# Integrated Active and Passive Acoustic System for Environmental Monitoring of Fish and Marine Mammals in Tidal Energy Sites (ISEM)

**Final Report**

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# Executive Summary

The Offshore Energy Research Association of Nova Scotia (OERA), the Technology Strategy Board of the United Kingdom (now Innovate UK) and the Province of Nova Scotia signed a Memorandum of Understanding (MOU) providing the framework to establish bilateral collaboration in tidal research between Canada and the United Kingdom. The aim of the MOU was to fund innovative industrial research to address current and compelling knowledge gaps related to sensing and monitoring technologies with the goal of improving quality and quantity of data available to the industry. The collection and processing of data relating to marine life in tidal energy sites has so far been limited to individual use of either active acoustic monitoring (AAM) or passive acoustic monitoring (PAM). A project team was assembled for this project to explore the amalgamation of AAM (sonar) and PAM (hydrophone) data to facilitate the development of improved sonar detection and classification software. The project is titled Integrated Active and Passive Acoustic System for Environmental Monitoring of Fish and Marine Mammals in Tidal Energy Sites (ISEM).

This integrated monitoring system incorporated two different sensors: the Tritech Gemini Imaging Sonar (active acoustic) and the Ocean Sonics icListenHF smart hydrophone (passive acoustic). These sensors were co-located on an OpenHydro turbine subsea structure and the team explored the creation of a data interface that would allow data from each sensor to be combined into an integrated fish and marine mammal data set.

The initial ISEM project objectives were as follows:

1. Improve existing sensor technology software to maximize individual sensor capability;
2. Integrate two complementary sensor technologies to improve ability to detect, classify, localize and track marine mammals (notably harbour porpoises) and fish in real-time; and
3. Test sensor capabilities and integrated system effectiveness in high energy sites in the Bay of Fundy.

Berth D, at Fundy Ocean Research Center for Energy (FORCE), was the location for the Cape Sharp Tidal (CST) project, a joint venture research project between OpenHydro, a Naval Energies company, and minority partner Emera Inc. involving the deployment of an Open Centre design gravity-base instream tidal turbine. ISEM devices were installed on the instream tidal turbine for a first deployment that took place in November 2016 with the turbine retrieved in June 2017. A second deployment took place on 22 July 2018; the turbine and all associated devices were isolated from the power grid following the announcement of OpenHydro's insolvency on 26 July 2018.

Due to the setbacks experienced as part of the CST project, the ISEM project objectives were adjusted from the original objectives laid out. Amalgamation of AAM and PAM data sets was not achieved, which limited the development of improved sonar detection and classification software, but a number of advancements were made in understanding the utility and challenges within each of the data streams to allow for future integration.

**Passive Acoustic Monitoring**

Four icListen hydrophones were installed on the turbine infrastructure in order to provide all-around porpoise (and dolphin) detection coverage of the turbine and theoretical localization of inbound echolocating porpoises at distances beyond the near-field. However, a number of issues arose which led to hydrophone performance and localization challenges, as summarized below:

- Loss of communication related to cabling;
- Sampling rates of .wav data sets during the first deployment were insufficient for full analysis using new porpoise detection software;
- Hydrophone damage from debris travelling in the water column;
- Masking from high background noise in the environment from tidal currents, turbine operation and signals emitted from various sensors;
- Large separation distance between individual hydrophones resulted in few vocalizations occurring on multiple hydrophones; and
- Turbine structure obstruction (further reduction in ability to achieve concurrent vocalization detections).

These challenges led to recommendations and lessons learned for future marine mammal monitoring projects. Some of the main recommendations are:

- Cables to be inspected and tested prior to deployment to ensure integrity, and sufficient data transfer rates when transferring data from multiple instruments simultaneously;
- Reinforced guards to be used to protect sensor elements (improved guards led to improved data during second turbine deployment);
- An analysis of the required positioning and spacing between hydrophone units for optimal localization of porpoise clicks and consideration for multiple hydrophone array/clusters;
- Placement of hydrophones to limit impact of noise emitted from other equipment; and
- Post-deployment testing to measure the sound profile of each instrument on the turbine.

Notwithstanding the above challenges, the *Coda* porpoise click detector, developed independently of the project for Ocean Sonics Ltd, performed well in datasets with strong tidal current noise. Further processing with the *Coda+* program can use the click results to detect porpoise click trains and create probability models. During the second turbine deployment, *Coda* was integrated into an automated program in order to keep the full bandwidth .wav files with detected porpoise clicks in real time. The automated program was not able to be fully tested or optimized due to the shutdown of the monitoring equipment following the announcement of OpenHydro's insolvency on 26 July 2018. Although there was insufficient time to run complete testing of the detector, *Coda* was shown to be functional on the substation computer before the deployment and performed well during the two days of monitoring post-deployment.

Given *Coda's* real-time analysis of .wav data to down-sample data and produce diagnostic output in text form, *Coda* shows the potential for interfacing with the software controlling other devices. *PAMGuard's* real-time diagnostic outputs has similar potential but would require a software update to be compatible with icListen input data. Integrating the automatic detection of clicks with an Active Acoustic Monitoring

(AAM) device could serve to increase the reliability of detection, localization and potential interactions of porpoise around a tidal turbine.

**Active Acoustic Monitoring**

The use of the Tritech Gemini sonar to manually observe and record large individual fish, schools of fish and other sea life (marine mammals, sharks) is now well established. Turbulence imparted by tidal flows or turbulent wakes, however, was shown to degrade the Gemini image quality, and thus limit fish target detection.

SeaTec software was used to automatically observe and record schools of fish in this project, albeit with mixed results. The main problem is one of recording false positives than missing false negatives. The reasons for this can be summarized as:

- Too much noise in defined localities of the image (e.g. backscatter from the seabed);
- Recording tidal/drift targets as sea life;
- Incorrect identification of flickering but non-moving targets; and
- Recording different parts of the same target as multiple targets.

Steps taken to correct these issues and implemented in the SeaTec software include:

- Use of configurable exclusion zones;
- Allow input of tidal direction (manually or via serial port) to filter out inanimate drifting targets;
- Evaluation and exclusion of static targets; and
- Use of "group" classification (especially useful for large targets like sharks).

Tritech also undertook software engineering to allow additional data streams (e.g. from hydrophone detections) to be incorporated within the SeaTec software architecture.

A short validation of marine mammal targets identified by the SeaTec software was undertaken. Similar to fish detection, false positives were often noted, mainly determined to be reflections from surface waves. The use of the SMRU marine mammal Classifier (using movement and shape parameters of validated targets) was helpful to identify higher probability targets and as such can help in efficiencies involved in the human validation process and removal of false positives. Nevertheless, a human validation step is still required after detection by the SeaTec software.

Overall, ISEM project results show that there is potential to use integrated active and passive acoustics to monitor harbour porpoise and tagged fish in the near field of tidal turbines. *Coda* was able to detect harbour porpoise clicks while the Gemini was operational. Localization of near-field porpoises, however, will likely require additional hydrophones.

Lessons learned and recommendations are highlighted in Sections 6.0 & 7.0, respectively, and include the need for frequent and direct communication between tidal turbine developers and both researchers and sensor/software developers to ensure essential sensor testing prior to deployment, proper equipment setup, monitoring of equipment, and data management. In particular, it is vital that engineers installing equipment provide verification of device settings and device alignment prior to deployment, as well as feedback on input data as soon as data is received after deployment.

Both PAM and AAM datasets result in high volumes of data (10-15 TB per month in this study) and these cannot be easily transferred or viewed without appropriate protocols and technology. A data management plan is essential for project success. It needs to be developed in advance of a project to ensure high quality data collection, long-term data storage, and timely access to the data for processing and analysis.

# Table of Contents

# List of Tables

## List of Figures

# Acronyms

| | |
|---|---|
| AAM | Active Acoustic Monitoring |
| ADCP | Acoustic Doppler Current Profiler |
| AMAR | Autonomous Multichannel Acoustic Recorder |
| CST | Cape Sharp Tidal |
| CSTV | Cape Sharp Tidal Venture |
| dB | Decibel |
| FAST | Fundy Advanced Sensor Technology |
| FFT | Fast Fourier Transform |
| FORCE | Fundy Ocean Research Center for Energy |
| Hz | Hertz |
| ISEM | Integrated Active and Passive Acoustic System for Environmental Monitoring of Fish and Marine Mammals in Tidal Energy Sites |
| kHz | Kilohertz |
| KTP | Knowledge Transfer Partnership |
| MM | Marine Mammal |
| MOU | Memorandum of Understanding |
| NS | Nova Scotia |
| OERA | Offshore Energy Research Association of Nova Scotia |
| PAM | Passive Acoustic Monitoring |
| PSD | Power Spectral Density |
| QA | Quality Assurance |
| QC | Quality Control |
| SMRU | Sea Mammal Research Unit |
| SNR | Signal-to-Noise Ratio |
| SVM | Support Vector Machines |

# 1.0 Introduction

The Offshore Energy Research Association of Nova Scotia (OERA), the Technology Strategy Board of the United Kingdom (now Innovate UK) and the Province of Nova Scotia signed a Memorandum of Understanding (MOU) providing the framework to establish bilateral collaboration in tidal research between Canada and the United Kingdom. While it was recognized that significant investments in research to better understand the resource, environmental impacts and technical challenges of in-stream tidal energy, knowledge gaps remain and create increased project risk with subsequent effects to investment in commercial scale energy production from in-stream tidal energy (OERA, 2014). The aim of the MOU was to fund innovative industrial research to address current and compelling knowledge gaps related to environmental sensing and monitoring technologies with the goal of improving quality and quantity of data available to the industry. Data improvements will contribute to resolving challenges, and reducing risk and costs associated with tidal development and the generation of new knowledge and skills will facilitate the development and commercialization of new products, processes or services; provide support to environmental permitting requirements; and contribute to building social license and acceptance within the sector (OERA, 2014).

Although significant efforts have been made globally over the past number of years in measuring and monitoring tidal environments, limitations and challenges with current technologies and associated data quality still persist (OERA, 2014). The collection and processing of data relating to marine life in tidal energy sites has so far been limited to individual use of either active acoustic monitoring (AAM) or passive acoustic monitoring (PAM). The data collected is therefore constrained by the limitations of each individual sensor technology, resulting in the need for further data collection and increased processing time.

A project team was assembled for this project to explore the amalgamation of sonar and hydrophone data to facilitate the development of improved sonar detection and classification software. The project is titled Integrated Active and Passive Acoustic System for Environmental Monitoring of Fish and Marine Mammals in Tidal Energy Sites (ISEM).

## 1.1 Cape Sharp Tidal Project

The Fundy Ocean Research Center for Energy (FORCE) is a test centre for in-stream tidal energy technology that is located in the Minas Passage area of the Bay of Fundy near Black Rock, 10 kilometres west of Parrsboro, Nova Scotia. The test site offers five berths, with subsea cables, for developers to test instream tidal devices. A wide variety of fish species utilize Minas Passage, but in terms of marine mammals, the harbour porpoise (*Phocoena phocoena*) is clearly the most commonly occurring species, detected on 99% of days based on long-term acoustic monitoring studies (Tollit et al., 2019). Strike risk and acoustic disturbance impacts remain a concern for this species, particularly due to its use of high-flow environments.

Berth D, at FORCE, was the turbine location for Cape Sharp Tidal Venture, a joint venture research project between OpenHydro, a Naval Energies company, and minority partner Emera Inc. The project involved the deployment of an Open Centre design, gravity-based instream tidal turbine. The first deployment took place in November 2016 and the subsea cable was disconnected in April 2017 as part of preparation operations for retrieval. The first turbine was retrieved from the berth in June 2017 for upgrades, repairs and to address issues with the placement of the Gemini sonar. A second turbine deployment took place on 22 July 2018. Although testing of the ISEM devices was initiated, the turbine and all associated devices were isolated from the power grid following the announcement of OpenHydro's insolvency on 26 July 2018. Naval Energies filed a petition with the High Court in Ireland for the liquidation of OpenHydro Group Limited and OpenHydro Technologies Limited. The Court appointed a provisional liquidator, Grant Thornton, and on 25 September 2018, OpenHydro Technology Canada was placed in creditor protection and Grant Thornton (Canada) was appointed as trustee.

Due to the setbacks experienced as part of the CST project, the ISEM project objectives were adjusted from the original objectives laid out in the proposal.

## 1.2 ISEM Project Introduction

The goal for this project was to not only improve how data from each individual sensor is processed and interpreted, but to also develop an interface between the two technologies (i.e. sonar and smart hydrophones) which would combine the strengths of each sensor type and would enable the efficient collection of high quality, synergistic data for environmental monitoring at high energy sites. An effective interface could be an enabler for the tidal energy industry and could facilitate the collection of monitoring data required for site consenting and regulatory approvals.

Rotating turbines are the most intuitive contenders for significant collision risks with marine vertebrates. Collisions are most likely in high flow environments where flows can combine with swimming speeds to produce high approach velocities with consequently reduced avoidance or evasion response times. To date, there are few near-field monitoring programs of tidal energy devices and consequently collision risks are not well understood, particularly for marine mammals (Joy et al., 2018). Detection of vocal marine mammals is typically achieved using Passive Acoustic Monitoring (PAM) techniques, however near-field localization is challenging and Active Acoustic Monitoring (AAM) methods using sonar (for fish and marine mammal detection) are likely required in conjunction with PAM to understand the likelihood of near-field interactions.

# 2.0 ISEM Project

The monitoring technology planned for development in this project was an integrated environmental monitoring system that uses data analysis software and encompasses active and passive acoustic sensors to provide real time detection, classification, localization and tracking of fish and marine mammals at high energy sites in the Bay of Fundy.

The integrated monitoring system incorporated two different sensors: the Tritech Gemini Imaging Sonar (active acoustic) and the Ocean Sonics icListenHF smart hydrophone (passive acoustic). These sensors were co-located on an OpenHydro turbine subsea structure and the team explored the creation of a data interface that would allow data from each sensor to be combined into an integrated fish and marine mammal data set. Tritech's Gemini SeaTec object detection and tracking software was to be further developed to interpret the data with the objective of obtaining real-time automated detection, classification, localization and tracking of fish and marine mammals. In addition, data from the passive acoustic instruments were to be interfaced with third party software to add further value to marine mammal interaction assessments.

Integrated sensor technologies and associated software programs have potential for global application. When successful, the resulting system could aid in the de-risking of the tidal energy industry, reduce costs of project development, and potentially help to accelerate the commercialization of the industry as a whole. In addition, the system has potential benefits for other industries (e.g., hydro operations, offshore wind, oil and gas etc.) where subsea monitoring is required.

## 2.1 ISEM Project Team

The project team included representation from Canada and the UK as follows:

- Emera Inc. (Canada)
- OpenHydro Technology Canada (Canada)
- Tritech International Ltd. (UK)
- Ocean Sonics Ltd. (Canada)
- Sea Mammal Research Unit, University of St Andrews (UK)
- SMRU Consulting Europe, University of St Andrews (UK)
- SMRU Consulting Canada Ltd. (Canada)
- Acadia University (Canada)

## 2.2 Project Objectives

The initial project objectives were as follows:

1. Improve existing sensor technology software to maximize individual sensor capability.
2. Integrate two complementary sensor technologies to improve ability to detect, classify, localize and track marine mammals and fish in real-time.
3. Test individual sensors capability and integrated system effectiveness in high energy sites in the Bay of Fundy.

As mentioned above, these objectives were adjusted to account for difficulties related to the CST Project.

## 2.3 Passive Acoustic Monitoring (PAM)

The passive acoustic monitoring objectives were focused on the ability to detect and where possible localize harbour porpoise in real-time around an active turbine and to deliver this information to the AAM sensor software to improve the accuracy of target detection and classification. This required incorporating effective click detection and classification software into the hydrophone system as well as developing data linkages with the AAM sensor.

The hydrophone data from the first deployment 2016/2017 and the second deployment from September and October 2018 were used to address the original objectives, where possible, and provide lessons learned and recommendations.

Some objectives changed because of the lessons learned throughout the first deployment and the issues faced with data collection. The first deployment allowed analysts to test different software systems for detecting marine mammal vocalizations, including *PAMGuard*, *Lucy,* and *Coda/Coda+. PAMGuard* is a general purpose, passive acoustic monitoring software platform including detectors for many types of marine mammal vocalizations. *Lucy* is based on using spectrograms and spectral analyses to visualize passive acoustic monitoring data including many types of marine mammal vocalizations. *Coda* is a specific purpose program for detection of harbour porpoise echolocation (clicks). Harbour porpoise are the most commonly observed marine mammal in Minas Passage so *PAMGuard*, *Lucy*, and *Coda* were all applied for the present project.

Hydrophones were set to provide time-series (.wav files) with low sampling rates during most of the first deployment (2016/2017), which obviated application of *Coda* and *PAMGuard* for porpoise click detection because this program operates on the time-series. Nevertheless, hydrophones did record high frequency information in the form of spectral data (colloquially called FFT files). For most of the first deployment *Lucy* was used for harbour porpoise click detection because *Lucy* is specifically designed to process FFT files from the hydrophones. *PAMGuard* can process recorded .wav files from hydrophones, but at project inception was not able to utilize the icListen data stream in real-time. It would have been feasible to create a module which would enable PAMGuard to process the icListen datastream but due to project budget limitations, this avenue was not explored.  An available alternate software program (*Coda*) was successfully used instead.

For the second deployment, hydrophone data with high sampling rate were obtained in September and October 2018. Measurements were archived as .wav files for subsequent analyses. The *Coda* program is designed to operate as measurements are made (or on previously obtained .wav files) in order to identify and down sample data segments that are likely to contain a harbour porpoise click. Identified measurements can be subsequently analyzed to obtain click trains and to calculate other metrics that might more thoroughly indicate porpoise echolocation events.

During the first deployment Ocean Sonics and Acadia University drew attention to multiple sound/noise sources that seemed to be associated with the turbine and active acoustic devices installed on it. A scientific priority for the second deployment was to isolate the signatures of all these sound sources by turning different devices on and off. This plan was abandoned in view of OpenHydro's insolvency shortly following the second deployment.

Section 3.0 presents analyses of the environmental factors and active acoustic equipment that effect noise levels. Measurements were analyzed for PAM, particularly regarding porpoise click detection with regard to the effect of noise levels.

## 2.4 Active Acoustic Monitoring (AAM)

The project used a Tritech Gemini 720id sonar for Active Acoustic Monitoring (AAM) of fish and marine mammals. Before deployment on the turbine, experiments were undertaken to test detection of fish and fish-like targets by the Gemini sonar (Appendix D). These measurements demonstrated that sonar alone would have little ability to identify species but could estimate target size providing the target was sufficiently close or sufficiently large.

Gemini sonar images from the first turbine deployment contained reflections from the bottom because the sonar was installed with an orientation that would have been appropriate if attached to a surface vessel but was upside down for our gravity base installation. Nevertheless, a substantial subsample of the images was manually processed to find fish-like targets (Appendix E). Before the second turbine deployment, a Gemini sonar was installed on the FORCE FAST-EMS platform and deployed in Minas Passage near Black Rock.  Again, data files were manually examined for fish-like targets (Appendix F) which were compared with the SeaTec automated target detection and tracking algorithms (Appendix H).

Gemini images from the second turbine deployment (2018) were compromised in the near field by reflections from a foot of the turbine platform, which limited the utility for detecting and tracking fish-like targets. Images were examined for evidence of marine mammals and other large targets in the far field (Appendix G).

Section 4.0 discusses Gemini sonar hardware and associated SeaTec software for the present project. Assessments of detection of fish and marine mammals are achieved and improvements to target detection and tracking software are documented. Challenges in operating sonar in this high current environment are documented (e.g. scattering from turbulence and entrained air bubbles).

## 2.5 Integration of PAM and AAM

This project aimed to undertake the significant challenge of integrating two very different sensor technologies (PAM and AAM), and to use data from both to facilitate the development of improved sonar detection and classification software. A key project objective was to improve the ability to detect, classify, localize and potentially track marine mammals in real-time. This required the testing and development of an interface between the two technologies (i.e. sonar and hydrophones) which would combine the strengths of each sensor type and would enable the efficient collection of high quality, synergistic data for environmental monitoring at high energy sites.

The relatively high vocal rates of echolocating harbour porpoise typically allows for robust PAM detection at distances beyond 100 metres (m). Tritech had previously developed software (SeaTec) to identify marine mammals using Gemini output data, but false positive rates required additional human validation to assess accuracy of this automated software classification. This validation step is not only time consuming but also precludes potential real-time mitigation decisions. The proposed real-time integration of PAM detections within the SeaTec algorithms was therefore considered to be a major improvement in automating turbine monitoring. For example, detections of porpoise using PAM might be used to increase the species detection probability rating outputted by the SeaTec, providing a more efficient monitoring method.

A number of steps are required to achieve the desired integration. These include 1) the ability of the icListenHF hydrophones (PAM) and Gemini multibeam imaging sonar (AAM) to consistently monitor for porpoise; 2) the use of automated PAM software to reliably detect porpoises (and ideally to provide locational information); 3) that noise sources from the Gemini and turbine operations and instrumentation do not preclude porpoise detection; 4) that porpoise detections made by PAM software can be relayed into the Gemini SeaTec software and be incorporated into that software's interface and tracking algorithm outputs. For a number of reasons and unforeseen logistical challenges, the full integration of the PAM and AAM sensors used in this project was not achieved. However, the project has made progress on potential future integration and has provided a number of advancements within each sensor technology and importantly provides a variety of lessons learned during a full-scale and real-world monitoring trial. Details of these challenges, learnings and future recommendations are made in the subsequent sections.

# 3.0 Passive Acoustic Monitoring Results

## 3.1 Ocean Sonics icListenHF Hydrophones

Four icListenHF hydrophones were mounted on the Cape Sharp Tidal turbine infrastructure to collect passive acoustic data (Figure 1). The primary objective in using the hydrophones was monitoring harbour porpoise (*Phocoena phocoena*) presence in the near-field environment (i.e. <100 m). Once the turbine was deployed, the hydrophone data was streamed and recorded at the FORCE substation for processing and storage.

*Figure 1. icListenHF Smart Hydrophone.*

One hydrophone was located at the top of the rotor assembly and the other three were located inside the three corners of the subsea base (Figure 2). Two hydrophones from the first deployment were replaced for the second deployment and hydrophone S/N 1404 switched its location. Heavy duty guards were added for the second deployment to ensure device protection and long-term operation.

The hydrophones recorded broadband acoustic data from 10 Hertz (Hz) to 200 kilohertz (kHz), sampling at 32-512 kilo-Samples per second (kS/s). The sound data was recorded in time series waveform (.wav) and processed spectral data (Fast Fourier Transform [FFT]). Both .wav and FFT data were streamed to the substation and recorded. The FFT data were also logged to the hydrophone's internal memory. The hydrophones were synchronized throughout the deployment to provide data for localization.

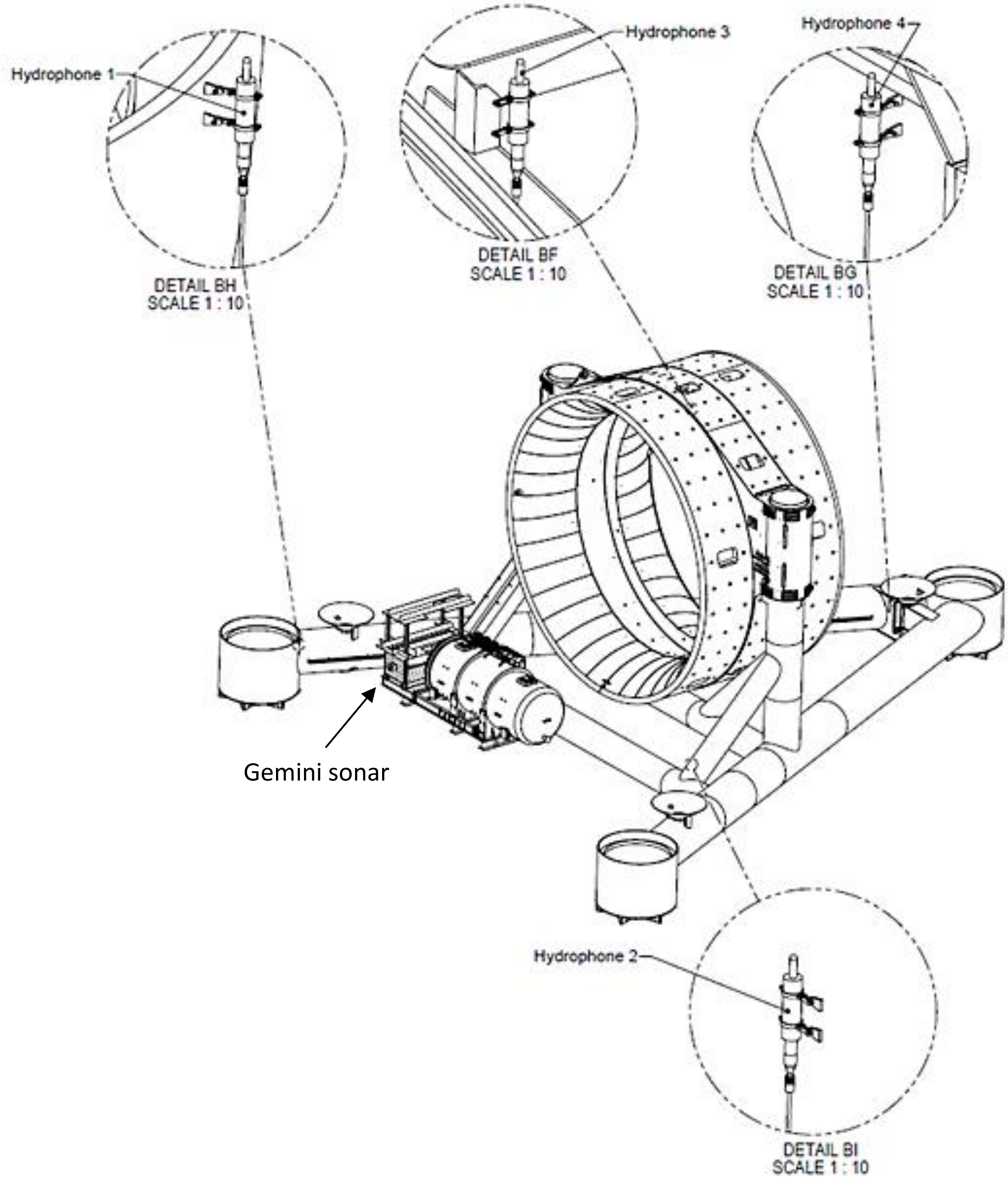



*Figure 2. Cape Sharp Tidal turbine platform with hydrophone positions. Serial numbers are given in the table below for each deployment.*

| Label on Figure | Location | Hydrophone Serial Number | |
|---|---|---|---|
| | | First Deployment | Second Deployment |
| **Hydrophone 1** | Fore Starboard | 1407 | 1404 |
| **Hydrophone 2** | Fore Port | 1404 | 1678 |
| **Hydrophone 3** | Top of Turbine | 1405 | 1677 |
| **Hydrophone 4** | Aft | 1406 | 1406 |

Over the first deployment, data sets were saved to hard drives and transferred to Ocean Sonics for processing. To improve data processing speeds and storage during the second deployment a computer was dedicated to the monitoring equipment. This computer was set up to provide remote access to the data, perform automatic processing and complete a data management protocol. The protocol included saving all FFT .txt files, down sampling .wav data and saving portions of full bandwidth .wav data with harbour porpoise click output from *Coda* detections (Appendix A).

## 3.2 Hydrophone Performance

Four hydrophones were installed on the tidal turbine and deployed from November 2016 to April 2017. Two hydrophones recorded data over the entire deployment while two hydrophones had communication issues resulting in intermittent recording (Table 1).

*Table 1. Hydrophone sampling during first deployment (2016-17).*

| Label on Figure 2 | Hydrophone Serial Number | Sampling Dates mm/dd/yy | Sampling Rate (kS/s) | |
|---|---|---|---|---|
| | | | FFT | WAV |
| **Hydrophone 1** | 1407 | 11/09/16 – 11/14/16 | 512 | 32 |
| **Hydrophone 2** | 1404 | 11/08/16 – 03/08/17 | 512 | 32 |
| | | 03/08/17 – 03/24/17 | 512 | 64 |
| | | 03/25/17 – 04/13/17 | 512 | 512 |
| **Hydrophone 3** | 1405 | 11/08/16 – 03/08/17 | 512 | 32 |
| | | 03/08/17 – 04/13/17 | 512 | 64 |
| **Hydrophone 4** | 1406 | Invalid data (intermittent recording) | | |

During the first deployment, Hydrophone 3 (S/N 1405), which was located on the top of the turbine, sustained damage, likely due to debris travelling in the water column. Although the unit still collected data, the damage compromised data past 11 November 2016 and could not be used for data analysis. Hydrophone 1 (S/N 1407) and Hydrophone 4 (S/N 1406) had communication issues related to cabling and collected data periodically. Hydrophone 2 (S/N 1404) collected data throughout the deployment and was used as the primary source of data for the analysis with the first deployment.

To detect harbour porpoise clicks (~130 kHz), a bandwidth of 250 kHz (512 kS/s) was needed. The porpoise click detector in *Lucy* was the only detector able to process the FFT files and was used for detecting porpoise clicks from November 2016 – April 2017. Sampling rates for .wav data were set too low from November 2016 to March 2017 to process the data with the porpoise click detectors in *PAMGuard* and *Coda*. The .wav sampling rate was corrected on 24 March 2017 and recorded full bandwidth data on one hydrophone (S/N 1404) from 25 March to 13 April 2017. For this dataset, the .wav data was post-processed with *PAMGuard* and *Coda*.

All hydrophone data were saved on hard drives and transferred to Ocean Sonics periodically. To reduce delays in data transfer rates, a data management protocol was created for the second deployment (Appendix A) and is discussed in Lessons Learned (Section 6.0).

Four hydrophones were similarly mounted to the turbine for the second deployment in July 2018. All four hydrophones recorded .wav and FFT data from July 24 to 26, at which time the hydrophones were shut down due to power disconnection associated with the liquidation of OpenHydro. On 4 September 2018, power to the monitoring devices (except Hydrophone 1 S/N 1404) was restored and three hydrophones commenced recording again (Table 2) but without data storage on the main hard drive at the FORCE site. Since 4 September 2018, all hydrophone data have been collected and backed up offsite by Ocean Sonics.

*Table 2. Hydrophone sampling during second deployment and status: September 2018 to January 2019.*

| Label on Figure 2 | Hydrophone Serial Number | Status | Sampling Rate (kS/s) | |
|---|---|---|---|---|
| | | | **FFT** | **WAV** |
| **Hydrophone 1** | 1404 | lost communication | 512 | 512 |
| **Hydrophone 2** | 1678 | connected & recording | | |
| **Hydrophone 3** | 1677 | connected & recording | | |
| **Hydrophone 4** | 1406 | connected & recording | | |

**Sound at the Turbine Platform**

Because hydrophones measure pressure fluctuations, non-acoustic noise can interfere with the measurement of sound (Strasberg, 1979). The hydrophone data were affected by tidal current noise and signal generating sensors on the turbine. Hydrophones at different positions on the turbine platform were subject to different levels of pressure fluctuation depending upon exposure to tidal flow. The hydrophone on the top of the turbine (Hydrophone 3, S/N 1677) had the greatest exposure to high current speeds and thus very large pressure fluctuations which resulted in clipping (i.e. sound not recorded). At peak tidal flow, sound levels differed with hydrophone position, as demonstrated by a 1/3 octave plot (Figure 3). Observed differences are substantial at frequencies less than 1250 Hz; received sound levels were similar between 1250 and 12500 Hz.

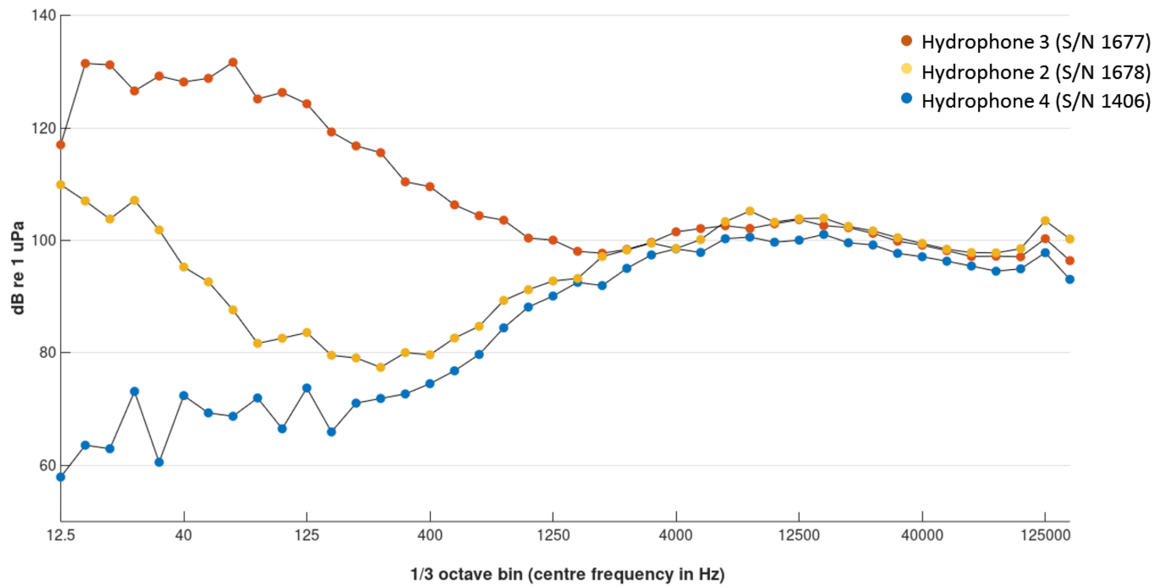



*Figure 3. Plot of sound level (dB) with 1/3 octave bin during peak tidal flow on 10 October 2018, for Hydrophones 2, 3 and 4. Hydrophone positions are shown in Figure 2.*

**<u>Influence of Tidal Flow and Current Speed on Noise Level</u>**

Over the first deployment it was noted that tidal flows had a significant impact on the pressure fluctuations recorded by the hydrophones. Data from the second deployment were plotted with the current speed to compare the sound/noise levels over a tidal cycle, during both spring and neap tides. The spring tide (high high tides and the low low tides) is characterized by fast current speeds while the neap tide has a much smaller range in tidal amplitude and slower current speeds.

ADCP (Acoustic Doppler Current Profiler) measurements from instruments mounted to the turbine infrastructure were provided to Ocean Sonics. However, essential metadata was lacking. Information on tidal currents was therefore obtained from hydrodynamic simulations (Karsten *et al*., 2008) using the following method:

- Obtain a time series of modelled currents at the location (45.36448 N, -64.42168 W) of the 2018 OpenHydro turbine installation.
- Fit tidal constituents to the modelled currents (Codiga, 2011).
- Use that fit to tidal constituents to reconstruct currents at the required time.

The method above fits tides to planetary motion, which can be accurately predicted over time. The model was used to calculate vertically averaged current speeds. For the present purposes, the model captures the essential variation of currents that is expected to be related to changes in sound level. Data from Hydrophone 2 (S/N 1678) and Hydrophone 4 (S/N 1406) were used to compare sound level with tidal current over time. The two hydrophones enable us to further explore differences in noise levels associated with hydrophone positions on the turbine platform (Figure 4). Hydrophone 3 was not used in the comparison because the data was clipped when noise levels exceeded 176 dB re µPa.

Sound level is expected to depend on bottom stress which scales as the square of current speed. In view of this expectation, Figure 5 plots time series of sound and the square of current speed. Spring tides are shown for 10 October 2018 and neap tides for 18 October 2018. Tidal currents (plotted as the square of current speed) vary over the tidal cycle and that variation is far greater during spring tides than during neap tides. Sound level is represented by a portion of the power spectral density (PSD) averaged over the frequency range 1-30 kHz. Figure 5 shows how the sound level varies over the tidal cycle and from spring tide to neap tide. Sound level is highest on peak flood during spring tides.

Dotted vertical lines in Figure 5 show the times at which the full PSD are plotted (Figures 6 & 7) in order to demonstrate the range of frequency variation associated with various stages of the tide: flood, slack, and ebb. Thus, snapshots of the full PSD can be put in context with variation of current and sound level over time.

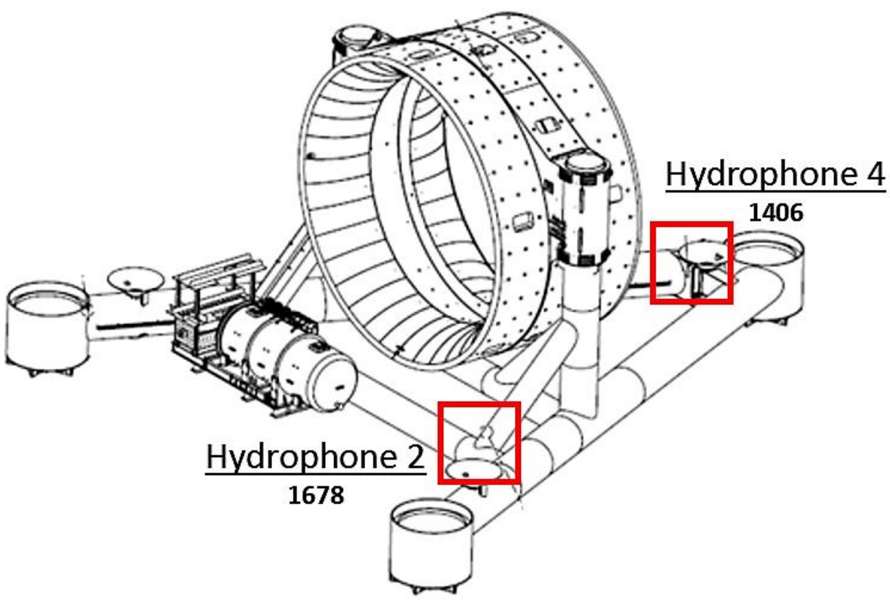



*Figure 4. Positions of Hydrophone 2 and Hydrophone 4 on the turbine platform.*

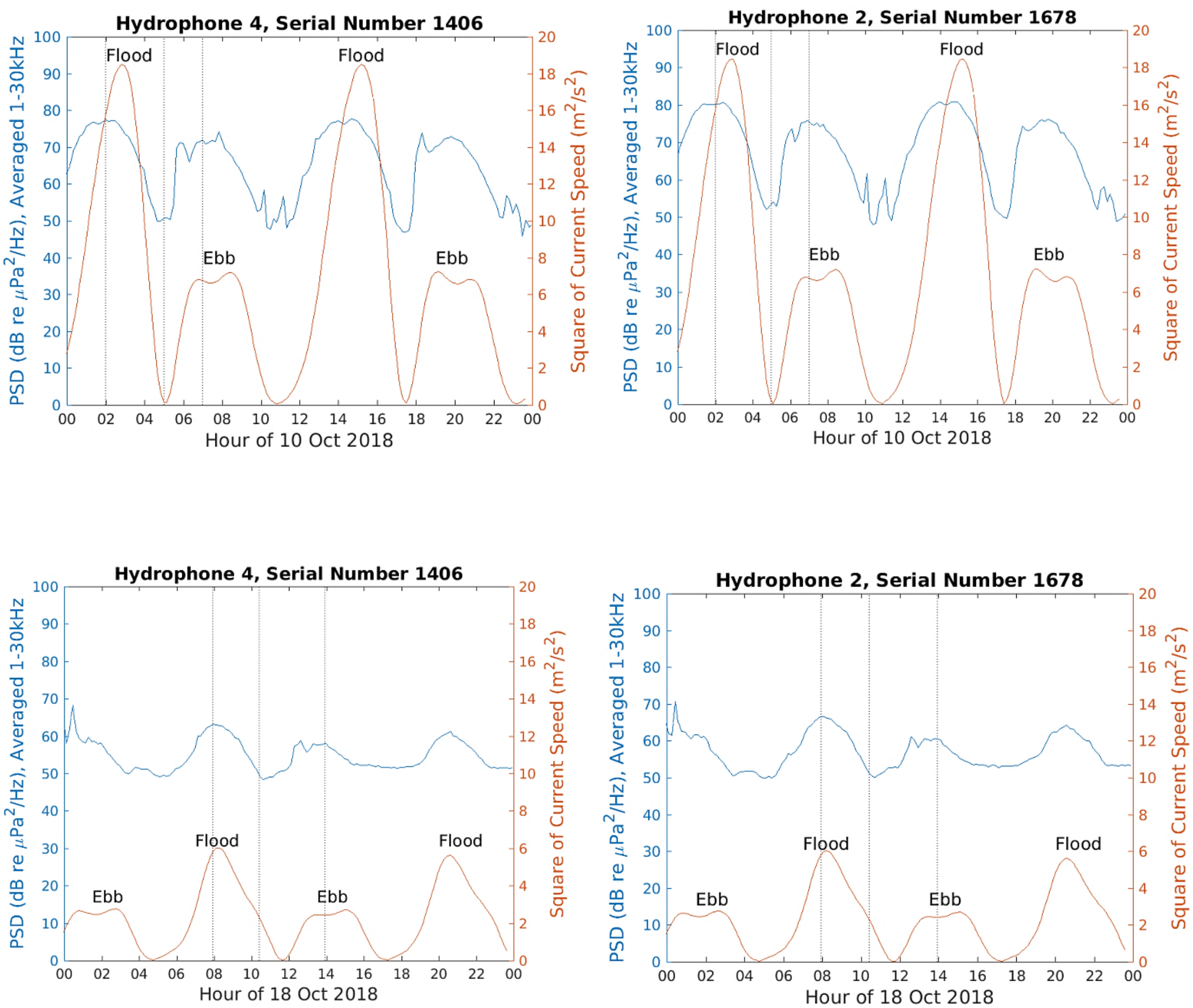



*Figure 5. TOP: Sound and squared current speed on 10 October 2018 during a spring tide. BOTTOM: Sounds and squared current speed on 18 October 2018 during a neap tide. Sound is the power spectral density (PSD) averaged over the frequency range 1-30 kHz.*

Figure 6 shows PSD obtained from Hydrophone 4 (S/N 1406) which was deployed at the western end of the turbine platform, at the greatest distance from the turbine. PSD varies from flood to slack to ebb tide and that variation is far greater during spring tides than neap tides. The flood-slack-ebb variation is observed for almost all frequencies measured. The one exception is for very narrow spikes that are apparent above 20 kHz and extend to the highest frequencies that the icListen hydrophone can record (discussed below). The bottom plots zoom in to see these spikes in the PSD for the frequency range 125-140 kHz. Porpoises use this frequency range and so such spikes may be of biological importance (e.g., by potentially masking effective echolocation processes).

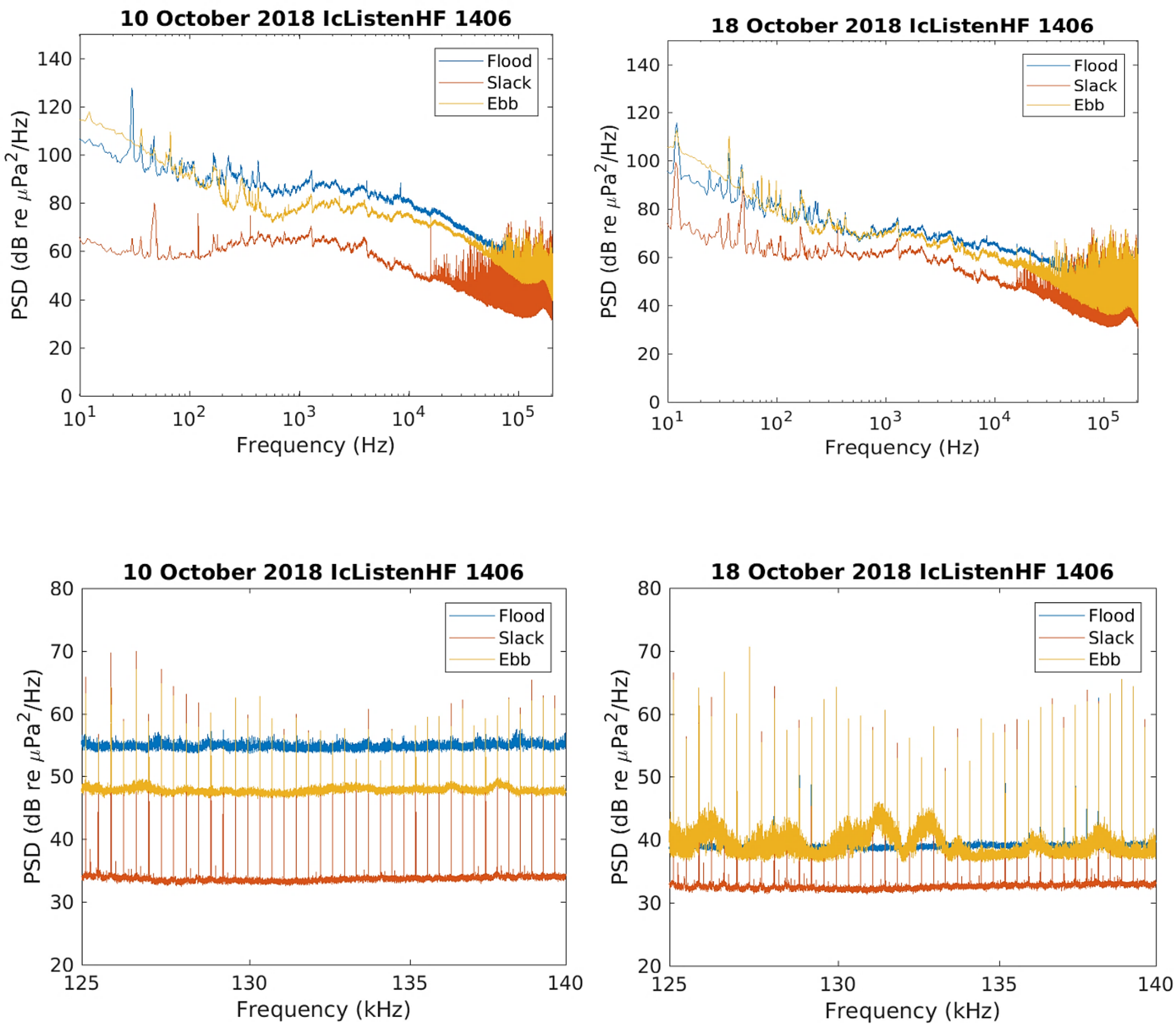



*Figure 6. PSD obtained from Hydrophone 4 (S/N 1406) during the 10 October 2018 spring tide (left) and 18 October 2018 neap tide (right). The bottom plots are zoomed in on the frequency band 125-145 kHz, where harbour porpoise vocalize.*

PSD from measurements by Hydrophone 2 (S/N 1678) are shown in Figure 7. The power spectra show a substantial variation from those obtained from Hydrophone 4 measurements. Similar trends are noted on spring and neap tides, where the variation is greater during spring tides, but the sound recorded by Hydrophone 2 is much greater, especially in the lower frequencies. There is also an increased noise level of the PSD in the range 132-138 kHz which is not associated with the tide. It is suspected that the noise is caused by a source located near Hydrophone 2.

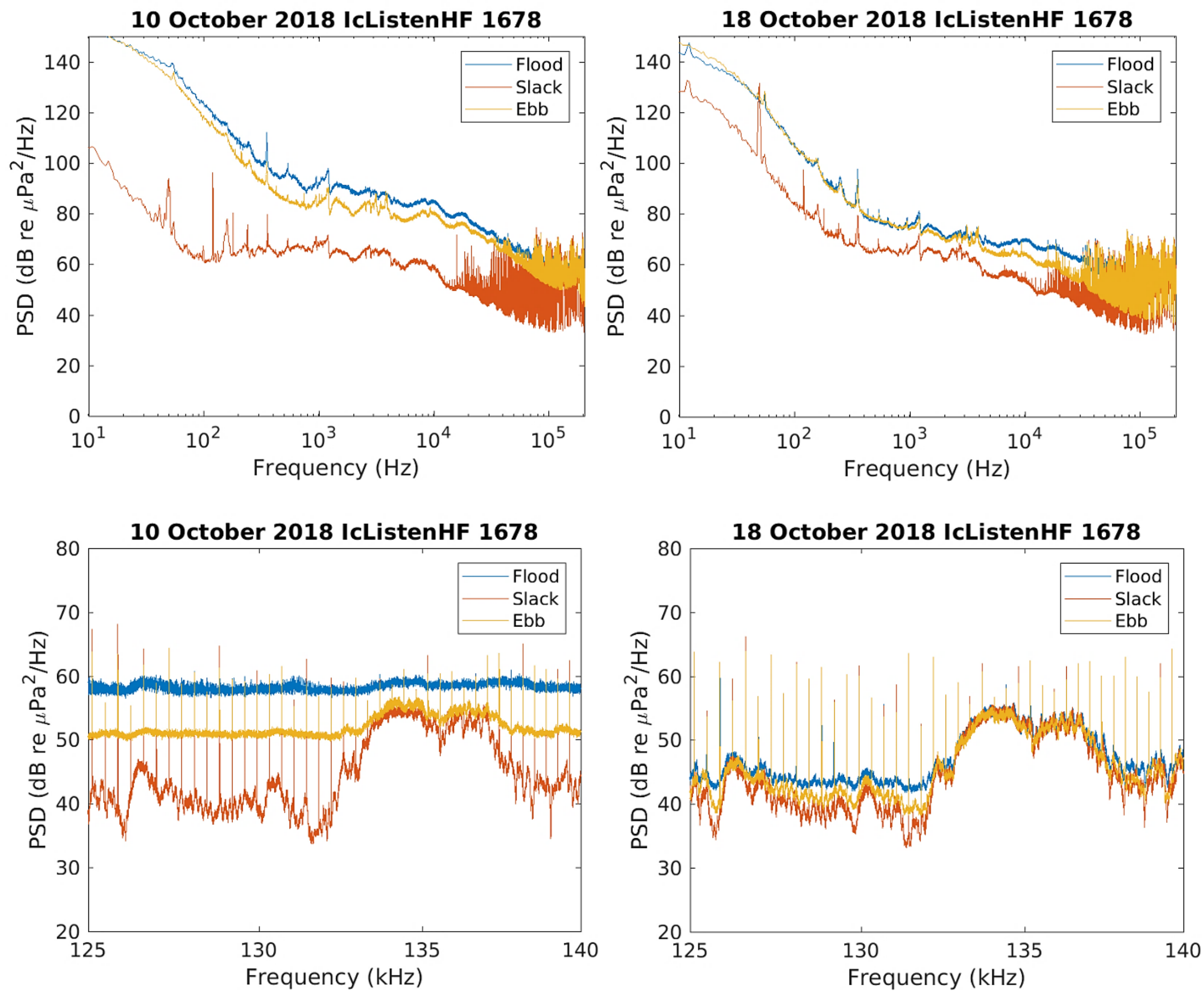



*Figure 7. PSD obtained from Hydrophone 2 (S/N 1678) during the 10 October 2018 spring tide (left) and 18 October 2018 neap tide (right). Below the plot is zoomed in on the frequency band 125-145 kHz, where harbour porpoise vocalize.*

The spikes in both Figure 6 and Figure 7 have a very narrow bandwidth and are consistently seen at frequencies separated by 372.4 Hz. The spikes are associated with the turbine installation. Measurements made in 2014 using icListenHF hydrophones on a Lander platform, at almost the same location (Porskamp, 2015) and without the presence of a turbine, showed PSD like those presently plotted but without these narrow band spikes. It is notable that such spikes were also seen in the PSD obtained from Hydrophone 2 measurements made in 2017 during the first deployment (Table 1).

The spikes were noted as an issue in 2017 and communicated to Cape Sharp Tidal and ISEM project members. At that time, the team was reminded that the preliminary tests in 2015 provided icListenHF measurements which indicated that an operational Gemini 720i elevated the sound levels at frequencies above 10 kHz and increasingly above 120 kHz (see details in Appendix D). Ocean Sonics developed a testing plan to measure noise levels from individual active acoustic devices over a tidal cycle. The sound level measurements were scheduled after OpenHydro's operations testing and were not completed. Since there were no measurements of this kind there is no definitive information on the contribution of various instruments to the noise recorded by each hydrophone. Nevertheless, given the spectral characteristics of results reported in Appendix D, it seems unlikely that the Gemini 720id was the cause of the spikes appearing in the frequency domain.

Spikes in the PSD plotted in Figure 8 were at very regular intervals in the frequency domain. The frequency of each spike was obtained, and a band-pass filter was designed for each of those frequencies (Figure 8, top plot). Measurements made by Hydrophone 4 (S/N 1406) were selected beginning 18 October 2018 at 10:17:51 UTC. This was at slack tide during neap tide conditions. A little more than 2 seconds of measurements (512 kS/s sampling rate) were selected, corresponding to $N = 2^{20}$ samples. The measurements were Fourier transformed, spectral components band-passed at frequency spikes, and the filtered time series plotted with a black line in the middle and bottom plots of Figure 8. This black line shows a small portion of the time series which is associated with spikes seen in the frequency domain (perhaps caused by ADCPs). The middle plot shows only 1 ms of that time-series.

A typical porpoise vocalization (100 dB amplitude) is overlaid on the plot (middle and bottom panels of Figure 8). Two things are obvious:

1. The 512 kS/s sampling rate does a reasonable job of resolving the porpoise signal, but it's not perfect. The Nyquist sampling theorem applies to long time series. Porpoise clicks are short.
2. Signals associated with spikes in the PSD do not match a porpoise signal but do cause troublesome signal-to-noise ratios when detecting the porpoise.

Figure 9 shows an overview of the month of October 2018 from Hydrophone 2 (S/N 1678). Spring tides near October 9 and October 24 show an increase in noise levels. It was reported that the Gemini stopped communicating on 26 October 2018. Noise interference bands most apparent between 120-200 kHz stop at the same time, potentially highlighting (harmonic) side-lobes emanating from the Gemini.

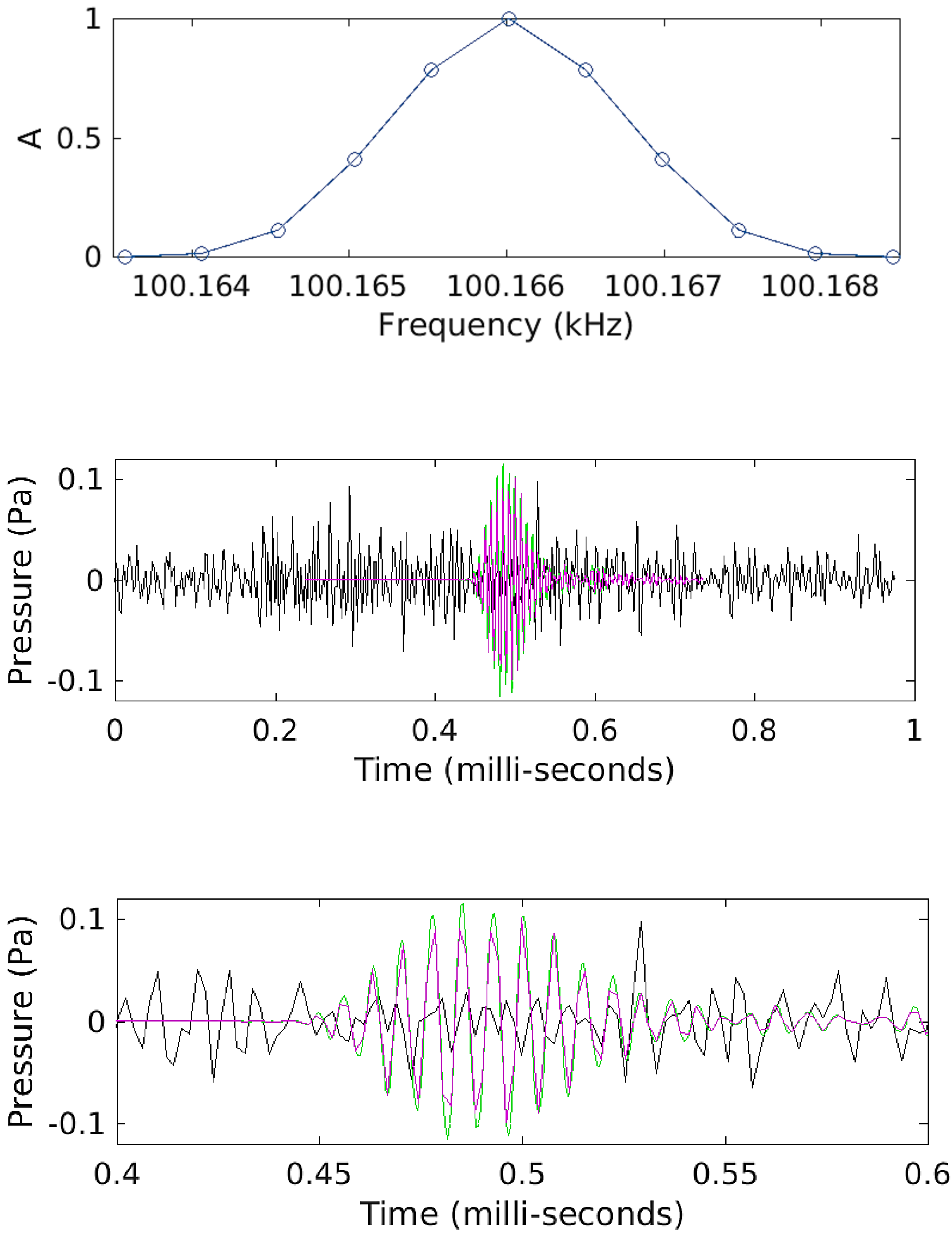



*Figure 8. TOP: Shape of the band-pass filter for each spike. MIDDLE: Time series associated with frequency spikes (black) and a 100-dB porpoise click with a 512 kS/s sampling rate (magenta) and with a Fourier interpolation to 2048 kS/s (green). BOTTOM: Porpoise click zoomed in.*

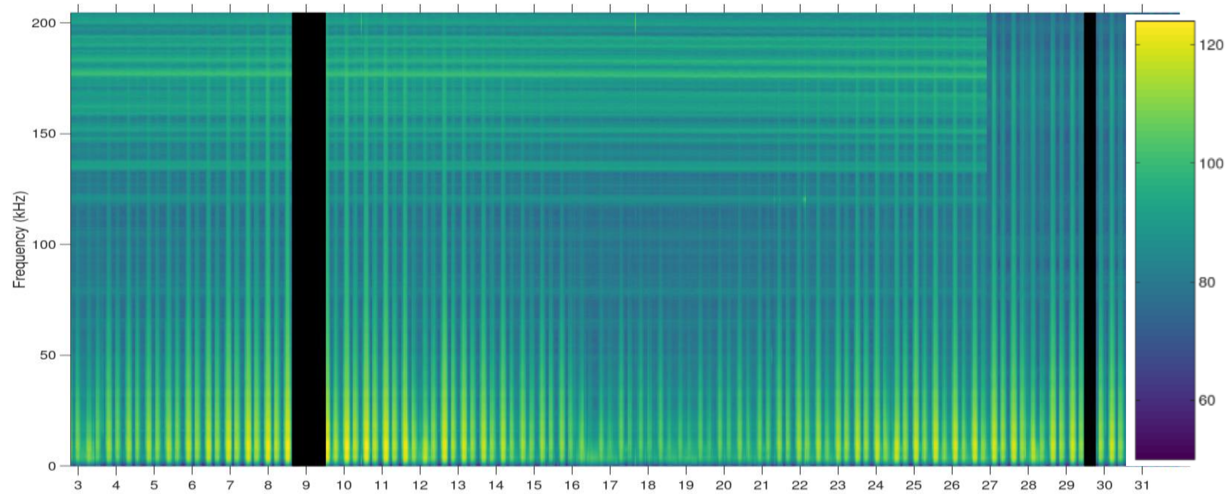



*Figure 9. Spectral data from hydrophone S/N 1678, 3 – 31 October 2018. The Gemini sonar stopped communicating on October 26. Data was unavailable for periods of time on October 8-9 and October 29. Colour scale bar represents dB.*

**Influence of Turbine Operation on Noise Levels**

Hydrophones did not record full-bandwidth time series when the turbine was operating but spectra (FFT .txt files) from the hydrophones were stored and can be analyzed to roughly estimate how turbine operations effect sound/noise levels near the turbine platform. Figure 10 characterizes turbine operation as: free-spinning (black), generating power (blue), not-free (brake on, magenta), and periods with no data (cyan). Hydrodynamic forces scale as the square of current speed which is larger on flood tides than on ebb tides. When the brake is off, rotational speed of the turbine scales with hydrodynamic force and is slightly higher when free-spinning (not generating power).

Regardless of the presence of a turbine, we can expect sound level to increase, particularly at low-mid range frequencies, as current speed increases (Porskamp, 2015; Sanderson *et al.,* 2017). Figures 6 & 7 show that hydrophone measurements made on the turbine platform generally show sound level increasing at all frequencies as current speed increases. The turbine is believed to be not-free for the time period of measurements shown in Figures 6 & 7.

The spectrogram in Figure 10 shows how sound/noise levels (as a function of frequency) vary over one day of turbine operations. The tendencies seen without the turbine (Porskamp, 2015; Sanderson *et al.,* 2017) are also apparent in Figure 10, although probably to an exaggerated extent. The most striking feature revealed in Figure 10 is the comparison of sound/noise levels at high frequencies (160-200 kHz) when the turbine is generating (blue) as opposed to when it is freely spinning (black). In particular, this effect is evident around hour 20 when the turbine is briefly generating but stuttering towards a free-spin. Near hour 14, the turbine very briefly switches to free-spin and this is associated with reduced sound/noise level at those high frequencies. Analyses of a more complete subset of the measurements through the 2016/2017 deployment might reveal whether or not this high frequency sound/noise is commonly occurring, or even a general feature of this class of turbine.

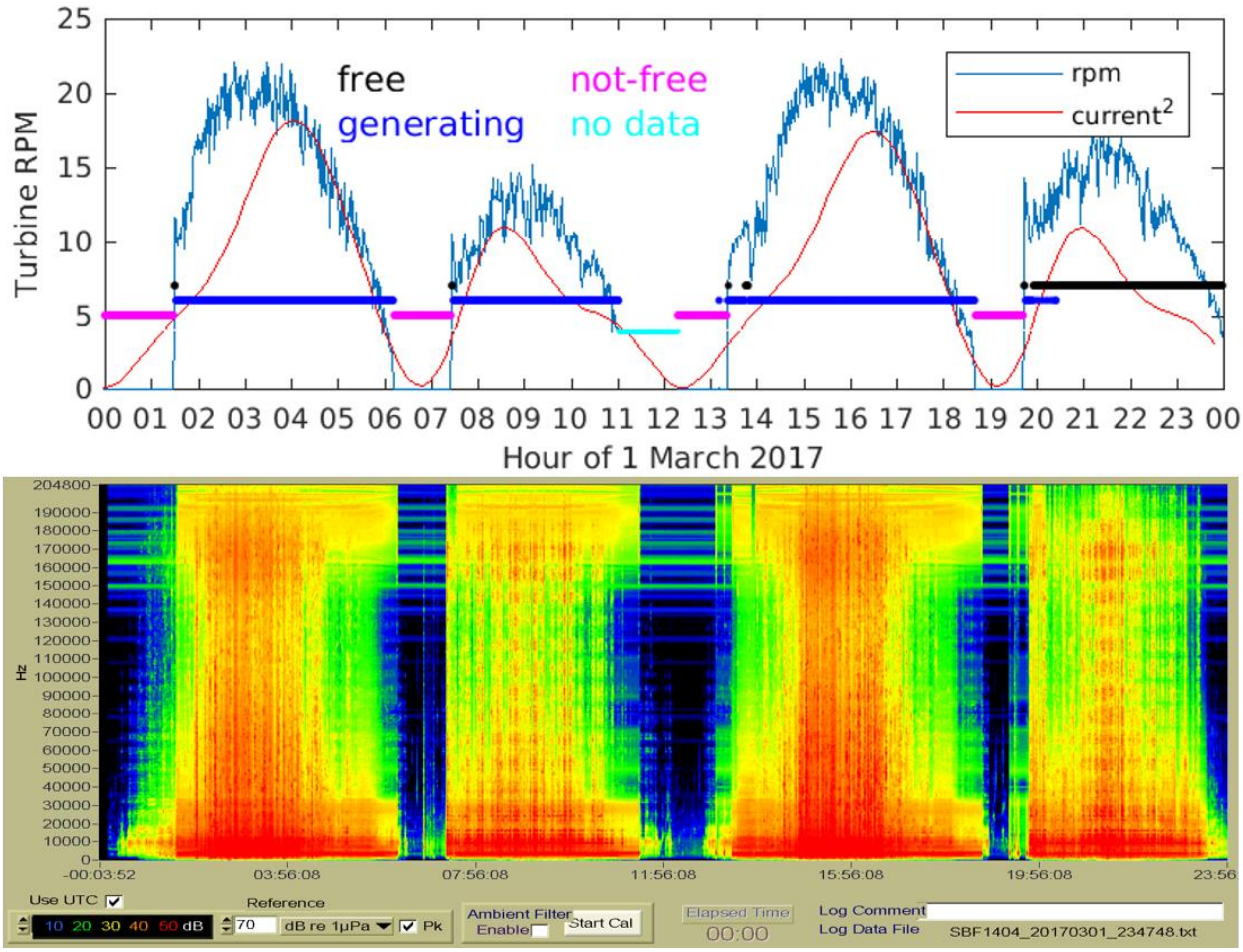



*Figure 10. Top plot shows turbine operations on 1 March 2017. The turbine revolutions per minute (RPM) are also plotted along with the square of the modelled current speed. Bottom plot shows a Lucy spectrogram of hydrophone 1404 measurements over the same 24-hour period.*

The data from the first deployment had limited information on noise created during turbine operation but did show that tidal turbine activities increase noise levels across both low and higher frequencies. Noise levels will be dependent on the nature of the operations at the turbine and may influence hydrophone detection of porpoise and fish tags. This should be an area of investigation in future effects monitoring projects.

## 3.3 Hydrophone Test Results

**Harbour Porpoise Click Detection**

Harbour porpoise click detection in the Minas Passage is dependent on the ability to detect a click above the background noise level, which varies with current speed. Additional noise sources in the area, including sound emissions from active acoustic monitoring equipment and turbine operations, increase the overall noise level. Strong currents can cause non-acoustic signals (Strasberg, 1979) that impact hydrophone performance and make click detection more difficult. At times, the background sound/noise can be larger than the signal levels of porpoise clicks and can thus eliminate any possibility of detection.

Measurements of wild Atlantic harbour porpoise clicks indicate source levels from 169 to 205 dB re µPa at 1 m (Villadsgaard *et al.,* 2007; Kyhn *et al.,* 2013) which are consistent with measurements in Minas Passage (Sanderson *et al.,* 2019a,b). Source levels as low 145 dB have been measured for captive animals (Linnenschmidt et al. 2012). Variations in reported source levels make it difficult to generalize a relationship between measurements of click level and range to a porpoise. Considering radial spreading and attenuation of 37.5 dB/km (Fisher & Simmons, 1977) we obtain maximum click level falling as a function of range from the hydrophone to the porpoise (Figure 11). Two source levels are considered in Figure 11 in order to illustrate that setting a threshold level of 110 dB for click detection amounts to constraining the maximum range for porpoise detection. Harbour porpoise clicks have a narrow beam width (Au et al., 1999) so most clicks are detected off the beam axis, and a 110 dB detection may be from an animal that is much closer than the maximum ranges indicated by Figure 11. Adverse propagation characteristics of strongly turbulent tidal currents may cause scintillation and other effects that further degrade detection range.

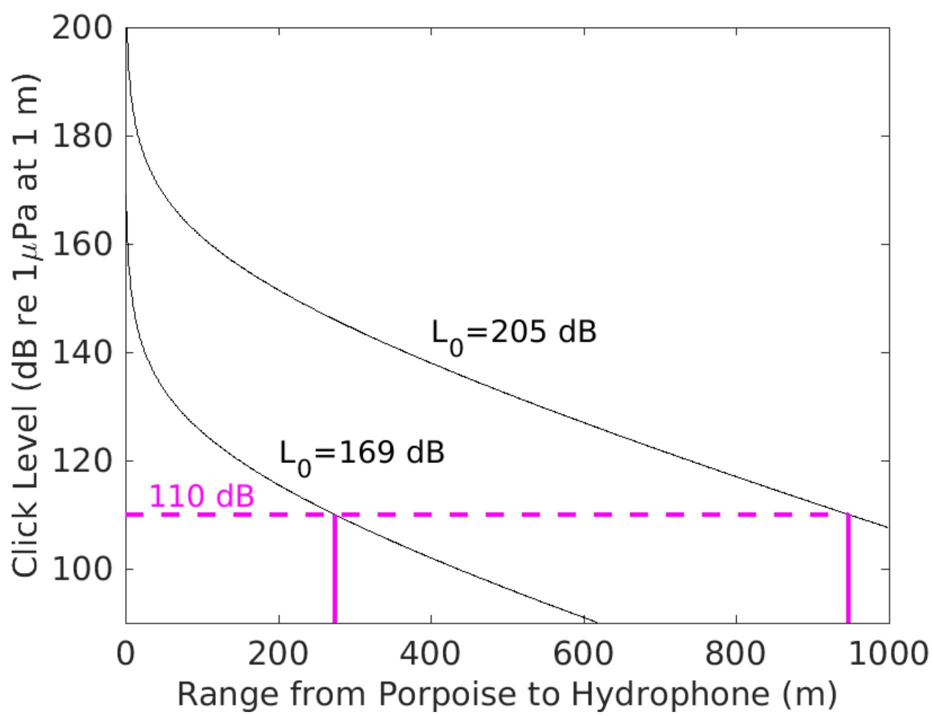



*Figure 11. Sound level of porpoise clicks with source levels 205 and 169 dB re 1µPa at a reference range of 1 m. Sound level falls with range due to radial spreading and attenuation of 37.5 dB/km. Ranges are shown corresponding to a 110 dB lower limit for click detection.*

**Click Detection Results from the 2016/2017 Tidal Turbine Deployment**

Hydrophones were configured to provide times series at 32 kS/s and 64 kS/s sample rates for most of the first turbine deployment (Table 1). Porpoise clicks are not resolved by such low sample rates and so neither *PAMGuard* nor *Coda* were used to detect porpoise clicks during that period. High frequency information was preserved, however, in the spectral representation of the measurements (FFT text files) for most of the first turbine deployment. The *Lucy* porpoise click detector can utilize spectral data, so *Lucy* was used to analyze the FFT text files when time series with high sample rates were not available to process with *PAMGuard* and *Coda*. The analysis is presented within the attached Ocean Sonics Report (2017), Appendix B.

Full bandwidth (512 kS/s) time-series were recorded from Hydrophone 2 (S/N 1404) from 25 March to 13 April 2017 (Table 1). The turbine ceased power generation on 23 March 2017 and so these hydrophone measurements are mostly representative of the turbine in free-spin, although records indicate not-free near slack tide. Given our previous observation of high-frequency sound/noise when the turbine is generating, the present measurements cannot be considered to be sufficient for a complete test of click detection for environmental monitoring. Three harbour porpoise click detectors were used to search for clicks in the time-series measurements from the first deployment: *Lucy*, a PC software program created by Ocean Sonics for use with the icListen hydrophone; *PAMGuard*[1]*,* an open source program used for passive acoustic monitoring; and *Coda*, a proprietary harbour porpoise click detector developed jointly by Brian Sanderson and Ocean Sonics Ltd.

The porpoise click detection programs in *Lucy* and *PAMGuard w*ere adjusted for the 512 kS/s hydrophone measurements in an attempt to optimize performance for conditions prevailing during the first turbine deployment. After reviewing results, it appeared that high tidal flow noise and active acoustic instruments (sonar, ADCPs, acoustic modem, etc.) caused many false positive and false negatives, with few true positive detections. *Coda* appeared to perform better in the high noise environment of Minas Passage. *Coda* contains several adjustable parameters which are probably well tuned for detecting porpoise in Minas Passage. In particular, *Coda* was set to only accept detections with signal levels 110 dB or higher and this probably minimized false positives. Adams et al., (2019) also found that *Coda* performed well when ambient sound level was high.

It must be stressed that *Coda* was designed to operate in real time with minimal computational cost in order to identify segments of data that should be down-sampled for storage because there is a good likelihood that they contain porpoise clicks. It is not a general-purpose program, but rather specialized for one task. An additional program, *Coda+*, was used to automatically obtain clicks trains from the *Coda* detections. Semi-automated review programs can undertake more detailed analyses and best-fit comparisons to a range of porpoise signals. Time limitations largely restricted the present analysis to detection of clicks and obtaining click trains. Limited reviews (not reported) did illustrate that the 110 dB threshold caused *Coda* to miss some clicks within a train of clicks.

[1] http://www.pamguard.org

*Coda* was used to detect clicks in hydrophone measurements from the second deployment (2018) and to down-sample segments of data corresponding to potential porpoise detections.

**Click Detection Results from the 2018 Tidal Turbine Deployment**

*Coda* was used to detect porpoise clicks in the data collected with Hydrophone 4 (S/N 1406) from September and October 2018. A down-sampled data set was created in order to enable detections to be more thoroughly scrutinized without the inconvenience of having to store large amounts of data. These click detections were then further processed to locate click trains in the data. The use of click trains helps to reduce false positive detections with both *Coda* and *PAMGuard*.

The *Coda* processing includes:

1. Eliminating multiple detections of the same click.
2. Identifying click trains. Characterized by a sequence of 3 or more clicks in which the maximum inter-click interval (ICI) is 0.25 s.
3. Reviewing click trains. Keeps only click trains where there is at least one value of PB2 > 2.5 and click level larger than 110 dB. Helps eliminate false positive detections and give the study detection criteria.

The above processing is automated. There is no review of individual clicks using this method but down-sampled data (in 1 second segments) contain measurements enclosing each click so an analyst can review clicks for false-positive detection.

Detected click trains were used to obtain 'detection positive 10-minutes' (DP10M). The DP10M were defined as 10-minute measurement periods that contained at least one of the above click trains (Table 3). Porpoises were detected in all fall time periods assessed, ranging from 1.7 to 6.3 DP10M, but were not detected uniformly through time (Figure 12).

*Table 3. The percentage of detection positive 10-minute intervals for various measurement periods. Measurements were made using Hydrophone 4 (S/N 1406).*

| Measurement Period Percentage | DP10M |
|---|---|
| 1-10 September 2018 | 2.8 |
| 11-20 September 2018 | 6.3 |
| 21-30 September 2018 | 4.1 |
| 1-10 October 2018 | 1.7 |
| 11-20 October 2018 | 4.9 |
| 21-31 October 2018 | 4.8 |

The number of click trains in each 10-minute measurement interval are plotted with current speed in Figures 12 & 13. Detections of porpoise vocalizations are clustered with respect to time. Previous studies have highlighted a strong preference for night-time detections of porpoise (Tollit et al., 2019), which is also evidenced in much of this dataset.

