15	2020-06-13	2020-01-14	2020-09-05
E1	45' 21.984	-64' 25.988	2019-08-14	2020-06-12	2019-12-13	2020-11-06	2019-08-15	2020-06-13	2019-12-13	2020-09-13
W2	45' 21.960	-64' 26.596	2019-08-14	2020-06-12	2020-01-14	2020-11-08	2019-08-15	2020-06-13	2020-01-14	2020-09-30
D1	45' 21.765	-64' 25.424	2019-08-14	2020-06-12	2019-12-13	2020-09-23	2019-08-15	2020-08-13	2019-12-13	2020-09-23
S2	45' 21.008	-64' 25.777	2019-08-14	2020-06-12	2019-12-13	2020-11-06	2019-08-15	2020-06-13	2019-12-13	2020-09-29

Table 2: C-POD instrument number and data duration. Gray cells highlight locations where the instruments were switched between deployments.

Location	C-POD number		Data Duration (Days)	
	Deployment 1	Deployment 2	Deployment 1	Deployment 2
W1	2790	2793	151	85
E1	2765	2765	77	93
W2	2792	2792	152	110
D1	2793	2790	121	29
S2	2931	2931	116	109

2.2. C-POD Data QA

C-POD.exe V2.044 was used to process the data and extract narrow bandwith high frequency (NBHF) click trains representative of porpoises. Custom Matlab R2020b code was used to calculate statistical outputs and create data plots using detection positive minutes (DPM) per day and DPM per 10-minute period (DPMp10M) as the key metrics for comparison. Data were excluded from each C-POD for the first 12 hours after the reported deployment time and one hour prior to the recovery time. This pruning procedure reduced any disturbance or artifacts in the data resulting from deploying and recovering the instruments.

The QA assessment specifically targets if non-biological interference has occurred, confirms that the porpoise click detector is operational and assesses the scale of % time lost due to click maximum buffer exceedance. Buffer exceedance occurs when noise generated from sediment movement and moorings exceeds internal memory of the C-POD and results in periods of lost recording time in each minute.

The instrument deployed at D1 ostensibly collected data from the deployment on June 12 until recovery on September 23, 2020. At around 02:30, the instrument appears to have become lodged in a horizontal position and ceased collecting data. The C-PODs have an on/off switch that can be controlled by their internal tilt meter. If the unit were stuck on its side or upside down, it would have stopped recording until the unit was upright again. The unit deployed at D1 was recovered September 23rd and the remainder of the instruments recorded continuously until either internal storage or battery capacity was exhausted. The data that were collected at D1 do not match up with known deployment dates and appear to show no time lost due to sediment interference which is unlikely. For this reason, we recommend that any statistical modeling of trends in porpoise detections (e.g. Wood et al. 2013) exclude data from the second the D1 deployment. For consistency with previous reports, we report the number the number of days this instrument was in the water but exclude it from any statistical calculations .

2.3. Porpoise click detection rates

2.3.1. Overall summary of detection rates

Across all years of the Minas Passage C-POD monitoring study, there have been a total of 7,581 C-POD days over 1,888 calendar days, with a total of over one million 10-minute periods (Table 3). This final report covers 110 calendar days, 426 C-POD days with a total of 60,842 10-minute periods (Table 3).

Porpoises were detected on 100% of days across all pods combined, with an overall average median of 17 minutes per day, and with the probability of presence detected in 5.64% of all 10-minute periods across this monitoring period. This later statistic (termed 'PBinDPM=1' within Joy et al. 2018) is considered the optimal comparative metric to assess potential effects, as mean values are skewed by the number of periods without detection. Across individual C-PODs, detection rates averaged 93.4% of days with a C-POD median DPM per day of 17 minutes (IQR =

10-24) when presence occurred (Table 4). The DPM value is similar to the previous recording period but the average detection rate across C-PODs was lower.

No dolphin clicks were detected in Minas Passage during this C-POD monitoring period, as also found during previous deployments (Wood et al. 2013; Joy et al. 2017, 2018).

Table 3: Definitions of deployment scenarios and associated summary of C-POD monitoring effort, turbine status, and EEMP details. The turbine operational period is highlighted in bold.

Deployment Scenario and Turbine Status	**Deployment Dates**	**# of Days Monitored**	**# of Pod-Days**	**# 10-Min Intervals**
2011 Deployment: Absent	2011-05-05 - 2012-01-17	258	958	136,446
2012 Deployment: Absent	2012-05-31 - 2012-12-03	137	391	56,795
2014 Deployment: Absent	2013-12-06 - 2014-07-01	208	689	99,108
2016 Deployment 1: Absent	2016-06-08 - 2016-08-30	84	252	35,775
2016 Deployment 2: Absent	2016-09-23 - 2016-11-06	45	225	32,065
***2016 Deployment 2: Turbine 1 Operational**	**2016-11-07 - 2017-01-18**	**73**	**332**	**47,403**
***2017 Deployment 3: Turbine 1 Operational**	**2017-02-24 - 2017-04-21**	**57**	**262**	**37,229**
2017 Deployment 3: Turbine 1 Free-spinning	*2017-04-22 - 2017-06-01*	41	146	20,756
2017 Deployment 4: Turbine 1 Free-spinning	*2017-06-03 - 2017-06-15*	13	39	5,382
2017 Deployment 4: Turbine 1 Absent	*2017-06-16 - 2017-09-14*	91	357	51,009
2017 Deployment 5: Turbine 1 Absent	*2017-09-27 - 2018-01-08*	104	520	74,135
2018 Deployment 6: Turbine 1 Absent	*2018-01-23 - 2018-05-18*	99	480	68,094
*2018 Deployment 7: **Turbine 2 operational or free-spinning 07-22 to 08-09**, then present (non-operational/non-free-spinning)	2018-05-05 - 2018-08-23	111	542	77,419
2018 Deployment 8: Turbine 2 Present, non-operational/non-free-spinning	2018-09-07 - 2018-11-30	85	367	51,722
2018 Deployment 9: Turbine 2 Present, non-operational/non-free-spinning	2018-12-07 - 2019-04-02	117	453	64,418

2019 Deployment 10: Turbine 2 Present, non-operational/non-free-spinning	2019-05-04 - 2019-08-14	103	506	72,090
2019 Deployment 11: Turbine 2 Present, non-operational/non-free-spinning	2019-08-14 - 2019-12-13	152	636	90,600
2020 Deployment 12: Turbine 2 Present, non-operational/non-free-spinning	2020-06-12- 2020-09-05	111	426	62,392
All Deployment data		**1,888**	**7,581**	**1,082,838**

Table 4: FORCE site monitoring summary: Percent of days (across all deployment locations) with high or moderate quality porpoise detections present. Mean percent of days (between deployment locations) with 'NBHF' detections. Number of days without porpoise detection and the median number of detection-positive minutes for days/units with detections.

Deployment Scenario and Turbine Status	Overall % Days Porpoise Present	% Days Across C-PODs Porpoise present	Days Without Porpoise (Days Monitored)	Median (IQR) of Minutes of Detection if Present
2011 Deployment: Absent	99.2	83.2	2 (258)	7 (2, 17)
2012 Deployment: Absent	95.6	82.9	6 (137)	5 (1, 13)
2014 Deployment: Absent	99.0	87.5	2 (208)	9 (3, 16)
2016 Deployment 1: Absent	98.8	92.5	1 (84)	7 (3.75, 14)
2016 Deployment 2: Absent	100.0	76.4	0 (45)	4 (1, 10)
2016 Deployment 2: Operational	**97.3**	**73.8**	**2 (73)**	**3 (0, 7)**
2017 Deployment 3: Operational	**100.0**	**92.4**	**0 (57)**	**7 (3, 14.75)**
2017 Deployment 3: Free-spinning	100.0	95.2	0 (41)	7 (4, 12)
2017 Deployment 4: Free-spinning	100.0	100	0 (13)	12 (7, 18.5)
2017 Deployment 4: Absent	100.0	96.9	0 (91)	12 (6, 21)
2017 Deployment 5: Absent	100.0	88.3	0 (104)	8 (2.75, 20)
2018 Deployment 6: Absent	100.0	88.3	0 (99)	7 (2, 16)
2018 Deployment 7: Present from 2018-07-22, unknown status	100.0	98.0	0(111)	12 (6, 20)
2018 Deployment 8: Turbine 2 Present, non-operational/non-free-spinning	98.8	84.7	1(85)	5 (1.5, 11)
2018 Deployment 9: Turbine 2 Present, non-operational/non-free-spinning	94.9	88.1	6(117)	7 (3, 19)
2019 Deployment 10: Turbine 2 Present, non-operational/non-free-spinning	100.0	99.8	0(103)	15 (8, 24)

2019 Deployment 11: Turbine 2 Present, non-operational/non-free-spinning	100.0	91.04	0(152)	11(5, 19.5)
2020 Deployment 12: Turbine 2 Present, non-operational/non-free-spinning	100.0	93.4	0(110)	17(10,24)
All Deployment data	**99.08**	**89.6**	**20(1888)**	**7(3, 16.5)**

2.3.2. C-POD location detection rates

Porpoise detections rates varied across locations. Table 5 provides summary of percent probability of detecting a porpoise in a 10-minute interval for both deployments. For the second deployment, E1 and S2 sites had the highest detection rates. The sum of daily detection positive minutes averaged below five minutes for W2 and D1 sites, however, D1 did not produce data for the majority of the study and the data it did produce appear to be spurious.

Table 5: Descriptive statistics for the 5 C-POD locations for the 4th year of EEMP. Percent probability (95% CI) of detecting a porpoise in a 10-minute Interval (P(BinDPM=1). Orange highlighted cells indicate non or inconsistent data recovery.

	Deployment 1		**Deployment 2**	
Location number	**Means (95%.C.I.)**	**# 10-minute Intervals**	**Means (95%.C.I.)**	**# 10-minute Intervals**
W1	3.87 (2.24 - 14.83)	10,760	6.8 (6.16 – 16.23)	12,139
E1	4.74 (3.47 - 14.58)	21,750	8.12(7.41 – 20.95)	13,369
W2	9.02 (6.25 - 25.56)	16,558	4.86 (4.16 – 11.11)	15,751
D1	3.3 (2.78 - 8.66)	17,241	0.47 (0 – 7.07)	4,032
S2	4.25 (3.47 - 12.64)	21,518	7.87 (7.63 – 13.73)	15,551

Data inspection indicated mid-June through October for the four functioning deployment locations (excepting D1). For the final deployment mean % time lost was 23.9%, with median of 0% and interquartile range of 0-52% (Figure 5).

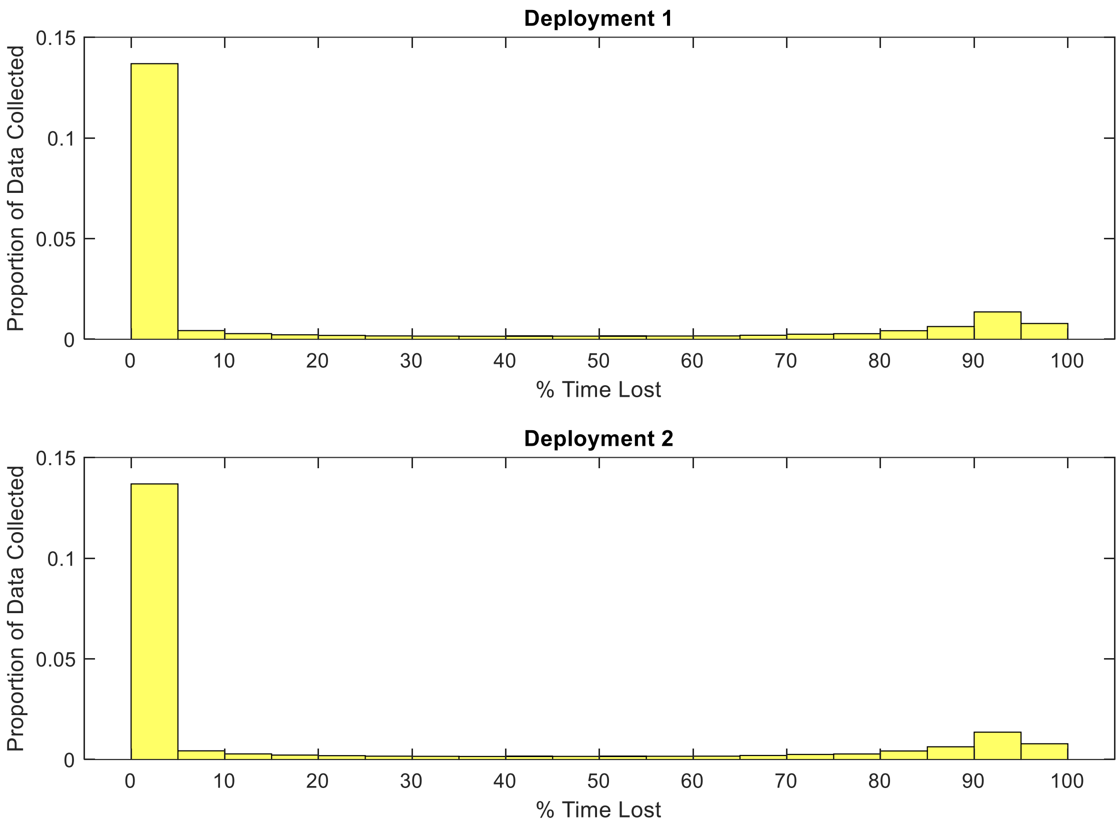

Figure 5: Distribution of time lost across the two year 5 deployments.

2.3.3. Temporal Trends in Detections

As with previous years, there was a seasonal trend in detections. However, the data gap between January and July across all sites and site-specific data failures preclude robust statistical analysis of seasonal trends. At the W2 deployment location there was considerably less variation in the average number of detection positive minutes per day in the second deployment than the first. There similarly appeared to be fluctuations in total detection positive 10 minute periods per day consistent with lunar cycles with peaks occurring every 30 days (Figure 6). This is most evident in W1 and W2 locations during the first deployment. The same trend was visible in the daily average proportion of time lost (Figure 7).

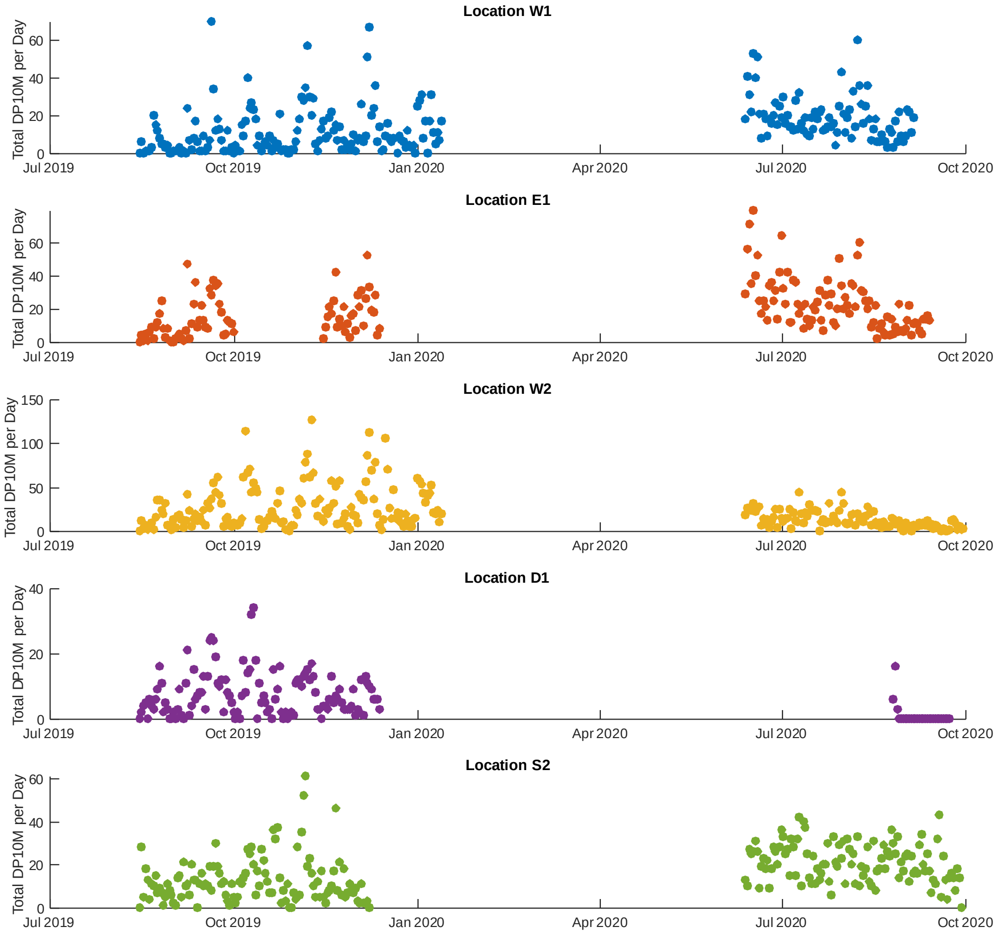

Figure 6: Total detection positive 10 minute periods throughout the year 4 EEMP. Data points prior to January represent the first deployment and data points after June 2020 represent the second deployment. C-PODS were not deployed between these periods due to the impact of COVID-19 on marine operations during winter and spring 2020.

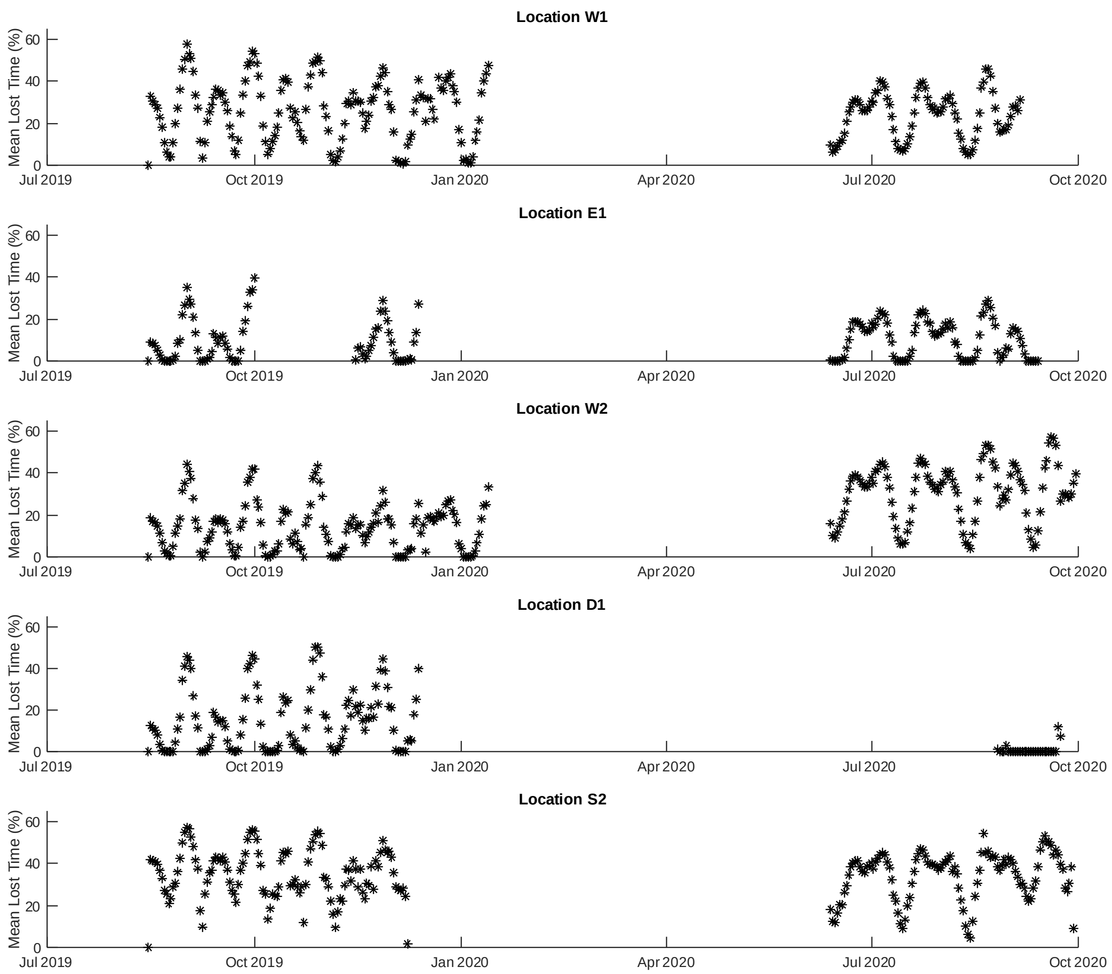

Figure 7: Average time lost per day for the fourth year of the EEMP. Tidal cycles are evident at all locations.

There was some evidence of diel trends in detection at the W1 and E1 sites and to a lesser degree the W2 site. At these locations there were fewer detection positive minutes during daylight hours (between 0500 and 1800) than in the evening hours (Figure 8). This trend was not present in the winter nor at the remaining three sites.

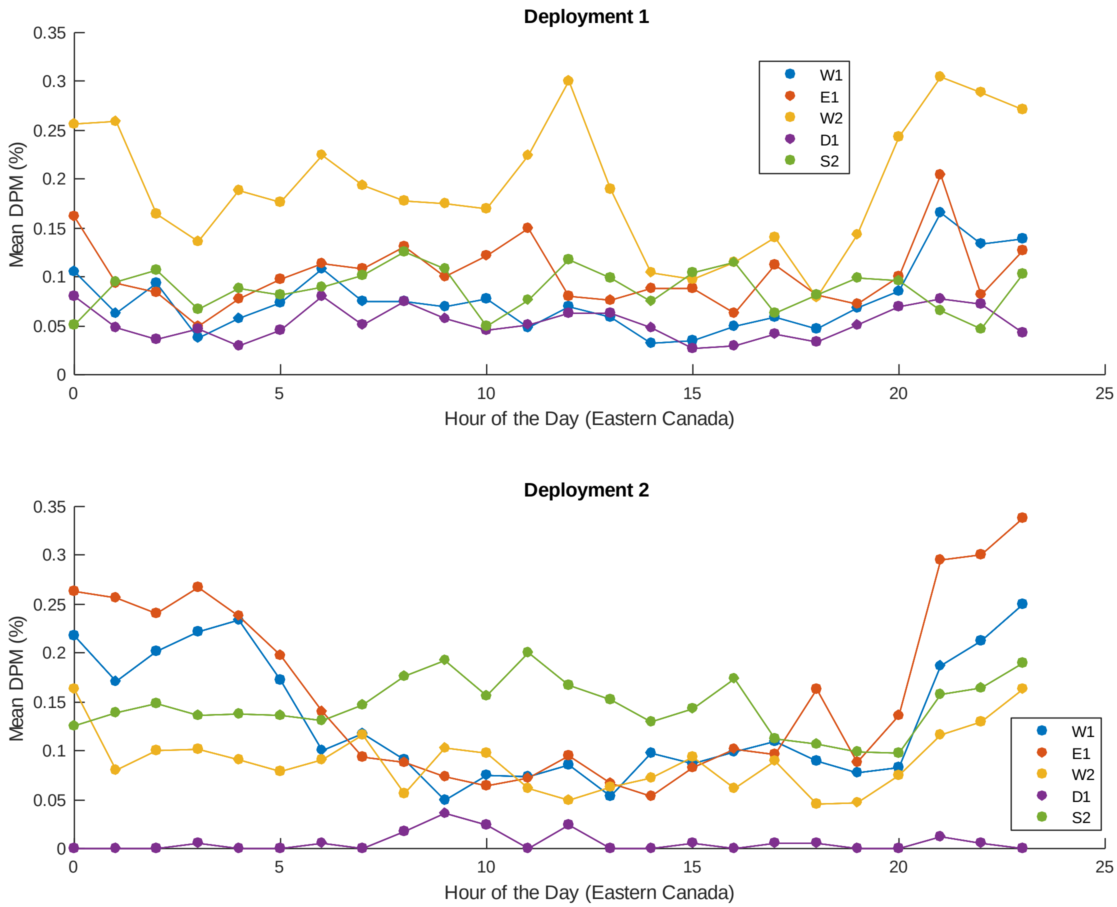

Figure 8: Relationship between the daily mean precent of time lost and the total detection positive 10-minute periods per day.

2.3.4 Comparison of year 4 EEMP porpoise detection rates with previous C-POD deployments

In year four of the monitoring effort there were no operational turbines deployed at the FORCE site. The percent probability of detecting a harbour porpoise in a 10-minute interval (P(BinDPM=1) at each C-POD deployment location was calculated for each period (Figure 9, top panel). Seasonal and site-specific trends in the detection probabilities are visible. The probability of detecting potential porpoise clicks was highest at the W2 site in the first deployment. In the second deployment, average detection rates were similar to previous deployments and years with the exception of 2016 where detection positive days for were considerably lower for the entirety of the survey period than subsequent years.

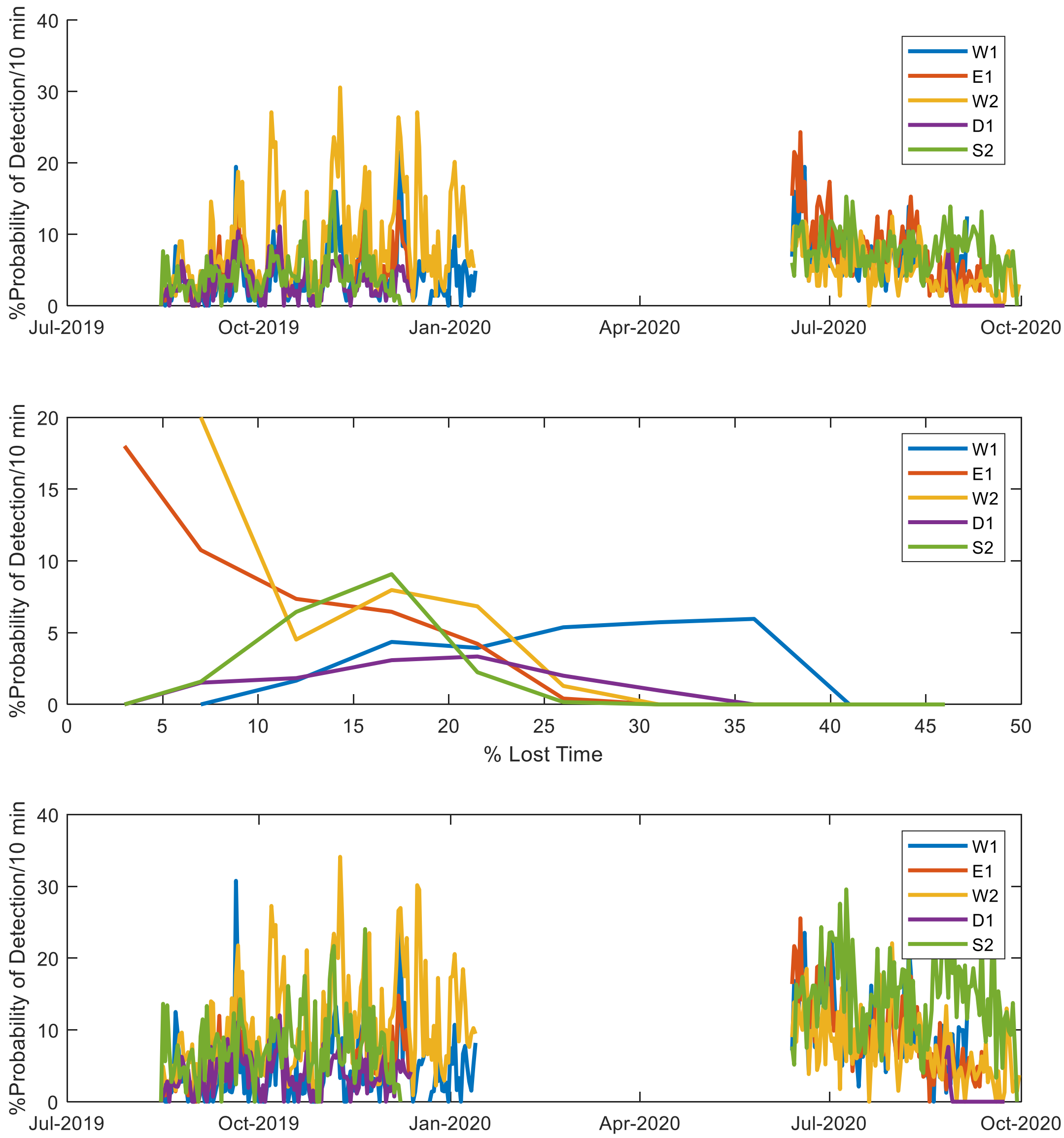

Figure 9: Percent probability of detecting a porpoise in a 10-minute Interval (P(BinDPM=1) at each C-POD monitoring location for year 4 of the EEMP. Top panel; probability of detection at each location throughout the season. Middle panel: the relationship between detection probability and time lost. Bottom panel: Probability of detection for only data where no time was lost.

The relationship between detection probability and time lost was also calculated and is shown in the middle panel of Figure 10. Again, there were site specific trends across the five survey locations. W2 had the strongest relationship between detection probability and the proportion of time lost. W1 showed a likely spurious positive relationship between detection probability and time lost, with more detections occurring with 35% of time lost than 15%. The third panel shows the probability of detection for each site through the deployments, excluding any periods where any time was lost. The general trends shown in the bottom panel are relatively consistent with those from the raw data (top panel).

3. Discussion

Five C-PODs were successfully deployed and recovered in Minas Passage as part of FORCE's marine mammal EEMP. Four C-PODs returned good quality and continuous data in each deployment while two instruments failed to return data (D1 in the first deployment and E1 in the second deployment). For the D1 instrument, inspection of the vertical angle data exceeded 90° for at least 300 minutes but this is insufficient to explain the duration of the data gap. We recommend that both instruments 2765 and 2790 be refurbished by the manufacturer.

Average percent time lost due to sediment noise interference (23.9%) was similar to previous studies at these locations. Across all years of the Minas Passage C-POD monitoring study, there have been a total of 7,581 C-POD days across 1,888 calendar days, with a total of 1,082,838 10-minute periods.

In this last period, across all C-PODs, harbour porpoise were detected across 93.4% of monitored days, and at higher rates than have previously been observed (17 min/day). No dolphins were detected as per previous baseline studies. Differences across deployment locations mirrored previous results.

The relationship between detection probability and the proportion of lost time was also investigated. The trend was again, location dependent but on average no porpoise click trains were detected in each 10-minute monitoring period where the proportion of lost time was greater than 50%.

As with previous studies the fairly convincing diel trend was found in the second deployment of the FORCE array (Tollit, Joy et al. 2019). Such trends can be indicative of animal behavior by providing insights beyond presence-absence. In Scotland, differing diel trends in porpoise detections have been linked to sediment type and tentatively linked to different foraging strategies. Ongoing evaluation of these trends, when operational turbines are deployed may also yield information regarding behavioral changes associated with turbine operations. Such analyses have the potential to be more informative and robust than simple presence-absence given the complexities in processing C-POD data in a tidal environment. Trend analysis allows for variation in measuring efficacy between instruments by considering only the relative probabilities between time and locations. For instance, if a diurnal trend is observed in one location prior to the turbine activation and detection rates remain constant but the diel trend changes, it could be indicative of a change in behavior (e.g., more or less foraging activity) during turbine operation. Furthermore, if the C-PODs are replaced with F-PODs, direct 1:1 comparison of DPM may not be possible. However, trends in small scale tidal and diel-linked patterns should be comparable between the instruments.

To date, we consider a sufficiently long timeline of C-POD baseline data has been collected to meet the goals of the FORCE EEMP. Optimally, additional baseline data collection would allow an improved understanding of natural variability and/or detect changing regional trends. However, until operational turbines are deployed at the FORCE tidal demonstration site, an adaptive management approach might be adopted, whereby baseline studies are curtailed, scaled back to every other year or potentially (to meet DFO expectations) continued at one single long-term monitoring site such as at W1.

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Appendix II

FINAL PROJECT REPORT (v1.6)

OERA Pathway 2020 Program

Field Assessment of Multi-beam Sonar Performance in Surface Deployments

OERA Project number: 200-216

February 1, 2021

Project Lead: SOAR – Sustainable Oceans Applied Research Ltd.

By: Greg Trowse, Dr. Tristan Guest, Gavin Feiel, Richard Cheel, and Dr. Alex Hay

Executive Summary

Multibeam imaging sonars have application to monitoring fish and marine mammal presence and behaviours in the near field of tidal turbine installations, including evaluating avoidance, evasion, and potential blade strikes. SOAR conducted field experiments to help reduce uncertainty in performance of the Tritech Gemini 720is and Teledyne Blueview M900-2250 multibeam imaging sonars for identifying and tracking discrete targets in high-flow environments. This information will help inform the Department of Fisheries and Oceans Canada, tidal energy developers, and other stakeholders in the design and implementation of effective monitoring systems for tidal energy projects in the Bay of Fundy and beyond. These two imaging sonars were the technologies recommended for testing by the subject matter expert for imaging sonars during the first phase (Global Capability Assessment) of the Pathway Program. The Tritech Gemini 720is operates at 720 kHz and has a maximum effective sampling range of approximately 50 m. The Teledyne Blueview M900-2250 has operating frequencies of 900 or 2250 kHz, with a 10 m range for the high frequency transducer head. As per the recommendation from the Global Capability Assessment, this report focuses on the Blueview's capabilities while operating at 2250 kHz, for which the effective sampling range is 10 m.

Field trials were conducted in Grand Passage aboard research vessel Grand Adventure. The two sonars and a camera were mounted on a pole which could be lowered over the vessel's port side and fixed in position. The deployed sonars were oriented such that the top of their ensonified areas extended behind the boat approximately parallel with the water surface and extended downward at a 20 degree angle. The Grand Adventure was anchored in mid-channel during ebb and flood tide flow conditions, such that current velocities ranged from approximately 1 to 2.5 m/s with the instruments oriented downstream. Targets were suspended approximately 2 m beneath a 3 m long surfboard (SciBoard) and included a 2.54 cm (1 inch) diameter tungsten carbide sphere, 0.45 kg (1 lb.) (9.5 cm long x 3.8 cm max diameter) lead fishing weight, approx. 12 cm diameter basalt rock in a lobster bait bag, and a V-Wing glider (approx. 52 cm wing tip to tip and 46 cm nose to tail) from Dartmouth Ocean Technologies. During data collection the SciBoard and suspended target were held at constant ranges from the sonars along the port side and downstream of the Grand Adventure, and also released to freely drift downstream with increasing range.

The visualization and organization of the data was conducted using the industry standard software for each sonar: Gemini SeaTec and Teledyne ProViewer. Data were exported to

video and organized into training and test data sets, which were shared with 9 sonar observers who conducted the manual analysis for target detection, identification, and tracking. Links to the training and test data sets for each sonar are provided below. The data are best viewed in video form. As such, readers of this report are encouraged to watch these data videos for better understanding of the results and conclusions discussed in this report.

Gemini training data	https://vimeo.com/473580369
Gemini test data with 50m range	https://vimeo.com/473665614
Gemini test data with 10m range	https://vimeo.com/473688042
Blueview training data	https://vimeo.com/473964794
Blueview test data	https://vimeo.com/474025663

The Gemini 720is and Blueview M900-2250 multibeam imaging sonars were both found to be useful for detection and tracking of all target sizes used in our experimentation. However, differentiation of similar targets such as the 2.54 cm (1 inch) tungsten carbide sphere (Target 1) and 0.45 kg (1 lb.) lead fishing weight (Target 2) proved difficult. The sonars performed best for detecting, identifying, and tracking the V-Wing. This is an expected result as it was the largest target and had the most recognizable backscatter signature due to its characteristic shape. Entrained air from turbulence, waves, and the vessel/pole wake made tracking targets more difficult, but target persistence allowed them to be effectively detected and tracked by eye for all target types tested.

SOAR recommends use of the Tritech Gemini 720is for application to monitoring interactions between marine animals and tidal turbines. With the 10 m range setting, the Gemini demonstrated comparable ability to the Blueview to identify targets and outperformed the Blueview in average target detection and tracking scores. At 50 m range, the Gemini still demonstrated a high level of utility for target detection, tracking, and presence/absence, though was less effective (ca. 50%) for target identification. It is likely that this technology will contribute significantly to effective monitoring and advancing knowledge of importance to regulators and other stakeholders. The Blueview M900-2250 was included in testing due to its higher frequency output, which is better suited for close range target detection and tracking. The Blueview is an impressive technology and offered the ability to resolve finer scale features of the targets and their movements in some cases. However, the MKI model of the Blueview M900-2250 has a hardware limitation which results in multiple high-noise bands in the output data, which limited our ability to detect and track targets considerably. We conclude that data from the Blueview did not add substantial value or insight to the target analysis when used in conjunction with the Gemini. This should not rule out potential use of other MHz frequency multibeam sonars for monitoring the 10 m range in a combined sonar approach, including MKII of the Blueview.

We evaluated the effects of acoustic interference (cross talk) between the Gemini and Blueview based on the ability of manual observers to detect, track, and identify targets through repeat collections of data with the sonars running both concurrently and independently. In general, the acoustic interference can be described as distracting, but tolerable. We observed no relationship between flow speed and observers' abilities to detect and track targets with testing up to approximately 2.5 m/s. Tidal flows are faster at the FORCE site in the Minas Passage, with flow speeds exceeding 2.5 m/s 30 to 40% of the time.

The project addressed the objective of assessing the performance of surface deployed multibeam imaging sonars for target detections, including the extent of signal interference from waves/turbulence, and entrained air. Further testing of and research into multibeam sonar usage from a vessel mounted (near surface) position would be useful in four focus areas, including:

1) fish and other marine animals in locations and seasons (times) with high levels of animal abundance and variety,
2) evaluating the most effective sonar orientations for monitoring the near field of tidal turbines,
3) flow speeds that exceed 3 m/s, and
4) increasing efficiency in data assessment, including reliable automation.

This work should build upon success in Grand Passage to conduct next steps in stronger flow conditions present in Petit Passage and Minas Passage. The report titled "Field Assessment of Multi-beam Sonar Performance in Bottom Mount Deployments" (Trowse et al. 2020) provides similar analysis for the case of seabed mounted Gemini 720is and Blueview M900-2250, including comparison of results and further recommendations for next steps.

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Acknowledgments

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- Offshore Energy Research Association of Nova Scotia
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- Clare Machine Works
- Luna Sea Solutions
- MarineSitu
- Mi'kmaw Conservation Group
- Fundy Ocean Research Centre for Energy (a.k.a. FORCE)
- Dasco Equipment Inc.
- Tritech and Teledyne technical support staff
- Canadian Hydrokinetic Turbine Test Centre

1.0 Introduction

Multibeam imaging sonars have application to monitoring fish and marine mammal presence and behaviours in the near-field of tidal turbine installations, including evaluating avoidance, evasion, and potential blade strikes (Hastie 2013; Viehman and Zydlewski 2014; Bevelhimer et al. 2016; Williamson et al. 2016, 2017; Sanderson et al. 2019). However, there is uncertainty in performance of these instruments in high-flow environments due to turbulence and associated entrained air in the water column, where a reduction in instrument efficacy may result from scattering of the transmitted acoustic signal through turbulent zones of the water column before the signal reaches potential targets, with further signal dilution on the return to the transducer (Melvin and Cochrane 2014). Some additional challenges include a) mounting sonars at sufficient depth in high-flow environments to avoid acoustic returns from the surface (horizontal sonar orientation) and reduce exposure to entrained air, and b) transferring, storing, and efficiently analyzing large amounts of data.

Several makes and models of multibeam imaging sonars are available, with a major source of difference being the frequency at which they transmit acoustic energy. Higher frequencies are associated with shorter wavelengths; this results in resolution increasing with frequency, and range decreasing with increasing frequency. The combined use of kHz and MHz frequency range multi-beam imaging sonars is of interest for monitoring marine animals because it offers potential for an instrument package to detect and track targets at ranges up to approximately 50 m with identification (and/or finer scale tracking) of targets at a range up to approximately 10 m. For environments with suitable visibility, the addition of an optical camera offers increased potential for target identification, target validation, and tracking at ranges of approximately 0.1 to 15 m in very clear waters.

As part of the Pathway Program, SOAR conducted work to help evaluate the performance of the Tritech Gemini 720is and Teledyne Blueview M900-2250 (2.25 MHz transducer head) multibeam imaging sonars for evaluating interactions between marine animals and tidal turbines. This information will help inform the Department of Fisheries and Oceans Canada (DFO), tidal energy developers, and other stakeholders in the design and implementation of effective monitoring systems for tidal energy projects in the Bay of Fundy and beyond.

The Tritech Gemini 720is multibeam imaging sonar has been used by MCT Seagen in Strangford Lough (Hastie 2013), OpenHydro at the Fundy Ocean Research Centre for Energy (FORCE) (Viehman et al. 2017), and other applications including studies commissioned by FORCE (Gnann 2017). With an operating frequency centered at 720 kHz, the Gemini has a target detection range of up to 100 m (Cotter, et al. 2017) but has reduced resolution in comparison to higher frequency systems. The dual frequency Teledyne Blueview M900-2250 has two sets of transducers, one set centered at 900 kHz (close to the Gemini) and the other set at 2250 kHz (2.25 MHz). Use of the Blueview 2.25 MHz transducer head may have application in shorter range monitoring, up to approximately 10 m (Cotter et al. 2017). These two imaging sonars are the technologies recommended for testing by the subject matter expert for imaging sonars during the first phase (Global Capability Assessment) of the Pathway Program (Joslin 2019).

SOAR's work in 2020 has included data collection and analysis from near surface (vessel mounted) and seabed deployments. This report covers the methodology and results for the vessel mounted experiment. "Field Assessment of Multi-beam Sonar Performance in Bottom Mount Deployments" (Trowse et al. 2020) discusses the seabed deployment and a comparison of results for the two approaches.

The **objective** of the work covered in this report is to assess the performance of surface deployed multibeam imaging sonars for target detections, including the extent of signal interference from waves/turbulence, and entrained air.

The **expected outcomes** include**:**

- Primary - Report on performance of surface deployed multibeam imaging sonars for target detections, and a recommendation on whether the use of surface deployed multibeam imaging sonars is feasible for monitoring interactions between marine animals and tidal turbines.
- Secondary - Data sets to support further research (beyond the scope and timeline of this project) including potential for calibration of multibeam imaging sonars, quantification of the effects of air entrainment on target detectability, and autodetection and classification algorithms (software).

2.0 Methodology

The methodology was developed to evaluate the performance of two multibeam imaging sonars when deployed near surface on a downward-oriented vessel mounted pole, including the Tritech Gemini 720is (Gemini) and the dual frequency Teledyne Blueview M900-2250 MKI (Blueview). The Gemini has 512 beams aligned along a 120° swath width (angular resolution of 0.25°), with each beam having a 20° width perpendicular to the swath. The Blueview has 768 beams aligned along a 130° swath width (angular resolution of 0.18°), with each beam having a 20° width perpendicular to the swath. Multibeam sonars resolve target locations as range along each beam. The resulting composite (by combining all beams) is used to generate a sonogram with target locations in the swath width but does not resolve target location in the beam width. For this experiment, the sonars were both aligned such that field of view had swath width on the horizontal plane (parallel to water surface) and beam width on the vertical plane (depth). The acoustic frequency and geometry of the ensonified area for each sonar is summarized in Table 1. The Subaqua SAIS IP Cam (optical camera) was also included for target verification, and to demonstrate ability for targets to be identified optically.

Table 1: Multibeam imaging sonar frequency and ensonified area

Sonar	Frequency (kHz)	Range (m)	Swath width	Beam width
Gemini	720	120 (1)	120°	20°
Blueview	900 or 2250(2)	10	130°	20°

Notes:

- The Tritech supplied specifications for the Gemini report a max range of 120 m, however the maximum effective range for monitoring marine animals in tidal channels is 50 to 60 m.
- The Blueview is dual frequency, with two transducer heads. Our work focused on the high frequency capabilities with the 2250 kHz (2.25 MHz) transducers, and associated range of 10 m. For brevity, ongoing reference to the Blueview in this report implies the high frequency transducer head.
- Both sonars transmit a “chirp” pulse that spans a range of frequencies, centered at the values listed above.

2.1 Data Collection

2.1.1 Method

An initial experiment was conducted in Freeport Harbour to a) evaluate potential interference between the Gemini and Blueview sonars in a controlled setting, b) test and refine the mounting arrangement and sonar angles, and c) evaluate various instrument configuration settings and how they affect the image quality. This was followed by a system test in tidal flow in Grand Passage to confirm the pole mount and anchor function, and the main field trials which were also conducted in Grand Passage.

The work was conducted aboard research vessel Grand Adventure, using a stand-alone power supply for the sonars, displays, and data acquisition computers. The Grand Adventure has an inboard diesel main propulsion system, backup outboard engine, and hydraulics for boom/winch and hauler/davit lifting systems. She is shown in Figure 1 in Westport Harbour fully outfitted for this work. The interior of the wheelhouse with sonar displays is shown in Figure 2 (photo taken during data collection in Grand Passage).

Figure 1: Research vessel Grand Adventure in Westport Harbour outfitted for work

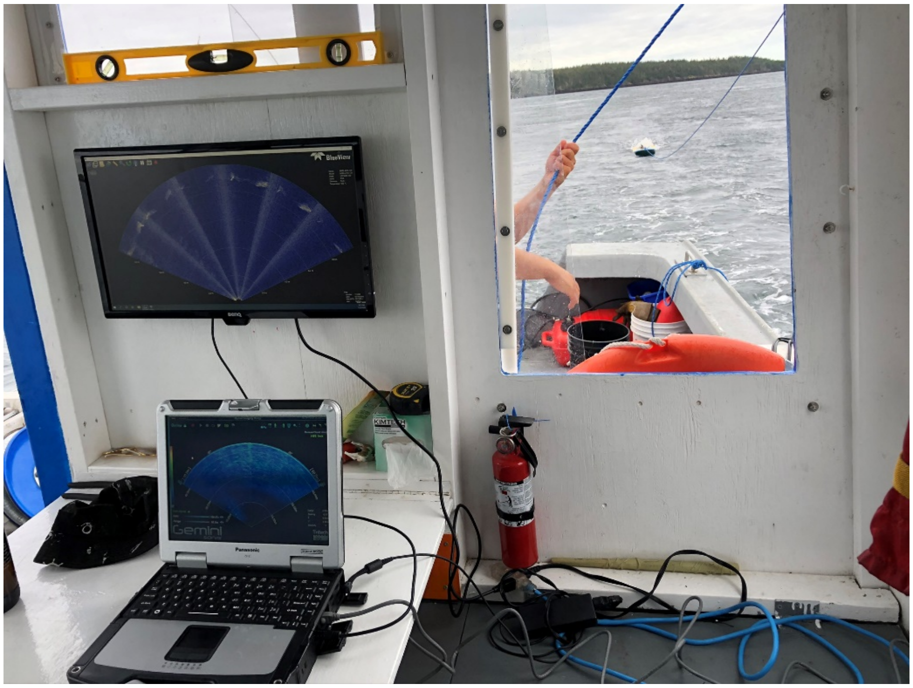


Figure 2: Data display and collection on research vessel Grand Adventure

The sonars and camera were mounted on a pole which could be lowered over the vessel's port side and fixed in position as shown in Figure 3. In the deployed position, the instruments were submerged to a depth of approximately 1 m. The deployed sonars were oriented such the that top of the ensonified area extended behind the boat approximately parallel with the water surface and extended downward at the 20 degree angle of the beam spread for both sonars. During the principle data collection periods, the Grand Adventure was anchored in mid-channel during ebb and flood tide flow conditions, such that current velocities ranged from approximately 1 to 2.5 m/s with the instruments oriented downstream. Targets were suspended approximately 2 m beneath a 3 m long surfboard (the SciBoard) outfitted with towing and instrument attachment points for use as a towed platform. The targets could then be introduced to the ensonified area by towing the SciBoard a known distance behind the Grand Adventure. This placed targets in the upper portion of the ensonified area that was also most susceptible to wake and wave related air entrainment. The targets' proximity to the sea surface was required in order for them to be ensonified while close to the sonars. The SciBoard and experiment setup are shown in Figures 4 and 5. The targets, shown in Figure 6, included a 2.54 cm (1 inch) diameter tungsten carbide sphere (Target 1), 0.45 kg (1 lb.) (9.5 cm long x 3.8 cm max diameter) lead fishing weight (Target 2), approx. 12 cm diameter basalt rock in a lobster bait bag (Target 3), and a V-Wing glider (Target 4) (approx. 52 cm wing tip to tip and 46 cm nose to tail) from Dartmouth Ocean Technologies (DOT). Targets 1, 2, and 3 were suspended from the

SciBoard using a combination of 40 pound and 200 pound test monofilament fishing line. Target 4 was suspended using 1/4 inch Polysteel fishing line due to the increased downward force, increased cost of the target (reducing risk of loss), and ease of handling. The V-Wing is designed to create downforce and maintain orientation in flow, with approximately (27 kg) 60 lbs. of downforce in 2.5 m/s flow. No metal was included in the target suspension system. Knots were used to secure the targets with no hooks, shackles, etc. below the water line.