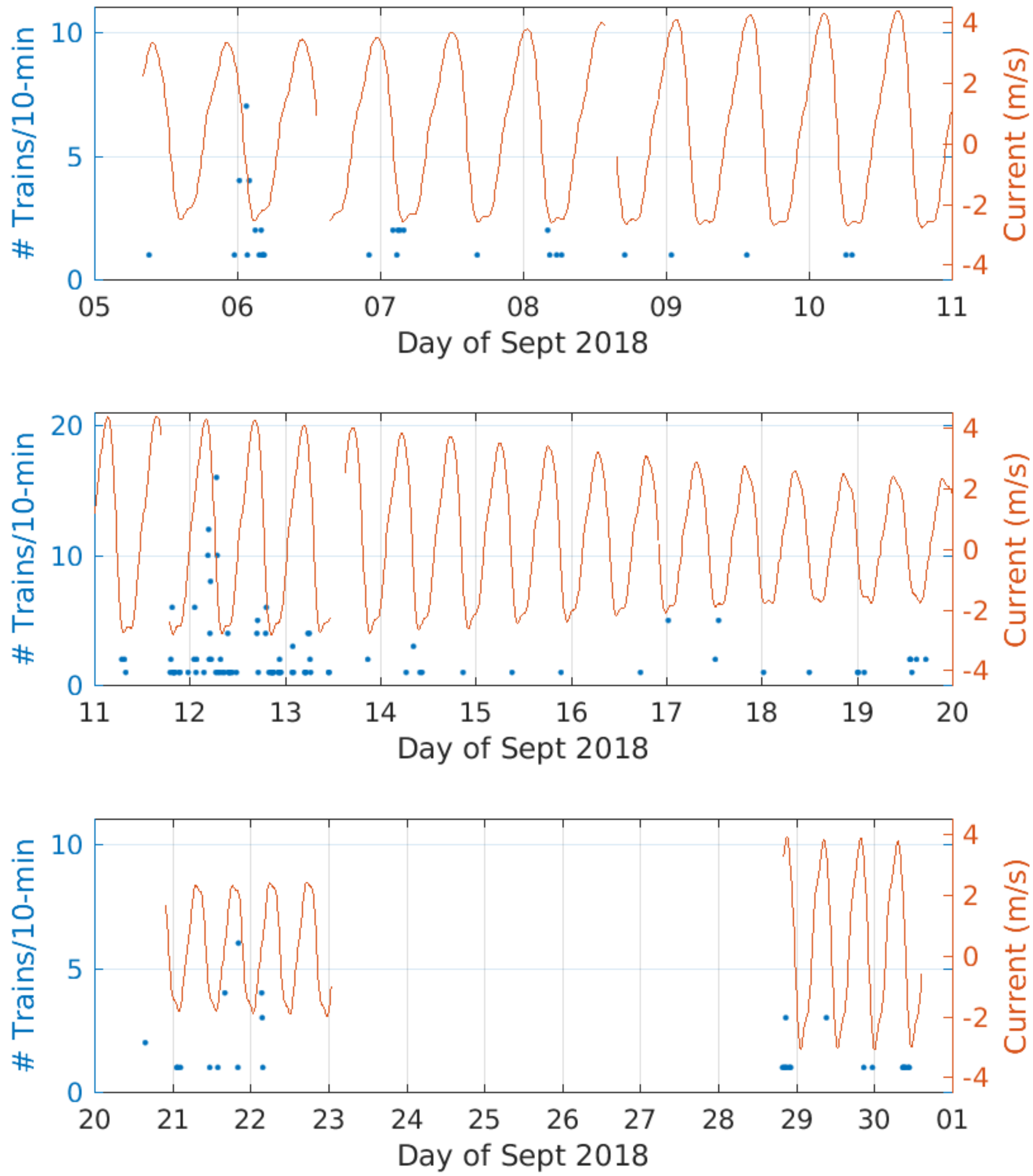



*Figure 12. Harbour porpoise click trains and current speed for September 2018 detected by Hydrophone 4. Dots show the number of click trains detected in each 10-minute interval. Intervals without a click train are not marked. Current speed is positive for flood tide and negative for ebb tide. Gaps in the current plots correspond to gaps in the hydrophone record.*

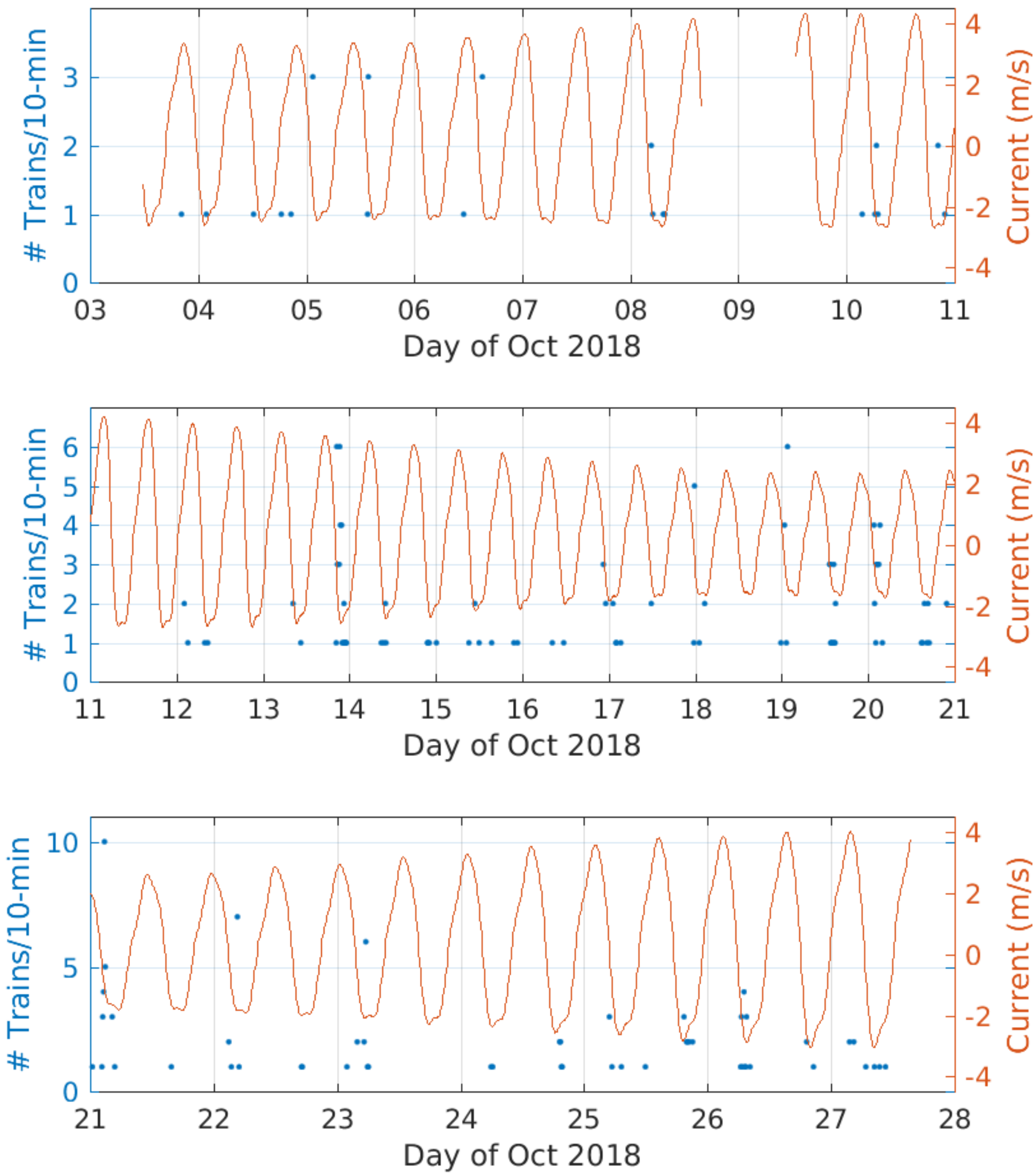



*Figure 13. Harbour porpoise click trains and current speed for October 2018 detected by Hydrophone 4. Dots show the number of click trains detected in each 10-minute interval. Intervals without a click train are not marked. Current speed is positive for flood tide and negative for ebb tide. Gaps in the current plots correspond to gaps in the hydrophone record.*

We reviewed some selected data segments within which spectra output from Hydrophone 2 were reviewed using *Lucy*. Corresponding time-series measurements were reviewed using *Audacity,* an open-source software program. Figures 14-18 show *Audacity* spectrograms for five data segments. Porpoise click trains are very evident in all five spectrograms.

Each of the spectrograms in Figures 14-18 also contain other high frequency clicks that we presume to originate from active acoustic devices installed on the turbine or from the turbine and its interaction with the environment. The data segments in September 2018 contained strong clicks at 1 second intervals with energy at discrete frequencies that lie in the range 70-250 kHz (Figures 14 & 15). Figure 19 more accurately resolves some of these discrete frequencies (e.g. 63, 67.5, 72, 76.5, 81 kHz). These 1-second interval clicks are not evident in the October 2018 data segments. Weak horizontal bands are present in the frequency range 85-210 kHz for all segments although they are more difficult to resolve when current speed is higher (Figures 15 & 18). When ambient sound is low (Figure 17), some of the horizontal bands are seen to be comprised of closely spaced clicks.

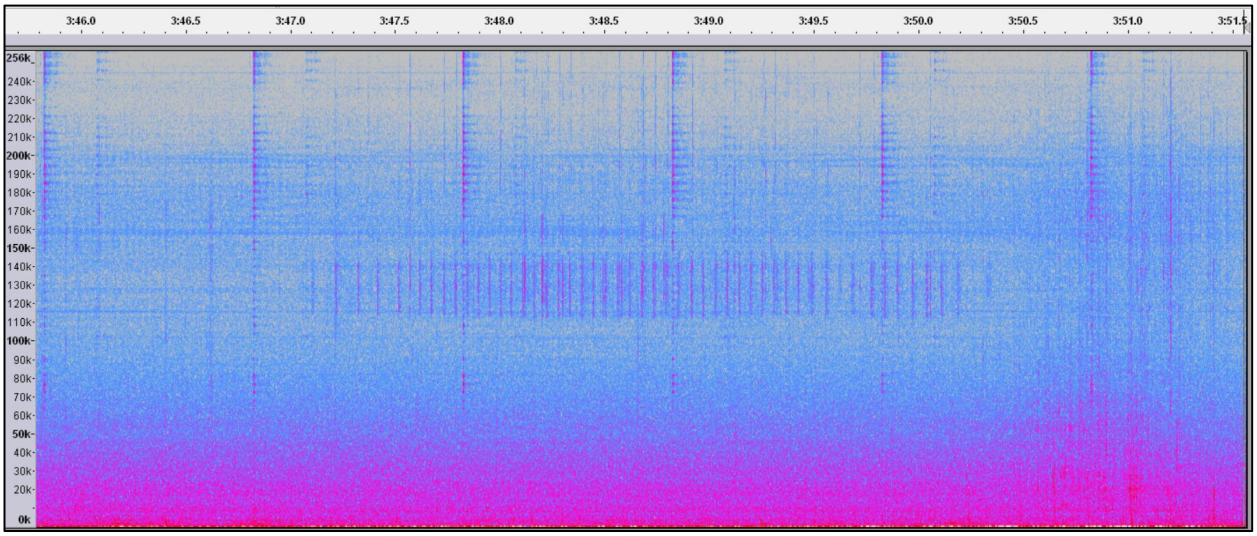



*Figure 14. Audacity spectrogram for 5 seconds of measurements beginning 0206:14 UTC on 6 September 2018. Audacity represents time (horizontal axis) in minutes and decimal seconds from the start of the file. The frequency scale is 0-250 kHz. Porpoise clicks found between 120-140 kHz. Strong clicks are found between 70-250 kHz at 1-second intervals. Weak horizontal bands are evident in the frequency range 85-210 kHz. Ebb current is -1.3 m/s.*

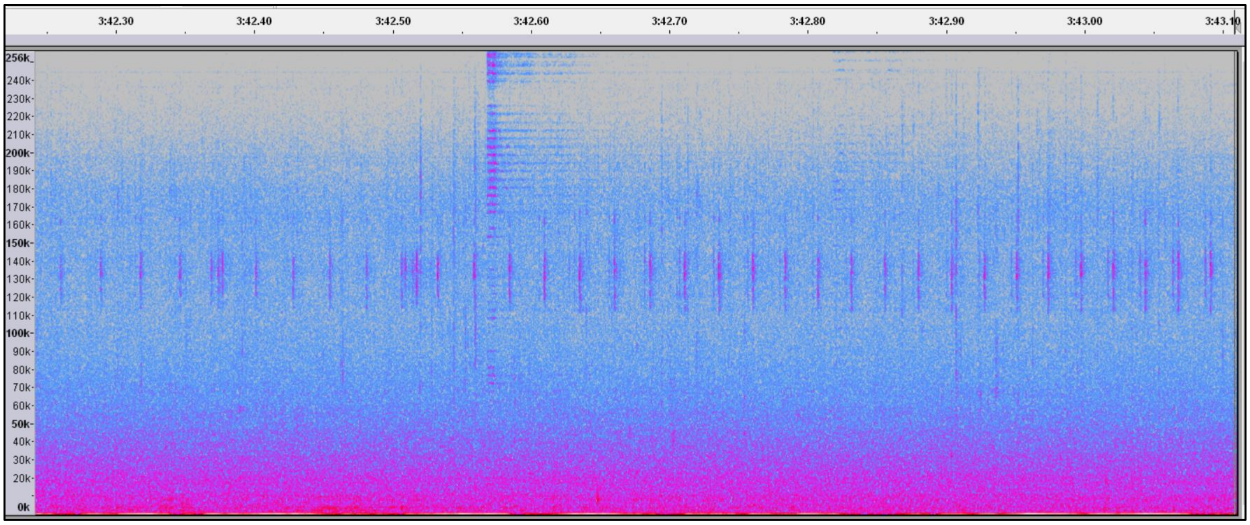



*Figure 15. Audacity spectrogram for 1 second of data beginning 0718:58 UTC on 10 September 2018. Audacity represents time (horizontal axis) in minutes and decimal seconds from the start of the file. The frequency scale is 0-250 kHz. Porpoise clicks are evident (120-140 kHz). A single strong click is found between 70-250 kHz within the 1-second interval. Ebb current is -2.7 m/s.*

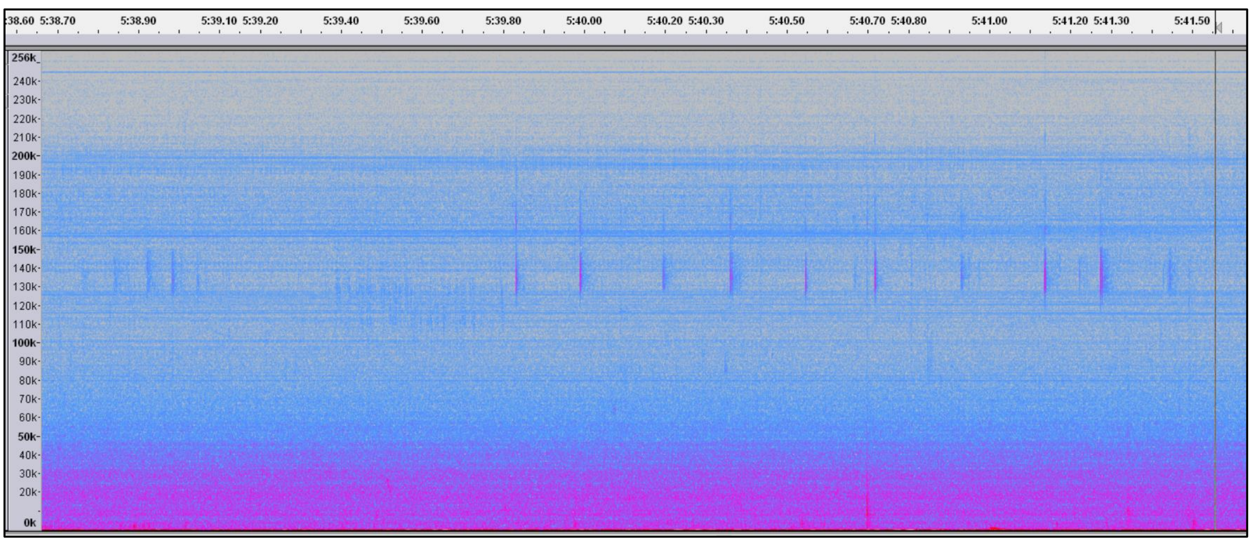



*Figure 16. Audacity spectrogram for 3 seconds of data beginning 0134:06 UTC on 5 October 2018. Audacity represents time (horizontal axis) in minutes and decimal seconds from the start of the file. The frequency scale is 0-250 kHz. Faint porpoise clicks in the first second are followed by louder porpoise clicks. Horizontal bands in the frequency range 85-210 kHz are now very clearly evident, perhaps because ambient sound level is low in the -0.9 m/s ebb current.*

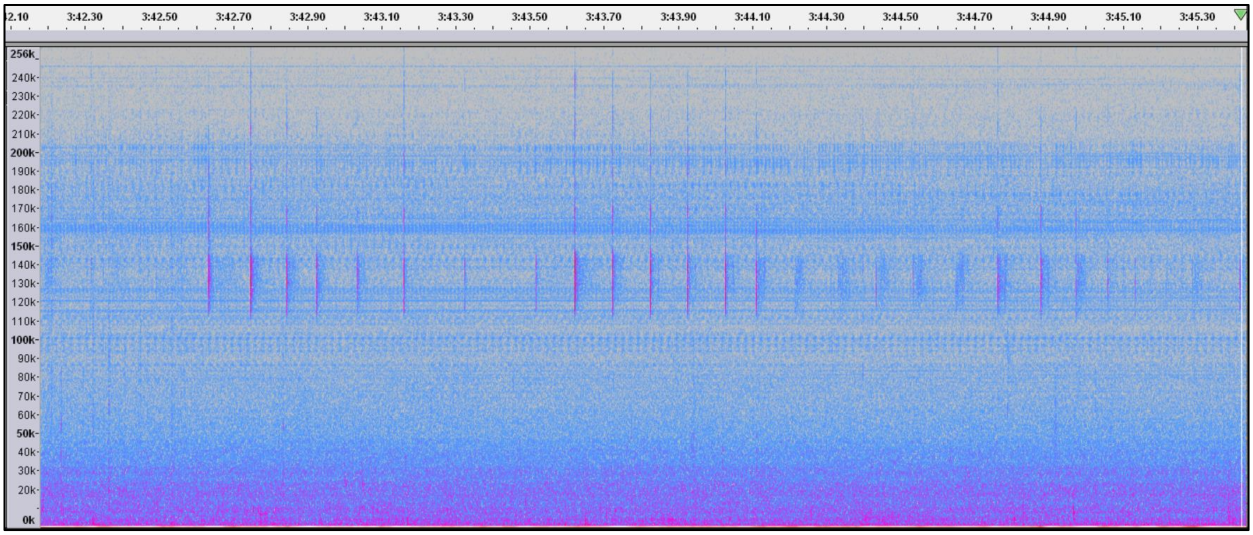



*Figure 17. Audacity spectrogram for 3 seconds of data beginning 0221:33 UTC on 20 October 2018. Audacity represents time (horizontal axis) in minutes and decimal seconds from the start of the file. The frequency scale is 0-250 kHz. Porpoise clicks are evident (120-140 kHz). Ambient sound level is low. Horizontal bands seen in the frequency range 85-210 kHz now appear to resolve closely spaced clicks. Ebb current is -1.0 m/s and ambient sound levels are probably low.*

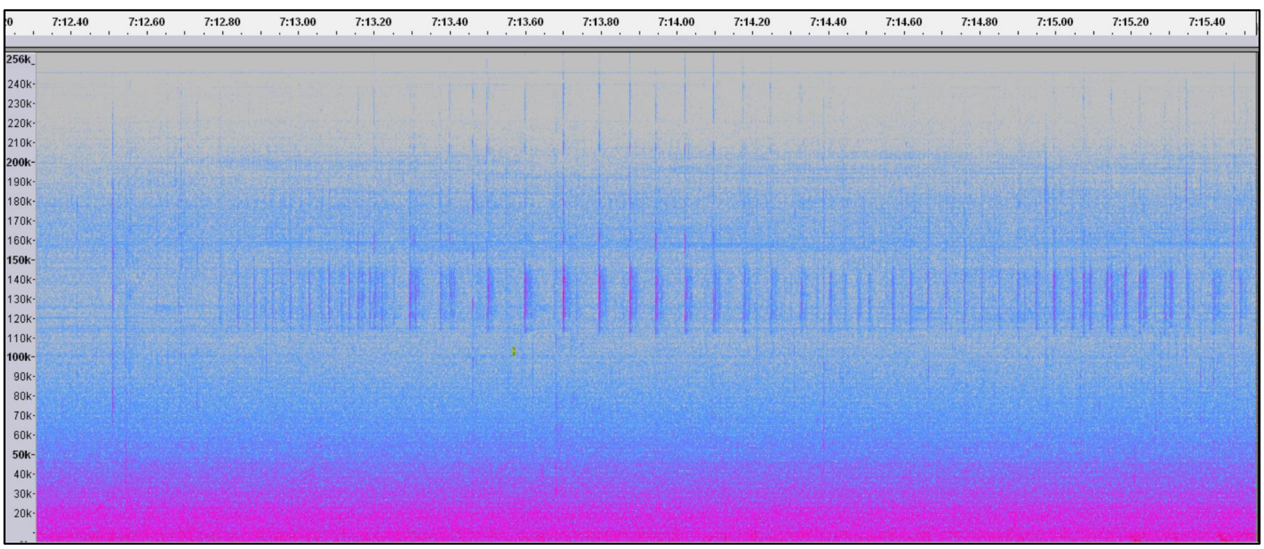



*Figure 18. Audacity spectrogram for 3 seconds of data beginning 0542:30 UTC on 23 October 2018. Audacity represents time (horizontal axis) in minutes and decimal seconds from the start of the file. The frequency scale is 0-250 kHz. Porpoise clicks show varying inter-click intervals. Ebb current is -2.1 m/s.*

## 3.4 Discussion of Localization

The positioning of hydrophones was selected primarily for "all around" acoustic coverage of the turbine to provide porpoise detection events for integration with AAM detection of porpoises. Secondarily, there was interest in the ability to localize (find position of) approaching porpoises. The four hydrophones installed on the tidal turbine structures were synchronized for potential localization of porpoise based on detected clicks. There were various issues that prevented localization of harbour porpoise which are outlined in the following subsection. Regardless, we were able to test the probability of obtaining signals that could be used for localization; results are presented in the second subsection below.

**Issues Encountered with Localization**

Localization issues originated from various sources. The first issue was with the accuracy of turbine drawings provided. Only relative size and positioning were available to the research team. The second issue was that the communications to Hydrophone 1 (S/N 1404) stopped after the power was restored in September 2018; without a fourth hydrophone, it was impossible to provide 3-dimensional localization.

A further issue relates to the layout of the hydrophones on the turbine. OpenHydro supplied technical drawings from which we obtained approximate separations of hydrophones: 17 m between Hydrophones 2 and 3, 20 m between Hydrophones 3 and 4, and 25 m between Hydrophones 2 and 4. Because harbour porpoise project clicks with 16° beam width (Au et al., 1999), large separation distances between hydrophones reduces the likelihood that the same click will be detected by multiple hydrophones. For example, consider two hydrophones separated by 25 m along a line orthogonal to the path of a click. The porpoise would have to be at a range of at least 90 m for the click to be detected by both hydrophones. In addition, turbine infrastructure between hydrophones effectively masks some click paths.

**Probability Testing for Porpoise Localization**

Hydrophone 4 (S/N 1406) detected 1656 high-quality clicks. Localization requires that the same click be detected by the other hydrophones. To test the possibility of localization, we searched for clicks within measurements made by the other hydrophones. The search was limited to an examination of data segments that bracketed time spans within which each of the clicks detected by Hydrophone 4 (S/N 1406) could have arrived at the other hydrophones. This time span is plus/minus the travel time of sound between instruments.

Hydrophone 2 (S/N 1678) obtained nine click detections that were potential matches to the 1656 detections by Hydrophone 4. There were three occasions when pseudo-sound caused signal clipping and 87 occasions when measurements were not available from Hydrophone 2. It follows that there were only nine chances in 1566 that Hydrophone 2 could potentially match a detection by Hydrophone 4.

Hydrophone 3 (S/N 1677) obtained seven click detections that were potential matches to the 1656 detections by Hydrophone 4. Hydrophone 3 was attached to the top of the turbine; fast currents caused pseudo-sound clipping on 360 occasions. Additionally, there were another 106 occasions when Hydrophone 3 measurements were not available. It follows that there were only seven chances in 1190 that Hydrophone 3 could potentially match a detection by Hydrophone 4. Finally, we note that there were only three times when both Hydrophones 2 and 3 obtained detections that might have matched those obtained by Hydrophone 4.

The four widely separated hydrophones were not optimal for localization of harbour porpoise, especially at close range, and were thus unable to allow determination of accurate ranges, depths, or positions of porpoises. This is not to say that the method might not apply under different circumstances or that methods cannot be adapted for the present circumstances. For example, if ambient sound levels were lower and the path between hydrophones not blocked by turbine infrastructure, an entirely different outcome might be achieved because porpoises could be detected from a greater range by all hydrophones.

Importantly, it was common to observe acoustic fish tags (69 kHz) in the hydrophone measurements. Because fish tags are an omnidirectional signal source, there is a greater probability that a given transmission would be detected by multiple hydrophones — especially if hydrophones are placed in an array so that instruments have an unimpeded path to a chosen monitoring region. Similarly, 'pinger' trials with an artificial sound source mimicking a porpoise click could be carried out to test the hydrophone array design for localization.

## 3.5 Discussion of *Coda* Click Detector

The *Coda* harbour porpoise click detector performed well in data with loud background noise levels and was chosen to process .wav data during the first and second deployments. During the second deployment *Coda* was integrated into an automated program on the computer dedicated to monitoring equipment at the FORCE turbine substation. *Coda* processed .wav files from the four hydrophones in real-time and results were used to down-sample portions of the full bandwidth .wav files that contained detected porpoise clicks. The automated program was not able to be fully tested or optimized due to the unexpected shutdown of the turbine and monitoring equipment on 26 July 2018. Nevertheless, *Coda* operated during the two days of monitoring before shutdown.

Given *Coda's* real-time analysis of .wav data to down-sample data and produce diagnostic output in text form, *Coda* shows the potential for interfacing with the software controlling other devices. *PAMGuard's* real-time diagnostic outputs has similar potential but would require a software update to be compatible with icListen input data. Integrating the automatic detection of clicks with an Active Acoustic Monitoring (AAM) device could serve to increase the reliability of detection, localization and potential interactions of porpoise around a tidal turbine.

## 3.6 PAM Discussion

The *Coda* porpoise click detector performed well on the hydrophone data collected and could distinguish between instrument clicks and porpoise clicks. During the second deployment the turbine was not operating and therefore prevented any measurements of the effect of turbine operations on performance of the monitoring system. The click detections from *Coda* created outputs that were further processed using *Coda+* to locate click trains, which is useful in identifying porpoise feeding buzzes and other behaviours.

The ability to detect clicks decreased as the noise levels in the frequency band of interest increased. The increase in noise was attributed to tidal flows, other equipment on the turbine and the turbine itself when operating, as shown in acoustic data during the first deployment (Figure 10).

Hydrophone placement will influence the noise levels recorded and therefore affects detection of porpoise vocalizations. The closer a hydrophone is to a sound source, such as an active acoustic instrument on the turbine, the noisier the data will be, thus decreasing the probability of detecting marine mammals.

Greater current speeds during spring tides caused an increase in tidal flow noise. A spring tide on 10 October 2018 was compared to a neap tide 18 October 2018 using two hydrophones, S/N 1406 and S/N 1678. An average noise level from 1-30 kHz was used to compare flow noise over a 24-hour tidal cycle. During a spring tide, great variation is found in the noise levels as well as the current speed. During a neap tide, less variation is found in both.

Hydrophones were arranged on the turbine platform in order to achieve multiple objectives with a minimal number of instruments. Different hydrophone setups are required to optimize for localization of porpoise clicks. Two general constraints apply for arranging hydrophones for localization. First, hydrophones must be sufficiently closely spaced so that there is a high probability that the narrow beam of a porpoise click will be detected by many hydrophones. Second, hydrophones must be sufficiently widely spaced with unobstructed paths so that the array has aperture within about an order of magnitude of the ranges over which localization is required. (This second principle also ensures greater probability that many narrow-beam clicks will be detected from porpoises that enter the area of interest.) Sanderson et al., (2019a) demonstrated how reflected clicks could be used to achieve both of these conditions by using only two closely-spaced hydrophones (2 m separation) in Minas Passage. Generally, meeting both of these conditions will require an array of many hydrophones separated by a range of scales. Studies undertaken for the Tidal Energy Ltd and MeyGen projects in the UK Scotland successfully used multiple closely positioned clusters of 3-4 hydrophones to track porpoises (Malinka et al., 2018; Sparling et al., 2016). Array design should be optimized according to specific objectives. For determination of abundance, it may be most efficient to use a vertical array because only range and depth are required. Hydrophones mounted to the OpenHydro gravity-base platform could not be serviced or replaced until the platform was recovered. Providing a sufficient number of hydrophones are used, an array can remain functional even if there are some instrument failures (Malinka et al., 2018).

Hydrophones can be used to detect fish tags and, potentially, to track tagged fish. Fish tags were found throughout the data recorded in September and October 2018 (Figure 19). Fish tag pings were found on 15 out of 21 days in September 2018. Multiple fish tags were detected throughout the day, predominately during slack tide. A table of fish tag detections can be found in Appendix C.

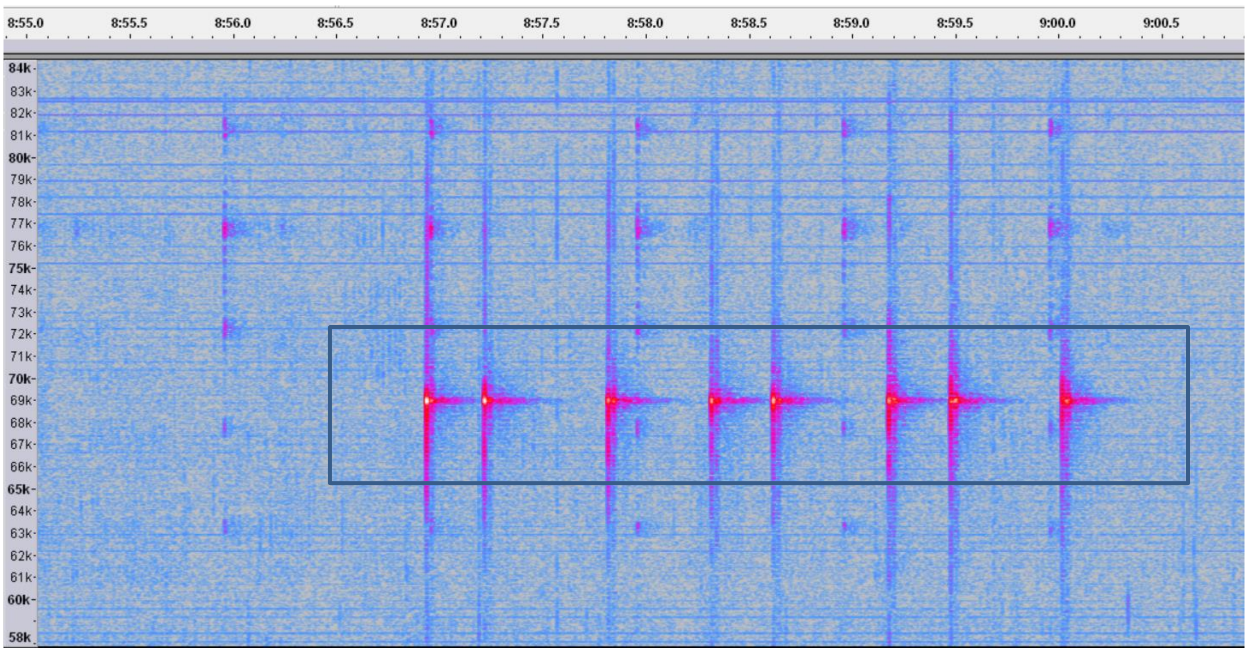



*Figure 19. Audacity spectrogram showing fish tag signals (69 kHz) for 3 seconds of data from hydrophone 1406 on 10 September 2018 at 10:14 UTC. Other noise is from nearby equipment.*

Potential dolphin whistles, buzzes and clicks were found in the data set (Figure 20 & Figure 21). Additional analysis of the data set could be done to review the occurrence of marine mammal species in Minas Passage, noting that there are occasional sightings of white-sided dolphins (*Lagenorhynchus obliquidens*) and long finned pilot whales (*Globicephala melaena*) (OERA, 2008).

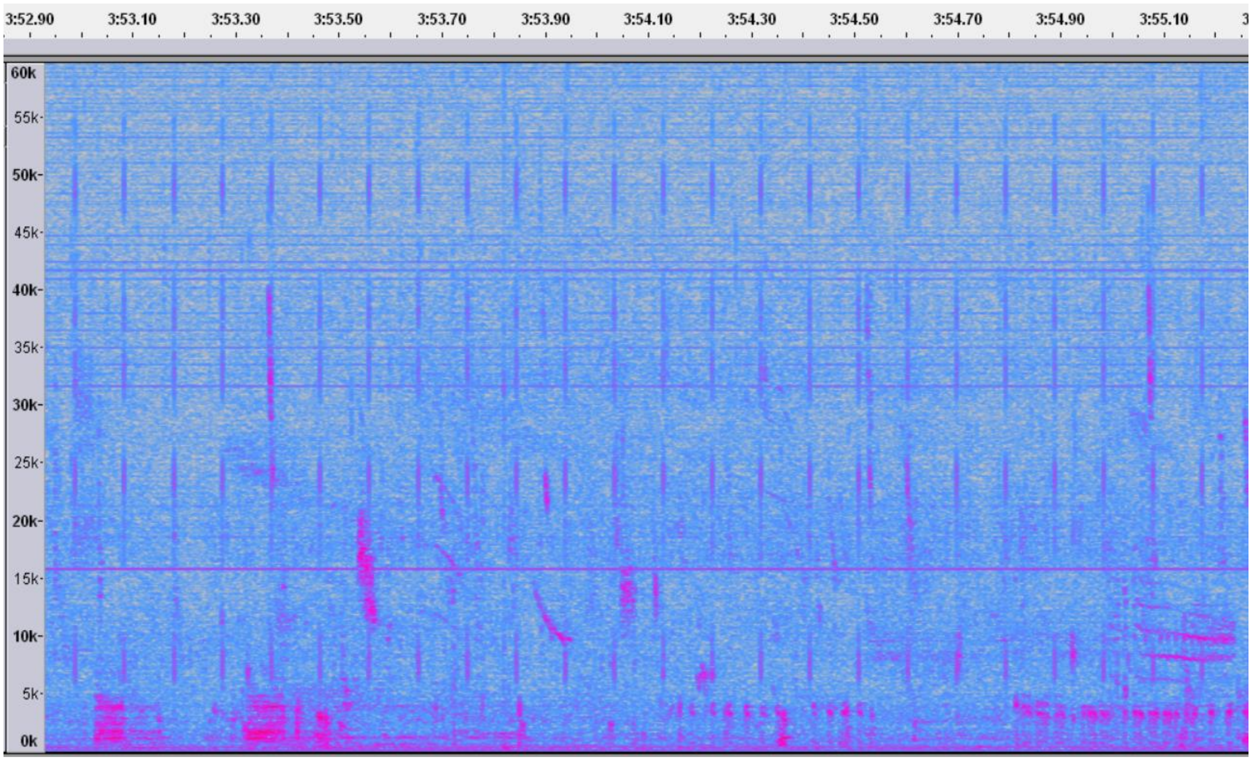



*Figure 20. Audacity spectrogram of 2 seconds from Hydrophone 1678 beginning 09:01:32 UTC on 8 October 2018. The frequency scale is 0 – 60 kHz.*

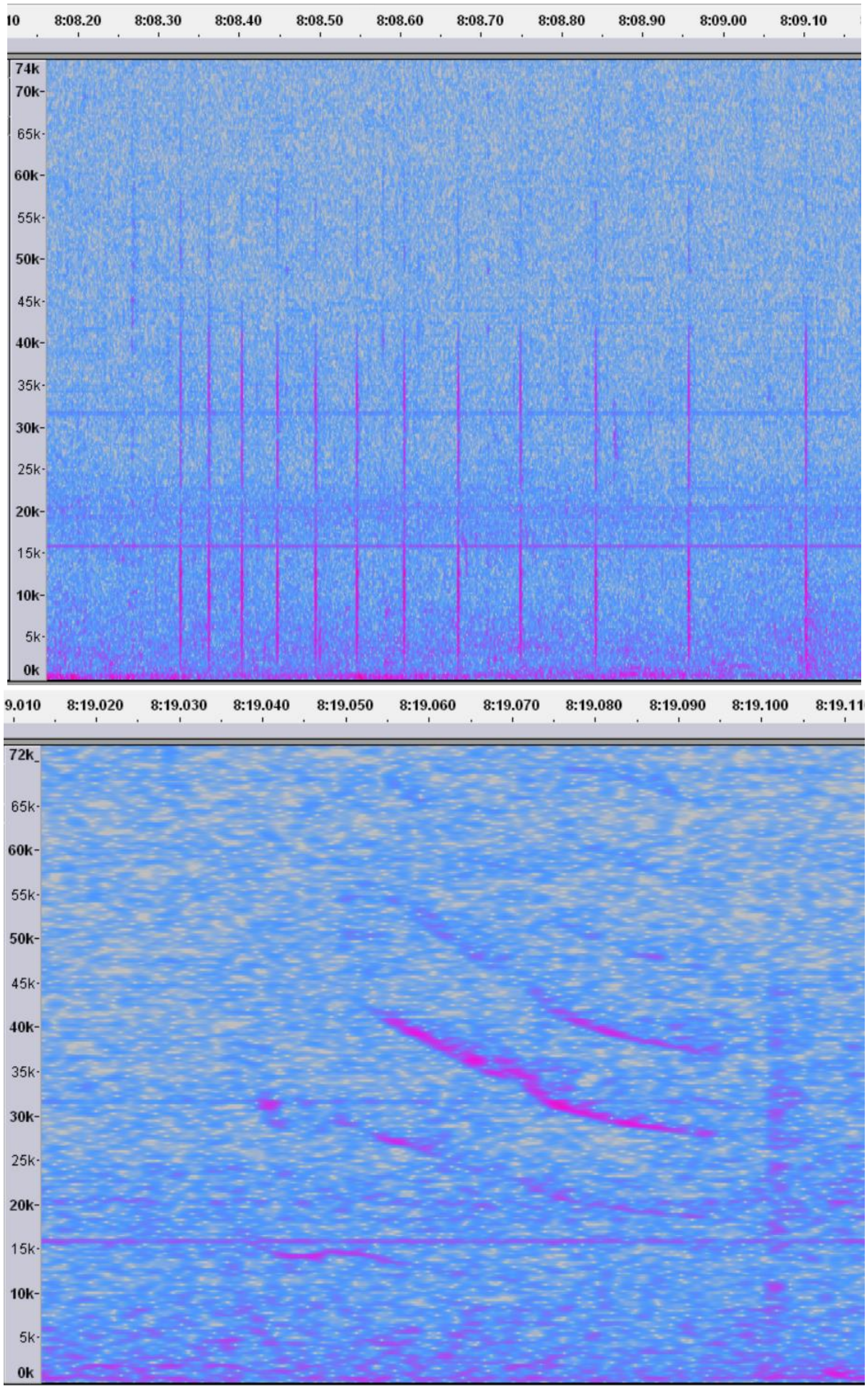



*Figure 21. Audacity spectrograms for records from Hydrophone 1677 on 8 October 2018. The frequency scale is 0 – 74 kHz for both plots. TOP: Clicks found in a 2 second interval beginning 0903:54 UTC. BOTTOM: Whistle found in a 0.2 second interval beginning 0904:05 UTC.*

# 4.0 Active Acoustic Monitoring Results

## 4.1 Tritech Gemini Sonar

The Tritech Gemini imaging sonar is a high frequency (720 kHz) multibeam sonar (AAM) that uses reflected sound to build up a picture of the underwater environment. The sonar sends out a 'ping' (an acoustic pulse), and the intensity of the echoes received from the multiple beams are used to create an image of the sampled volume.  The sonar pings multiple times per second, resulting in a video-like record of the sampled volume. The size, shape, and movements of objects (targets) within the sampled volume can be extracted for identification (but not at species level) and trajectory analyses.

Images created by high frequency sonars like the Gemini are low-resolution when compared with contemporary video technologies.  However, unlike video cameras, multibeam sonars function without light and in high turbidity (cloudiness or haziness of water caused by suspended solids). This makes multibeam sonars a highly suitable tool for observing marine life in environments such as Minas Passage, where light penetration is limited.

The specific model of sonar chosen for installation on the turbine was the Gemini 720id, which is a deep-rated, real-time multibeam imaging sonar. The very high frequency used by this sensor aims to reduce noise at frequencies detectable to marine mammals, thus providing monitoring during typical behaviour, not behaviour resulting from sonar detection. Notably, Section 3.0 does highlight potential noise from the Gemini at frequencies detectable by porpoise.  Utilizing an array of transducers, Gemini 720id provides the operator with a 120° constant field of vision of the underwater scene ahead. Gemini 720id has an integrated sound velocity sensor which assists in providing the sharpest real-time images possible and range readings of the highest accuracy.

## 4.2 Sonar Detection of Fish

The ISEM project involved two planned fish detection studies using Gemini sonars, and a third opportunistic study involving a Gemini sonar on the FORCE EMS sensor platform. The first study included a series of day tests at multiple sites using a Gemini 720i on loan from Tritech in summer 2015 for preliminary testing of the sonar coupled with icListen hydrophones.  The study is fully reported in "Preliminary field tests of a Gemini 720i multibeam imaging sonar with icListen hydrophones and associated spectral analyses" (Appendix D).  The main objectives were to: 1) evaluate the performance of the Gemini 720i multibeam imaging sonar in detecting fish of various types in environments ranging from low to moderate flows; and 2) evaluate the sound emission profile and potential instrument interference of the Gemini sonar, as determined by co-located icListen hydrophones and spectral analyses of hydrophone data.  A draft report of the Gemini tests was reviewed by the project team prior to the first deployment of the turbine in 2016.

The main sonar study involved installing a Gemini 720id on the OpenHydro gravity base (Figure 2) which was deployed at Berth D in FORCE from November 2016 to April 2017 and again in July 2018. Data collected were from the near-field area immediately in front of the turbine (facing into the current during ebb tide).  This deployment and sonar study was compromised by an incorrect sonar orientation (upside-down) when installed on the gravity base, resulting in too much of the seafloor being captured and not enough of the water column being viewed (Figure 22). Given the extensive seafloor signal interference, the Gemini data files collected could not be automatically processed using SeaTec software. The data files were therefore manually processed using representative subsamples of the dataset, and these are fully described in the document “Cape Sharp Tidal Gemini Multibeam Imaging Sonar: Monitoring Report (November 2016 – April 2017)” (Appendix E). The objectives were to (1) assess trends in target abundance within the sampled volume, over short and long-time scales, and with respect to tidal stage and current speed; (2) characterize target movement with respect to current direction; and (3) identify targets that may be fish schools.

Given the challenges in collecting high quality data from the first turbine deployment, a separate multi-week test of the performance of the Gemini sonar (model Gemini 720is) was successfully conducted using a bottom-deployed sensor platform near Black Rock in May-June 2018. This work was conducted opportunistically in association with FORCE’s FAST EMS program and did not include a hydrophone. The Gemini 720is performed well for the duration of the FAST-EMS trial. Data were available for download throughout the FAST platform deployment and any issues with the data were due to other factors such as interference with the co-located Nortek AWAC ADCP or entrained air. Full details are available in the report “Test of the FAST-EMS Sensor Platform for Assessing Gemini Multibeam Imaging Sonar and SeaTec Software Performance (May – June 2018)” (Appendix F). Data from the FAST platform test of the Gemini led directly to algorithm development for Tritech SeaTec software as well as the addition of useful features such as the use of dynamic exclusion zones to blank out areas of high noise due to e.g. entrained air. The study provided an opportunity to report on improvements made to the SeaTec software as well data management and access.

Gemini data files from the second turbine deployment in July 2018 were compromised by the OpenHydro shutdown two days after the deployment date and before any data from the deployment was made available, and subsequently by the quality of that data for detecting fish targets within 20 m of the sonar.

Figure 22 shows that the 2016/17 deployment had the Gemini beam oriented in the azimuth so that the nearby foot of the turbine support structure appeared as a target (near the location marked with an A). Figure 23 shows an image from the 2018 deployment during which the Gemini was re-oriented to better view the water column. It is still poorly oriented in the azimuth. Again, the nearby foot of the turbine support structure clips the edge of the image. Only now, that edge appears on the other side of the image, exactly as expected given that left rotates to right when the image is rotated upside down. Thus, the cause of the spurious signals in the first 15 m appears to be due to interference from the turbine support structure. The gain may ameliorate the effects of this installation error, but it cannot completely compensate. In particular, it seems that the large gravity base foot scatters signals very strongly and some of those signals are returned by multiple paths (other parts of the turbine, perhaps the bottom, and very likely reflections off the sea surface). Again, as noted for the hydrophones, gravity base platforms have the disadvantage of reducing the possibility, if any, of servicing and adjusting instrumentation. For that reason, if no other, scientific protocols for sensor installation and parameter setting must be well-developed on more accessible types of platforms before attempts are made to translate them to gravity base platforms.

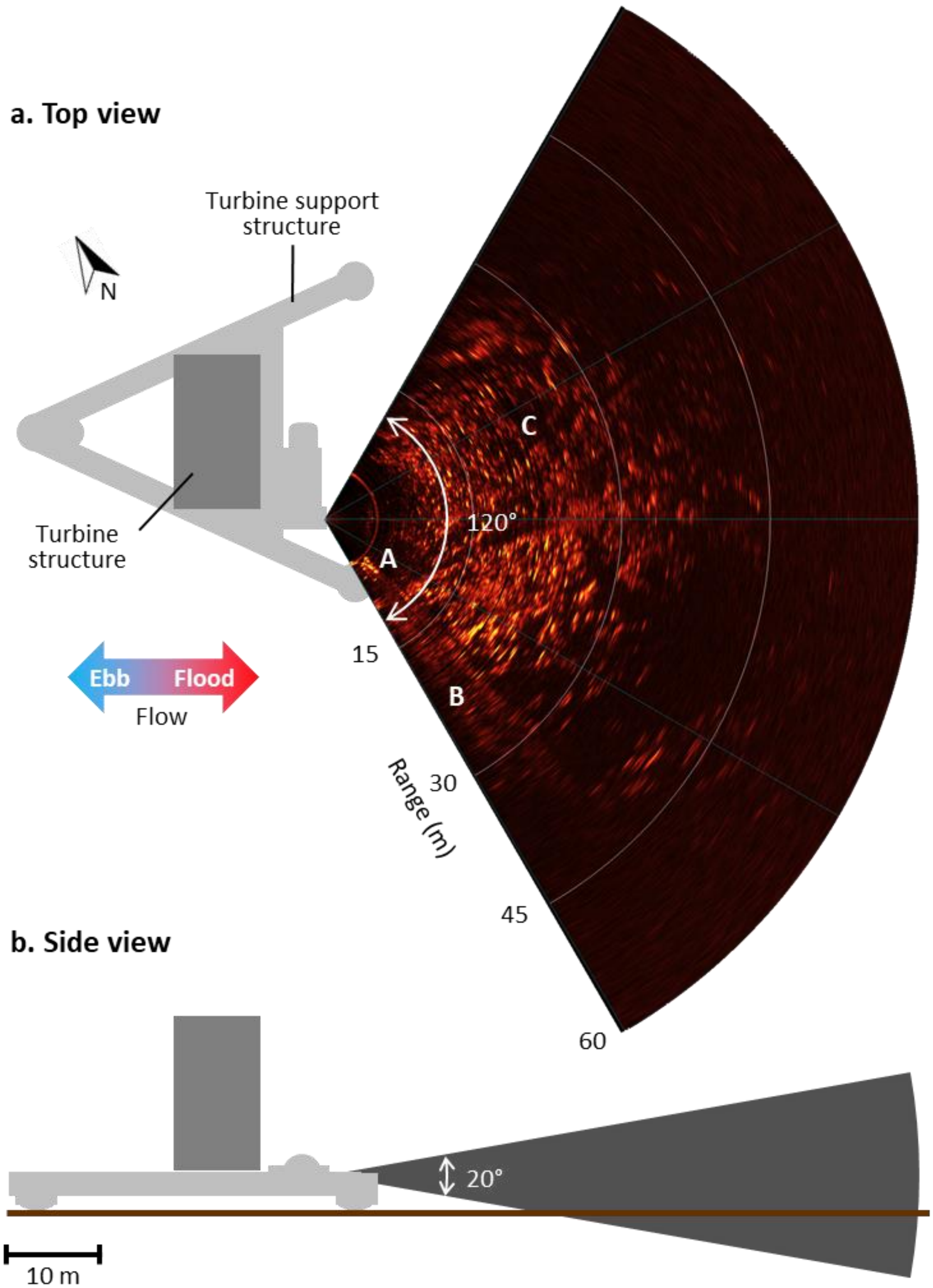



*Figure 22 Positioning of the Gemini sonar during the first deployment (Nov 2016-April 2017)*

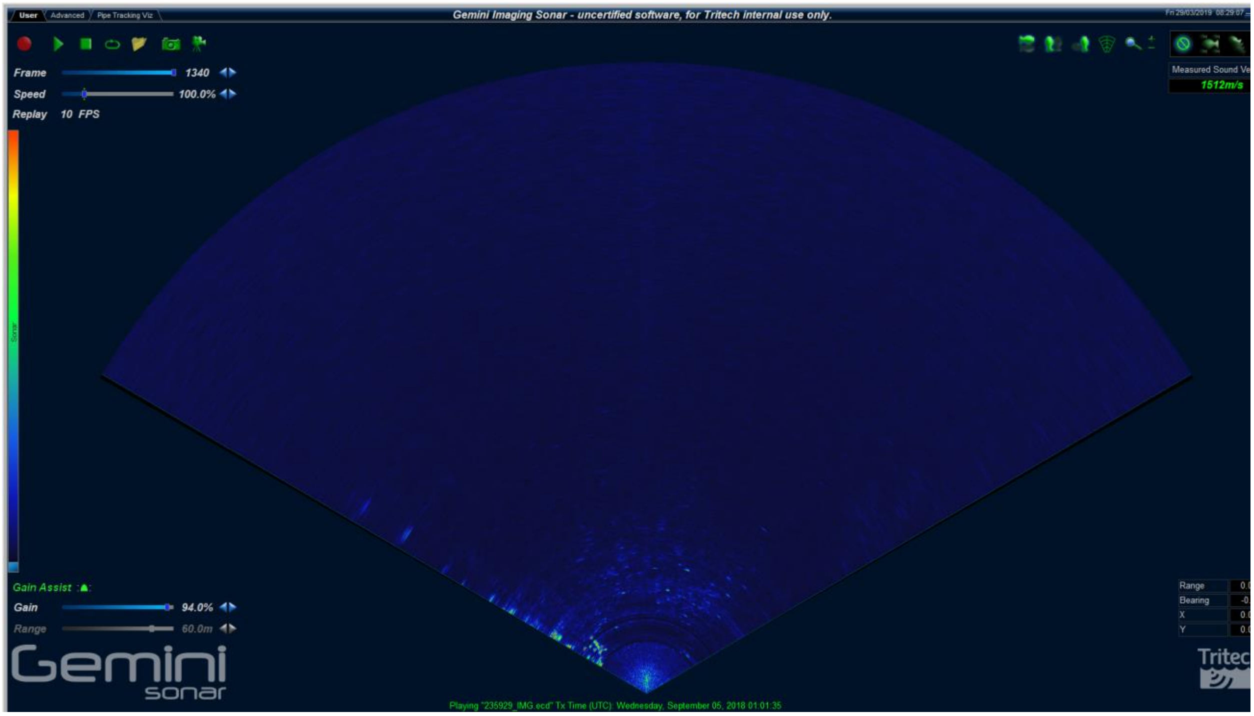



*Figure 23. Degraded image from the Gemini sonar during the second deployment (July 2018)*

Figure 23 shows that there are fixed high intensity targets on the left of the image. It is a feature of the 720id that this leads to an auto reduction of gain at those ranges creating the banding effect observed. As discussed above, the source of the high intensity targets is likely to be part of the turbine support, most likely a nearby large foot structure as shown in Figure 22.

**Results of Target Detectability**

In the 2015 summer study (Appendix D), the Gemini was found to be very effective in the detection of schools of small fish (<0.1 m) at close range, at a hydro dam (River Herring) and in both Minas Basin and Minas Channel. Medium-to-large sized schooling fish, in this case Striped Bass (~0.5-0.8 m), were resolved easily at close range (<6 m) at the North River Fish Farm aquaculture site. Detection of small individual fish (<0.1 m) cannot be resolved by the Gemini 720i multibeam sonar. For fish >0.2 m, size determination was accurate at short to mid-range (<20 m), as evidenced by trials with frozen American Shad and Atlantic Mackerel. Accuracy results are also presented by Jepp (2017) in Appendix H. It was noted that turbulence imparted by tidal flows or turbulent wakes degraded the Gemini image quality, and thus limited fish target detection.

During the first turbine deployment, fish-like targets could be manually identified with the Gemini sonar when the quality of the image was good (i.e. without jumps due to communication issues between the Gemini and the on-shore computer) (Appendix E). Over the study period, abundance of detected targets was found to decrease with falling winter temperatures, which is consistent with other biological surveys of this area. Target abundance did not differ significantly between day and night for the duration of the dataset, but abundance of targets in the volume sampled was consistently lower during the flood tide than the ebb tide, possibly due to effects on the flow field in the area sampled by the sonar as flood tide waters moved through and around the turbine. Target movement direction exhibited patterns that reflected the flow environment, with most targets moving in the same general direction as the current. However, variation in movement direction of targets within the sampled volume was greater during the flood tide, when targets were downstream of the turbine, than during the ebb tide, when targets were upstream (approaching the device). This difference could be related to the physical effect of the turbine on the flow regime in the near-field; examination of fine-scale hydrodynamics upstream and downstream of the device would be needed to determine wake effects.

The opportunistic Gemini dataset collected from FORCE's FAST-EMS platform near Black Rock was processed using both SeaTec software and manual processing (Appendix F). While the vertical range of sonar detection in this test was variable and limited by water levels at the Black Rock site, especially near low water, the cabled FAST-EMS served well as a sensor platform. Manual counts of individual fish and schools indicated contrasting trends in detection probability with range, which will need to be considered when interpreting any Gemini data, and in setting the range for the detection of fish. SeaTec was not able to automatically detect individual fish but could detect and count schools of fish. The numbers of schools detected, however, were inflated near low tide by a number of false positives due to surface interference.

For the second turbine deployment, due to time and budget constraints following the Open Hydro insolvency, a small dataset obtained from 29 September 2018 (04:08 to 10:00 UTC), was processed using SeaTec and the results shared with all partners. SMRU conducted an assessment of this data which is presented in Section 4.4.

## 4.3 SeaTec Software Development

A number of bug fixes and enhancements were made to the SeaTec software, based on data collected during the ISEM Project. This has resulted in a number of software releases throughout the course of the project. Some of these releases have been shared with project partners SMRU and Acadia University. A significant release was distributed to OpenHydro personnel with the understanding that it would be installed at the FORCE substation and used to create daily reports on marine life activity. The opportunity to test it on site was lost when OpenHydro ceased operations two days after turbine deployment.

Further details of SeaTec software changes and developments made are given below:

### *Version 2.4.7*

Use of group classification so that multiple parts of the same fish target (head, tail, fin) are identified as belonging to one target and not recorded as multiple targets.

Addition of a rolling data retention option, whereby only data files containing probable targets are kept on disk, to help with data management over a long monitoring period.

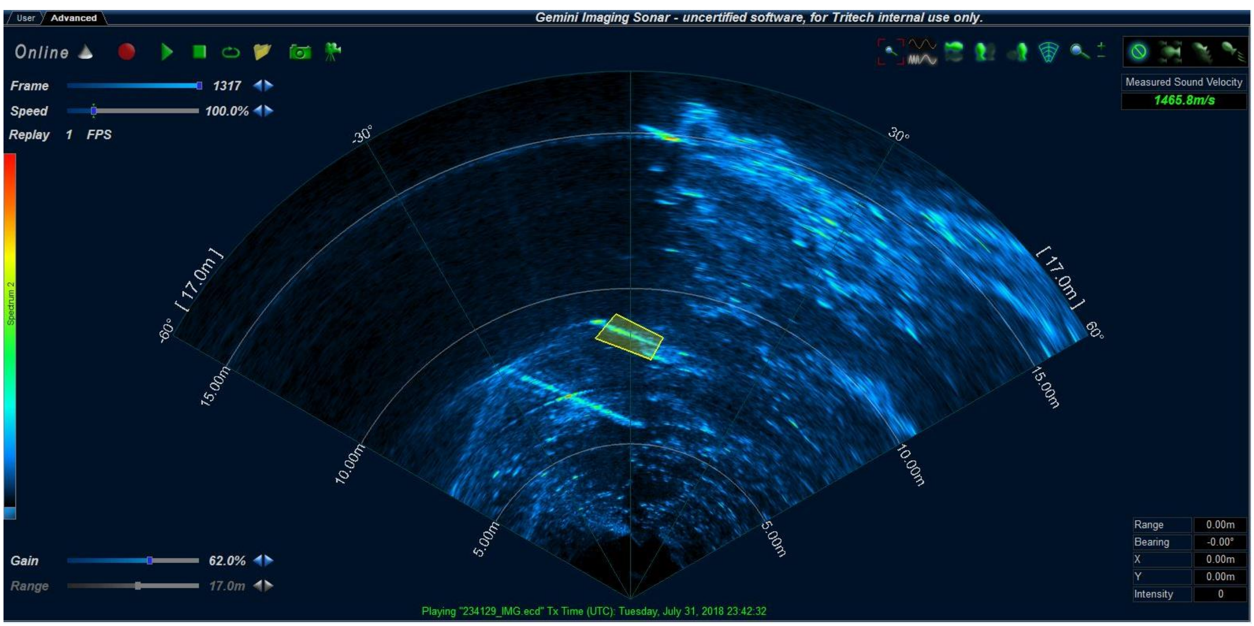
Static target evaluation whereby targets which are mostly stationary (non-biological in origin) can be excluded from the list of probable animal targets.

Sonar data has always been recorded in a format independent of local time zones which can be easily interpreted as UTC time. However, names of data files and other outputs from SeaTec were created using the local time at recording/playback leading to confusion when trying to match SeaTec outputs to other important time-dependent information like tidal stage / modelled current speed. This issue has been rectified and all times are recorded in UTC.

A daily summary of detected marine activity is created at midnight during live data acquisition.

### *Version 2.4.9*
A summary of detected marine activity is created after batch playback of previously acquired data files.

### *Version 2.5.0*
The ability to specify exclusion zones within which targets will be ignored has been added. This is achieved via a simple point and click mechanism. This functionality should be used with caution but it is essential if there are specific locations in the sonar field of view which are throwing up a lot of false negatives due to noise or other issues. An example is given below (exclusion zone in yellow).




### *Version 2.5.4*
Allow user to set the direction of the tide and to filter out targets which are moving without deviation in the direction of the tide. The sensitivity of this functionality can be adjusted to filter out more or fewer “Tidal Drift” targets.

### *Version 2.5.5*
Enhanced the report files to specify details on every target detected, including direction of travel with respect to tidal flow and estimate of measurement.

Tritech is continuing the work started in the ISEM project under a KTP (Knowledge Transfer Partnership) project - Underwater Object Detection, Recognition and Tracking System using Sonar Imagery.

## 4.4 Marine Mammal Sonar Data Assessment

**Methods**

A variety of project-based issues, including sensor positioning, resulted in only a small amount of data being processed for marine mammal identifications and subsequent human validation. Gemini data covering a six-hour period of recording on the 29 September 2018 was provided to the SMRU and SMRU Consulting teams for secondary human validation. This dataset had previously been processed by Tritech using SeaTec software (version 2.5.0). This dataset consisted of 178 300 MB ECD files. Initially these were manually viewed by an observer using SeaTec software (version 2.5.4.5), this involved manual playback of each ECD file in real time to view the images and identify moving targets of sufficient size that could be marine mammals. The known species of marine mammals at the site are primarily harbour porpoise although harbour seals could also be present.

Data recorded for each visible target included the time at which it became visible, range and bearing information and comments regarding appearance and behaviour. Although the presence of other moving targets that were likely to be fish (i.e. were thought to be too small to be marine mammal targets) was noted, no systematic recording of any target features (position, size, movement) was carried out. The initial manual review of targets was conservative, i.e. the observer erred on the side of caution if there was any doubt whether a target was a marine mammal or a fish. A second reviewer with more experience of reviewing marine mammal detections in sonar data then inspected all identified potential targets to make a final assessment of whether these identified targets were likely to be marine mammals based on size, shape and pattern of movement.

All of the outputs from the SeaTec target detection processing were then run through a series of marine mammal classification analyses in the R software package (Hastie et al., 2019b). Specifically, movement and shape parameters associated with each target were used as a basis to estimate the probability that it was a marine mammal based on a series of Kernel Support Vector Machines (SVM) trained previously using validated seal targets. This approach aims to process large numbers of mobile targets in sonar data and provides an efficient means of identifying high probability marine mammal targets that can be validated manually post-hoc.

**Results**

Despite concerns about the high gain settings (detailed above) the images from the files were relatively ‘clean’ throughout most of the imaging range (out to 60 m). There was a high degree of noise in the first 15 metres of the image which was thought to be backscatter from the seabed. Reflections from other static targets on the seabed are also visible throughout. Other static objects were visible, e.g. a structure between 5 and 7 metres from the sonar, at a bearing of -45°, which is presumably part of the turbine support structure (see Figure 24). There is clear ‘banding’ in the images as a result of these static features. Occasionally there were what appeared to be reflections from surface waves – generally seen between 45 and 60 m from the sonar head (Figure 25).

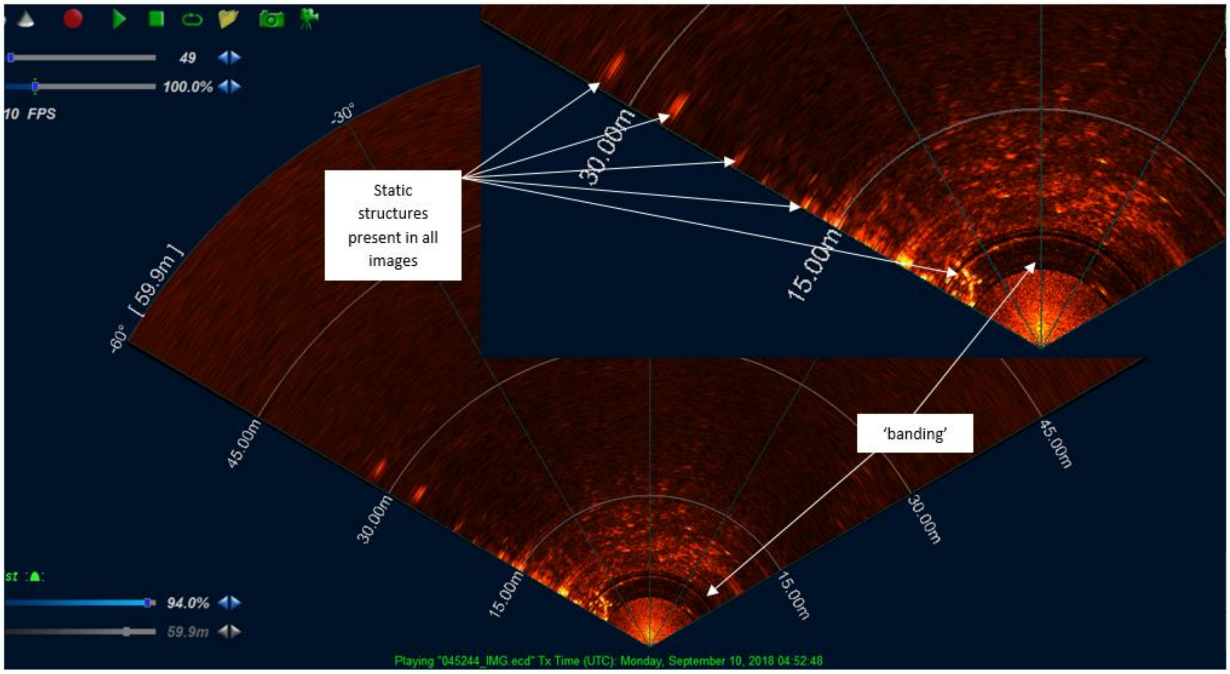



*Figure 24. Screenshot of sonar image showing static features present through all of the images and associated 'banding'.*

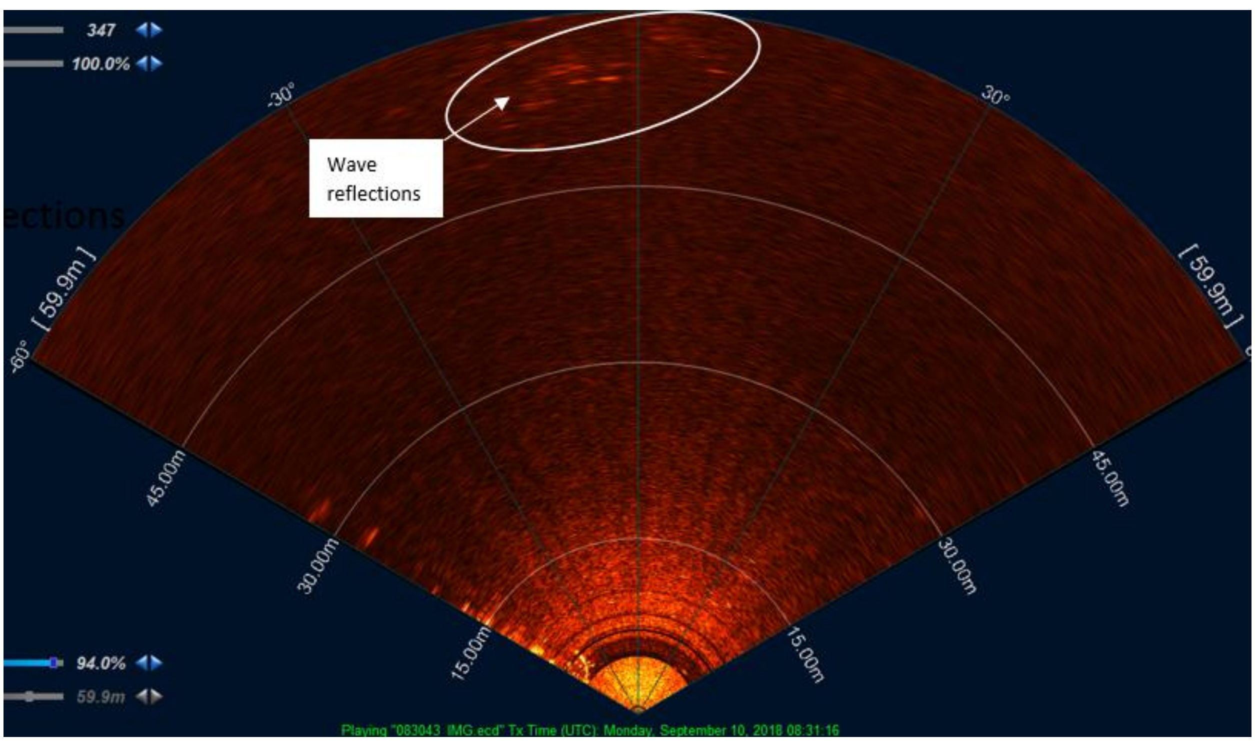



*Figure 25. Screenshot of sonar image showing wave reflections, 10 September 2018*

The results of the comparison between the automatic SeaTec detections and the two-stage human manual visual review are presented in Appendix G. Out of a total of 178 ECD files, 25 files had no targets identified by either SeaTec or the human observer. 122 files had targets detected by SeaTec but no potential marine mammal targets identified by the human observer. When restricted to targets outside of the area of high noise within the first 15 m, this number reduced to 86.

A total of four ECD files had no targets identified by SeaTec yet had potential marine mammal targets identified by the human observer. Two of these were agreed by the second reviewer to contain potential targets (044626 and 045244).

Out of 30 files indicated by the first human reviewer to have potential marine mammal targets in them, 12 of these were agreed by the second reviewer to contain potential marine mammal targets (a total of 14 targets across 12 files). The reasons for rejecting the other 18 files were generally because the targets were judged as being too small to be marine mammals and were therefore likely to be fish, or reflections were not strong enough to indicate an animal target or the pattern of movement was too uniform and matched the current indicating an inanimate object moving in the current.

Processing the SeaTec outputs through the SMRU Classifier algorithms resulted in the majority of all SeaTec detected targets being assigned a low probability of being a marine mammal (Figure 26).

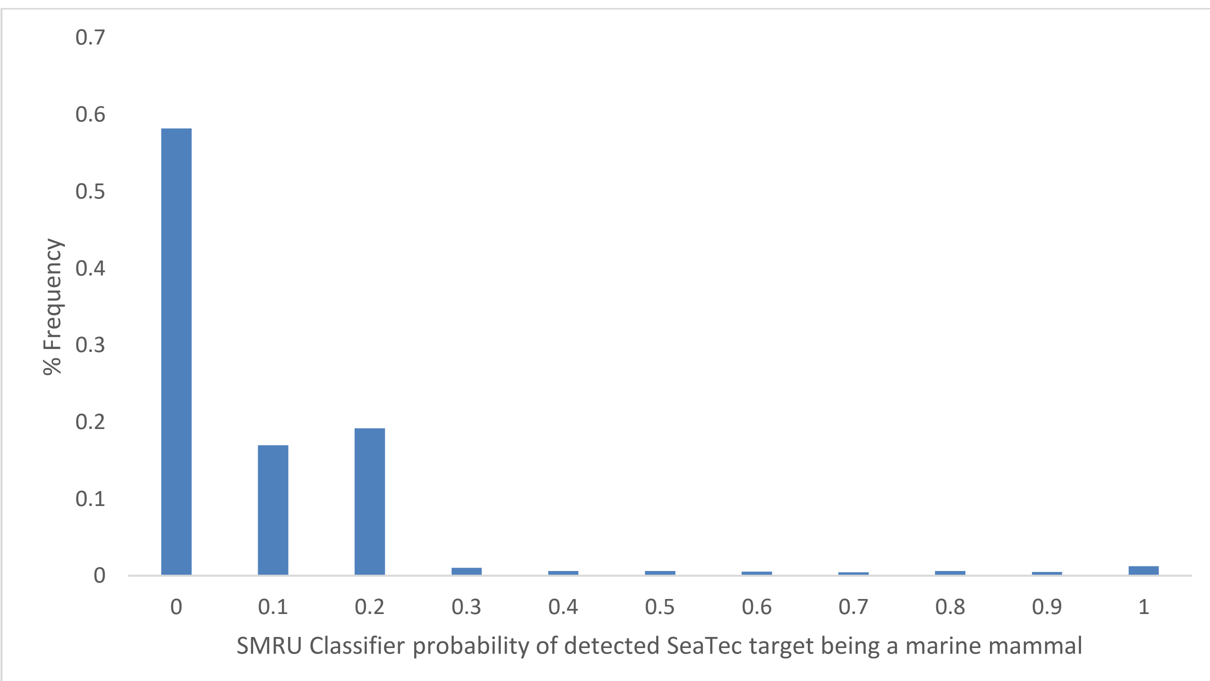



*Figure 26. Frequency distribution of SMRU Classifier assigned probabilities for all SeaTec target detections.*

There was a total of 35 high probability (equal to 0.99 probability or above) marine mammal targets detected within four ECD files. Many of these target detections were likely to be multiple identifications of the same targets based on the position and timing details so the actual number of real targets will be lower than this. Only one of these targets matched with any of the human observer detected targets. On post-hoc review, 25 of the SVM high probability targets (≥ 0.99) were determined to be reflections from surface waves. The image shown in Figure 25 is one of these.

Only one of the SVM high probability targets were also identified by the human reviewers – the target in ECD file 055332 (Figure 27). This target measured approximately 1.7 m by 0.5 m and was first seen at approximately 55 m from the turbine, moving towards the turbine then disappearing out of the sonar beam at an approximate range of 30 m.

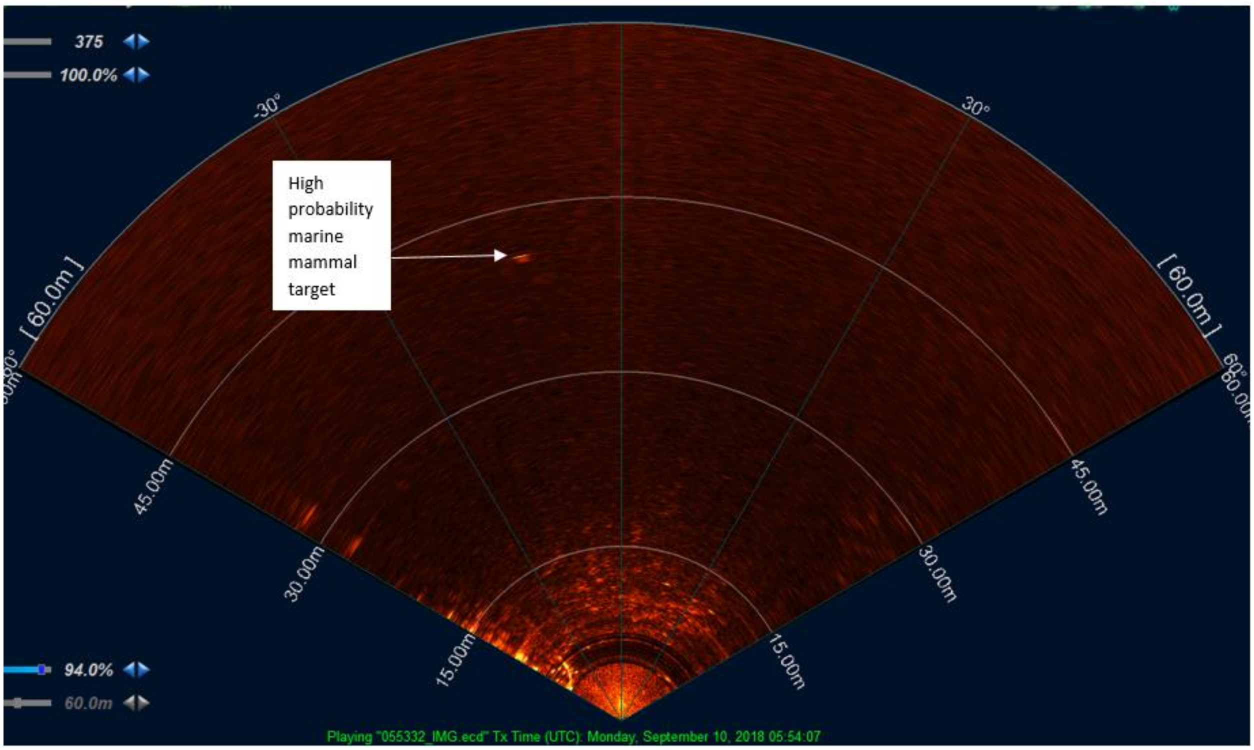



*Figure 27. Screenshot of target identified by human review and also assigned a high probability by the SVM classifier*

The possible marine mammal (MM) targets (identified manually) had a wide range of SVM classifier assigned probabilities – out of the 14 human detected targets the probabilities generated by the SMRU Classifier ranged between 0.12 and 1 (Table 4).

A total of five possible MM targets (identified manually) were not detected by SeaTec. Visual inspection of these targets indicated a range of possible reasons for this including too low target strength and low persistence.

*Table 4 Human detected targets and corresponding SVM classifier probabilities. Where a range of probabilities are reported, the SVM classifier has identified the target under >1 target id. The targets in italics were not detected by the SeaTec software.*

| **File** | **Frame # first detected (human)** | **Bearing** | **Range** | **Detected by SeaTec?** | **SVM classifier probability** | **SVM classifier target id** |
|---|---|---|---|---|---|---|
| *041705_IMG.ecd* | *250* | *15* | *22* | *N* | - | - |
| *042940_IMG.ecd* | *634* | *17* | *36* | *N* | - | - |
| *044626_IMG.ecd* | *228* | *-14* | *25* | *N* | - | - |
| 045244_IMG.ecd | 578 | -8 | 41 | Y | 0.84 | 45338000002 |
| *053234_IMG.ecd* | *1059* | *39* | *25* | *N* | - | |
| 055332_IMG.ecd | 308 | -5 | 55 | Y | 0.99-1 | 55408000011/ 5409000021 |
| 055949_IMG.ecd | 933 | 4 | 33 | Y | 0.71 | 60123000006 |
| 083043_IMG.ecd | 227 | 39 | 31 | Y | 0.2/ 0.12/ 0.12/ 0.29 | 83112000028/ 83113030015/ 83113070015/ 83114000012 |
| 083455_IMG.ecd | 55 | 5 | 40 | Y | *0.68* | 83505000042 |
| *092722_IMG.ecd* | *185* | *-14* | *37* | *N* | - | - |
| 093340_IMG.ecd | 55 | 8 | 40 | Y | *0.29/ 0.9* | 93400000011/ 93405000005 |
| " | 317 | 60 | 16 | Y | *0.12* | 93410000008 |
| " | 480 | 47 | 42 | Y | *0.88* | 93425000004 |
| 094823_IMG.ecd | 25 | 45 | 40 | Y | *0.79* | 94830000018 |

To provide further information on whether any of the potential marine mammal targets could be matched to times when porpoises were detected on hydrophones, the passive acoustic monitoring data associated with this period of data collection was requested from Ocean Sonics. Data processed using the *Coda* click detector was provided for one of the four hydrophones installed on the turbine structure (hydrophone 1406 which was installed to the aft of the turbine (see Figure 2)). Although there were acoustic detections of harbour porpoises throughout this recording period, there were no acoustic detections that could be temporally matched to the sonar detections. The closest matches were potential sonar detections within 2-4 minutes of passive acoustic detections.

## Discussion

Although whether or not any of these potential targets were actually marine mammals cannot be verified, these results support previous reports that the SeaTec marine mammal detection software is highly conservative, leading to high numbers of false positives. Relying on the SeaTec software as a data reduction tool, the total reduction in files for post-hoc review was 17% if using all SeaTec target detections, and 39% if only considering targets at >15 m range.

There were four targets that had been identified by the human reviewers as potentially being marine mammals but were not detected by SeaTec. On review, most of these did not look appreciably different to the other targets that did match, although they may have been slightly lower in target strength and target persistence. This should be further investigated with Tritech software developers.

Given the relatively low abundance of marine mammals in the area, there is the high probability that none of these sonar targets were marine mammals; in support of this, there was a lack of very distinct marine mammal like features and patterns of movement that have been observed in other studies ( Hastie, 2012; Hastie et al., 2019a). The overall number of very high probability targets identified by the SVM classifier is consistent with the rate of false positive classification reported by Hastie et al. (2019b) of 8% of all targets being incorrectly classified as marine mammals. This highlights that the SVM classifier can be used as an efficient data reduction tool. However, it is recommended that the chosen probability threshold (here it was 0.99) for identifying marine mammals be set relatively low at the start of any data collection period and subsequently refined once manual review has been carried out. The human detected possible marine mammal targets had a wide range of classifier probabilities and therefore further indicates that initial reviews may require a low probability threshold to ensure no missed detections. It is important to note that the SVM classifier is reliant on the outputs from the SeaTec target detections software and highlights the importance of marine mammals being reliably detected at the initial SeaTec detector stage.

Although there were no apparent matches between the PAM and sonar detections, the comparison was relatively limited, particularly as the hydrophone for which data was examined for matches was installed on the opposite side of the turbine from the sonar. It would therefore be useful to compare processed data from the remaining three hydrophones for matching harbour porpoise click detections before making conclusions about the degree of matching. The highly directional nature of the harbour porpoise echolocation beam means that the likelihood of an echolocating porpoise being detected by a single hydrophone, even at relatively close range, could be relatively low.

Although these analyses only cover data collected over a very short period of time, the results clearly indicate that sonar has the potential to detect marine mammals (and fish) from a turbine-mounted orientation at this site. However, further refinement of the data reduction process is required to reduce the amount of manual review required. Manual target detection was extremely time consuming and is likely to be impractical for larger datasets. The SVM classifier shows promise as a data reduction tool although further refinement and validation for a wider range of sites and species would be recommended. In general, it is recommended that a degree of manual verification of target detections should be carried out at each site and for each different marine mammal species. This would likely help to train marine mammal detection algorithms and help to lower the rate of false positives.

## 4.5 AAM Discussion

The use of the Tritech Gemini sonar to visually review select data files and manually record the presence (and size, trajectory, etc) of individual large fish, schools of fish and other sea life (marine mammals, sharks) is now well established but is very time consuming, leading to representative subsampling of large datasets (i.e. small fraction of data is processed).

Automatic detection and recording of targets using Tritech's SeaTec software was employed on high quality datasets examined during this project, albeit with mixed results. The main problem is one of recording false positives than missing false negatives. The reasons for this can be summarized as:

1. Too much noise in defined localities of the image (i.e. backscatter from the seabed).
2. Recording tidal/drift targets as sea life.
3. Incorrect identification of flickering but non-moving targets.
4. Recording different parts of the same target as multiple targets.

Steps have been taken to correct these issues and implemented in the software:

1. Use of configurable exclusion zones.
2. Allow input of tidal direction (manually or via serial port) to filter out inanimate drifting targets.
3. Evaluation and exclusion of static targets.
4. Use of "group" classification (especially useful for large targets like sharks).
5. The use of further post-hoc processing on the detected targets such as the SVM classifier.

The use of the SVM Classifier was found to help to identify higher probability targets and as such can help in efficiencies involved in the human validation process and removal of false positives. Nevertheless, a human validation step is still required.

# 5.0 Conclusions

## 5.1 Project Challenges

Aside from direct challenges related to the deployment issues experienced by Cape Sharp Tidal, there were additional challenges experienced by the ISEM project that need to be considered for future research that aims to improve the use of PAM and AAM technologies in the marine environment. The challenges can be broken out into three main topics: communications and set-up of the sensors; data management; and data analysis.

**<u>Communications and Device Set-Up</u>**

1. Direct communication between turbine engineers and both project scientists and sensor developers was not sufficient during the planning and pre-deployment phases and led to a number of instrument set-up problems:
   a) the hydrophones were set with incorrect sampling rates for the first deployment which made it impossible to apply some of the porpoise click detection algorithms. It also limited diagnosis of noises associated with the turbine and active acoustic instruments.
   b) the Gemini sonar was not oriented correctly (i.e. installed upside down) on the first turbine deployment, in part due to the manufacturer's "this side up" markings on the instrument. The sonar was also installed with an error in the azimuth that resulted in the edge of the sonar beam striking one foot of the turbine. Gain settings were set too high for fish detection on the second deployment. These factors affected image quality and limited the development of automated

target identification and tracking. It is recommended that in future a sensor technology scientist is permitted to do QA/QC test checks on all sensors before turbine deployment and during the commissioning phase to ensure data of sufficient quality and quantity is collected. This critical step would have likely resolved most of the identified sensor set-up problems.

2. There were cable communication issues for the hydrophones on both deployments as well as difficulty with the transfer of data via cable to the substation. Between the first and second deployments, two damaged cables were replaced in an effort to improve communications. It was reported to Ocean Sonics that one of the four hydrophones lost communication after the power to the equipment on the turbine was regained. The reason is unknown but could arise from communication error or damage to the equipment.

3. One hydrophone element was sheared off during the first deployment. On the second deployment, large heavy-duty sensor guards were installed to better protect the hydrophones from physical disturbance.

**Data Management**

Data management, including data collection, remains an issue that needs to be resolved for effective use of acoustic sensors for monitoring in the marine environment. Due to the large amount of data generated by PAM and AAM sensors, the different stages of data transfer (between instruments, the hard drives, the FTP site and to different platforms for analyses by project partners) created a 'bottleneck' that has been identified as one of the most important issues affecting access to data and the extent to which it could be analyzed. Data management techniques that can be implemented to improve the data collection and sharing process for large data sets will be essential to the success of future projects that incorporate passive and active acoustic monitoring sensors. A level of automated (or semi-automated) on-site analysis will probably be required to down-sample both PAM and AAM measurements to obtain a more accessible subset of the data stream which is likely to contain useful information for environmental monitoring objectives.

Ocean Sonics created a data management plan for hydrophone data (Appendix A) for implementation during the second turbine deployment. The initial setup, used during the first couple of days of data collection, was impacted by the loss of power to the turbine, after which no further work could be done in developing the plan.

**Data Analysis**

If large amounts of data are being transferred physically via hard drives, this transfer must happen in a timely manner for data analyses and reports to be completed on schedule. Remote access to subsets of the data or processing the data remotely is beneficial.

Access to hydrophone data was via a physical copy (hard drive) following the first deployment. The delay in data transfer caused delays in data processing / analysis and reporting and in resolving issues with hydrophone setup (i.e. sampling rates). It was suggested, for the second deployment, remote access be provided for quickly reviewing the quality of the data as it is collected, and for timely data processing / analysis.

During the second deployment, where automated processing was setup and remote access was given, there was insufficient time to review and adjust the process. The setup of the computer to resize (down sample) data as well as run the *Coda* detector was not fully implemented. The unexpected OpenHydro shut down removed the opportunity to optimize the data management plan for ISEM datasets.

## 5.2 Overall Conclusions

Results show that there is potential to use a sensor integration approach using active and passive acoustics to monitor fish and marine mammals (especially harbour porpoise) in the near field of tidal turbine sites. It also has promise for detecting and tracking individual fish implanted with acoustic fish tags.

The attempt to use four widely spaced hydrophones positioned on the turbine was not successful in achieving porpoise localization. Prior to installation of hydrophones, sonars and other acoustic devices on turbine infrastructure, an investigation into the optimal locations for sensors is required. This includes understanding the spacing needed between hydrophones for effective localization of porpoise clicks and allowances made for potential hardware failures. The hydrophones should also be placed as far as possible from other signal emitting instruments or large structures that could interfere with sensor performance. Desktop simulations should be used to test the theoretical efficacy of hydrophone arrays to optimize array design.

Frequent and open communication between tidal turbine engineers and researchers is required to enable project success. Collaborative activities should include decisions made in sensor positioning, testing procedures, setup of equipment, monitoring of instruments, and data transfer. Data Management Plans will also need to be implemented to ensure data collection is of high quality and allows for future post-processing of data.

# 6.0 Lessons Learned – PAM and AAM

**<u>Passive Acoustic Monitoring – icListen Smart Hydrophones</u>**

A. Hydrophone Positioning and Protection
    a. The use of multiple hydrophones requires accurate positioning on the turbine infrastructure so that they have the necessary angular resolution, array aperture and unobstructed paths in order to locate harbour porpoise within some zone that is specified according to the requirements for environmental monitoring.
    b. Hydrophones should be positioned away from the direct beams of active acoustic monitoring devices (e.g. Gemini sonar) to avoid interfering signals.
    c. The method of mounting a hydrophone to turbine infrastructure will influence recorded noise. Alternative mount systems should be experimented with, so the hydrophone sensor can be aligned with the current and preferably within a flow stagnation zone.

d. Current speed affects recorded tidal flow noise. The hydrophone located at the top of the turbine exhibited data with the greatest noise, often with clipping during strong currents, and thus poor data quality.
e. Reinforced sensor guards are required to protect sensitive sensor elements from damage and to ensure long-term, quality datasets.
f. Sound profiles of each installed hydrophone are needed to provide location-specific noise measurements and an assessment of equipment and/or infrastructure interference.

B. Detection
a. icListen hydrophones detect harbour porpoise clicks, fish tag pings, dolphin whistles and clicks, and other sounds in the 10 Hz - 200 kHz range.
b. The probability of marine mammal detection is influenced by tidal flow-induced noise, as well as noise contributed by other sensors, and the turbine and its infrastructure.
c. Harbour porpoise clicks were effectively detected using the *Coda* porpoise click detection program which performed well in noisy tidal currents.
d. icListen hydrophones are sensitive to rainfall, which increases sound levels in a broad band centred at 10 kHz but extending from about 1 kHz to 100 kHz. It is thus a factor to consider in hydrophone data analyses.

C. Communication Cables
a. Communication cables should be tested prior to deployment to ensure there are no issues in transferring hydrophone data simultaneously with data from other instruments.
b. Cables must be inspected prior to deployment to ensure there are no issues, such as broken cables or cables with insufficient data transfer rates.

D. Data Management
a. An agreed plan for Data Management is essential. Volume of data should be considered along with methods of processing. The optimal setup will depend on the deployment and data transfer capabilities.
b. Ideally, a portion of the data processing is done onsite (e.g. harbour porpoise click and fish tag detections). Ambient sound measurements could also be processed onsite providing computational requirements are available. Remote access to data could be used to verify reported detections and to regularly monitor the data being collected.

**<u>Active Acoustic Monitoring – Gemini Imaging Sonar</u>**

A. Sonar Positioning and Interference
a. The Gemini sonar should be mounted on infrastructure well above the sea floor, and with the correct orientation, so that its field of view is more aligned with the path taken by water flowing through the turbine.
b. The beam of the Gemini sonar needs to be clear of the turbine structures as reflections from objects like the foot of the subsea base can cast acoustic ‘shadows’ or wash out the signal from targets occurring at the same range.

c. The beam should also not intersect with either the sea surface or sea floor. To achieve that goal and also achieve long range, it may be necessary to use two Gemini units vertically offset by a small distance – one sonar with a beam angle less than 20 degrees in the vertical to monitor the far-field, and the other with a 20 degree beam in the vertical for monitoring the near-field.
d. An ADCP, co-located on the FORCE FAST-EMS platform with the Gemini, was found to interfere with Gemini sonar images; the two instrument types may need to be programmed to alternate with each other when deployed concurrently.

B. Detection / Data collection
a. Preliminary studies (day tests) of the sonar in different environments were useful in assessing the detection accuracy and limitations of the sonar, and also the effects of sonar pulses on datasets of co-located icListen hydrophones.
b. Turbulence imparted by tidal flows or turbulent wakes was noted to degrade the Gemini image quality, and thus reduce target detection performance.
c. For targets >0.2 m, size determination is accurate at short to mid-range (<20 m); small targets (<0.1 m) cannot be resolved by the Gemini 720i multibeam sonar. Individual fish detection should not be expected beyond approximately 20 m based on the size limits of fish and decreasing resolution with distance. Fish schools, however, may be detected at larger distances.
d. Sonar identification of fish targets to species level is not possible. Fish capture methods and/or co-located cameras (if low turbidity), would be needed to confidently identify fish targets to species level.
e. Measurements made with the icListen hydrophone indicate that the Gemini sonar increased the sound level over a wide range of frequencies, particularly above 140 kHz. Such sound generation may be problematic if it interferes with marine life.
f. This study highlighted the importance of simultaneous collection of biological and physical data. The modelled current speed and direction data were useful for examining general trends, but high-resolution current speed and direction information, up- and down-stream of the turbine, would help with separating active and passive target behaviours.
g. Communication with the sonar must be high-quality and consistent, which can be difficult when multiple instruments are communicating with shore via the same cable. In this case, communications interruptions resulted in numerous small gaps throughout the dataset. Such gaps make automated target detection and tracking more difficult.

C. Data Processing and Analysis
a. Further advances in SeaTec software development will be needed for detecting and tracking targets <0.5 m in length, in particular fish targets.
b. There may be potential to integrate fish tag ping detection and tracking in the Gemini software.
c. Improvements in automation of data processing will be needed for large, continuous monitoring datasets.

d. Automated tracking algorithms could export many more potentially useful metrics for target behaviour analysis, including frame-by-frame location within the beam, size, and echo strength.
e. A certain amount of manual processing will always be necessary to validate the results of an automated system, to quantify its error rate relative to a human observer, and to ensure its continued functionality over time.
f. It is essential that those involved in manual processing of data be trained on a data subset prior to processing Gemini data for use in monitoring or validating automated detections. An observer's precision and consistency should be reassessed periodically with previously examined data subsets.

D. Data Management
   a. As with hydrophone data, storage of large sonar datasets is an issue. Protocols for data collection, storage, transfer, sharing and long-term management are needed.
   b. The plan should be developed collaboratively with project partners and planning should commence well in advance of the project start date.

# 7.0 Recommendations

The following provides a summary of recommendations to improve acoustic monitoring in relation to tidal energy developments in the marine environment.

1. Frequent and direct communication between tidal turbine engineers and researchers is required to enable project success. Collaboration and cooperation is needed in sensor positioning, testing procedures, setup of equipment, sampling rates, monitoring of instruments, and data transfer.
2. Sensor testing should be conducted at the test-site prior to deployment.
3. Real-time access to hydrophones is needed during deployment to identify potential concerns and to implement timely solutions.
4. A QC/QA on the data recorded should be conducted as soon as possible after deployment to ensure quality data is being collected.
5. Acoustic emissions from each installed instrument should be measured and characterized in order to identify instrument signal sources in the near-field environment of the tidal turbine.
6. A data management plan needs to be developed prior to data collection to facilitate data access and analyses. As the amount of data collected could exceed 10-15 TB per month, a formal data handling protocol is needed. Automated processing and down sampling can minimize the data needed for transfer.
7. Further development of porpoise click detector programs (and other marine mammal detection software) would improve monitoring performance for the development of a strike risk model.
8. Further progress on integration of PAM detections into Gemini SeaTec software.
9. Mounting and positioning of the Gemini sonar should involve consideration of the sources and degree of turbulence that could impact the acoustic image quality.

10. Deployment of two (possibly stacked), integrated sonar units would enable useful additional information for use in marine life behavioural studies.
11. Gain and range settings of imaging sonars need to be optimized to align with the monitoring objectives (i.e. near-field vs far-field) and deployment type (i.e. vessel survey vs stationary platform).
12. The directionality and range-dependence of signals emitted from a sonar needs to be measured. This will enable sensors to be mounted so as to minimize the interaction of the sonar(s) with any hydrophones installed on the same infrastructure.
13. Detection probability of targets should be assessed throughout the Gemini's field of view, under a range of environmental conditions—for example, at low to high current speeds. This is necessary for understanding potential sources of bias in the results.
14. Effective monitoring of tidal energy installations will require multiple integrated acoustic (active and passive) instruments and optical sensors for the assessment of turbine interactions with marine life. If multiple instruments cannot function adequately at the same time, they should be integrated (e.g., alternate pings) or potentially duty-cycled. Any non-continuous data collection (duty cycling) should ensure that sampling occurs often enough to characterize changes related to short-term cycles, such as the tide, but over enough of a time span to capture longer-term changes, such as those related to the seasonal cycle. For example, sampling several minutes of every half hour may be sufficient to characterize behavioural responses over the course of a tidal stage, and it is possible that not every day of the year will need to be sampled to capture seasonal differences.
15. The cabled FORCE FAST-EMS platform serves well as a complementary marine life monitoring platform and may be useful for contingency planning for future bottom-deployed turbines. In such cases, the platform should be placed as close as possible to the turbine (<40 m) to observe the nearfield movements of marine mammals and schools of fish, as beyond this distance, decreasing resolution and interference from entrained air or the surface are likely to heavily affect detection probability.
16. Ideally, development and testing of an integrated sensor system would involve exploration and experimentation from a non-commercial, surface floating but moored platform, equipped with suitable sensor mounts, power, Wi-Fi, and communication cables to a shore station. A transportable surface platform would offer the opportunity to test various sensor options under a range of environmental conditions, including flow speed.

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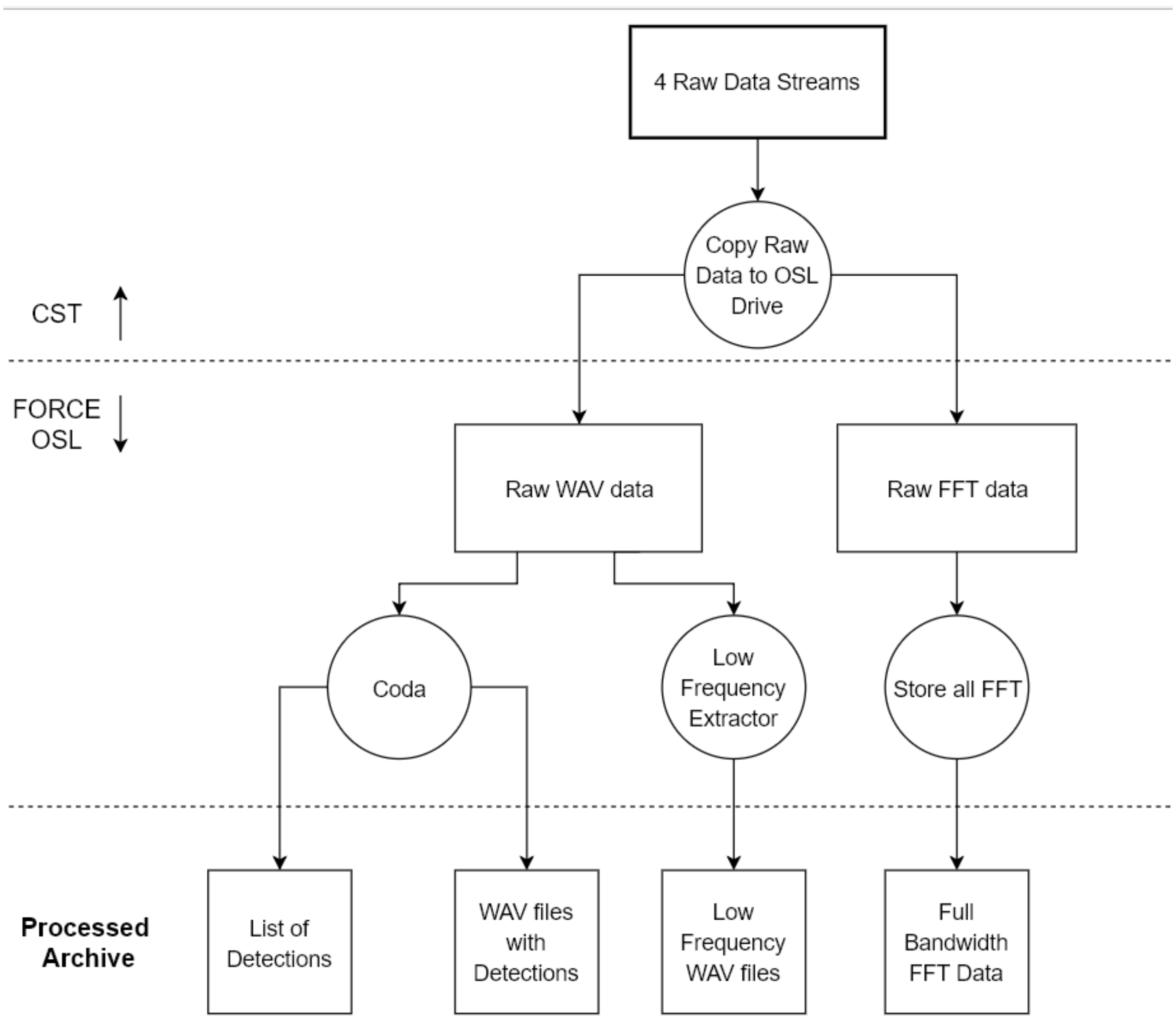
# Appendix A – Hydrophone Data Management Plan



# Appendix B – Data Analysis Report – Ocean Sonics

# DATA ANALYSIS REPORT

Ocean Sonics
The Smart Hydrophone Company

Ocean Sonics Ltd.

JANUARY 2018

# Table of Contents

# Executive Summary

Ocean Sonics analyzed the acoustic data collected by icListen Smart Hydrophones from the Cape Sharp Tidal Turbine during the 2016/2017 deployment. Four icListen Smart Hydrophones were set up to sample both waveform data (WAV) and processed spectral data (FFT). The hydrophones would then stream the data sets (WAV and FFT) from the turbine to an onshore FORCE substation via a subsea cable. Due to logistical issues, only a subset of this data was recovered. The limited data prevented a full analysis of the deployment.

The data recovered was processed using harbour porpoise click detectors on *Lucy* and *Coda* to determine when harbour porpoises were detected in the Minas Passage. Visual inspection, screenshots of spectral data and third octave processing was also performed.

Results show porpoise click detections on multiple days per month during the deployment period from November 2016 to April 2017. *Lucy* detected the most harbour porpoise clicks during March and April, which would relate to seasonal variability of the area. March had the most porpoise detections, with detections present on 15 days. April had porpoise detections 8 of the 13 days data was collected, matching the trend found in March. The *Lucy* click detector had difficulty detecting clicks in high tidal flow noise. *Coda* detected harbour porpoise click trains throughout the tidal cycle in current speeds between -70% to +90%. *Coda* detected more harbour porpoise click trains during the night.

Ocean Sonics recommendations for future monitoring

- Collection of acoustic emissions for other instruments involved,
  to model the soundscape near the turbine
- Increased protection of hydrophones
- Improved on-site data management plan
- Scheduled real-time remote access to hydrophones for diagnostics
- Further investigation using porpoise click detectors with future tidal turbine data
- Further comparison analysis is suggested with published reports

## Introduction

This report describes the data analysis performed by Ocean Sonics on the acoustic data received from the Cape Sharp Tidal (CST) turbine deployment from November 2016 to April 2017. The report addresses the marine mammal component of the Environmental Effects Monitoring Program, EEMP; specifically, for the harbour porpoise (*Phocoena phocoena*).

## Overview

During the 2016/2017 deployment, acoustic data from the CST turbine site was collected using four icListen Smart Hydrophones (Figure 1). The hydrophones were mounted in four different locations on the turbine and subsea base prior to deployment. One hydrophone was located at the top of the rotor assembly and the other three were located inside the three corners of the subsea base (Appendix A).

*Figure 1. icListen Smart Hydrophone*

Each of the four icListen Smart hydrophones were set up to sample both waveform datasets (WAV) and processed spectral Fast Fourier Transform datasets (FFT). The WAV data is the raw data sampled by the hydrophone in the time series domain. This data is needed to replay the audio part of the recording. FFT is an algorithm that samples a signal over a period of time and divides it into frequency components. This method is used by the hydrophone to convert waveform data (time domain) to frequency data (spectrum). The FFT data is a more compact representation of the acoustic soundscape. Much of the data is not audible to humans but it can be visualized by analysts with real-time processed FFT data.

Both data sets (WAV and FFT) were set-up to stream from each icListen stationed on the turbine to an onshore FORCE substation via a subsea cable. The substation stored both WAV and FFT datasets with the use of *Lucy*, a PC program that allows researchers to view and interact with acoustic data collected by the hydrophones. *Lucy* is a powerful program capable of streaming and recording accurate real-time acoustic measurements. The hydrophones themselves also stored the FFT data in their internal memory. The hydrophones were set-up by OpenHydro at the beginning of the deployment with sampling rates logged at the shore station of 512 kilo-samples per second (kS/s) for FFT data and 32 kS/s WAV data.

The FFT data was first reviewed in *Lucy*. The program includes a porpoise click detector that uses intensity to indicate a porpoise click in the data, amongst other user configurable event triggering. An overview of each day was collected, and events in the spectral data were noted. The porpoise click detector was used and visual confirmation was made for each potential click found in the program. After a click was confirmed it was recorded as a porpoise click. The data from each hydrophone was then reviewed and compared for discrepancies in the quantity and quality of data logged. The results were also compared to operational data of the turbine as seen in Appendix B.

The data was then run using two types of porpoise click detector software; *PAMGuard* and *Coda*. These software programs were first used to locate porpoise clicks in the data and then the matches were used to find porpoise click trains. A porpoise click train is series of clicks, described by the time between clicks, the inter-click interval (ICI). The click detectors used a minimum of 3 clicks and an ICI of 0.2 seconds to define a click train. The click train is used to minimize false positive detections by eliminating single clicks from other sources. Each click detector has different algorithms, and thus behave differently under the full range of conditions. *PamGuard* settings were adjusted for the data but the high tidal flow noise and sonar signals caused many false positive and false negatives, with few true positive detections. *Coda* performed better in the high noise environment, so it was chosen as the preferred program for assessing porpoise presence.

The final data processing step involved a third octave analysis which was used to compare acoustic data during different tidal flows: flood (loud); and slack (quiet) tides. The third octave analysis is performed as a sound power distribution which splits the power spectrum into adjacent one-third octave frequency bands. This presents the acoustic data in a logarithmic frequency scale on the x-axis and sound pressure level on the y-axis of a graph. The third octave analysis is useful because it can be used to understand the broadband sound pressure level and demonstrate frequency dependent propagation characteristics of an environment, over time. The acoustics community has adopted standard 1/3-octave frequencies to facilitate comparisons between studies which are used in this report (MacGillivray & Chapman, 2005).

The high tidal flow noise environment of the FORCE site is important to note because of the interference, especially in the upper frequencies where porpoise clicks are located. If the sound of the tidal noise is greater than the porpoise clicks (signal), the detectors would not be able to differentiate a click from the surrounding sound. This would be too low signal to noise ratio and shows the importance of signal to noise ratio in detecting porpoise clicks. The tidal flow noise would be considered acoustic masking when it is masking or concealing the signals of interest. The turbine also has active sonar equipment that create additional sound in the upper frequencies where harbour porpoise clicks occur further increasing the difficulty of detection by the hydrophones.

Some issues were experienced during the deployment (Table 1). The hydrophone (Hydrophone 3 – Appendix A) located on the top of the rotor was damaged early in deployment, likely due to debris travelling in the water column. Although the unit still collected data, the damage compromised that data past November 11, 2016 and it could not be used for the analysis. Hydrophones 1406 and 1407 had communication issues related to cabling during the deployment and collected data periodically. Hydrophone 1404 collected data throughout the deployment.

On March 8, 2017, the hydrophone sampling rate for the WAV data from one hydrophone (1404) was remotely increased to 64 kS/s and then increased further on March 24, 2017 to 512 kS/s (200 kHz). OpenHydro increased the sampling rate by remote access to the FORCE substation while the turbine was still deployed. The sampling increase was made for hydrophone 1404 as it had the most reliable communication. This increased sampling rate for the waveform was needed because early analyses of data indicated that the original set-up was a suboptimal sampling rate for use in the click detector programs. The optimal sampling rate needed for *Coda* and *PAMGuard* is 512 kS/s to sample up to 256 kHz.

## Data Analysis

Table 1 provides a summary of the FFT and WAV data recorded for each hydrophone during specific periods.

*Table 1. Data recorded on each hydrophone from November 8, 2016 to April 13, 2017*

| Hydrophone Serial Number | Dates | FFT | WAV |
|---|---|---|---|
| 1404 | 11/08/16 – 03/08/17 | 512 | 32 |
| | 03/08/17 – 03/24/17 | 512 | 64 |
| | 03/25/17 – 04/13/17 | 512 | 512 |
| | | | |
| 1405 | 11/08/16 – 03/08/17 | 512 | 32 |
| | 03/08/17 – 04/13/17 | 512 | 64 |
| | | | |
| 1406 | Invalid data (periodic recording) | | |
| | | | |
| 1407 | 11/09/16 – 11/14/16 | 512 | 32 |

### *Tidal Current Percentages*

Percentages were used as a measurement of current speed by OpenHydro with -100% and +100% being the greatest current speeds and 0 being no current speed known as slack tide. The negative and positive current speeds are used to show the ebb (falling) and flood (rising) tides respectively.

### *Lucy*

The *Lucy* click detector software was used with the FFT data from November 8, 2016 to April 13, 2017. A detected click was reviewed visually by a data analyst to determine viability and if a positive visual identification of a click was made, the day was recorded. Preliminary results from *Lucy* showed porpoise clicks on multiple days each month of the deployment. March had the most visits with 15 days over the month (Table 2); however, it should be noted that data was only collected until April 13 (at which time hydrophones were disconnected for retrieval). The number of porpoise click detections in the beginning of April is at least proportional to March. This demonstrates the seasonal frequency of harbour porpoise detection in the FFT data set.

*Table 2. Days with Detected Porpoise Clicks with the Lucy Click Detector*

| Month | Days of Porpoise Detections |
|---|---|
| November | 10, 11 |
| December | 23, 24, 25, 29 |
| January | 1, 4, 8, 29 |
| February | 2, 5, 23, 24, 26 |
| March | 1, 2, 3, 5, 10, 12, 13, 20, 21, 23, 25, 26, 28, 30, 31 |
| April | 1, 2, 6, 7, 9, 10, 11, 12 |

The results from the days of porpoise detection (Table 2) were also compared to operational data of the turbine as seen in Appendix B. The graph shows time during turbine power generation and porpoise click detections. Initial results could suggest an inverse relation when power is being generated, however, further research over a longer time period and with fully functioning devices is required in order to draw any conclusions.

Lucy porpoise click detections were made by visual inspection so individual clicks could be identified as porpoise activity, as well as, click trains. Porpoise clicks were detected with high frequency sonar signals in the data and identified during slack tide and during the beginning of tidal flow. Verification of porpoise clicks during tidal flow was difficult because the low signal to noise ratio which caused acoustic masking. *Lucy* had difficulty detecting clicks during high tidal flow noise. Examples of porpoise detection in the *Lucy* program are shown below in Figures 2 and 3.

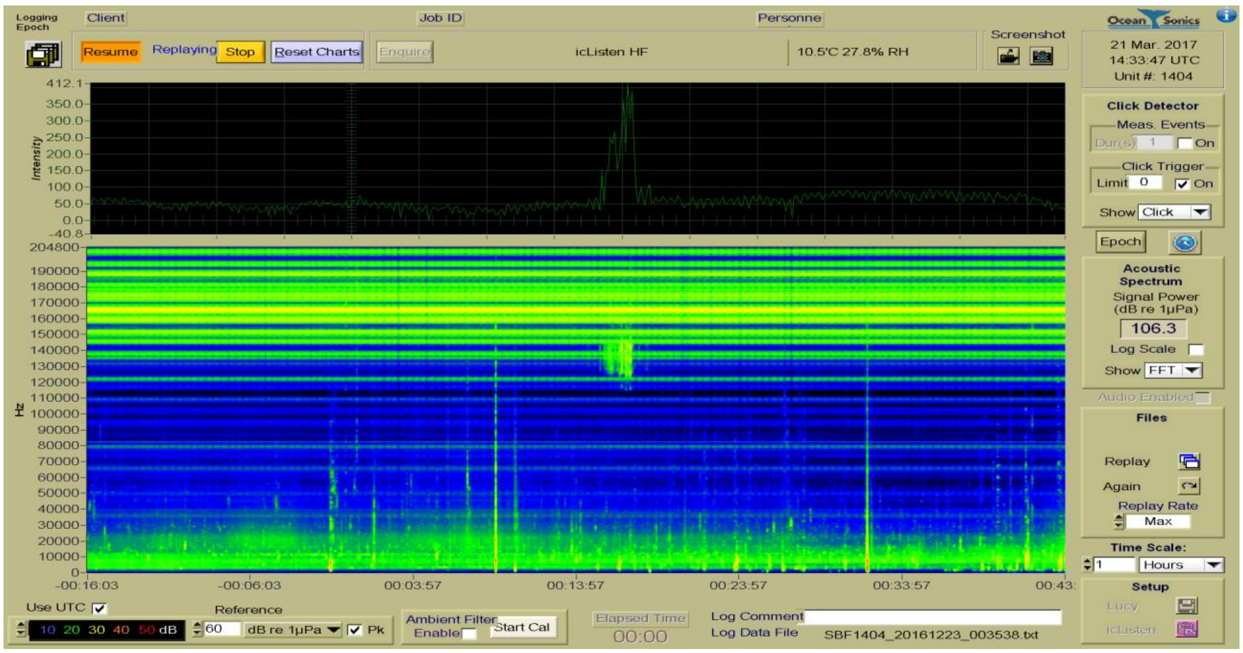



*Figure 2. Screenshot from Lucy. Dec. 23, 2016. Reference 60 dB re 1µPa with a 10 dB step.*
*Porpoise clicks are shown in the middle of the spectrogram with the detection intensity spiking in the upper graph. Horizontal banding from 120 to 204 kHz is found throughout the spectrogram, the sound was created by the sonar impulse signals. This shows the Lucy Click Detection software can identify porpoise clicks while there are sonar signals present.*

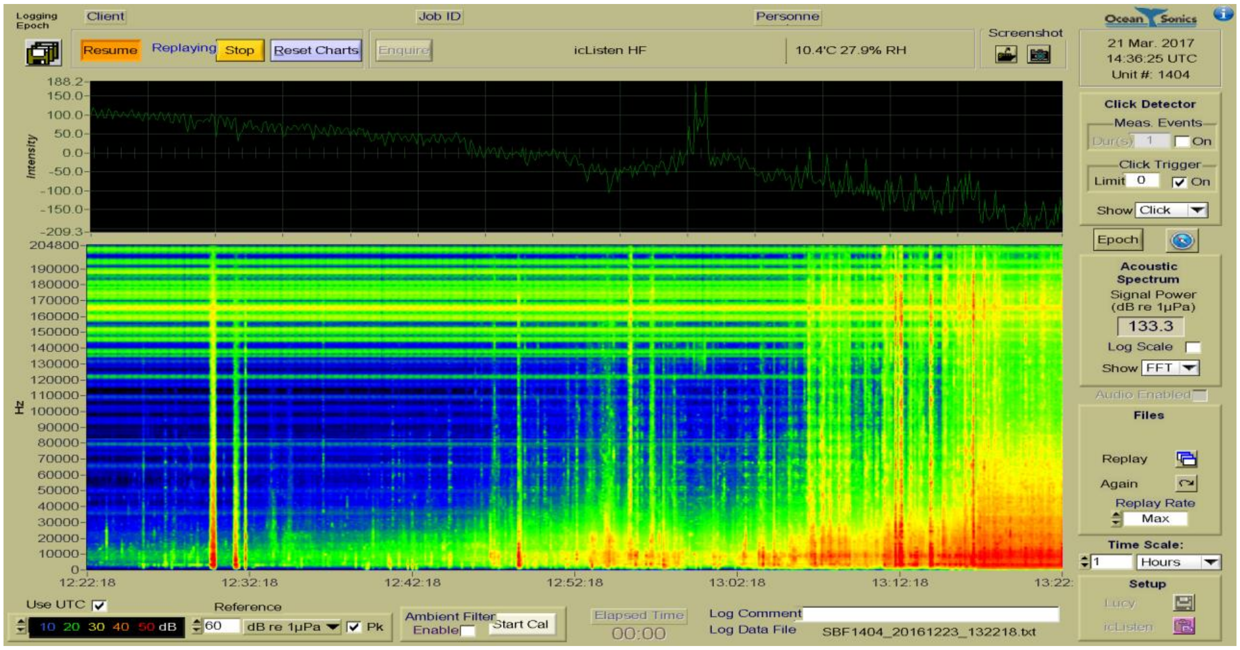



*Figure 3. Screenshot from Lucy. Dec. 23, 2016. Reference 60 dB re 1µPa with a 10 dB step.*
*Porpoise clicks are shown in the middle of the spectrogram, at the beginning of a tidal flow. The graph indicates increasing noise on the right-hand side of the spectrum as tidal flow increases. The upper graph shows the rise in intensity where the clicks detected by the Lucy Click Detector.*

## Coda

*Coda* was used to detect porpoise clicks for the tidal turbine data from March 25 to April 13, 2017. The porpoise clicks detections were noted for four days in March and 11 days in April (Table 3).

*Table 3. Days with Porpoise Click Trains Detected by Coda*

| Month | Days with Porpoise Click Train Detection |
|---|---|
| March | 25, 27, 28, 31 |
| April | 1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13 |

For the data collected from March 25 to April 13, 2017; *Coda* detected porpoise clicks all days except for March 26, 29, and 30 and April 3 and 4, 2017. High intensity harbour porpoise detections were found by the *Lucy* Click Detector as well as *Coda* on April 11 and 12, 2017. The mean current when there were click train detections was 44.25 %, of peak current.

*Coda* detected, and recorded porpoise clicks in the data and then processed the detection results further to find and record click trains. Click trains were used as a detection method and further verification of the clicks to minimize false positive and maximize true positive detections. The click train parameters used were 3 or more detected clicks with a maximum 0.2 second inter-click interval. The click train data were then recorded, reviewed and then analyzed to provide more information on the porpoise clicks detected, as described in the table below (Table 4). The click trains were then compared to the current speed to determine the rate of detections regarding current speed.

The following graphs and tables use **DP5M** (detection positive five-minutes) as the base measurement for detection. This was used because the acoustic waveform data files were five minutes in length. **DP5M** refers to the number of detection-positive 5-minute intervals.

*Table 4. Coda Statistics on Click Trains Detected.*

| Day | #DP5M | #Trains | #5minute | p | se |
|---|---|---|---|---|---|
| 25-Mar-17 | 1 | 1 | 148 | 0.007 | 0.0067 |
| 26-Mar-17 | 0 | 0 | 288 | 0 | 0 |
| 27-Mar-17 | 4 | 20 | 288 | 0.014 | 0.0069 |
| 28-Mar-17 | 6 | 17 | 288 | 0.021 | 0.0084 |
| 29-Mar-17 | 0 | 0 | 288 | 0 | 0 |
| 30-Mar-17 | 0 | 0 | 288 | 0 | 0 |
| 31-Mar-17 | 2 | 3 | 288 | 0.007 | 0.0049 |
| 01-Apr-17 | 3 | 10 | 288 | 0.01 | 0.006 |
| 02-Apr-17 | 4 | 7 | 288 | 0.014 | 0.0069 |
| 03-Apr-17 | 4 | 5 | 288 | 0.014 | 0.0069 |
| 04-Apr-17 | 0 | 0 | 288 | 0 | 0 |
| 05-Apr-17 | 2 | 3 | 288 | 0.007 | 0.0049 |
| 06-Apr-17 | 6 | 10 | 288 | 0.021 | 0.0084 |
| 07-Apr-17 | 8 | 18 | 288 | 0.028 | 0.0097 |
| 08-Apr-17 | 6 | 15 | 288 | 0.021 | 0.0084 |
| 09-Apr-17 | 5 | 10 | 288 | 0.017 | 0.0077 |
| 10-Apr-17 | 5 | 9 | 288 | 0.017 | 0.0077 |
| 11-Apr-17 | 40 | 1424 | 288 | 0.139 | 0.0204 |
| 12-Apr-17 | 10 | 136 | 288 | 0.035 | 0.0108 |
| 13-Apr-17 | 2 | 3 | 54 | 0.037 | 0.0257 |

*Notes:*
*#5minute refers to the number of 5-minute intervals of acoustic data that were collected each day;*
*#Trains refers to the number of harbour porpoise click trains;*
*p refers to the proportion of detection-positive 5-minute intervals in a day;*
*(p = #DP5M /#5minute);*
*se refers to the standard error of p; [se = sqrt{p*(1-p) / #5minute}]*

The graphs below show the proportion of detection positive 5-minutes distributed as a function of hour of the day, in 2-hour increments (Figure 4) and current speed (Figure 5). The vertical lines indicate standard error.

As shown in Figure 4, the hours with the highest proportion of porpoise clicks were found between 22:00 to 06:00 (UTC); at the turbine site this would have been between 19:00 to 03:00 ADT, Atlantic Daylight Time, suggesting greater use of the site at night.

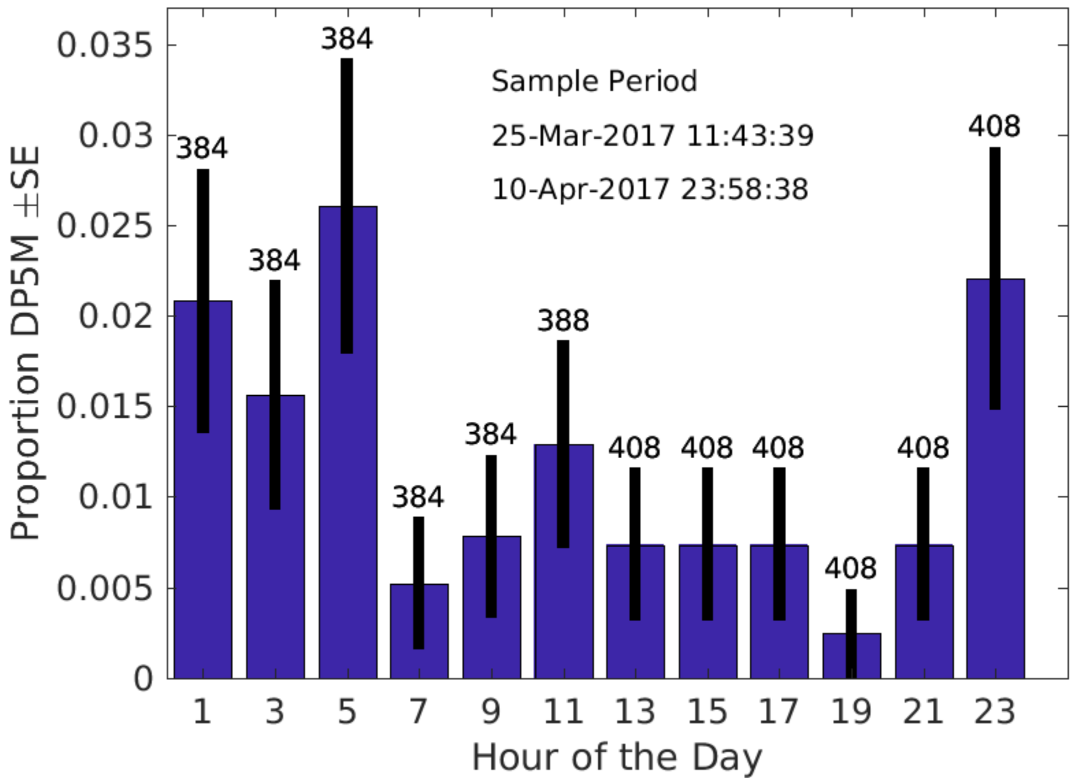



*Figure 4. Proportion of Detection Positive 5 minutes, +/- standard error comparing hours of the day.*

Figure 5 indicates that the current speed with the highest proportion of DP5M is -30%.

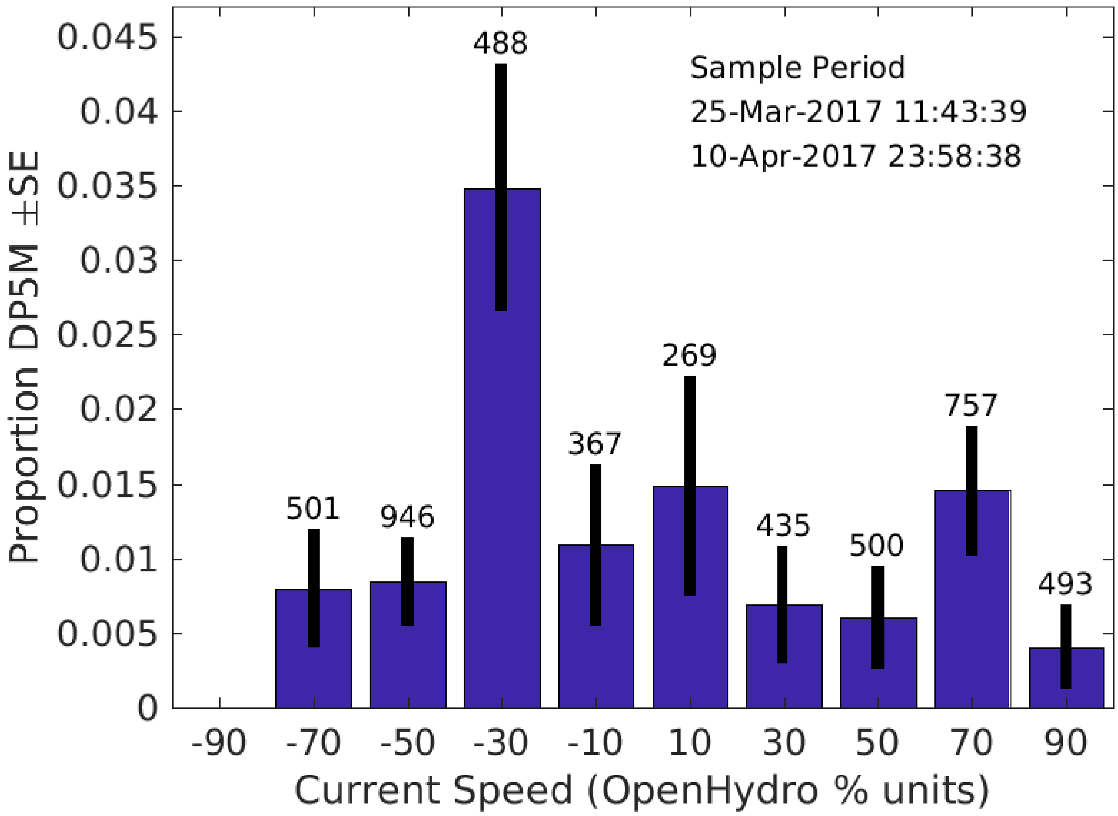



*Figure 5. Proportion of Detection Positive 5 minutes, +/- standard error comparing current speed based on OpenHydro measurements using percentages.*

### *Overview of Click Detection Methods*

***Lucy with Visual Inspection***

- Can use FFT or WAV data for processing
- Loses ability to detect porpoises in high flow noise environments
- Can process real-time or stored data
- Based on spectral cross-correlator
- Click model can be fine-tuned
- Labour intensive due to visual inspection
- Detections based on single porpoise clicks

***Coda***

- Only uses WAV data
- Created to identify clicks in noisy data
- Can process real-time or stored data
- Data output of detections can be reviewed, and results further processed in the program
- Can be programmed to selectively record data based on porpoise click detections
- Detections can be shown by each click or by click trains

Lucy was used to identify clicks in the FFT data, while Coda was used for the last month of data where there was full bandwidth WAV data collected. Coda was developed based on the experience of the past five years using the Lucy Click Detector.

Differences found between results in days with porpoise detection is based on the different algorithms used in the two methods. Lucy used single clicks or click trains but all clicks were individually confirmed by a data analyst, increasing labour intensity. Coda used a further processing method of detecting only porpoise clicks that were in click trains, this allowed for less false and more true positive detections.

### *Third Octave Analysis*

Sound levels were found using third octave processing for a tidal cycle on April 3, 2017. April 3, 2017 was chosen for third octave analysis because it had a representative tidal cycle from the waveform data after the sampling rate was increased to full bandwidth. The third octave graph shows the difference in sound levels during the tidal cycle. The increased ambient noise levels created by the flow of tides is around 130 kHz which is the level at which a porpoise clicks (Table 5 and Figure 6). This can create difficulty in detecting clicks because of the low signal to noise ratio. Table 5 shows the SPL at 1 kHz, chosen as a base measurement for tidal noise and 130 kHz the frequency where harbour porpoise clicks are located.

*Table 5. Sound pressure level (SPL) at two chosen frequencies 1 kHz and 130 kHz*

| State of Tide | SPL at 1 kHz | SPL at 130 Hz |
|---|---|---|
| Slack Tide | 79 dB re µPa | 94 dB re µPa |
| Flood Tide | 135 dB re µPa | 144 dB re µPa |

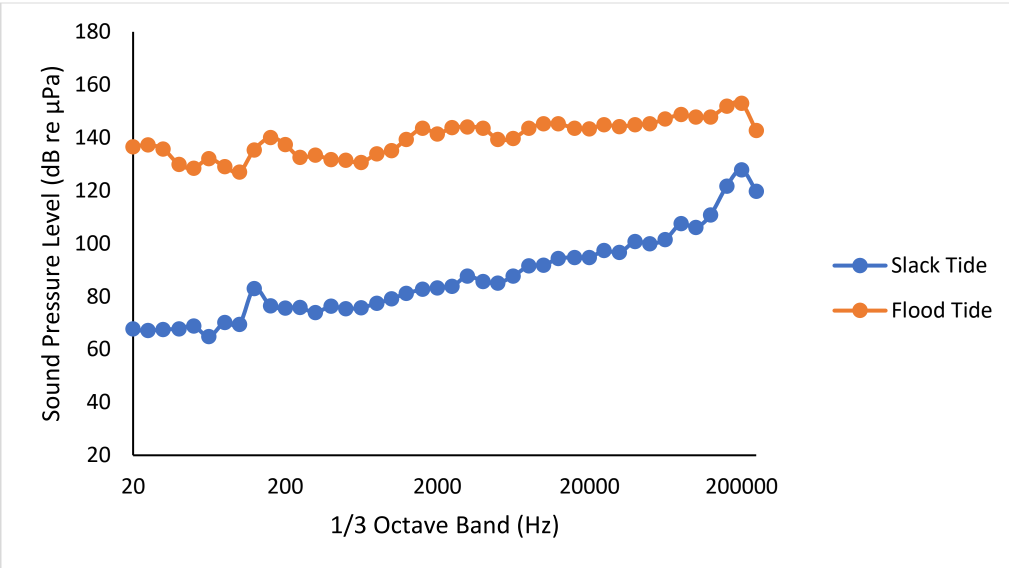



*Figure 6. Third Octave Graph showing the difference in sound pressure level (dB re µPa) between slack tide and flood tide.*

### *Localization*

Using four hydrophones allows for the option of localizing sound sources that were detected (*i.e.*, determine the position of a vocalizing animal in relation to the turbine). During the recent deployment however, only one usable channel was acquired so localization could not be performed.

### *Marine Mammal Vocalizations*

Marine mammal vocalization processing was not performed due to the quality and quantity of recorded data.

## Acoustic Patterns

### *Impulsive Signals from Active Sonar*

The majority of the data contained many broadband impulsive signals, believed to be from the active sonar mounted on the CST turbine. The sonar created the impulsive signals at various intervals and the sound intensity was greatest between 150 to 200 kHz. The sonar emitted sound between 720 kHz +/- 50 kHz. The impulsive signals found in the data between 150-200 kHz were sideband effects from the higher frequency emissions of the sonar.  The signals increased the noise levels in the upper frequencies where harbour porpoise clicks are located. The impulse signals created false positive porpoise clicks in *PAMGuard* without revised settings.

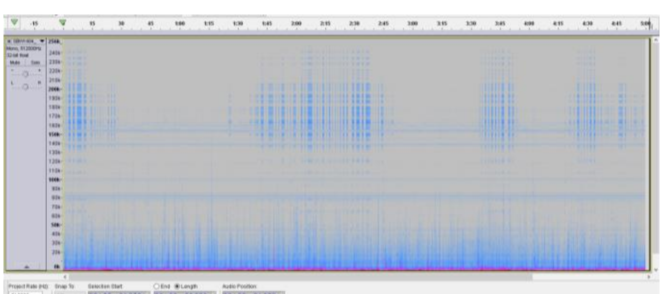


*Figure 7. Screenshot from Audacity showing the sonar signals over 5 minutes. The spectrum display has frequency on the left side between 0-256 kHz. The top of the display on the figure is the time axis, with 0-5 minutes.*

## *Tidal Flow Pattern*

During both flood and ebb tides there is a substantial amount of noise being recorded by the hydrophone due to the tidal flow noise. A distinct pattern of high-frequency ambient sound increases as current picks up as can be seen in Figures 8 and 9.

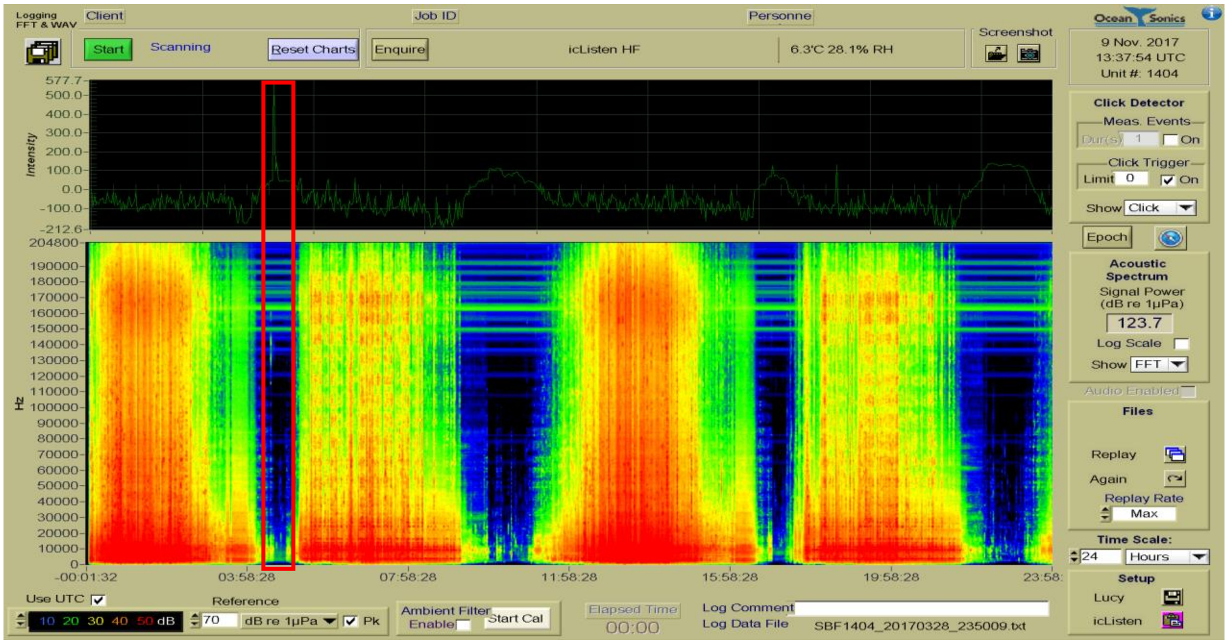



*Figure 8. Lucy screenshot from hydrophone 1404 on March 28, 2017. A reference of 70 dB re µPa, 10 dB steps.*
*The waterfall display shows the flood and ebb tides, from a 24-hour period. The spectrogram begins with a flood tide then the ebb, and repeats. There is a porpoise click detection between the first flood and ebb tide detected by the spike in the Lucy Click Detector in the upper intensity graph shown by a red box.*

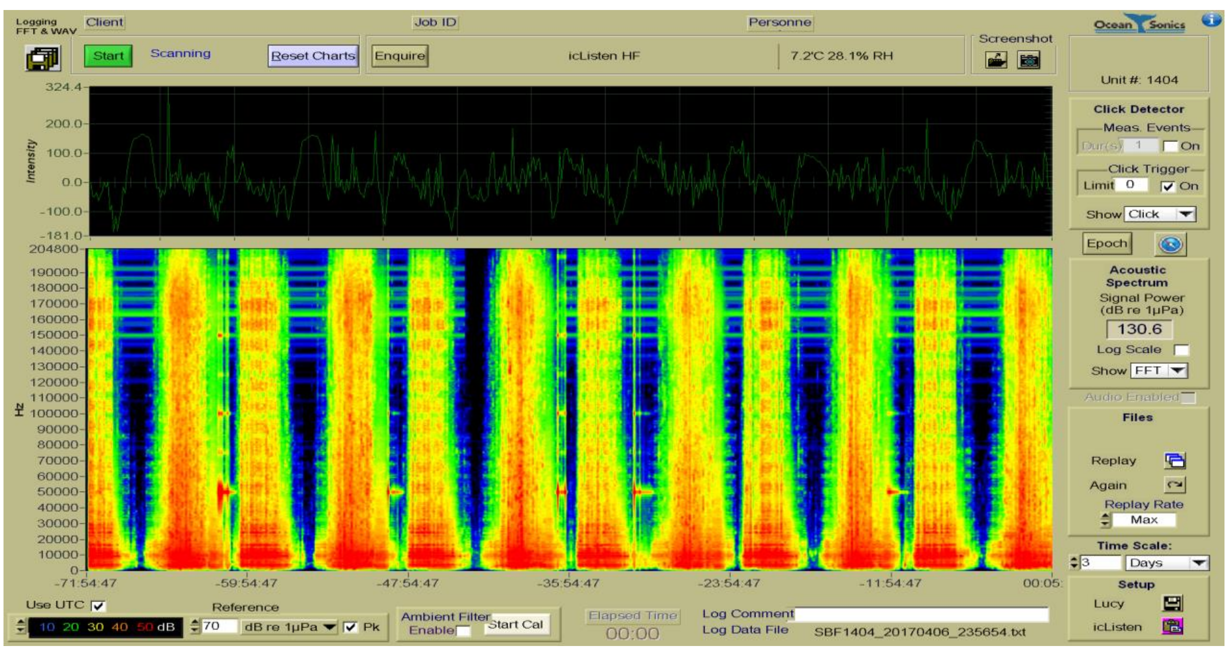



*Figure 9.Lucy screenshot from hydrophone 1404. A reference of 70 dB re µPa, 10 dB steps.*
*Three days of data showing tidal cycle pattern from April 4th, 5th and 6th, 2017. Tones from the sonar are clearly visible in the upper frequencies.*

# Planning for Next Deployment

## Lessons Learned

Over the course of the deployment there were learning opportunities that can be used to improve the data quality and quantity for the next deployment. Issues with data loss (due to a failure of the communication network), synchronization set-up issues and loss of the sensor in the hydrophone mounted on the top of the rotor have all been discussed with OpenHydro and integrated into a plan to prepare for future monitoring during the next deployment.

Mitigation measures and improvements have also been developed for implementation in the next deployment to progress the passive acoustic monitoring of the near-field area of the turbine. This includes detailed set-up for the hydrophones to sample at full bandwidth, new cabling, more robust guards for increased protection of the sensor tips and specialized guard bars on either side of the hydrophone on the top of the rotor. All hydrophones will be able to record data that can be used in the porpoise click detectors. There is also ongoing work to understand the synchronization of the units with the active acoustic system. The result will be a fully synchronized system that is expected to use passive acoustic data to locate noise based on arrival times, such as the detection of porpoise clicks used for harbour porpoise localization.

Although there was success in determining porpoise clicks, no localization was performed because data was recorded on just one channel, preventing the possibility of localization. Specific speed categories were not defined because the turbine was in a commissioning phase over the deployment period. This will be further investigated during the next deployment.

## Recommendations for Future Monitoring Considerations

The following are recommendations to consider for future monitoring

1. A better understanding of other equipment on the tidal turbine and the acoustic emissions with respect to passive acoustic monitoring. This will be useful for a more in-depth acoustic analysis in the future.

2. Scheduled real-time access to hydrophones, as required, for ongoing diagnostics will improve identification of potential concerns and timely implementation of solutions.

3. Implementation of protective devices for the hydrophones to protect from debris carried by the current.

4. Improvements to data management prior to the planned increase in data collection will facilitate the access and analyses of data. It is expected that the hydrophones will be recording and sending 200 kHz processed spectral data and up to 200 kHz waveform data to the shore station resulting in up to 512 GB of sound data per day or approximately 15 TB per month. This requires a formal data handling protocol.

5. Further investigation of the *PAMGuard* and *Coda* porpoise click detector programs to increase understanding of when porpoises are present in comparison to turbine operations. Further investigation of *PAMGuard* with additional full bandwidth WAV data could also provide more

favourable results. Building on datasets such as this will result in a greater understanding of the use of the Minas Passage by harbour porpoise, allowing for the development of a future strike risk model.

6. Further data analysis is suggested for the following
    a. Comparison of turbine operations and acoustic data;
    b. Comparison of published studies with full bandwidth WAV data; and
    c. Marine mammal detection with *PAMGuard* whistle and moan detectors.

# References

MacGillivray, A. O., & Chapman, N. R. 2005. Results from an acoustic modelling study of seismic airgun survey noise in Queen Charlotte Basin. University of Victoria report.

# Appendix A

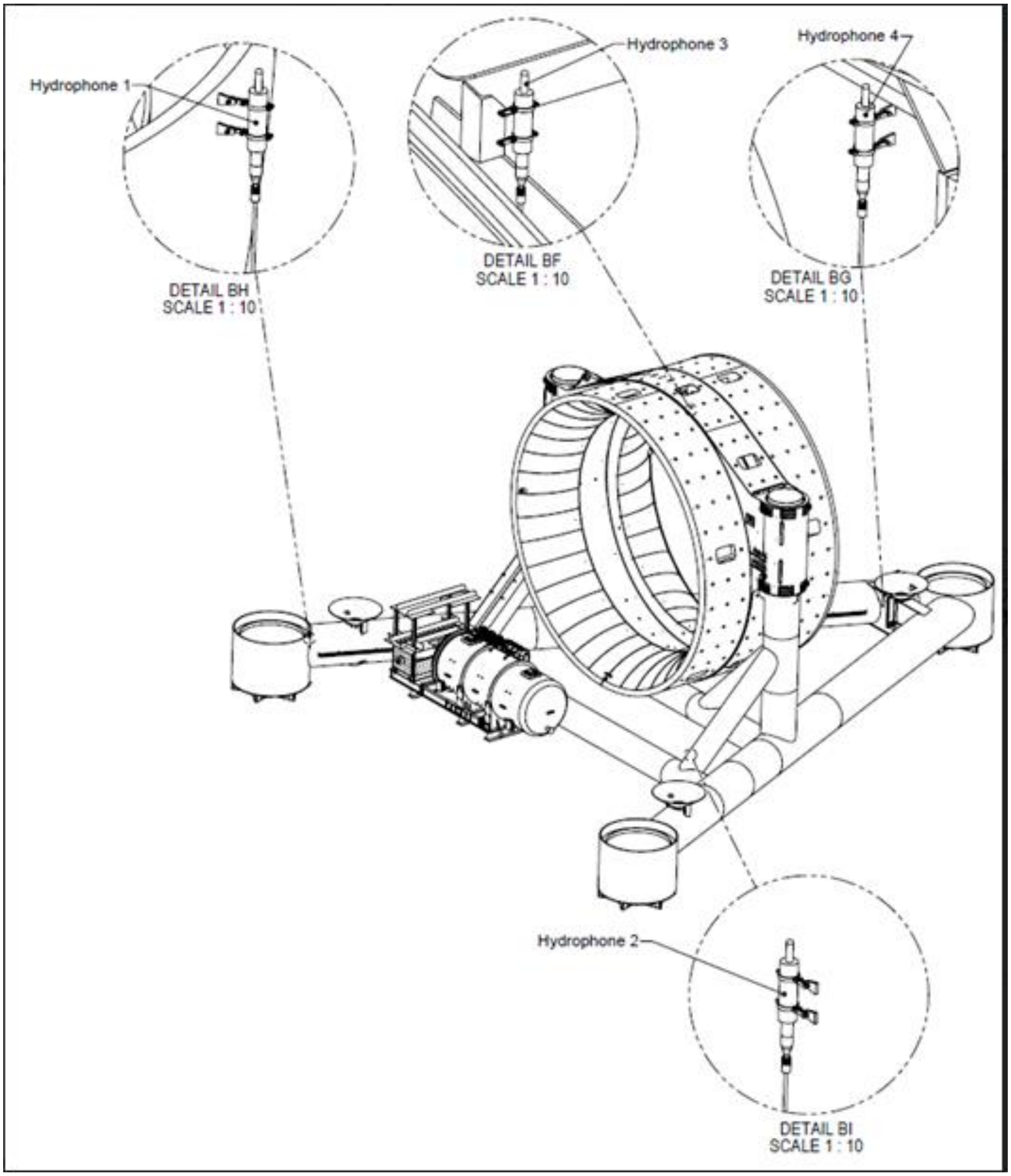
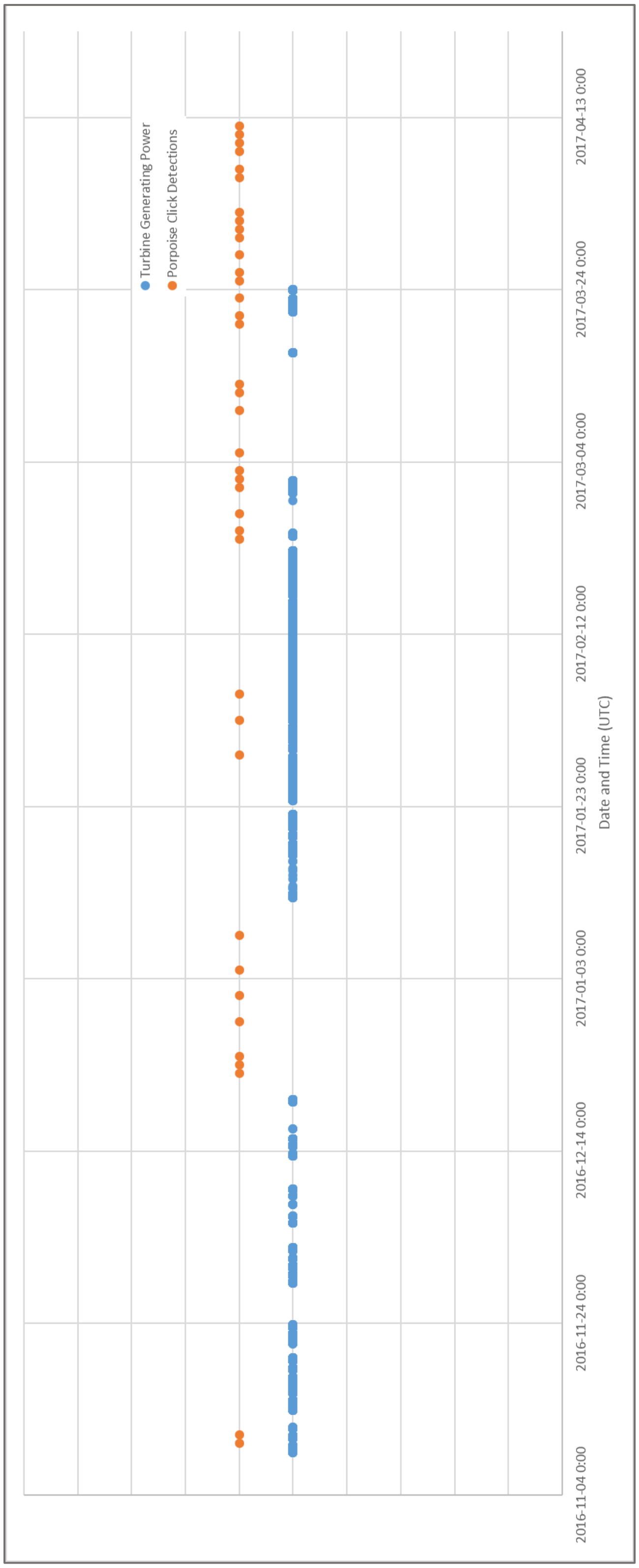



*Figure 10. Tidal Turbine diagram showing hydrophone placement*

| Caption in Figure | Hydrophone Serial Number |
|---|---|
| Hydrophone 1 | 1407 |
| Hydrophone 2 | 1404 |
| Hydrophone 3 | 1405 |
| Hydrophone 4 | 1406 |

# Appendix B


Turbine Generating Power
Porpoise Click Detections
2016-11-04 0:00
2016-11-24 0:00
2016-12-14 0:00
2017-01-03 0:00
2017-01-23 0:00
2017-02-12 0:00
2017-03-04 0:00
2017-03-24 0:00
2017-04-13 0:00
Date and Time (UTC)

# Appendix C – Detections of Fish Tags

| Date | Time (UTC) | |
|---|---|---|
| | Start | End |
| 04-Sep-18 | 10:00:00 | |
| | 16:55:00 | |
| 05-Sep-18 | 4:50:00 | |
| | 5:47:00 | |
| | 11:23:00 | |
| | 18:30:00 | |
| 06-Sep-18 | 5:10:00 | 6:26:00 |
| | 12:30:00 | 13:10:00 |
| | 16:42:50 | 17:32:00 |
| | 19:05:00 | 19:30:00 |
| | 19:32:00 | 20:10:00 |
| 07-Sep-18 | 1:40:00 | |
| | 6:30:00 | 7:45:00 |
| | 13:15:00 | 13:55:00 |
| | 17:50:00 | 19:12:00 |
| | 20:14:00 | 21:00:00 |
| 08-Sep-18 | 20:00:00 | 21:00:00 |
| | 08:00:00 | |
| 09-Sep-18 | 9:00:00 | |
| | 9:55:00 | 10:30:00 |
| | 15:44:00 | 16:13:00 |
| | 21:30 | 22:45:00 |
| 10-Sep-18 | 3:53:00 | 4:30 |
| | 9:00 | 10:00 |
| | 10:30 | 11:30 |
| | 17:08 | 17:30 |
| | 21:00 | 22:30 |
| 11-Sep-18 | 10:02:00 | |
| 14-Sep-18 | 8:35:00 | |
| | 11:45 | |
| 15-Sep-18 | 1:09:00 | |
| | 2:02 | |
| | 21:02 | |

| Date | Time (UTC) | |
|---|---|---|
| | Start | End |
| 16-Sep-18 | 9:45:00 | |
| | 13:02 | 14:10 |
| | 15:00 | 15:20 |
| | 15:50 | 16:10 |
| 17-Sep-18 | 4:00 | |
| | 9:45 | 10:30 |
| | 15:55 | 16:10 |
| | 16:46 | 17:02 |
| 18-Sep-18 | 3:43 | 4:04 |
| | 14:55 | 15:25 |
| | 17:40 | 18:00 |
| | 23:48 | |
| 19-Sep-18 | 12:00 | 12:38 |
| | 13:00 | |
| | 18:38 | 19:02 |
| 20-Sep-18 | 5:30 | 6:10 |
| | 11:50 | 12:25 |
| | 12:10 | v loud |
| | 18:51 | 19:11 |
| | 19:46 | |
| | 20:00 | 20:10 |
| 21-Sep-18 | 6:21 | 6:40 |
| | 13:13 | 13:40 |
| | 19:00 | 19:06 |
| | 20:00 | 20:40 |
| 22-Sep-18 | 6:02 | |
| | 7:24 | 7:30 |
| 29-Sep-18 | 10:18 | 11:30 |
| | 12:30 | 13:55 |
| 30-Sep-18 | 1:36 | 1:53 |
| | 8:00 | |
| | 10:50 | 12:20 |
| | 12:30 | 14:00 |

# Appendix D – Preliminary field tests of a Gemini 720i multibeam imaging sonar with icListenHF hydrophones and associated spectral analyses

# Preliminary field tests of a Gemini 720i multibeam imaging sonar with icListenHF hydrophones and associated spectral analyses

Final Report (included in ISEM Report to OERA)

30 May 2019

Prepared and submitted by

Brian Sanderson, Jeremy Broome, Mike Adams and Anna Redden

Acadia Centre for Estuarine Research (ACER)
Acadia University
Nova Scotia, Canada

**ACER Technical Report No. 125**

Citation:

Sanderson B., Broome J.E., Adams M. and A.M. Redden. 2019. Preliminary field tests of a Gemini 720i multibeam imaging sonar with icListenHF hydrophones and associated spectral analyses. Acadia Centre for Estuarine Research Technical Report No. 125, 32 pp, Acadia University, Wolfville, NS, Canada.

ACADIA ESTUARINE CENTRE FOR RESEARCH

# Table of Contents

## Introduction

To date, there have been few near-field environmental monitoring programs of tidal energy devices and consequently the impact on marine life is not well understood. In the Minas Passage, the highest environmental monitoring priority for the Fundy Ocean Research Centre for Energy (FORCE) is the acoustic detection of marine life - turbine interactions. Understanding how instream turbines interact with fish and marine mammals is essential to the development of this nascent industry and its regulation, and the design of effective mitigation measures, if required.

The preliminary work described herein contributes to a large, multi-partnered project, led by Emera/Cape Sharp Tidal, which aims to advance the use of acoustic monitoring technologies to enable the collection of data on fish and marine mammals at and near instream tidal turbines. The subsequent analysis and interpretation of environmental sensor data is helpful in informing direction for policy makers, regulators, industry, Bay of Fundy fishers, Aboriginal communities and the general public who are watching the industry's progress in addressing the potential effects of in-stream tidal turbines on marine life.

The research project presented in this technical report describes preliminary field tests of the Gemini 720i multibeam imaging sonar and icListenHF hydrophones, technologies which were selected for installation on a 16m diameter 2 MW OpenHydro turbine deployed by Cape Sharp Tidal Venture at FORCE in Minas Passage in late 2015. Tests were conducted at various sites in summer 2015 to examine the capabilities of the sonar to detect and track fish prior to installation of sensors on the turbine infrastructure, as intervention post-turbine deployment in Minas Passage would not be possible.

This preliminary study informs the application of the Tritech Gemini 720i multibeam imaging sonar for fish detection and tracking in high flow tidal energy development sites in the Bay of Fundy and elsewhere. While the Gemini multibeam imaging sonar has been frequently used for environmental effects monitoring of marine mammals at tidal turbine test sites in the UK, it has not been specifically applied for fish detection and, prior to this field study, has never been used in the high flow waters of the upper Bay of Fundy where potential fish-turbine interactions remain a concern.

## Project Objectives

This project involves performance testing and optimization of the Gemini 720i sonar settings for use in recognition and tracking of fish targets. The main objectives are to:

A. Evaluate the performance of the Gemini 720i multibeam imaging sonar in detecting fish of various types in environments ranging from low to moderate flows. A draft version of this section of the report was shared with OpenHydro and other ISEM project team in late 2015.

B. Evaluate the sound emission profile and potential instrument interference of the Gemini sonar, as determined by co-located icListenHF hydrophones and spectral analyses of hydrophone data.

## Field Study Sites

The range of field study sites examined spanned freshwater systems to Bay of Fundy marine waters, and included a fish aquaculture site. Gemini 720i multibeam imaging sonar and icListenHF hydrophone tests were conducted at the following six locations:

1. Black River Lake, NS: Examination of the performance of the Gemini technology and other system components in a local lake.
2. Minas Basin, Bay of Fundy: Detection of fish at a near-shore tidal site off Kingsport, NS. An opportunistic comparison with a Didson imaging sonar (with Dr Gayle Zydlewski, U Maine) was also made at that time (results not included here).
3. Gaspereau River, NS: Detection of fish in a local river with Gaspereau, including near a hydro dam
4. North River Fish Farms, Truro, NS (on land): Sonar detection/tracking of known fish targets (Striped Bass). Two icListenHF hydrophones were also deployed at the site to examine sound profiles with and without Gemini operation.
5. Halls Harbour, Bay of Fundy: Wharf test of the Gemini with icListenHF hydrophones.
6. Minas Channel, Bay of Fundy: Detection of fish while drifting in Minas Channel (off Halls Harbour). This included drifting with a pole mounted Gemini unit and an icListenHF hydrophone that was independently drifting.

## Acoustic Instruments Tested

The Gemini 720i (Tritech, UK) system (Figure 1) is a 300m depth rated, multibeam imaging sonar, which operates at 720kHz, with beam widths of $120^{o}$ horizontal (scanning sector) and $20^{o}$ vertical. The transducer is angled downward $10^{o}$. The scanning sector is composed of 256 beams with resolution of $0.5^{o}$. The operational range is 0.2 – 120m, with a range dependent resolution of 8mm.


**Figure 1.** Tritech Gemini 720i multibeam acoustic imaging sonar. Image retrieved from: http://www.seascape.nl/wp-content/uploads/Gemini-720i-3.jpg

The icListenHF (Ocean Sonics Ltd) is a small and compact broadband digital hydrophone (Figure 2) with a 200m or 1000m depth rating, depending on the housing material. Bandwidth is ±6 dB over the frequency range 10 Hz to 200 kHz. Sensitivity is -169 dBV re. µPa and dynamic range is 95 dB. An onboard computer, along with internal battery and data storage allows the icListenHF to be deployed as an autonomous unit for abut 7 hours. Porskamp (2013) reported detection ranges of ~500m in Minas Passage.


**Figure 2**. IcListenHF (High Frequency) hydrophone (OceanSonics, Great Village, NS). Image retrieved from https://oceansonics.com/

# PART A: Gemini 720i Imaging Sonar Performance in Detecting Fish

## Test 1 – 2015-08-05 - Black River Lake, NS

The first in-water trial of the Tritech Gemini 720i sonar was conducted in Black River Lake, NS. Black River Lake is an impoundment which forms part of Nova Scotia Power's hydroelectric system. The Lake contains dark, tannin-stained water, which limits visibility. Macroalgae were also observed in the water column. The shoreline of Black River Lake is composed of granite rock interspersed with a mud/sand bottom. Smallmouth Bass (*Micropterus dolomeiu*) were the primary fish targets expected to be detected in this system.

The sonar was deployed from a small boat (5m). The sonar head was mounted on a galvanized steel pole and suspended over the gunnel to a depth of 0.5m below surface (Figure 3). This mounting orientation positioned the Gemini with a horizontal field of view (FoV).

The boat was positioned in deep water of the central basin looking toward shoreline. To obtain a clear image, sonar gain levels had to be set to >90%. When settings were optimized and images successfully recorded, the boat was repositioned closer to the shoreline which provided a rocky backdrop where fish were expected. The boat was anchored parallel to shore and pivoted on a single point mooring. Images of fish-like targets are shown in Figure 4. Rowing the boat resulted in turbulent wakes that were detected by the sonar (Figure 5).

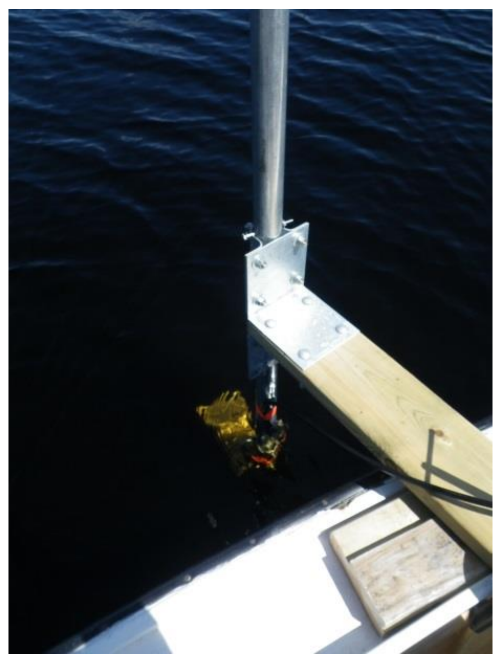


**Figure 3**. Tritech Gemini 720i attached to mounting bracket on dock prior to departure (Left). Gemini 720i mounted on adjustable pole structure and positioned perpendicular to the boat approximately 30cm below the surface (Right).

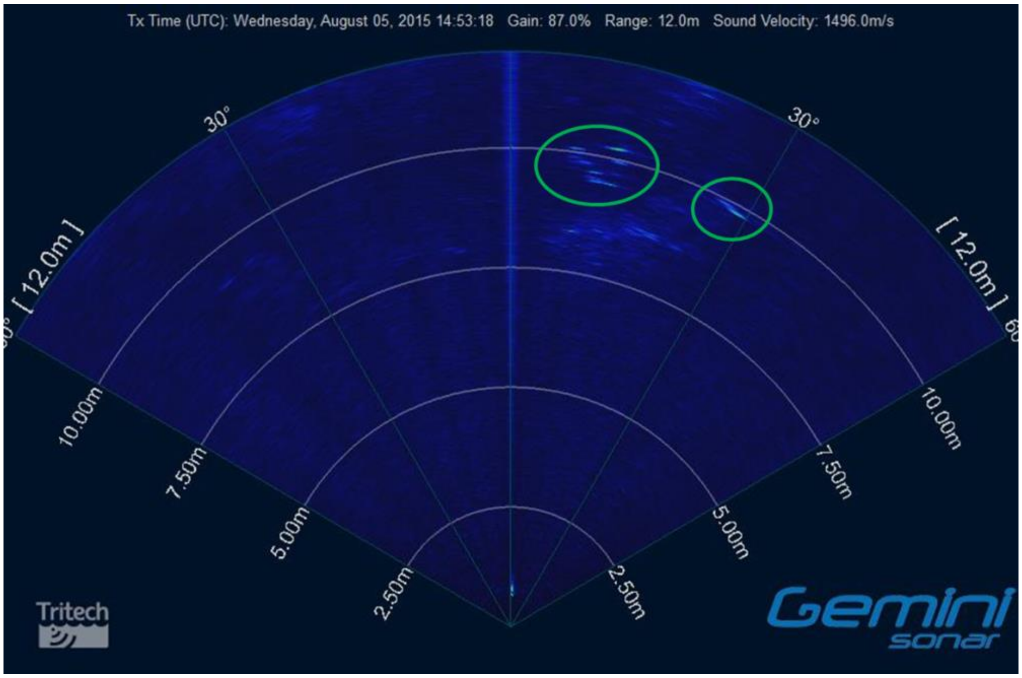



**Figure 4**. Small group of fish-like targets at a distance of 10m, with a larger target following behind.

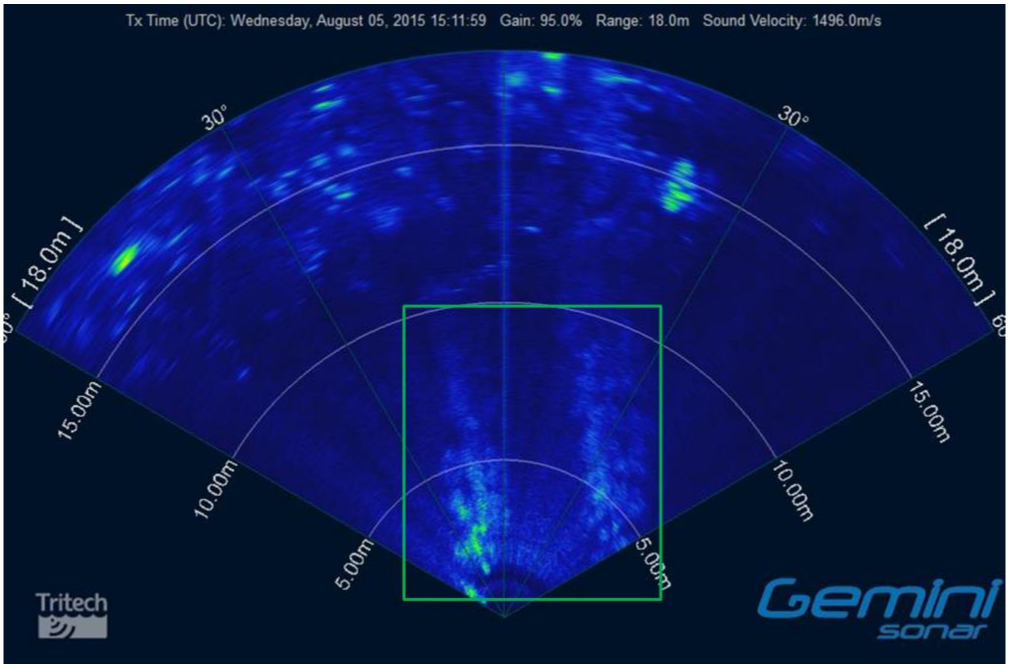



**Figure 5**. Surface turbulence plumes trailing behind the vessel while being repositioned by rowing. Note that image quality is degraded within the turbulent wakes, similar to turbulent wakes which may be found downstream of an operational tidal turbine.