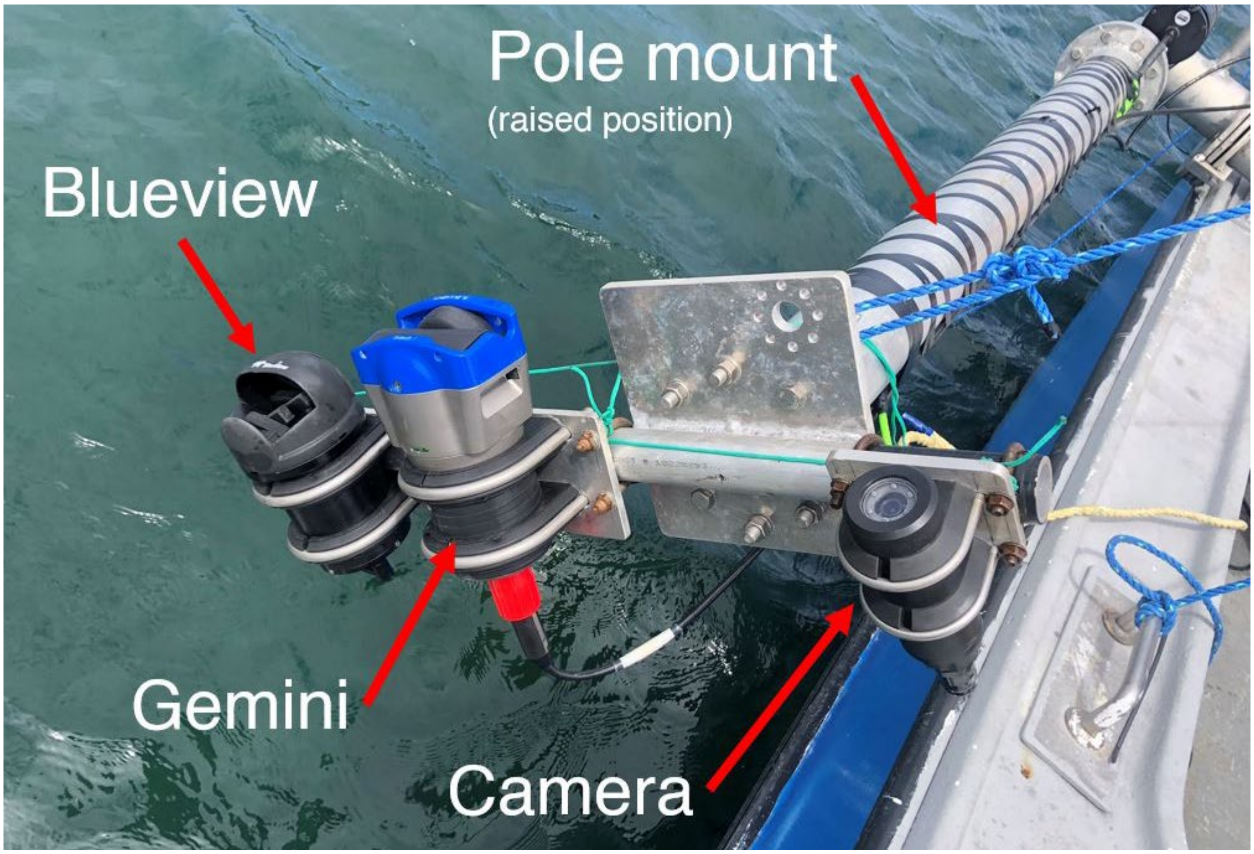


Figure 3: Pole mounted sonars and camera

Figure 4: SciBoard

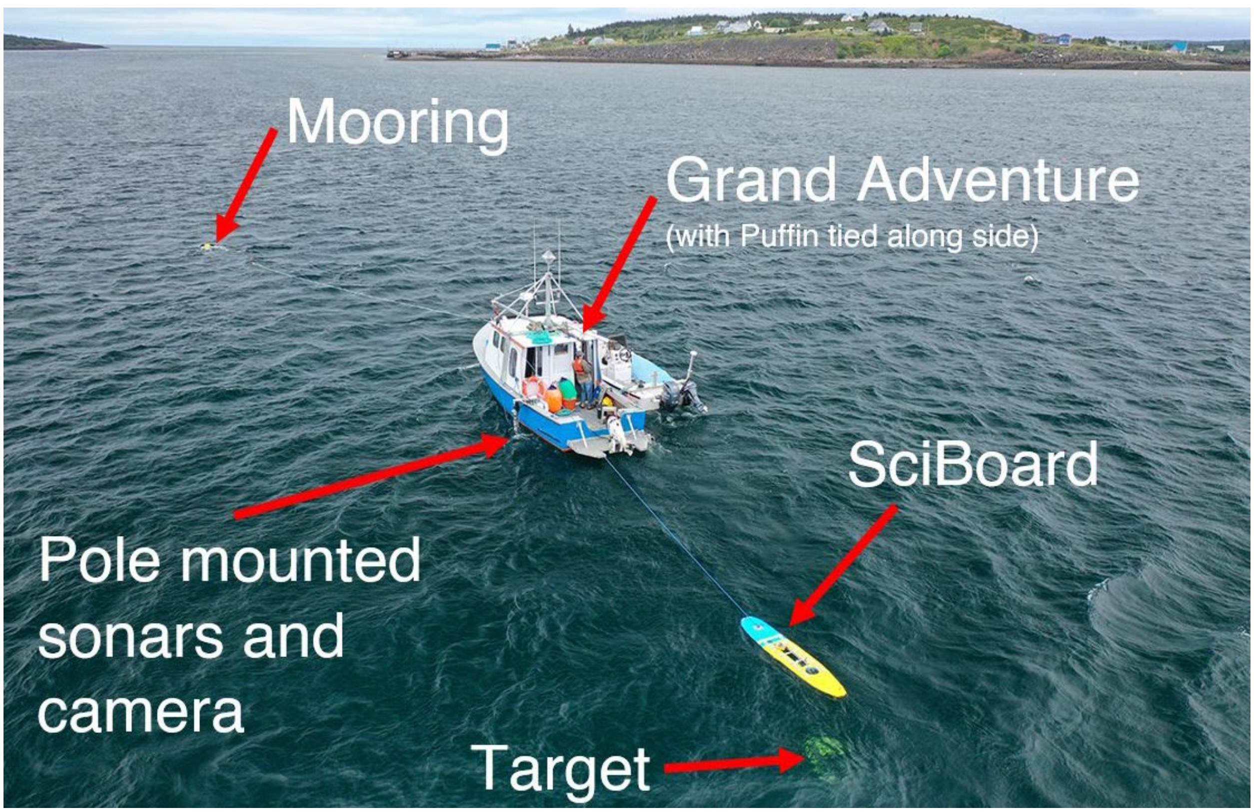


Figure 5: Aerial image of experiment layout

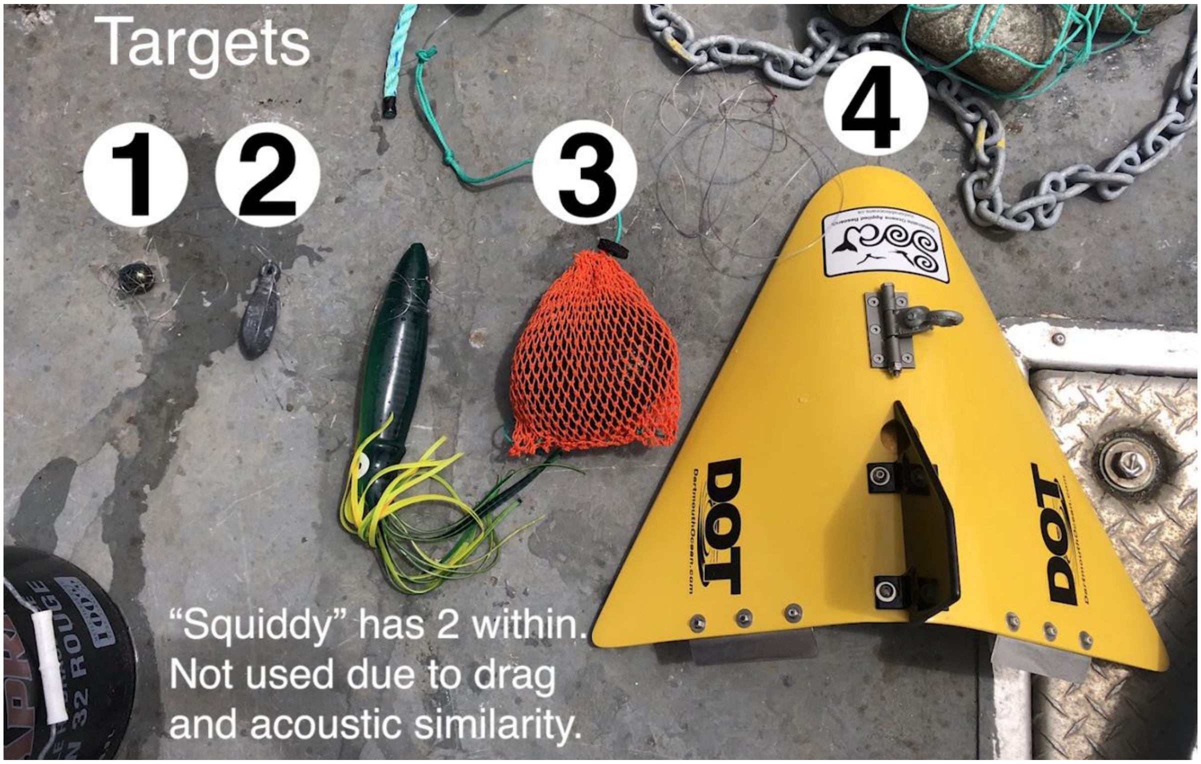


Figure 6: Targets

During data collection the SciBoard and suspended target were held at constant ranges from the sonars along the port side and downstream of the Grand Adventure, and also released to freely drift downstream with increasing range. Holding targets at a constant range had the advantage of allowing plumes of entrained air (bubbles) to pass by the targets. For each target, a series of data files were collected using: the Gemini with the sampling range set to 50 m then 10 m, and the Blueview with the range set to its maximum value of 10 m. A video of the experiment setup is available at https://vimeo.com/473592147, and a schematic showing the profile and plan views is provided in Figure 7.

Although the Grand Adventure was powered down during data collection, the wake induced by tidal flow along the hull and pole mount created significant entrained air downstream of the vessel in the focus area for data collection. This is an inherent limitation of vessel mounted systems. The experimental setup should be considered similar to deployment of a multibeam sonar from a tidal power platform, looking downstream towards turbines, with entrained air introduced from the mounting pole and tidal platform hull/structure.

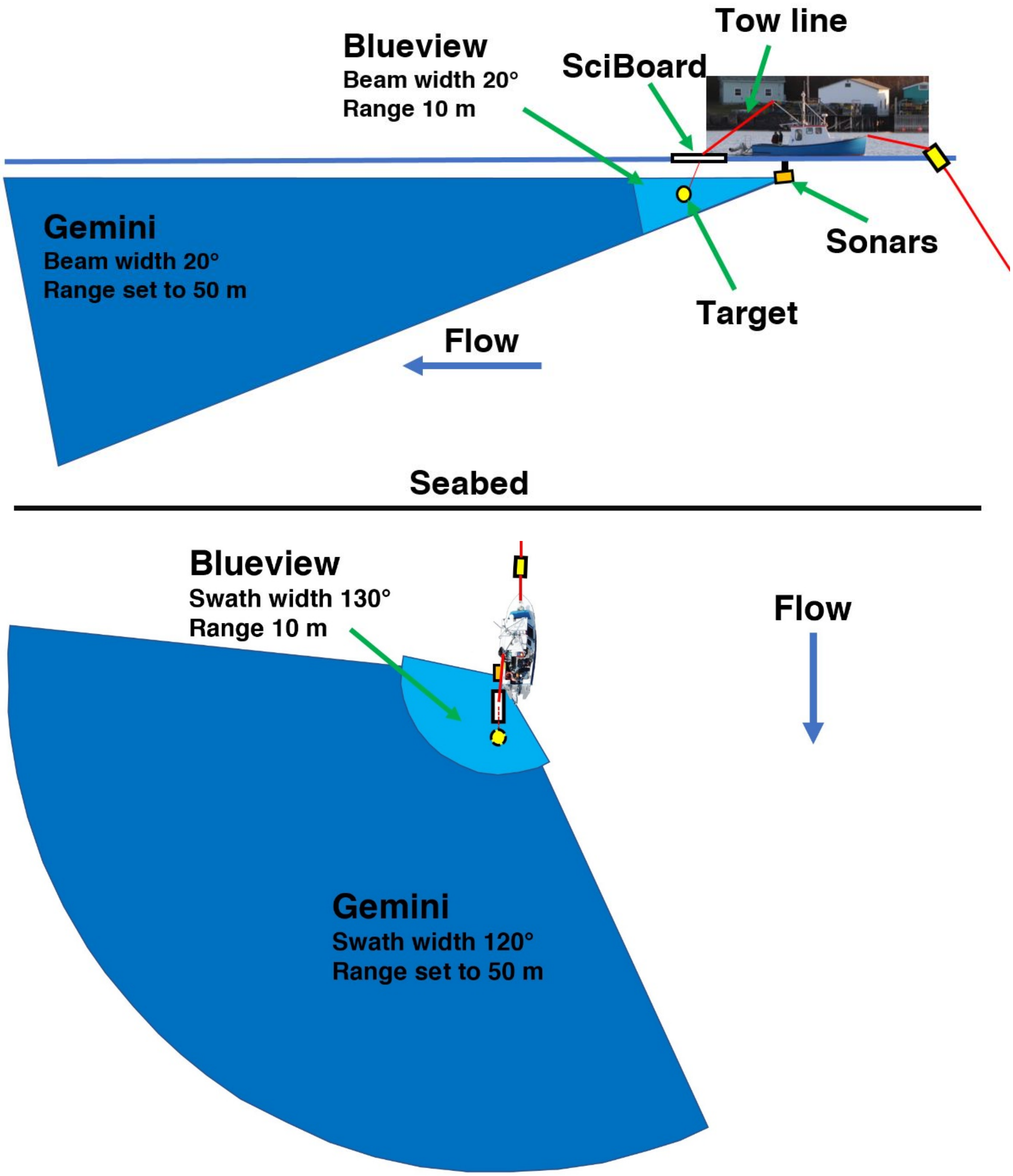


Figure 7: Schematic of experiment setup

2.1.2 Locations

The data collection locations are shown in Figure 8. Location 1 was selected for initial trials to provide a relatively shallow depth (15 m at low tide) in order to test our ability to anchor in strong tidal flow. The shallow depth imposed a limitation on the Gemini's ensonified area, which reached bottom at distances greater than approximately 25 to 30 m, depending on the stage of the tide. A sample sonogram of this case is shown in Figure 9. Location 1 was used for sampling on 2020-07-16 (flood) and 2020-07-17 (ebb) and was subject to maximum current velocities of approximately 2.5 m/s during sampling. Location 2 was characterized by depths of 25 to 30 m at low tide. Here, no returns from the seabed were recorded out to the full 50 m range utilized for the experiments. Data collection was conducted at Location 2 on 2020-07-31 (flood) and 2020-08-07 (ebb), with peak current velocities of approximately 2.5 m/s.

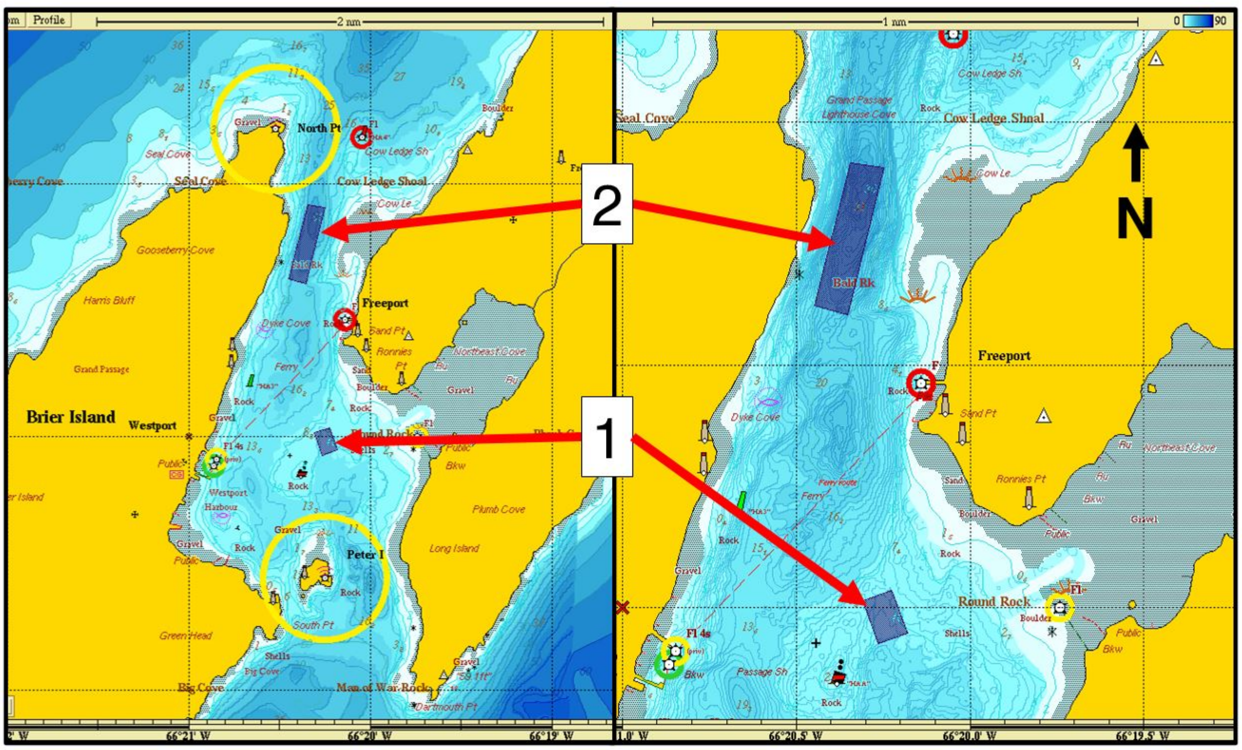


Figure 8: Data collection locations in Grand Passage

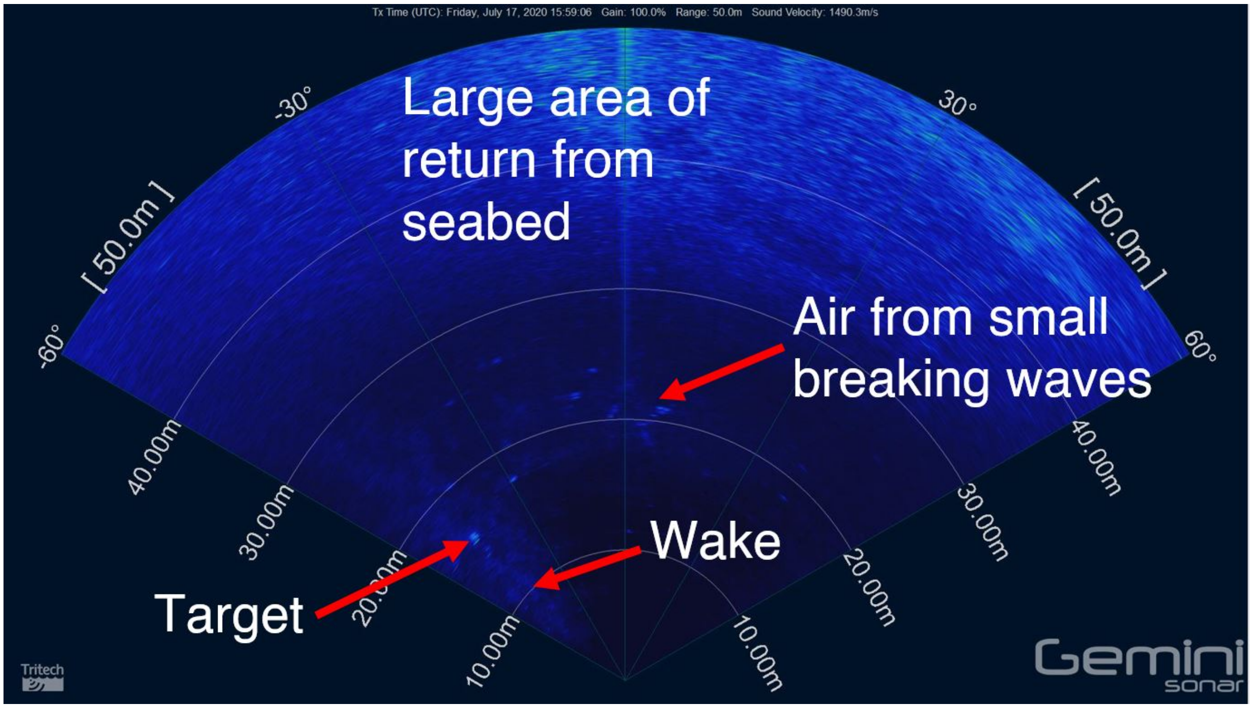


Figure 9: Example of seabed returns, wake, and air from waves on the Gemini

2.1.3 Acoustic Interference

Acoustic interference was not present at observable levels during the initial testing in Freeport Harbour but was persistent during sampling in Grand Passage. This may be due to an increase in sound scatterers in Grand Passage, as the water was observed to have high levels of plankton and entrained air that both produce stronger overall returns of acoustic energy to the sonars. As a result, data were collected in Grand Passage with the sonars operating both concurrently and independently to allow evaluation of the effect of acoustic interference (or 'cross talk') between the two instruments. Figures 10 and 11 provide examples of acoustic interference in sonogram images from each of the sonars caused by cross talk from the other. The interference pattern is consistent for both cases, appearing as radially symmetric bands on the Gemini and more localized jagged patterns on the Blueview visible in sectors 1, 2, and 6 of the sonogram in Figure 11. The interference signatures in both instruments are not static in position nor continuous or persistent in movement. The effects of acoustic interference are best viewed in the video files provided in the Results section of this report and are discussed further therein.

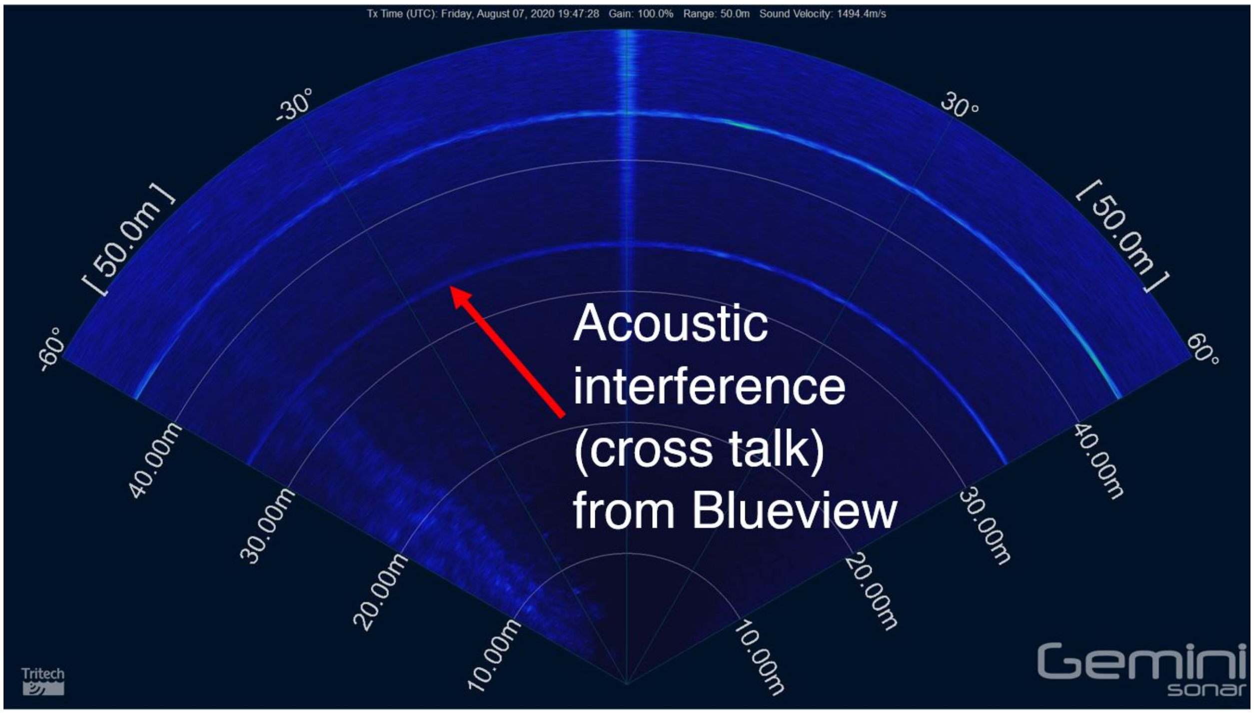


Figure 10: Example of acoustic interference for the Gemini

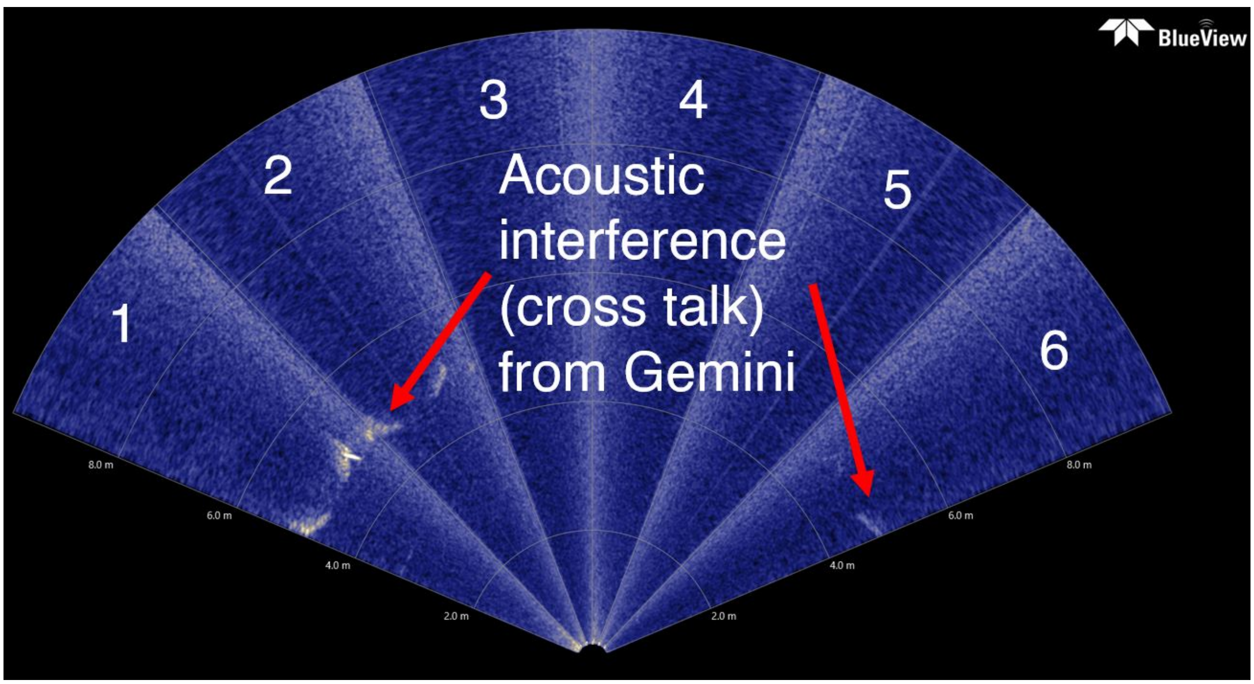


Figure 11: Example of acoustic interference for the Blueview

2.2 Data analysis

The data collected in Grand Passage were manually analyzed to evaluate the performance of the Gemini and Blueview multibeam imaging sonars for detecting and tracking near surface targets in strong tidal flow with a high level of air entrainment. The visualization and organization of the data was conducted using the industry standard software for each sonar: Gemini SeaTec and Teledyne ProViewer[1]. SOAR used these software packages for live viewing of all data as it was collected, followed by initial review and organization by target type.

The sonar images were exported to video (1920 x 1080 resolution) to facilitate ease of sharing and consistency in the manual analysis. Video framerates were set to display data at 2x real-time speed. The ability to use increased playback speed was apparent from SOAR's initial analysis of the data files and utilized to demonstrate an increase in efficiency that may be applicable to active monitoring of tidal turbines.