## Test 2 – 2015-08-06 - Kingsport, Minas Basin, NS

Kingsport is a near shore, intertidal site located within the Southern Bight of Minas Basin. This test site featured turbid water, and strong tidal flow around an exposed point near the anchoring position. Substrate in this area is largely sand with some sandstone ridges within the intertidal zone. The area is generally free of macrophytes. Multiple fish species were expected to be present at this location.

The Gemini sonar was positioned with a horizontal FoV on the vessel based pole mount described for Test 1. A single point anchor was used. Wind caused the boat to pivot on the anchor line, producing movement of the Gemini and altering the position of the FoV within the collected data files. The Gemini was also concurrently deployed with an icListenHF hydrophone attached to a weighted rope, suspended over the gunnel to approximately 1m above bottom. An underwater camera (GoPro) was also fixed to the Gemini mounting structure. Due to poor water clarity/high turbidity the video footage collected was not useful.

Similar to Test 1, the gain setting was required to be very high (>80%) to obtain images of reasonable quality. Further, the image quality of the Gemini output files was found to change considerably during the recording period. A distinct reduction in image clarity was found to correspond with the changing tidal direction, where during ebb tide image quality decreased (Figure 6). Increased turbidity during this period is suspected to be the cause.

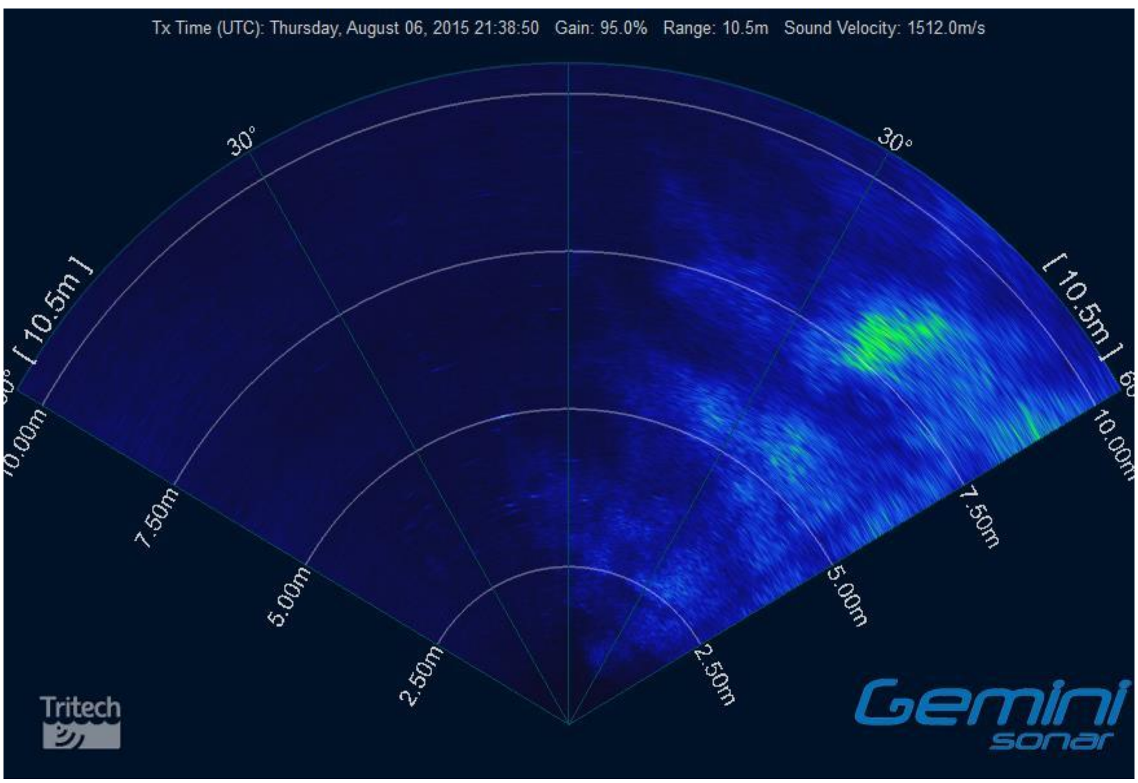



**Figure 6**. Decay in image quality during transition from ebb to flood tide at Kingsport, NS.

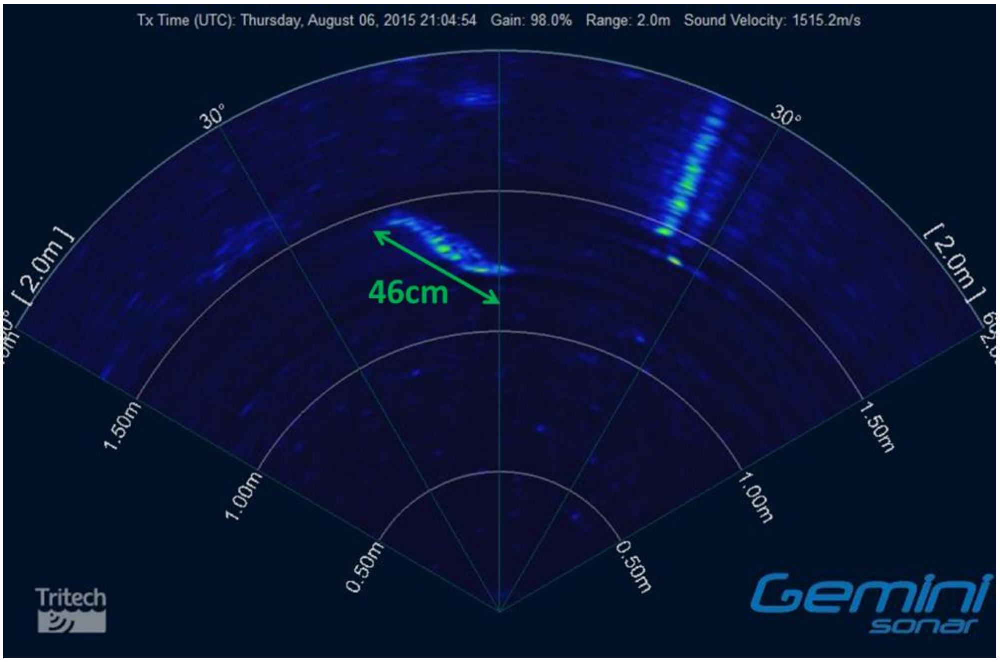



**Figure 7.** Image of a 0.45m TL American Shad (*Alosa sapidissima*) attached to fishing line and suspended in the Gemini 720i FoV on flood tide off Kingsport, NS. There was good agreement between the measured size and size estimated by the Gemini software (0.46m).

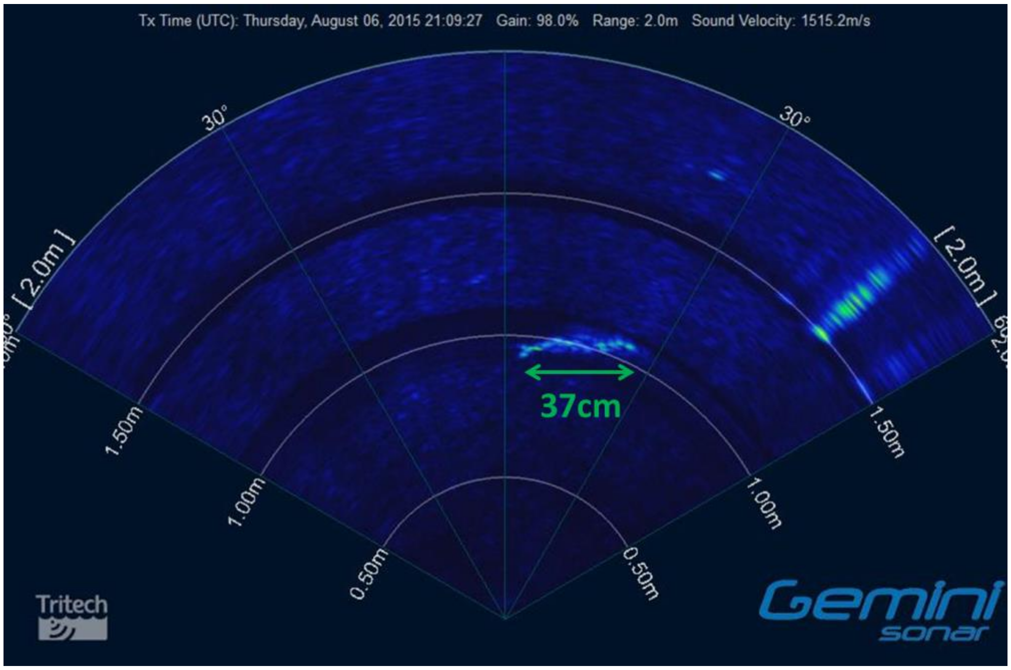



**Figure 8.** Image of a 0.36m TL Atlantic Mackerel (*Scomber scombrus*) attached to a fishing line and suspended in the Gemini 720i FoV on flood tide off Kingsport, NS. There was good agreement between the measured size (0.36m) and the size estimated by the Gemini software (0.37m).

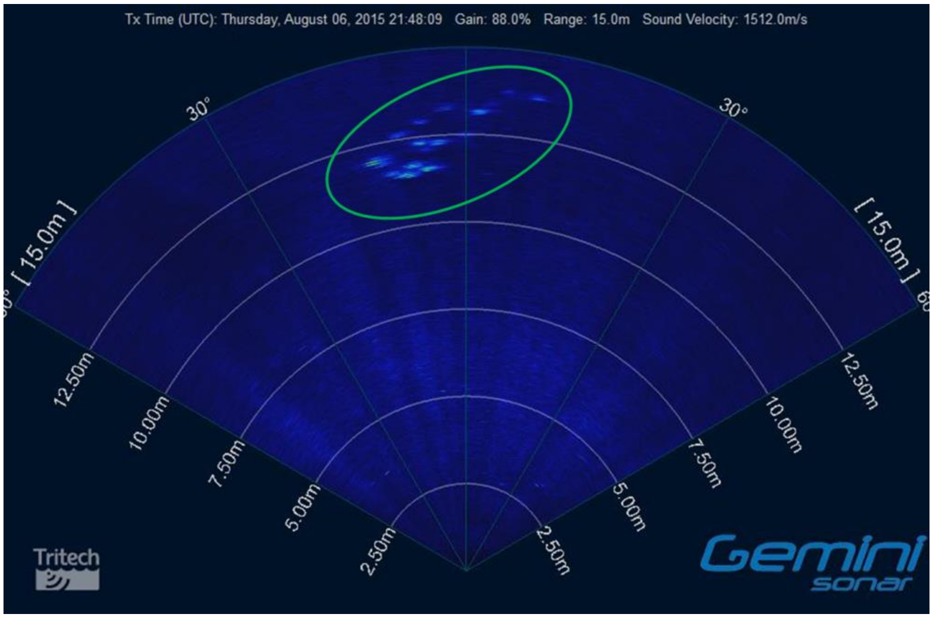



**Figure 9.** School of fish-like targets detected at Kingsport, NS during ebbing tide.

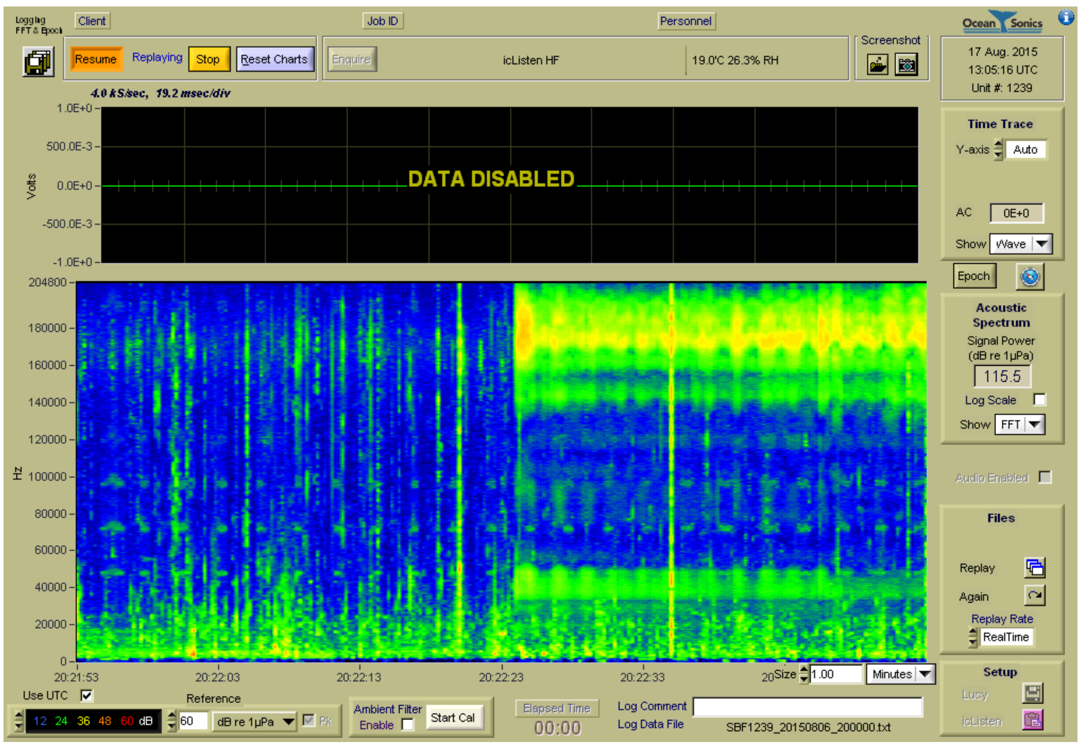



**Figure 10.** IcListenHF hydrophone recording at Kingsport, NS. Sound frequency (kHz) is indicated along the y axis with time (60 sec window) indicated along the x axis. The Gemini sonar (720kHz operational frequency) was powered on at 20:22:23. Distinct bands of frequency, not present in the ambient condition, were present and centered at 40 and 170 kHz.

## Test 3 – 2015-08-07 - Gaspereau River, NS

The Gaspereau River is a heavily impacted freshwater system which features several hydro dams over its course. Three sites were surveyed within the system, and we thank NSPI for providing site access. The water was dark and tannin - stained, and was shallow during the survey.

The three sites were surveyed with equipment (generator power source, laptop, and converter boxes) based on shore. The Gemini sonar was positioned with horizontal FOV and mounted on the galvanized steel pole as described in previous tests. The pole was held and positioned manually by a team member who waded in the shallow water, aided by another team member who assisted and tended the cabling.

The first site was a large pool below a fish ladder (45.05562, -64.39758). An attractant water chute originating from the fish ladder and water being bypassed over the dam provided areas of turbulent surface currents. Water depth in the pool was shallow (1-2m) but the pool was large in diameter (approx. 20m). During the first test a small school of juvenile Alewives were observed (Figure 11). A GoPro camera was also concurrently deployed with the sonar. Due to poor water clarity the video camera recordings were not useful.

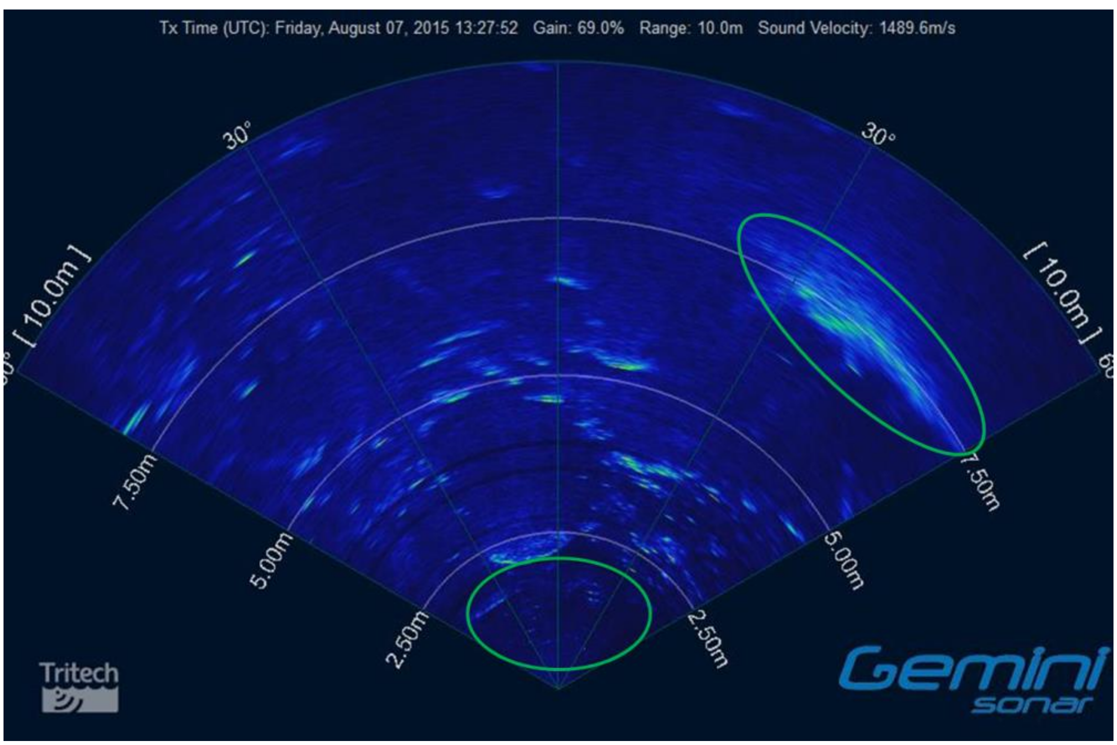



**Figure 11**. Gaspereau River Hydro Fishway. The attractant water flow of the fishway is outlined in the FoV on the right at 7.5m horizontal distance. A school of juvenile Gaspereau (*Alosa pseudoharengus*) is outlined in the near-field at ~2m.

The second area examined in the Gaspereau River system was downstream of a non-generating turbine at White Rock, NS (45.06211, -64.38049). Water levels were low as no water was being passed through the turbine. Two fish bypasses provided some turbulent flow. Macrophyte growth may have impacted image quality in some of the collected data files. The Gemini was used to view upstream into the flow produced by the bypass chutes. No fish or fish-like targets were observed at that time.

The third area examined was at Hells Gate hydro dam, downstream of the bypass channel (45.04887, -64.41254). Again, water was shallow and macrophytes were present which limited the quality of images collected. No fish or fish-like targets were observed at that time.

## Test 4 – 2015-08-13 - Halls Harbour Wharf, NS

The port of Halls Harbour is a tidally dominated site which features an active commercial fishing wharf. The harbour is dry at low tide. Substrate is composed of gravel and cobble and the harbour features a dredged channel. Wharf and wooden piling cribwork are found on both sides of harbour.

The Gemini sonar was deployed on the pole mount described previously which provided a horizontal FoV. The pole was shackled to a vertical wharf cable allowing the mount to slide freely (Figure 12). Floatation just above the Gemini sonar kept the sonar head 0.3m below the water surface, and allowed the entire mount to rise/fall with the tide. The predicted high tide time was 12:06 UTC. The Gemini was deployed concurrently with an icListenHF hydrophone. The icListen was suspended over the side of the wharf on a weighted line and positioned 1m above the seabed and 3m from the Gemini sonar.

To attract fish into the Gemini FoV, a baited mesh bag was deployed over the side of the wharf. Angling was used to capture fish present for use in detecting known fish targets. Several Pollock (*Pollachius virens*) and Longhorn Sculpin (*Myoxocephalus octodecimspinosus)* were angled (Figure 13). Captured fish were briefly positioned, using the fishing line, within the FoV of the Gemini. After each fish had been detected by the Gemini, it was measured and released.

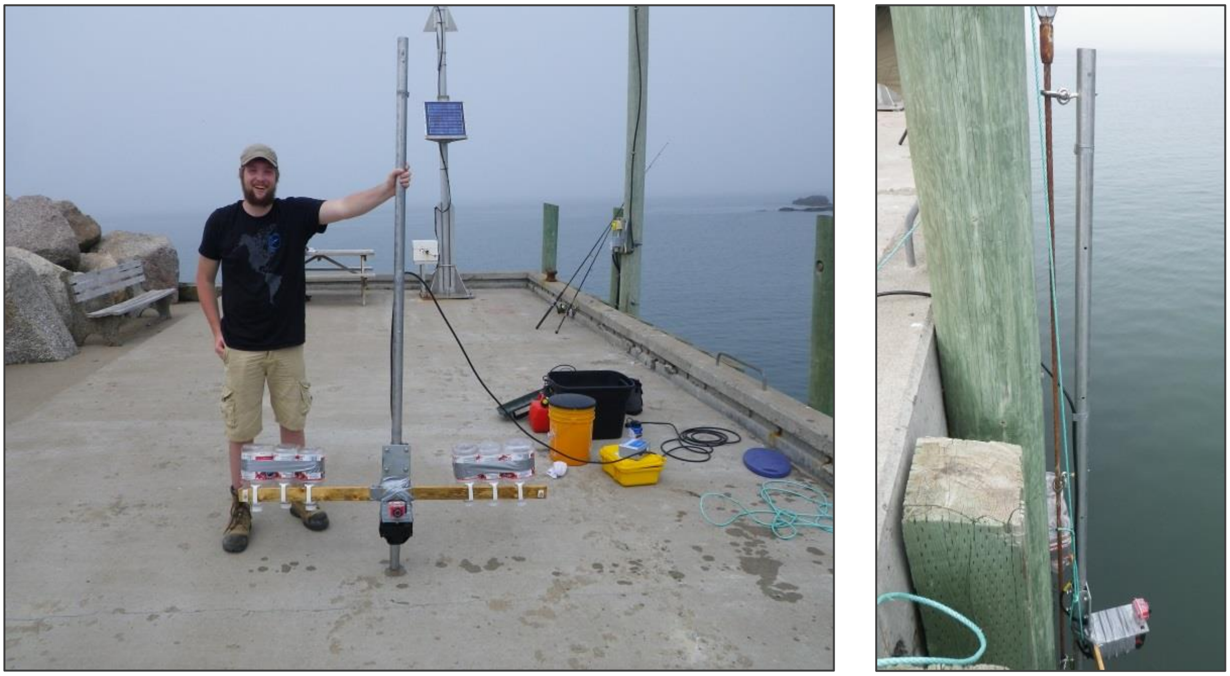


**Figure 12.** Acadia student Mike Adams holds the Gemini 720i sonar mount used at the Halls Harbour wharf (left). The mount was attached to a vertical wharf cable, and floatation permitted the Gemini to rise/fall with the tide while keeping the Gemini at a constant depth below the surface (right).

**Figure 13**. Fish angled from the Halls Harbour wharf test site. The photo on the left shows a 0.22m Pollock and the right a 0.30m Longhorn Sculpin.

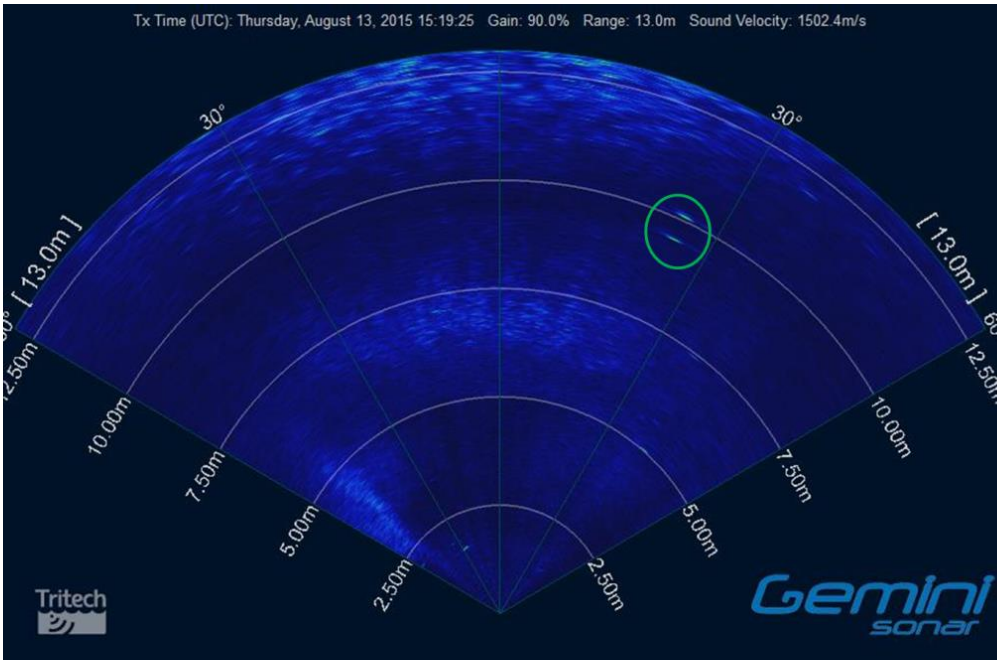



**Figure 14**. Two fish-like targets moving into Halls Harbour at mid-flood tide, at a horizontal distance of 10m, along the eastern edge of the channel.

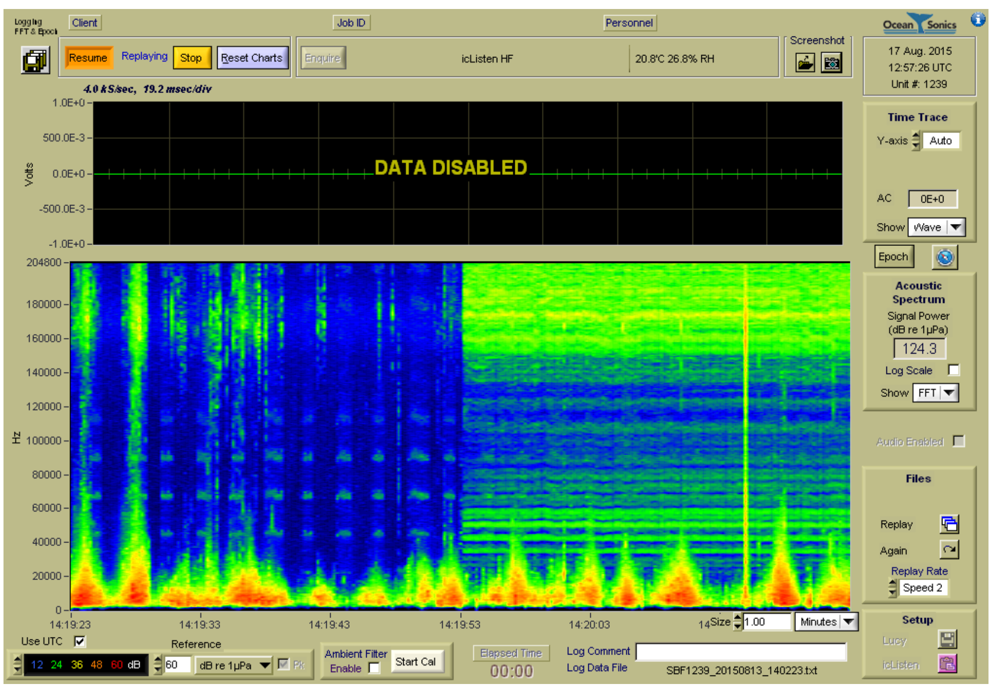



**Figure 15.** IcListenHF hydrophone recording at Halls Harbour, NS. Sound frequency (kHz) is indicated along the y axis with time (60 sec window) indicated along the x axis. The Gemini sonar (720kHz operational frequency) was powered on at 14:19:53. Distinct bands of frequency, not present in the ambient condition, were present and again centered at 40 and 170 kHz.

## Test 5 – 2015-08-20 - Striped Bass Fish Farm, Upper North River, NS

The North River Fish Farm, near Truro Nova Scotia, is an aquaculture facility which raises Striped Bass (*Morone saxatilis*) and Rainbow Trout (*Oncorhynchus mykiss*) in several terraced, uncovered, man-made ponds. Pond water was highly colored and algal-laden. Visibility was poor, rendering the concurrently collected underwater video footage of limited use.

Striped Bass were concentrated in netted floating enclosures (Figure 16) within the pond and provided an ideal opportunity to examine schooling/milling and feeding behavior at close range of a known target. Striped Bass in the enclosed pen were approximately 2.5kg with a few larger fish up to 6kg. There were about 200 bass (50-80 cm) in the pond selected for this test.

The large body size of the Striped Bass held at the fish farm allowed easy detection with the sonar. Individual fish could be discerned, even when the school was densely compacted (Figure 17). Striped Bass were fed food pellets at various locations within the pond allowing for detection of targets exhibiting behavior such as darting and changes in direction (Figure 18).


**Figure 16**. View of the netted pen and boardwalk structure on pond #2 at North River Fish Farms (Left). Preliminary positioning of the Gemini sonar on the pole mount (Right).

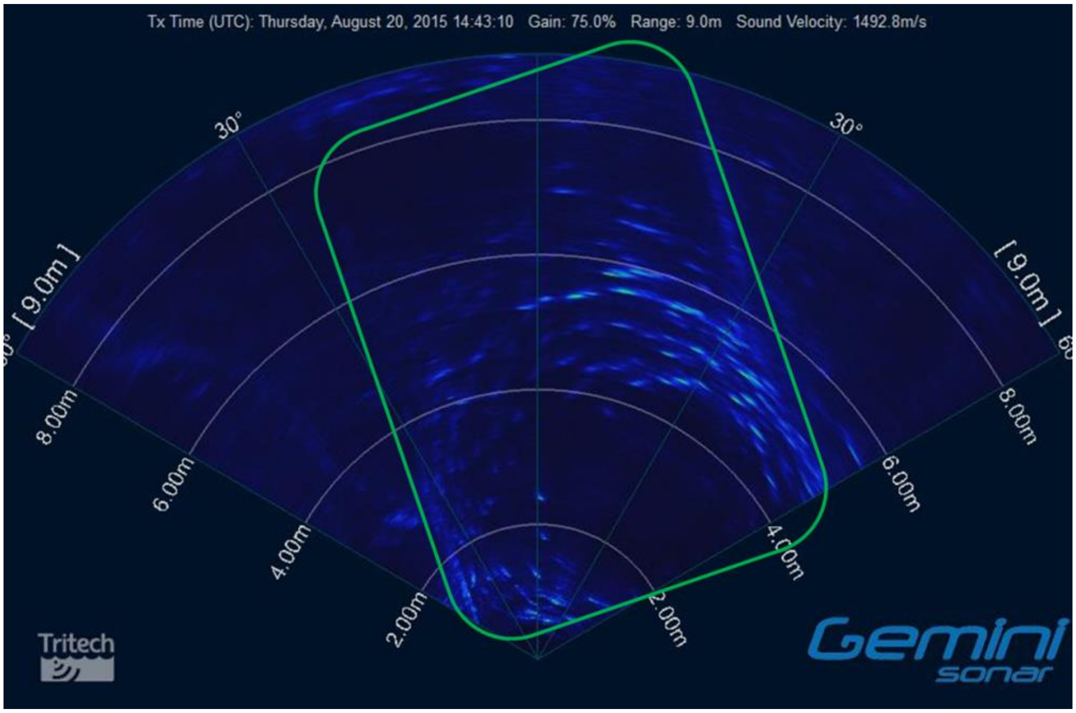



**Figure 17**. Gemini screenshot of Striped Bass (*Morone saxatilis*) schooling/milling within the netted impoundment of the North River Fish Farm. The green rectangle outlines the approximate dimensions of the netted impoundment.

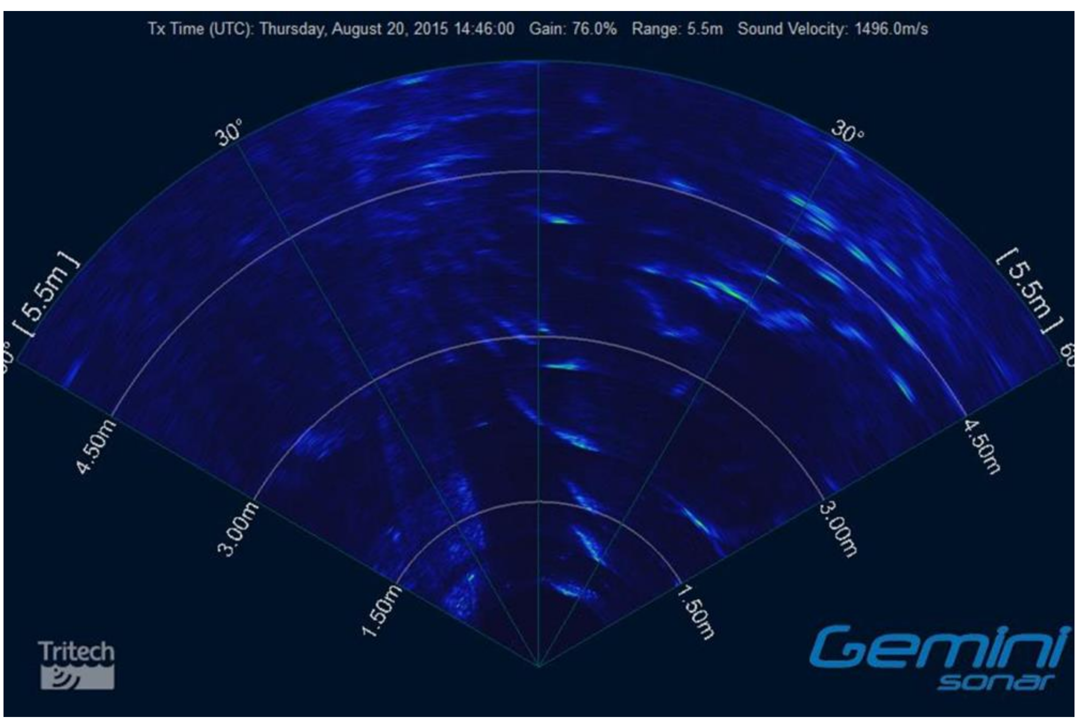



**Figure 18**. Gemini screenshot of Striped Bass (*Morone saxatilis*) approaching food pellets tossed into the netted impoundment of the North River Fish Farm.

## Test 6 – 2015-08-27 - Minas Channel Drift

Tide: Baxter's Harbour 13:34 UTC, 10.7m. Diligent River: 10:51 UTC, 11.5m

Given the marine operations in the FORCE test site in August 2015, instrument drift tests were conducted in Minas Channel using a 45ft fishing vessel, chartered from Halls Harbour.

Drift speed peaked at 2.1knots (1.08m/s), and therefore we did not reach surface flow speeds which would be expected in Minas Passage. While not tested, we assume both turbulence and turbidity within Minas Channel are lower than in Minas Passage.

The Gemini sonar was lowered on a pole mount (Figure 19) to a depth of 3m below the surface. By positioning the FoV in a downwards orientation it was possible to determine the approximate size of fish-like targets as well as depth of those targets within the column. The 20$^{o}$ vertical beam width generally permitted only quick visuals of targets, particularly those at shallower depths in closer proximity to the sonar. Behavioral observations were not possible with such brief encounter periods.

An IcListenHF hydrophone was deployed concurrently with the Gemini sonar. The hydrophone was attached to spar buoy drifter fitted with an attached GPS. The drifter buoy was allowed to float away from the vessel, but was connected to the vessel via a fishing rod and reel (300m of 65lb test braided line). The hydrophone was position approximately 3-4m below surface.

**Figure 19**. Pole mount clamped to the gunnel of the charter vessel. The Gemini 720i was positioned in a vertical viewing orientation during the Minas Passage drift test.

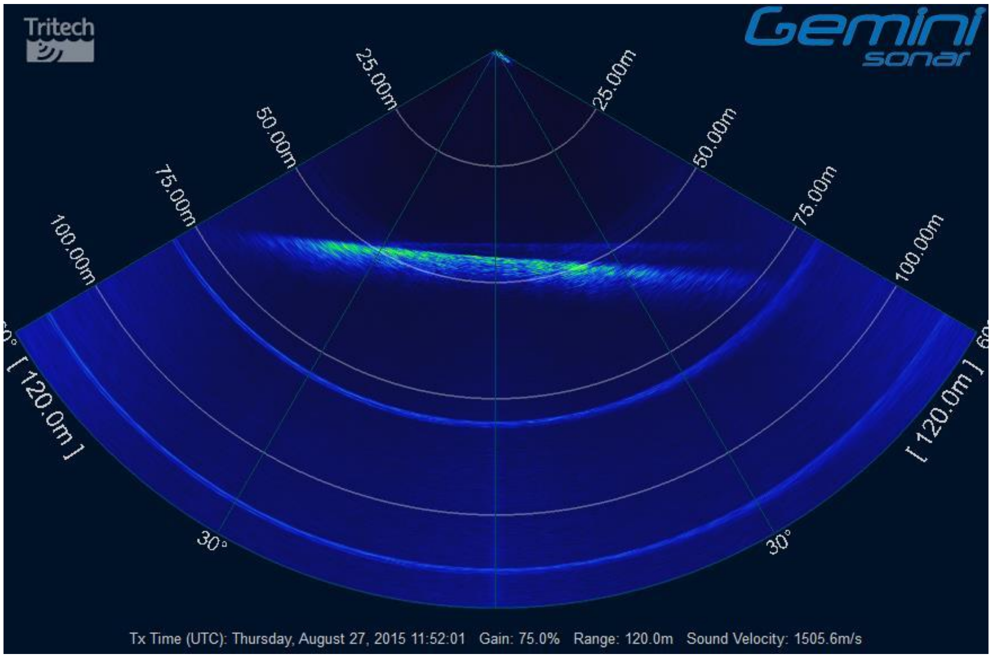



**Figure 20**. Horizontal line indicates the return signal from the seabed (~50m) during the Minas Channel drift test. Bands arching around the FoV indicate interfering pulses from the charter vessel's depth sounder at the start of the drift.

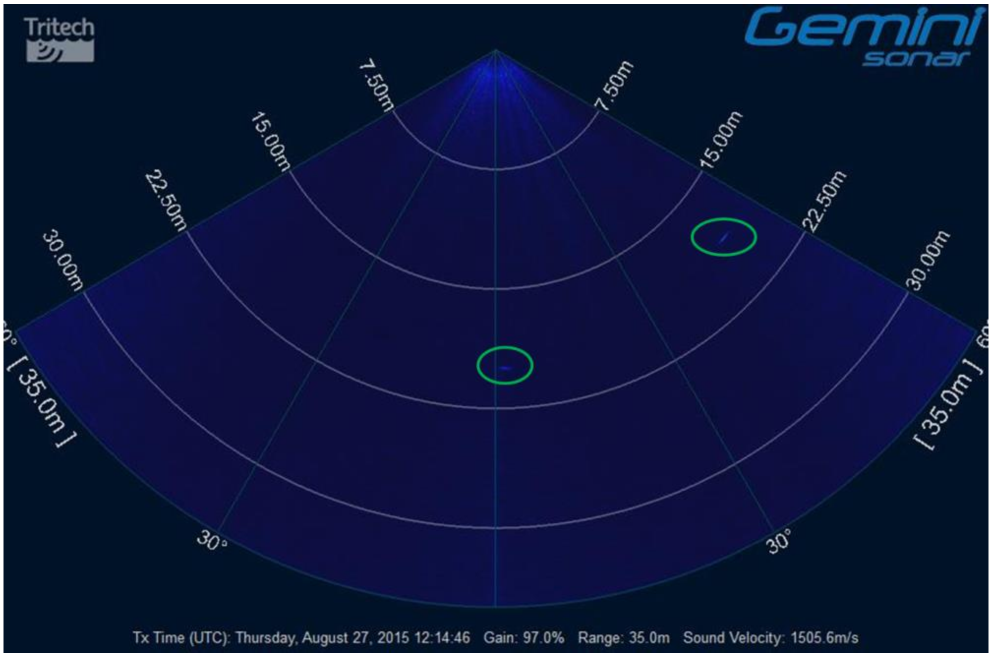



**Figure 21.** A frozen 45cm American Shad, lowered with a 2kg lead weight on a monofilament fishing line, is highlighted in the central portion of the FoV at 20m depth. Highlighted at the right side, at 18m depth, is a fish-like target.

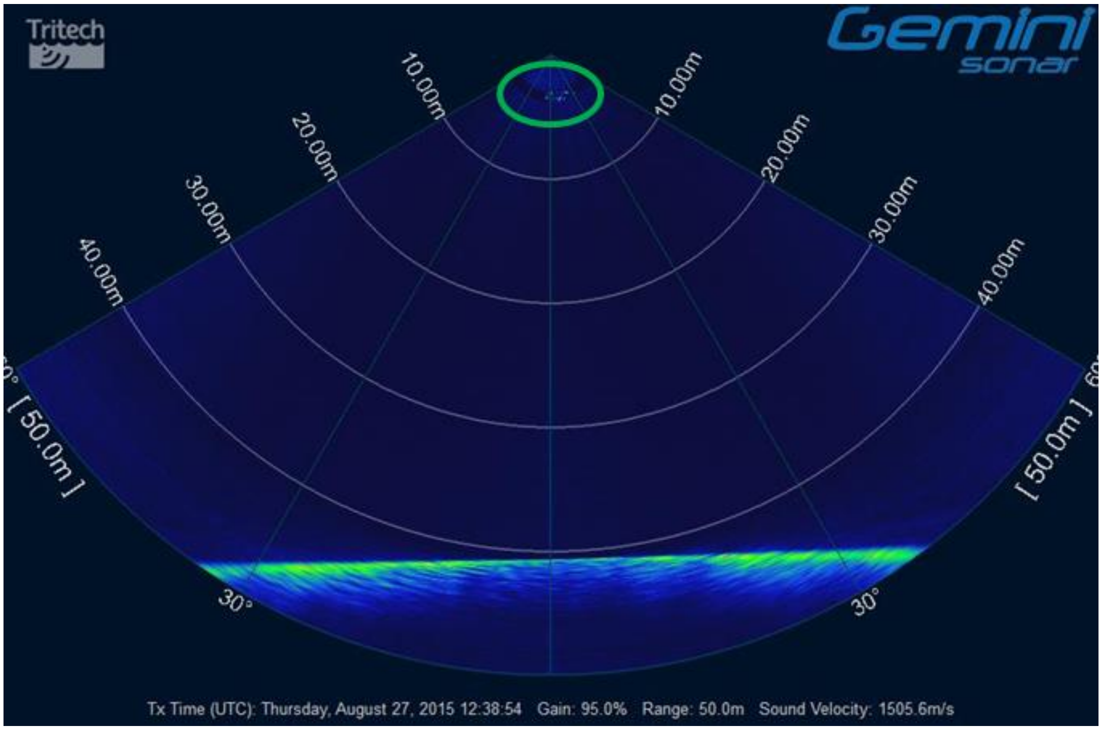



**Figure 22.** The green oval indicates a school of fish-like targets detected a few meters below the Gemini. Individual targets are discernable and rapid directional changes can be seen in the data file.

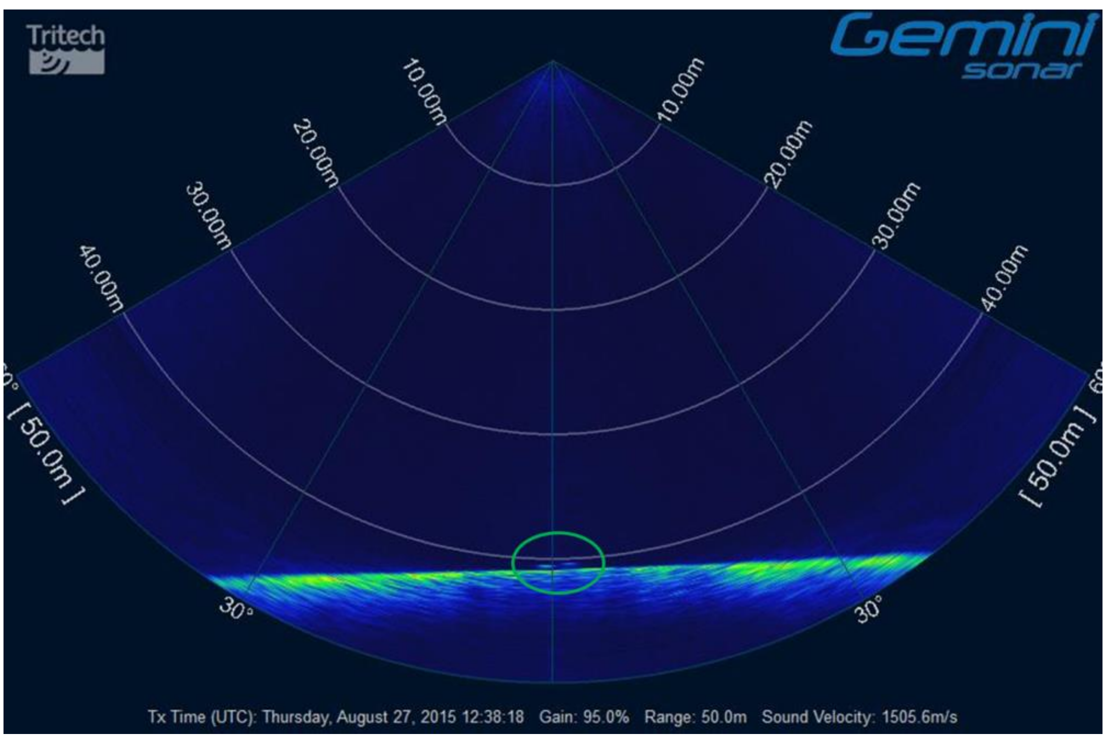



**Figure 23.** The green oval indicates 2 large fish-like targets detected near the bottom at 40m depth.

# PART B: Spectral Analyses of Hydrophone Data with a Co-located Sonar

## B1. Halls Harbour: 13 August 2015

The Gemini 720i 300M multibeam sonar (Tritech, UK) was deployed concurrently with an icListenHF (OceanSonics Ltd) hydrophone at a wharf in Halls Harbour on 13 August 2015 to resolve any acoustic noise due to the operation of the gas generator from any acoustic noise due to the operation of the Gemini.

Figure 24 shows the spectrogram that was recorded by the icListenHF-1239 over a 20-minute period. From 14:10-14:17 GMT the sound level was measured with both the Generator and the Gemini powered off. Averaging the spectrum over this period gives the black line in Figure 25. From 14:17-14:20 GMT the Generator was running with the Gemini off. The Generator seems to have little influence upon sound level (magenta line in Figure 25). Subsequently the Gemini was also powered on and this substantially increased sound levels, particularly for the higher frequencies (above 150 kHz).

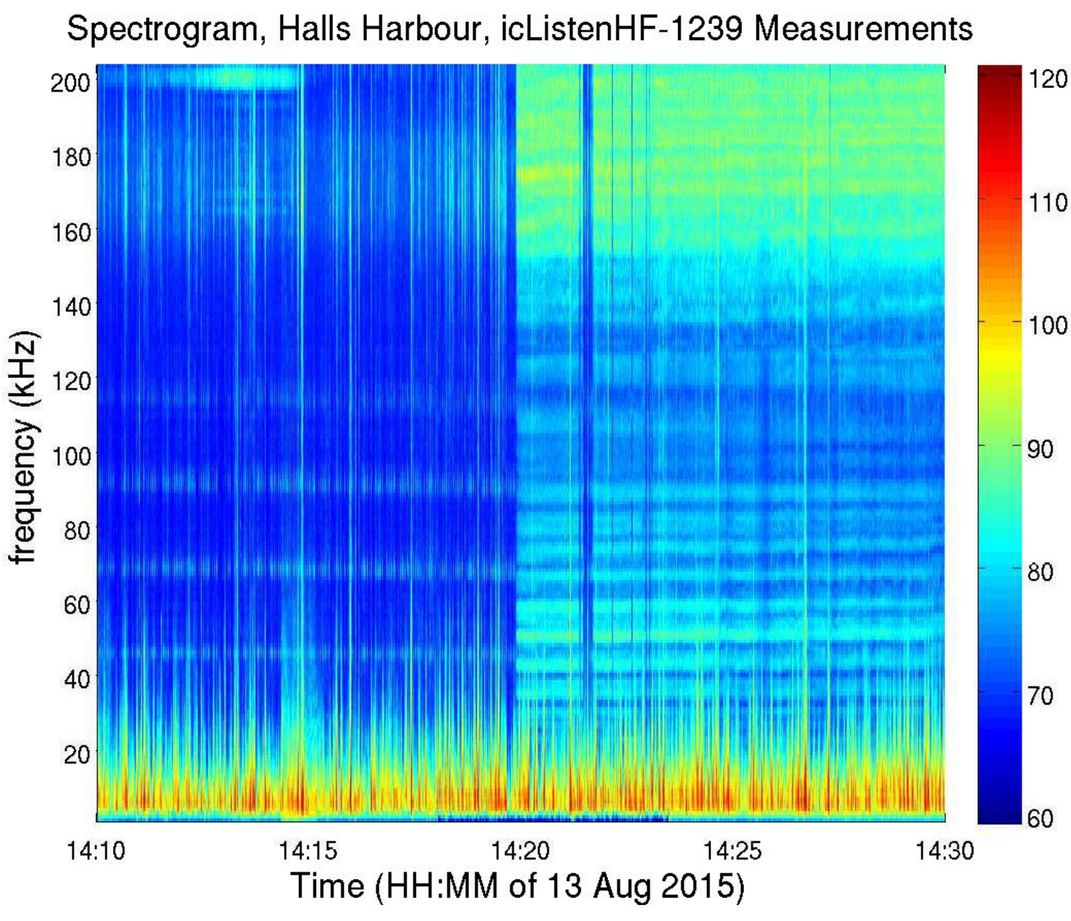



**Figure 24.** Measurements made at Halls Harbour using the icListenHF-1239. Power spectral density (PSD) computed internally by the icListen software were averaged over 1 second intervals and plotted as a function of time and frequency above. The colour bar shows a scale for PSD in dB re $\mu$Pa/Hz.

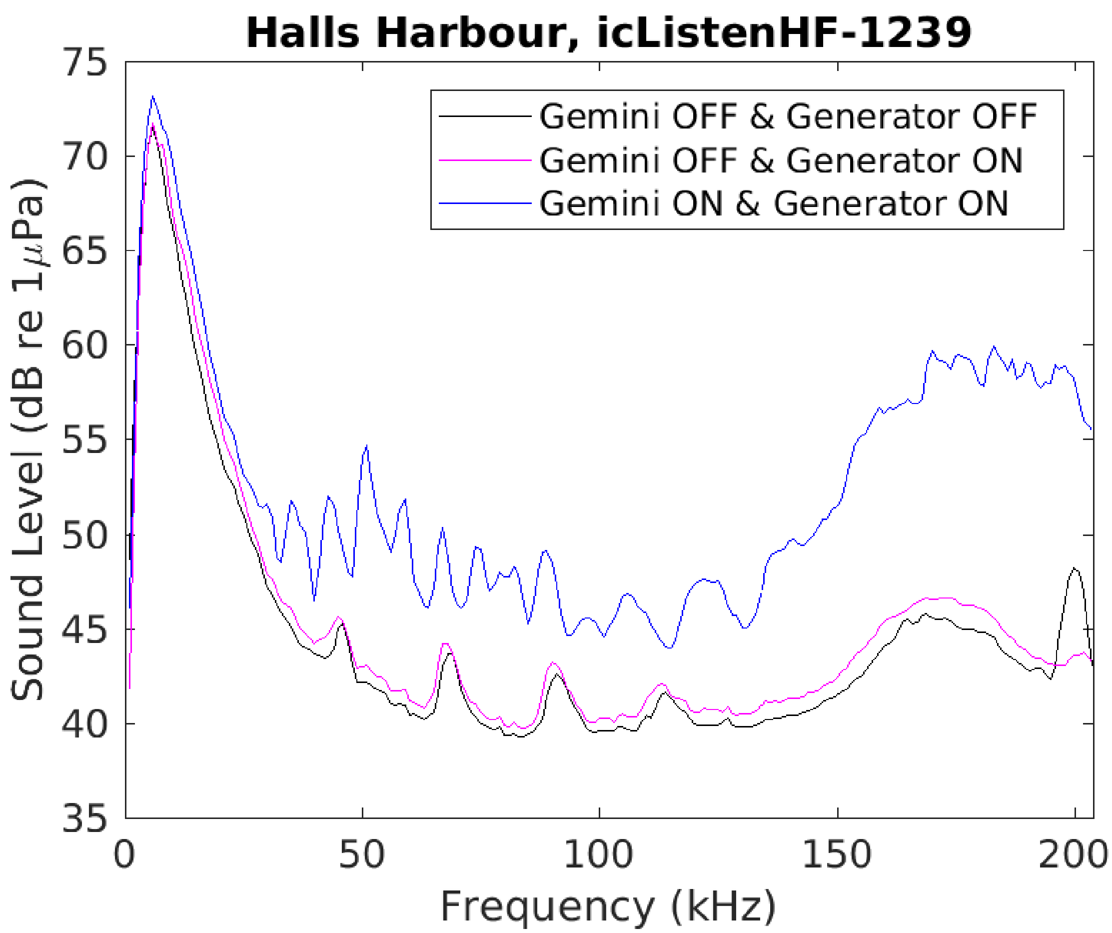



**Figure 25.** Measurements made at Halls Harbour using the icListenHF-1239. Power spectral density (PSD) is plotted as a function of frequency for three periods. The black line is when only the icListenHF-1239 is operating. The magenta line is for a time period when the Generator was also operating, and the blue line is when both the Generator and Gemini 720i were operating.

Figure 26 shows the spectrogram measured by the icListenHF-1211 at Halls Harbour later in the day, from 17:10 to 17:30 GMT. The low frequency signal on-and-around 17:25 GMT is caused by a boat. Again, we can compare a period before 17:18 GMT when both the Gemini and Generator were operating and compare it with a period subsequent to 17:19 GMT but before the boat traffic. Figure 27 shows, again, that the Gemini substantially increases sound levels over a broad spectral range but particularly so for frequencies above 140 kHz. Interestingly, artefact spikes are not evident for this time period.

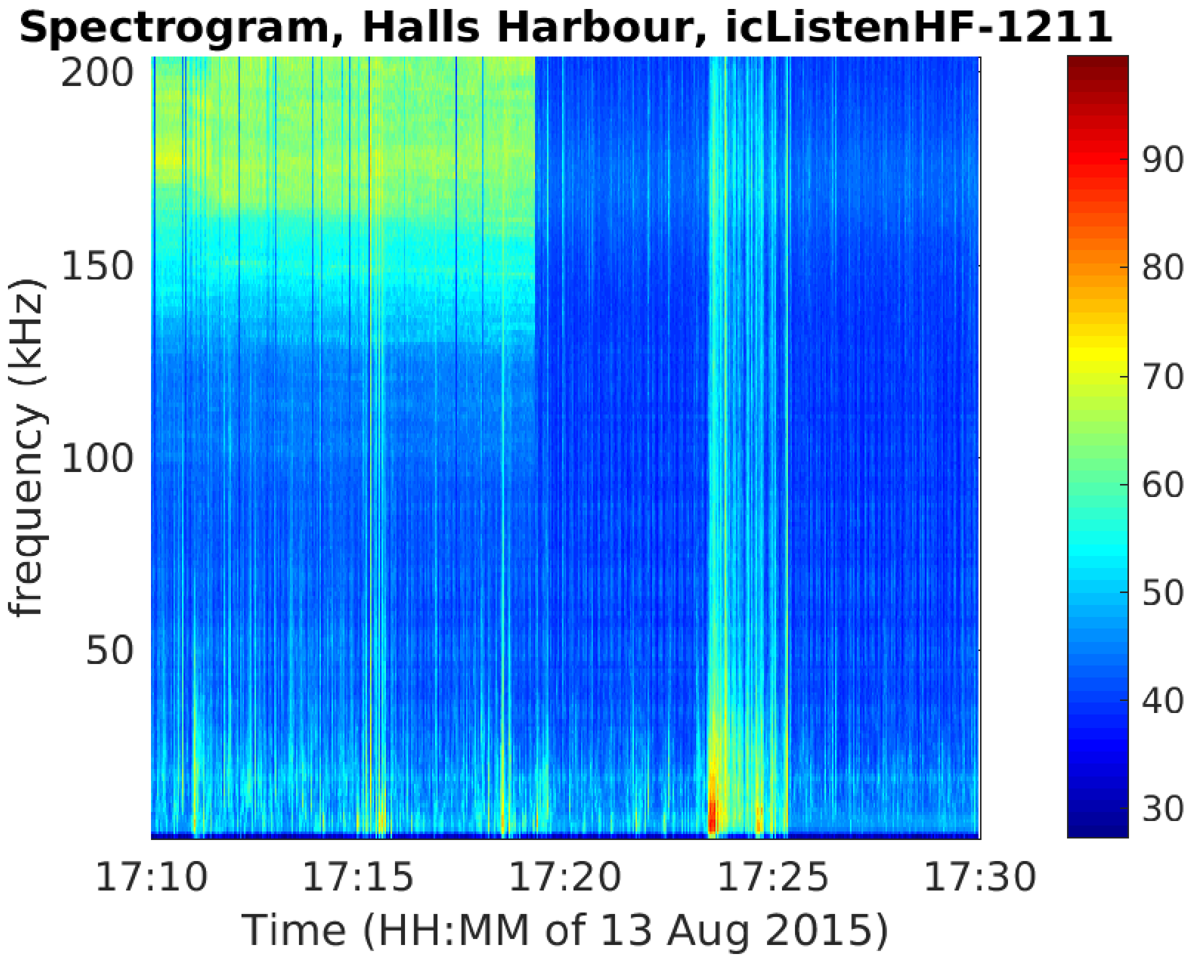



**Figure 26**. Measurements made at Halls Harbour using the icListeenHF-1211. Power spectral density (PSD) computed internally by the icListen software were averaged over 1 second intervals and plotted as a function of time and frequency above. The colour bar shows a scale for PSD in dB re $\mu$Pa/Hz.

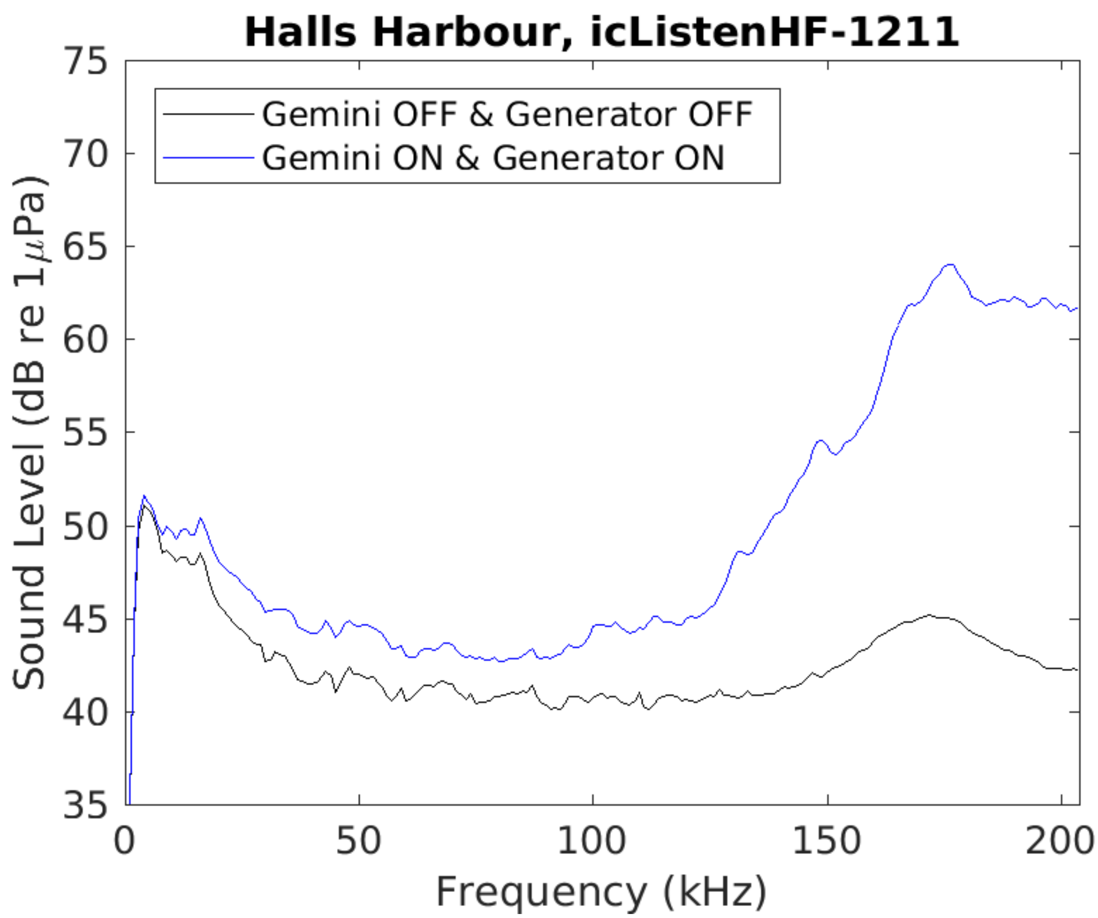



**Figure 27**. Measurements made at Halls Harbour using the icListenHF-1211. Power spectral density (PSD) is plotted as a function of frequency for two periods. The black line is when only the Generator and Gemini are both turned off. The blue line is when both the Generator and Gemini 720i are operating.

## B2. Fish Farm:  20 August 2015

Measurements were also made in a small pond at a Truro Fish Farm. These measurements afforded an opportunity to compare the icListenHF-1239 with the icListenHF-1211. These hydrophones are of the same type, just different instrument numbers. The two hydrophones were deployed on the same tether, one immediately above the other, in close proximity to the Gemini 720i. The Generator was located on shore so its vibrations would be unlikely to transmit into the fish pond.

Power Spectral Density (PSD) from the icListenHFs were averaged over a 6-minute period during which the Gemini (and Generator) were operating and over a 10-minute period when both the Gemini and Generator were turned off. There was a marked difference between the PSD obtained in those two periods (Figure 28).

Results from the icListenHF-1239 showed artifact spikes which are not present in the icListenHF-1211 measurements. These relatively small spikes in the 1239 measurements do not detract from the basic result. Both hydrophones clearly show that the Gemini substantially increases the sound level over a broad range of frequencies, particularly for frequencies above 140 kHz. Indeed, the result is very similar to that inferred from measurements at Halls Harbour (Figure 25). The sound increase is more marked in the fish pond than for measurements made in Halls Harbour. This is as expected, given the proximity of the Gemini to the icListenHFs and the small dimensions of the fish pond.

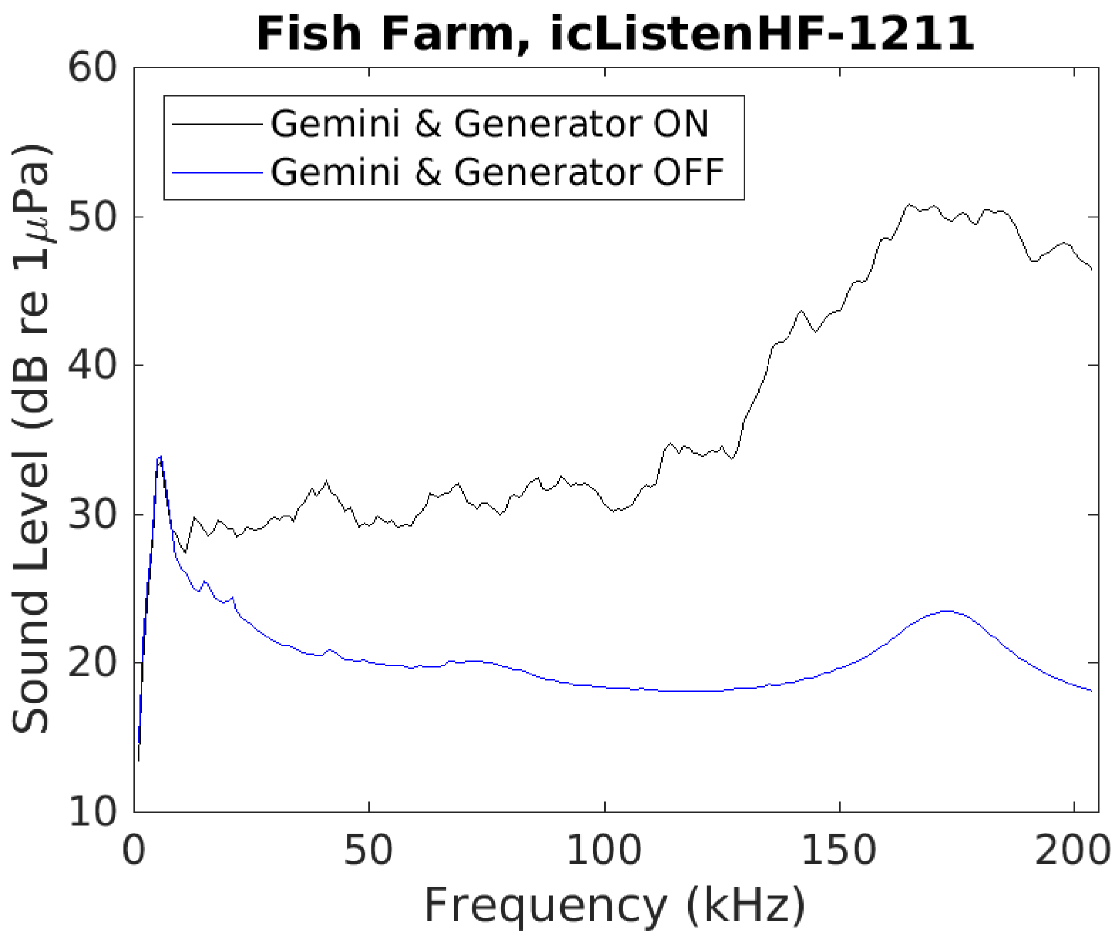



**Figure 28**. Measurements made at the North River Fish Farm using the the icListenHF-1211. The blue line is for a period of time when only the icListenHF was operating. The black line shows how the sound level changes when the Gemini 720i and the generator are also operating.

## B3. Minas Channel: 8 September 2015

Measurements were made in Minas Channel from a 45 ft fishing vessel on 8 September 2015. The Gemini 720i was deployed at the starboard side of the boat looking downwards and 10 degrees towards starboard. Times are recorded relative to GMT.

A petrol-driven generator was used to supply power for the Gemini. The boat's engine was turned off so the boat drifted roughly side on to the wind. The icListenHF-1211 was deployed about 3-4 m below a spar buoy. A GPS was attached to the spar buoy and the spar buoy was tethered to the boat using a fishing line and rod. The length of fishing line was about 300 m.

Figure 29 shows the power spectra density (PSD) as a function of time. The Generator was on and the Gemini was deployed throughout the period plotted (except, perhaps, during the last minute). The boat's echo sounder was turned on at the beginning of the deployment and this is evident as a strong signal at a frequency at about 50 kHz. The second and third harmonics of the echo sounder are clearly measured, and the fourth harmonic is also resolvable at the high-frequency detection limit of the icListenHF. Note, at this time, the hydrophone was relatively close to the boat.

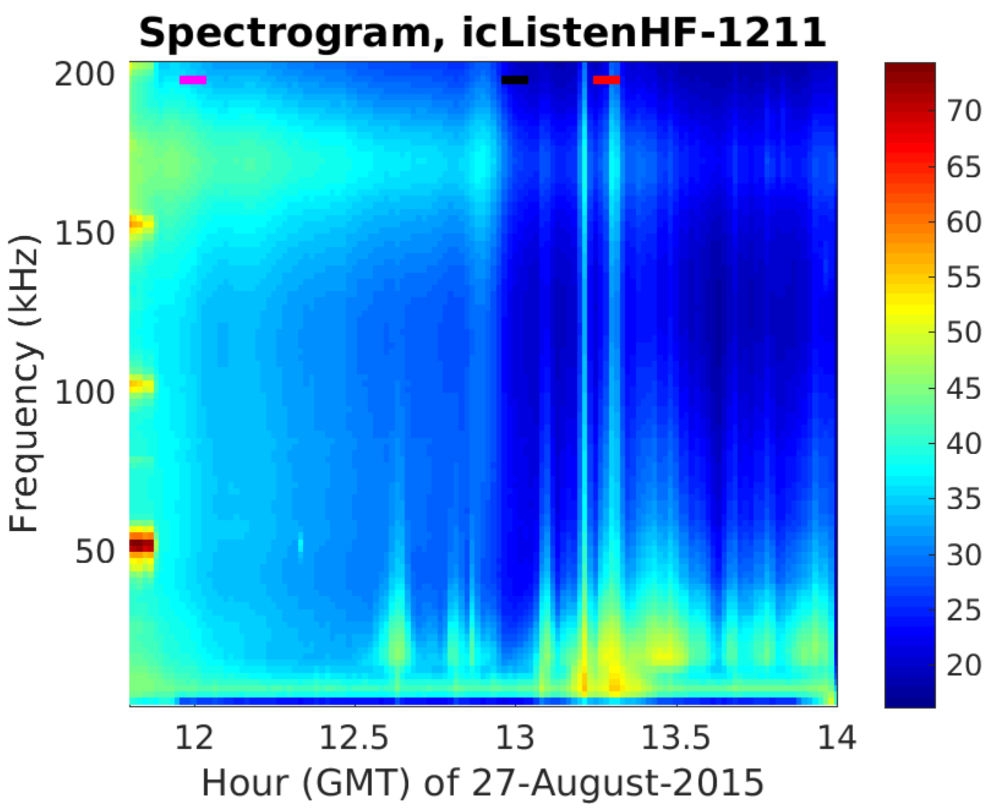



**Figure 29**. Measurements made in Minas Channel using the icListenHF-1211 hydrophone. Power spectral density (PSD) computed internally by the icListenHF software were averaged over 1 second intervals and plotted as a function of time and frequency above. The colour bar shows a scale for PSD in dB re $\mu$Pa/Hz.

The vessel's echosounder was turned off and the icListenHF-1211 slowly drifted away from the boat, until about 300 m of fishing line had been played out. There is a spectral peak at about 170 kHz which largely reflects hydrophone sensitivity being higher near 170 kHz. The frequency dependence of the PSD is examined by averaging over a 5-minute interval (1158-1202 hours) shortly after the echosounder was turned off. At this time the boat's GPS indicated that the boat was drifting at about 1.08 m/s. This time interval is indicated by a magenta line in Figure 29. The averaged PSD is plotted in Figure 30.

A 5-minute quiet period (1258-1302 hours) is indicated by the black line in Figure 29 and the PSD is plotted in black in Figure 30. At this time the wind dropped and the spar buoy (which had been astern and starboard) moved to astern and port. The Gemini was transmitting towards starboard, so the quite period also corresponds with the icListenHF-1239 being located behind the direction that the Gemini was "looking". Also, the current speed was reduced at this time, being 0.67 m/s at 1310 hours.

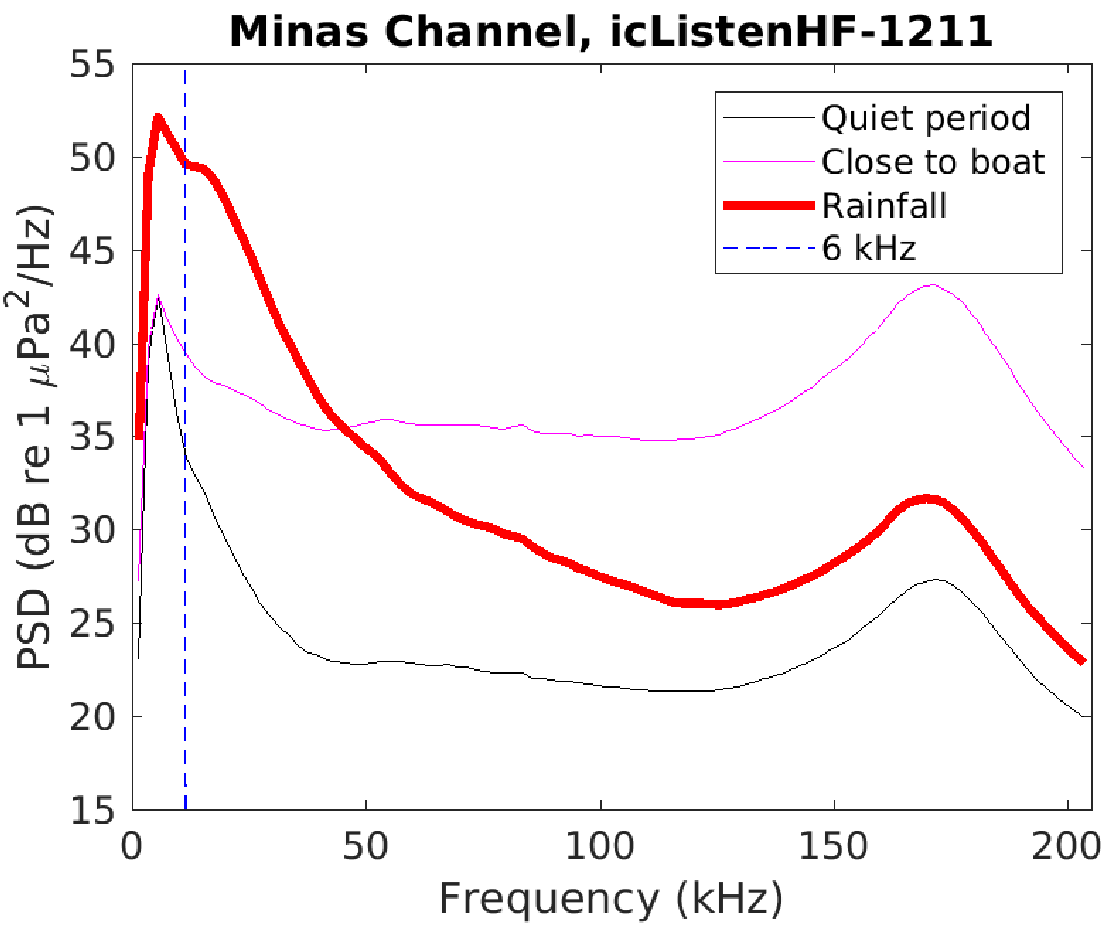



**Figure 30.** PSD averaged over 5-minute intervals. Magenta shows the PSD shortly after deployment when the icListenHF-1211 was still relatively close to the boat. Black shows the PSD during a quiet period when wind dropped. Red shows the PSD during a period with heavy rain.

Figure 31 shows how the PSD changes at 5-minute intervals as the spar buoy drifted astern and starboard: starting with the blue line when the icListenHF-1239 is closest to the boat until the red line when the icListenHF-1239 is further from the boat. When the wind dropped and the icListenHF-1239 moved astern and to the port, the PSD showed quiet conditions (black line in Figure 31). These measurements are consistent with the Gemini contributing to all but the low-frequency part of the spectrum measured by the icListenHF-1239.

Heavy rain was observed during the 5-minute period (1315-1319 hours) as indicated by the red line in Figure 29 and the averaged PSD for this period is plotted in red in Figure 30. Rainfall clearly increases the sound amplitude, particularly at lower frequencies.

The Gemini has a carrier wave frequency of 720 kHz which is much higher that can be measured by the icListenHF. Nevertheless, Figures 30 and 31 indicate that the Gemini emits energy at acoustic frequencies detected by the icListenHF.

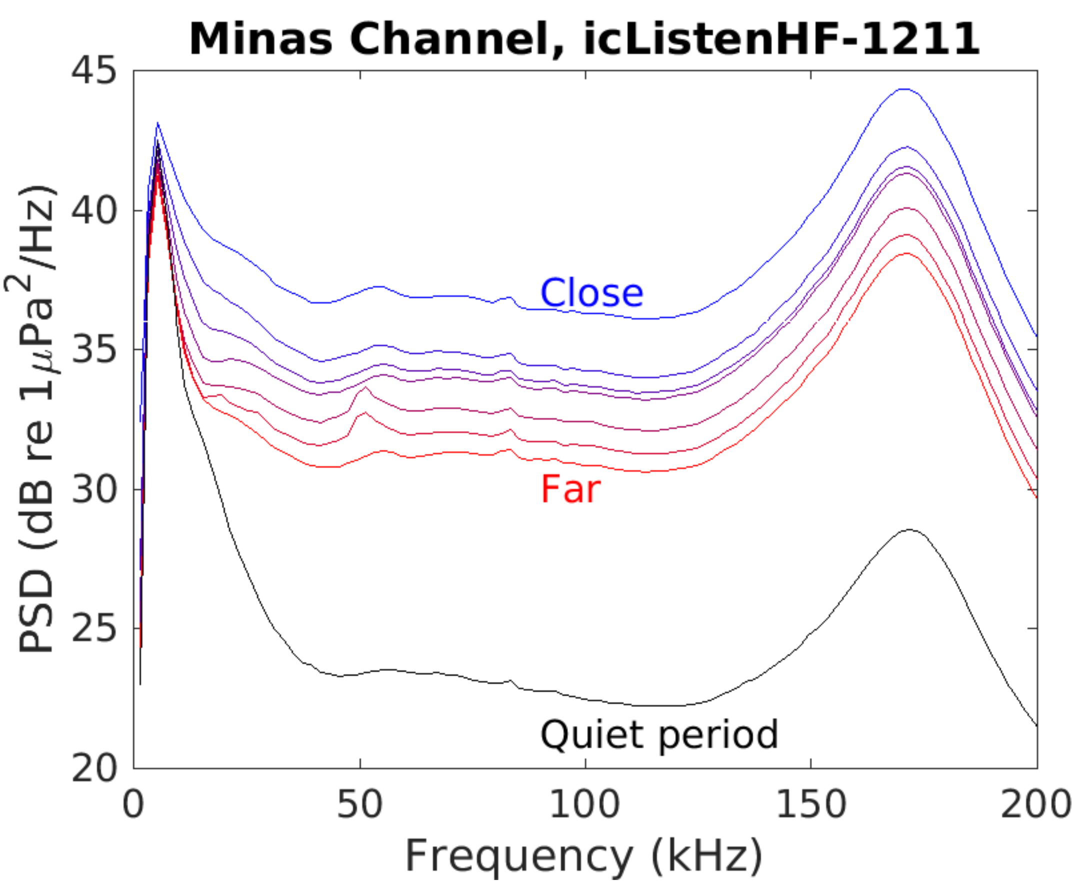



**Figure 31**. PSD at 5-minute intervals as the icListenHF-1211 drifts away from the boat (blue to red). When the wind dropped (black), the position of the drifter had shifted so that it was behind the direction of the acoustic signal from the Gemini 720i.

Notice the PSD drops dramatically for frequencies higher than 6 kHz (indicated by a dashed blue line in Figure 30). This is an artifact of the spectra being computed from short segments of data (FFT on a sample of 1024 measurements). Also note that the spectra drops off steeply near the upper frequency limit of the instrument. This is probably due to physical filtering by the pressure sensor — given that similar roll-off was observed in the Minas Passage measurements.

Figure 32 shows spectra that were computed from longer segments of waveform measurements and averaged over each of the 5-minute intervals. Now the low frequency response is not severely compromised by the window width used for the spectral calculation. As expected, the spectral maximum is at the frequency of wind waves (about 0.3-0.4 Hz). Rainfall increases sound levels in a broad band centered on 10 kHz but seeming to extend from about 1 kHz to 100 kHz. Measurements made close to the boat indicates the Gemini is contributing to the spectrum of frequencies above 10 kHz.

The Minas Channel measurements all indicated a small increase in sound level at around 170 kHz. Figure 2 in Porskamp (2015) shows that the receiver sensitivity of the icListenHF has 5 dB peak at about 170 kHz.

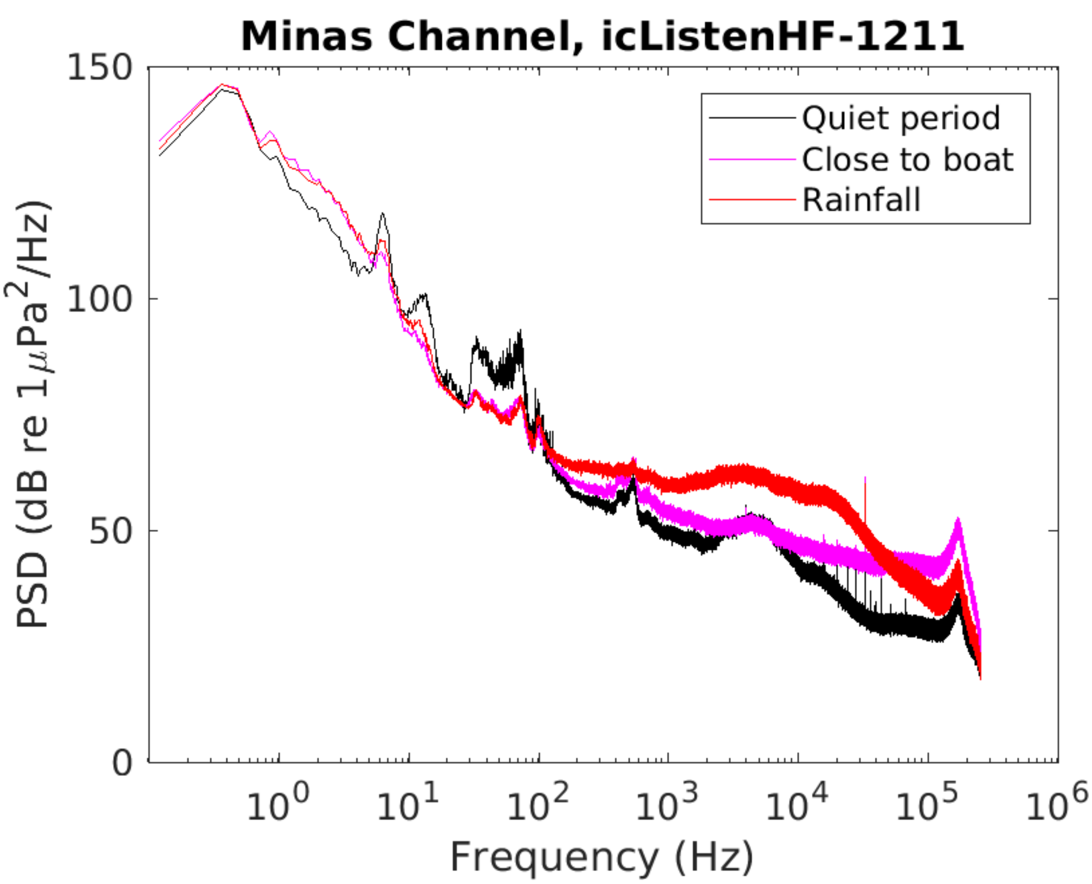



**Figure 32**. PSD obtained from the 5-minute data intervals. In this case the FFT were computed from 7.5-second segments of the waveform measurements.

## Summary Points

1. All field deployments of the Gemini 720i sonar, which included lake, river, fish pond (aquaculture) and Bay of Fundy tidal environments, provided sonar images of fish and/or fish-like targets.
2. At most sites the gain setting needed to be set very high (>80%) to obtain quality target returns.
3. Any change made to either the gain or distance settings of the Gemini 720i sonar while in recording mode temporarily disabled the user's ability to detect targets. In surveys over variable bathymetry or heterogeneous substrate this could be problematic as the range and/or gain may need to be changed regularly. This problem has been addressed in Tritech's newer Gemini sonar technologies.
4. Targets were detected by the Gemini sonar at various depths throughout the water column using both horizontal and vertical mounting configurations.
    a. Vertically orientated, the Gemini provided information on targets in the x (horizontal) and z (vertical/depth) axes but limited the time that targets remained in the FoV.
    b. Horizontally orientated, the Gemini provided information in the x and y axes with targets remaining in the FoV for longer intervals of time but without resolving the z (vertical/depth) axis.
5. Schools of small fish, most likely juvenile Alewife (<0.1m), were resolved at close range (<2.5m) at the Gaspereau River hydro site. Other small schooling fish were resolved at both Kingsport and in Minas Channel at close range (<10m).
6. Large schooling fish, in this case Striped Bass (~0.5-0.8m), were resolved easily at close range (<6m) at the North River Fish Farm aquaculture site.
7. For targets >0.2m, size determination is accurate at short to mid-range (<20m), as evidenced by trials with frozen American Shad and Atlantic Mackerel.  Results also presented in Jepp (2017).
8. Based on these preliminary tests, sonar identification of fish to species level was not be possible.  Co-located cameras, in clear waters, would be required to confidently identify fish to species level.
9. Detection of individual small targets (~0.1m) cannot be resolved by the Gemini 720i multibeam sonar.
10. Turbulence imparted by tidal flows or turbulent wakes was noted to degrade the Gemini image quality, and thus target detection performance.
11. While water clarity did not seem to degrade the Gemini image quality, a co-deployed optical camera was unable to provide useful visual data.
12. Heavy rainfall increases sound levels in a broad band centred at 10 kHz but extending from about 1 kHz to 100 kHz.
13. Vessel based survey methods, using a horizontally mounted, mobile sonar head limited the stability of the background reflectance surface and in many cases produced images with a constantly moving seafloor which impacts target detection/identification.
14. All measurements made with the icListenHF hydrophone indicate that the Gemini sonar increased the sound level over a wide range of frequencies, particularly at frequencies above 140 kHz, much lower than the Gemini's reported carrier wave frequency of 720 kHz. Such sound generation may be problematic if it interferes with marine life. It could also interfere with other acoustic devices deployed with or in the vicinity of an instream tidal turbine.

## Considerations and Recommendations for Effects Monitoring

1. Vertical positioning of the Gemini 720i sonar (20$^o$ beam width x 120$^o$ scanning sector) provides limited viewing time of targets when within the FoV, particularly when targets are moving within high velocity currents. For gravity base turbine infrastructure, a horizontal FoV is recommended. This would permit longer temporal records of individual targets as they approach the turbine infrastructure.
2. Gain and range settings for any imaging sonar need to be optimized to align with the monitoring objectives (i.e. near-field vs far-field) and deployment type (i.e. vessel survey vs stationary platform). Since the field tests in 2015, Tritech has advanced its Gemini sonar hardware and software. Recent and ongoing improvements have been addressing detection and tracking capabilities.
3. Mounting and positioning of the Gemini sonar should involve consideration of the sources and degree of turbulence that could impact the acoustic image quality.
4. Deployment of two (possibly stacked), integrated sonar units would enable useful additional information for use in marine life behavioral studies.
5. The Gemini 720i sonar emits sounds at frequencies that harbour porpoise use in echolocation. This may have implications for passive acoustic monitoring of porpoise presence and behaviour.
6. We advise measuring the directionality and range-dependence of signals emitted from any sonar installed. This will enable sensors to be mounted so as to minimize the interaction of the sonar(s) with any hydrophones installed on the same infrastructure.
7. The icListenHF hydrophone is sensitive to rainfall. It clearly increases the sound amplitude, particularly at lower frequencies, and is thus a factor to consider in hydrophone data analyses.
8. Effective monitoring of tidal energy installations will require multiple integrated acoustic (active and passive) instruments and optical sensors for the assessment of turbine interactions with marine life. Such integrated systems need to be carefully designed to reduce the possibility of inter-device interference, and to maximize detection of fish and marine mammal behaviour.

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Porskamp, P.H.J. 2015. Detecting and assessing trends in harbour porpoise (*Phocoena phocoena)* presence in and around the FORCE test site. Masters thesis. Acadia University, Wolfville, NS.

## Acknowledgements

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# Appendix: Field Activity Log Summary

| Site | Date (m/d/yyyy) | Time (UTC) | Notes |
|---|---|---|---|
| Kingsport | 8/6/2015 | 19:00 | Launched boat at Kingsport |
| Kingsport | 8/6/2015 | 19:30 | Medford Beach, anchored |
| Kingsport | 8/6/2015 | 19:37 | IcListen power up with generator on |
| Kingsport | 8/6/2015 | 19:50 | IcListen (1239) in water, other boat approaching from Kingsport and away at 19:55 |
| Kingsport | 8/6/2015 | 20:10 | Gemini (fitted with GoPro) lowered 1m below surface |
| Kingsport | 8/6/2015 | 20:17 | Generator on, IcListen recording background |
| Kingsport | 8/6/2015 | 20:22 | Power on, Gemini recording |
| Kingsport | 8/6/2015 | 20:34 | Started bait fishing on bottom |
| Kingsport | 8/6/2015 | 20:44 | Caught Sculpin 28cm TL, dangled in front of Gemini @ 1.5 m |
| Kingsport | 8/6/2015 | 20:50 | Detected interference from another boat – depth sounder @ ~100m |
| Kingsport | 8/6/2015 | 21:03 | Dangled frozen Shad (45cm TL) in front of Gemini @ 1.5m |
| Kingsport | 8/6/2015 | 21:10 | Dangled whole fresh Mackerel (36cm TL) in front of Gemini @ 1.5m |
| Kingsport | 8/6/2015 | 21:12 | Dangled small chunks of Mackerel (4-5cm) on hooks attached to line with weight in front of Gemini @ 1.5m |
| Kingsport | 8/6/2015 | 21:15 | Didson powered up (both Gemini and IcListen on as well) |
| Kingsport | 8/6/2015 | 21:29 | Angling for Striped Bass while recording |
| Kingsport | 8/6/2015 | 21:35 | 3.5m Aluminum boat approached to see what we were doing |
| Kingsport | 8/6/2015 | 21:37 | Another boat nearby moves off, no boats nearby |
| Kingsport | 8/6/2015 | 21:40 | Skate (30cm TL) captured |
| Kingsport | 8/6/2015 | 21:44 | Didson off, Gemini on |
| Kingsport | 8/6/2015 | 21:50 | Gemini off, mounting poles disassembled |
| Kingsport | 8/6/2015 | 22:06 | IcListen pulled up, on deck of boat |
| Kingsport | 8/6/2015 | 22:07 | Motor on, anchor up |
| Kingsport | 8/6/2015 | 22:10 | Motor off, IcListen back in water ~5m, drifting for 5 min |
| Kingsport | 8/6/2015 | 22:14 | IcListen hauled up, on deck of boat |
| Halls Harbour | 8/13/2015 | 14:10 | IcListen on, 1m above bottom, 3m from Gemini |
| Halls Harbour | 8/13/2015 | 14:17 | Generator on |
| Halls Harbour | 8/13/2015 | 14:20 | Gemini on and recording |
| Halls Harbour | 8/13/2015 | 14:41 | Caught small Pollock returned to water in front of Gemini |
| Halls Harbour | 8/13/2015 | 14:43 | Boat at mouth of harbour, interference from fish finder |
| Halls Harbour | 8/13/2015 | 14:47 | Larger Pollock on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 14:51 | Small Pollock on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 14:54 | Small Pollock on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 15:00 | Small Pollock on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 15:04 | Small Pollock on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 15:05 | Boat (26ft) in front of sonar, Mike's line caught |

| | | | |
|---|---|---|---|
| Halls Harbour | 8/13/2015 | 15:13 | Longhorn Sculpin (on line in front of Gemini) |
| Halls Harbour | 8/13/2015 | 15:44 | Boat in front of Gemini |
| Halls Harbour | 8/13/2015 | 15:45 | Boat (45ft) at mouth of harbor |
| Halls Harbour | 8/13/2015 | 15:50 | Longhorn Sculpin on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 15:53 | Boat in front of Gemini |
| Halls Harbour | 8/13/2015 | 16:10 | Longhorn Sculpin on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 16:21 | Small boat in front of Gemini, Small Pollock caught. |
| Halls Harbour | 8/13/2015 | 16:25 | Boat (45ft) in front of Gemini |
| Halls Harbour | 8/13/2015 | 16:57 | Longhorn Sculpin on line in front of Gemini |
| Halls Harbour | 8/13/2015 | 17:18 | Gemini off |
| Halls Harbour | 8/13/2015 | 17:19 | Generator off |
| Halls Harbour | 8/13/2015 | 17:33 | IcListen out of water |
| Fish Farm | 8/20/2015 | 14:27 | IcListen 1239 on |
| Fish Farm | 8/20/2015 | 14:00 | IcListen 1211 on |
| Fish Farm | 8/20/2015 | 14:43 | Food pellets thrown pond center |
| Fish Farm | 8/20/2015 | 14:44 | Food pellets thrown pond centre and far right corner |
| Fish Farm | 8/20/2015 | 15:04 | Plank with tape 1m from Gemini |
| Fish Farm | 8/20/2015 | 15:05 | Plank with tape 2m from Gemini |
| Fish Farm | 8/20/2015 | 15:06 | Plank with tape 3m from Gemini |
| Fish Farm | 8/20/2015 | 15:06 | Plank with tape 4m from Gemini |
| Fish Farm | 8/20/2015 | 15:07 | Plank with tape 0.5m from Gemini |
| Fish Farm | 8/20/2015 | 15:16 | Both hydrophones in water |
| Fish Farm | 8/20/2015 | 15:17 | Food pellets thrown in front of Gemini |
| Fish Farm | 8/20/2015 | 15:22 | Food pellets thrown directly in front of Gemini/camera |
| Fish Farm | 8/20/2015 | 15:24 | Food pellets thrown at stick 1.25m from Gemini/camera |
| Fish Farm | 8/20/2015 | 15:27 | Feeding stopped |
| Fish Farm | 8/20/2015 | 15:28 | Gemini off |
| Fish Farm | 8/20/2015 | 15:29 | Generator off |
| Fish Farm | 8/20/2015 | 15:30 | Food pellets thrown near hydrophones. Note wind blowing over pipe created a whistling signature that may be present in hydrophone data |
| Fish Farm | 8/20/2015 | 15:46 | Hydrophones out of water |
| Minas Channel | 9/8/2015 | 11:46 | Gemini recording @ 3m depth, IcListen in water on spar buoy |
| Minas Channel | 9/8/2015 | 11:52 | Vessel sounder on, depth 24.9ftm |
| Minas Channel | 9/8/2015 | 11:56 | Engine off, sounder off, portable generator on |
| Minas Channel | 9/8/2015 | 12:04 | Vessel GPS drift speed 2.1 knots |
| Minas Channel | 9/8/2015 | 12:10 | Shad (45cm TL) lowered with 2kg lead weight |
| Minas Channel | 9/8/2015 | 12:19 | Vessel sounder on briefly, depth 24.5ftm |
| Minas Channel | 9/8/2015 | 12:20 | Shad on bottom, and return trip to surface |
| Minas Channel | 9/8/2015 | 12:35 | Chum bag deployed at stern |
| Minas Channel | 9/8/2015 | 12:38 | 2 targets near bottom |
| Minas Channel | 9/8/2015 | 12:39 | Vessel GPS drift speed 1.8knot |

| | | | |
|---|---|---|---|
| Minas Channel | 9/8/2015 | 13:10 | Vessel GPS drift speed 1.3knot, near HW |
| Minas Channel | 9/8/2015 | 13:18 | Bait bag lost over side |
| Minas Channel | 9/8/2015 | 13:30 | School of fish ~10m depth |
| Minas Channel | 9/8/2015 | 13:31 | Bottom feature |
| Minas Channel | 9/8/2015 | 13:50 | Gemini off |
| Minas Channel | 9/8/2015 | 13:59 | IcListen on board after reeling in |
| Minas Channel | 9/8/2015 | 14:00 | Steamed back to port |

# Appendix E – Cape Sharp Tidal Gemini Multibeam Imaging Sonar: Monitoring Report (November 2016 – April 2017)

# Cape Sharp Tidal Gemini Multibeam Imaging Sonar: Monitoring Report (November 2016 - April 2017)

Report to Cape Sharp Tidal

December 2017

Prepared and submitted by


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## Executive Summary

Cape Sharp Tidal (CST) installed an OpenHydro Open-Centre tidal in-stream energy conversion (TISEC) device on 7 Nov 2016, in Berth D at the Crown Lease Area at the Fundy Ocean Research Center for Energy (FORCE). The turbine was retrieved in June 2017. As part of this demonstration project, CST implemented an environmental effects monitoring program (EEMP). The EEMP was initiated upon deployment (November 2016) until disconnection with the subsea cable in April 2017, as part of the preparation operations for retrieval.

The overall purpose of the CST EEMP is to better understand potential effects and interactions of specific environmental components (i.e., fish, marine mammals, operational sound) in the near-field environment with the Open-Center in-stream tidal device. This understanding will be useful for verifying the accuracy of the environmental effect predictions made in the environmental assessment and will inform future monitoring plans.

This report addresses the fish component of the EEMP. Active acoustic monitoring was used to gather information on the occurrence of fish within the near-field (i.e., < 100 m) area of the turbine. To achieve this, a Gemini multibeam imaging sonar was mounted on the turbine structure and used to monitor marine life in the near-field area during the 2016/2017 deployment. The Acadia Centre for Estuarine Research at Acadia University was contracted to analyze the data collected by the sonar and address the specific objectives of the active acoustic Gemini sonar study under the CST EEMP.

The goals of the Gemini sonar study were to increase understanding of potential interactions of marine life with in-stream tidal turbines, including the use of the site by wildlife, as determined by target detection and tracking, and to further develop monitoring methodology as it relates to Gemini data collection, processing, analysis, and presentation. The work described in this report used manually-processed Gemini data to (1) assess trends in target abundance within the sampled volume, over short and long-time scales and with respect to tidal stage and current speed; (2) characterize target movement with respect to current direction; and (3) identify targets that may be fish schools.

Data collected were from the near-field area immediately in front of the turbine (facing into the current during ebb tide). Given the sonar's downward-angled orientation, the volume sampled was below the depth of the turbine rotor. A subset of the sonar dataset was manually processed to identify and track targets in the volume of water column sampled. This involved a human observer reviewing five-minute long video clips at two-hour intervals for 1 full day per week, for the full five-month period of data collection. The observer searched for 'targets,' which are defined as objects moving independently of the seafloor background that could be marine life. The time of detection and the net movement direction was recorded for each target. Target abundance was found to decrease with falling winter temperatures, which is consistent with other biological surveys of this area. Target abundance did not differ significantly between day and night for the duration of the dataset, but abundance of targets in the volume sampled was consistently lower during the flood tide than the ebb tide, possibly due to effects on the flow field in the area sampled by the sonar as flood tide waters moved through and around the TISEC

device. Target movement direction exhibited patterns that reflected the flow environment, with most targets moving in the same general direction as the current. However, variation in movement direction of targets within the sampled volume was greater during the flood tide, when targets were downstream of the turbine, than during the ebb tide, when targets were upstream (approaching the device). Again, this difference could be related to the physical effect of the TISEC device on the flow regime in the near-field; examination of fine-scale hydrodynamics upstream and downstream of the device would be needed to determine wake effects.

The results of target detection and tracking presented here are encouraging for the future use of the Gemini sonar to monitor marine life presence and behavior at turbine rotor height in the near-field of the CST TISEC device. Efficiency and extent of sonar data processing will increase greatly with further development and validation of automated Gemini data processing techniques. Assessment of the near-field hydrodynamics, and examination of the data provided by FORCE's mobile and stationary active acoustic surveys of fish, will be important for the interpretation of Gemini sonar data collected from turbine rotor height in future studies.

The potential for an overall improved dataset from a re-oriented Gemini sonar and a longer (planned) deployment of a turbine will provide an opportunity to obtain data with increased spatial and temporal coverage. This will help to clarify the results presented and discussed in this report, improve understanding of year-round presence and spatial distributions of marine animals, and therefore help to meet the overall objective of understanding how fish and marine mammals might interact with the CST in-stream turbine.

# Contents

# 1 Introduction

## 1.1 Overview and EEMP context

The Cape Sharp Tidal (CST) tidal in-stream energy conversion (TISEC) device was deployed at the Fundy Ocean Research Center for Energy (FORCE) test site from November 2016 to June 2017 (Figure 1). This test site is located in the 5.5-km wide Minas Passage of the upper Bay of Fundy, where the tidal range reaches 13 m and currents can exceed 5 $m \cdot s^{-1}$ (Karsten et al. 2013). The CST device is an OpenHydro design, which consists of an open-center turbine mounted on a stationary bottom support frame, the subsea base, resting on the bottom (Figure 1b). The device is 20 m high, and the turbine is 16 m in diameter.

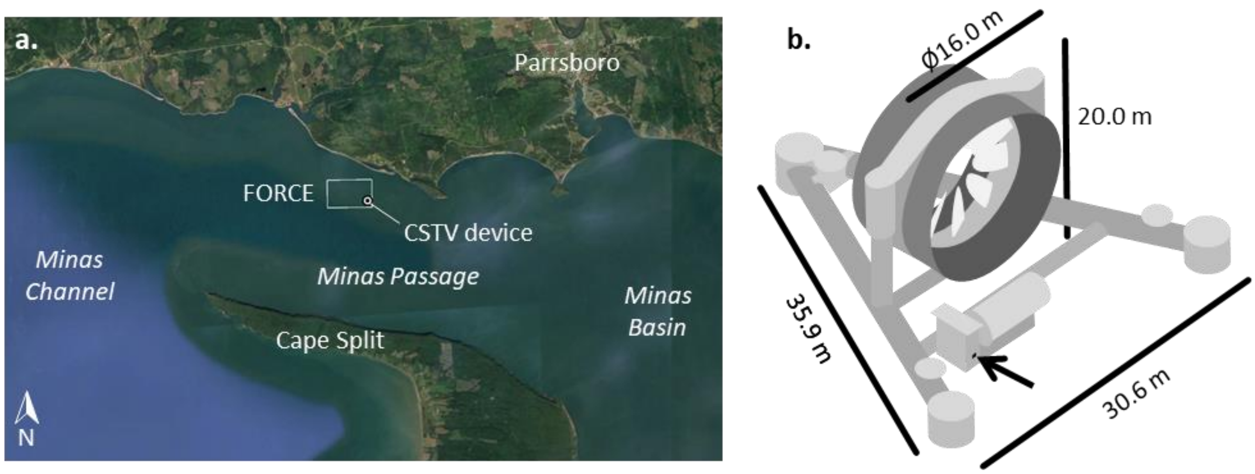


Figure 1. Study location and diagram of in-stream tidal energy device. (a) the Fundy Ocean Research Center for Energy (FORCE) tidal energy demonstration site in Minas Passage, Nova Scotia, showing the location of the device within Berth D. (b) The Cape Sharp Tidal TISEC device, with arrow indicating Gemini imaging sonar.

The upper Bay of Fundy is home to a diverse seasonal assemblage of fish, marine mammals, seabirds, and other marine fauna, some of which are commercially important (e.g. river herring, *Alosa sp.*), threatened (e.g., Atlantic sturgeon, *Acipenser oxyrinchus*; American eel, *Anguilla rostrata*) or endangered (e.g., striped bass, *Morone saxatilis*) (Baker et al. 2014, Keyser et al. 2016, Redden et al. 2014, Stokesbury et al. 2017). The potential effects of in-stream tidal devices on marine life in the Minas Passage are currently unknown. The uncertainty is mainly due to the low number of TISEC devices that have been deployed worldwide to date. However, recent years have seen a growth in the extent of research on marine life and potential interactions with in-stream turbines in areas with fast tidal currents (Copping et al. 2016), including:

1. behavior of animals near TISEC devices (Bevelhimer et al. 2017, Hammar et al. 2013, Viehman and Zydlewski 2015);
2. spatial and temporal distribution of animals at tidal energy sites (Benjamins et al. 2016a&b, Daroux and Zydlewski 2017, FORCE 2017, Keyser et al. 2016, Melvin and Cochrane 2014, Redden et al. 2014, Stokesbury et al. 2017, Viehman and Zydlewski

2017, Viehman et al. 2015, Viehman et al. 2017, Waggitt et al. 2016a&b, Waggitt et al. 2017);
3. likelihood that animals may overlap with TISEC devices (Sanderson et al. 2017, Shen et al. 2016, Viehman et al. 2017); and
4. methods and best practices for gathering and analyzing the necessary data to detect TISEC device effects (Fraser et al. 2017, Jacques and Horne 2014, Jepp 2017, Wiesebron et al. 2016a&b, Williamson et al. 2015, Williamson et al. 2017).

This study aims to reduce uncertainty by building knowledge of the presence and behaviour of marine wildlife in the near-field of a CST TISEC device at FORCE. The research presented here forms part of the CST environmental effects monitoring program (EEMP). The overall purpose of the CST EEMP is to better understand interactions of specific environmental components (i.e., fish, marine mammals, operational sound) with the CST TISEC device and any resulting device effects. This understanding will be useful for verifying the accuracy of the environmental effects predictions made during the environmental assessment and will inform future monitoring plans.

To monitor animal behavior in the near-field area of the CST TISEC device, a Gemini multibeam imaging sonar (manufactured by Tritech Ltd) was mounted on the turbine's subsea base structure (Figure 1b). The intent was to view the area of the water column directly aligned with the turbine rotor and to determine the seasonal frequency of occurrence, and behavior, of targets that could be marine life within the near-field environment. However, an error in mounting the instrument resulted in a view comprised of near-bottom water and the sea floor rather than the water column at turbine rotor height. This limited the applicability of the data for assessing animal behavior in relation to the turbine. Regardless, the data collected over the course of the deployment period were biologically relevant and useful for assessing general trends in target abundance and movements and also allowed a better understanding of the performance and potential of the Gemini sonar. In addition, this work will provide a foundation for developing and refining the methodologies to be implemented for future Gemini data collection, processing, analysis, presentation and interpretation.

### 1.3 Gemini multibeam sonar

The Tritech Gemini imaging sonar is an active acoustic monitoring device. It is a high frequency multi-beam sonar that uses reflected sound to build up a picture of the underwater environment. The sonar sends out a 'ping' (an acoustic pulse), and the intensity of the echoes received from the multiple beams are used to create an image of the sampled volume. The sonar pings multiple times per second, resulting in a video-like record of the sampled volume. The size, shape, and movements of objects (targets) within the sampled volume can be extracted for identification (but may not be at species level) and behavior analyses.

Images created by high frequency sonars like the Gemini are low-resolution when compared with contemporary video technologies. However, unlike video cameras, multibeam sonars function without light and in high turbidity (cloudiness or haziness of water caused by suspended solids). This makes multibeam sonars a highly suitable tool for observing marine life in environments such as Minas Passage, where light penetration is limited and the water is highly turbulent and at times turbid.

### 1.4 Project objectives

The CST EEMP includes use of a Gemini sonar to investigate the presence and behavior of marine animals in the near-field (images extend to 60 m) of the CST TISEC device. The specific EEMP objective was to determine the seasonal frequency of fish and marine mammals within the near-field environment of the turbine and to track their movements. Under this objective, the tasks included an assessment of the performance of the Gemini imaging sonar, analysis of the dataset collected while the device was deployed from November 2016 to April 2017, assessment of the data for trends in target presence and behavior, and development of a general set of methodologies for processing and analysing Gemini data for future deployments.

The types of analyses presented here can be used with data processed manually or via automation. All data used for this report were manually processed (i.e. human observations of Gemini video files), but future analyses will likely utilize automated data processing techniques as algorithms are further developed and validated (Jepp 2017, Appendix 1). Automated processing is likely to provide a larger suite of metrics than can be realistically extracted manually from the data (e.g., the position and size of a target in every frame in which it is detected, Jepp 2017).

The work described in this report used manually-processed Gemini data to: (1) describe trends in target abundance within the sampled volume, over short and long-time scales; (2) characterize target movement with respect to current speed and direction and stage of tide; (3) identify potential fish schools; and (3) develop recommendations for future data collection, processing, and analysis. Information gained from this study improves understanding of the presence and activities of marine animals at this site, provides methods for future data processing and analyses of Gemini data sets, and will inform future research and monitoring of the potential effects of TISEC devices.

## 2 Methods

### 2.1 Data collection

A Gemini 720i multibeam imaging sonar was mounted on the CST device's subsea base structure (Figure 2), facing into the current (upstream) during the ebb tide and facing downstream during the flood tide.

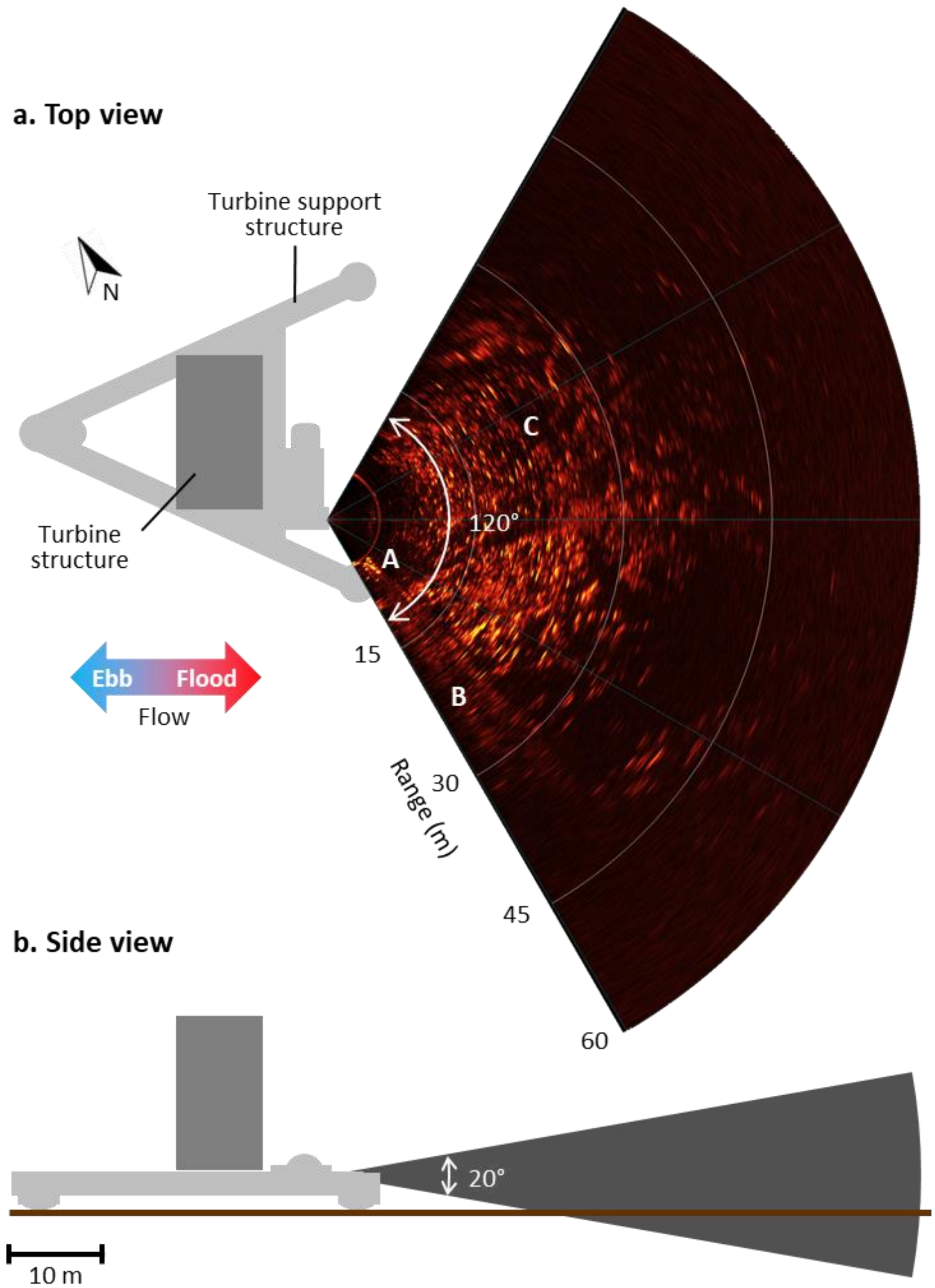


Figure 2. Volume sampled by the Gemini sonar. View from above includes a still frame from the footage, which shows one of the three feet of the sub-sea base (A), its acoustic shadow (B), and the sea floor (C).

The sonar was located approximately 4 meters above the seafloor and 6.6 m away from the face of the turbine, and it sampled a 20° by 120° swath of water using an array of 256 acoustic beams operating at 720 kHz (Jepp 2017). Due to the mounting orientation, the acoustic beam was angled horizontally and slightly downward (Figure 2b), thereby capturing more of the seafloor and less of the water column than what was intended. The volume sampled was therefore mainly below the turbine, and the view was dominated by acoustic backscatter from the sea floor rather than from the water column.

The sampled volume spanned 120° in the horizontal direction and 20° in the vertical direction, and extended to a range of 60 m. The imaging sonar would have encompassed a volume on the order of $5.3 \cdot 10^4$ $m^3$ if not intercepted by the bottom. The Gemini sampled this volume at a rate of approximately 11 frames per second, resulting in a 2D, video-like representation of the sampled swathe (Figure 2a). The angular resolution of the Gemini was approximately 1°, so resolution was highest near the instrument (approximately 9 cm at 5 m range) and decreased with range as the acoustic beams spread (approximately 1 m at 60 m range).

The sonar data collection period spanned 08 November 2016 to 13 April 2017. During this period, communication issues with the Gemini caused frequent interruptions in data transfer, resulting in very small data files and time gaps between adjacent frames (Figure 3). High-quality data files were available for only 40% of the entire collection period. Although most data gaps were on the order of a few seconds in length, this resulted in jumpy Gemini footage which hindered ease and completeness of target detection and tracking. Manual processing of the data allowed some subsampling flexibility and thus reduced the magnitude of this effect; for example, the 5-minute samples analyzed were sometimes shifted slightly to include better-quality data. For future long-term monitoring of the TISEC device, and for automated target tracking to be successful, communication issues that result in data gaps will need to be addressed. Uninterrupted data collection should achieve closer to 100% coverage of the periods of time when the Gemini is operating, whether that be continuously or on a duty cycle (e.g., several minutes per hour).

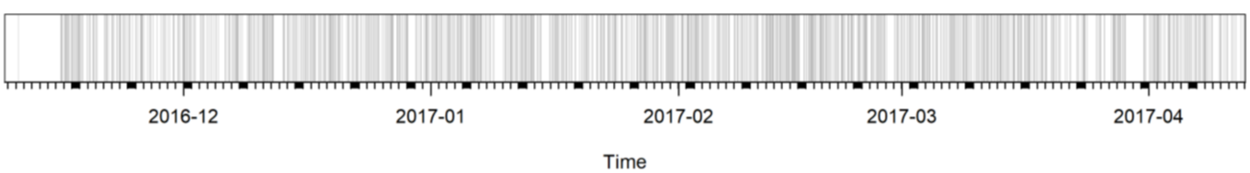


Figure 3. Gemini data collection from 08 November 2016 to 13 April 2017. Gray indicates periods of uninterrupted data collection. Days used in analysis are highlighted in black on the horizontal axis.

## 2.2 Data processing

Manual data processing was undertaken using Tritech's Gemini *SeaTec* software (version 2.01.04.01), and required a human observer to play the footage and search for moving objects (targets) that could be marine animals. Efforts are ongoing to adapt Tritech's target tracking algorithm for use on small targets (e.g. fish; Appendix 1, Jepp 2017). The current version of automated target tracking software was not used for this assessment due to gaps in the data files and backscatter interference from the sea floor. Though movement filters can help remove a relatively stationary backdrop, the reflection from the seafloor was bright enough to wash out the weaker signals from targets above it. Validation of the automated tracking algorithms that are under development will proceed during the next turbine deployment, when the orientation of the Gemini is adjusted to view the water column at turbine rotor height.

*2.2.1 Target identification*

The Gemini sonar can resolve shapes and track their movement, but cannot determine the identity (marine life or debris) of the acoustic targets. Acoustic targets are defined as objects moving independently of the background that could possibly be marine life. Many targets showed some degree of directed movement, which is expected of marine vertebrates, but it is possible that some targets were debris moving with the flow. Targets were most easily seen while using a high-persistence filter (see Appendix 1 for more information on the data processing software and settings). This filter made the path taken by a target more obvious against the background (Figure 4). Targets were easiest to see when within approximately 10 m of the Gemini. Over this distance, Gemini image resolution was high and the view was relatively uncontaminated by the sea floor. Where backscatter from the bottom was very strong, targets were difficult to see, and small targets (such as fish) were furthermore less likely to be detected at greater ranges due to decreasing resolution with distance from the sonar.

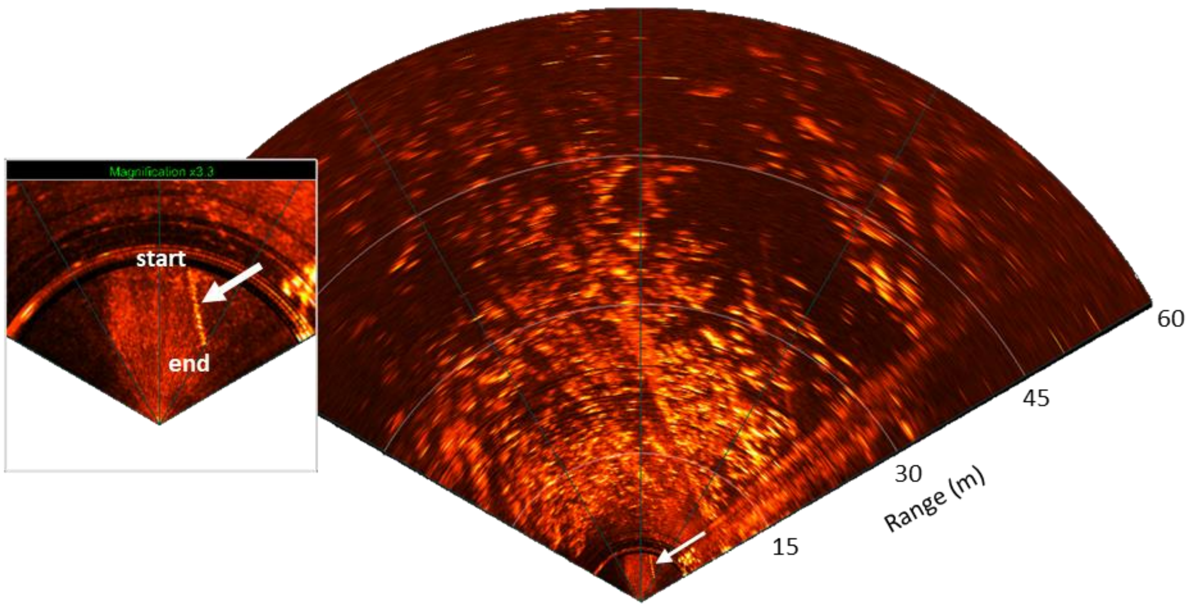


Figure 4. Example of an identified target in Gemini video. Target track indicated by white arrows in the larger Gemini view and in the inset magnification window. Start and end locations of the track indicated in the inset.

Data recorded for each target detected included the time at which it became visible and then no longer visible, the corresponding x and y coordinates, and any observations of unusual appearance or behavior. All targets were also measured (sized) using the click-and-drag measurement tool available in the Gemini *SeaTec* software. Measurement accuracy was limited by the resolution of the Gemini as well as the resolution of the viewing screen. Because measurements could only be obtained in the main viewing window, not the magnification window, targets within a few meters of the sonar were difficult to measure. For this reason, targets were assigned coarse size categories: < 0.5 m, 0.5 to 1.0 m, and > 1.0 m. If a target appeared to be an aggregation of smaller objects (e.g., a school of fish; Figure 5), it was recorded as such and its longest dimension was measured (Appendix 1).

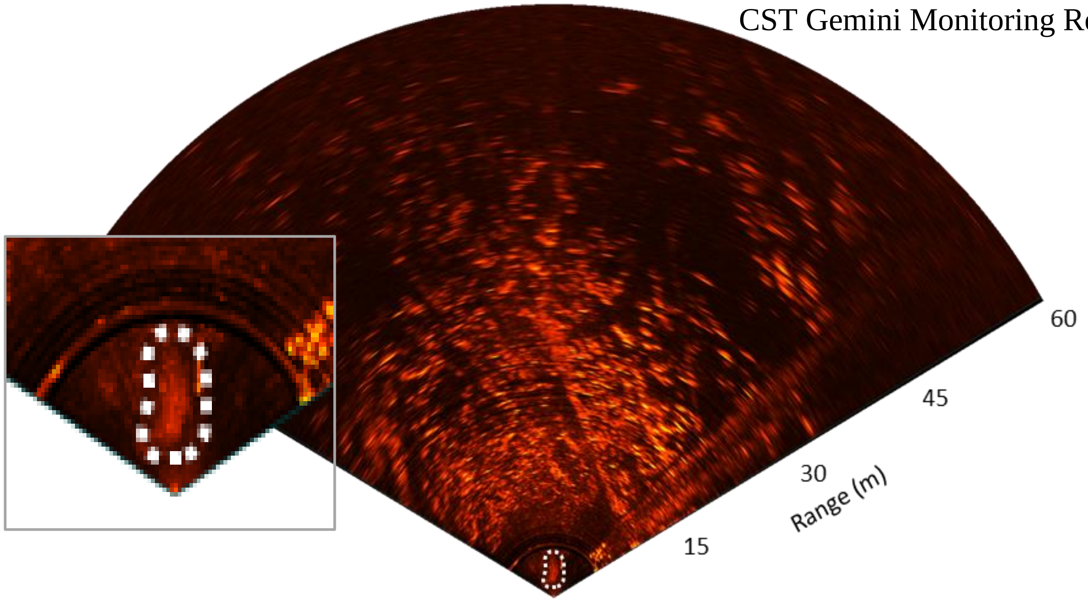


Figure 5. Example of a target that may be a fish school. Note that targets are more clearly seen when their movements in the video clip are observed.

The human observer who processed the Gemini data for this study was trained on a separate data subset prior to beginning work on this project (see Appendix 1). This training period was essential for the observer to become comfortable with the data and the software and to be able to consistently judge what constituted a target and what did not. In addition, observer precision was tested at the end of this study by re-processing ten of the samples previously examined over a 2-month processing period. Target detection data from initial and repeated sample processing showed strong matching of results (88% similar on average). There was also no effect of time (since initial processing of the samples) on the percent target match. This indicated no drift in observer bias over time, confirming that sufficient training had taken place before processing of data samples began.

*2.2.2 Data subsampling*

Manual target detection is extremely time consuming, and a single 5-minute span of data can take a human observer up to 40 minutes to process, depending on the number of targets present. For this reason, a subsampling program was designed to examine a subset of the nearly 5 months of data collected. Five minutes of every 2-hour period were processed for one entire day (midnight to midnight) from each week of data collected. This subsampling regime was chosen to allow the characterization of longer-term (e.g. lunar or seasonal) trends in target abundance, as well as the observation of any shorter-term patterns (e.g., diel or tidal) occurring within each sampled day while avoiding signal aliasing (Viehman 2017). Some gaps in data collection resulted in some missing samples (Table 1). A total of 268 5-minute samples was processed for this study.

Table 1. Hours for which 5-minute samples were analyzed for each day of data collection. Blank spaces indicate data gaps.

| Date | Samples analyzed (hour of day, UTC) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0000 | 0200 | 0400 | 0600 | 0800 | 1000 | 1200 | 1400 | 1600 | 1800 | 2000 | 2200 | 2400 |
| 17 Nov 2016 | | | | | | | | | | | | | |
| 24 Nov 2016 | | | | | | | | | | | | | |
| 01 Dec 2016 | | | | | | | | | | | | | |
| 08 Dec 2016 | | | | | | | | | | | | | |
| 15 Dec 2016 | | | | | | | | | | | | | |
| 22 Dec 2016 | | | | | | | | | | | | | |
| 29 Dec 2016 | | | | | | | | | | | | | |
| 05 Jan 2017 | | | | | | | | | | | | | |
| 12 Jan 2017 | | | | | | | | | | | | | |
| 19 Jan 2017 | | | | | | | | | | | | | |
| 26 Jan 2017 | | | | | | | | | | | | | |
| 02 Feb 2017 | | | | | | | | | | | | | |
| 09 Feb 2017 | | | | | | | | | | | | | |
| 16 Feb 2017 | | | | | | | | | | | | | |
| 23 Feb 2017 | | | | | | | | | | | | | |
| 02 Mar 2017 | | | | | | | | | | | | | |
| 09 Mar 2017 | | | | | | | | | | | | | |
| 16 Mar 2017 | | | | | | | | | | | | | |
| 23 Mar 2017 | | | | | | | | | | | | | |
| 31 Mar 2017 | | | | | | | | | | | | | |
| 06 Apr 2017 | | | | | | | | | | | | | |
| 13 Apr 2017 | | | | | | | | | | | | | |

*2.2.3 Auxiliary data*

One-minute averages of current speed (normalized to the maximum) and current direction were modeled by CST using data from Acoustic Doppler Current Profilers (ADCPs) deployed on the CST turbine. The normalized current speed and direction data were used to classify each target as occurring during flood, ebb, or slack tide and for assessing the movement direction of targets relative to the modeled flow.

Water temperature data for the collection period were also available from a temperature and depth logger deployed at a Minas Passage site near the FORCE visitor center (www.oceannetworks.ca/observatories/atlantic/bay-fundy-minas-passage). This temperature logger is located close to shore and may therefore record temperatures slightly warmer or colder than water at the CST TISEC device location.

## 2.3 Data analysis

*2.3.1 Temporal trends in target detections*

Target abundance was calculated for each 5-minute data sample that was manually processed. Based on start and end times, these 5-minute samples were then each assigned tidal stage (ebb, flood, low slack, or high slack), diel stage (day or night), temperature, normalized current speed, and average current direction.

Data from the 5-minute samples were grouped by day to assess trends occurring over the length of the data collection period (e.g., seasonal changes). To assess shorter-term changes, such as differences in day and night target abundance and how these changed over the study period, the entire sample set was divided into three groups, each spanning a third of the collection period (i.e., late fall/early winter, mid-winter, late winter/early spring). Statistical tests were used where applicable and included chi squared and ANOVA tests with 5% confidence levels.

*2.3.2 Target movement*

The movement direction of each target was calculated using the target's start and end position in the beam. Movement directions were presented graphically to assess differences related to current speed and direction, tidal stage, and diel stage. Directional movements of marine wildlife are important to understand. At other tidal energy sites, fish have been found to generally move with the current, with more random movement occurring at slack tides (Viehman and Zydlewski 2015, Viehman and Zydlewski 2017). Greater variability in target movement may therefore be a useful indicator of unusual behavior, such as responses to a tidal energy device. The spatial dependence of movement variability was explored by splitting the sampled swathe into a grid. Due to the low sample sizes in the subsampled dataset, a coarse grid with 8.3 m x 5 m cells was used. The circular variance of target movement directions was calculated for each cell, with 0 variance indicating uniform movement and 1 indicating completely random movement.

# 3 Results and Discussion

## 3.1 Trends in target abundance and size

A total of 2,056 targets were detected within the subsampled dataset (268 5-minute samples), with 45 targets identified as potential schools of fish (Table 2). These numbers need to be interpreted keeping in mind that the sampled volume of water, over each 5-minute sample duration, varies with current conditions. For example, many more targets per sample were detected during the flowing tide (ebb or flood) than slack tides, probably due to the greater volume of water that is sampled when the current is moving through the beam than when the water it is relatively still. Similarly, the period of data collection occurred during the late fall to early spring, when nights were longer than daytime periods. Thus, more samples reflect nighttime conditions, somewhat inflating the total number of fish detected at night compared to day (Table 2). When the counts are normalized for the number of samples within each diel and tidal stage category (Table 3), the diel stage difference is not as large.

Table 2. Number of individual targets and (number of schools) detected in all processed data samples.

| | Tidal stage | | | | |
|---|---|---|---|---|---|
| Diel stage | Ebb | Flood | High slack | Low slack | Total |
| Day | 476 (14) | 253 (6) | 3 (0) | 1 (0) | 733 (20) |
| Night | 843 (11) | 395 (14) | 21 (0) | 19 (0) | 1,278 (25) |
| Total | 1,319 (25) | 648 (20) | 24 (0) | 20 (0) | 2,011 (45) |

Table 3. Number of individual targets and (number of schools) detected, normalized by number of samples within each category.

| Diel stage | Ebb | Flood | High slack | Low slack | Total |
|---|---|---|---|---|---|
| | Tidal stage | | | | |
| Day | 9.3 (0.3) | 4.7 (0.1) | 0.8 (0) | 0.2 (0) | 15.0 (0.4) |
| Night | 12.4 (0.2) | 5.5 (0.2) | 3.0 (0) | 2.4 (0) | 23.3 (0.4) |
| Total | 21.7 (0.5) | 10.2 (0.3) | 3.8 (0) | 2.6 (0) | 38.3 (0.8) |

Although flood tide currents at the deployment site were approximately 30% faster than ebb tide currents (Figure 7), there were fewer targets detected during flood than ebb (Tables 2 and 3). There are several potential explanations. For example, water velocity downstream of a turbine operating at maximum efficiency could be reduced to as little as one third of the upstream velocity (Figure 8), which would reduce the flood-tide sampled volume to approximately half that of the ebb. Even with no change in target behavior or concentration, this reduction in speed could halve the number of targets observed during the flood tide compared to ebb, which is consistent with the above results (Table 2, Table 3). With future Gemini datasets, the dependency of target numbers on volume sampled over time should be explored in more detail to inform the interpretation of results. To improve estimates of sampled volume, more information is required on the effects of the TISEC device on the local flow field, either through validated models or concurrent measurements of the flow within the volume sampled by the Gemini.

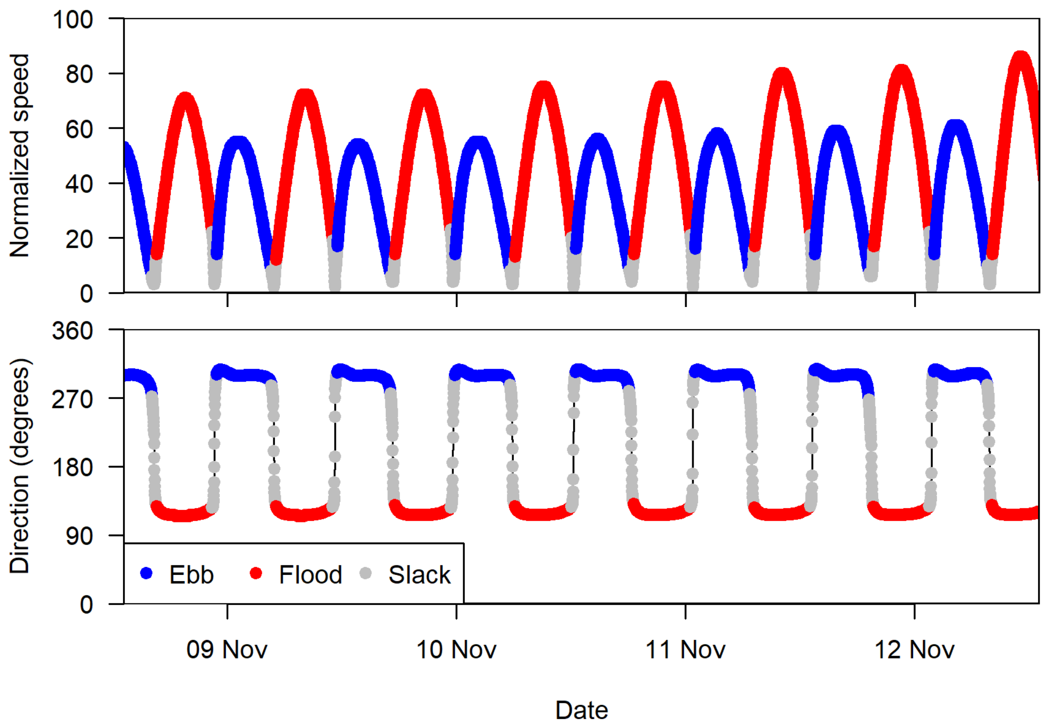


Figure 7. Example of current speed and direction data. Points are one-minute averages, derived by CST from a model informed by ADCP data collected at the device.

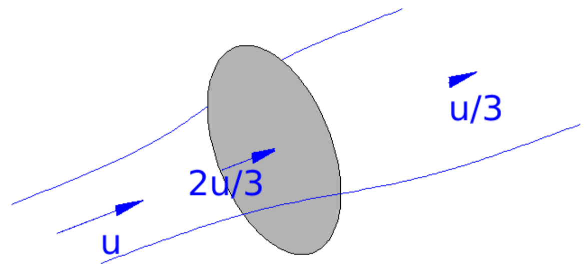


Figure 8. Current speed through a generic in-stream turbine that is operating at the Betz limit (maximum efficiency). The area swept by the blades of the turbine is shaded gray. Blue lines schematically indicate streamlines that enclose the flow through the turbine. The far upstream current is u. At the turbine, current is two-thirds u and downstream it is one-third u. Source: Brian Sanderson.

The observed tidal stage differences (ebb vs. flood) in target presence in near-bottom waters close to the turbine could also be related to animal distribution patterns and behavior. For example, we might expect fewer targets to be detected on the flood tide than ebb if animals move higher in the water column during the flood. Alternately, asymmetric flow could carry animals through different parts of the passage during ebb and flood tides. While examination of broad-scale distribution patterns are beyond the scope of the CST EEMP, relevant data for interpretation purposes is available via mobile and stationary active acoustic fish surveys, which are conducted in Minas Passage at regular intervals by FORCE.

Few targets were detected beyond the first 10 m of the sampled volume (Figure 9), which corresponds to where the interference from the seafloor became obvious in the view. Most of the detected targets occurred within the first 5 m; a dip in numbers at exactly 5 m is likely related to sound reflected by the foot of the subsea base (Figure 2, A). It should be noted that many more targets, albeit small (e.g., < 20 cm in length), appeared to be present in the first 5 m of the Gemini's view, but could not be included in the results here because they could not be accurately placed or measured with the manual tools available in the Gemini *SeaTec* software (Appendix 1). This data processing limitation could be overcome by improvements to the software (e.g., being able to make measurements in the magnification window) and/or automated tracking.

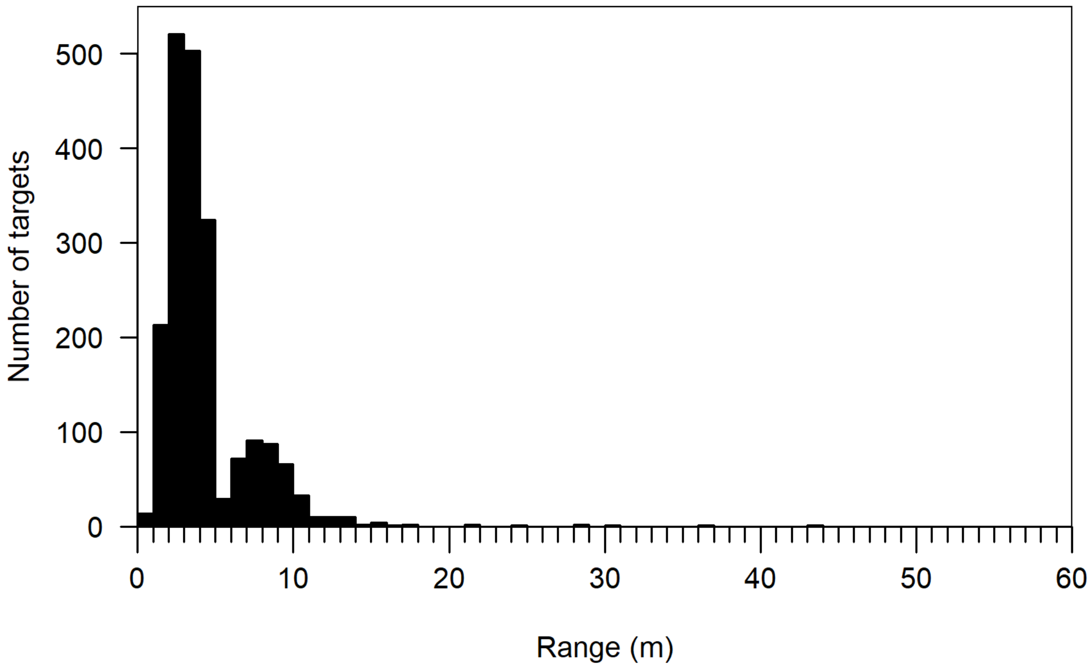


Figure 9. Number of targets detected vs. range from the Gemini sonar.

The number of targets detected in each grid square (Figure 10) showed the same range dependency, with most targets detected within 10 m of the sonar. The lack of targets at greater ranges is probably related to interference from the seafloor and the decreasing resolution of the Gemini—not necessarily to more targets being present near the turbine. To verify this, when the Gemini is reoriented with a more upward view of the water column, it would be beneficial to calculate the detection probability of different sized targets at various ranges (up to 60 m) from the Gemini, perhaps with field measurements of known objects, and compare this with the spatial distribution of targets detected within the beam.

### *3.1.1 Seasonal trend in target size*

The number of targets in each size category did not vary significantly over time (Figure 11; chi-square p-value > 0.05). Most targets were in the smallest category (97.0% were < 0.5 m), with comparably very few in the larger categories (1.2% were 0.5 – 1.0 m, and 1.8% were > 1.0 m). This suggests that most targets present were fish. Some of the larger targets (>0.5 m) may have been striped bass, which are known to overwinter in Minas Passage and adjacent waters (Keyser et al. 2016). Marine mammals known to occupy the Minas Passage include harbour porpoise, harbour seals, and occasionally white-sided dolphins, most of which are over a meter in length. Small schooling fish like Atlantic herring are likely to occupy the Minas Passage during the winter (Melvin and Cochrane 2014; Viehman et al. 2017). Rainbow smelt and other fishes <0.5 m in length may also be present during the late fall to early spring period (Dadswell 2010).

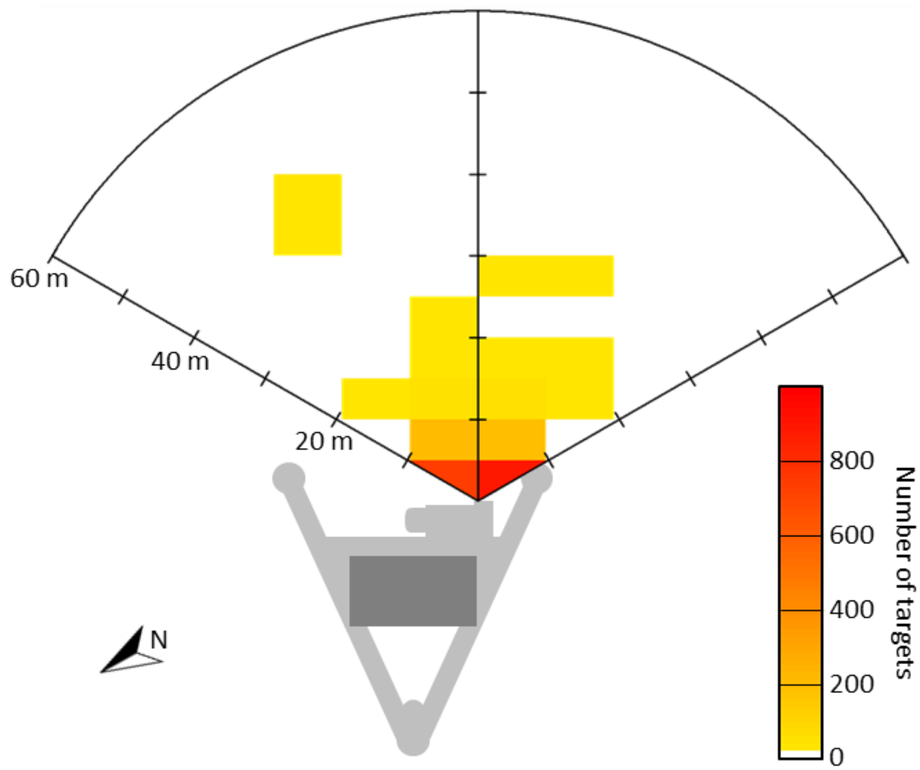


Figure 10. Spatial distribution of detected targets. Color indicates number of targets detected per grid cell (8.3 m wide by 5 m high).

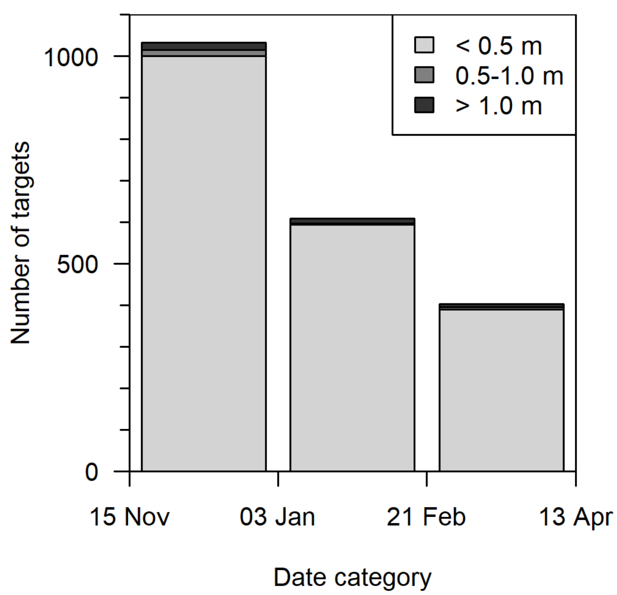


Figure 11. Target size distribution over time.

More accurate target size measurements would be useful in estimating which types of animals (and possibly species in some cases) are present and how their distribution may change over time. This is potentially something that can be improved with automated tracking algorithms, as well as small changes to the software, such as being able to make measurements in the magnification window (see Figure 4).

*3.1.2 Seasonal trend in target abundance*

The number of targets detected per 5-minute sample decreased over the 5 months of data collection, from 10-15 targets per sample in December to 0-5 fish per sample in April (Figure 12). This trend closely mirrored the decreasing temperature, and could reflect a general decrease in the abundance of animals in the area over the winter, preceding the return of many migratory species in the spring (e.g., river herring). Few fish surveys have occurred in this region in the coldest months of winter, so it is difficult to say with certainty if fish were less abundant then, or if they were simply inhabiting a different part of the water column or Passage. However, this trend in declining fish abundance in winter has been recorded by an ongoing before-after-control-impact acoustic study of fish at the FORCE site (FORCE 2017), which found slightly higher fish densities in December surveys compared to January and March (Daroux and Zydlewski 2017). Another acoustic study at this site found fish density to be higher in early December to early January compared to June to July (Viehman et al. 2017). Acoustically tagged striped bass have been found to be present in Minas Passage through December but scarcer as temperatures drop below 1° C (Keyser et al. 2016). Year-round passive acoustic monitoring of harbour porpoise indicates that their abundance is lowest during winter (Porskamp 2015).

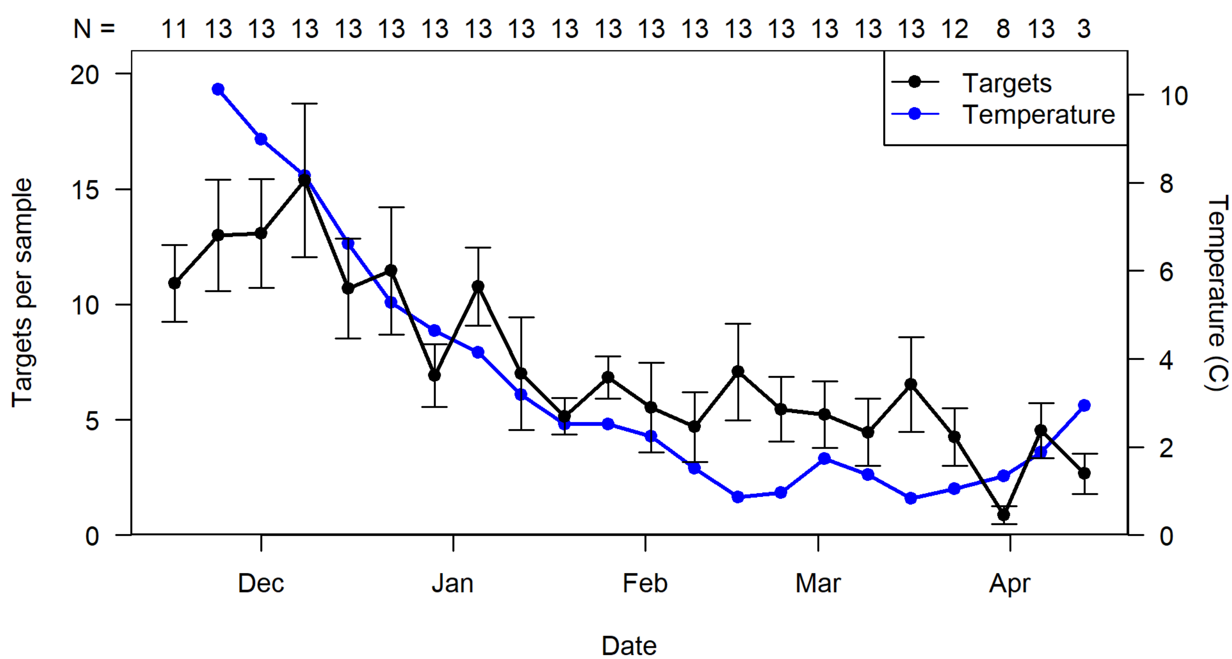


Figure 12. Number of targets detected from November 2016 to April 2017. Points are mean number of targets per 5-minute sample, whiskers represent +/- one standard deviation. Water temperature is shown in blue.

*3.1.3 Diel and tidal trends in target abundance*

There was a large, statistically significant difference in the average rate of target detection per 5-minute sample between ebb and flood tide over the duration of the dataset (Figure 13a), but little difference between day and night (Figure 13b). The higher detection rate of targets during ebb tide reflects the absolute target numbers reported in Table 2. As discussed previously, lower target abundance during flood conditions could be due to the effects of the TISEC device structures on the near-field flow conditions (Figure 8), and/or to differences in animal behavior or distribution related to current direction (e.g., asymmetric flow dynamics in the Passage or changing depth preferences of animals).

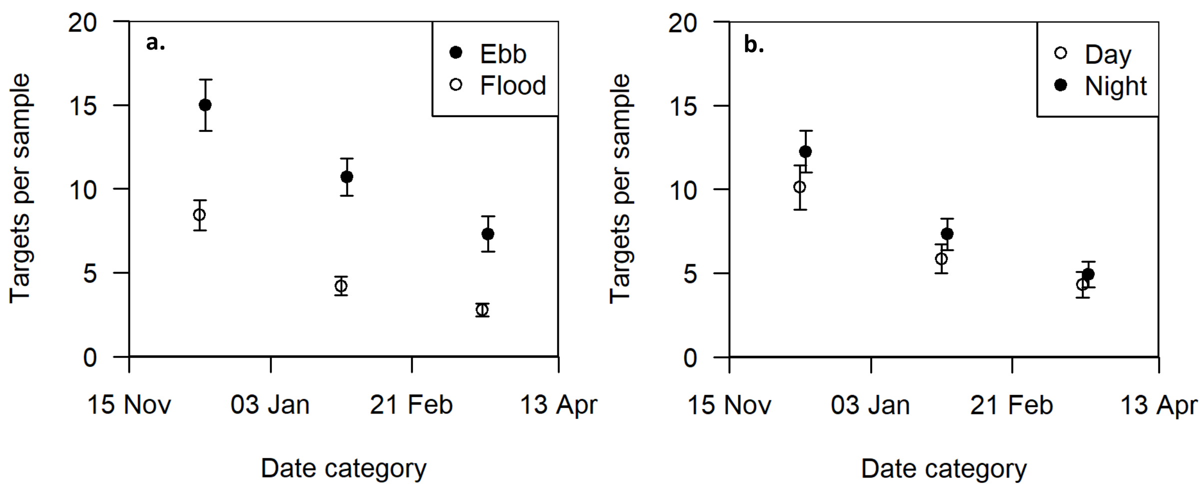


Figure 13. Number of targets per 5-minute sample during (a) ebb and flood tides and (b) day and night. Points are means, error bars show +/- 1 standard error for each third of the sampling period, as per Section 2.3.1.

The small difference between day and night detection rates compared to the absolute target counts discussed earlier highlights the influence that environmental conditions and data partitioning can have on results. While the total number of targets detected at night was much higher than during the day (Table 2), the number of targets per 5-minute sample (which normalizes for time) indicated a much smaller effect of diel stage on abundance in the portion of water column sampled by the Gemini (Figure 13b).

The tidal and diel differences in target detection rate contrast some results from other acoustic studies conducted in the Minas Passage. However, this study includes only the acoustic detection of targets within approximately 4 m of the sea floor; most other active acoustic surveys of this region omitted the upper- and lower-most layers of the water column due to acoustic interference from the surface and seafloor, respectively. One of those previous studies used an upward-facing echosounder, mounted to a FORCE sensor platform on the seafloor, to examine the vertical distribution of fish during December 2015 to January 2016 (Viehman et al. 2017). That study, which omitted the lowest 3 m of water column, found the vertical distribution of fish in December to January changed noticeably from day to night. However, most of that change occurred in the upper 10-20 m of the water column; target abundance along the sea floor could have remained relatively unchanged over the course of a day, as was seen here.

Interestingly, Viehman et al (2017) did not observe any noticeable difference in fish vertical distribution or overall density between ebb and flood tides, which contrasts the very obvious difference observed here in waters just above the sea floor. It is possible that animal activity close to the sea floor is not strongly connected to activity in the mid-water-column, which is a very different hydrodynamic environment. The two different studies may also not be comparable due to spatial or temporal variability in the area, neither of which is well understood at this or other tidal energy sites. More datasets collected simultaneously with a variety of acoustic methods would facilitate the merging of results from different portions of water column and different locations within the Passage, leading to a better understanding of fish distribution patterns.

Another difference between this study and previous work in Minas Passage was the presence of the TISEC device. This could certainly contribute to the tidal difference in target detection rates, as the targets detected during ebb tide would have been approaching the device and those detected during flood tide would have been departing from it, potentially at much lower speeds. Additionally, the sampled volume during flood tide is within the device wake, which is likely more turbulent than the water sampled during the ebb. Targets traveling in more turbulent flow would have more variable echo strength as their orientation changes, and they could spend less time travelling laterally within the beam, both of which could lower their probability of detection. Near-field avoidance of the device structure could also result in fewer target detections downstream (flood tide) than upstream (ebb tide), but whether avoidance of the structure would occur along the sea floor cannot yet be determined.

The observed diel and tidal differences in target detection rates were consistent across the sampling period, indicating no major shift in target responses to either. This contrasts previous studies, which found the vertical distribution of fish to change with tidal and diel stages depending on the time of year and species present (Viehman et al. 2017, Melvin and Cochrane 2014, Viehman and Zydlewski 2017, Viehman et al. 2015, Daroux and Zydlewski 2017). More information is needed on the species present over the course of the winter to know if the lack of change observed here is due to a more consistent animal assemblage (and therefore consistent responses to environmental factors) or to the portion of water column observed (which has been omitted from most previous studies). It is possible the animal assemblage did not change much from November to April, as major migrations through Minas Passage occur primarily in the spring (April through May) and fall (September to October) (Baker et al. 2014, Dadswell 2010, Redden et al. 2014). Alternately, if animal movement is primarily governed by the strong currents, shifts in species assemblage structure may not be reflected in observed detection rates.

#### *3.1.4 Target abundance in relation to current speed*

Interestingly, target detection rates were higher during mid-range current speeds than at low or high speeds (Figure 14). This was especially evident for the ebb tide. The increase in detection rate from low to mid-range speeds during ebb tide could be due to the increased volume of water sampled. However, this relationship does not hold for higher speeds, which could indicate that either the detection probability of targets decreases at the fastest speeds (e.g., they get harder to see), or targets are less abundant at this depth and/or location at higher current speeds (e.g., flow-related changes to animal vertical or horizontal distribution could mean they are outside of the sampled volume at peak flows). Note that flood tide current speeds, as modelled and shown in Figure 14, are representative of the water column at rotor height and not the portion of the water column sampled by the sonar, where flow is likely reduced by the presence of the CST TISEC device.

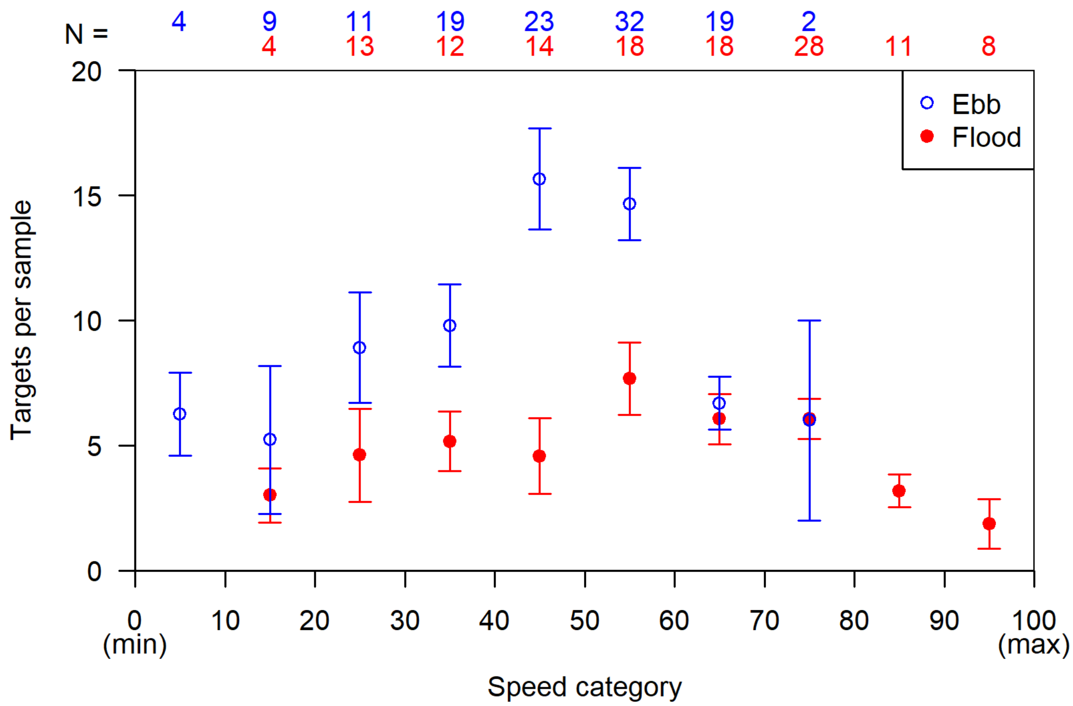


Figure 14. Targets per 5-minute sample at different current speeds during ebb (blue) and flood (red) tides. Points are mean targets per sample for each speed category, whiskers are 1 standard error. Normalized current speed data for turbine rotor height, courtesy of OpenHydro.

### *3.1.5 Seasonal trend in size of target aggregates (potential schools)*

Forty-five large targets were detected that appeared to be aggregations of smaller targets, (i.e. possibly schools of fish; Table 2). The sizes of these targets were on the order of 1 to 3 m across (Figure 15), and appeared to increase in size slightly toward the end of the sampling period, though the sample size was not large enough for statistical assessment. The frequency of these school-like targets decreased over the course of the sampling period (Figure 15). Fish in schools have previously been found to react to a test tidal turbine at slightly greater ranges than individual fish (Viehman and Zydlewski 2015). As monitoring continues, the behaviors of individuals and schools should be compared.

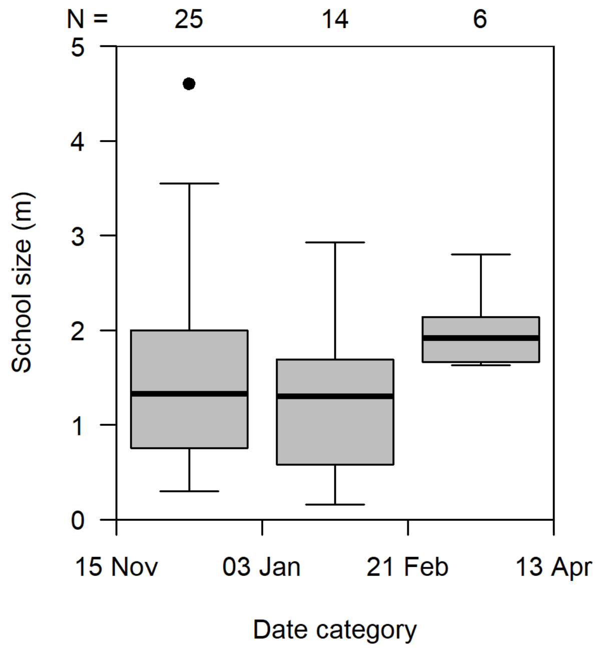


Figure 15. School size over time. Horizontal lines indicate the median, boxes span the 25th to 75th percentile, whiskers extend to 1.5 times the interquartile range, and points are outliers.