The video files from both sonars were organized into training and test data sets, which were shared with 9 sonar observers who conducted the manual analysis, including participants from SOAR, Luna Sea Solutions, FORCE, Mi'kmaw Conservation Group, and MarineSitu. The training data sets provide examples in which each target is detected and tracked with a red circle indicating target position and a photograph from the optical camera identifying the target.
The test data sets include:

- 21 files with the Gemini set to 50 m range,
- 14 with the Gemini set to 10 m range, and
- 30 files with the Blueview set to 10 m range,
  - 14 of these 30 files were simultaneous data collection with the Gemini at 10 m for direct comparison of the sonars.

[1] The development of automatic data processing algorithms for multibeam imaging sonars is an active area of research. Recent publications (e.g. Cotter and Polagye, 2020) on these methods have demonstrated the ability to detect and track targets with some ability to automatically classify between biologic and non-biologic classes. This classification level of processing typically relies on information from multiple instruments for co-registration of known targets (Joslin 2019). However, there is currently no software readily available with known ability to conduct reliable data analysis in turbulent flow with high levels of air entrainment. Therefore, data were analyzed manually to meet the primary objectives of the study.

The test data sets included additional data files, for which it was left to the observers to detect, track, and identify the targets. A standard spreadsheet was provided to each observer including columns for:

- File number (for SOAR to cross-reference the data files)
- Target present (yes/no)
- Target identification
    - Type (1 through 4)
    - Certainty (1 low to 5 high)
- Detection range (minimum and maximum)
- Ability for detection and tracking (1 low to 5 high)
- Notes describing the trajectory of the target.

The results were categorized by sonar and target type and used to evaluate the performance of each sonar including the effects of flow speed and acoustic interference. Links to the training and test data sets for each sonar are provided below. The data are best viewed in video form. As such, readers of this report are encouraged to watch these data videos for better understanding of the results and conclusions discussed in the following sections. Some example screen shots from the training data sets are also provided in Figures 12 through 15.

Gemini training data	https://vimeo.com/473580369
Gemini test data with 50m range	https://vimeo.com/473665614
Gemini test data with 10m range	https://vimeo.com/473688042
Blueview training data	https://vimeo.com/473964794
Blueview test data	https://vimeo.com/474025663

Through use of the Vimeo platform we also tested video review functionality that allowed observers to directly enter notes encoded to video in space and time. In the case of Vimeo this review functionality was created to facilitate collaboration in video editing. For our analysis it provides the ability to visually verify what the observers were identifying. It was important for each observer to work independently, so links were provided to private review pages. Vimeo or another similar collaborative video editing system may be useful for future manual analyses of video data from multibeam sonars and/or optical cameras at active tidal project sites, including facilitating communication of times and locations of interest for further investigation and analysis.

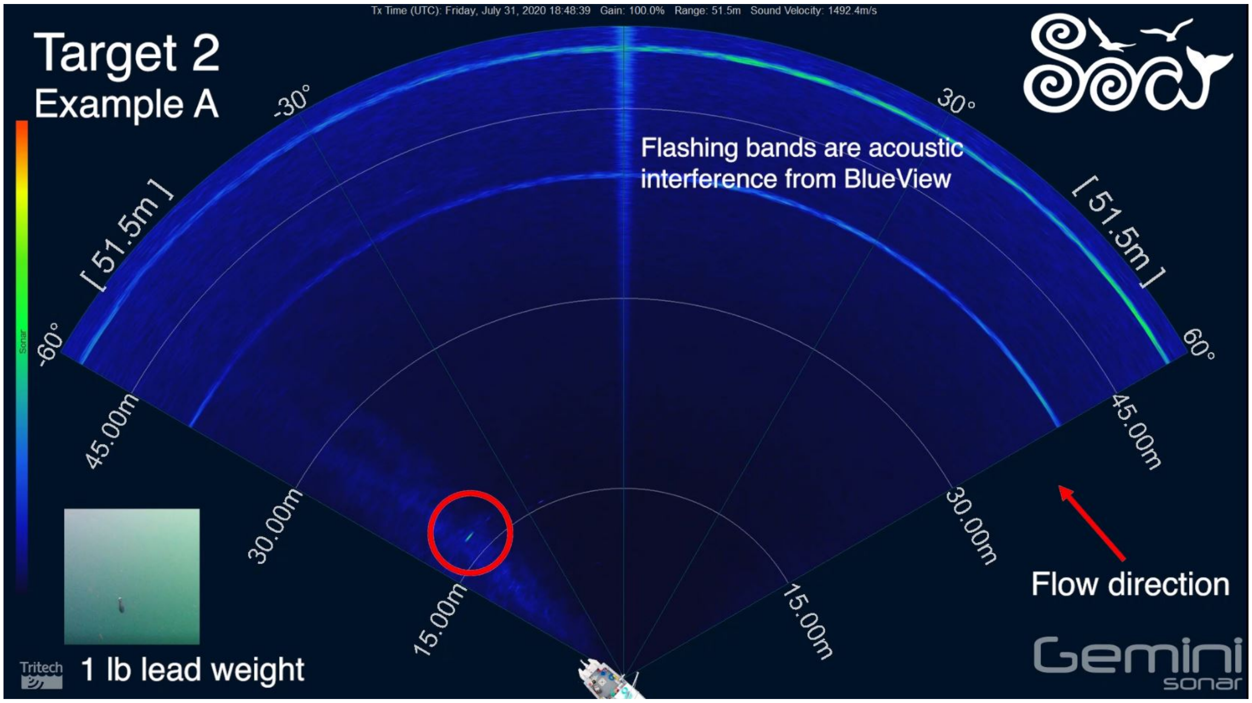


Figure 12: Example from training data - Gemini - 50m range - Target 2

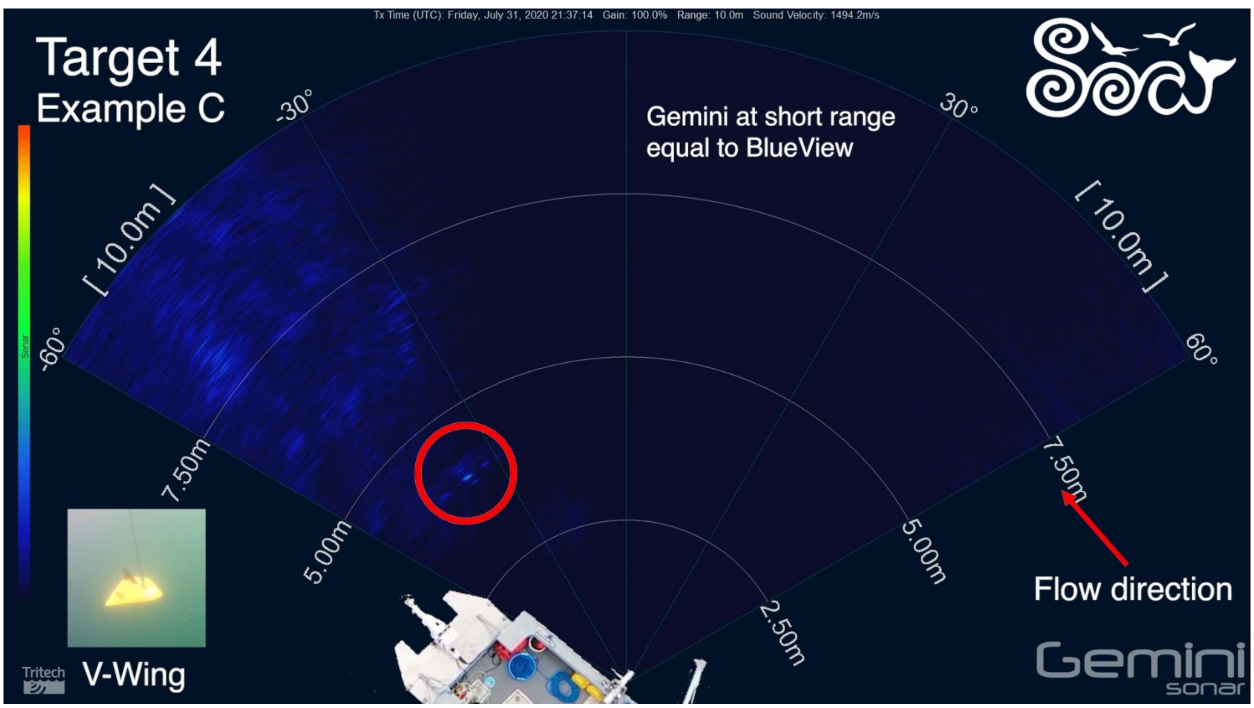


Figure 13: Example from training data - Gemini - 10m range - Target 4

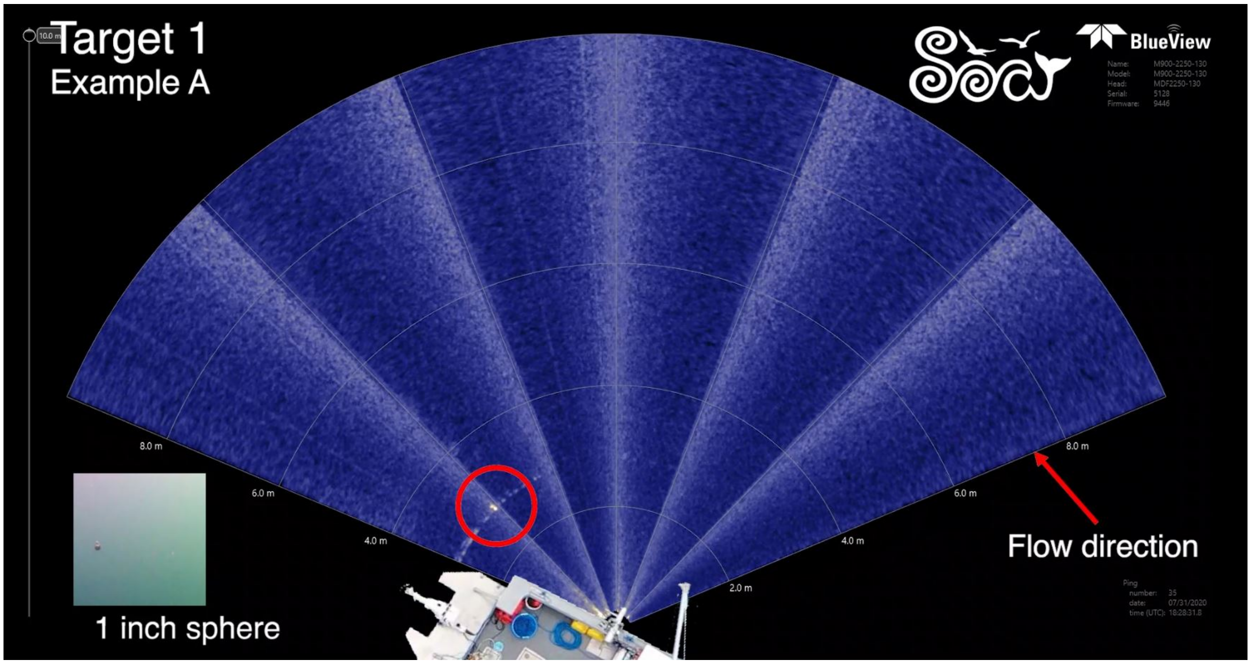


Figure 14: Example from training data - Blueview - 10m range - Target 1

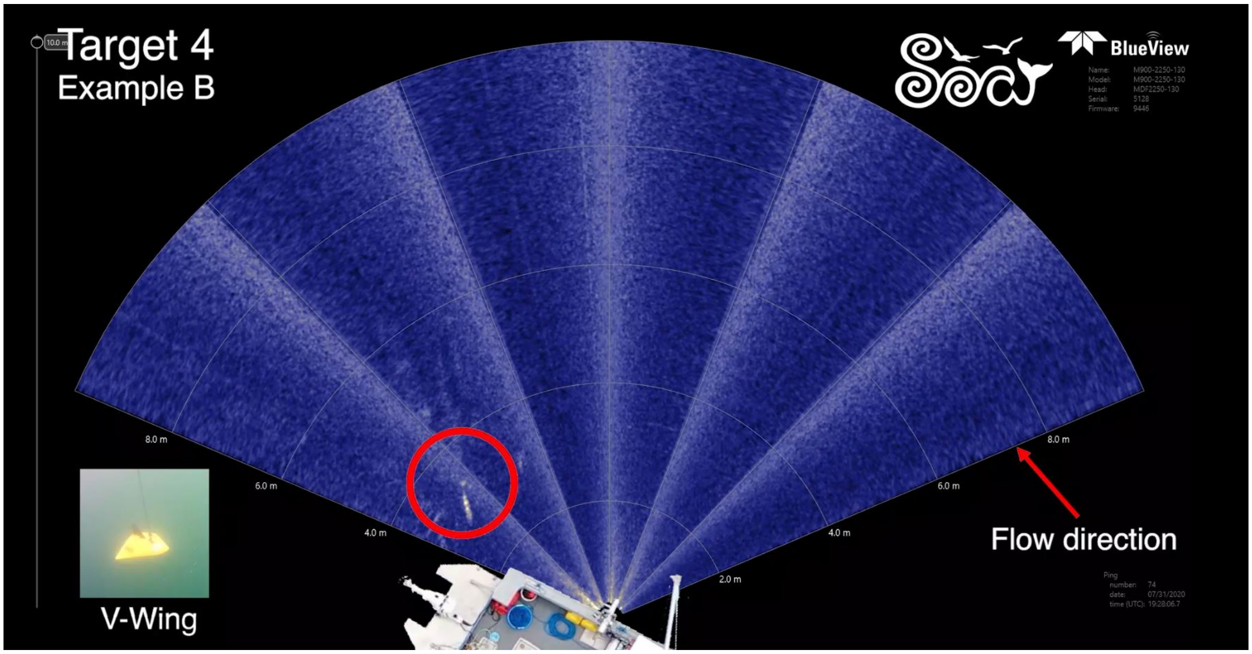


Figure 15: Example from training data - Blueview - 10m range - Target 4

3.0 Results

3.1 Detection, identification, and tracking

A summary of results from the manual analysis of test data organized by sonar type is provided in Table 2. The observers' scores for target present (detected), target identified, max range tracked, ability to detect and track targets are used to evaluate the performance of the sonars.

The Tritech Gemini with range set to 10 m preformed particularly well, with 99% of all targets detected, and 63% correctly identified. On average, the targets were tracked to 92% (9 m) of the set range, and the detection and tracking abilities scored greater than 4 out of 5. The reduced ability to detect and track targets with the Gemini range set to 50 m is an expected result, primarily due to targets occupying fewer pixels in the sonogram image and the presence of additional returns from potential targets other than our own.

Using the Blueview data, observers demonstrated the ability to resolve finer-scale differences between targets (highest average score for target type correct). However, the Blueview was limited in detection and tracking due to the areas of increased noise on the sonogram. This most significantly affected the ability to track targets as they passed into or through the high-noise areas, but also reduced ability to initially detect and identify targets depending on target location. The intensity of backscatter returned from the targets also varied depending on which sector of the sonogram it was in, potentially due to variable sensitivity of the receiving transducer elements.

Table 2: Summary of results by sonar

Sonar	Target present % correct	Target type % correct	Max range tracked % of set value	Ability to (1 to 5)	
				Detect	Track
Gemini 50m	93%	43%	85%	3.8	3.6
Gemini 10m	99%	63%	92%	4.3	4.2
Blueview 10m	98%	68%	83%	3.7	3.5

A further breakdown of the survey results by sonar and target type is provided in Table 3. As expected, the results indicate an increase in sonar performance with increasing target size. Observers had the most trouble with the 2.54 cm (1 inch) tungsten carbide sphere (Target 1) and the 0.45 kg (1 lb.) (9.5 cm long x 3.8 cm max diameter) lead fishing weight (Target 2), and were more successful in identifying and tracking the basalt rock in a lobster bait bag (Target 3) and the DOT V-Wing (Target 4). The detection and tracking results by target type are summarized in Figures 16 and 17.

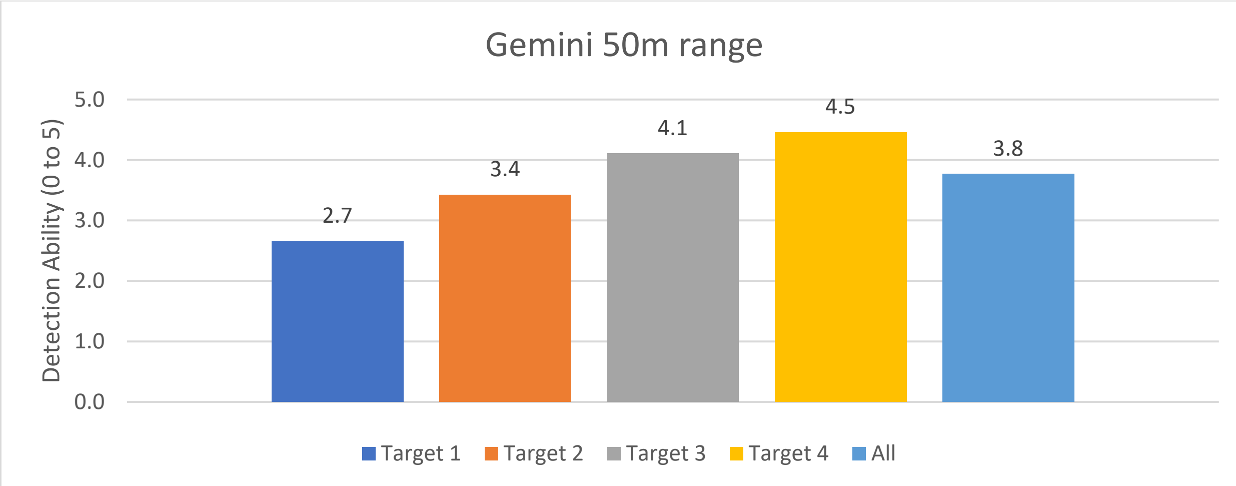
Table 3: Summary of results by sonar and target type

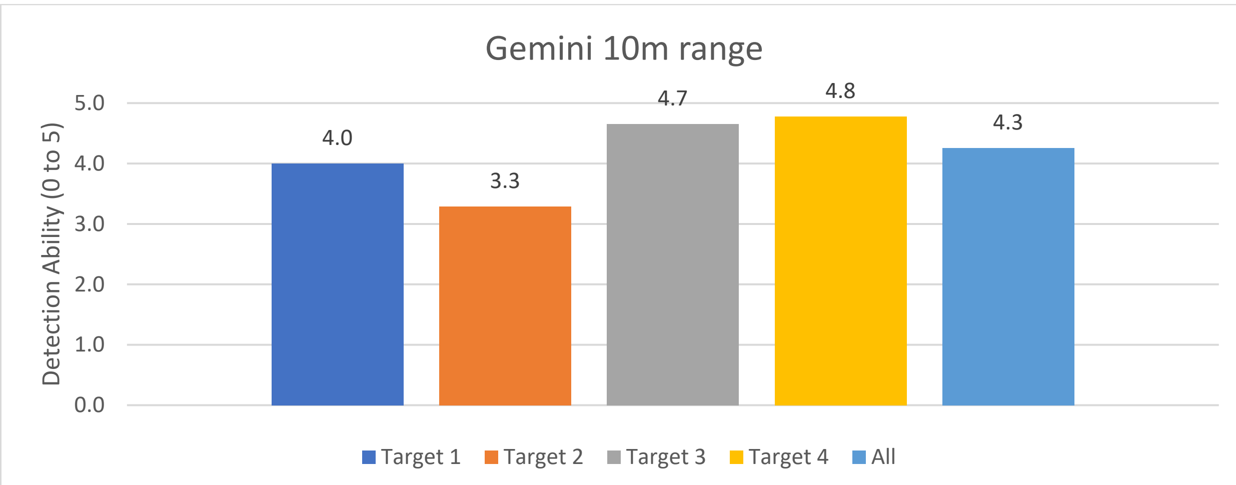
Target type	Target present % correct	Target type % correct	Max range tracked % of set value	Ability to (1 to 5)	
				Detect	Track
Gemini (50m range)					
1	75%	31%	51%	2.7	2.2
2	95%	23%	82%	3.4	3.1
3	96%	33%	93%	4.1	3.9
4	100%	79%	102%	4.5	4.5
All	**93%**	**43%**	**85%**	**3.8**	**3.6**
Gemini (10m range)					
1	100%	63%	96%	4.0	3.8
2	96%	25%	81%	3.3	3.0
3	100%	59%	95%	4.7	4.7
4	100%	94%	93%	4.8	4.8
All	**99%**	**63%**	**92%**	**4.3**	**4.2**
Blueview (10m range)					
1	100%	57%	70%	3.1	2.8
2	89%	50%	76%	3.0	3.0
3	100%	71%	92%	4.0	3.9
4	100%	88%	91%	4.5	4.3
All	**98%**	**68%**	**83%**	**3.7**	**3.5**

An example interpretation of the tabulated results is as follows. For the case of Target 1 with the Gemini at 50 m range, sonar observers were able to:

- correctly detect a target present 75% percent time
- correctly identify it as Target 1 31% of the time, and
- track the target to 51% of the maximum set range – in other words, track the target from 0 to approximately 25 m.

The observers' scores indicate the Gemini 50 m, Target 1, case to be the least effective of all tested for detecting and tracking, with average scores of 2.7 and 2.2 for ability to detect and track, respectively.





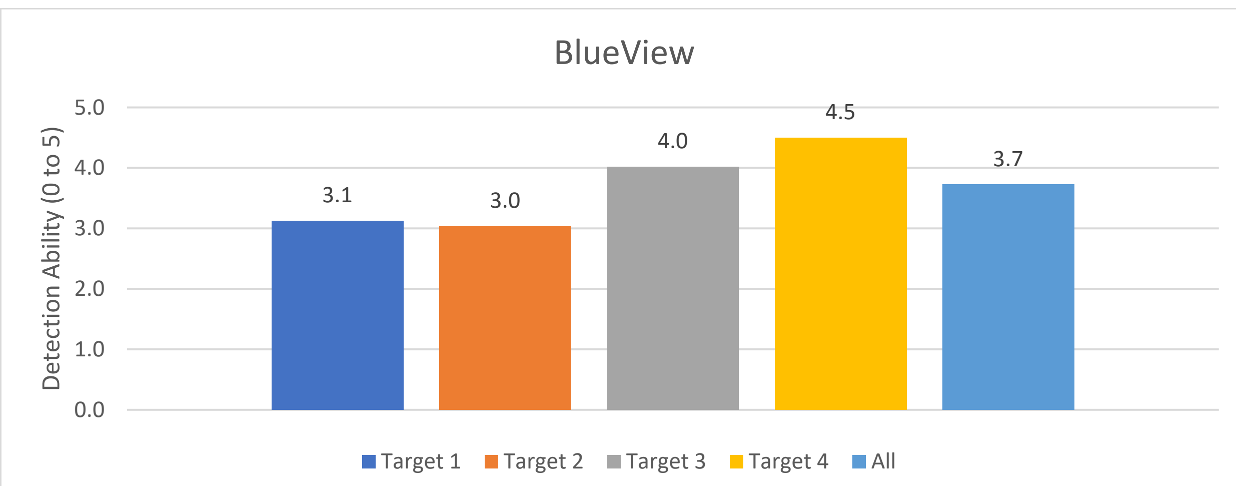


Figure 16: Detection ability for each sonar by target type

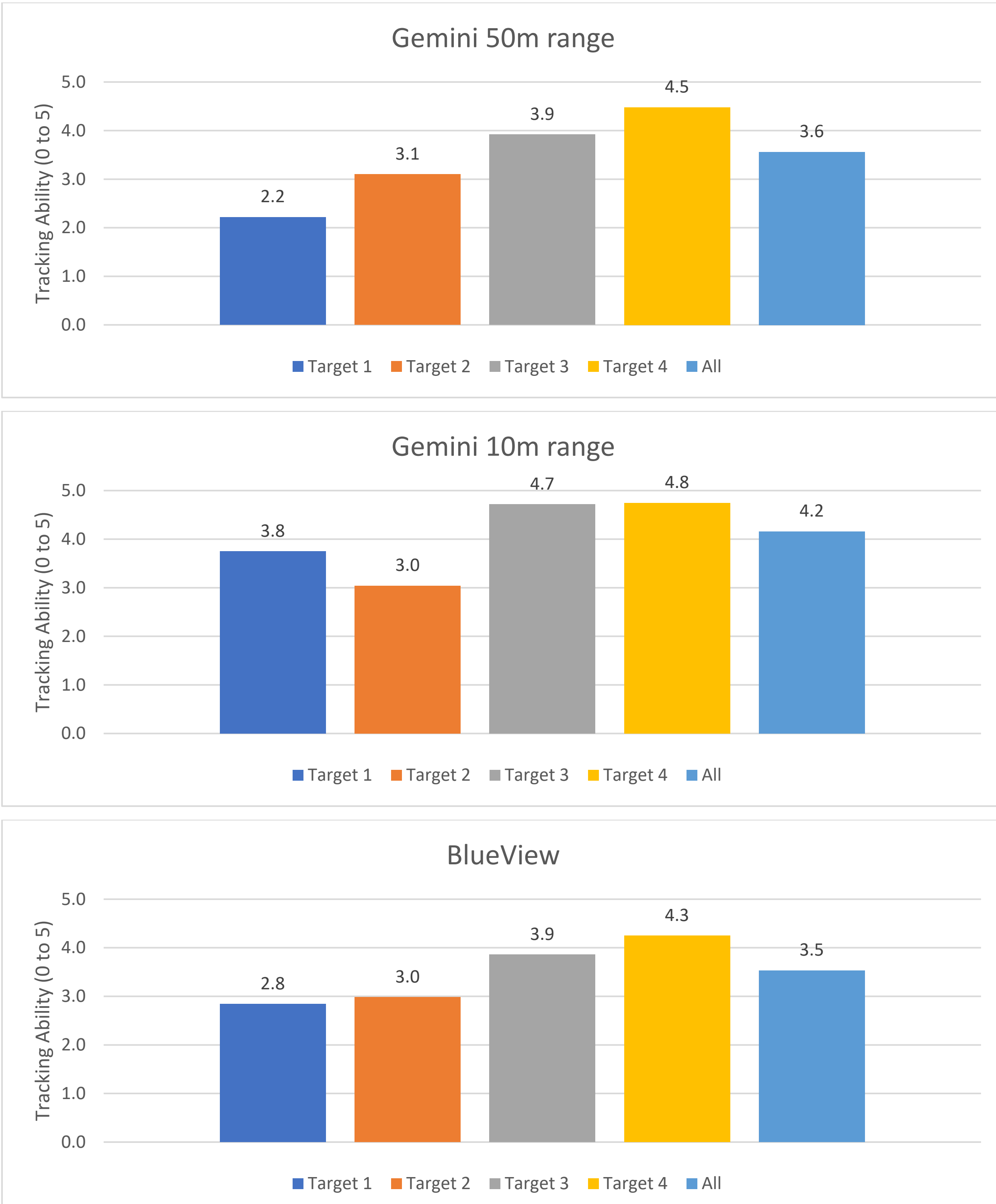


Figure 17: Tracking ability for each sonar by target type

3.2 Effect of Flow Speed

The relationship between flow speed and sonar performance was evaluated by calculating the coefficient of determination, R^2, value between the flow speed and the detection and tracking scores. R^2 is a measure of the proportion of the variance in the dependent variable (detection and tracking scores) that can be predicted from the independent variable (flow speed). R^2 values range from 0 to 1, with 1 being one-to-one correlation. Maximum flow speeds were between 2 and 2.5 m/s, with R^2 values ranging from 0.00 to 0.05 based on 65 data points (N = 65), suggesting no significant relationship between flow speed and sonar performance. A summary of the R^2 values is provided in Table 4.

Table 4: Effect of flow speed on sonar ability to detect and track targets (R^2 with N=65)

Sonar	R^2	
	Detect	Track
Gemini 50m	0.02	0.00
Gemini 10m	0.05	0.01
Blueview 10m	0.04	0.03

3.2 Hardware Limitations

The Blueview was included in testing due to its higher frequency output, which is better suited for close range target detection and tracking. However, the MKI model of the Blueview M900-2250 has a hardware limitation resulting in several persistent high-noise bands in the data. The high-noise bands resulted in difficultly for detection and tracking when target backscatter values were similar to the background noise levels. This effect is observed in all training and test data examples (see Figures 11, 14, and 15). SOAR contacted Teledyne technical support for further information and were informed that Teledyne have now released a second version MKII of the M900-2250 sonar to help alleviate this problem, at the sacrifice of narrowing the field of view (swath width) from 130 to 45 degrees.

"The inconsistency between sectors in the MKI model is due to the BlueView FLS systems producing a Chirp signal that sweeps across frequencies, for example the 900 kHz actually sweeps from ~600 kHz to 1200 kHz across each sector. With the 3 transducer model (MKI), we had to map the sectors so that the high frequency end of a sector was adjacent to the low frequency end of the next sector. This produces imagery that is not nearly as consistent or "smooth" across all sectors. With the 4/2 transducer model (MKII), we can map sectors so that

high frequency is adjacent to high frequency and low adjacent to low for a much better image on both the 900 kHz head and 2250 kHz head. We decided to sacrifice FOV on the 2250 head to make the system more affordable and much smaller and less cumbersome." – Correspondence from Teledyne Engineer (2020-10-07)

An inconsistency in acoustic returns between sectors of the Blueview sonogram was also observed during data collection and analysis, which manifested as one or both of sudden changes in the magnitude of the acoustic return, and a discontinuity in the angular coordinate. This was most evident for natural targets (bubbles and potential fish) as they travelled with the flow (right to left) across the swath width. Numbering the sectors 1 to 6 from left to right, sector 3 seems to have the most notable decrease in returns. There is uncertainty in the cause, as at least some of the targets likely changed vertical position (and may have left the ensonified area), but the consistent nature of decreased returns in this sector suggests variability in transducer/beam sensitivity and/or difference in alignment. This effect can be observed in the training and test data set videos, with links provided in the Methods section.

The Gemini 720is has a similar technical hardware limitation that produces the single "spike" of increased return down the middle of the image which is easily viewable with range set to 50 m (see Figures 9, 10, and 12). This single and narrow spike cause minimal issues with data analysis, but correspondence from Tritech suggests that it might be reduced in a future hardware upgrade for the sonar.

3.3 Acoustic Interference

We evaluated the effects of acoustic interference (cross talk) between the Gemini and Blueview on the ability of manual observers to detect, track, and identify targets through repeat collections of data with the sonars running both concurrently and independently. The results of the comparison are shown in Table 5 and indicate a reduction on the order of 10% in ability to detect, identify, and track targets on the Gemini when the Blueview is operated concurrently. The results for the Blueview look similar with and without acoustic interference from the Gemini. In general, the acoustic interference can be described as distracting, but tolerable.

Table 5: Effect of acoustic interference

Sonar	Target present % correct	Target type % correct	Max range tracked % of set value	Ability to (1 to 5)	
				Detect	Track
Independent Operation					
Gemini 50m	97%	47%	88%	3.9	3.7
Blueview 10m	99%	66%	83%	3.8	3.6
Acoustic Interference					
Gemini 50m	86%	38%	77%	3.6	3.3
Blueview 10m	96%	70%	82%	3.6	3.5
Difference					
Gemini 50m	-11%	-10%	-11%	-0.3	-0.3
Blueview 10m	-4%	3%	-1%	-0.2	-0.1

4.0 Conclusions

The project addressed the objective of assessing the performance of surface deployed multibeam imaging sonars for target detections, including the extent of signal interference from waves/turbulence, and entrained air.

The Gemini 720is and Blueview M900-2250 multibeam imaging sonars were both found to be useful for detection and tracking of all target sizes used in our experimentation. However, differentiation of similar targets such as the 2.54 cm (1 inch) tungsten carbide sphere (Target 1) and 0.45 kg (1 lb.) lead fishing weight (Target 2) proved difficult. The sonars performed best for detecting, identifying, and tracking the V-Wing glider. This is an expected result as it was the largest target and had the most recognizable backscatter signature due to its characteristic shape. Entrained air from turbulence, waves, and the vessel/pole wake made tracking targets more difficult, but target persistence allowed them to be effectively detected and tracked by eye for all target types tested. We observed no relationship between flow speed and observers' abilities to detect and track targets with testing up to approximately 2.5 m/s, which is near to the maximum flow speed at Grand Passage. The Minas Passage is known to have higher flow speeds, which may result in higher levels of air entrainment. For comparison to the Minas Passage a flow speed exceedance curve is provided in Figure 18 calculated using depth averaged ADCP measured flow speeds from FORCE Berth Site A (45.3649 -64.4308). It shows maximum flow speeds of approximately 4.5 m/s and 2.5 m/s to be exceeded approximately 36% of the time, or conversely, flow speeds to be less than 2.5 m/s 64% of the time.

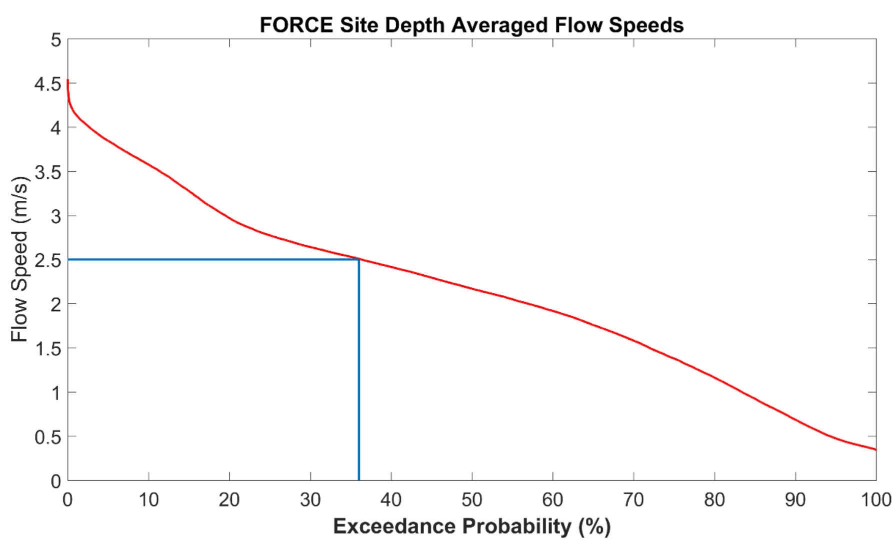


Figure 18: FORCE Site flow speed exceedance curve

SOAR recommends use of the Tritech Gemini 720is for application to monitoring interactions between marine animals and tidal turbines. With the 10 m range setting, the Gemini demonstrated comparable ability to the Blueview to identify targets and outperformed the Blueview in average target detection and tracking scores. At 50 m range, the Gemini still demonstrated a high level of utility for target detection, tracking, and presence/absence, though was less effective (ca. 50%) for target identification. It is likely that this technology will contribute significantly to effective monitoring and advancing knowledge of importance to regulators and other stakeholders.

The Teledyne Blueview M900-2250 MKI is an impressive technology that offered the ability to resolve finer scale features of the targets and their movements in some cases. However, the persistent high-noise bands resulting from the hardware limitation discussed in Section 3.2 represented a substantial impediment to reliable target detection and tracking. We conclude that data from the Blueview did not add substantial value or insight to the target analysis when used in conjunction with the Gemini. This should not rule out potential use of other MHz frequency multibeam sonars for monitoring the 10 m range in a combined sonar approach, including MKII of the Blueview.

Data analysis was successful for manual observers viewing data played back at 2x real time speed. Future work should consider efficiencies associated with accelerated data playback and could support use of software with variable speed playback that also allows for time and space encoded notes. Manual observer-based analyses should transition to automated feature detection and tracking, where possible, if multibeam sonar data are to be used for regular or long-term site monitoring.

For planning future data collection careful consideration of sonar orientation is critical. In an oceanographic context, the ensonified areas are relatively small and are sensitive to returns from seabed and sea surface. Careful planning of the ensonified area is required based on the questions to be addressed by the monitoring while minimizing unwanted returns. The ability to adjust orientation is highly beneficial, as we were able to do in this work by raising the pole and adjusting sonar pan and tilt by hand.

Another critical component for near surface deployments is the stability of the pole mount system to withstand strong flow with minimal vibrations. Upon initial tests in Grand Passage the pole mount aboard the Grand Adventure required additional strengthening prior to data collection. The image on the Acknowledgements page shows sparks flying at Meteghan Wharf as welding was being conducted by Clare Machine Works.

Some level of acoustic interference from other active sonar systems must be expected when carrying out deployments in or near active ports or passages, whether from passing pleasure or commercial craft, or from other marine operations. Data analysis methods and systems should be designed with this in mind, treating acoustic interference as an element to be anticipated and mitigated where possible through software processing.

Manufactured targets were the focus of this experiment, but marine animal targets were also observed in abundance in Grand Passage and adjacent Bay of Fundy waters. Data were collected that also show the multibeam sonars are likely to perform well in detection and tracking of fish, dolphins, and whales. These data require additional analysis, but some preliminary images are available. An example of a Humpback whale (belly up) diving into a school of fish in the Bay of Fundy (Gemini orientated downward) is shown in Figure 18. This connects with the secondary expected outcome of the project, providing data sets to support further research beyond scope/timeline of this project.

Further testing of and research into multibeam sonar usage from a vessel mounted (near surface) position would be useful in four focus areas, including:

1) fish and other marine animals in locations and seasons (times) with high levels of animal abundance and variety,
2) evaluating the most effective sonar orientations for monitoring the near field of tidal turbines,
3) flow speeds that exceed 3 m/s, and
4) increasing efficiency in data assessment, including reliable automation.

This work should build upon success in Grand Passage to conduct next steps in stronger flow conditions present in Petit Passage and Minas Passage.

The report titled "Field Assessment of Multi-beam Sonar Performance in Bottom Mount Deployments" (Trowse et al. 2020) provides similar analysis for the case of seabed mounted Gemini 720is and Blueview M900-2250, including comparison of results and further recommendations for next steps.

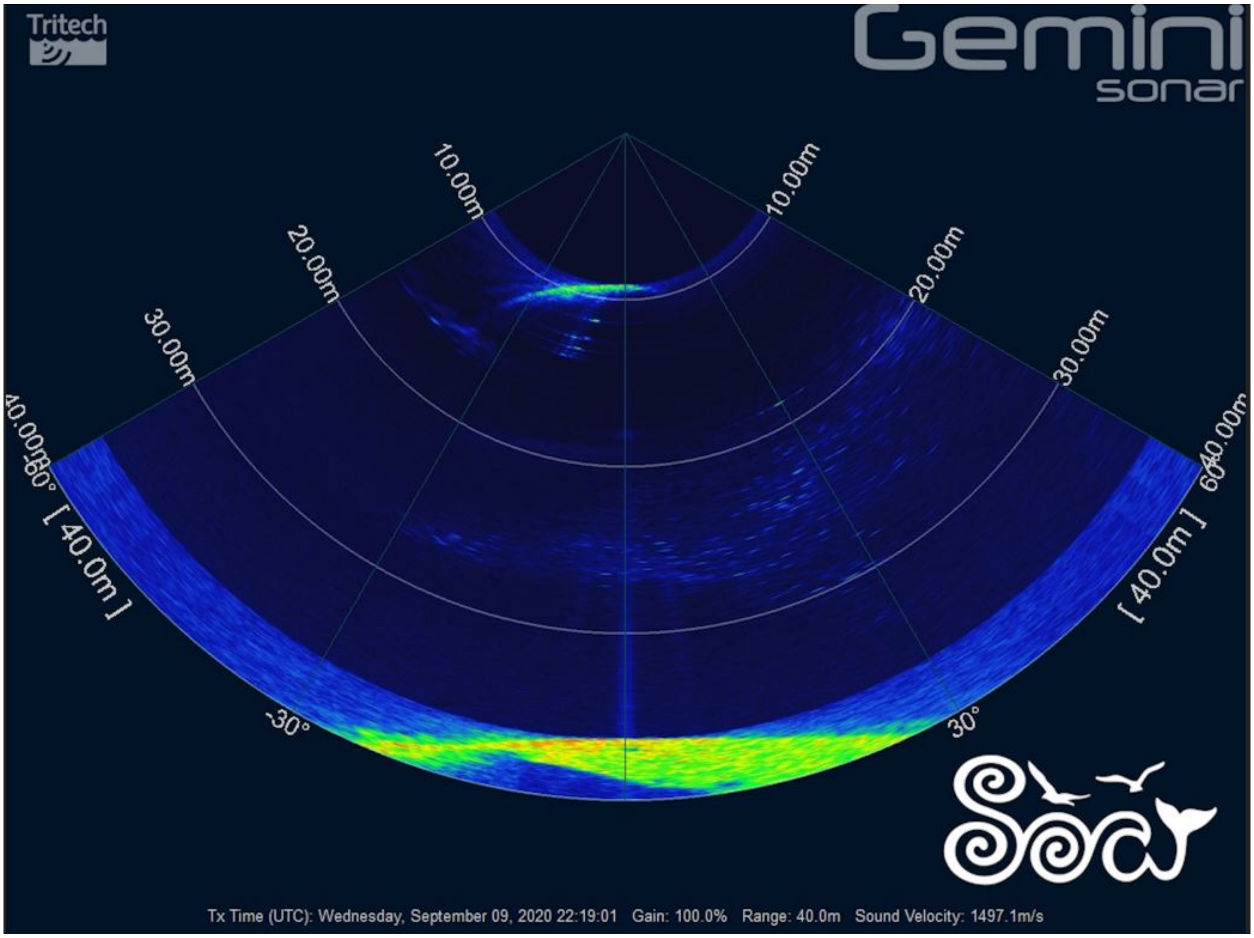


Figure 19: Gemini example of Humpback whale and school of fish

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Appendix III

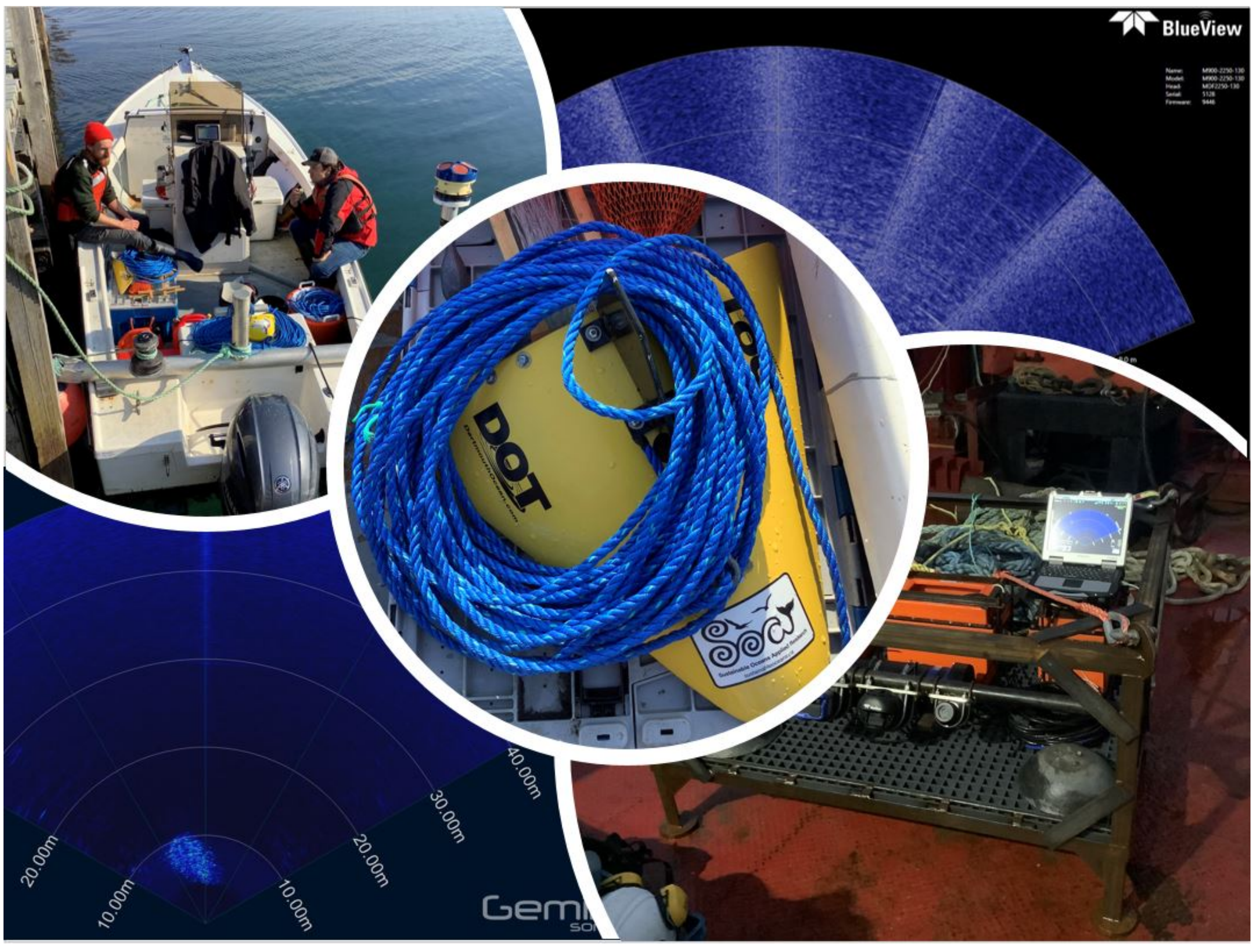
FINAL PROJECT REPORT (v1.4)

OERA Pathway 2020 Program

Field Assessment of Multi-beam Sonar Performance in Bottom Mount Deployments

OERA Project number: 200-219

February 1, 2021



Project Lead: SOAR – Sustainable Oceans Applied Research Ltd.

By: Greg Trowse, Dr. Tristan Guest, Gavin Feiel, Richard Cheel, and Dr. Alex Hay

Executive Summary

Multibeam imaging sonars have application to monitoring fish and marine mammal presence and behaviours in the near field of tidal turbine installations, including evaluating avoidance, evasion, and potential blade strikes. SOAR conducted field experiments to help reduce uncertainty in performance of the Tritech Gemini 720is and Teledyne Blueview M900-2250 multibeam imaging sonars for identifying and tracking discrete targets in high-flow environments. This information will help inform the Department of Fisheries and Oceans Canada, tidal energy developers, and other stakeholders in the design and implementation of effective monitoring systems for tidal energy projects in the Bay of Fundy and beyond. These two imaging sonars were the technologies recommended for testing by the subject matter expert for imaging sonars during the first phase (Global Capability Assessment) of the Pathway Program. The Tritech Gemini 720is operates at 720 kHz and has a maximum effective sampling range of approximately 50 m. The Teledyne Blueview M900-2250 has operating frequencies of 900 or 2250 kHz, with a 10 m range for the high frequency transducer head. As per the recommendation from the Global Capability Assessment, this report focuses on the Blueview's capabilities while operating at 2250 kHz.

Field trials included deployments of an Autonomous Multibeam Imaging Sonar (AMIS) monitoring system in Grand Passage. The depth at the deployment location is approximately 25 m at low water, with flow speeds up to approximately 2.5 m/s. The deployed sonars were oriented with their ensonified areas directed downstream. The instruments' horizontal fields of view oriented across-channel and vertical fields of view tilted upward from the bed.

Three targets were used during data collection: a 0.45 kg (1 lb.) (9.5 cm long x 3.8 cm max diameter) lead fishing weight, approx. 12 cm diameter basalt rock in a lobster bait bag, and a V-Wing glider (approx. 50 cm diameter) from Dartmouth Ocean Technologies. The targets were suspended beneath research vessel Puffin while drifting through the study area. The Puffin repeatedly travelled to a position upstream from the sonars, then drifted with the tidal flow such that the drift trajectory allowed the targets to pass through the sonars' ensonified areas. The AMIS system was fully autonomous, so no live view of data collection was available.

The data were manually analyzed to evaluate the performance of the Gemini and Blueview multibeam imaging sonars for detecting and tracking targets in strong tidal flow. The visualization and organization of the data were conducted using the proprietary software

packages associated with each sonar: Gemini SeaTec and Teledyne ProViewer. Data from the Gemini were exported into video and organized into training and test data sets, which were shared with 7 sonar observers who conducted the manual analysis to detect, track, and identify the targets. Links to the training and test data sets for are provided below.

Gemini training data https://vimeo.com/483141927
Gemini test data with 50m range https://vimeo.com/483142328

Due to the small ensonified area of the Blueview, insufficient sightings of known targets were collected to generate training and test data sets. A manual analysis was conducted by SOAR, with a focus of events of concurrent detection by the Blueview and Gemini including natural targets (primarily fish) and occasionally the artificial targets used in our methodology. A link to a video file with 21 comparative cases is provided below.

Concurrent Blueview and Gemini https://vimeo.com/487808248

The Tritech Gemini 720is received high scores from the observers in the ability to identify the presence of, visually detect, and track targets in videos displaying sonogram data output. The observers correctly identified the presence of a target in 99% of cases, and gave average scores greater than 4 out of 5 describing their visual detection and tracking ability. Targets were correctly identified roughly 50% of the time. No significant relationship between flow speed and ability to detect and track the targets was observed.

The Teledyne Blueview M900-2250 MKI is an impressive technology that offered the ability to resolve finer scale features of the targets and their movements in some cases. However, persistent high-noise bands resulting from a known hardware issue and an apparent transducer alignment issue represented substantial impediments to reliable target detection and tracking. We conclude that data from the Blueview did not add substantial value or insight to the target analysis when used in conjunction with the Gemini. This should not rule out potential use of other MHz frequency multibeam sonars for monitoring the 10 m range in a combined sonar approach, including MKII of the Blueview.

SOAR recommends use of the Tritech Gemini 720is for application to monitoring interactions between marine animals and tidal turbines. The Gemini demonstrated a high level of utility for detecting and tracking targets from vessel and bottom mounted orientations in tidal flows up to approximately 2.5 m/s in Grand Passage. It is likely that this technology will contribute significantly to effective monitoring and advancing knowledge of importance to regulators and other stakeholders. Tidal flows are faster at the FORCE site in the Minas Passage, with flow speeds exceeding 2.5 m/s 30 to 40% of the time.

With respect to deploying multibeam sonars from the surface (i.e., vessel) or seabed, the sonars performed well from both positions, despite increased levels of air entrainment in the vessel mount case. The selection of deployment position for monitoring tidal turbines is likely to be defined by the nature of the tidal device (floating or seabed mounted) and the questions to be addressed by the monitoring.

The project addressed the objective of assessing the performance of bottom deployed multibeam imaging sonars for target detections, including the extent of signal interference from waves/turbulence, and entrained air.

Further testing of bottom mounted multibeam sonars would be useful in four focus areas, including:

1) fish and other marine animals in locations and seasons (times) with high levels of animal abundance and variety,
2) evaluating most effective sonar orientations for monitoring the near field of tidal turbines,
3) flow speeds that exceed 3 m/s, and
4) increasing efficiency in data assessment, possibly including reliable automation.

This work should build upon success in Grand Passage to conduct next steps in stronger flows present in Petit Passage and Minas Passage. The report titled “Field Assessment of Multi-beam Sonar Performance in Surface Mount Deployments” (Trowse et al. 2020) provides similar analysis for the case of surface mounted Gemini 720is and Blueview M900-2250.

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Acknowledgments

SOAR thanks the following support organizations and supply chain who helped us deliver on this work:

- Offshore Energy Research Association of Nova Scotia
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- Clare Machine Works
- Luna Sea Solutions
- MarineSitu
- Mi'kmaw Conservation Group
- Fundy Ocean Research Centre for Energy (a.k.a. FORCE)
- Dasco Equipment Inc.
- Tritech and Teledyne technical support staff
- Canadian Hydrokinetic Turbine Test Centre

1.0 Introduction

Multibeam imaging sonars have application to monitoring fish and marine mammal presence and behaviours in the near-field of tidal turbine installations, including evaluating avoidance, evasion, and potential blade strikes (Hastie 2013; Viehman and Zydlewski 2014; Bevelhimer et al. 2016; Williamson et al. 2016, 2017; Sanderson et al. 2019). However, there is uncertainty in performance of these instruments in high-flow environments due to turbulence and associated entrained air in the water column, where a reduction in instrument efficacy may result from scattering of the transmitted acoustic signal through turbulent zones of the water column before the signal reaches potential targets, with further signal dilution on the return to the transducer (Melvin and Cochrane 2014). Some specific and additional challenges include a) mounting sonars at sufficient depth in high-flow environments to reduce exposure to entrained air, b) achieving optimal orientation such that the area of interest is ensonified while minimizing acoustic returns from surface and/or seabed, and c) transferring, storing, and efficiently analyzing large amounts of data.