## 3.2 Target movement and direction

### *3.2.1 Individual targets*

The start and end locations of each target were used to calculate each target's net direction of movement (Figure 16). It should be noted that this method doesn't take into account changes in direction between start and end points, and may not reflect a target's final direction if the path was not direct. As automated tracking algorithms are improved, parameters such as track tortuosity (i.e., how much the tracks twist and turn) can be calculated and potentially used as metrics of target behaviour, or as a method to separate passively drifting debris from actively moving organisms. These techniques will be applied to future Gemini datasets that span a large fraction of the water column and a range of 60 m, thus offering better opportunities to determine the nature of the target, and to assess animal avoidance and evasion behaviours.

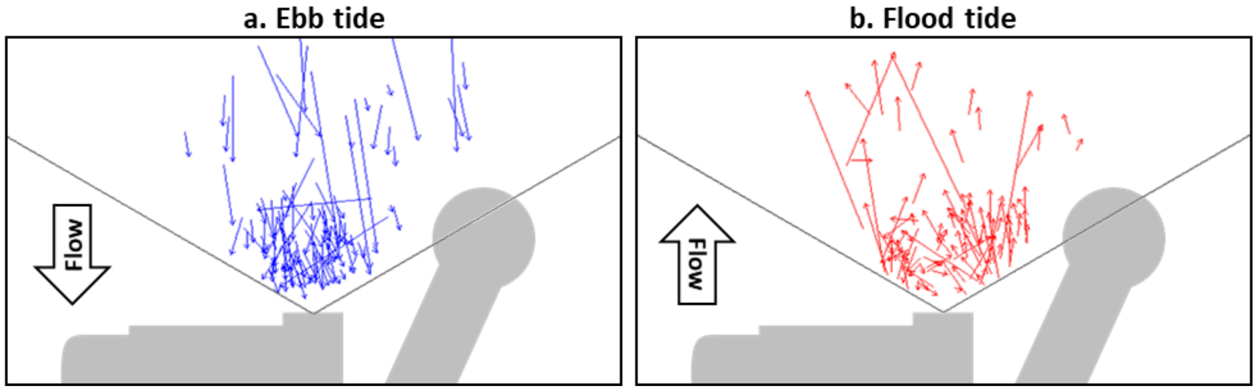


Figure 16. Examples of target movement. Shown are 100 randomly sampled targets detected during (a) ebb and (b) flood tide. A random subset was used because plotting of all targets makes the paths impossible to see. Note that data available for this study is limited to targets detected within 10 m of the sonar.

The majority of target movement was in the general direction of the modelled flow (Figure 17), as has been observed at other tidal power sites (Hammar et al. 2013, Viehman and Zydlewski 2015, Viehman 2017). However, there were some notable deviations from the modelled current direction. First, during the ebb tide, a large proportion of targets moved at an angle slightly offset from the modelled flow (approximately 5° to 20° counter-clock-wise, Figure 17a). It is possible that this reflects the deflection of flow around the device, or a behavioral response of animals as they approached the structure. During the flood tide, there was noticeably more variation in target movement (Figure 17b). This variation was highest closest to the CST device, directly downstream of the turbine structure (Figure 18b), but this was not seen during the ebb tide, during which variation was relatively constant regardless of location (Figure 18a). This difference could also be explained by changes to the flow field caused by the device structure. During the flood tide, most of the sampled area would have been directly in the wake of the device. The higher turbulence within this wake could cause targets moving with the flow to exhibit greater variation in movement than they would in the relatively uninterrupted flow upstream. Fish have been observed milling in the wake of a test turbine at another location (Viehman and Zydlewski 2015), and it is also possible this was occurring downstream of this device. More fine-scale information on the flow field up- and down-stream of the device, either measured or modelled, would improve our ability to determine whether observed movements were due to the passive movement of targets with the flow or to active behavioral responses of targets to the device or flow field. Automated tracking could also provide further insight on passively vs. actively moving targets by introducing more in-depth target parameters, such as track tortuosity and variation in echo intensity.

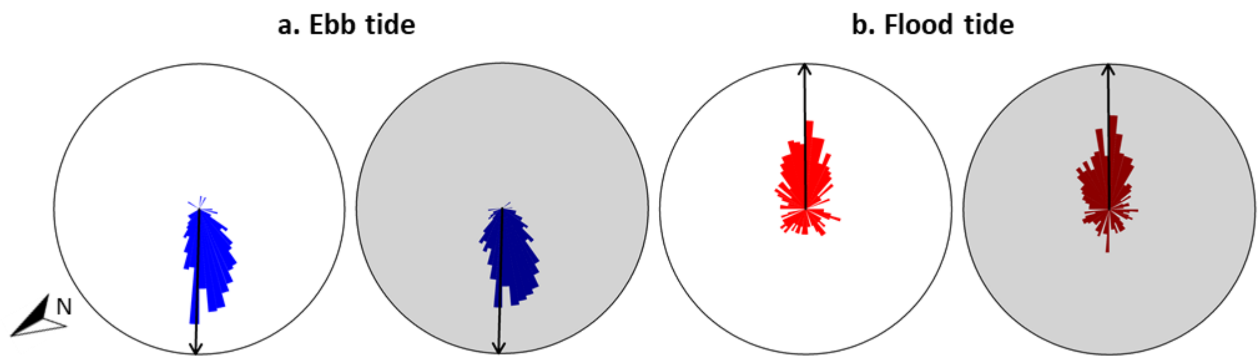


Figure 17. Directions traveled by targets during ebb (a) and flood (b) tides. Results are shown for day (white) and night (gray). Bars indicate the proportion of targets moving in each direction, and the arrow indicates the mean modelled flow direction for each tide.

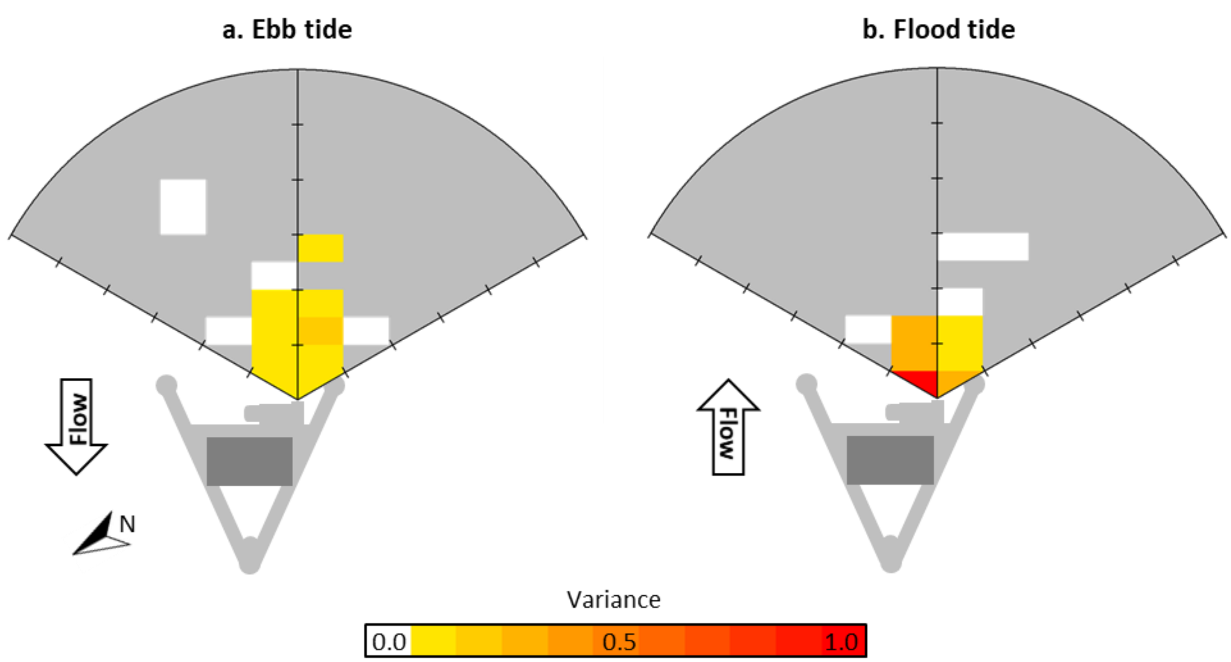


Figure 18. Variation in movement direction. The variance of movement direction for each beam grid cell was calculated for (a) ebb tide and (b) flood tide. Variance of 0 indicates unidirectional movement, while variance of 1 indicates random movement.

There was no noticeable difference in target movement direction between day and night (Figure 17). However, when the Gemini is reoriented and viewing the water column at turbine rotor height, comparisons between day and night may detect turbine effects on movement (targets may be more likely to react to the structure when it is visible; Viehman and Zydlewski 2015).

### *3.2.2 School-like targets*

No general trends in movement could be determined for school-like targets (aggregations of small targets), as there were few detected during each tidal stage (Table 2). There were however visually interesting differences in movement paths (Figure 19). For example, target aggregates approaching on the ebbing tide appeared to move toward the beam center (Figure 19a), while those departing on the flood tide (Figure 19b) displayed generally uniform movement compared to that of other targets (Figure 16b). Fish schools have been found to respond differently to threats and obstacles than individuals—e.g., reacting farther away from a test tidal turbine (Viehman and Zydlewski 2015). The differences in behavior between individual targets and aggregated targets should be assessed in the future, as they may respond differently to tidal energy devices.

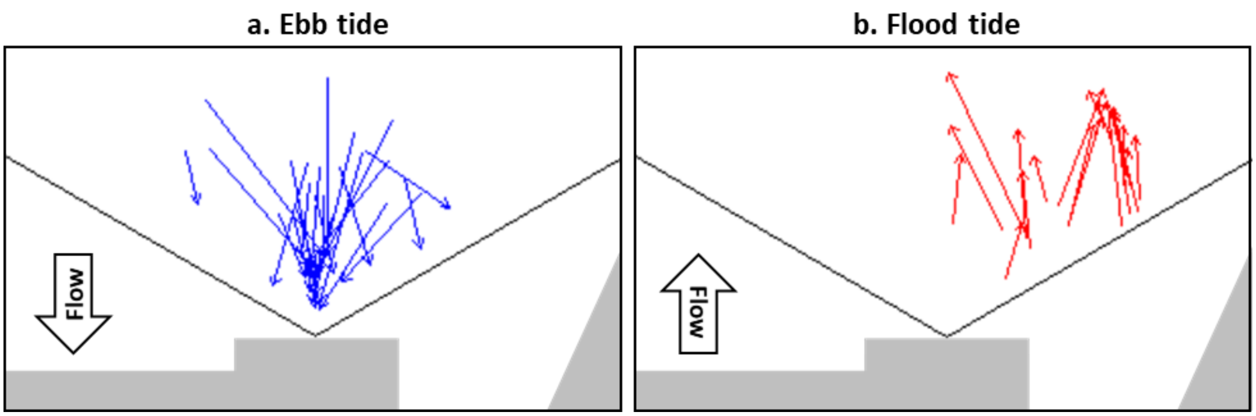


Figure 19. Movement paths of detected aggregates (possibly schools) during (a) ebb and (b) flood tides.

# 4 Conclusions

Biologically relevant trends were apparent during this study. The decrease in target abundance with decreasing winter temperatures is consistent with other biological surveys of the area. The differences observed between day and night and ebb and flood tide were remarkably consistent over time and raise interesting questions about animal activity near the sea floor as opposed to mid-water-column in high-flow tidal channels.

Target movement direction, though calculated using only start and end target locations, also exhibited patterns that aligned well with the physical environment. Differences in movement direction during ebb and flood tides and across a range of current speeds indicated a relationship with water flow, which is to be expected in currents of this magnitude. These data may have also indicated an effect of turbulence downstream of the CST device, during flood tide, on target movement. More information on the fine-scale hydrodynamics around the device could help determine if this is the case.

While there remain many improvements that should be made to the data processing and analysis methods (e.g., automated processing techniques), the results presented here, albeit for a lower than anticipated portion of the water column, are encouraging for the future use of the Gemini sonar to monitor animal presence and behavior in the near-field of the CST TISEC device.

The potential for an overall improved dataset from a re-oriented sonar device and a longer (planned) deployment of a turbine will provide an opportunity to obtain data with increased spatial and temporal coverage. This will help to clarify the Gemini results discussed in this report, improve understanding of year-round presence and spatial distributions of marine animals, and therefore help to meet the overall objective of understanding how fish and marine mammals might interact with the in-stream turbine.

# 5 Recommendations

Aspects of data collection, processing, and analysis that can be improved in future applications are described below.

### *5.1.1 Data collection*

To obtain high-quality data amenable to automated processing, care must be taken to orient the Gemini in a way that provides a view of only the water column (i.e., removal of the sea floor from the view) and that reduces any interference from solid structures. For the next deployment, the re-orientation of the sonar will be confirmed through a number of commissioning tests prior to deployment, while the turbine is in port and partially submerged. The influence of turbine structures on the view will also be considered at this time since reflections from objects like the foot of the subsea base can cast acoustic 'shadows' or wash out the signal from targets occurring at the same range (Figure 2a).

This study highlights the importance of simultaneous collection of biological and physical data. The modelled current speed and direction data were useful for examining general trends, but high-resolution current speed and direction information, up- and down-stream of the turbine, would help with separating active and passive target behaviors. Communication with the sonar must be high-quality and consistent, which can be difficult when multiple instruments are communicating with shore via the same cable. In this case, communications interruptions resulted in numerous small gaps throughout the dataset that made target detection and tracking more difficult, and these gaps would greatly complicate automated tracking in the future. To address this, all instruments will be run together and tested while the turbine is still in port (i.e. prior to deployment) to ensure that the new cabling and set-up provides improved data acquisition.

If multiple instruments cannot function adequately at the same time, they could be integrated (e.g., alternate pings) or potentially duty-cycled. The results of the present study indicate diel, tidal, and seasonal differences in target abundance and movement, congruent with other studies at tidal power sites (e.g., Viehman and Zydlewski 2017). Any non-continuous data collection (duty cycling) should ensure that sampling occurs often enough to characterize changes related to short-term cycles, such as the tide, but over enough of a time span to capture longer-term changes, such as those related to the seasonal cycle. For example, sampling several minutes of every half hour may be sufficient to characterize behavioral responses over the course of a tidal stage, and it is possible that not every day of the year will need to be sampled to capture seasonal differences. However, the most appropriate subsampling routine for the Gemini sonar mounted on the CST device should be determined based on a high-quality, continuous dataset.

### *5.1.2 Data processing*

Validated, automated processing methods are needed for the Gemini sonar if it is to be used for monitoring purposes. It can take a highly-trained observer up to 40 minutes to extract even the basic metrics used above from a 5-minute Gemini data file. While this time may be reduced with a cleaner dataset, manual data processing is simply too labor- and time-intensive for use in long-term monitoring. Moreover, an automated tracking algorithm could export many more potentially useful metrics for target behavior analysis, including frame-by-frame location within the beam, size, and echo strength. Gemini data processing has been automated for large targets such as seals and other marine mammals (Jepp 2017), but the methods for detecting and tracking smaller targets, such as fish, are still in progress (Jepp 2017, Appendix 1). The development of suitable processing algorithms will be facilitated when the Gemini's view is reoriented to cover only the water column.

A certain amount of manual processing will be necessary to validate the results of an automated system, to quantify its error rate relative to a human observer, and to ensure its continued functionality over time. Manual data processing with the Gemini *SeaTec* software can be improved substantially by allowing measurements to be taken in the magnification window. This would allow many more of the small targets within the first 10 m of the Gemini to be located and measured for inclusion in the dataset. It is essential that the human observer be trained on a data subset prior to processing Gemini data for use in monitoring or validating automated detections. Afterward, an observer's precision and consistency should be reassessed periodically with previously examined data subsets.

### *5.1.3 Data analysis and interpretation*

This report explored some of the ways Gemini data can be partitioned and displayed. To detect turbine effects, it will be important to continue to assess temporal and spatial variation in metrics extracted from Gemini data. Combining these data with information on the physical environment (e.g., wake characteristics) will improve identification of active and passive target behaviors and which of those may be responses to the device. Due to the sonar orientation error prior to the November 2016 deployment, almost all targets identified were within 10 m of the device. With a correctly oriented sonar, future assessments will include tracking of target movements over a wider range of distances from the device. Additionally, with more targets detected throughout the sampled volume, a finer grid could be applied to generate summary statistics and images that are more useful for turbine effect assessment.

As automated processing methods are implemented, new metrics will become available for use in behavioural analyses. For example, obtaining target location across multiple frames, rather than just the starting and ending positions, would allow metrics such as tortuosity to be used, and any substantial changes in a target's path could be assessed as potential responses to the device. Frame-by-frame position, echo strength, and size is likely to be useful in separating passively drifting objects (debris) from those with directed movement (animals).

It will also be important to assess the detection probability of targets throughout the Gemini's field of view under a range of environmental conditions—for example, at low to high current speeds. This is necessary for understanding potential sources of bias in the results.

All results obtained from the near-field of the CST device must be considered in the larger context of Minas Passage and the fish populations that utilize it. Mid- and far-field monitoring are well outside of the CST EEMP requirements, but information from broader-scale studies of the area will help with Gemini data interpretation. Spatial and temporal distribution of animals in the Passage are currently being characterized with various methods, including drifting hydrophones (Sanderson et al., in preparation), mobile active acoustic surveys (Daroux et al. 2017, FORCE 2017, Melvin and Cochrane 2014), and stationary active acoustic fish surveys (Viehman et al. 2017).

Overall, a better general understanding of the fish present in Minas Passage during all times of the year would help interpret any active acoustic data, whether from imaging sonars like the Gemini or from scientific echosounders (e.g. Viehman et al. 2017, Daroux and Zydlewski 2017, Melvin and Cochrane 2014). While not within the scope of the CST EEMP, this information could be acquired by the broader scientific community through physical sampling methods, such as trawling. Given that trawling can be very difficult and dangerous in fast tidal flows, a potential solution, first suggested by Keyser et al. (2016), would be to sample down-stream of the passage, at the start of Minas Channel or Minas Basin, just before slack tide. Then, any fish captured would likely have just been within the passage itself. Acoustically tagging and tracking a variety of fish species and life stages would also be helpful in determining their seasonal to year-round presence and spatial distribution. This has been done for Atlantic sturgeon (Stokesbury et al. 2017), striped bass (Keyser et al. 2016, Broome 2014), and to some extent for American eel (see Redden et al. 2014). Further tagging studies to track fish in Minas Passage are planned for 2018 (pers. comm., Mike Stokesbury, Acadia University), and will contribute to the knowledge base on fish movements through the FORCE test site.

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# Appendix 1

# Gemini Imaging Software Target Identification:

# Preliminary Analysis Report

## Introduction

The following document is a summary of a preliminary comparison of automated target tracking and human visual identification of possible targets using video recorded by the Gemini Multibeam Imaging Sonar installed on the Cape Sharp Tidal Turbine gravity base and deployed at the Fundy Ocean Research Center for Energy in November 2016. For this report, the Gemini Imaging Sonar Software was used to detect targets in the available Cape Sharp video files recorded on November 17th, 2016. Automated target detection was conducted by Tritech International Ltd. The following manual target detection and comparison with automated detection was carried out by Acadia University. This analysis was conducted in order to examine the performance characteristics of the automated target detection software, with the assumption being that the manual target detection would be an accurate and reliable reference point. The eventual goal of this work is to use automated and manual target detection comparisons to improve the automated target tracking algorithm.

## Gemini Data

The Gemini Multibeam Imaging Sonar was mounted on the Cape Sharp turbine gravity base at approximately 4 meters above the seafloor, and facing east towards Minas Basin. The Gemini acoustic camera images a swath of water using an array of 256 acoustic beams at 720 kHz. With the Gemini oriented horizontally, it has a 120° spread in the horizontal dimension and a 20° spread in the vertical direction. In the data files examined, the first few meters of data show the water column, after which the sampled volume extends to the seafloor (Figure 1).

The video files were recorded at approximately 11 frames per second, which allowed the identification of potential targets (moving objects that could possibly be marine life). Figure 2 shows a typical example of an identified target moving toward the turbine (the target appears as a line, which traces its movement across the screen), although targets may vary in color, shape, and brightness depending on such variables as target size and distance to the Gemini Sonar. The individual video files reviewed were on average 307,400 KB in size and approximately five minutes long.

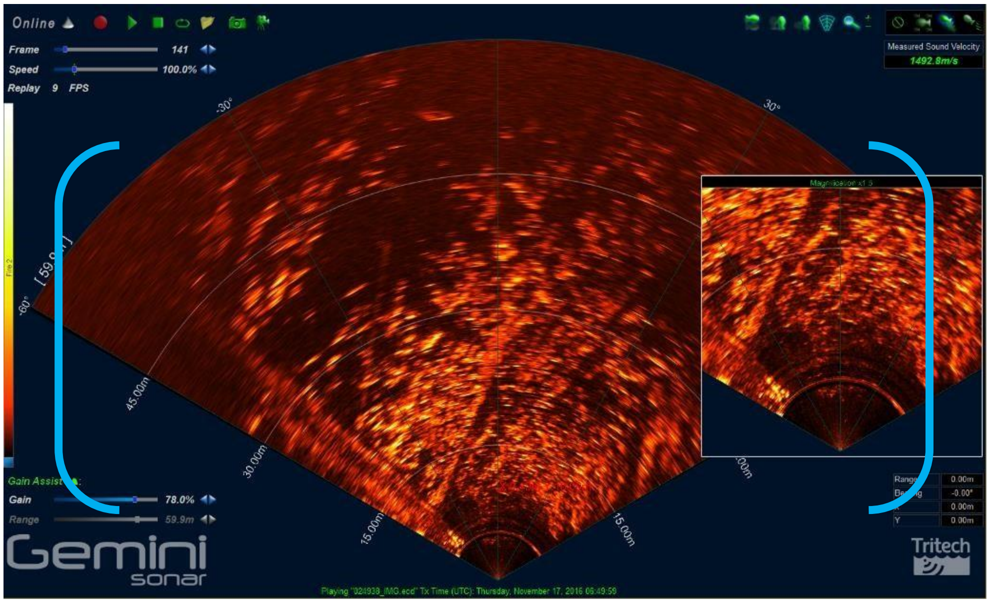


*Figure 1. Gemini Imaging Software screenshot, with the first five meters shown in white brackets and the view that includes the seafloor in blue brackets. The first 20 meters are shown in the magnification window overlaid on the right.*

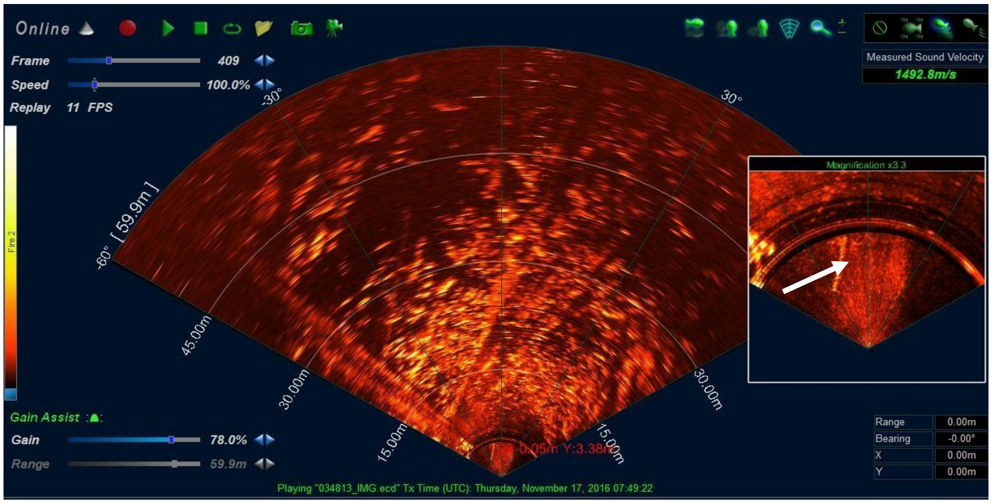


*Figure 2. Example of an identified target in the Gemini video, labelled with a white arrow in the magnification window.*

The semidiurnal tidal pattern on 17 November 2016, with two high and two low tides within 24 hours, is shown in Table 1. This day was chosen for an example because it was the day with the overall highest rate of detections, mostly false positives. Conversely, other days (e.g., November 21) were chosen because of the lowest rate of detections, which meant it was easier to examine each target individually.

These comparisons allow researchers to compare different days and understand the scope of the analysis and how it can vary.

*Table 1. Tidal cycle at the FORCE tidal test site for November 17, 2016. (Fisheries and Oceans Canada, 2016)*

| Atlantic Standard Time (hh:mm) | Coordinate Universal Time (hh:mm) | Water level (m) | Tidal Stage |
|---|---|---|---|
| 02:05 | 06:05 | 12.9 | high |
| 08:21 | 12:21 | 0.3 | low |
| 14:26 | 18:26 | 13.1 | high |

The tidal cycle and direction of current help to explain specific behaviours exhibited by targets, such as moving away from the turbine (ebb) or towards the turbine (flood).

## Software Settings

The following settings were used when manually reviewing the video footage:

- **Image Orientation:** The image was inverted upwards, oriented to the left, and rotated upward (Figure 3). The most prominent feature on screen was a v-shaped structure, which was located at a range of (-7.50 m, 8.48 m).

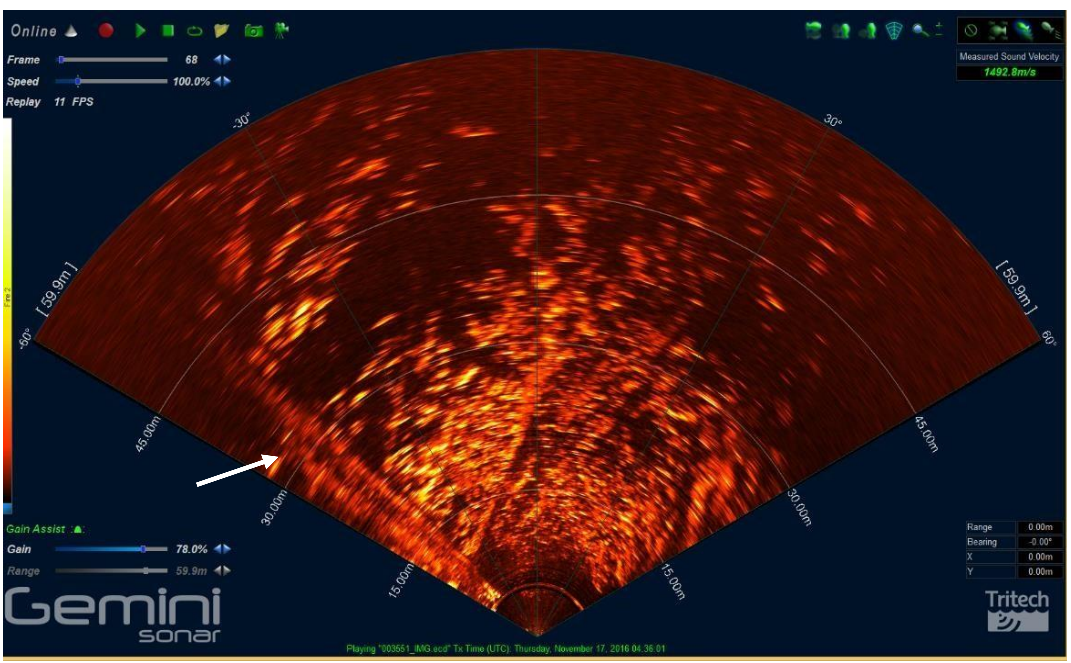


*Figure 3. Image orientation of Gemini video during analysis showing vertex of prominent vshaped structure (arrow).*

- **Gain:** The gain, or brightness of the video on screen, was usually kept between 78% and 100% (Figure 4) depending on the background noise present, which showed up as 'speckles' on the screen. However, for some video files lower gain was necessary as the video image itself already appeared very bright, making it difficult to identify brighter targets. Higher gain proved to be more effective in the identification of smaller targets.

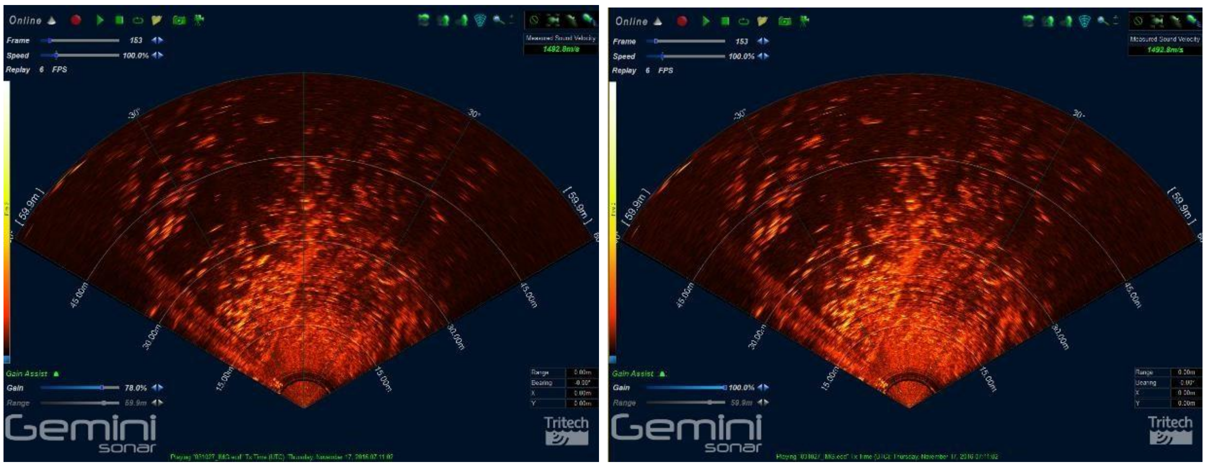


*Figure 4. Comparison of Gemini video frame viewed at 78% gain (left) and 100% gain (right).*

- **Speed:** The speed of the video replay was adjusted according to ease of viewing and the number of identifiable targets. When there was an increase in background noise or number of targets present, the speed was reduced to 90%.
- **Averaging filter:** Averaging (in the 'Advanced' tab, under filter settings) takes a weighted average over current and previous frames to smooth frame-to-frame variation, which can make moving targets easier to see against the stable background. Averaging was left at 50% because no improvement in the video quality could be observed when changing this setting.
- **Persistence filter:** The persistence can be used to highlight movement across frames. As the frames progress, the persistence filter retains a decreasing number of earlier frames as well as the current frame, creating a line that tracks a target's movement over time. The persistence level was changed depending on the targets being identified. Extreme persist (99% and 99.5%) was the most effective when trying to track smaller, dimmer targets, as their track would persist longer, making it easier to pinpoint target position over time. Long persist (96% or 98%) was more suitable for larger and brighter targets, as they were easily identifiable without extreme persistence (Figure 5). The shorter persistence caused the tracks to disappear faster, which made it easier to move forward and backward frame by frame without the track remaining in view.

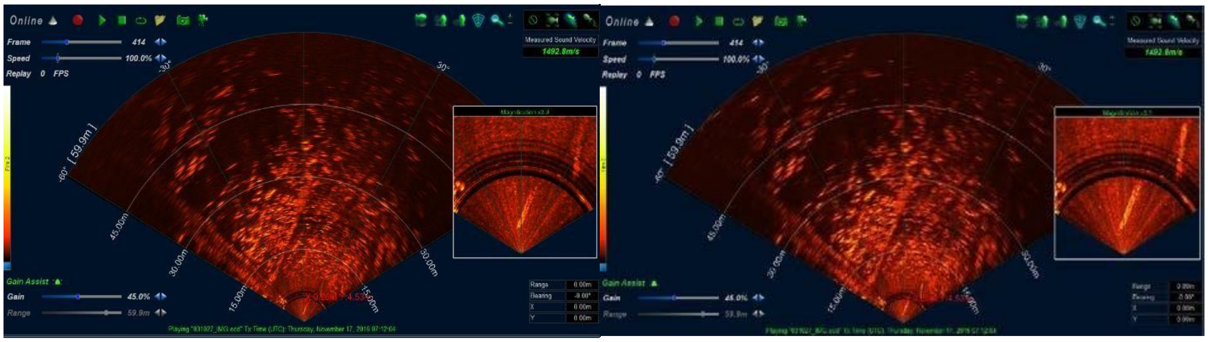


*Figure 5. Comparison of the same target identified from the Gemini video with 96% (left) and 99.5% (right) persistence, with magnification windows focused on target.*

- **Movement filter:** The movement filter, which reduces signal from any objects that remain stationary from frame to frame, was kept at 60% to allow better identification of targets, but this filter level could be increased if background noise is low (Figure 6).

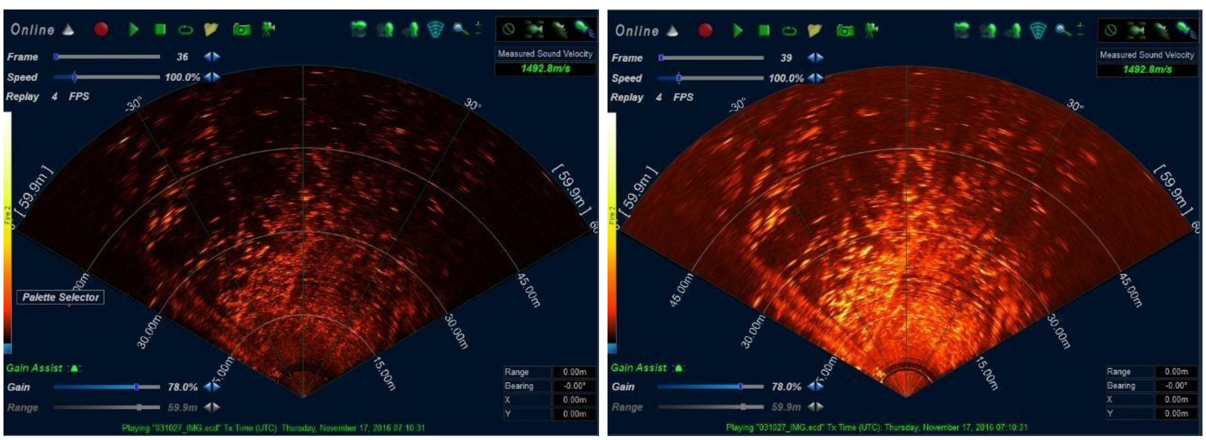


*Figure 6. Comparison of video viewed with 100% movement filter (left) versus 0% movement filter (right).*

- **Target tracking:** Target tracking was not enabled as it was not accurate enough for smaller targets (less than 0.5 meters). For this study, only manual target detection was used for tracking movements.

## Target Identification

The following procedure was used to identify possible targets (moving objects that may be marine animals). The automated tracking program was used by Pauline Jepp at Tritech to identify files with many potential targets, and these files were then reviewed to get an idea of what targets look like. Once accustomed to target identification, entire five-minute files were viewed. Each video file was watched twice, focusing on different ranges each time. First, the 0-15 m range was watched using 1.5x magnification to identify smaller targets (Figure 7), which were generally only visible at close range due to decreasing resolution with range in addition to bottom interference and 'specks' decreasing visibility on the screen.

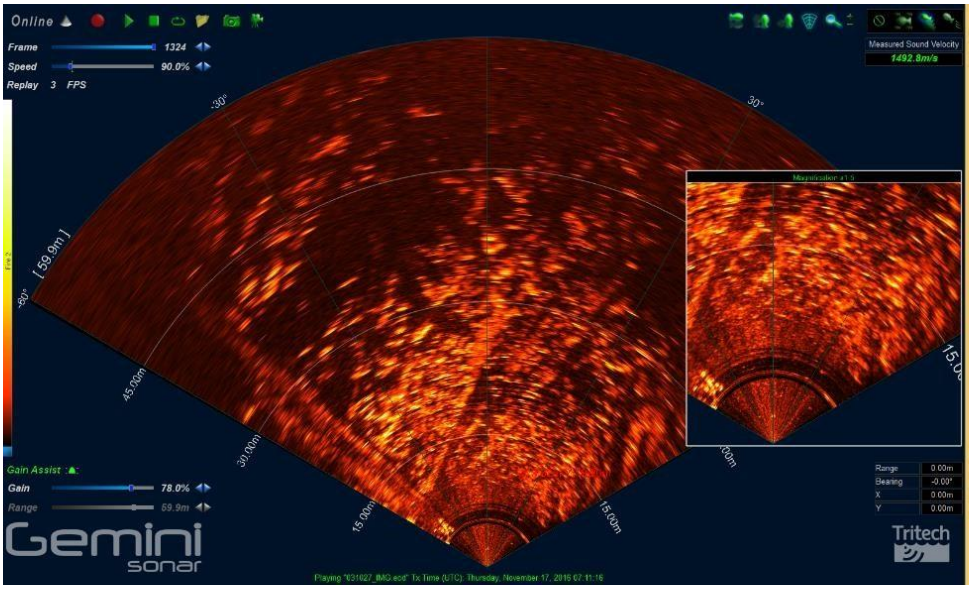


*Figure 7. Example of the larger view of the Gemini video, with the 1.5x magnification window (right) used for viewing the first 15 m.*

When watching a second time, the focus was on the 15-60 m range. The use of magnification was discontinued after examining three videos because often what could be seen on the magnification screen could not be identified on the larger view.

During viewing of the Gemini video, potential targets were first identified, then the video was rewound and watched frame by frame (by clicking the frame button). The target position and time was recorded for every second, or more if the target was either moving larger distances over the one second time frame or the track showed up within one second (Table 2).

*Table 2. Example of Excel sheet created for targets manually detected in Gemini video. Columns are file number, date, time, position, notes, tidal stage, target size, matched automated detection, and the numerical IDs of automated targets not detected manually.*

| File # (re-recorded data) | Date dd/mm/yyyy | Time (UTC) | X | Y | Notes | Tidal Stage | target size category & length (m) | matched automated detection (Y or N) | automated targets not dectected manually |
|---|---|---|---|---|---|---|---|---|---|
| 024938 | 17/11/2016 | 06:50:30 | -1.00 | 2.68 | towards turbine, | ebb | <0.5, (0.16m) | N | 403100074 |
| 024938 | 17/11/2016 | 06:50:32 | -0.87 | 1.54 | possibly also something further to the left but could also be shadow (-1.14, 1.67) | ebb | | | 403100243 |
| 024938 | 17/11/2016 | | | | | ebb | | | 405010062 |
| 024938 | 17/11/2016 | 06:50:36 | 1.00 | 7.29 | towards turbine | ebb | <0.5, (0.25m) | N | 405200053 |
| 024938 | 17/11/2016 | 06:50:37 | 1.14 | 6.69 | | ebb | | | 405500017 |
| 024938 | 17/11/2016 | 06:50:39 | 1.20 | 6.42 | | ebb | | | 407200082 |
| 024938 | 17/11/2016 | | | | | ebb | | | 407500006 |
| 024938 | 17/11/2016 | 06:50:41 | 14.57 | 40.58 | towards turbine, | ebb | 1-1.5m, (1.38m) | N | 407560146 |
| 024938 | 17/11/2016 | 06:50:42 | 15.24 | 39.51 | Possibly the same | ebb | | | 407590120 |
| 024938 | 17/11/2016 | 06:50:43 | 15.37 | 38.71 | target | ebb | | | 408140071 |
| 024938 | 17/11/2016 | 06:50:46 | 17.18 | 35.97 | | ebb | | | 408140110 |
| 024938 | 17/11/2016 | 06:50:50 | 18.45 | 33.83 | | ebb | | | 408150063 |

Later, only the positions at the start and end of the target track were recorded. If a target could not be clearly identified (e.g., if there was increased background noise, or a broken up path), the uncertain targets were classified as either possible or probable targets.

Possible fish aggregations (Figure 8) were identified as a single unit, with a singular time stamp and estimate of the general range of the fish aggregation. Any unusual properties of a target (e.g. very bright and/or wide track) or any particular movements (e.g. moving away from the turbine) were also noted.

## Comparison of automated and manual target detections

Once all videos in which the automated tracking had identified targets were reviewed, automated detections were compared to those detected manually and matches were identified. A match was determined using the time of automatic detection and the range. Only 2 of the 135 targets identified through the automated tracking were matched to the manually detected targets in the videos reviewed to date. It should also be noted that the automated program identified fewer targets than detected by the human observer.

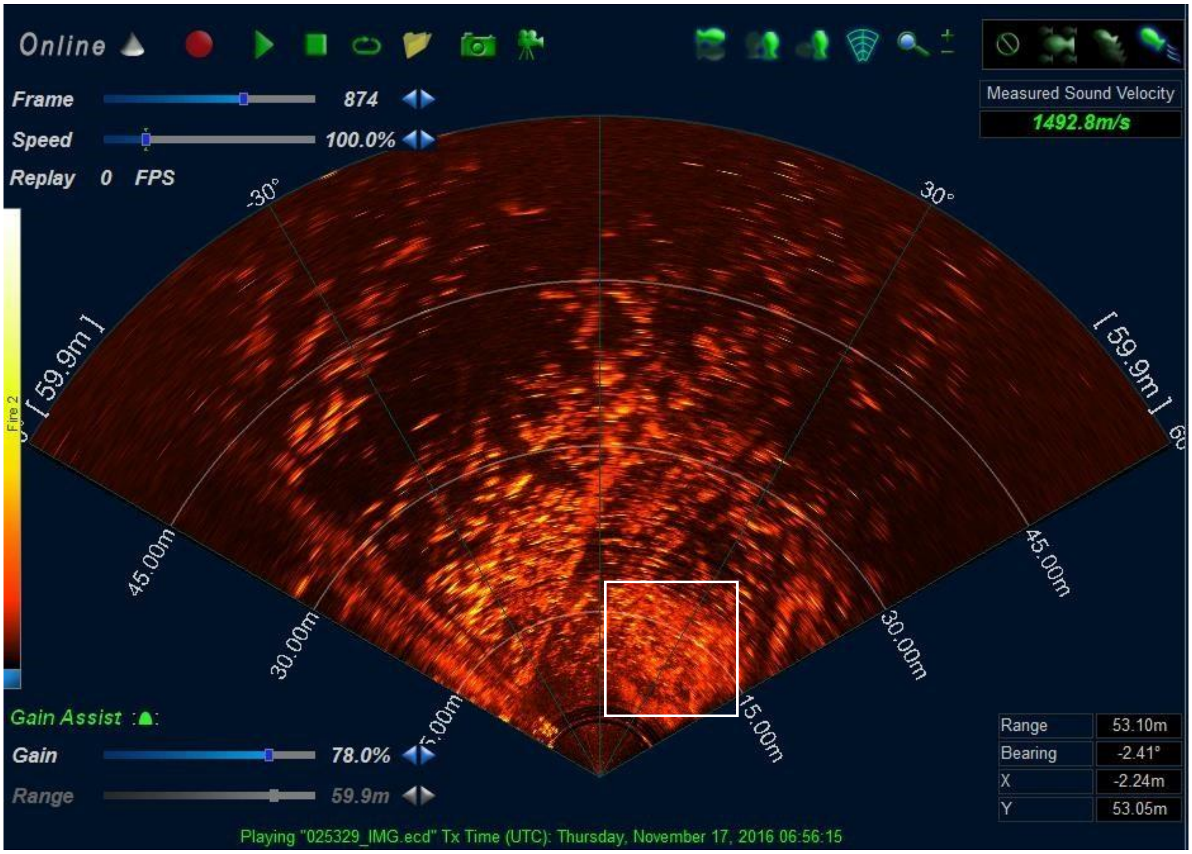


*Figure 8. Example of a possible fish aggregation (white box).*

## Conclusion

Overall, the quality of the video was sufficient to become comfortable with target identification. With experience, targets can be distinguished easily and confidently. One issue that was encountered was that the video did not run smoothly. Jumps of a second or more were common, making target identification and tracking more difficult. This was due to communications issues between the on-shore computer and the Gemini, which has been addressed for the future deployment (refer to Section 4.1.2 of the main Q3 Report). The automated tracking performance needs improvement, as substantially fewer targets were identified by the automated software than by the human observer, and even fewer could be matched with the manually detected targets.

There are a couple of changes that could be made to the software to make it more "user" friendly. It would be beneficial if the position of a target could be pinpointed more accurately. This could be done, for example, if one were able to pinpoint a target's position directly on the magnification window instead of only in the larger view.

Next steps will include further examination of more of the collected Gemini data. This will provide more comparison material for the development of the automated target detection algorithms. Attempts will also be made to better identify the targets (e.g. as fish).

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# Appendix F – Test of the FAST-EMS Sensor Platform for Assessing Gemini Multibeam Imaging Sonar and SeaTec Software Performance (May – June 2018)

# Test of the FAST-EMS Sensor Platform for Assessing Gemini Multibeam Imaging Sonar and SeaTec Software Performance (May – June 2018)

Final Report to Cape Sharp Tidal Venture

November 2018

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# Contents

# 1 Introduction

Cape Sharp Tidal Venture (CSTV) installed an OpenHydro Open-Centre tidal in-stream energy conversion (TISEC) device at Berth D in the Fundy Ocean Research Center for Energy (FORCE) Crown Lease Area in July 2018. For this demonstration project, CSTV was required to have an environmental effects monitoring program (EEMP). The overall purpose of the CSTV EEMP is to better understand potential effects and interactions of specific environmental components (i.e., fish, marine mammals, operational sound) in the near-field environment of the Open-Centre in-stream tidal device. This understanding will be useful for verifying the accuracy of environmental effects predictions made in the environmental assessment and will inform future monitoring plans.

Part of the EEMP addresses monitoring the potential effects of the TISEC device on fish with a Tritech Gemini acoustic imaging sonar. It involves one sonar housed on the TISEC device sub-sea gravity base, and another deployed on a remote sensing platform, FORCE's FAST-EMS (Environmental Monitoring System) positioned 30-40m from the TISEC device during times of particular interest (e.g., key periods of fish migration).

Manually processing the Gemini imaging sonar data (visual observations of video files) is extremely time consuming and is unrealistic for a long-term monitoring project. The manufacturer (Tritech International Ltd) has been advancing its SeaTec software to automatically detect and track fish within the Gemini's viewing window. The software development work is part of the Integrated Sensor Environmental Monitoring (ISEM) project that is underway and led by Cape Sharp Tidal Venture.

The purpose of this report is to present the Gemini data results of a test with the FAST-EMS sensor platform and to communicate on SeaTec fish-tracking software, identify limitations, and suggest future directions for research and development. The study also provides an opportunity to report on recent improvements made to the SeaTec software as well data management and access.

# 2 Methods

## 2.1 Gemini Sonar and Deployment

A Tritech Gemini 720is was mounted to a Kongsberg pan and tilt on the FAST-EMS remote sensor platform developed by FORCE (Figure 1). The platform was deployed from 27 May to 4 June 2018, between the FORCE beach front area and Black Rock Island, where FORCE has much prior platform deployment experience (Figure 2). Water depth was approximately 20 m at low tide. The platform sensors also included a Nortek AWAC Acoustic Doppler Current Profiler, for current speed measurements, and a camera. All devices communicated with shore via an underwater data cable.

The Gemini recorded data continuously for the duration of the deployment period, with data transferred to a shore-based server. Data files were made available via ftp and a subset of the data was visually examined by human observers at Acadia University. The same data subset was also processed by Tritech staff using SeaTec software.

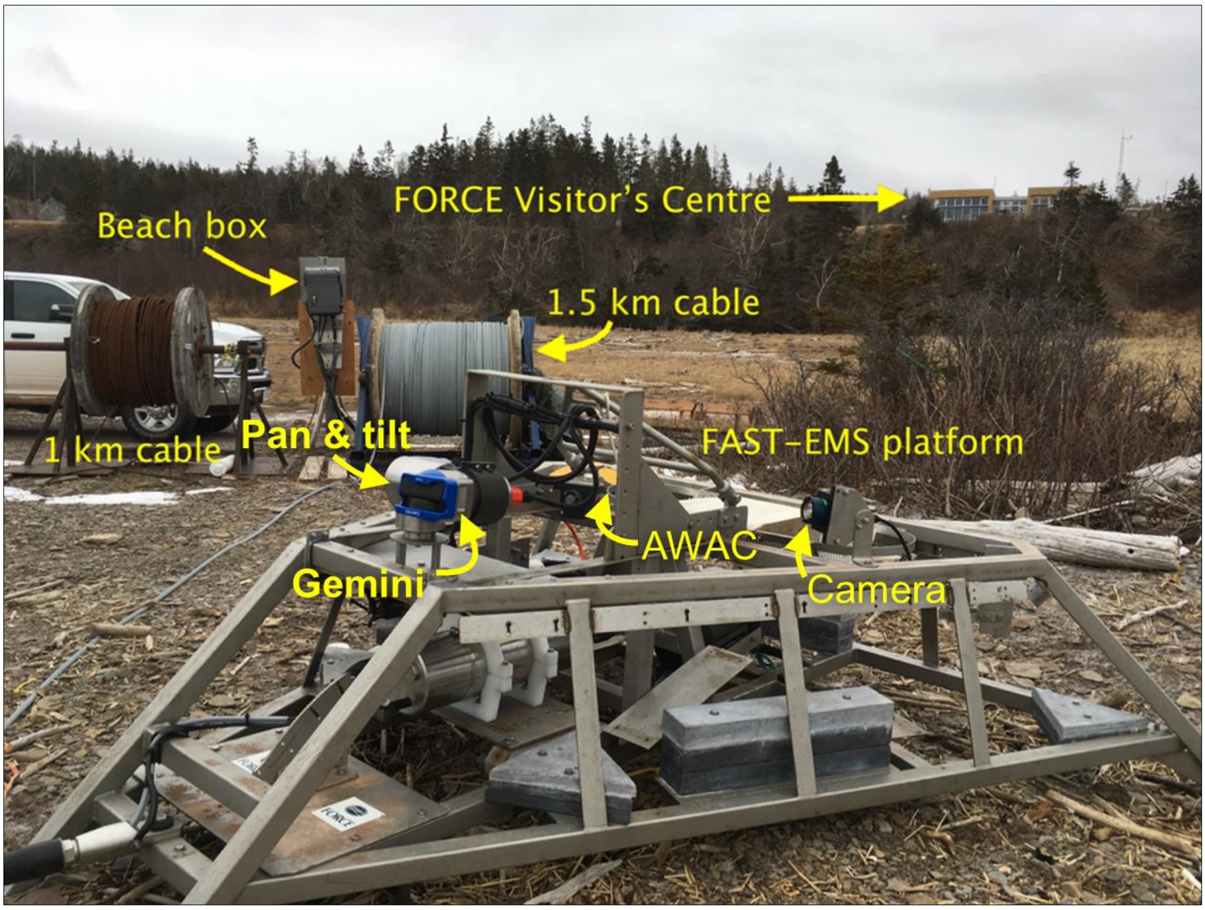

Figure 1.  FORCE's FAST-EMS remote sensing platform showing instrument locations.
Image courtesy of FORCE.


Figure 2. Location of platform in Minas Passage, 250m northeast of Black Rock. Shown are two different orientations of the Gemini sonar field of view (A and B). Eddies generated by Black Rock during ebb tide are visible at the surface.

The Gemini imaging sonar operated at a frequency of 720 kHz, with a frame rate of 10 frames per second, and insonified a 120˚ x 20˚ swath of water extending to 60 m range (Figures 3 and 4). Angular resolution was approximately 1°, so resolution was highest nearest the Gemini and decreased with range (approximately 9 cm at 5 m range, and 1 m at 60 m range) (Jepp 2017, Viehman et al. 2017b). The AWAC ADCP operated at 400 kHz and recorded data for 5 minutes every 15 minutes during deployment.

Data were collected continuously for the duration of the test. Testing procedures included establishing the effective ranges of motion of the Gemini sonar using the pan and tilt, assessing interference of the AWAC sonar with Gemini data, and determining optimal Gemini orientation for data collection at this site (Figure 3).

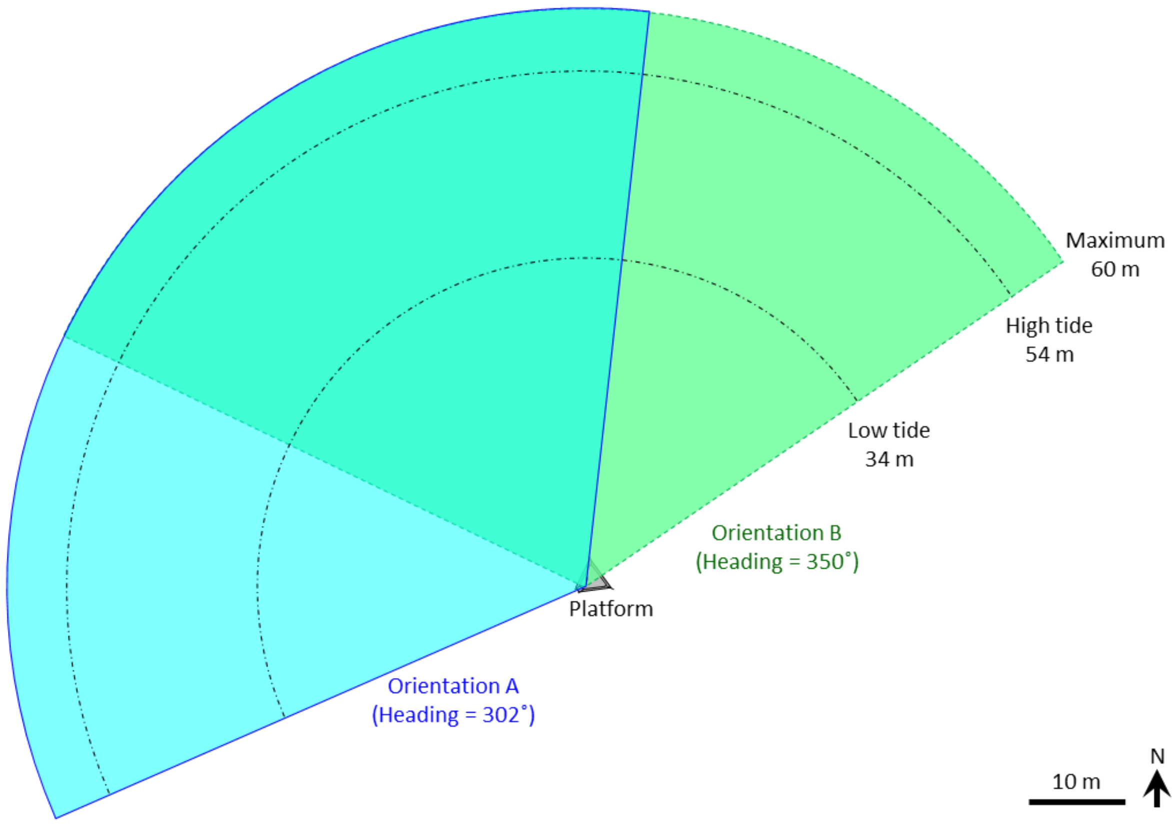


Figure 3. Schematic of platform and Gemini sonar fields of view from above, in the two tested orientations (A and B). Approximate ranges of surface interference at low and high tide are indicated by dashed black lines.

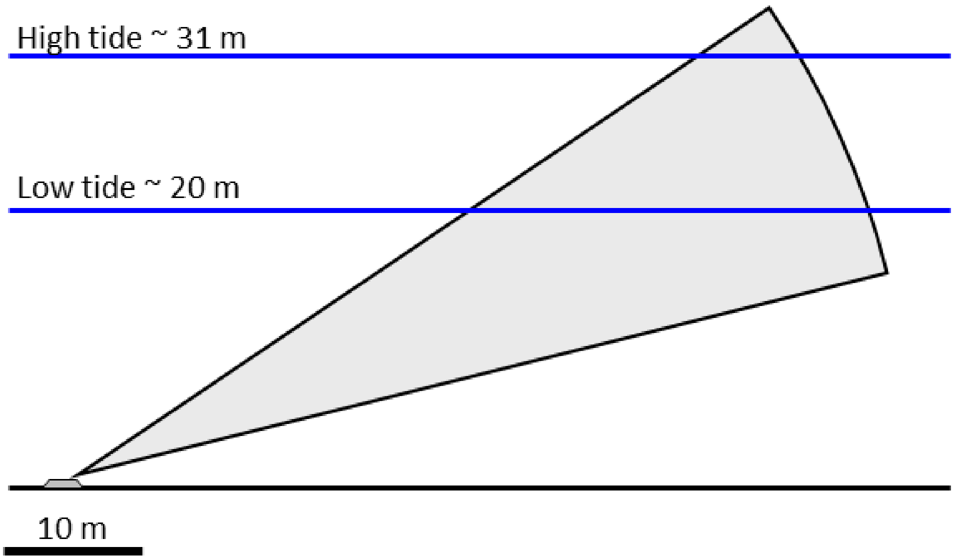


Figure 4. Profile schematic of Gemini orientation in the vertical dimension, with approximate water levels at low and high tide.

The lower limit for Gemini tilt angle at this location was 10˚ below horizontal (when the seafloor came into view), and the upper limit was 28˚ above horizontal (when the sea surface obscured most of the view). These limits will change depending on Gemini location relative to the surface and bottom. The FAST-EMS platform frame itself did not interfere with the Gemini view until 20˚ below horizontal was reached. The final tilt angle chosen for data collection was 14˚ above horizontal as this angle offered the best viewable window at high tide.

### 2.2 Data processing

Gemini data were subsampled to facilitate manual processing by human observers. One data file (approximately 2 minutes long) was chosen from each tidal stage (low, flood, high, and ebb) for each day of data collection. These files were watched by human observers at Acadia University. Observers recorded acoustic "targets" moving through the Gemini's view, defined as in Viehman et al. (2017b). Targets were classified as either individual fish, school of fish, entrained air, or unknown. General observations included target direction of movement (e.g., left, right, towards, away, or stationary), approximate fish school size (where applicable), the level of entrained air contaminating the view (low, medium, or high), and whether acoustic interference from the AWAC was observed. If AWAC interference in a file made target detection difficult, the next clean file was used for processing. Details on target location and movement direction were made available to Tritech for fine-tuning the automated detection software.

The visually analyzed data files, by human observers at Acadia, were processed by Tritech staff using the latest version of SeaTec software (2.4.5). This version of the SeaTec software is tuned to larger targets like seals or sharks and still requires refinement to identify individual fish, especially with low acoustic intensities or at farther ranges. However, schools of fish were very apparent. SeaTec detections of schools were compared with detections made by human observers, and results are presented and discussed below. SeaTec detection of small targets, assumed to be individual fish, was limited. It is therefore not addressed in the results presented in this report. Tweaking of two software parameters (detection sensitivity and tracking sensitivity) did not provide an increase in software detection of individual fish.

## 3 Results and Discussion

### 3.1 Data management

Gemini data management and access were improved since the 2016 TISEC deployment (Viehman et al. 2017b). All Gemini data (a continuous series of 2-min files, ~300 MB each) were stored within an external hard drive at the FORCE Visitor Centre. Data files were uploaded to an ftp site accessible by Acadia and Tritech personnel. All files selected for visual analysis were stored on a computer at Acadia. Images shown in this report are from data files viewed.

### 3.2 Data quality

The Gemini sonar operated smoothly, with no noticeable gaps in the analyzed files, and only minor electrical interference around 0° and at 37-39 m range (Figure 5).

Interference from the intermittent operation of the AWAC ADCP (5 min every 15 min) was observed as a series of short, high-intensity pulses in the Gemini data (Figure 6).

Other sources of interference were the surface of the water (Figure 7) and clouds of entrained air (Figure 8). Entrained air is surface-oriented but can, at times, extend far below the surface at highly energetic tidal sites (Viehman et al. 2017a, Fraser et al. 2017). Interference from the surface and entrained air was greatest at lower water levels (about 20 m deep) and higher current speeds, particularly during ebb tide, but was mostly contained in the 40-60 m range at the study site. Entrained air was likely exacerbated at certain tidal stages and flow levels by the proximity of Black Rock Island, which generates strong eddies during peak flow (Figure 2). These patterns in entrained air prevalence and intensity may not be the same at the turbine berth sites in the FORCE Crown Lease Area.

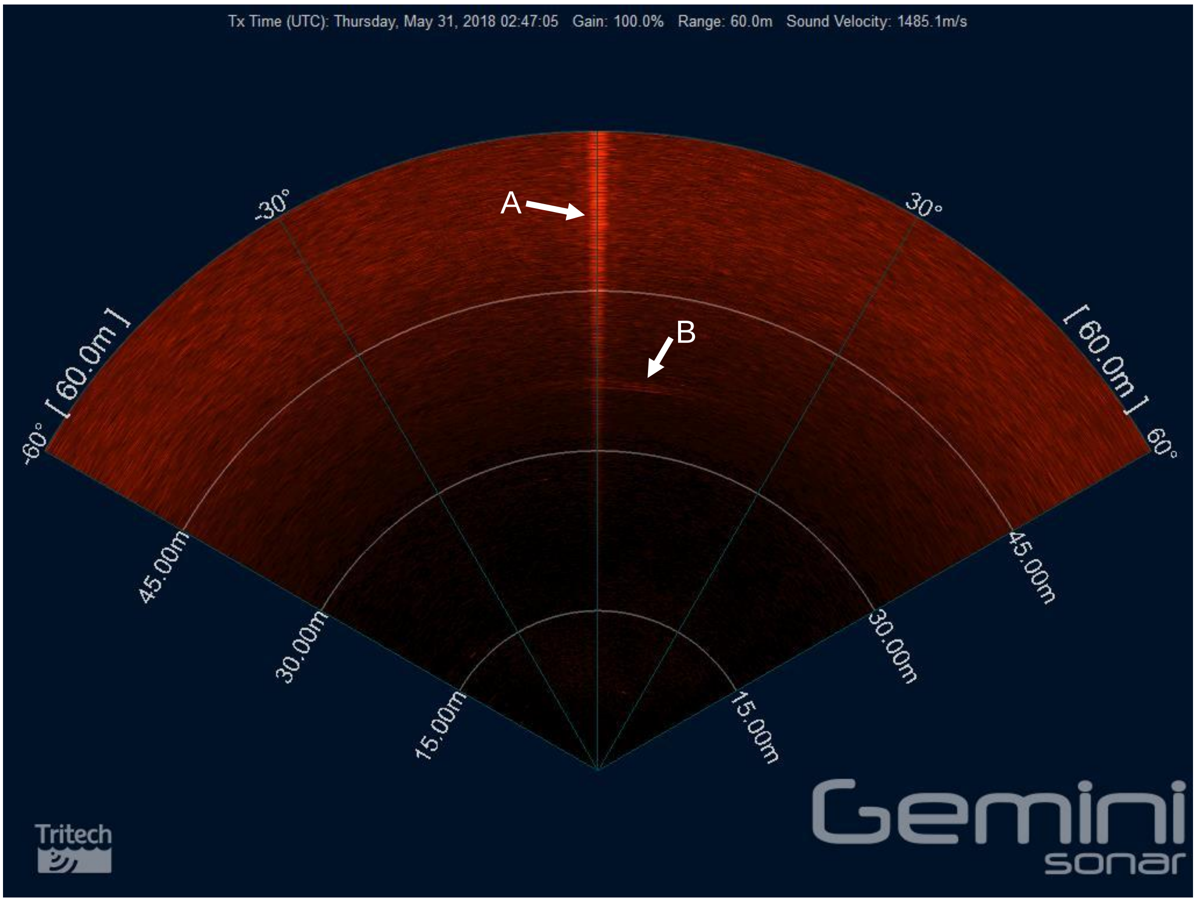

Figure 5. Gemini frame showing constant minor electrical interference (A) around 0° and (B) at 36-37 m range.

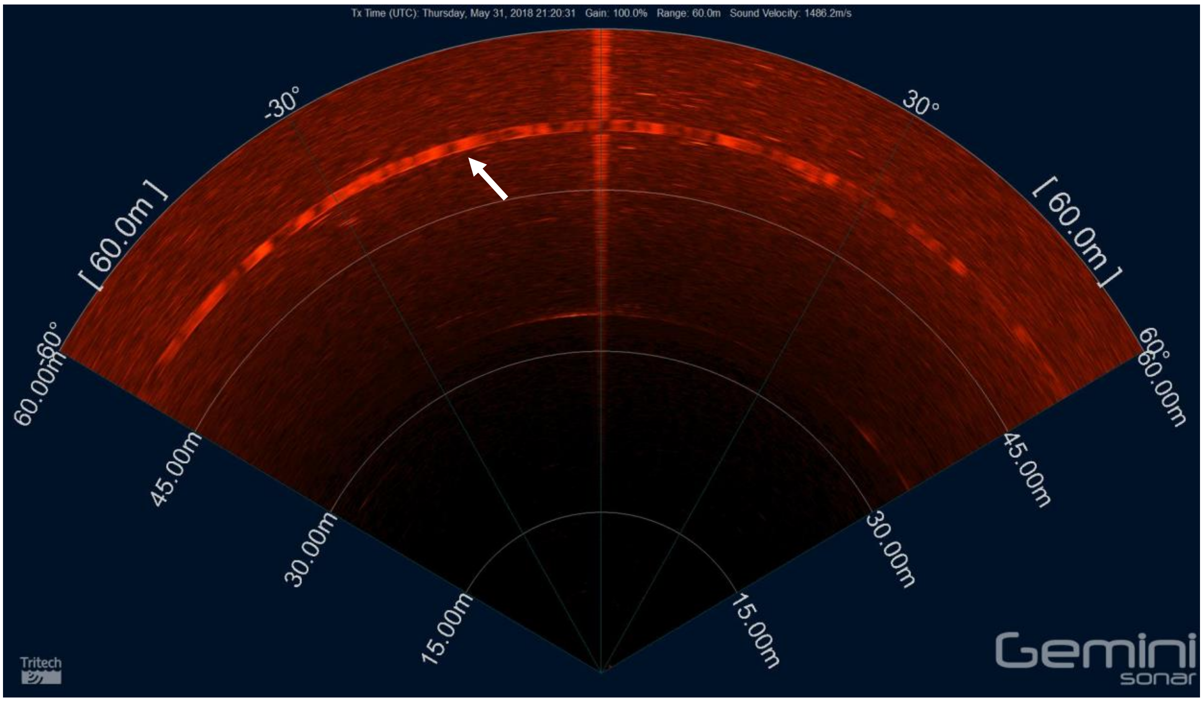


Figure 6. Gemini screenshot showing AWAC noise at 50-52 m range during mid-ebb tide on 31 May 2018.

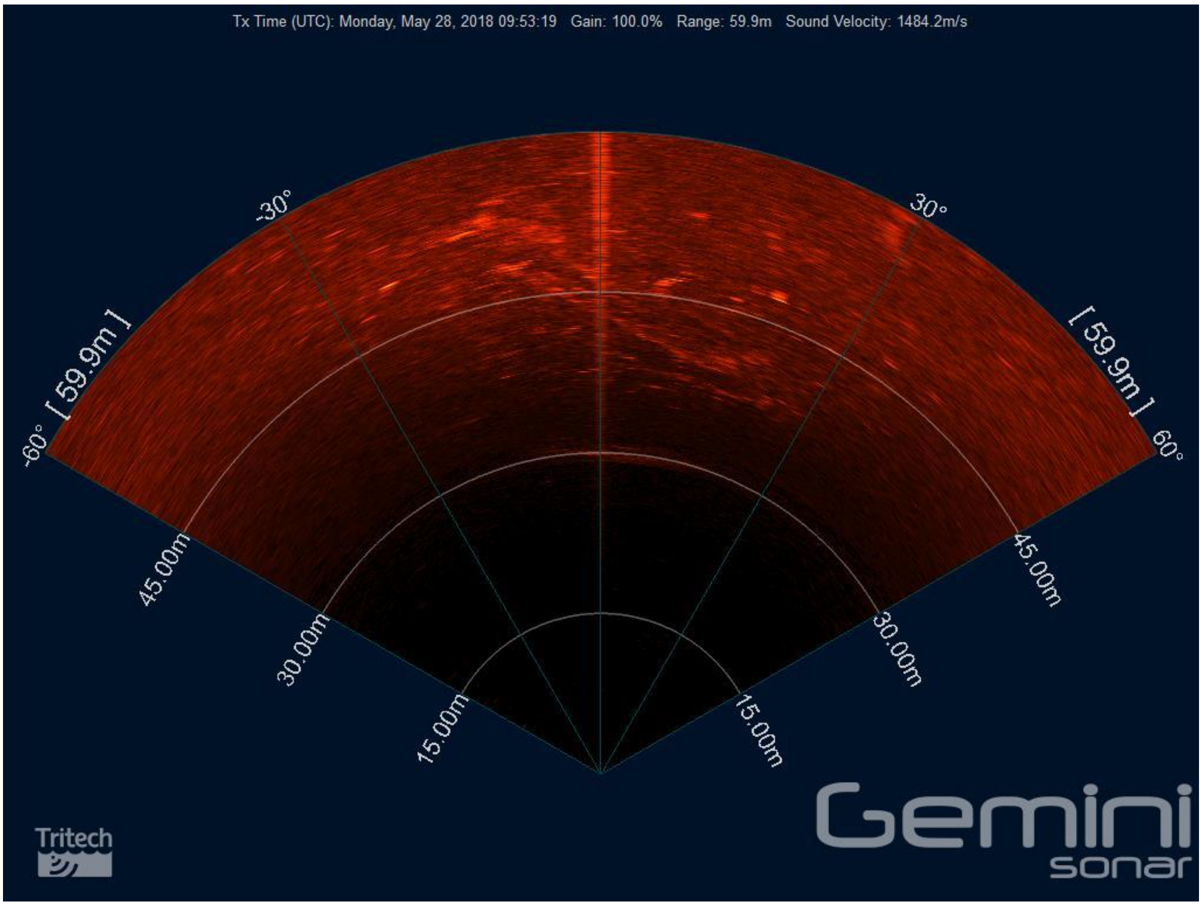


Figure 7. Gemini frame showing surface interference beyond 35 m during low tide at 0952 h (UTC) on 28 May 2018. Note the reduced range under low tide conditions in Figure 4.

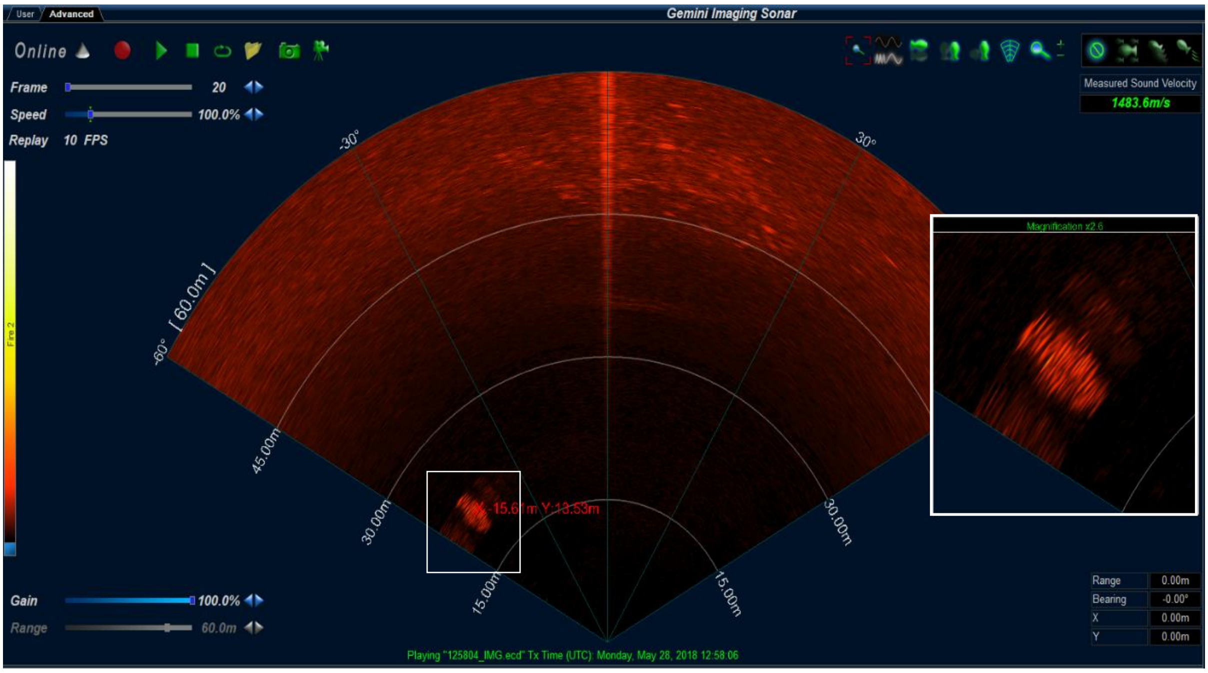


Figure 8. Gemini frame showing a fish school at 20-25 m (shown in magnification x2.6 window) and what appears to be entrained air and possibly also surface interference beyond 45 m. Data from mid-flood tide at 1258 h (UTC) on 28 May 2018.

### 3.3. Target detection

Moving targets appearing to be individual fish and schools were detectable by human observers, with examples shown in Figures 8 and 9. The SeaTec software detected schools but was unable to positively identify individual fish. This is an area that Tritech will continue to develop using fish datasets from multiple sites.

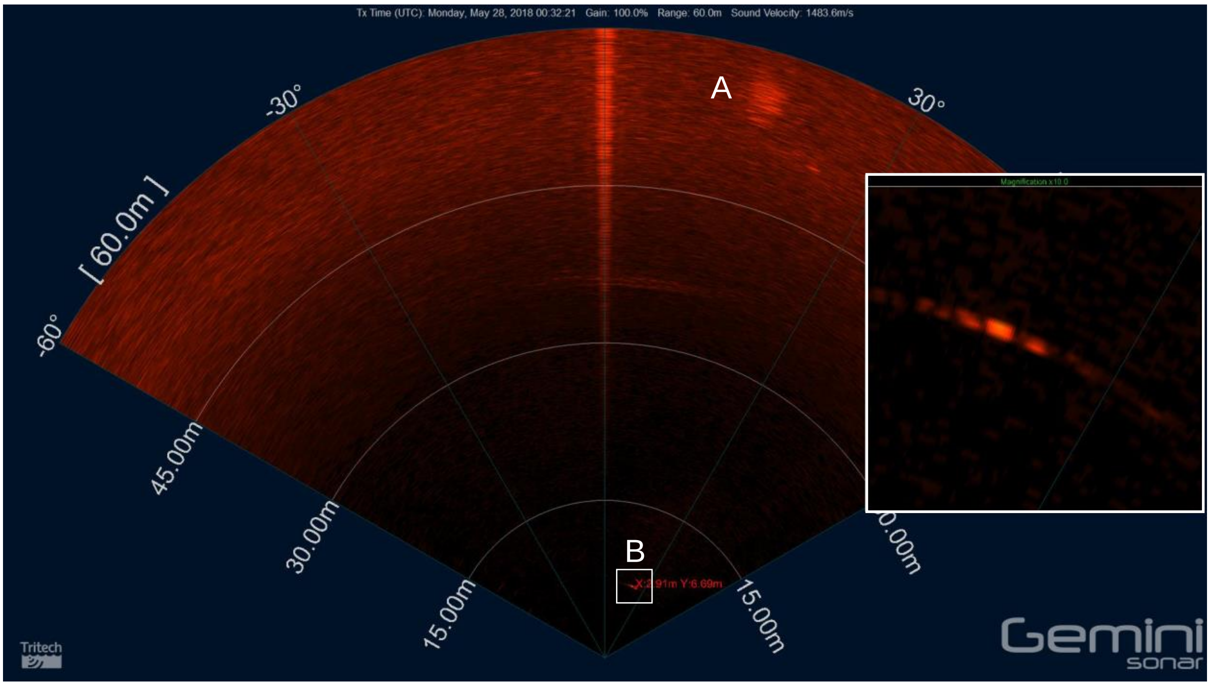


Figure 9. Gemini frame showing (A) a possible fish school at 55 m and (B) an individual target and its track (shown in magnification x10 window) at 6.7 m from the sensor. Data from a flood tide at 0031 h (UTC) on 28 May 2018.

Data from each 2-minute file selected for analysis is summarized in Table 1. Note that counts were not normalized for sampled volume, which changed with water depth, nor for flow speed (low to high).

All observed individual targets (assumed to be fish) and schools (most likely Atlantic herring, given the time of year) appeared to be moving with the flow across the field of view, with few detections in close proximity to the sonar.

Table 1. Summary of Gemini data files analyzed. Manual counts of acoustic targets include individual fish and schools; SeaTec automated counts of targets include only fish schools and are shown for two sets of tracking parameters (SeaTec A and SeaTec B). Level of entrained air interference is classified as none, low (L), medium (M), or high (H).

| Date | File start (UTC) | Orientation | Tide stage | Manual counts | | SeaTec school count | | Entrained air |
|---|---|---|---|---|---|---|---|---|
| | | | | Individuals | Schools | SeaTec A | SeaTec B | |
| 27-May | 16:01:53 | A | High | 5 | 0 | 0 | 0 | L |
| 27-May | 18:16:03 | A | Ebb | 155 | 4 | 7 | 6 | H |
| 27-May | 21:05:32 | A | Low | 2 | 0 | 0 | 0 | M |
| 27-May | 23:58:11 | A | Flood | 57 | 1 | 0 | 0 | L |
| 28-May | 00:31:08 | A | Flood | 64 | 1 | 0 | 1 | L |
| 28-May | 03:26:03 | A | High | 3 | 0 | 0 | 0 | None |
| 28-May | 06:50:47 | A | Ebb | 76 | 0 | 11 | 12 | H |
| 28-May | 09:52:07 | A | Low | 14 | 5 | 28 | 43 | H |
| 28-May | 12:58:04 | A | Flood | 27 | 4 | 4 | 4 | M/H |
| 28-May | 15:57:44 | A | High | 0 | 2 | 0 | 0 | None |
| 28-May | 19:10:41 | A | Ebb | 79 | 12 | 6 | 10 | M/L |
| 28-May | 22:11:24 | A | Low | 9 | 3 | 9 | 5 | H |
| 29-May | 01:18:07 | A | Flood | 46 | 1 | 0 | 0 | L |
| 29-May | 03:21:35 | A | High | 8 | 0 | 0 | 0 | None |
| 29-May | 07:37:40 | A | Ebb | 66 | 0 | 23 | 21 | M/H |
| 29-May | 10:38:43 | A | Low | 8 | 2 | 44 | 40 | H |
| 29-May | 13:54:49 | A | Flood | 42 | 1 | 10 | 2 | M |
| 29-May | 16:54:44 | A | High | 7 | 1 | 0 | 0 | L |
| 29-May | 19:54:15 | A | Ebb | 50 | 0 | 19 | 16 | L/M |
| 29-May | 22:55:05 | A | Low | 24 | 9 | 0 | 0 | None |
| 30-May | 02:00:02 | A | Flood | 41 | 2 | 2 | 2 | L |
| 30-May | 05:10:20 | A | High | 26 | 1 | 0 | 0 | None |
| 30-May | 08:23:20 | A | Ebb | 155 | 3 | 6 | 2 | M |
| 30-May | 11:23:13 | A | Low | 23 | 0 | 8 | 10 | H |
| 30-May | 14:29:20 | A | Flood | 52 | 5 | 0 | 0 | L |
| 30-May | 17:29:04 | A | High | 9 | 0 | 0 | 0 | M |
| 30-May | 20:38:10 | A | Ebb | 53 | 1 | 33 | 27 | H |
| 30-May | 23:41:20 | A | Low | 18 | 9 | 0 | 0 | L |
| 31-May | 02:46:18 | A | Flood | 78 | 1 | 1 | 1 | None |
| 31-May | 05:46:43 | A | High | 15 | 0 | 0 | 0 | None |
| 31-May | 09:08:20 | A | Ebb | 85 | 0 | 40 | 42 | H |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 31-May | 12:08:29 | A | Low | 23 | 5 | 0 | 0 | L |
| 31-May | 15:12:57 | A | Flood | 72 | 0 | 4 | 4 | L |
| 31-May | 18:12:51 | B | High | 4 | 0 | 1 | 1 | L |
| 31-May | 21:24:20 | B | Ebb | 90 | 0 | 3 | 2 | L |
| 31-May | 23:57:47 | B | Low | 10 | 4 | 0 | 0 | L |
| 1-Jun | 00:15:10 | B | Low | 21 | 2 | 0 | 0 | None |
| 1-Jun | 03:27:24 | B | Flood | 73 | 0 | 6 | 5 | L |
| 1-Jun | 06:38:45 | B | High | 32 | 0 | 0 | 0 | L |
| 1-Jun | 09:55:18 | B | Ebb | 49 | 6 | 0 | 0 | L |
| 1-Jun | 12:58:48 | B | Low | 13 | 5 | 0 | 0 | None |
| 1-Jun | 15:55:14 | B | Flood | 36 | 1 | 6 | 6 | M |
| 1-Jun | 18:56:53 | B | High | 1 | 2 | 0 | 0 | None |
| 1-Jun | 22:00:02 | B | Ebb | 24 | 1 | 2 | 3 | M |
| 2-Jun | 01:08:21 | B | Low | 50 | 1 | 0 | 0 | L |
| 2-Jun | 04:09:19 | B | Flood | 28 | 0 | 0 | 0 | L |
| 2-Jun | 07:10:28 | B | High | 12 | 0 | 0 | 0 | None |
| 2-Jun | 10:25:02 | B | Ebb | 45 | 0 | 0 | 0 | L |
| 2-Jun | 13:26:45 | B | Low | 21 | 0 | 0 | 0 | L |
| 2-Jun | 16:37:26 | B | Flood | 39 | 3 | 0 | 0 | L |
| 2-Jun | 19:38:59 | B | High | 5 | 0 | 0 | 0 | L |
| 2-Jun | 22:53:31 | B | Ebb | 53 | 1 | 0 | 0 | H |
| 3-Jun | 01:38:36 | B | Low | 28 | 0 | 5 | 4 | M |
| 3-Jun | 04:52:09 | B | Flood | 45 | 0 | 2 | 2 | M |
| 3-Jun | 07:53:52 | B | High | 5 | 0 | 0 | 0 | H |
| 3-Jun | 11:08:31 | B | Ebb | 37 | 1 | 0 | 0 | M |
| 3-Jun | 14:10:45 | B | Low | 4 | 8 | 34 | 44 | H |
| 3-Jun | 17:23:23 | B | Flood | 70 | 3 | 0 | 0 | L |
| 3-Jun | 20:21:50 | B | High | 2 | 2 | 0 | 0 | L |
| 3-Jun | 23:55:53 | B | Ebb | 40 | 3 | 0 | 0 | None |
| 4-Jun | 02:22:56 | B | Low | 17 | 1 | 0 | 0 | M |
| 4-Jun | 05:37:48 | B | Flood | 31 | 0 | 1 | 1 | L |
| 4-Jun | 08:38:27 | B | High | 13 | 3 | 0 | 0 | None |
| 4-Jun | 11:53:08 | B | Ebb | 16 | 2 | 0 | 0 | L |

### 3.4 Range dependency

Ranges of schools (distance from Gemini sonar) detected with the SeaTec software were not reported, but manual (visual) detections were recorded in three range categories: 0-15 m, 15-30 m, and 30-60 m. Individual fish detections decreased with range, with almost none detected beyond 30 m range (Figure 10). Conversely, most schools were detected at ranges greater than 15 m. This opposite trend for individuals and schools reflects a difference in detection probability related to the range-dependent resolution and sampled volume of the Gemini. The detection probability for individual fish decreases with increasing range due to the small size of the target relative to the resolution of the Gemini, which worsens with increasing range. Schools are larger targets, and therefore their probability of detection is less effected by decreasing resolution. Instead, the increasing size of the sampled volume with range leads to higher detection probability of schools as range increases. This effect is likely modified at greater ranges by the increasing interference from entrained air and the surface.

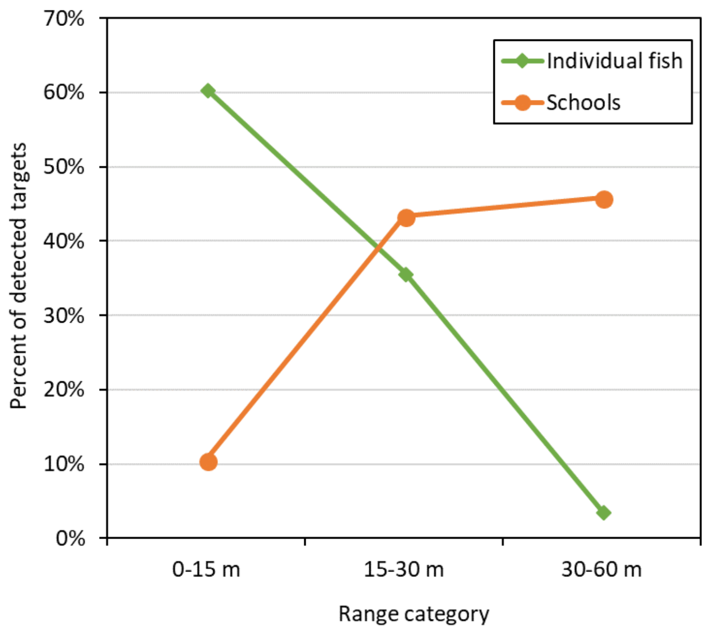


Figure 10. Percentage of targets (individual fish and schools) manually detected in each range category.

### 3.5 Software performance versus manual data processing

Human observers noted that individual fish were much easier to see at closer ranges, where resolution was best; however, the image was dim at closer ranges, even with image gain maximized. If the image could be brightened further, and if the user could control display contrast, more targets may be detectable at closer ranges. Furthermore, the window allowing observers to zoom in on different parts of the screen does not allow measurements to be made (e.g. range, bearing, or length of a target), and it jumps across the screen if the cursor is placed over it. These are areas that Tritech is aware of and are addressing.

The agreement between school counts obtained automatically and by human observers varied greatly from file to file (Figure 11).

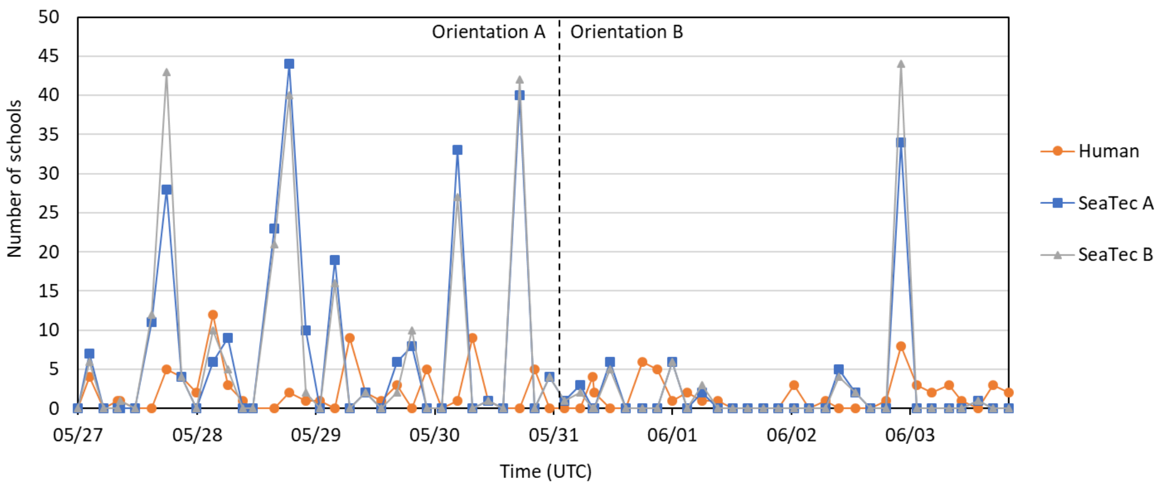


Figure 11. Number of schools detected in each selected 2-minute Gemini file by human observers and the SeaTec software, which used two different sets of detection parameters (SeaTec A and SeaTec B).

Under conditions of no, low or medium levels of entrained air, the discrepancy in the number of schools detected by the SeaTec software was low (Figure 12). However, with high levels of entrained air, automated counts were highly inflated by false detections (Figure 12). This is evident as well in the difference between automatic detections with the Gemini in orientations A and B (Figure 11); data collected in orientation A included higher levels of entrained air than data collected in orientation B (Table 1), resulting in more false positive detections by the SeaTec software with the Gemini in orientation A.

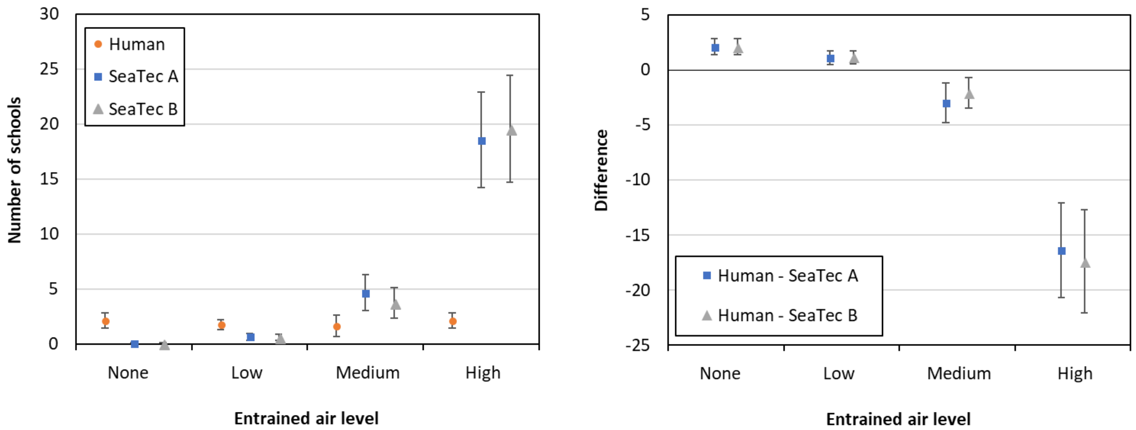


Figure 12. Left: Number of schools detected in each 2-minute Gemini file by human observers and the SeaTec software, for different levels of entrained air interference. Right: Difference in number of detections made by human observer and SeaTec software for different levels of entrained air interference. SeaTec detections were made under two different sets of detection parameters (SeaTec A and B). Points represent average values, and whiskers indicate +/- 1 standard error.

False detection of fish schools, due to entrained air, may be reduced if interference from entrained air can be limited. For example, at this site, most entrained air was detected beyond the 40 m range. If data were collected only out to 40 m, rather than 60 m, automated counts may have more closely matched the manual counts. This can be achieved by changing the maximum range setting on the Gemini sonar to 40 m rather than the default setting which extends to 60 m. It is important to note, though, that conditions will likely be different for the Gemini deployed on the TISEC device at FORCE. Any adjustment of sonar settings (e.g.

gain, range) to optimize software performance and target detection should be done remotely following a viewing of data files collected, and as soon as possible after deployment.

In addition to false positive detections by the automated Sea Tec software, there were also some false negatives: low-density schools were difficult for the software to detect and tended to be mistaken as background noise. This led to low automated counts relative to manual counts in some cases and will need to be addressed in future iterations of the detection algorithms.

## 4 Conclusions

The Gemini sonar performed well for the duration of this test. The physical limits of motion for a Gemini mounted on the FAST-EMS platform were assessed, and these will inform sensor attachment and platform placement in close proximity to a turbine. The horizontal range of motion was found to be limited by the roll-bar and cabling, so FAST-EMS platform positioning will need to be as accurate as possible to capture footage of the TISEC device. The vertical range of the sonar in this test was limited by surface interference, which is an effect of depth at the platform deployment location (near Black Rock).

Overall, the cabled FAST-EMS served well as a sensor platform and will be useful for contingency planning towards meeting the goals of the CSTV EEMP, if and when required. We suggest the platform be placed within approximately 40 m of the TISEC device (if possible) to observe the nearfield movements of schools of fish, as beyond this distance, decreasing resolution and interference from entrained air or the surface is likely to heavily affect school detection probability. Individual fish detection should not be expected beyond approximately 15 m range due to fish size and decreasing resolution with distance.

The Nortek AWAC ADCP, co-located on the platform with the Gemini, was found to interfere with Gemini data, and the two instruments may need to be programmed to alternate with each other if deployed concurrently. These matters should be addressed prior to the deployment of the FAST platform as a supplement to future turbine deployments.

Manual counts of individual fish and schools indicated opposing trends in detection probability with range, which will need to be considered when interpreting any Gemini data, and in setting the range for the detection of fish.

The automated counts obtained with the current version of the SeaTec software (2.4.5) did not closely match manual counts obtained by the human observers, particularly when entrained air was present and thus falsely classified entrained air as fish schools. Performance may be improved if entrained air can be limited in future Gemini data collected, e.g. by limiting the maximum range of the viewing window.

The SeaTec software continues to be improved. In the meantime, manual processing of data files should continue, and visually obtained counts used to test and improve future iterations of the SeaTec software.

There are several adjustments that could be made to the SeaTec software to improve manual data processing. The most important of these would be to allow more user control of image brightness and contrast, as well as to modify the zoom feature to allow better detection and measurement of targets at close ranges.

## 5 Enhancements to SeaTec Software

Since the ISEM project commenced in 2015, the following enhancements were made to advance the SeaTec software:

1. Addition of a rolling data retention option, whereby only data files containing probable targets are kept on disk, to help with data management over a long monitoring period.
2. Static target evaluation whereby targets which are mostly stationary (non-biological in origin) can be excluded from the list of probable animal targets.
3. Two additional methods of tracking targets with algorithms which use a combination of movement filter and the original sonar image, rather than just using the movement filter.
4. A major recent enhancement is the use of a "licence" file written to the flash drive of the sonar which is detected by the software and turns on the SeaTec capabilities.
5. More consistent use of UTC time. Previously, some outputs were dependent on the local time for both recording and playback, leading to confusion, especially when critical to compare detection times against tidal state conditions.
6. Creation of a daily summary file for each day of data recording, giving a table of files with number of targets detected at different ranges and totals for the whole day. This file can be used to quickly detect trends in target detections over a long period of monitoring. The ability to create a summary file has also been added into replay mode and is produced at the end of batch playback of multiple data files.

All of the above changes have been incorporated into SeaTec version 2.4.10. This version of software has recently shown good results, broadly consistent with human observations, when trialed at a fish detection facility in a Scottish river.

While data from the FAST-EMS platform near Back Rock Island was useful to start the process of algorithm enhancement, we recommend that further work is carried out using data from a Gemini housed on a turbine deployed at FORCE, where water depth is greater and where turbulence may be less of an issue.

## 6 References

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## Acknowledgements

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# Appendix G – Marine mammal sonar target validation results

*Table 1. Comparison between SeaTec target detection and human observer manual review. Lighter blue shaded rows indicate identification of potential marine mammal targets by initial reviewer, darker shaded rows indicate corroboration by 2nd reviewer.*

| | Range of target (m) | | | | Total SeaTec detections | | Human observer visual review | |
|---|---|---|---|---|---|---|---|---|
| filename | <15 | 15-30 | 30-45 | >45 | total | total >15m | Review 1 – potential MM? | Review 2 |
| 040841_IMG.ecd | 0 | 0 | 1 | 0 | 0 | 1 | Yes | No |
| 041047_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 041253_IMG.ecd | 6 | 0 | 0 | 0 | 6 | 0 | No | |
| 041459_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 041705_IMG.ecd | 2 | 0 | 0 | 0 | 2 | 0 | Yes | Possible |
| 041911_IMG.ecd | 3 | 0 | 0 | 0 | 3 | 0 | No | |
| 042116_IMG.ecd | 4 | 0 | 0 | 0 | 4 | 0 | No | |
| 042322_IMG.ecd | 15 | 0 | 0 | 0 | 15 | 0 | No | |
| 042528_IMG.ecd | 14 | 0 | 0 | 0 | 14 | 0 | No | |
| 042734_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 042940_IMG.ecd | 7 | 0 | 0 | 0 | 7 | 0 | Yes | Possible |
| 043145_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 043351_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 043557_IMG.ecd | 3 | 0 | 0 | 0 | 3 | 0 | No | |
| 043803_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 044009_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 044215_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 044421_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 044626_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | Yes | Possible |
| 044832_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 045038_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |

| | Range of target (m) | | | | Total SeaTec detections | | Human observer visual review | |
|---|---|---|---|---|---|---|---|---|
| filename | <15 | 15-30 | 30-45 | >45 | total | total >15m | Review 1 – potential MM? | Review 2 |
| 045244_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | Yes | Possible |
| 045450_IMG.ecd | 3 | 0 | 0 | 0 | 3 | 0 | No | |
| 045655_IMG.ecd | 4 | 1 | 0 | 0 | 5 | 1 | No | |
| 045901_IMG.ecd | 8 | 0 | 0 | 0 | 8 | 0 | No | |
| 050107_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 050313_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 050519_IMG.ecd | 3 | 0 | 0 | 0 | 3 | 0 | No | |
| 050725_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 050930_IMG.ecd | 2 | 0 | 0 | 0 | 2 | 0 | No | |
| 051136_IMG.ecd | 3 | 0 | 0 | 0 | 3 | 0 | No | |
| 051342_IMG.ecd | 16 | 1 | 0 | 0 | 17 | 1 | No | |
| 051548_IMG.ecd | 47 | 1 | 0 | 0 | 48 | 1 | No | |
| 051754_IMG.ecd | 37 | 3 | 0 | 0 | 40 | 3 | No | |
| 052000_IMG.ecd | 26 | 2 | 0 | 0 | 28 | 2 | No | |
| 052205_IMG.ecd | 53 | 1 | 0 | 0 | 54 | 1 | No | |
| 052411_IMG.ecd | 45 | 2 | 0 | 0 | 47 | 2 | Yes | No |
| 052617_IMG.ecd | 22 | 4 | 0 | 0 | 26 | 4 | No | |
| 052823_IMG.ecd | 22 | 6 | 0 | 0 | 28 | 6 | No | |
| 053028_IMG.ecd | 56 | 2 | 0 | 0 | 58 | 2 | No | |
| 053234_IMG.ecd | 39 | 1 | 0 | 0 | 40 | 1 | Yes | Possible |
| 053440_IMG.ecd | 45 | 0 | 0 | 0 | 45 | 0 | Yes | No |
| 053646_IMG.ecd | 53 | 0 | 0 | 0 | 53 | 0 | No | |
| 053851_IMG.ecd | 40 | 0 | 0 | 0 | 40 | 0 | No | |
| 054057_IMG.ecd | 16 | 0 | 0 | 0 | 16 | 0 | No | |
| 054303_IMG.ecd | 10 | 0 | 0 | 0 | 10 | 0 | Yes | No |
| 054508_IMG.ecd | 5 | 0 | 0 | 0 | 5 | 0 | No | |
| 054714_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 054920_IMG.ecd | 2 | 0 | 0 | 0 | 2 | 0 | No | |
| 055126_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |

| | Range of target (m) | | | | Total SeaTec detections | | Human observer visual review | |
|---|---|---|---|---|---|---|---|---|
| filename | <15 | 15-30 | 30-45 | >45 | total | total >15m | Review 1 – potential MM? | Review 2 |
| 055332_IMG.ecd | 2 | 1 | 1 | 0 | 4 | 2 | Yes | Possible |
| 055538_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 055743_IMG.ecd | 4 | 0 | 0 | 0 | 4 | 0 | No | |
| 055949_IMG.ecd | 5 | 2 | 0 | 0 | 7 | 2 | Yes | Possible |
| 060155_IMG.ecd | 1 | 1 | 0 | 0 | 2 | 1 | No | |
| 060401_IMG.ecd | 4 | 1 | 0 | 0 | 5 | 1 | No | |
| 060606_IMG.ecd | 7 | 0 | 0 | 0 | 7 | 0 | No | |
| 060812_IMG.ecd | 3 | 0 | 0 | 0 | 3 | 0 | No | |
| 061018_IMG.ecd | 14 | 1 | 0 | 0 | 15 | 1 | No | |
| 061224_IMG.ecd | 35 | 1 | 0 | 0 | 36 | 1 | No | |
| 061429_IMG.ecd | 28 | 0 | 0 | 0 | 28 | 0 | No | |
| 061635_IMG.ecd | 11 | 2 | 0 | 0 | 13 | 2 | No | |
| 061841_IMG.ecd | 28 | 0 | 0 | 0 | 28 | 0 | No | |
| 062046_IMG.ecd | 19 | 1 | 0 | 0 | 20 | 1 | No | |
| 062252_IMG.ecd | 28 | 0 | 0 | 0 | 28 | 0 | No | |
| 062458_IMG.ecd | 21 | 1 | 0 | 0 | 22 | 1 | No | |
| 062704_IMG.ecd | 27 | 2 | 0 | 0 | 29 | 2 | No | |
| 062909_IMG.ecd | 65 | 1 | 0 | 0 | 66 | 1 | No | |
| 063115_IMG.ecd | 54 | 0 | 0 | 0 | 54 | 0 | Yes | No |
| 063321_IMG.ecd | 52 | 0 | 0 | 0 | 52 | 0 | No | |
| 063526_IMG.ecd | 61 | 1 | 0 | 0 | 62 | 1 | No | |
| 063732_IMG.ecd | 58 | 0 | 0 | 0 | 58 | 0 | No | |
| 063938_IMG.ecd | 63 | 1 | 0 | 0 | 64 | 1 | No | |
| 064143_IMG.ecd | 34 | 0 | 0 | 0 | 34 | 0 | No | |
| 064349_IMG.ecd | 27 | 0 | 0 | 0 | 27 | 0 | No | |
| 064555_IMG.ecd | 30 | 1 | 0 | 0 | 31 | 1 | No | |
| 064800_IMG.ecd | 7 | 4 | 0 | 0 | 11 | 4 | No | |
| 065006_IMG.ecd | 5 | 1 | 0 | 1 | 7 | 2 | No | |
| 065212_IMG.ecd | 7 | 2 | 0 | 1 | 10 | 1 | No | |

| | Range of target (m) | | | | Total SeaTec detections | | Human observer visual review | |
|---|---|---|---|---|---|---|---|---|
| filename | <15 | 15-30 | 30-45 | >45 | total | total >15m | Review 1 – potential MM? | Review 2 |
| 065417_IMG.ecd | 4 | 14 | 0 | 0 | 18 | 14 | Yes | No |
| 065623_IMG.ecd | 9 | 14 | 0 | 0 | 23 | 14 | Yes | No |
| 065829_IMG.ecd | 11 | 8 | 0 | 1 | 20 | 8 | No | |
| 070035_IMG.ecd | 0 | 12 | 0 | 0 | 12 | 12 | Yes | No |
| 070241_IMG.ecd | 0 | 7 | 0 | 0 | 7 | 7 | No | |
| 070446_IMG.ecd | 0 | 3 | 0 | 0 | 3 | 3 | No | |
| 070652_IMG.ecd | 0 | 7 | 0 | 1 | 8 | 8 | No | |
| 070858_IMG.ecd | 0 | 10 | 0 | 1 | 11 | 11 | No | |
| 071104_IMG.ecd | 0 | 14 | 0 | 0 | 14 | 14 | No | |
| 071309_IMG.ecd | 0 | 13 | 0 | 0 | 13 | 13 | No | |
| 071515_IMG.ecd | 0 | 7 | 0 | 2 | 9 | 9 | No | |
| 071721_IMG.ecd | 0 | 5 | 0 | 0 | 5 | 5 | No | |
| 071927_IMG.ecd | 0 | 12 | 0 | 2 | 14 | 14 | No | |
| 072133_IMG.ecd | 0 | 12 | 0 | 2 | 14 | 14 | No | |
| 072338_IMG.ecd | 0 | 6 | 0 | 2 | 8 | 8 | No | |
| 072544_IMG.ecd | 0 | 11 | 0 | 0 | 11 | 11 | No | |
| 072750_IMG.ecd | 0 | 9 | 0 | 6 | 15 | 15 | No | |
| 072956_IMG.ecd | 0 | 10 | 0 | 1 | 11 | 11 | No | |
| 073201_IMG.ecd | 0 | 4 | 0 | 6 | 10 | 6 | No | |
| 073407_IMG.ecd | 0 | 10 | 0 | 0 | 10 | 10 | No | |
| 073613_IMG.ecd | 0 | 6 | 0 | 2 | 8 | 8 | Yes | No |
| 073819_IMG.ecd | 0 | 5 | 0 | 2 | 7 | 7 | No | |
| 074025_IMG.ecd | 0 | 11 | 0 | 0 | 11 | 11 | No | |
| 074230_IMG.ecd | 0 | 8 | 0 | 2 | 10 | 10 | No | |
| 074436_IMG.ecd | 0 | 3 | 0 | 7 | 10 | 10 | No | |
| 074642_IMG.ecd | 0 | 9 | 0 | 5 | 14 | 14 | Yes | No |
| 074848_IMG.ecd | 0 | 3 | 0 | 1 | 4 | 4 | Yes | No |
| 075054_IMG.ecd | 0 | 4 | 0 | 10 | 14 | 14 | No | |
| 075259_IMG.ecd | 0 | 8 | 0 | 2 | 10 | 10 | No | |

| | Range of target (m) | | | | Total SeaTec detections | | Human observer visual review | |
|---|---|---|---|---|---|---|---|---|
| **filename** | **<15** | **15-30** | **30-45** | **>45** | **total** | **total >15m** | **Review 1 – potential MM?** | **Review 2** |
| 075505_IMG.ecd | 0 | 7 | 0 | 2 | 9 | 9 | No | |
| 075711_IMG.ecd | 0 | 7 | 0 | 2 | 9 | 9 | Yes | No |
| 075917_IMG.ecd | 0 | 8 | 0 | 3 | 11 | 11 | No | |
| 080122_IMG.ecd | 0 | 5 | 0 | 8 | 13 | 13 | No | |
| 080328_IMG.ecd | 0 | 9 | 0 | 1 | 10 | 10 | No | |
| 080534_IMG.ecd | 0 | 14 | 0 | 4 | 18 | 18 | No | |
| 080740_IMG.ecd | 0 | 4 | 0 | 11 | 15 | 15 | No | |
| 080946_IMG.ecd | 0 | 3 | 0 | 6 | 9 | 9 | No | |
| 081151_IMG.ecd | 0 | 1 | 0 | 5 | 6 | 6 | No | |
| 081357_IMG.ecd | 1 | 0 | 0 | 1 | 2 | 1 | No | |
| 081603_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 081809_IMG.ecd | 0 | 1 | 0 | 3 | 4 | 4 | No | |
| 082014_IMG.ecd | 0 | 2 | 0 | 0 | 2 | 2 | No | |
| 082220_IMG.ecd | 0 | 1 | 0 | 1 | 2 | 2 | No | |
| 082426_IMG.ecd | 0 | 2 | 0 | 0 | 2 | 2 | No | |
| 082632_IMG.ecd | 0 | 0 | 0 | 2 | 2 | 2 | No | |
| 082838_IMG.ecd | 0 | 0 | 0 | 3 | 3 | 3 | No | |
| 083043_IMG.ecd | 0 | 6 | 0 | 16 | 22 | 22 | Yes | Possible |
| 083249_IMG.ecd | 0 | 0 | 0 | 8 | 8 | 8 | No | |
| 083455_IMG.ecd | 0 | 2 | 0 | 2 | 4 | 4 | Yes | Possible |
| 083701_IMG.ecd | 0 | 1 | 0 | 3 | 4 | 4 | No | |
| 083906_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 084112_IMG.ecd | 0 | 0 | 0 | 1 | 1 | 1 | Yes | No |
| 084318_IMG.ecd | 0 | 1 | 0 | 2 | 3 | 3 | No | |
| 084524_IMG.ecd | 0 | 0 | 0 | 5 | 5 | 5 | Yes | No |
| 084730_IMG.ecd | 0 | 0 | 0 | 6 | 6 | 6 | No | |
| 084936_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 085141_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 085347_IMG.ecd | 1 | 2 | 0 | 0 | 3 | 2 | No | |

| | Range of target (m) | | | | Total SeaTec detections | | Human observer visual review | |
|---|---|---|---|---|---|---|---|---|
| filename | <15 | 15-30 | 30-45 | >45 | total | total >15m | Review 1 – potential MM? | Review 2 |
| 085553_IMG.ecd | 0 | 1 | 0 | 2 | 3 | 3 | No | |
| 085759_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 090005_IMG.ecd | 0 | 1 | 1 | 12 | 14 | 14 | No | |
| 090211_IMG.ecd | 0 | 0 | 2 | 8 | 10 | 10 | No | |
| 090417_IMG.ecd | 0 | 0 | 0 | 1 | 1 | 1 | No | |
| 090623_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 090829_IMG.ecd | 0 | 0 | 2 | 2 | 4 | 4 | No | |
| 091035_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | Yes | No |
| 091240_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 091446_IMG.ecd | 0 | 0 | 0 | 1 | 1 | 1 | No | |
| 091652_IMG.ecd | 0 | 3 | 0 | 0 | 3 | 3 | No | |
| 091858_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 092104_IMG.ecd | 0 | 0 | 0 | 1 | 1 | 1 | No | |
| 092310_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 092516_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 092722_IMG.ecd | 0 | 2 | 0 | 0 | 2 | 2 | Yes | Possible |
| 092928_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 093134_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 093340_IMG.ecd | 0 | 4 | 0 | 0 | 4 | 4 | Yes | Possible |
| 093547_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | Yes | No |
| 093753_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 093959_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 094205_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 094411_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 094617_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 094823_IMG.ecd | 0 | 4 | 0 | 0 | 4 | 4 | Yes | Possible |
| 095029_IMG.ecd | 0 | 0 | 0 | 1 | 1 | 1 | Yes | No |
| 095235_IMG.ecd | 1 | 1 | 0 | 1 | 3 | 2 | No | |
| 095441_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |

| | Range of target (m) | | | | Total SeaTec detections | | Human observer visual review | |
|---|---|---|---|---|---|---|---|---|
| **filename** | **<15** | **15-30** | **30-45** | **>45** | **total** | **total >15m** | **Review 1 – potential MM?** | **Review 2** |
| 095647_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 095853_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 100100_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 100306_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 100512_IMG.ecd | 0 | 7 | 0 | 0 | 7 | 7 | Yes | No |
| 100718_IMG.ecd | 0 | 7 | 0 | 0 | 7 | 7 | No | |
| 100924_IMG.ecd | 1 | 0 | 0 | 0 | 1 | 0 | No | |
| 101130_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |
| 101337_IMG.ecd | 0 | 1 | 0 | 1 | 2 | 2 | No | |
| 101543_IMG.ecd | 0 | 1 | 0 | 0 | 1 | 1 | No | |
| 101749_IMG.ecd | 0 | 0 | 0 | 0 | 0 | 0 | No | |

# Appendix H – Target Tracking using Sonar for Marine Life Monitoring around Tidal Turbines (Jepp 2017)

# Target Tracking using Sonar for Marine Life Monitoring around Tidal Turbines.

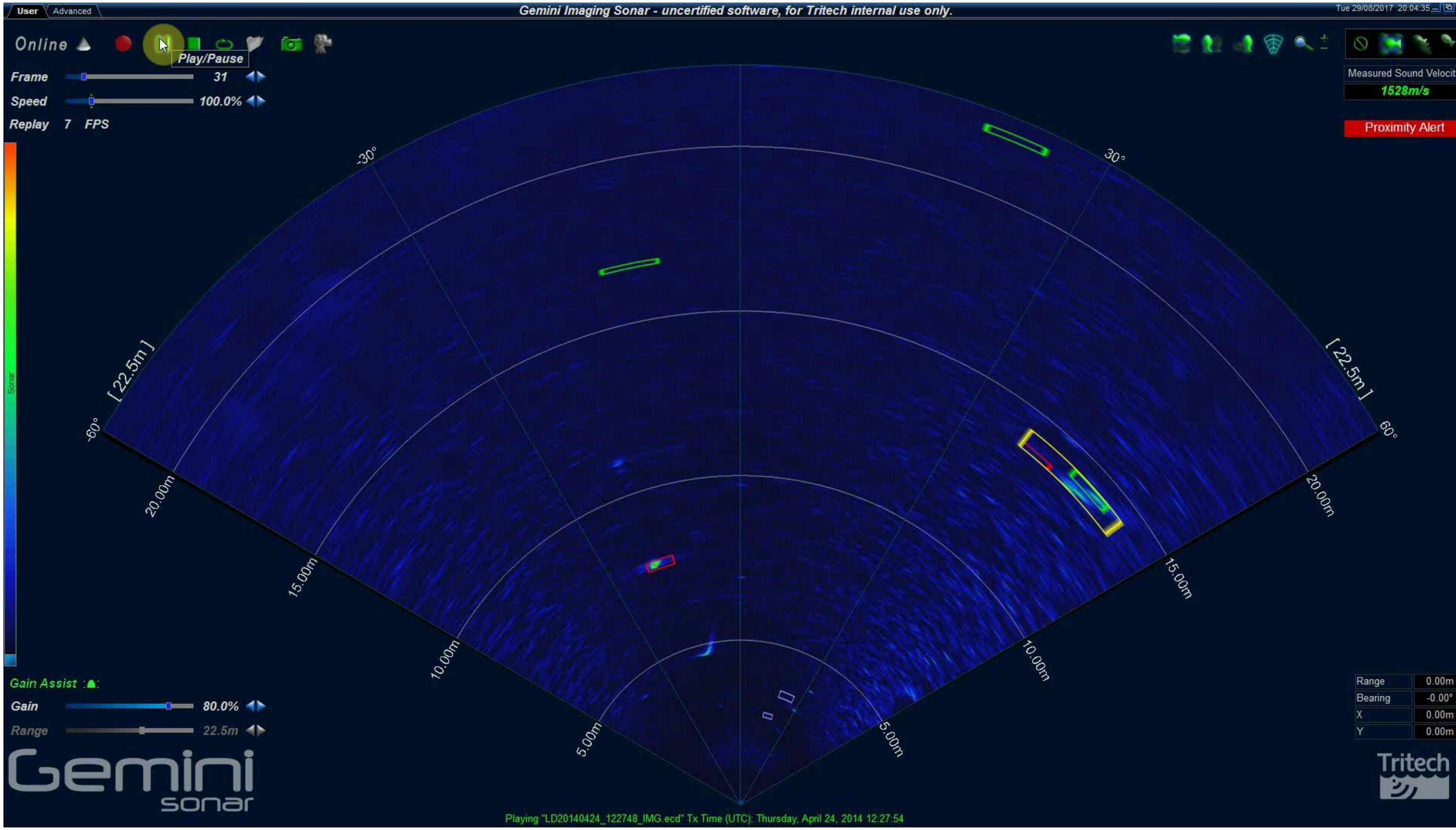
12th EWTEC 2017
European Wave and Tidal Energy Conference Series

Presented by: Pauline Jepp

Tritech

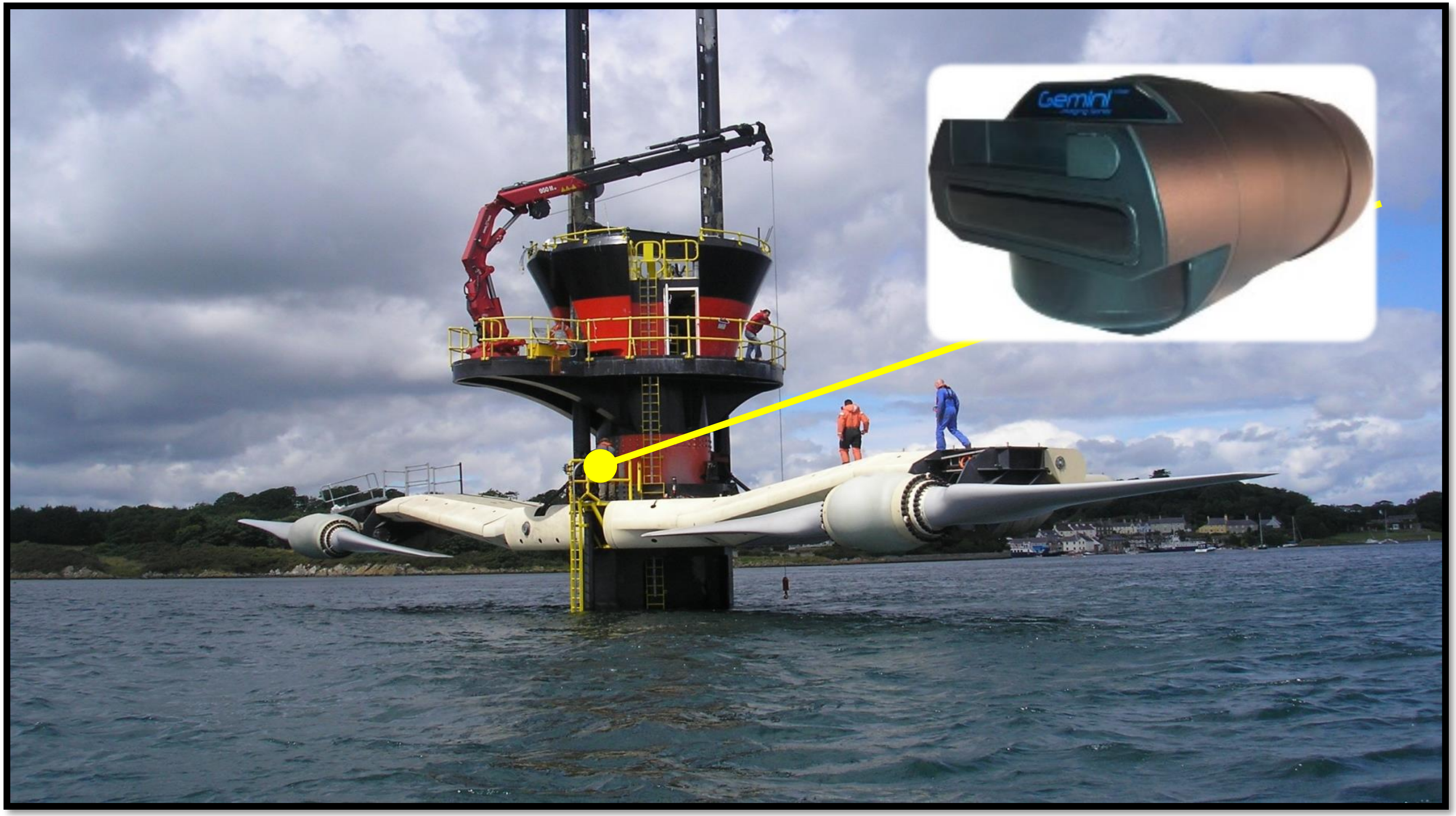
Outstanding Performance in Underwater Technology

# Introduction: SeaTec system



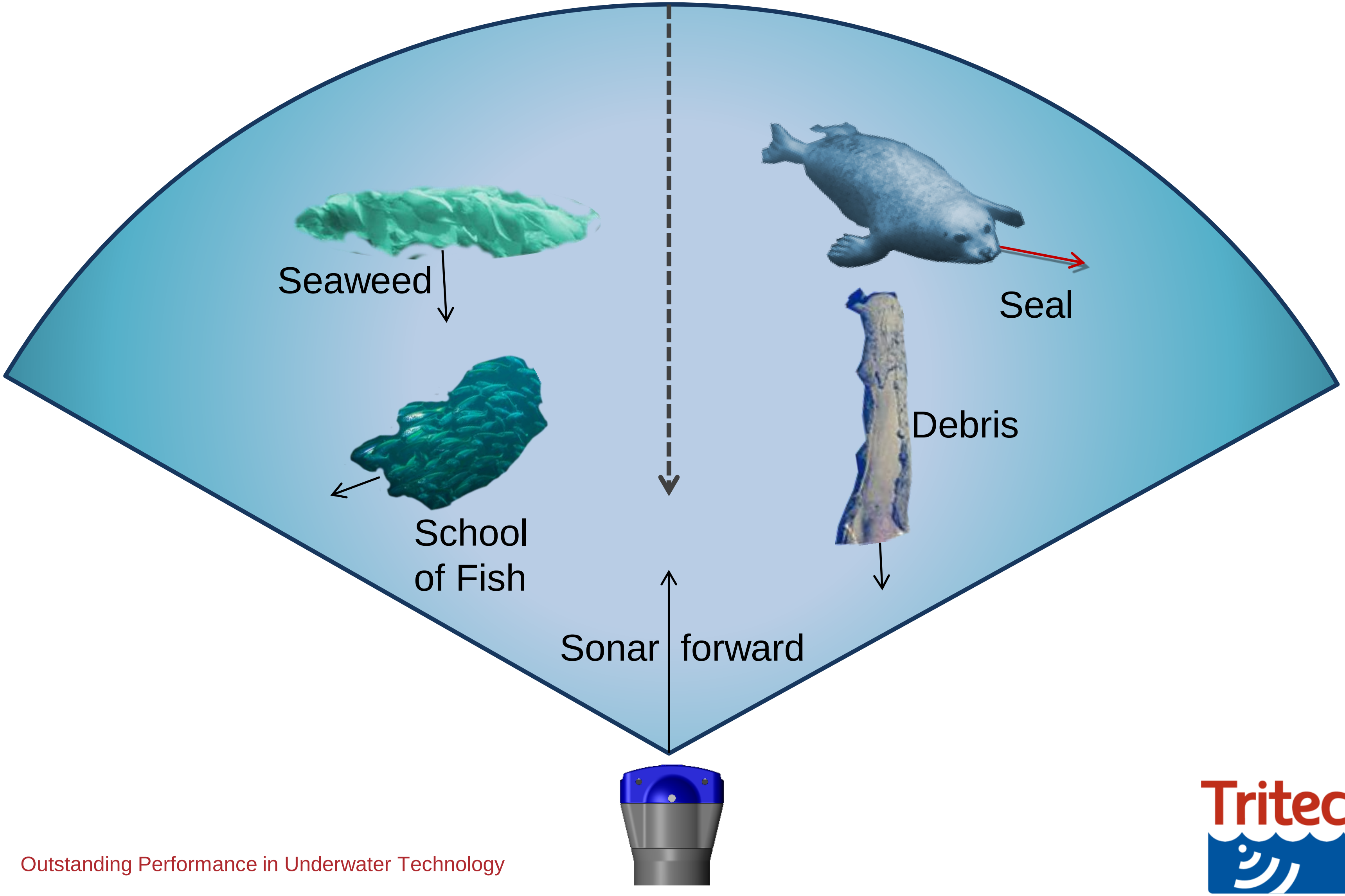

Outstanding Performance in Underwater Technology

# Introduction: SeaTec system



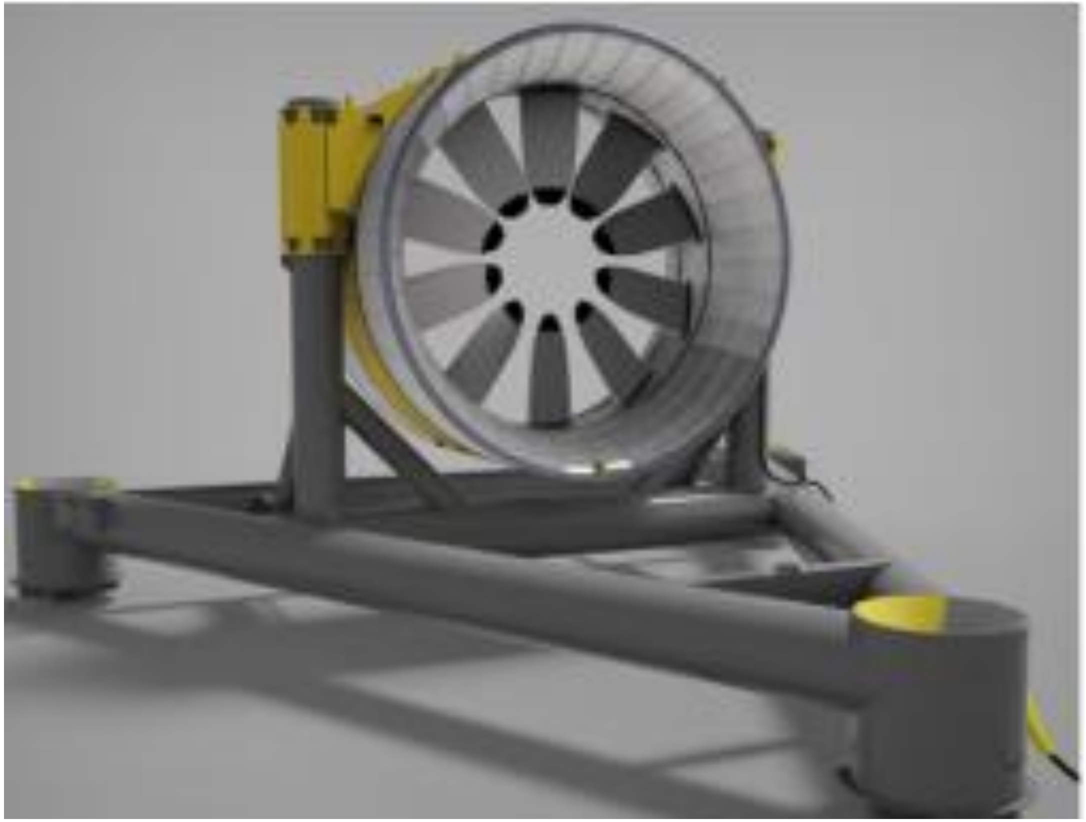

Outstanding Performance in Underwater Technology

# Target Evaluation




Outstanding Performance in Underwater Technology

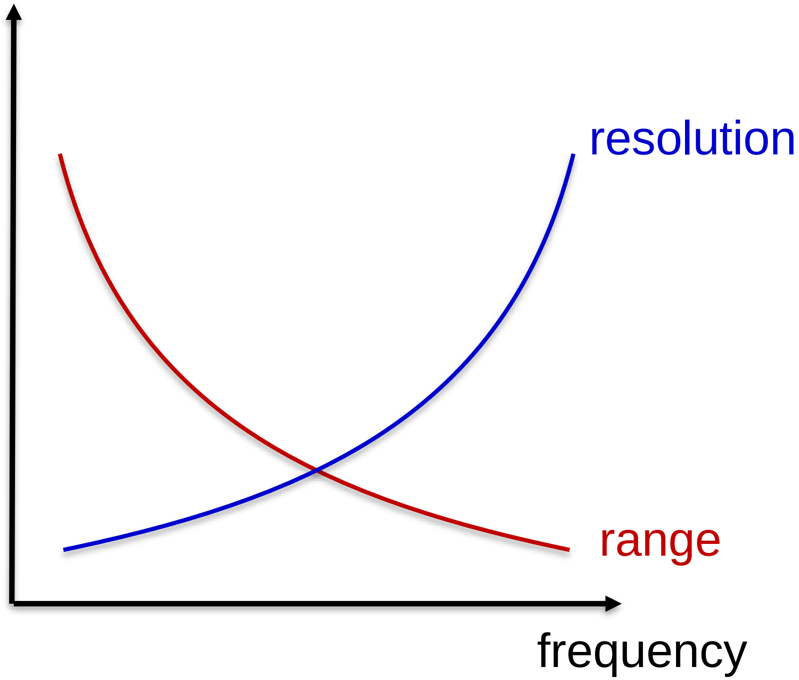
# Introduction: SeaTec system



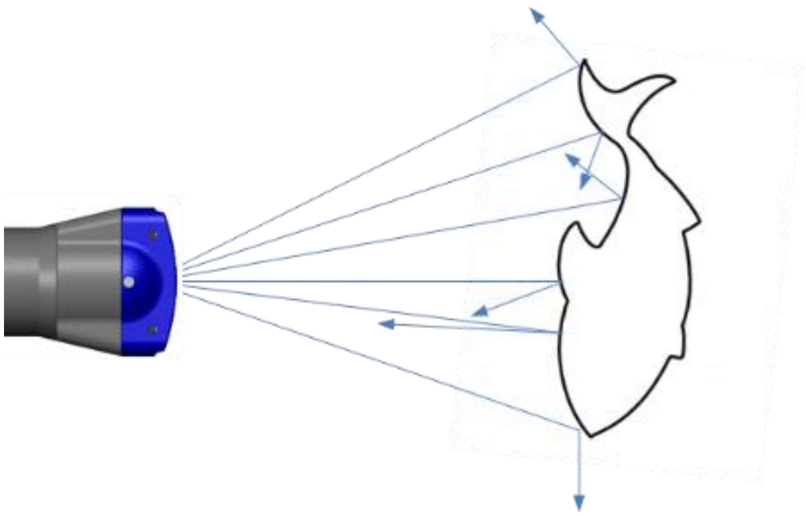
# Sonar Technology

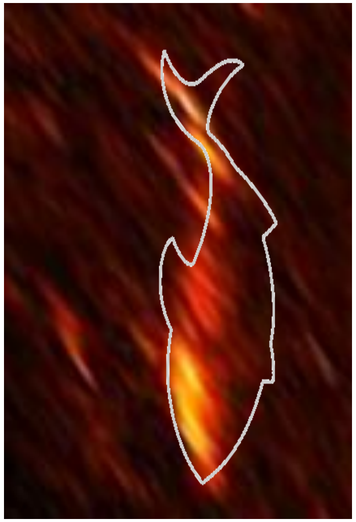
Frequency

# Frequency Vs Range / Resolution



# Frequency: Target Reflection





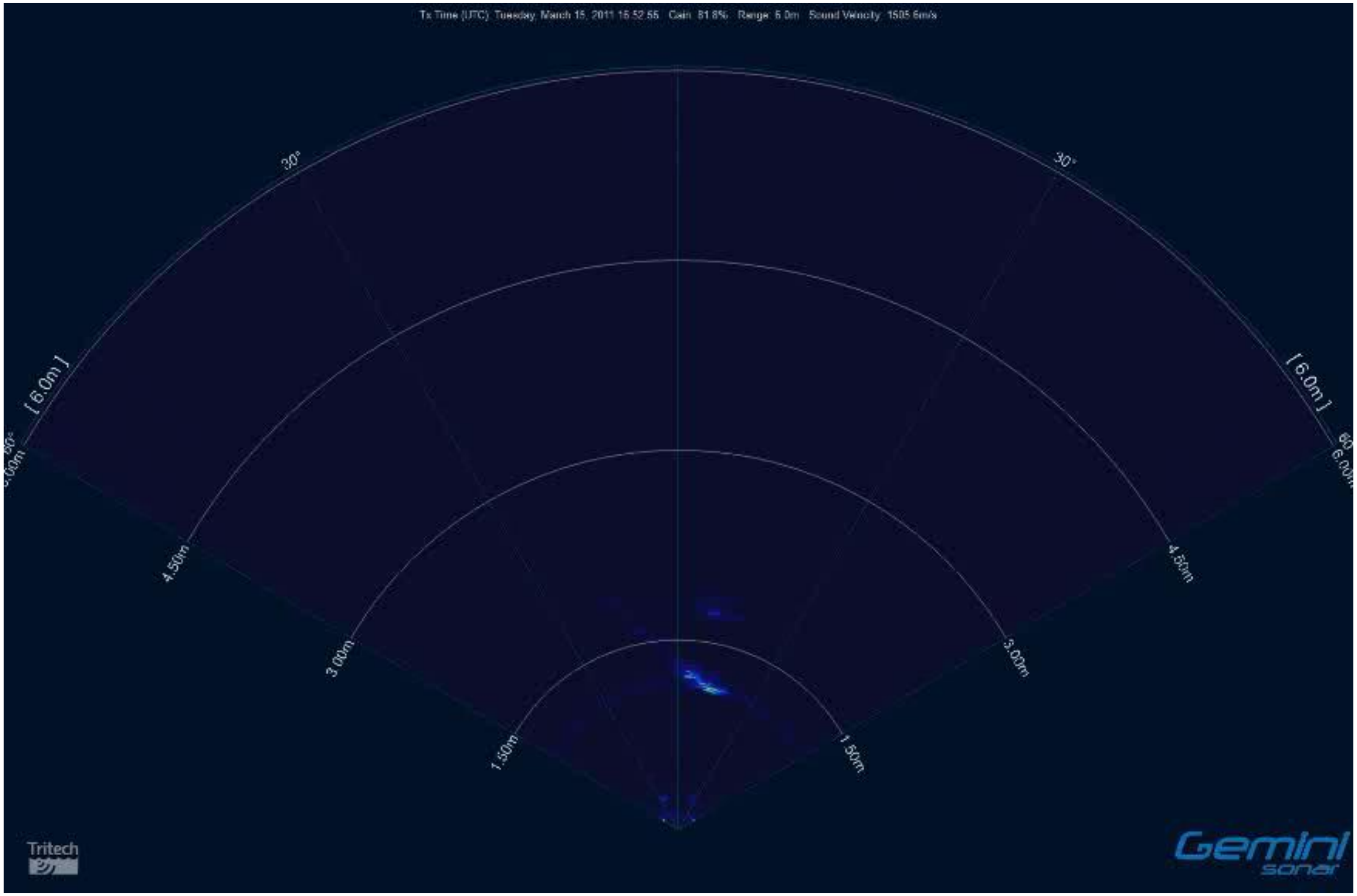
# Sonar Technology

## Target Detection

# Targets

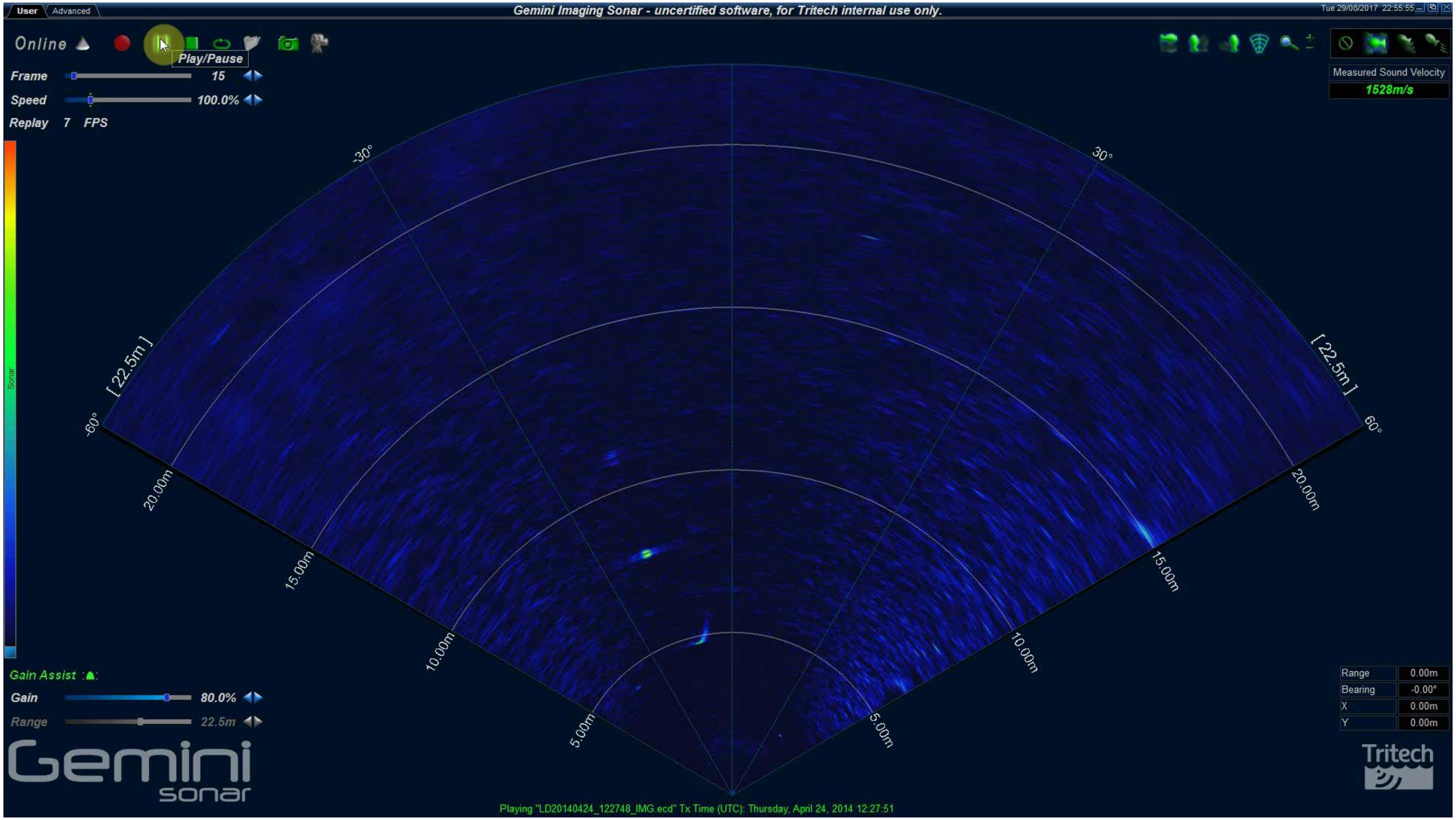
What they look like → How to find them → How they move