Several makes and models of multibeam imaging sonars are available, with a major source of difference being the frequency at which they transmit acoustic energy. Higher frequencies are associated with shorter wavelengths, which results in resolution increasing with frequency, and range decreasing with increasing frequency. The combined use of kHz and MHz frequency range multi-beam imaging sonars is of interest for monitoring marine animals because it offers potential for an instrument package to detect and track targets at ranges up to approximately 50 m with identification (and/or finer scale tracking) of targets at a range up to approximately 10 m. For environments with suitable visibility, the addition of an optical camera offers increased potential for target identification, target validation, and tracking at ranges of approximately 0.1 to 15 m in very clear waters.

As part of the Pathway Program, SOAR conducted work to help evaluate the performance of the Tritech Gemini 720is and Teledyne Blueview M900-2250 (2250 kHz transducer head) multibeam imaging sonars for evaluating interactions between marine animals and tidal turbines. This information will help inform the Department of Fisheries and Oceans Canada (DFO), tidal energy developers, and other stakeholders in the design and implementation of effective monitoring systems for tidal energy projects in the Bay of Fundy and beyond.

The Tritech Gemini 720is multibeam imaging sonar has been used by MCT Seagen in Strangford Lough (Hastie 2013), OpenHydro at the Fundy Ocean Research Centre for Energy (FORCE) (Viehman et al. 2017), and other applications including studies commissioned by FORCE (Gnann 2017). With an operating frequency centered at 720 kHz, the Gemini has a target detection range of up to 100 m (Cotter, et al. 2017) but has reduced resolution in comparison to higher frequency systems. The dual frequency Teledyne Blueview M900-2250 has two sets of transducers, one set centered at 900 kHz (close to the Gemini) and the other set at 2250 kHz (2.25 MHz). Use of the Blueview 2.25 MHz transducer head may have application in shorter range monitoring, up to approximately 10 m (Cotter et al. 2017). These two imaging sonars are the technologies recommended for testing by the subject matter expert for imaging sonars during the first phase (Global Capability Assessment) of the Pathway Program (Joslin 2019).

SOAR's work in 2020 has included data collection and analysis from near surface (vessel mounted) and seabed deployments. This report covers the methodology and results for the bottom mounted experiment. "Field Assessment of Multi-beam Sonar Performance in Surface Mount Deployments" (Trowse et al. 2020) discusses the vessel mount deployment (vessel mount project).

The **objective** of the work covered in this report is to assess the performance of seabed deployed multibeam imaging sonars for target detections, including the extent of signal interference from waves/turbulence, and entrained air.

The **expected outcomes** include**:**

- Primary - Report on performance of bottom deployed multibeam imaging sonars for target detections, and a recommendation on whether the use of bottom deployed multibeam imaging sonars is feasible for monitoring interactions between marine animals and tidal turbines.
- Secondary - Data sets to support further research (beyond the scope and timeline of this project) including potential for calibration of multibeam imaging sonars, quantification of the effects of air entrainment on target detectability, and autodetection and classification algorithms (software).

2.0 Methodology

The methodology was developed to evaluate the performance of two multibeam imaging sonars when deployed on the seabed, including the Tritech Gemini 720is (Gemini) and the dual frequency Teledyne Blueview M900-2250 MKI (Blueview). The Gemini has 512 beams aligned along a 120° swath width (angular resolution of 0.25°), with each beam having a 20° width perpendicular to the swath. The Blueview has 768 beams aligned along a 130° swath width (angular resolution of 0.18°), with each beam having a 20° width perpendicular to the swath. Multibeam sonars resolve target locations as range along each beam. The resulting composite (by combining all beams) is used to generate a sonogram with target locations in the swath width but does not resolve target location in the beam width. For this experiment, the sonars were both aligned such that field of view had swath width on the horizontal plane (parallel to water surface) and beam width on the vertical plane (depth). The acoustic frequency and geometry of the ensonified area for each sonar are summarized in Table 1. The Subaqua SAIS IP Cam (optical camera) and a GoPro were included for target verification, and to demonstrate ability for targets to be identified optically.

Table 1: Multibeam imaging sonar frequency and ensonified area

Sonar	Frequency (kHz)	Range (m)	Swath width (degrees)	Beam width (degrees)
Gemini	720	120 m(1)	120	20
Blueview	900 or 2250(2)	10	130	20

Notes:

- The Tritech supplied specifications for the Gemini report a max range of 120m, however the maximum effective range for monitoring marine animals in tidal channels is 50 to 60 m.
- The Blueview is dual frequency, with two transducer heads. Our work focused on the high frequency capabilities with the 2250 kHz (2.25 MHz) transducers, and associated range of 10 m. For brevity, ongoing reference to the Blueview in this report implies the high frequency transducer head.
- Both sonars transmit a "chirp" pulse that spans a range of frequencies, centered at the values listed above.

2.1 Instrument Configuration and Deployment

SOAR worked with Dalhousie Ocean Acoustics Laboratory, Clare Machine Works, and Dasco Equipment to design and build an Autonomous Multibeam Imaging Sonar (AMIS) monitoring system including the bottom lander/frame with sonar mounts, power supply (three 24 V Deepsea Power and Light SeaBattery Power Modules), subsea data acquisition system (sonar control and data storage with an Intel NUC computer and power conditioning inside a Nortek 500 m depth rated pressure case with custom end cap), and custom cables for power supply and communication. The frame also carried 140 kg of lead ballast. The AMIS monitoring system is shown in Figure 1.

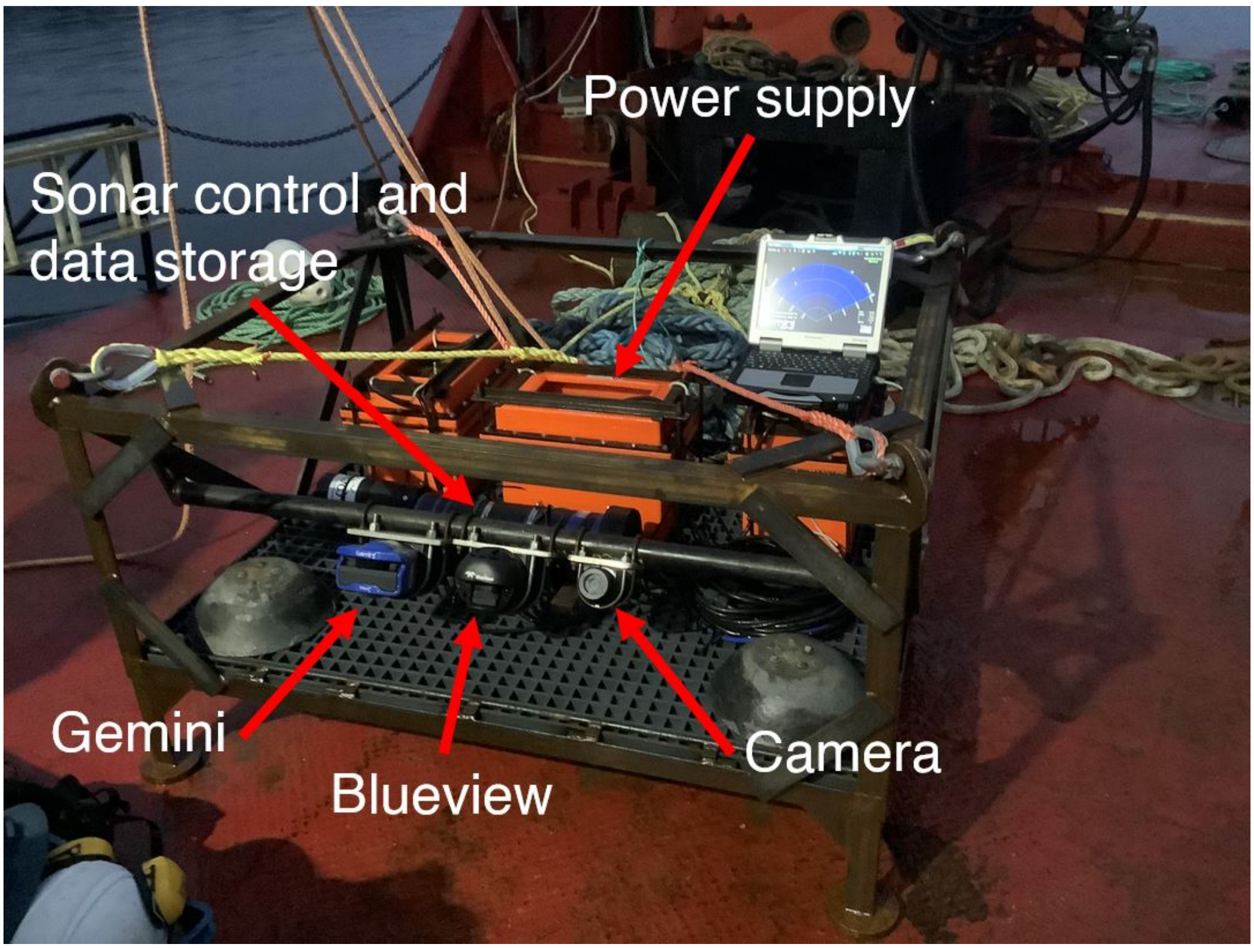

Figure 1: Autonomous Multibeam Imagining Sonar (AMIS) monitoring system

Submergence tests were conducted in Westport Harbour prior to each of two principal deployments in Grand Passage. The submergence tests allowed for a) testing and refinement of the mounting arrangement and sonar angles, b) testing the subsea data acquisition system, and

c) refinement of the deployment methodology. A time-lapse video of frame assembly and harbour testing is available at: https://vimeo.com/488171392

The vertical tilt angles of the sonars were refined to avoid or limit acoustic returns from both the seabed and the AMIS instrument frame (see the horizontal frame member above the sonars in Figure 1), which imposed lower and upper constraints on the range of possible sonar orientations, respectively. During the harbour testing, efforts were made to remove or reduce the acoustic returns from the AMIS frame by changing the tilt angles and positions of the sonars. However, returns from the frame were found to persist unless the transducer heads were positioned outside of the frame's perimeter, increasing the risk of damage to the sonars. The frame-returns do not appear to create an acoustic shadow, suggesting they may be related to the presence of acoustic sidelobes outside of the principle 20° beam width.

The principal experiment consisted of two deployments in Grand Passage, on 2020-10-20 and 2020-10-22, hereafter referred to as Deployments 1 and 2. The deployment location is shown in Figure 2. On both occasions, AMIS was deployed during low water slack and retrieved during high water slack, data being collected during the flood tide. The depth at the deployment location is approximately 25 m at low water, with flow speeds up to approximately 2.5 m/s. A video of the deployment is available at: https://vimeo.com/483103490.

The deployed sonars were oriented such that their ensonified areas were directed downstream, with the instruments' horizontal fields of view oriented across-channel. The configuration was chosen to minimize limitations of the ensonified areas by the sea surface or bottom, while maximizing the horizontal (i.e., downstream) extent over which targets would be visible if drifting downstream at a fixed depth. The horizontal alignment of the instruments was accomplished through use of a ground line and clump weight, which were attached to the AMIS frame. The weight and ground line were lowered first, upstream of the target location for the instrument frame, so that the taught ground line would ensure the correct orientation of the frame when it reached bottom. For both deployments, a diver verified the orientation of the frame and made minor adjustments, and confirmed that no boulders or other obstructions were apparent in the field of view. The diver reported the frame to be sitting well on relatively level ground (less than approximately 5° slope) in both cases.

For Deployment 1, the Gemini was tilted such that the vertical beam width spanned from 5 to 25° above the horizontal plane of the instrument frame. The vertical field of view of the Blueview spanned 20 to 40°. The sampling range of the Gemini was set to 30 m with an associated sampling rate of 13 to 14 Hz, and the range for the Blueview set to its maximum of 10 m with an associated sampling rate of 15 to 16 Hz. For Deployment 2, both sonars were tilted such that their ensonified areas spanned from 15 to 35° in the vertical. The increase in Gemini tilt for the second deployment was applied due to the presence of consistent returns from the seabed during Deployment 1. The Blueview was tilted down 5° relative to Deployment 1 to align with the Gemini. The sampling range of the Gemini was set to 50 m with an associated sampling rate of 10 to 11 Hz during Deployment 2, and the range for the Blueview set to 10 m.

Schematics of the sonar orientations are provided below, with the plan view shown in Figure 3 and profile views for the first and second deployments in Figures 4 and 5. Example sonograms for the Gemini and Blueview are provided in Figures 6 and 7.

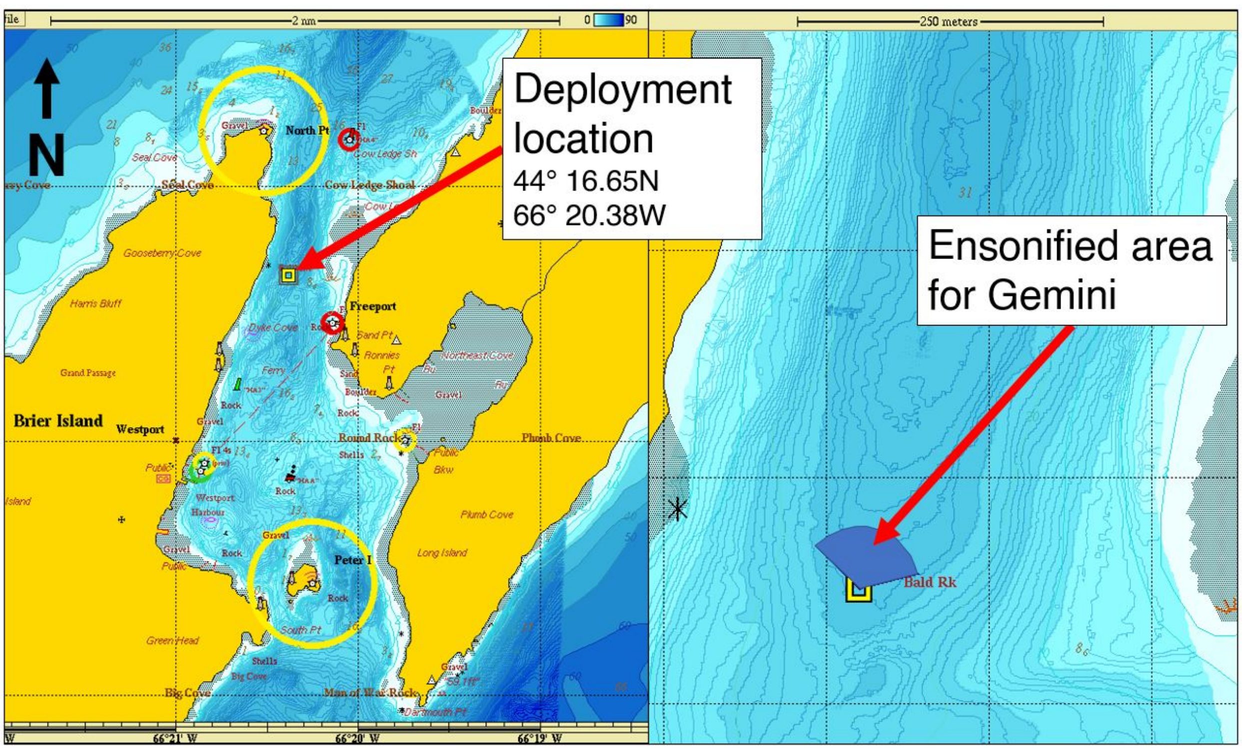

Figure 2: Deployment location

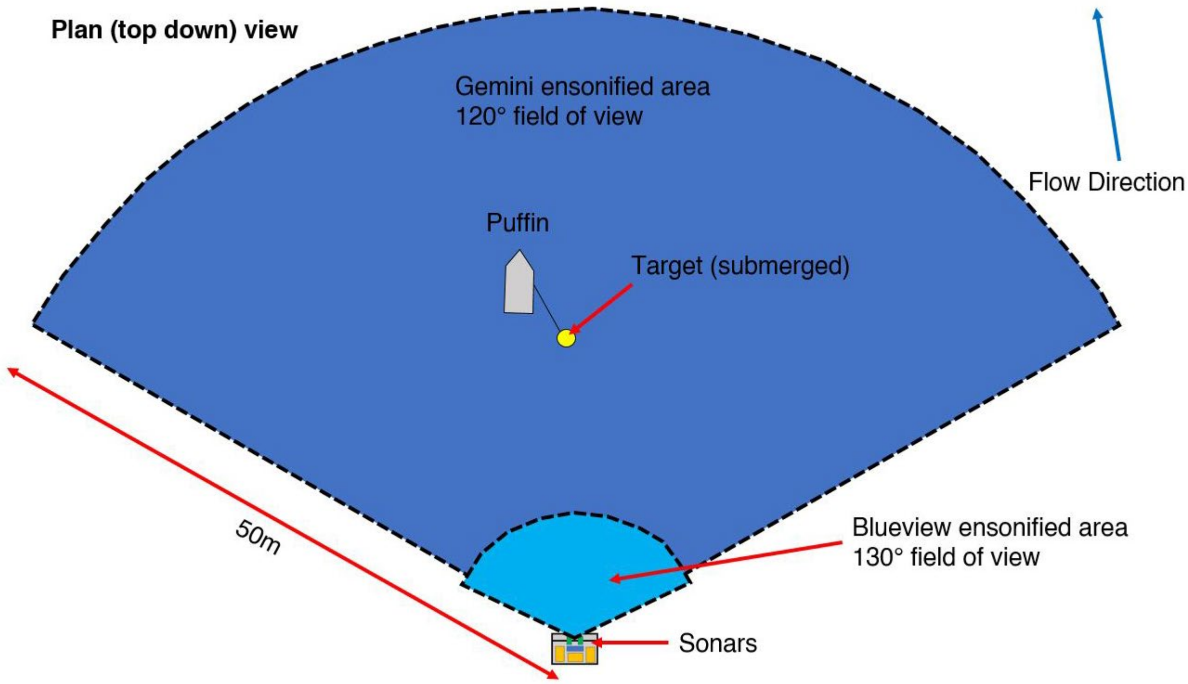

Figure 3: Experiment schematic - plan view

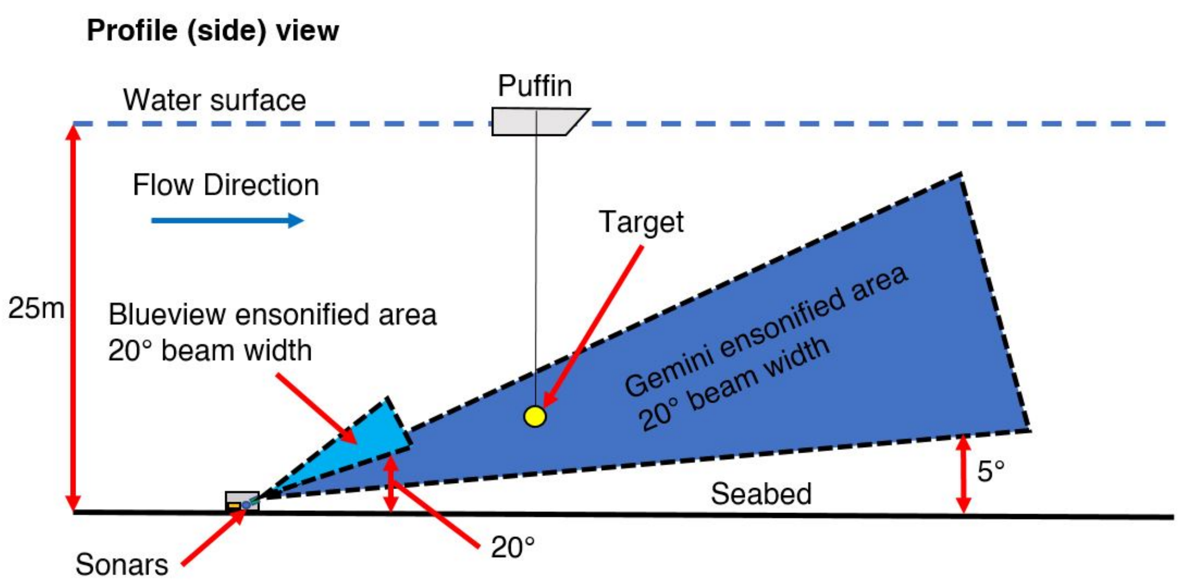

Figure 4: Experiment schematic - profile view - deployment 1

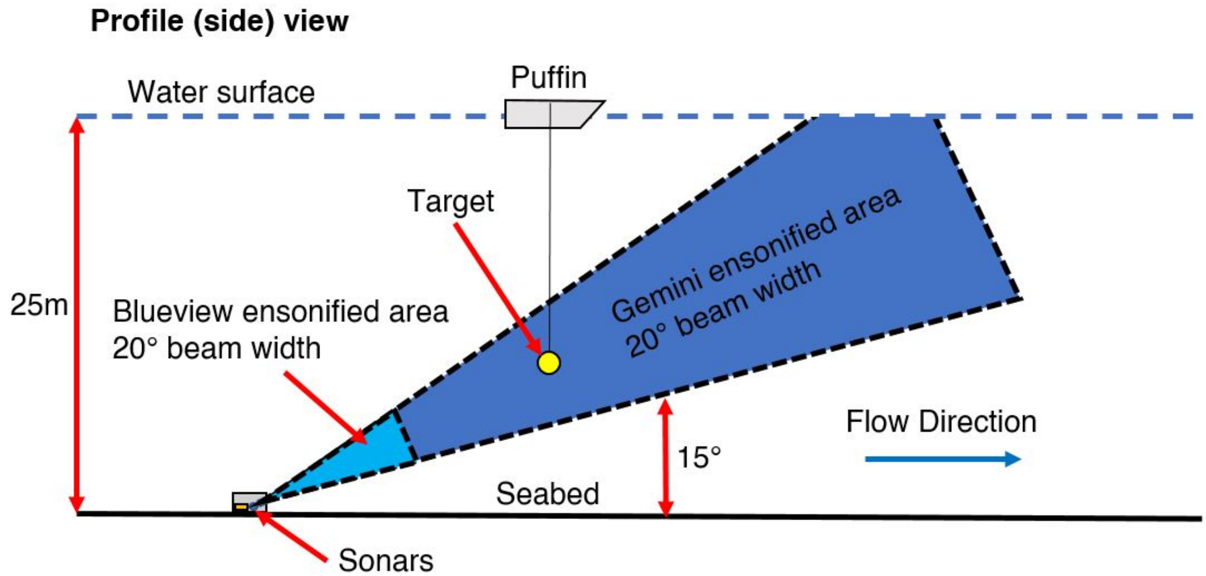

Figure 5: Experiment schematic - profile view - deployment 2

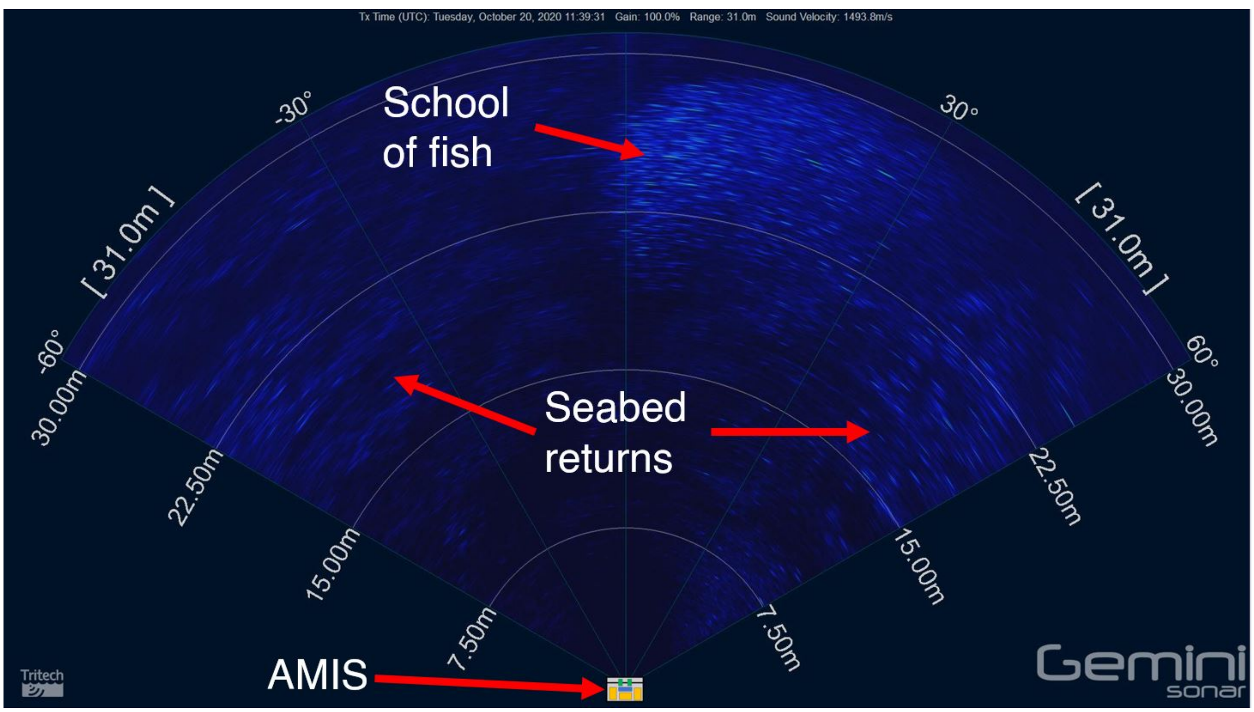

Figure 6: Example sonagram - Gemini first deployment

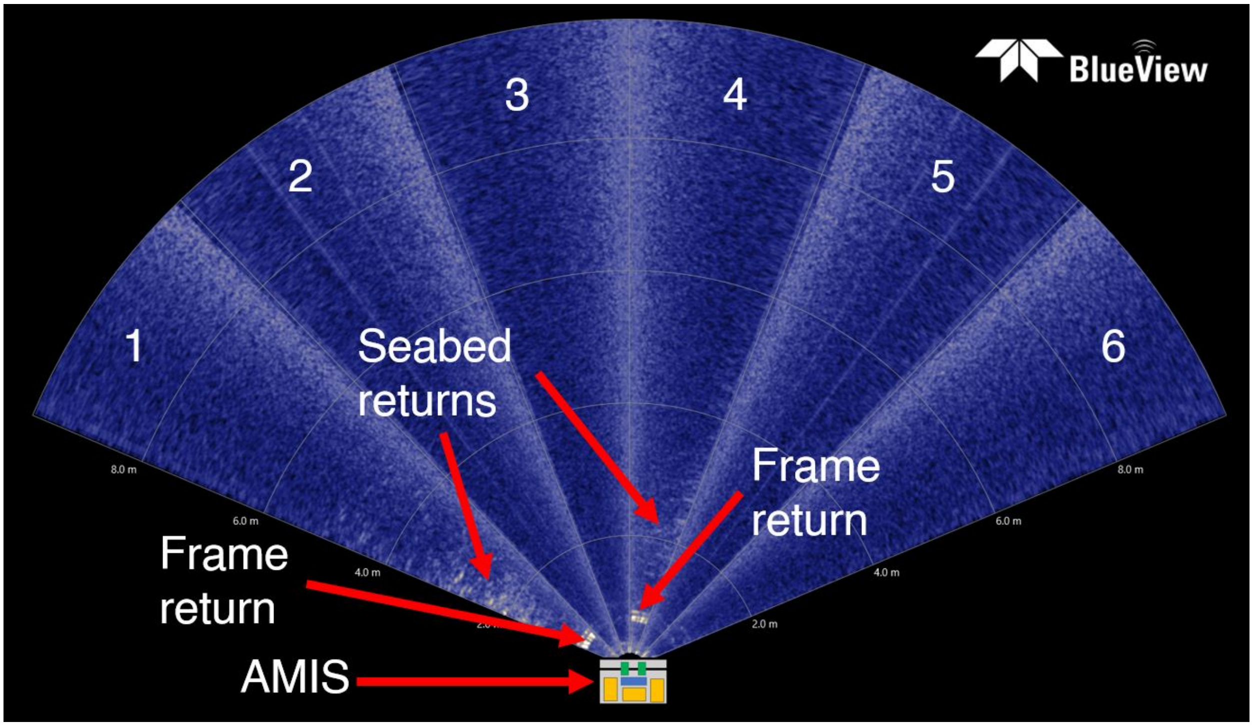

Figure 7: Example sonogram – Blueview second deployment

2.2: Data Collection

Three targets were used during data collection: a 0.45 kg (1 lb.) (9.5 cm long x 3.8 cm max diameter) lead fishing weight (Target 2), approx. 12 cm diameter basalt rock in a lobster bait bag (Target 3), and a V-Wing glider (Target 4) (approx. 52 cm wing tip to tip and 46 cm nose to tail) from Dartmouth Ocean Technologies (DOT). The V-Wing is designed to create downforce and maintain orientation in flow, with approximately (27 kg) 60 lbs. of downforce in 2.5 m/s flow. The target numbers were chosen to remain consistent with the convention used in vessel mount project (Trowse et al. 2020). The 1 inch diameter tungsten carbide sphere (Target 1 in the vessel mount project) was not included due to its acoustic similarity to Target 2 and the need to reduce the number of targets based on a relatively short data collection window.

Targets were suspended beneath research vessel Puffin (shown in Figure 8) while drifting through the study area. The Puffin repeatedly travelled to a position upstream from the sonars, then drifted with the tidal flow such that the drift trajectory allowed the targets to pass through the sonars' ensonified areas. The Puffin operated with its dual frequency Raymarine transducer (depth sounder and fish finder) turned off to avoid acoustic interference and collected flow measurements with a RDI 600 kHz ADCP periodically when changing between target types. The ADCP was out of the water during target deployments.

Targets 2, and 3 were suspended from the Puffin using a hand line spool with 200 pound test monofilament fishing line. Target 4 was suspended using 1/4 inch Polysteel fishing line due to the increased downward force, increased cost of the target (reducing risk of loss), and ease of handling. No metal was included in the target suspension system, knots were used to secure the targets with no hooks, shackles, etc. below the water line.

A series of 5 to 15 drifts were conducted for each target, with heights above the seabed that were consecutively increased at 3.6 m (2 fathom) intervals and with minor variations in the drift trajectory to the east and west of the AMIS deployment location. More drifts were conducted for Target 4 due to the higher level of control over depth and horizontal position relative to the Puffin. The AMIS system was fully autonomous, so no live view of data collection was available.

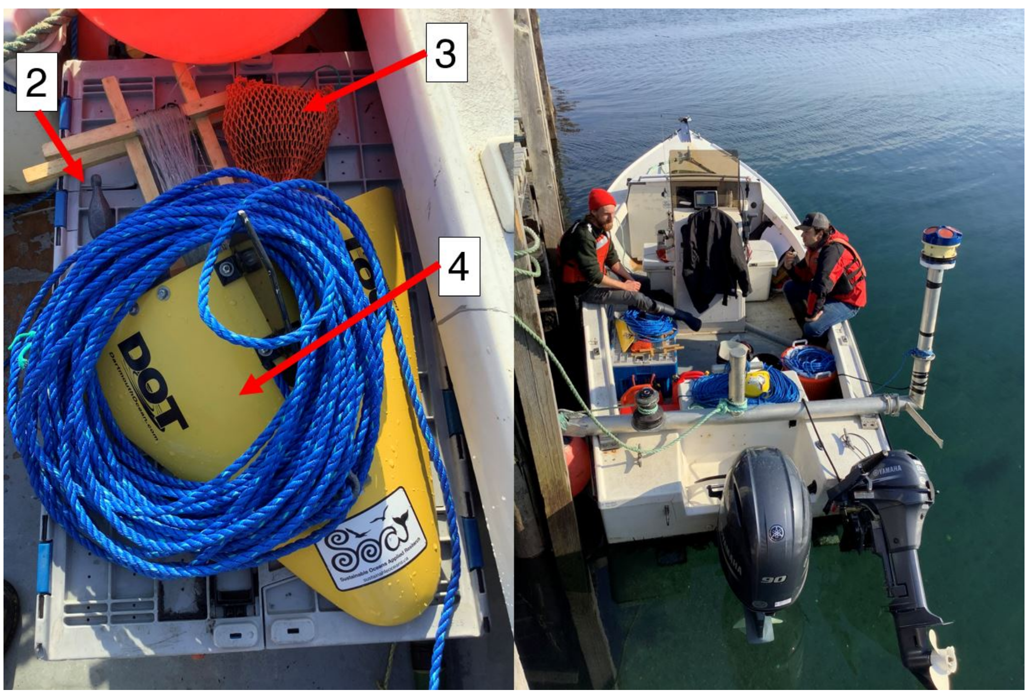

Figure 8: Targets and research vessel Puffin

2.2 Data analysis

The data collected in Grand Passage were manually analyzed to evaluate the performance of the Gemini and Blueview multibeam imaging sonars for detecting and tracking targets in strong tidal flow. The visualization and organization of the data were conducted using the proprietary software packages associated with each sonar: Gemini SeaTec and Teledyne ProViewer[1]. SOAR used these software packages for data review and organization by target type.

Consistent with the vessel mount project the sonar images were exported to video (1920 x 1080 resolution) to facilitate ease of sharing and consistency in the manual analysis. Video framerates were set to display data at 2x real-time speed. The ability to use increased payback speed was apparent from SOAR's initial analysis of the data files and utilized to demonstrate an increase in efficiency that may be applicable to active monitoring of tidal turbines.

Based on the results of Trowse et al. (2020), acoustic interference between the Gemini and the Blueview was expected. The signatures of acoustic interference for both instruments were consistent with those observed in the Trowse et al. vessel mount study.

2.2.1 Gemini

The video files from the Gemini were organized into training and test data sets, which were shared with 7 sonar observers who conducted the manual analysis, including participants from SOAR, Luna Sea Solutions, FORCE, Mi'kmaw Conservation Group, and MarineSitu. The training data set provides examples where each target is detected and tracked with a red circle indicating target position and a photograph from the optical camera identifying the target. The test data set included 41 data files where it was left to the observers to detect, track, and identify the targets.

[1] The development of automatic data processing algorithms for multibeam imaging sonars is an active area of research. Recent publications (e.g. Cotter and Polagye, 2020) on these methods have demonstrated the ability to detect and track targets with some ability to automatically classify between biologic and non-biologic classes. This classification level of processing typically relies on information from multiple instruments for co-registration of known targets (Joslin 2019). However, there is currently no software readily available with known ability to conduct reliable data analysis in turbulent flow with high levels of air entrainment. Therefore, data were analyzed manually to meet the primary objectives of the study.

A standard spreadsheet was provided to each observer including columns for:

- File number (for SOAR to cross-reference the data files)
- Target present (yes/no)
- Target identification
    - Type (1 through 4)
    - Certainty (1 low to 5 high)
- Detection range (minimum and maximum)
- Ability for detection and tracking (1 low to 5 high)
- Notes describing the trajectory of the target.

The results were categorized by target type and used to evaluate the performance of the Gemini including the effects of flow speed. The test data set included 3 files for Target 2, 9 files for Target 3, and 29 files for Target 4. The analysis was consistent with methodology for the vessel mount project, providing a quantitative comparison of performance for the Gemini sonar.

Links to the training and test data sets for are provided below. The data are best viewed in video form. As such, readers of this report are encouraged to watch these data videos for better understanding of the results and conclusions discussed in the following sections. A screen shot from the training data set is provided for each target in Figures 9 through 11.

Gemini training data	https://vimeo.com/483141927
Gemini test data with 50m range	https://vimeo.com/483142328

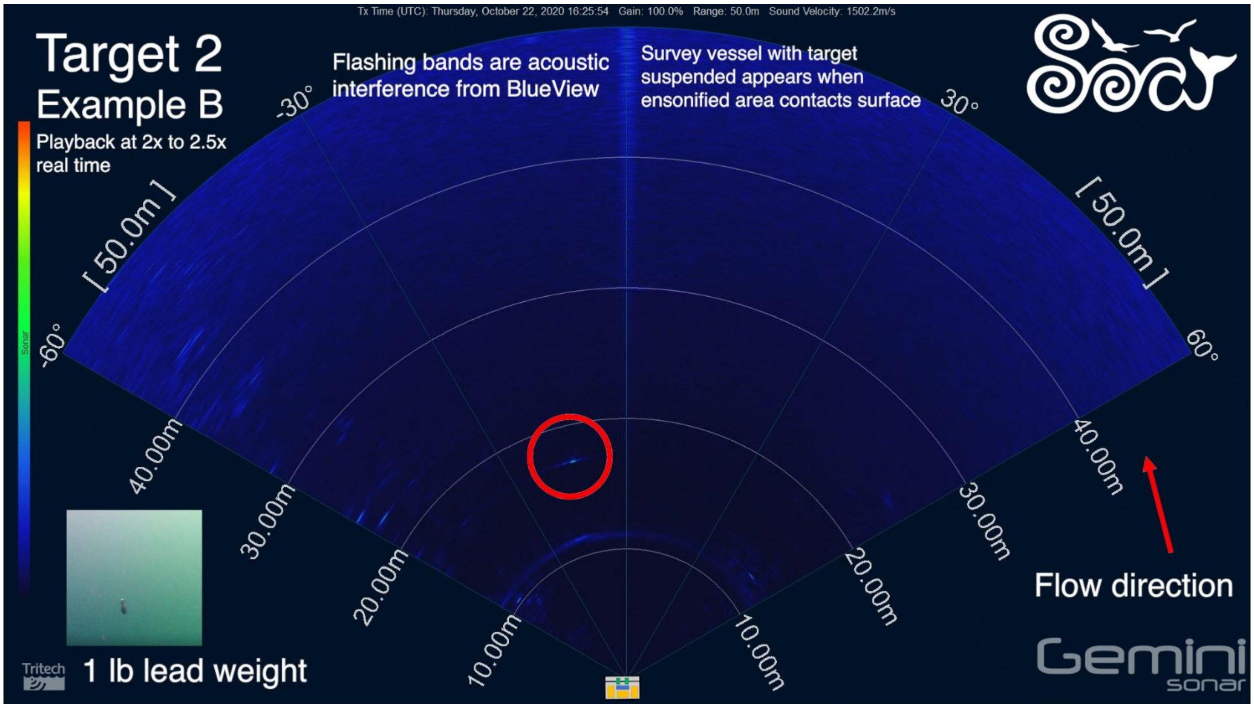

Figure 9: Example from training data - Gemini - Target 2

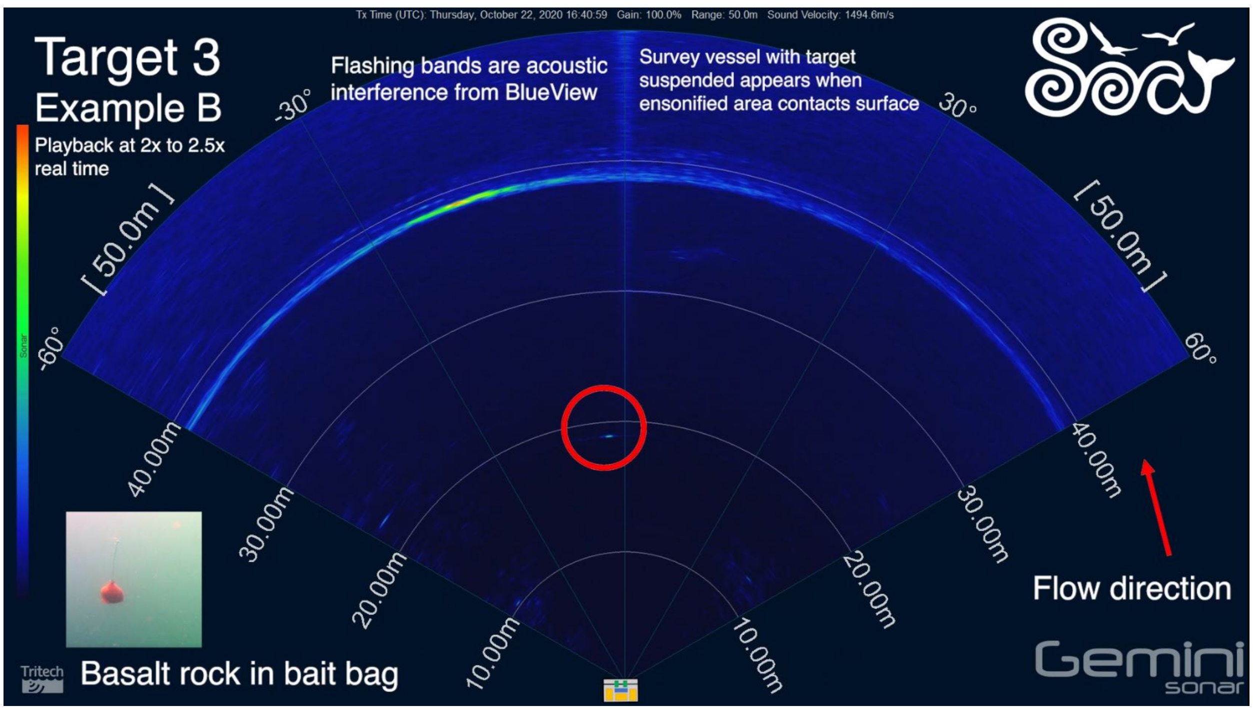

Figure 10: Example from training data - Gemini - Target 3

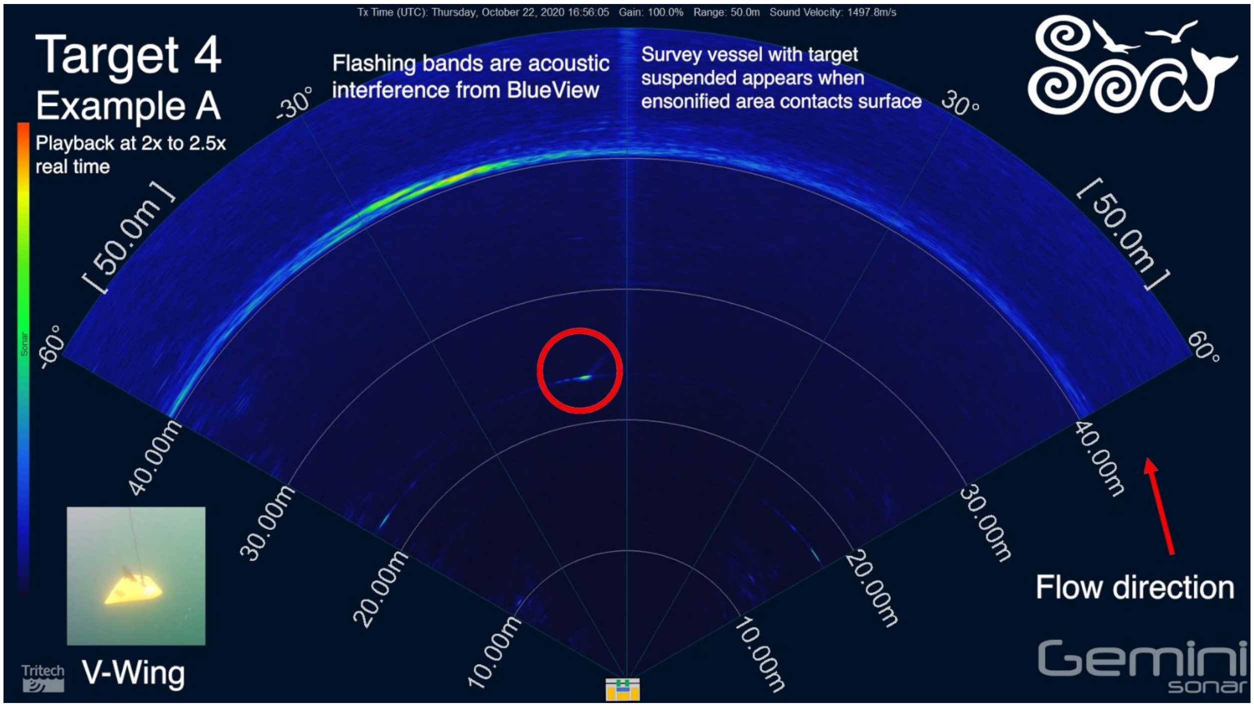

Figure 11: Example from training data - Gemini - Target 4

2.2.1 Blueview

Due to the small ensonified area of the Blueview, insufficient sightings of known targets were collected to generate training and test data sets. A manual analysis was conducted by SOAR, with a focus of events of concurrent detection by the Blueview and Gemini including natural targets (primarily fish) and occasionally the artificial targets used in our methodology. The data are discussed further in the Results section, including comparison of the two sonars.

3.0 Results and Discussion

3.1 Analysis of Gemini training and test data

A summary of results from the manual analysis of the Gemini test data is provided in Table 2, where observers' scores for target present (detected), target identified, max range tracked, and ability to detect and track targets were used to evaluate the performance of the sonar. Only data from Deployment 2 were used for consistent range (50 m) with the vessel mount project, with the comparison discussed in Section 3.4.

Table 2: Summary of results for Gemini, Deployment 2

Target type	Target present % correct	Target type % correct	Max range tracked % of set value	Ability to (1 to 5)	
				Detect	Track
Gemini (50m range)					
1					
2	95%	81%	74%	3.4	2.7
3	100%	43%	91%	4.3	3.8
4	100%	58%	99%	4.6	4.3
All	**99%**	**56%**	**95%**	**4.4**	**4.1**

The observers were able to reliably detect all targets in the majority (99%) of the test files, with tracking close to the 50 m range for Targets 3 and 4. Tracking range was reduced for Target 2, which is significantly smaller than targets 3 and 4. However, it is not clear whether the target tracks ended due to performance of the sonar or our ability to keep the 1 lb lead weight within the ensonified area. Conversely, the smaller size of Target 2, relative to Targets 3 and 4, aided in target identification, with 81% of the instances being correctly identified. Greater difficulty differentiating between Targets 3 and Target 4 is reflected by the lower target type percent correct scores.

The relationship between flow speed and sonar performance was evaluated by calculating the coefficient of determination, R^2, value between the flow speed and the detection and tracking scores. R^2 is a measure of the proportion of the variance in the dependent variable (detection and tracking scores) that can be predicted from the independent variable (flow speed). R^2 values range from 0 to 1, with 1 being one-to-one correlation. Flow speeds ranged from 1.4 to 2.4 m/s. The R^2 values for detection and tracking are 0.07 and 0.04, respectively, suggesting no significant relationship between flow speed and ability to detect and track the targets. A wider distribution of ability scores is apparent for the higher flow speed cases (see Figure 12). However, this may be a result of a larger number of samples at higher flow speeds as well as the distribution of target usage relative to flow speed.

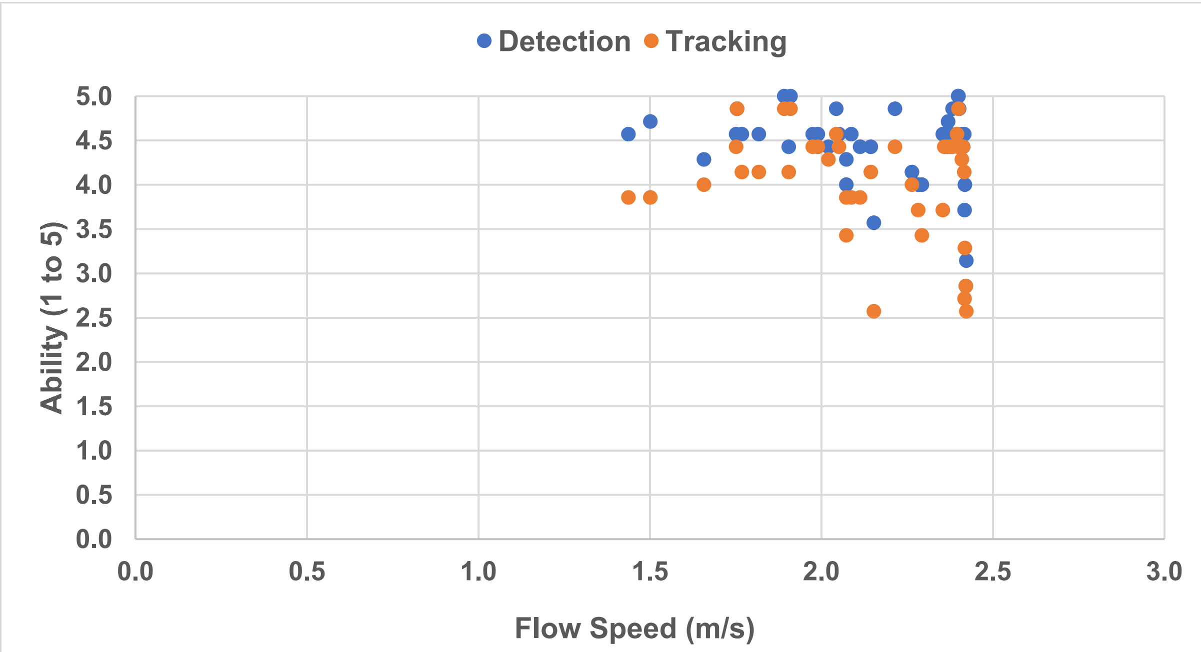

Figure 12: Effect of flow speed on Gemini target detection and tracking

3.2 Comparative analysis of Gemini and Blueview concurrent target detections

Data sets from both deployments were reviewed by SOAR to identify instances where natural targets (primarily fish) and occasionally the artificial targets used in our methodology could be identified in the data from both the Gemini and the Blueview. A link to a video file with 21 comparative cases is provided below, where cases 1 through 15 are from Deployment 1 and cases 16 through 20 are from Deployment 2. As with the training and test data analysis, the sonar data are best viewed in video form. Screen shots from cases 1, 4, 8, and 18 are also provided in Figures 13 through 16.

Concurrent Blueview and Gemini https://vimeo.com/487808248

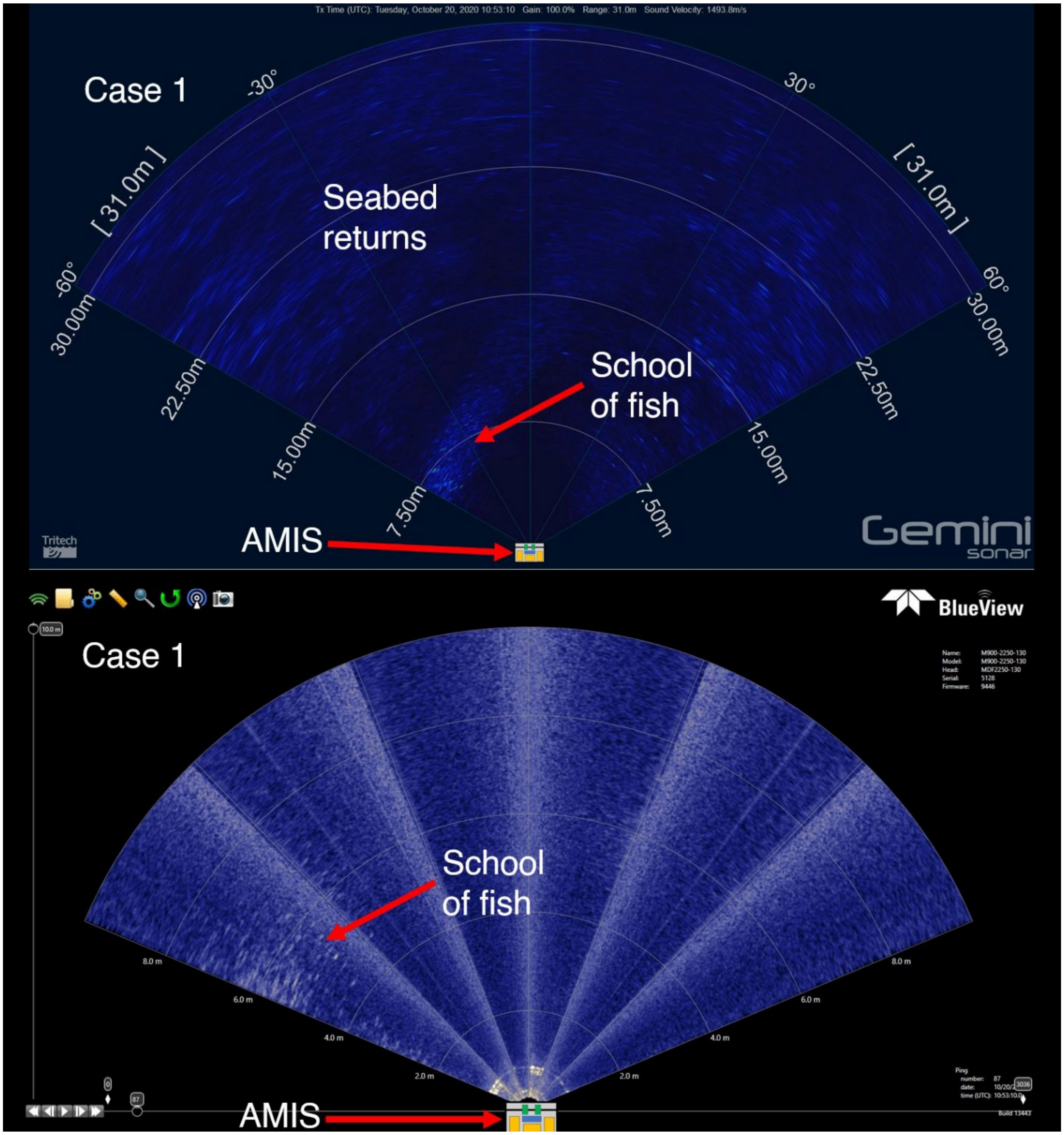

Figure 13: Concurrent Gemini and Blueview target detection - Case 1

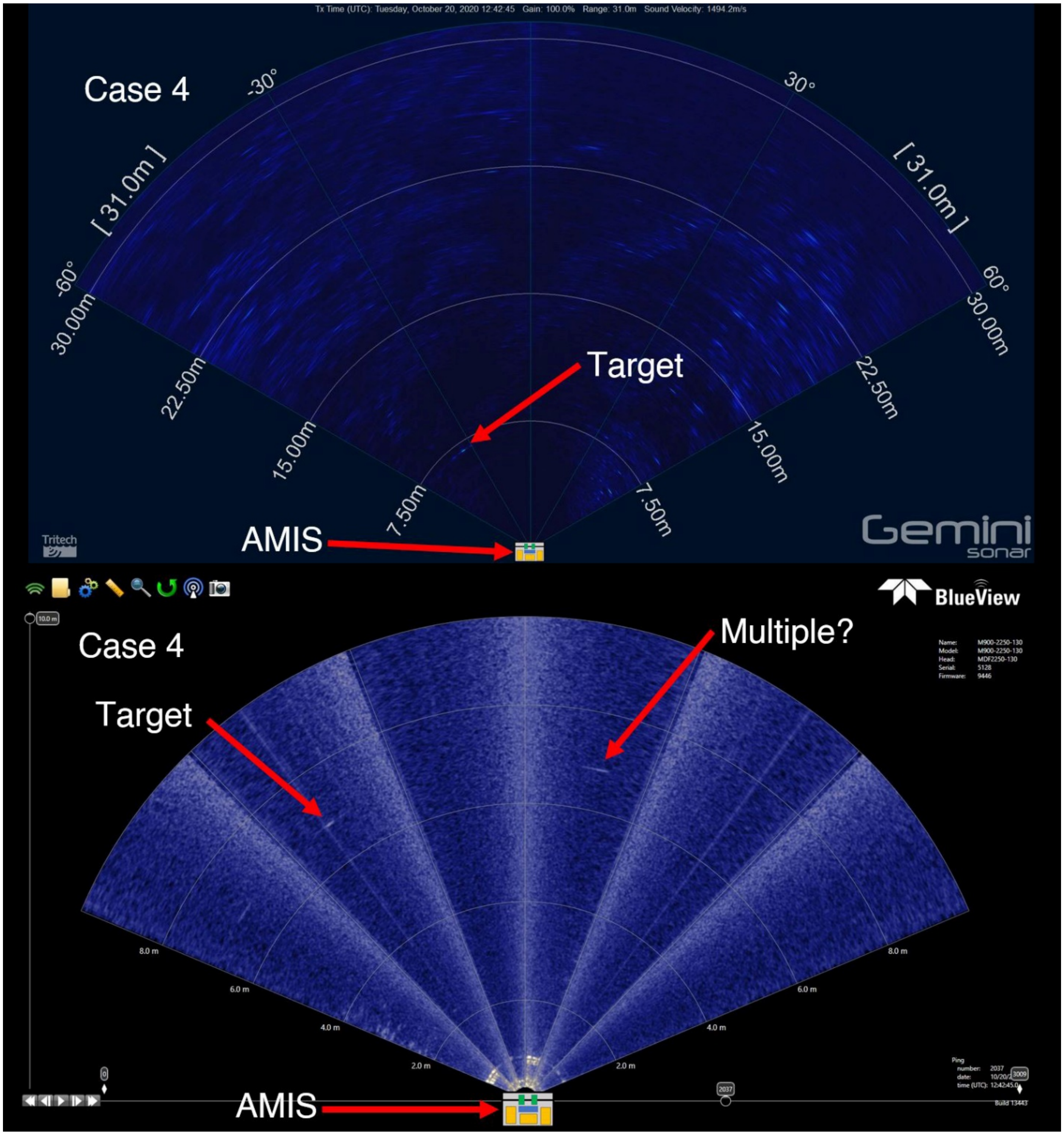

Figure 14: Concurrent Gemini and Blueview target detection - Case 4

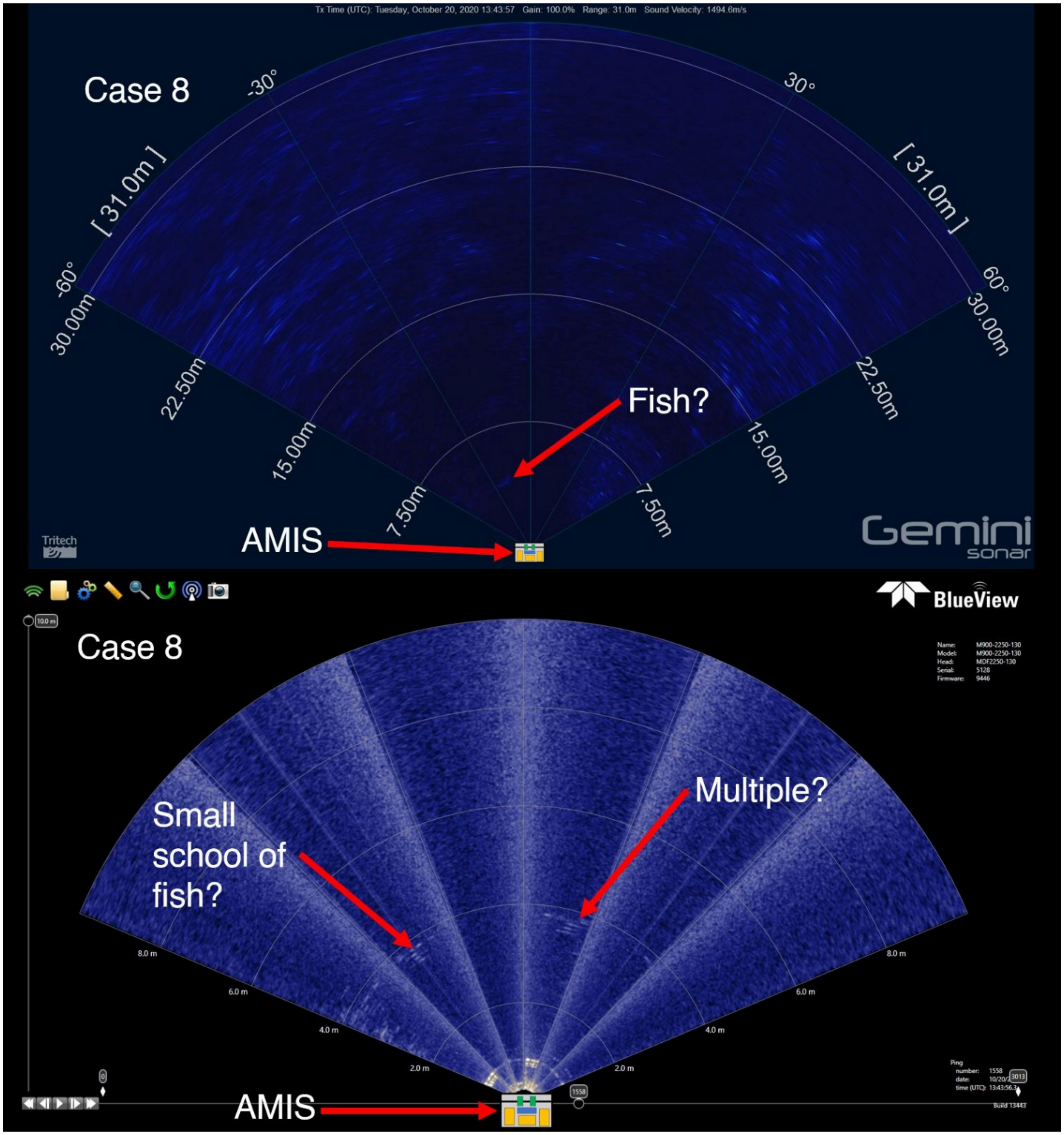

Figure 15: Concurrent Gemini and Blueview target detection - Case 8

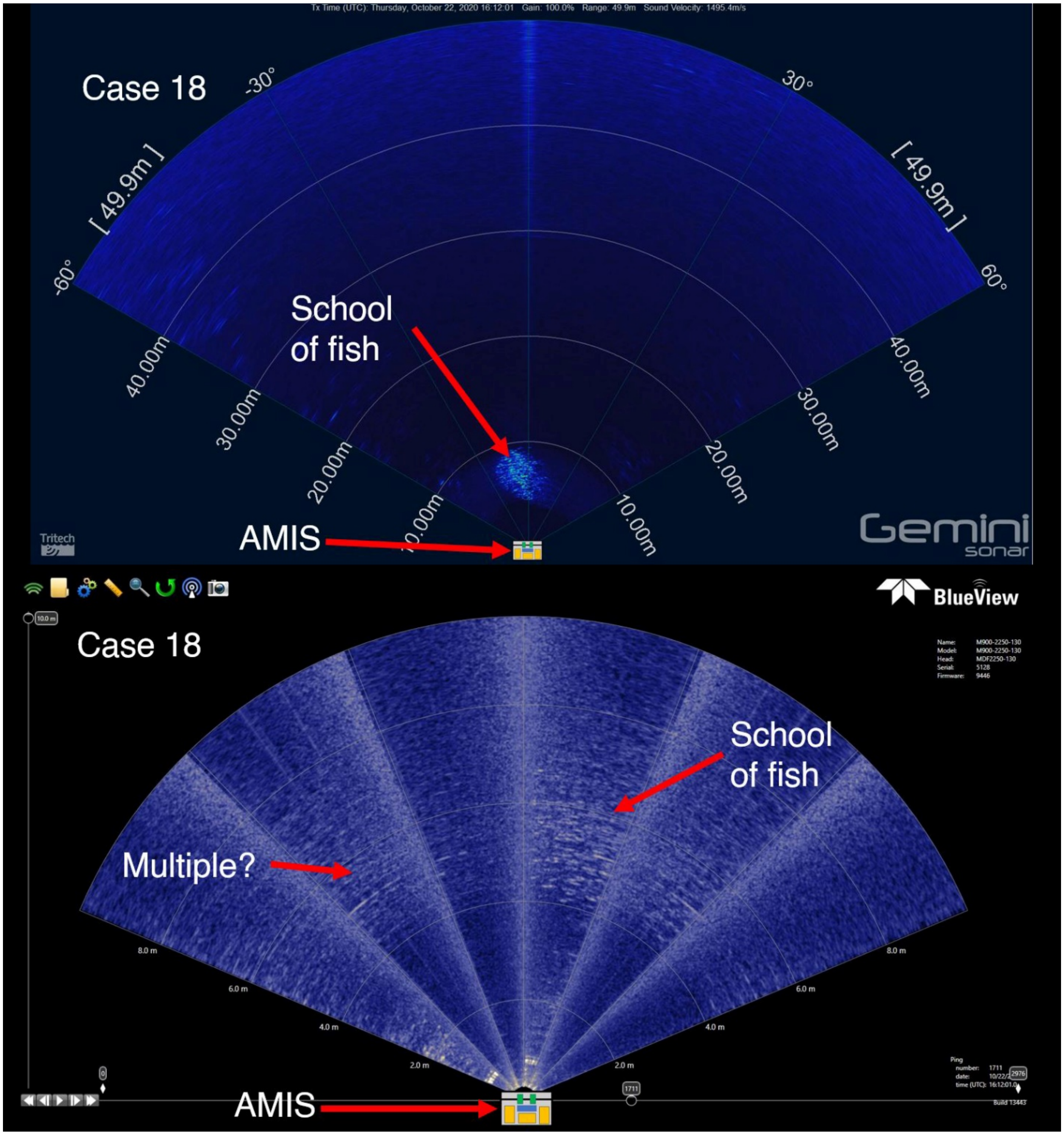

Figure 16: Concurrent Gemini and Blueview target detection - Case 18

Targets that were visible in the sonograms of both the Gemini and Blueview (up to 10 m range) were generally visible at larger ranges using the Gemini – often to its full sampling range of 30 m for Deployment 1 and 50 m for Deployment 2. For the first deployment with the ensonified area angled at 5 to 25° there were areas of seabed returns, but target identification and tracking were still possible due to the static nature of the seabed and continuous movement of the target.

When observing targets at close range, the Blueview demonstrated ability to provide the additional resolution expected of a higher frequency system. For example, in case 8, shown in Figure 15, individual fish in a small school are clearly identifiable. Fish in close proximity (< 2 m) to AMIS were well resolved by the Blueview. Though identifying discrete targets (i.e., individual fish in a school) was also possible with the Gemini at close range, it was subject to limitations associated with sampling frequency (range dependent), wavelength of the transmitted ping (720 kHz), and resolution of the sonogram (pixels/m).

3.3 Hardware limitations

The MKI model of the Blueview M900-2250 suffers from hardware limitations, one of which manifested in this study as multiple high-noise bands at fixed angular coordinates in the sonograms (see the lighter-coloured boundaries between numbered sectors in the Blueview sonogram shown in Figure 7). Targets generally could not be identified when they coincided with the bands, as the backscattered target signals were of comparable magnitude to the background noise level. This is consistent with observations made during the Trowse et al. (2020) vessel mount project.

SOAR contacted Teledyne technical support for further information, and were informed that Teledyne have released a second version (MKII) of the M900-2250, which mitigates this issue at the expense of a narrower swath width (reduced to from 130 to 45°). Further information is provided in the report for the vessel mounted project.

Some phenomena observed in the Blueview data suggest a transducer alignment issue. As noted in the Methodology section, despite the upward tilt of the Blueview at angles of 20° to 40° from the horizontal plane of the AMIS frame (Deployment 1) and 15° to 35° (Deployment 2), the frame and seabed are visible in sectors 1 and 4 of the sonogram. The lack of an acoustic shadow suggests that the frame and bottom returns are from sidelobes rather than the main acoustic beam. A potential transducer misalignment could explain target disappearance observed during data collection and analysis for the vessel mount project, where target tracks were regularly lost when travelling from the area occupied by one sector to the adjacent one. In some cases the Blueview sonograms show multiple returns from targets, as shown in Figures 14 through 16, that are not visible on the Gemini. If an artifact of a hardware issue it could result in uncertainty in target position, especially relevant in application to monitoring near-field interactions between marine animals and tidal turbines. Note that we have not yet contacted Teledyne regarding these issues.

3.4 Comparison to vessel mounted multibeam sonars

A comparison of the observers' scores for the bottom and vessel mounted Gemini cases is provided in Table 3. The vessel mount data (see Trowse et al. 2020) were analysed using the same methodology outlined in this report: that is, manual review by sonar observers using training and test data sets. For the vessel mount data, the values for "All" are increased from those in Trowse et al. 2020 due to the exclusion of Target 1 (1 inch tungsten carbine sphere) from the calculation. Target 1 was the smallest of the four targets and was characterized by the lowest scores.

Table 3: Comparison of results from bottom and vessel mounted Gemini

Target type	Target present % correct	Target type % correct	Max range tracked % of set value	Ability to (1 to 5)	
				Detect	Track
Gemini Bottom Mount					
2	95%	81%	74%	3.4	2.7
3	100%	43%	91%	4.3	3.8
4	100%	58%	99%	4.6	4.3
All	**99%**	**56%**	**95%**	**4.4**	**4.1**
Gemini Vessel Mount					
2	95%	23%	81%	3.4	3.1
3	96%	33%	92%	4.1	3.9
4	100%	79%	100%	4.5	4.5
All	**97%**	**46%**	**91%**	**4.0**	**3.9**
Bottom - Vessel Mount Scores					
2	0%	58%	-7%	0.0	-0.4
3	4%	10%	0%	0.2	-0.1
4	0%	-22%	-1%	0.1	-0.2
All	2%	10%	4%	0.4	0.2

The target-averaged scores for the bottom mount data set are slightly higher in all categories relative to the vessel mount data. We had substantially greater control of target positioning during the vessel mount data collection. We were able to start tracks closer to the sonars and hold targets at a constant range. This provided observers more time to detect and identify the targets at close range. Despite this, the greater bottom mount scores may not be surprising given the reduction in data contamination by wave and wake-related entrained air.

Proximity to the sonars likely increased the observers' ability to correctly identify Target 4 from the vessel mounted sonar. The characteristic shape of Target 4 was easily recognizable when viewed at close range (i.e., within ca. 20 m), but it exhibited acoustic returns that were less easily differentiated from Target 3 at larger ranges. The omission of Target 1 from the bottom mount experiment led to Target 2 being easier to distinguish (no confusion between similar targets) and is likely the reason for greater success compared to the vessel mount case. The reduced ability to identify Target 4 in the bottom mount data is most likely related to the reduced amount of time it was present in close range to the sonars.

4.0 Conclusions

The project addressed the objective of assessing the performance of bottom deployed multibeam imaging sonars for target detections, including the extent of signal interference from waves/turbulence, and entrained air.

The Tritech Gemini 720is received high scores from the observers in the ability to identify the presence of, visually detect, and track targets in videos displaying sonogram data output. The observers correctly identified the presence of a target in 99% of cases, and gave average scores greater than 4 out of 5 describing their visual detection and tracking ability. Targets were correctly identified roughly 50% of the time.

The results indicate a slight increase in visual detection and tracking ability relative to similar data collected from a vessel mounted orientation, and a net decrease in ability to correctly identify targets. We attribute the apparent increase in efficacy in the bottom mount case to the reduced presence of entrained air from waves and vessel wake in the sonar's ensonified areas. The reduction in percentage of correctly identified targets in the bottom mount case may be attributable to the increased ranges between target and sonar, as well as faster movement of the targets through the ensonified area. In general, the range to the target within the Gemini's detection area appears to play an important role in the ability to resolve and identify targets with diameters between ca. 5 and 50 cm.

For the bottom mount experiment, we were drifting guided by the currents and the AMIS deployment location, and were highly successful in getting detectable, identifiable, and trackable targets into the Gemini's ensonified area. Due to the smaller area ensonified by the Blueview, we had difficulty getting targets into the field of view. The limited number of target sightings precluded our use of the planned training and test video methodology. SOAR instead conducted a comparative analysis for which targets of opportunity (e.g., fish) were detected in the fields of view of both sonars. The Blueview demonstrated ability to resolve close-range (less than 10 m) targets. However, the use of the Blueview data was limited by the same hardware issues described by Trowse et al. (2020), and in the Hardware Limitations section of this report.

The Teledyne Blueview M900-2250 MKI is an impressive technology that offered the ability to resolve finer scale features of the targets and their movements in some cases. However, the persistent high-noise bands resulting from a known hardware issue and an apparent transducer alignment issue (discussed in Section 3.3) represented substantial impediments to reliable target detection and tracking. We conclude that data from the Blueview did not add substantial value or insight to the target analysis when used in conjunction with the Gemini. This should not rule out potential use of other MHz frequency multibeam sonars for monitoring the 10 m range in a combined sonar approach, including MKII of the Blueview.

SOAR recommends use of the Tritech Gemini 720is for application to monitoring interactions between marine animals and tidal turbines. It is likely that this technology will contribute significantly to effective monitoring and advancing knowledge of importance to regulators and other stakeholders. The Gemini demonstrated a high level of utility for detecting and tracking targets from vessel and bottom mounted orientations in tidal flows up to approximately 2.5 m/s, which is near to the maximum flow speed at Grand Passage. The Minas Passage is known to have higher flow speeds, which may result in higher levels of air entrainment. For comparison to the Minas Passage a flow speed exceedance curve is provided in Figure 18 calculated using depth averaged ADCP measured flow speeds from FORCE Berth Site A (45.3649 -64.4308). It shows maximum flow speeds of approximately 4.5 m/s and 2.5 m/s to be exceeded approximately 36% of the time, or conversely, flow speeds to be less than 2.5 m/s 64% of the time.

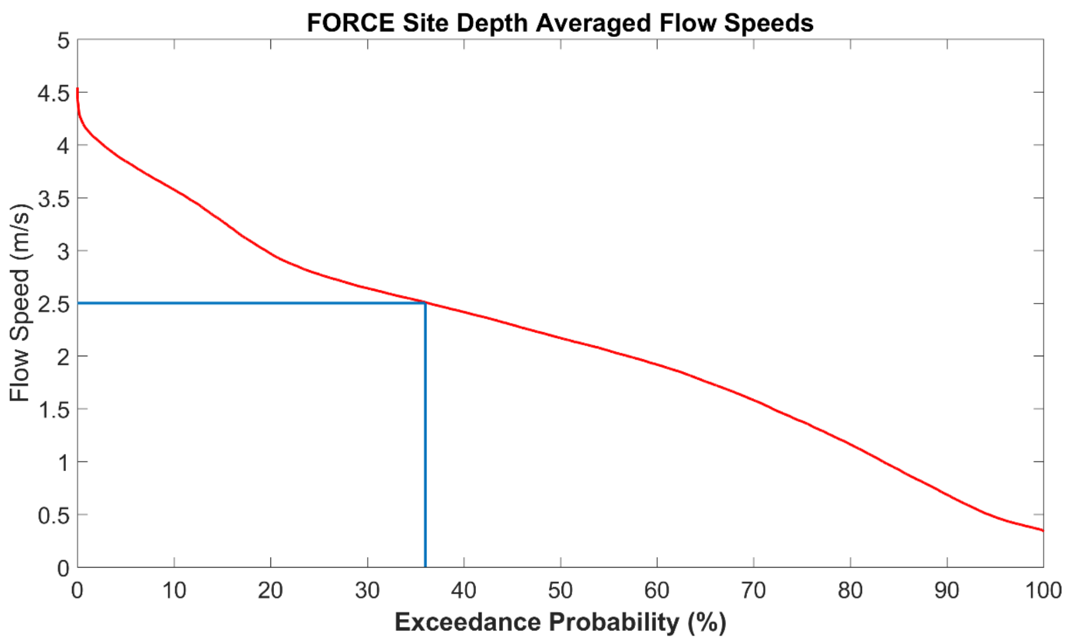

Figure 17: FORCE Site flow speed exceedance curve

Data analysis was successful for manual observers viewing data played back at 2x real time speed. Future work should consider efficiencies associated with accelerated data playback and could support use of software with variable speed playback that also allows for time and space encoded notes.

For planning future data collection careful consideration of sonar orientation is critical. In an oceanographic context, the ensonified areas are relatively small and are sensitive to returns from seabed and sea surface. Careful planning of the ensonified area is required based on the questions to be addressed by the monitoring while minimizing unwanted returns. The ability to adjust orientation is highly beneficial.

With respect to deploying multibeam sonars from the surface (i.e., vessel) or seabed, the sonars performed well from both positions, despite increased levels of air entrainment in the vessel mount case. The selection of deployment position for monitoring tidal turbines is likely to be defined by the nature of the tidal device (floating or seabed mounted) and the questions to be addressed by the monitoring.

Some level of acoustic interference from other active sonar systems must be expected when carrying out deployments in or near active ports or passages, whether from passing pleasure or commercial craft, or from other marine operations. Data analysis methods and systems should be designed with this in mind, treating acoustic interference as an element to be anticipated and mitigated where possible through software processing.

Manufactured targets were the focus of this experiment, but marine animal targets were also observed in abundance in Grand Passage. Data were collected that show the multibeam sonars to perform well in detection and tracking of fish and other targets of opportunity. These data require additional analysis, but some preliminary images are available. This connects with the secondary expected outcome of the project, providing data sets to support further research beyond the scope and timeline of this project.

Further testing of bottom mounted multibeam sonars would be useful in four focus areas, including:

1) fish and other marine animals in locations and seasons (times) with high levels of animal abundance and variety,
2) evaluating most effective sonar orientations for monitoring the near field of tidal turbines,
3) flow speeds that exceed 3 m/s, and
4) increasing efficiency in data assessment, possibly including reliable automation.

This work should build upon success in Grand Passage to conduct next steps in stronger flows present in Petit Passage and Minas Passage.

The report titled "Field Assessment of Multi-beam Sonar Performance in Surface Mount Deployments" (Trowse et al. 2020) provides similar analysis for the case of surface mounted Gemini 720is and Blueview M900-2250.

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