## What they look like: Sealion

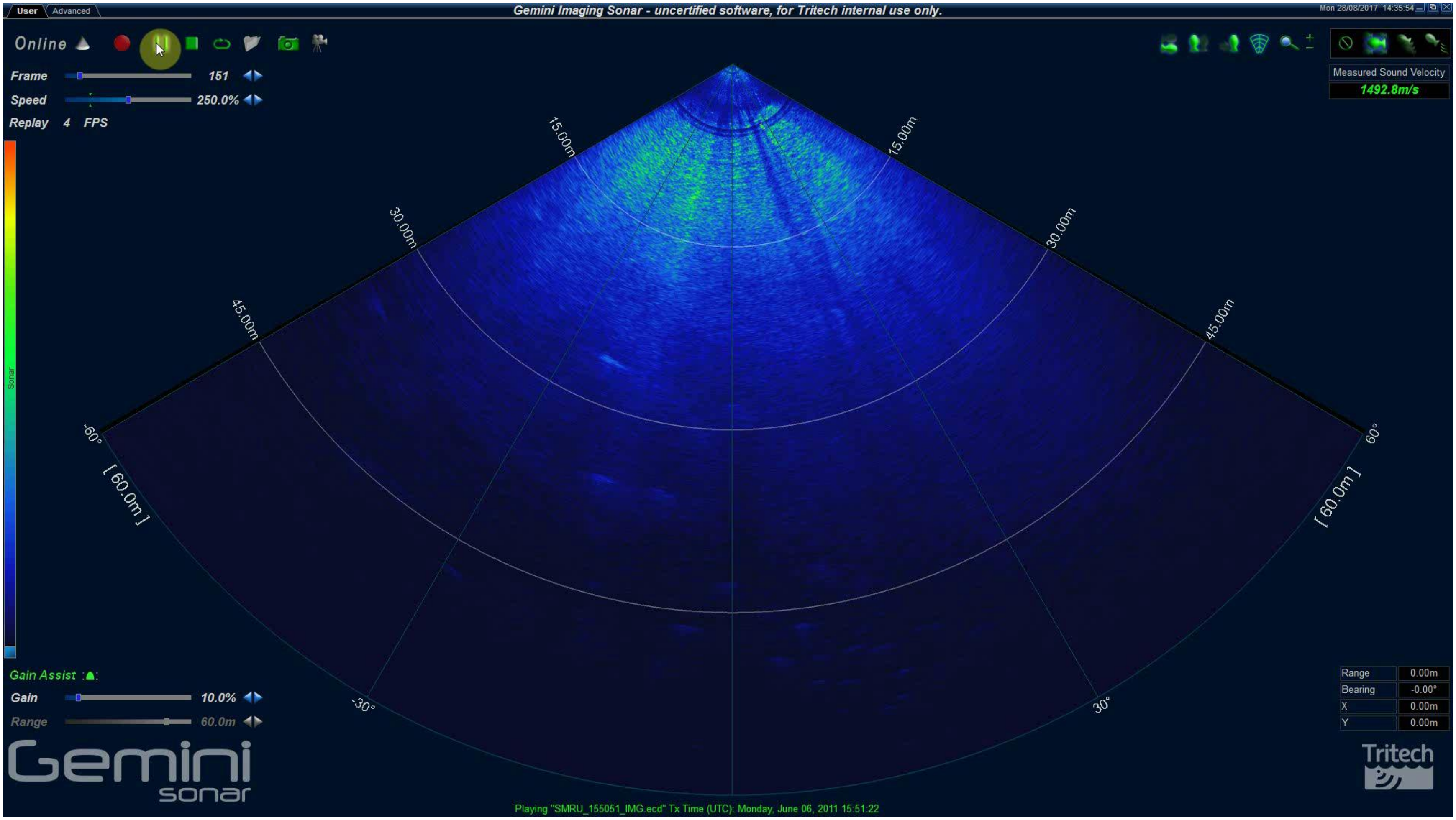


# Target detection

## Shark



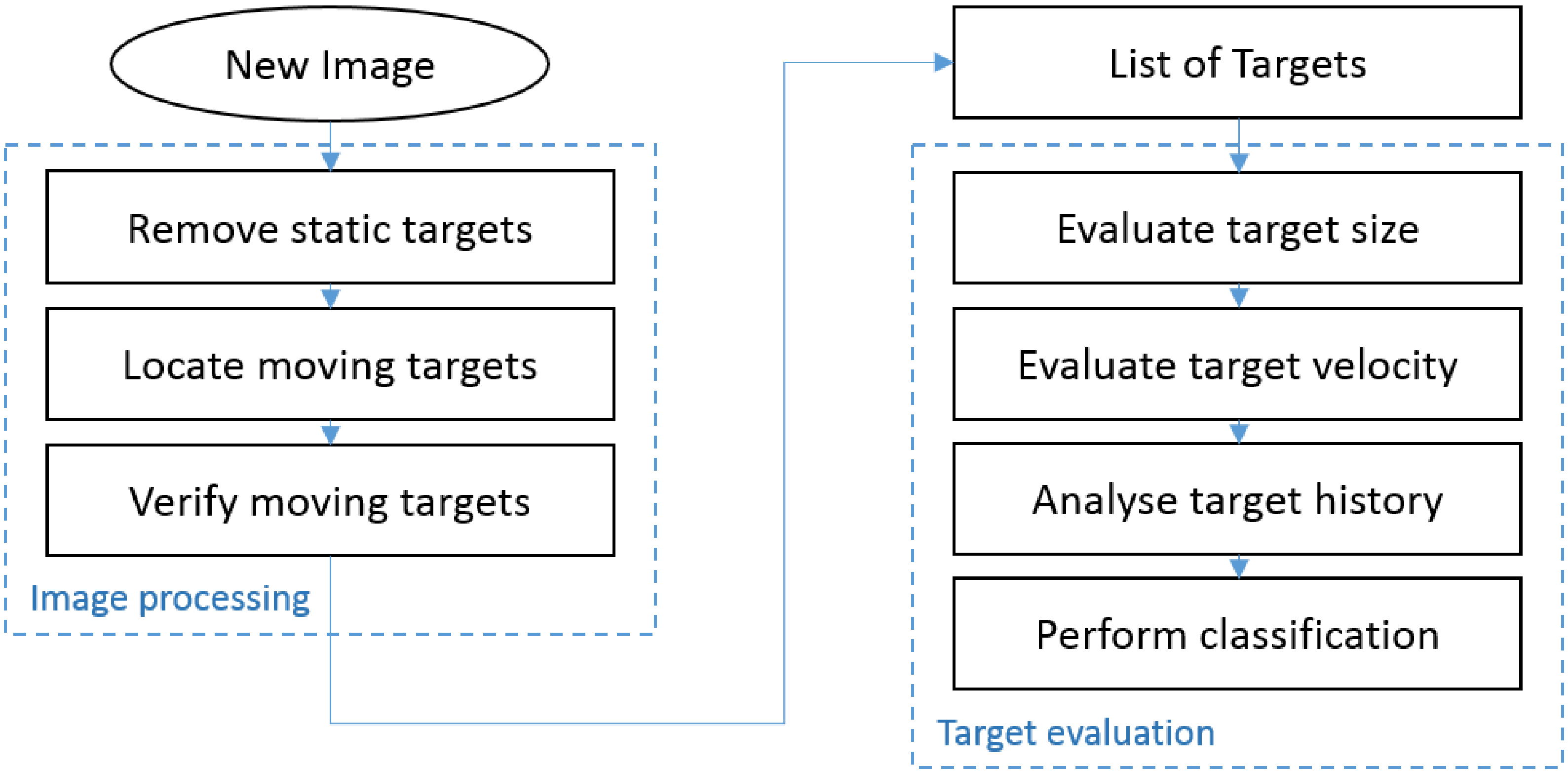
# Target Detection



# Automatic Target Tracking

SeaTec Introduction

# SeaTec Target Identification and classification

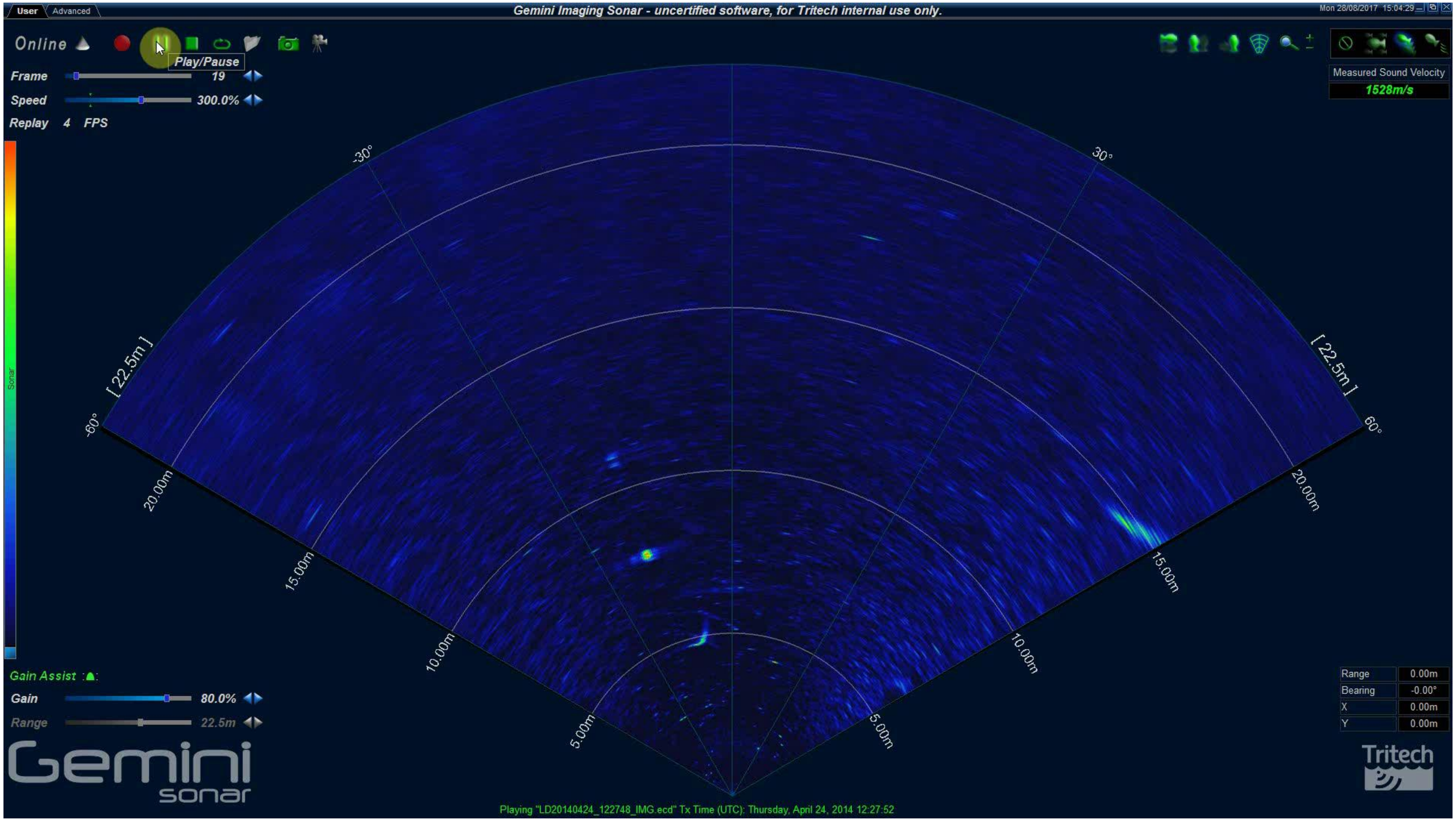


# Automatic Target Tracking

Image Processing

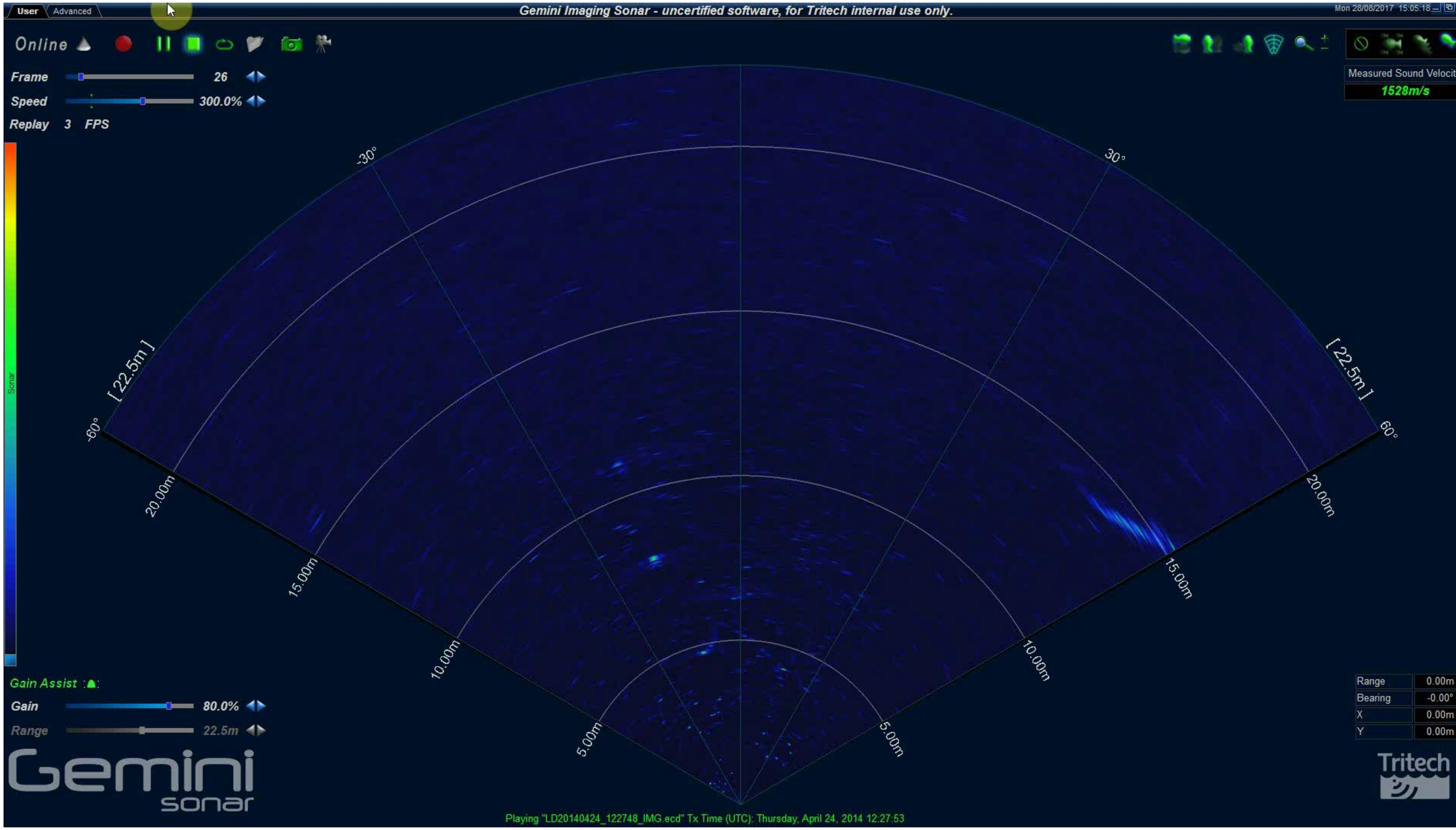
# Remove Static Targets

## Accumulation Buffer



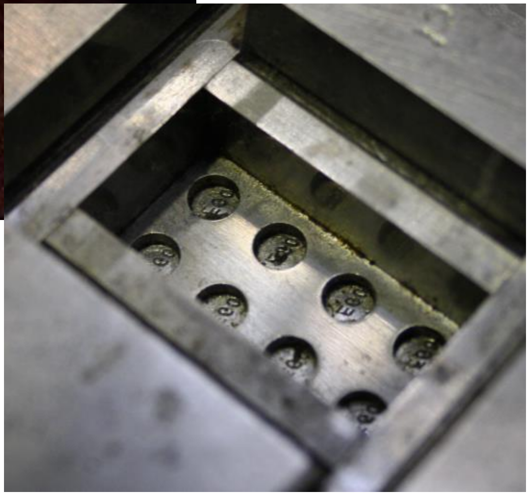
# Remove Static Targets

## Movement Buffer



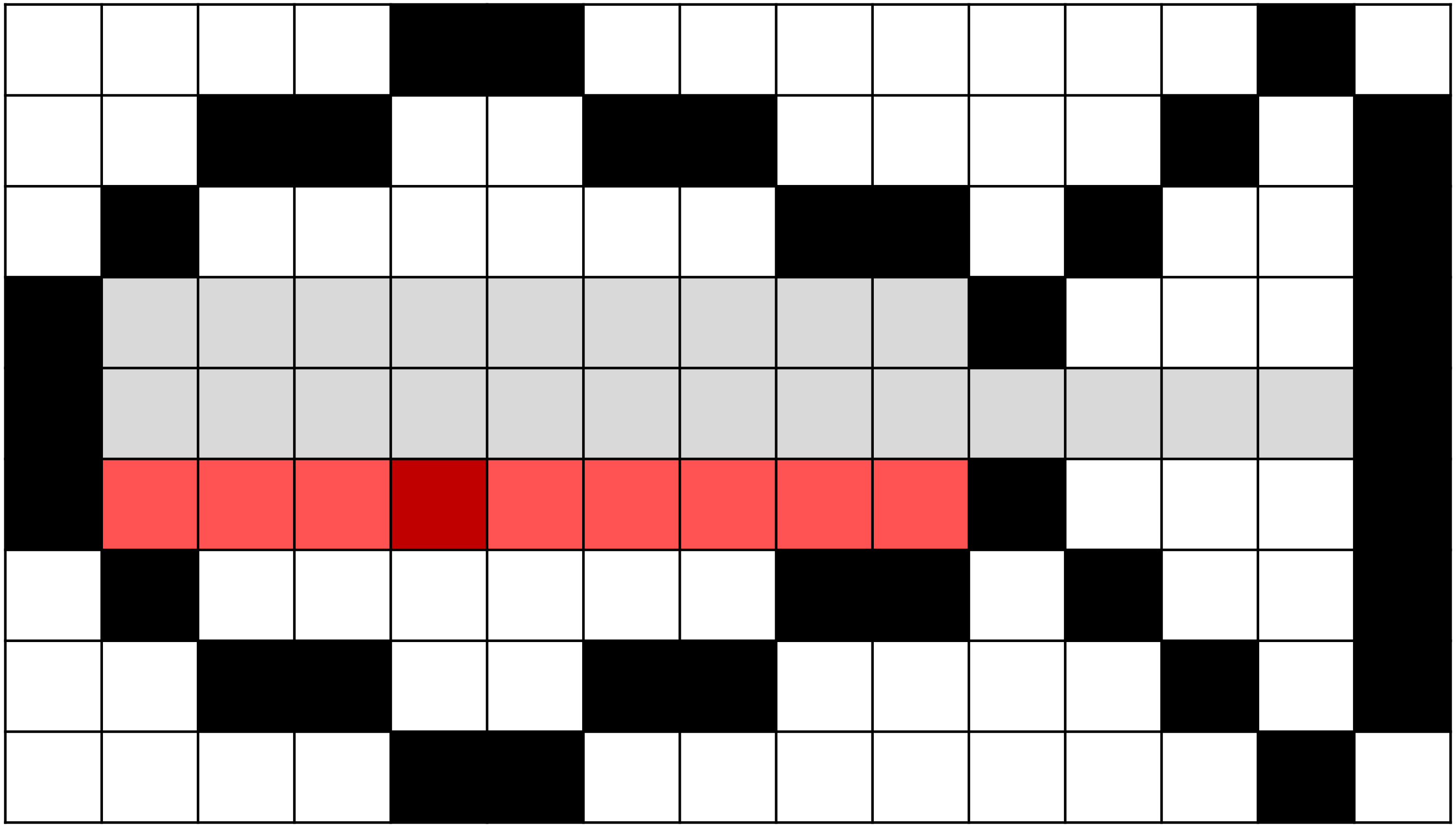
# Locate Moving Targets

## Flood Fill

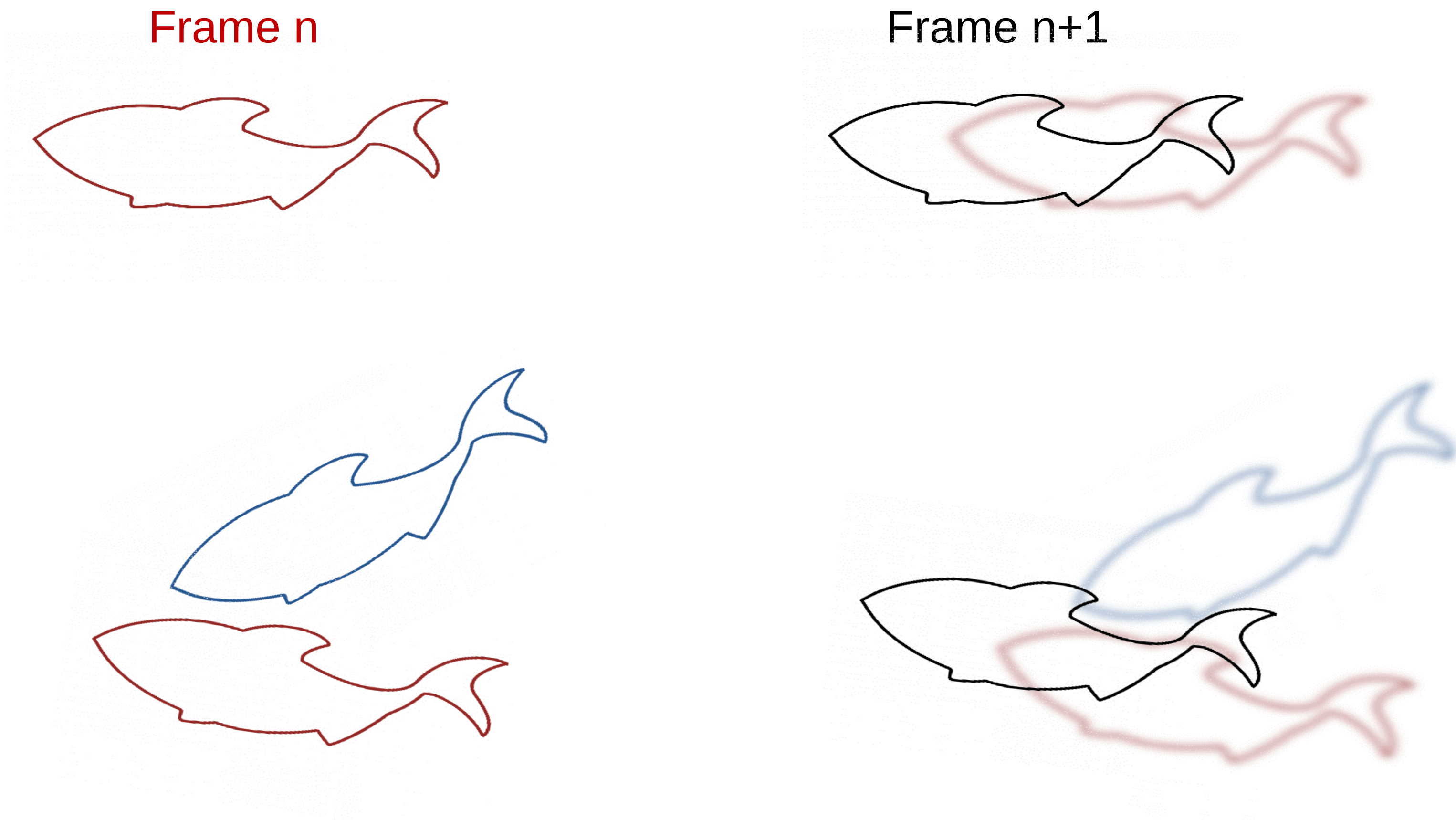


# Locate Moving Targets

## Flood Fill

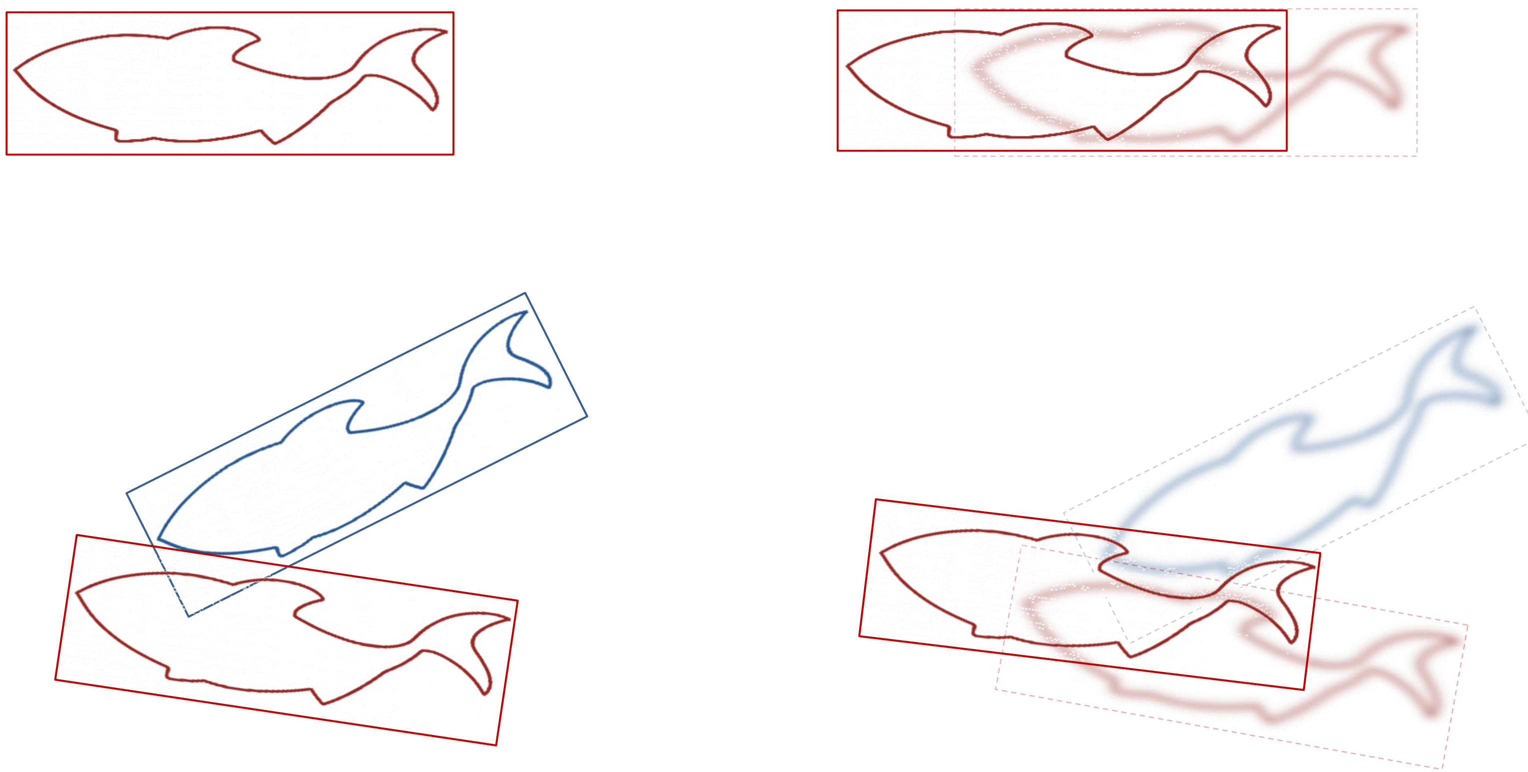


# Verify Moving Targets

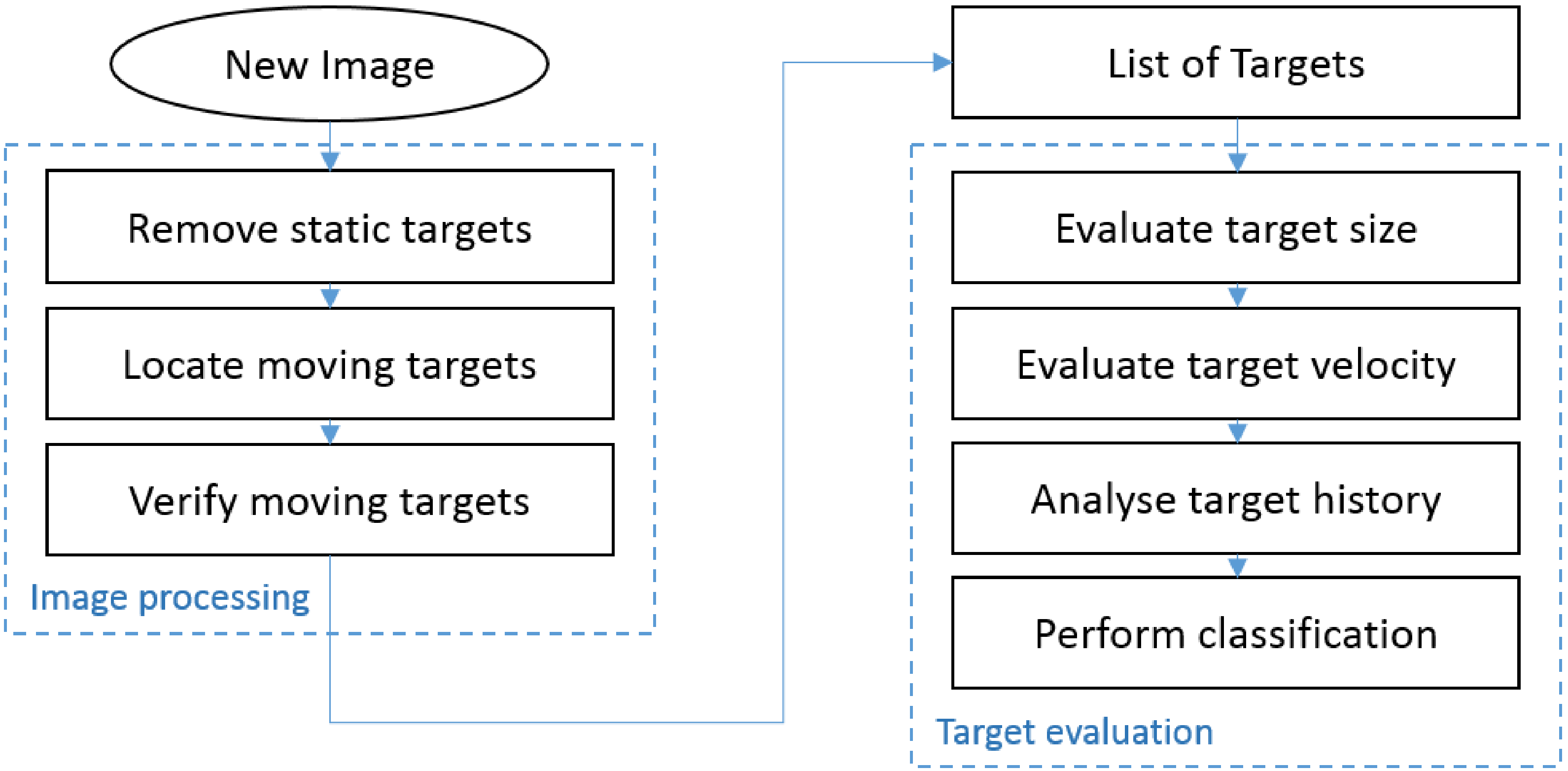


# Verify Moving Targets

Frame n | Frame n+1



# SeaTec Target Identification and classification

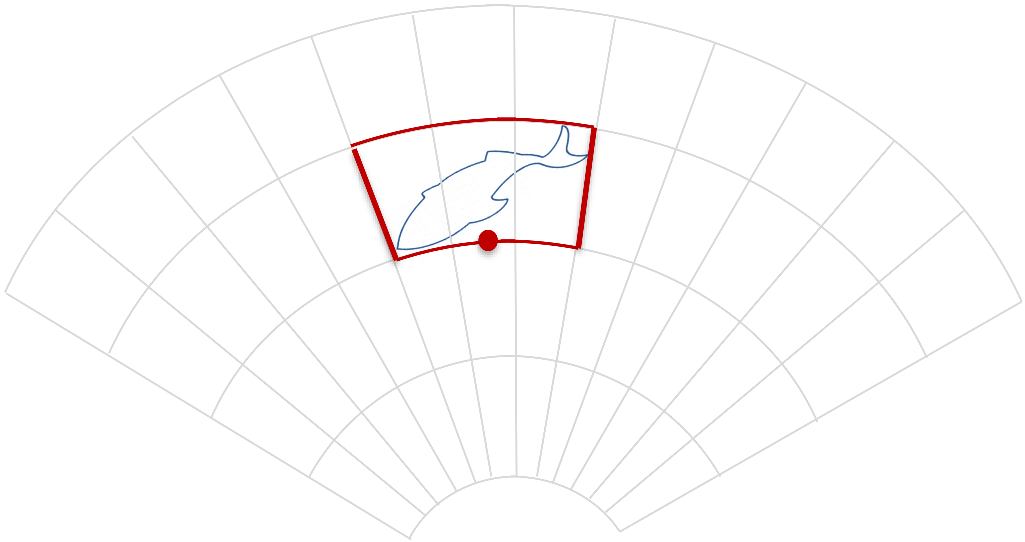


# Automatic Target Tracking

## Target Evaluation

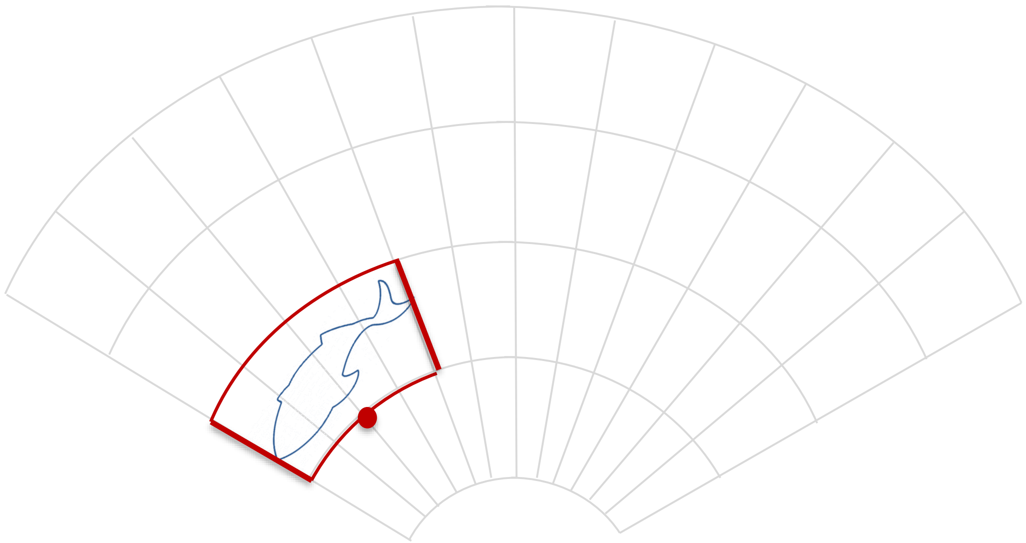
# Evaluate Target Size

## Bounding Box



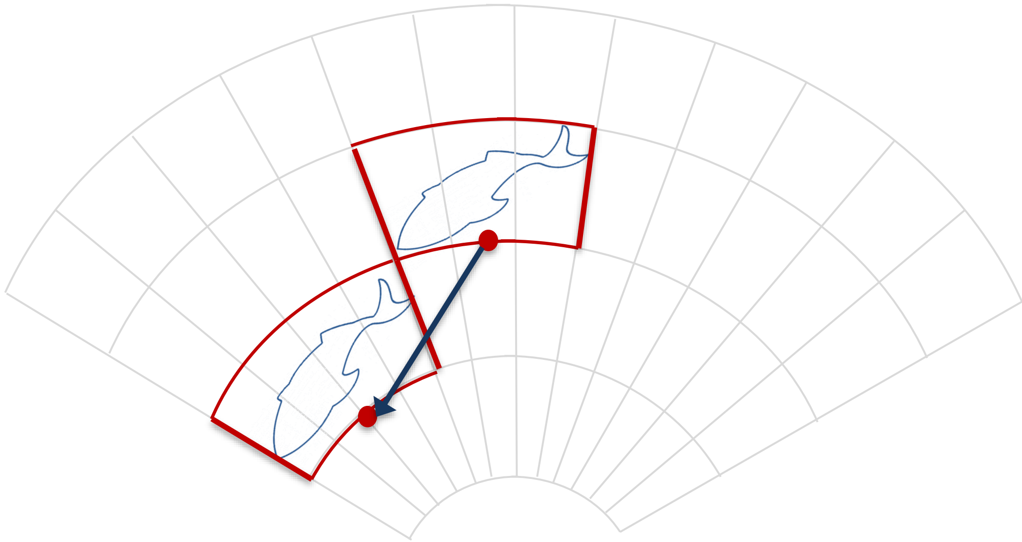
# Evaluate Target Size

## Bounding Box



# Evaluate Target Velocity

Build up tracks



MOOG

# Perform Classification

| | | |
|---|---|---|
| Probable | red | 2 |
| Potential | yellow | 0 |
| Possible | green | 14 |

***Probable*** =
*Potential* **+**
longer path with stable measurements

***Potential*** =
*Possible* **+**
direction not tidal/drift

***Possible*** =
Shape **+**
Size

| | | |
|---|---|---|
| Small | blue | 1 |
| Large | purple | 0 |
| Tidal/Drift | olive | 0 |

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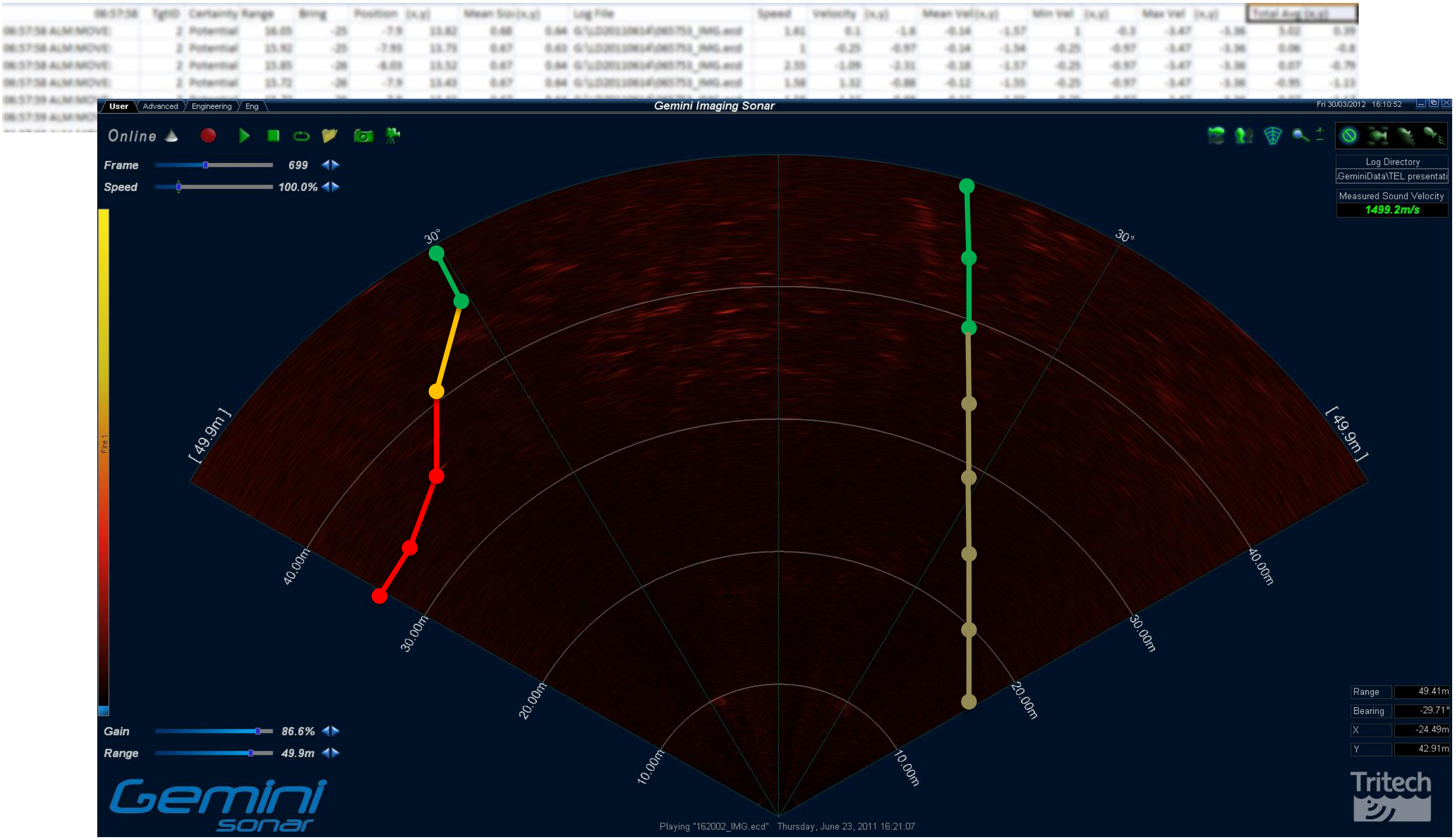
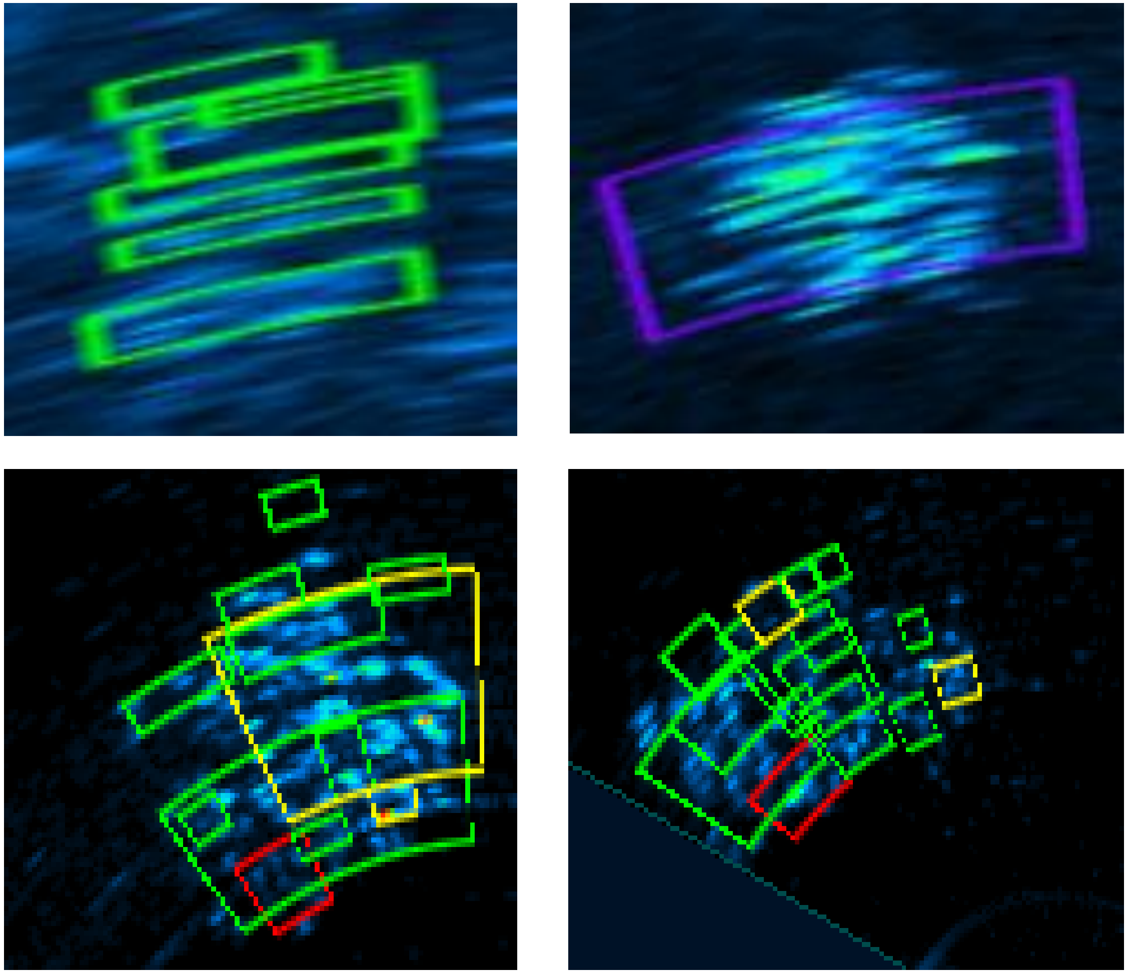
# Perform Classification



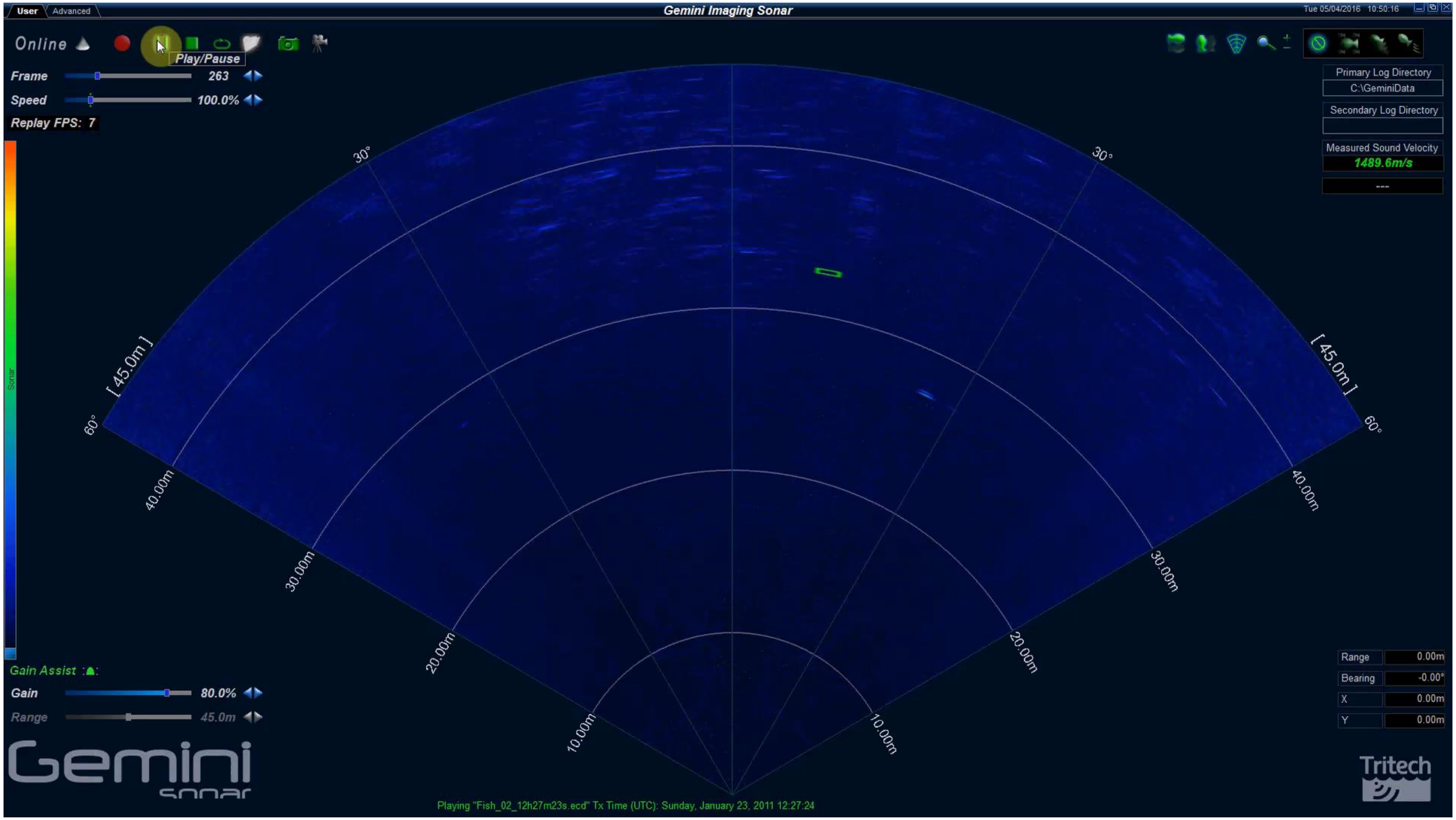
# Automatic Target Tracking

Drawbacks: Classification and Measurement

# Drawbacks: Classification & Measurement



# Results: Strangford

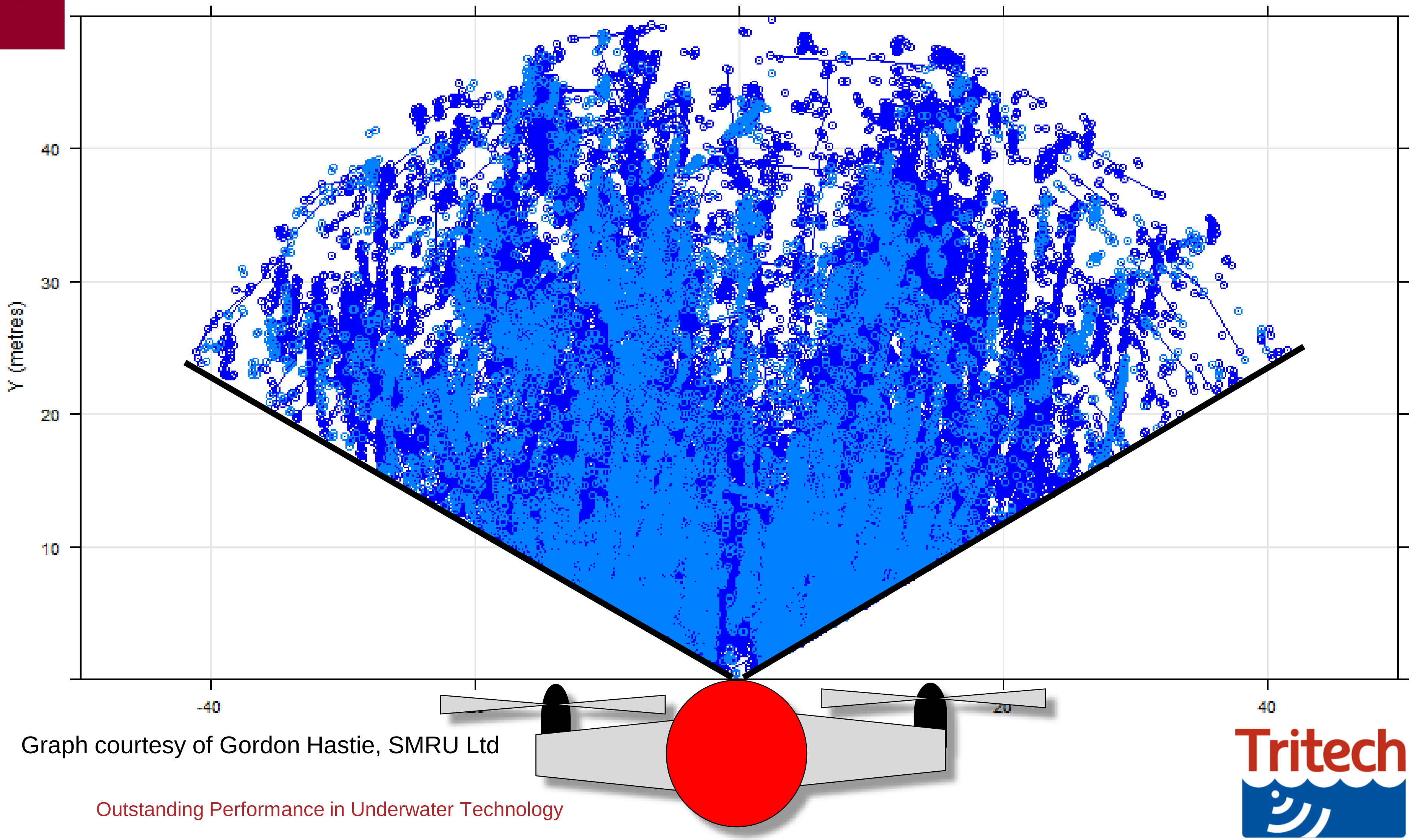


# Results

Target Tracks

# Gemini SeaTec

## Marine Current Turbine (MCT) @ Strangford Lough




Graph courtesy of Gordon Hastie, SMRU Ltd

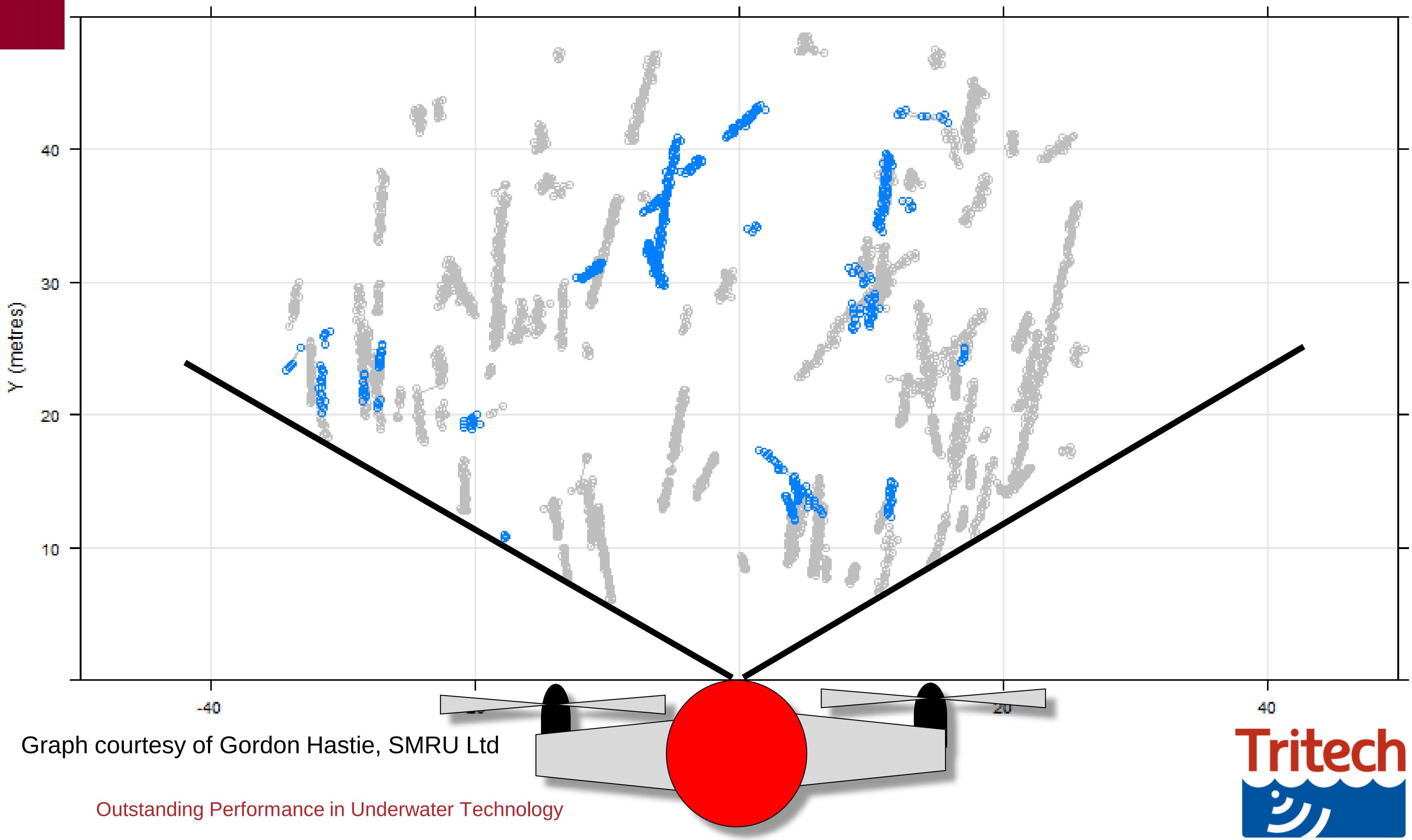
MOOG

# Gemini SeaTec

## Marine Current Turbine (MCT) @ Strangford Lough

SMRU

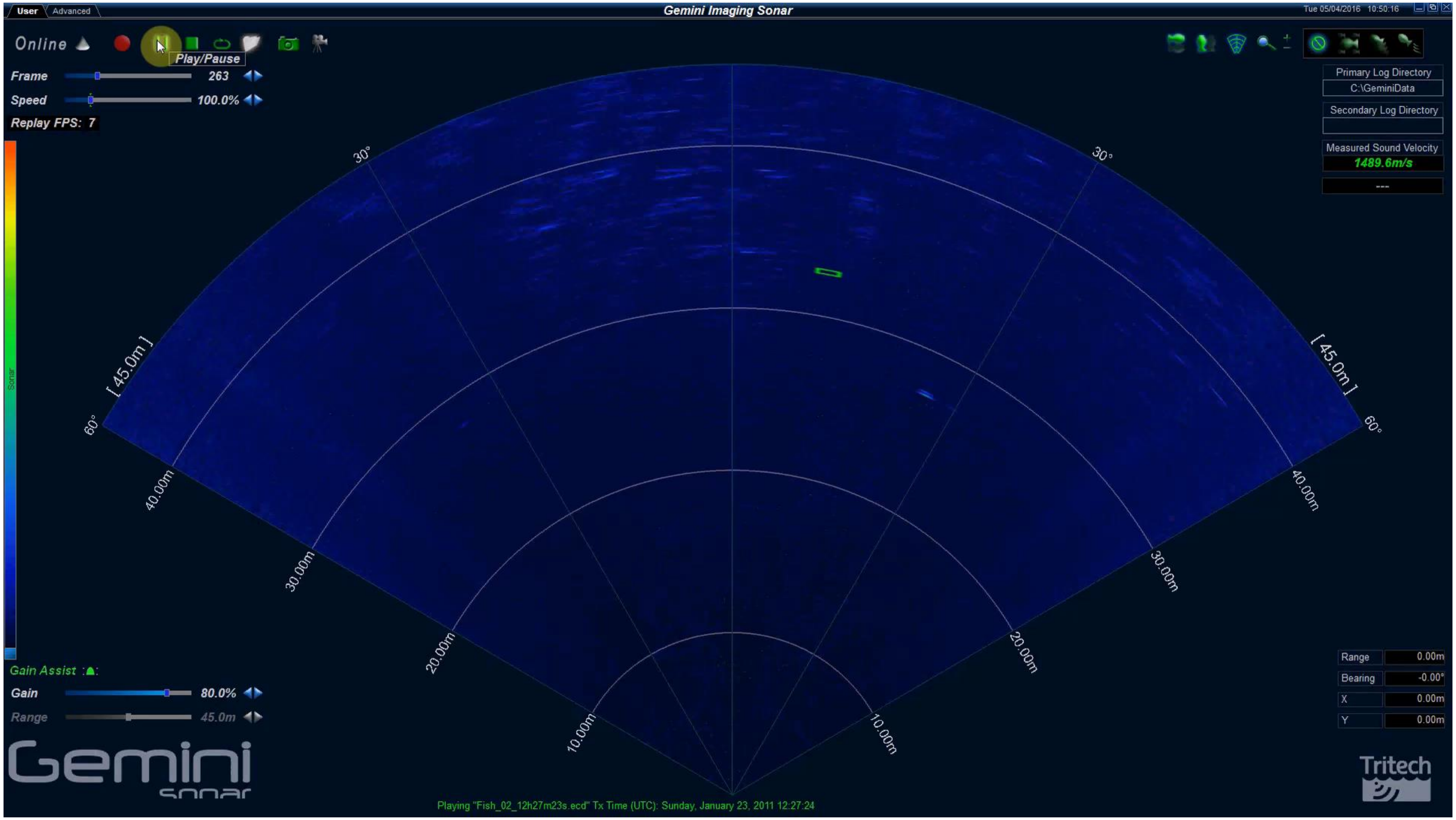
smru
LIMITED



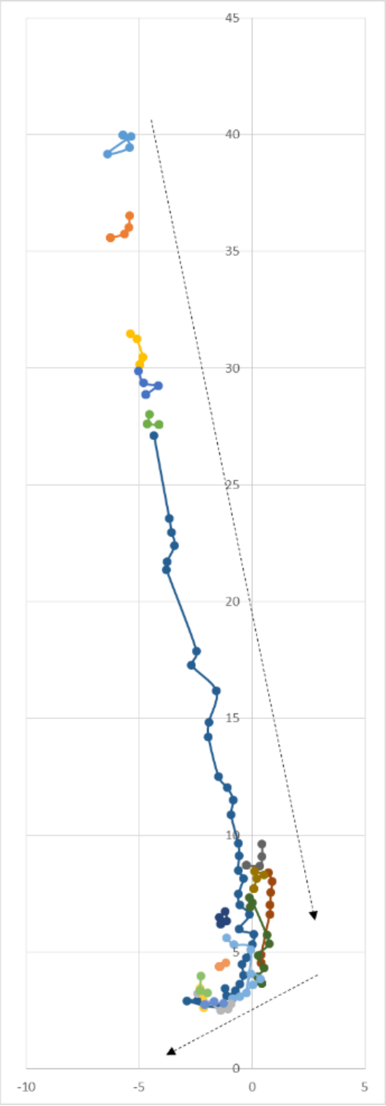

Graph courtesy of Gordon Hastie, SMRU Ltd

Tritech

# Results: Strangford



# Results: Strangford

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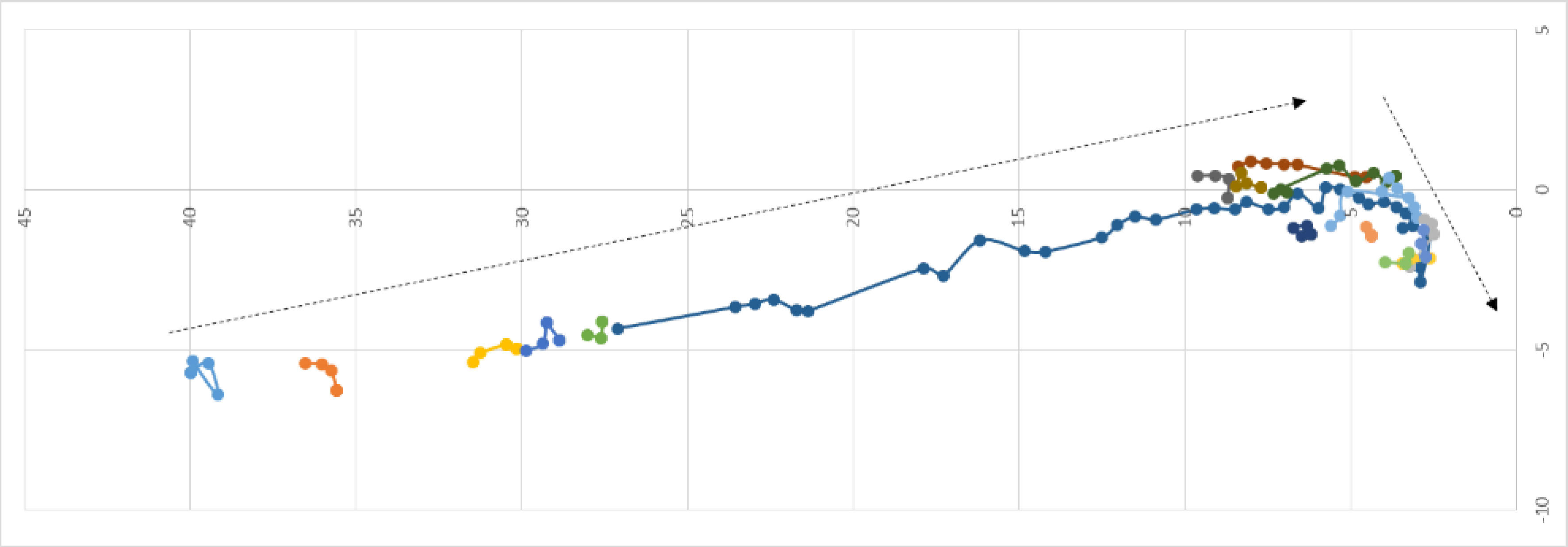
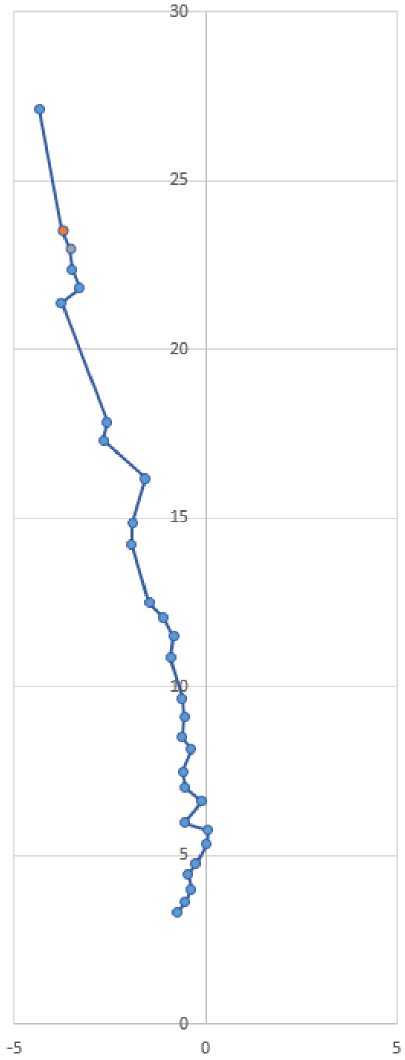
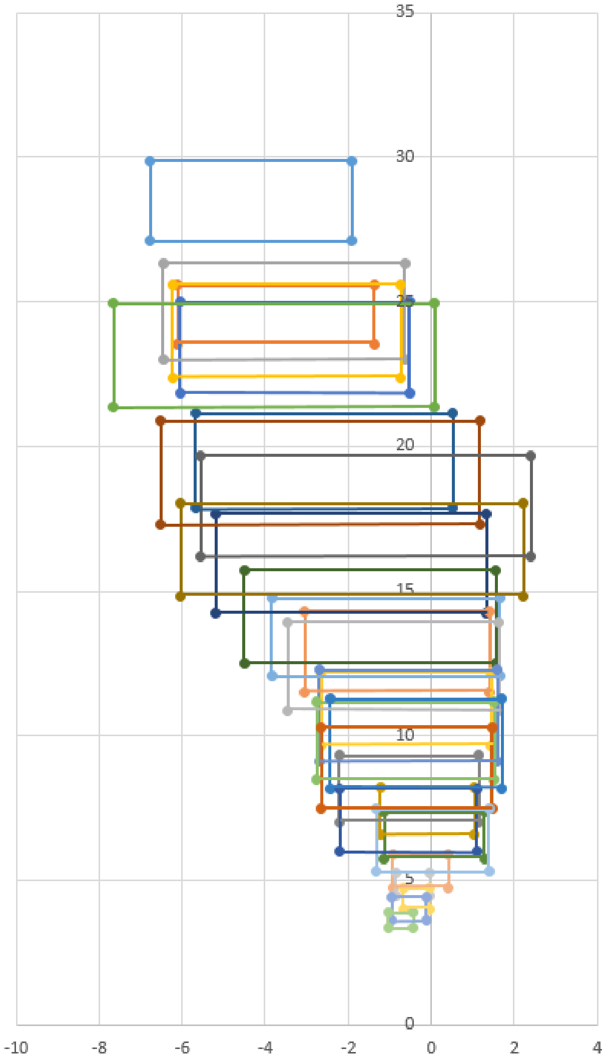
# Results: Strangford




Outstanding Performance in Underwater Technology

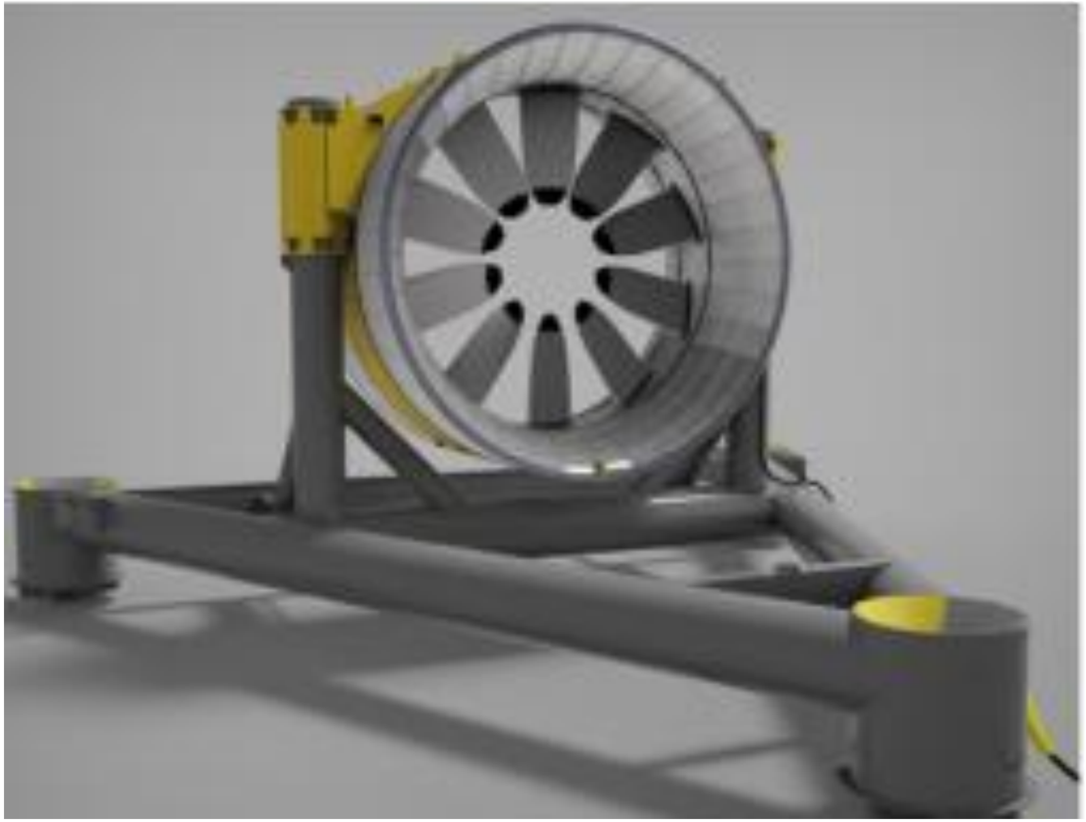
# Results: Strangford



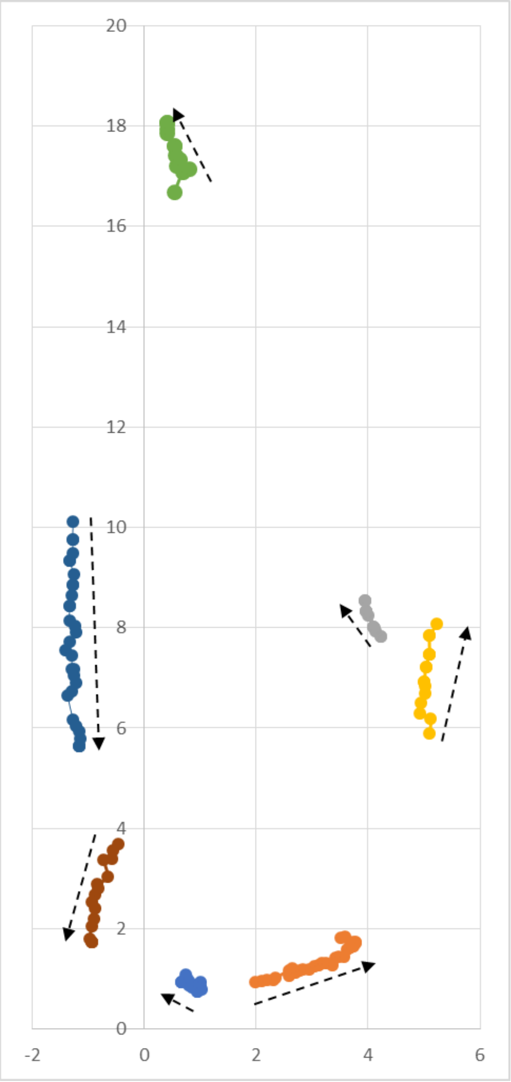



# Results: Bay of Fundy

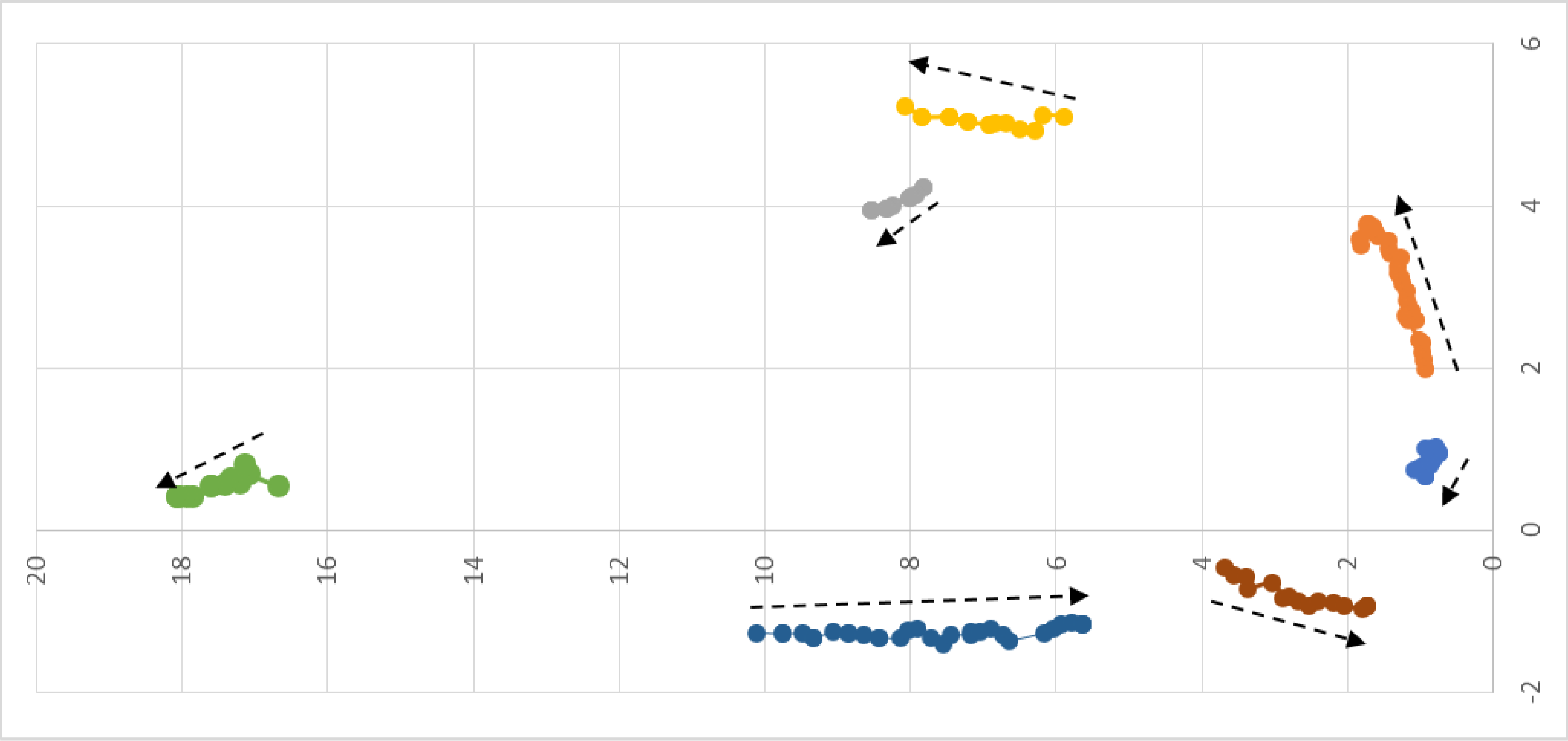
## OpenHydro & Emera



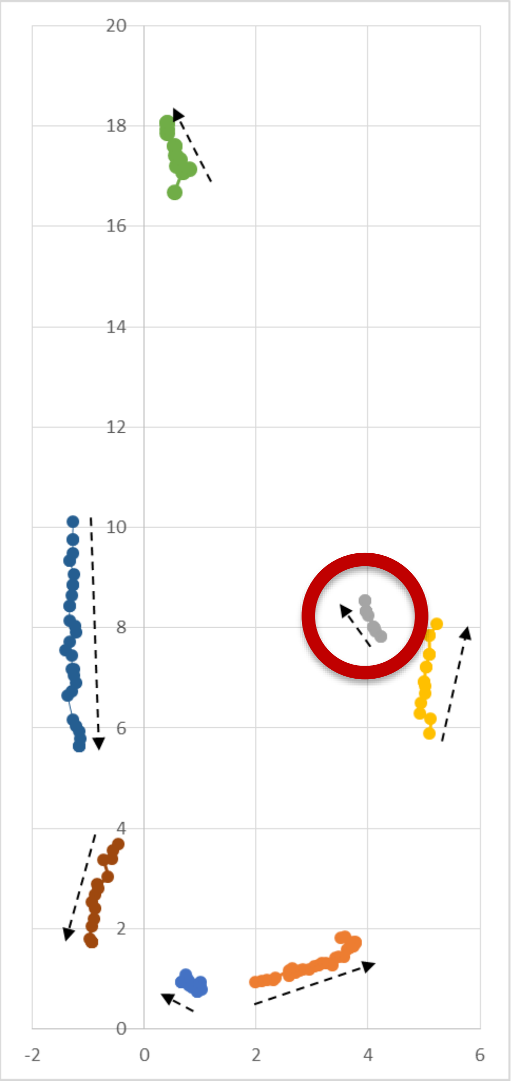
# Results: Bay of Fundy



# Results: Bay of Fundy



# Results: Bay of Fundy



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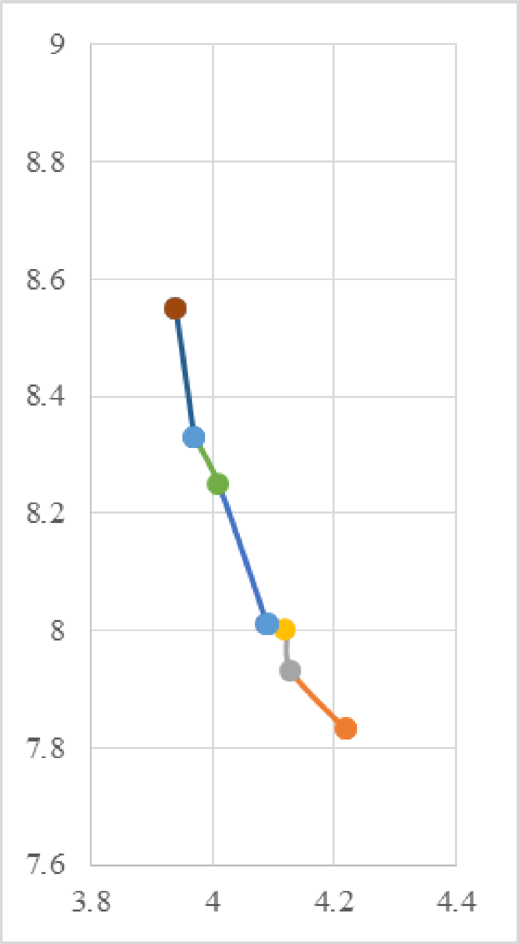
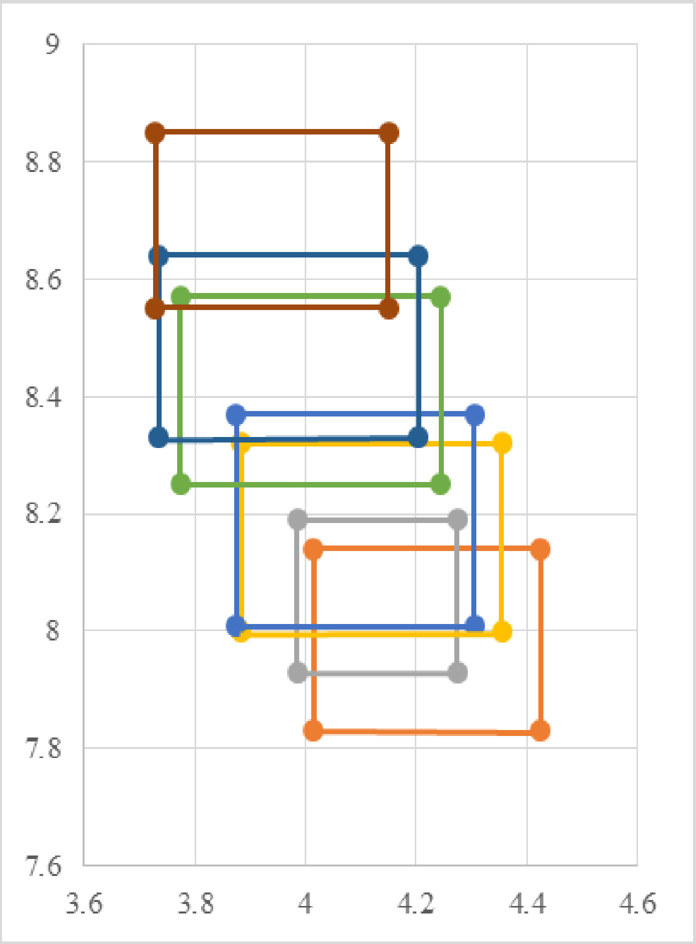


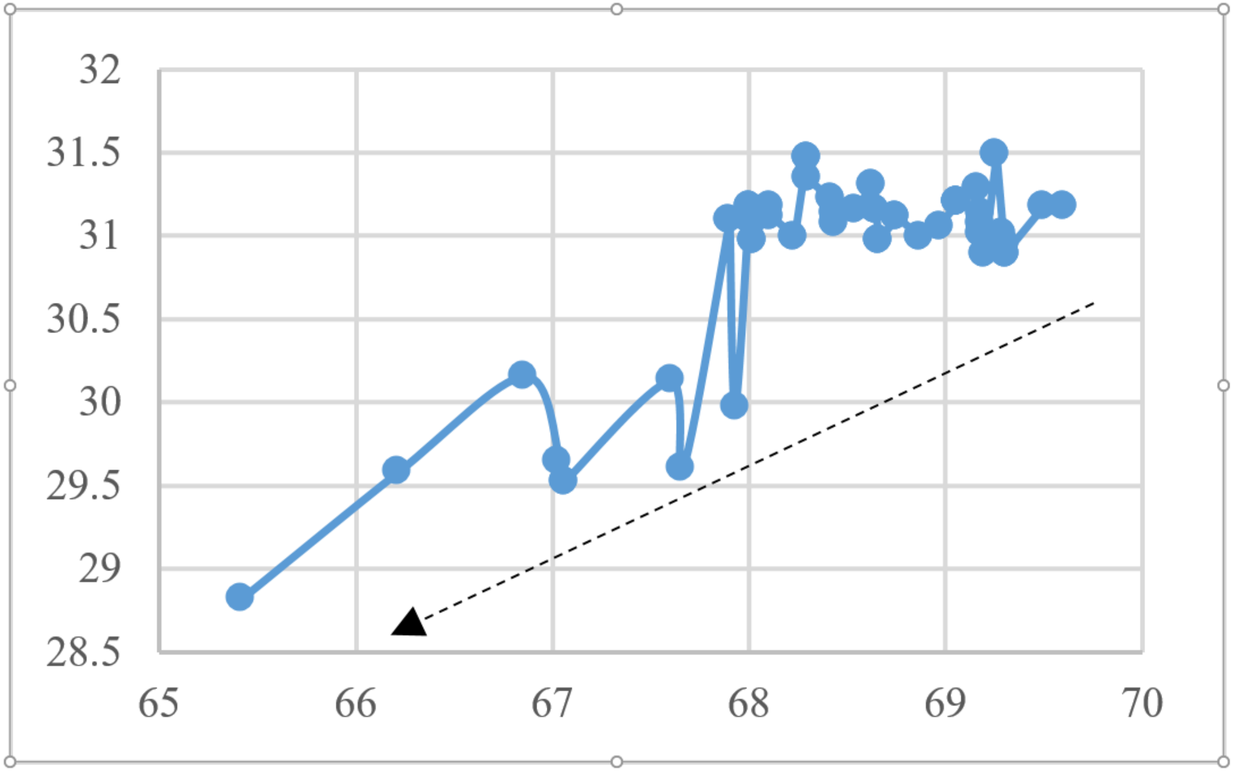



# Results

Sample Data Sets and Size Verification

# SMRU Tagged Seal

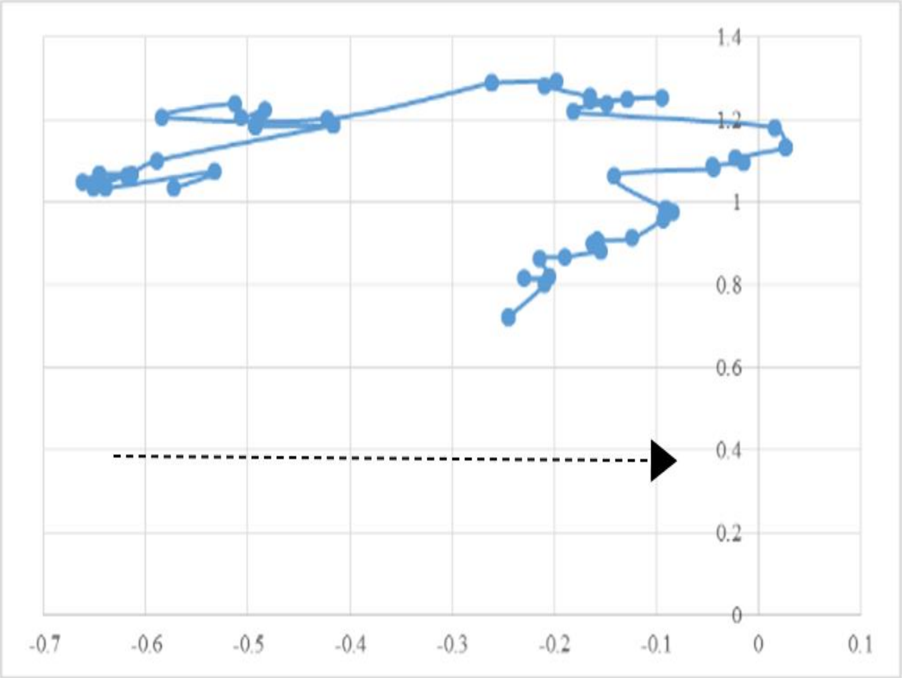
- Seal:
  - ~31m range
  - 1.05m length
- 5 seconds
- 85 images
- 245 measurements
- 6 probable tracks:
  - 5 used
  - 1 removed: >70m from the seal




| | Width | Length | Diagonal |
|---|---|---|---|
| Minimum | 0.1318 | 0.60727 | 0.6214082 |
| Maximum | 0.527199 | 1.49187 | 1.5822815 |
| Median | 0.205022 | 0.850684 | 0.875682 |
| Mean | 0.2226956 | 0.978922 | 1.0057312 |

# ACER Fish

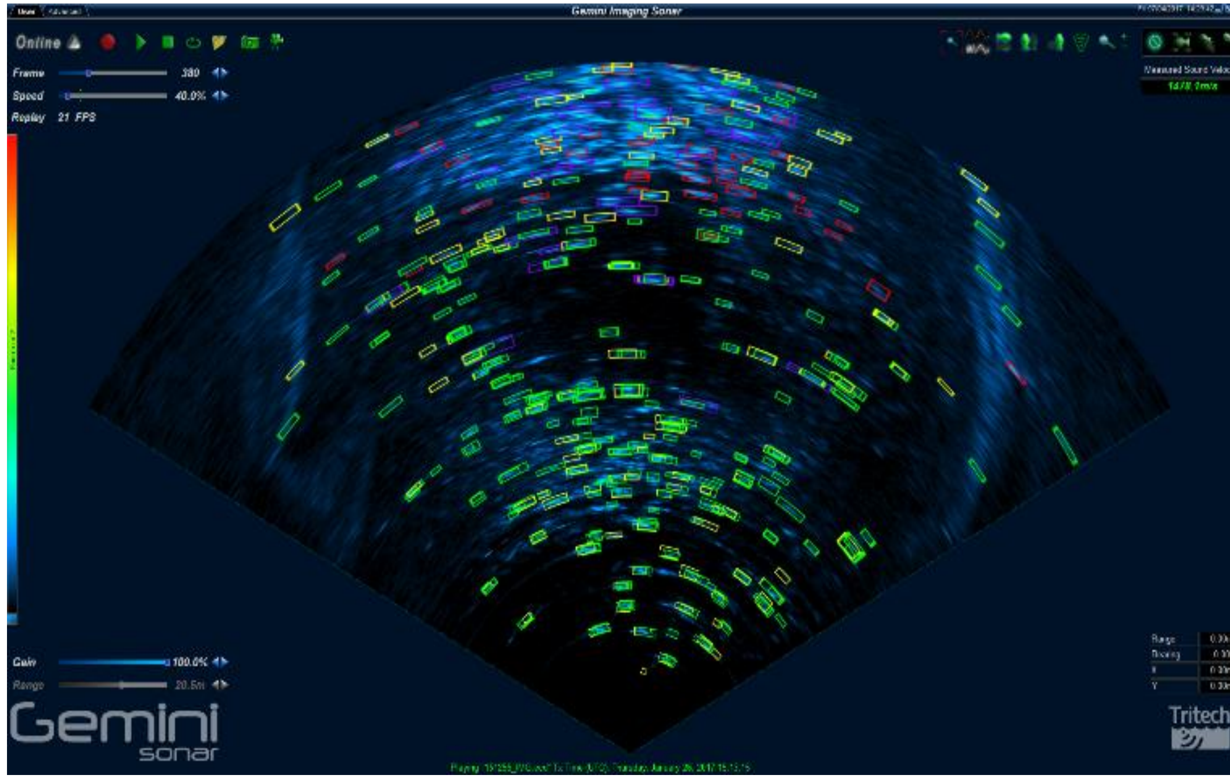
- 0.45m American Shad
- 10 seconds
- 108 images
- 64 measurements
- 16 probable tracks:
  - 5 used
  - 11 removed: >0.5m from the fish




| | Width | Length | Diagonal |
|---|---|---|---|
| Minimum | 0.050271 | 0.166471 | 0.1782798 |
| Maximum | 0.326761 | 0.616828 | 0.6238532 |
| Median | 0.092163 | 0.388762 | 0.4413439 |
| Mean | 0.1300167 | 0.4136823 | 0.4422415 |

# Fish Farm

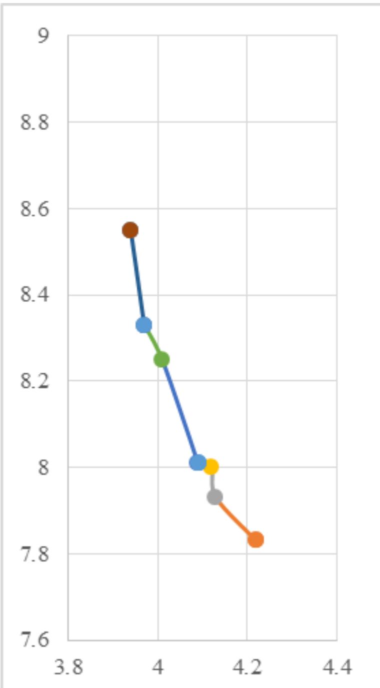
- Weekly sample weigh: 60-70cms
- 4 seconds
- ~377 targets per ping
- 37325 measurements
- (tracks not used)



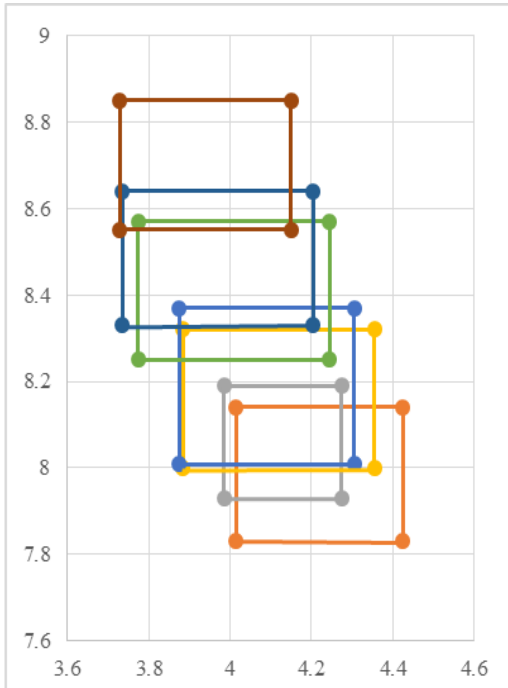

| | Width | Length | Diagonal |
|---|---|---|---|
| **Minimum** | 0.032692 | 0.178207 | 0.19952 |
| **Maximum** | 1.144216 | 1.49494 | 1.4992136 |
| **Median** | 0.130768 | 0.618363 | 0.6398077 |
| **Mean** | 0.1452224 | 0.6509893 | 0.6730434 |

# Conclusions & Future work

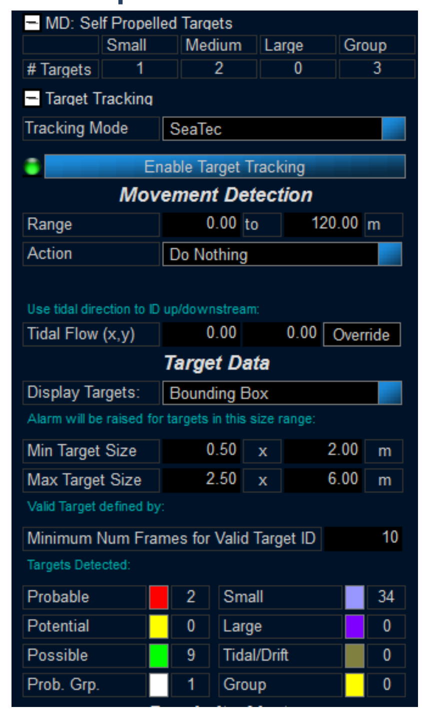
Tracks



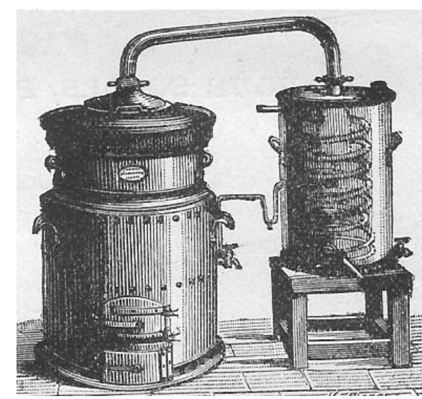

Sizes




Evaluation improvements




Algorithmic improvements from expert knowledge



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# Acknowledgements

OERA Offshore Energy Research Association

CAPE SHARP TIDAL

Innovate UK

ACADIA CENTRE FOR ESTUARINE RESEARCH

SMRU Consulting
Europe • North America • Asia Pacific

openhydro
a DCNS company

Emera

12th EWTEC 2017
European Wave and Tidal Energy Conference Series

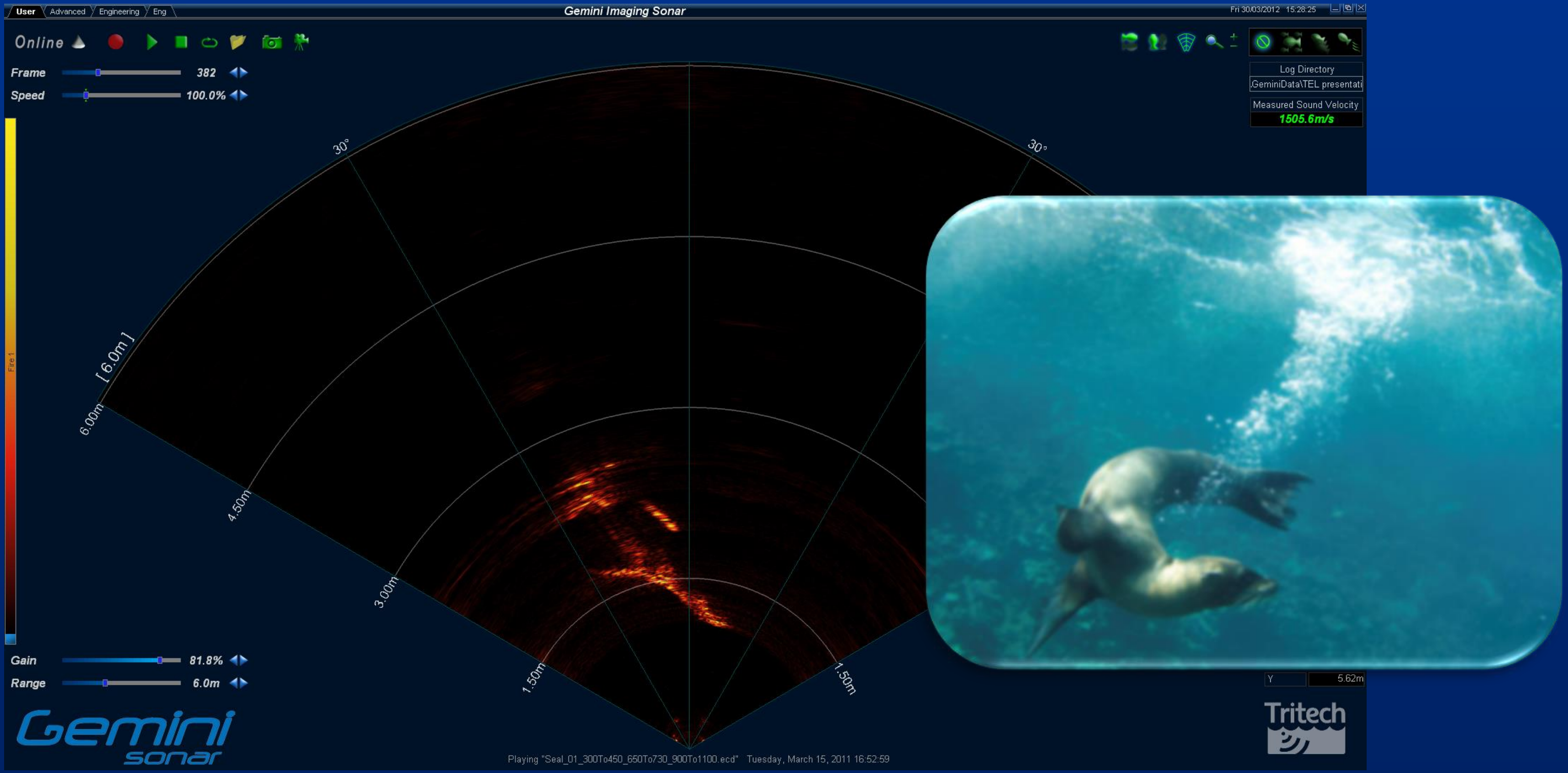
Tritech

# Thank you & Questions

Images courtesy of Gordon Hastie, SMRU Ltd

Tritech

# SeaTec: Marine Mammals

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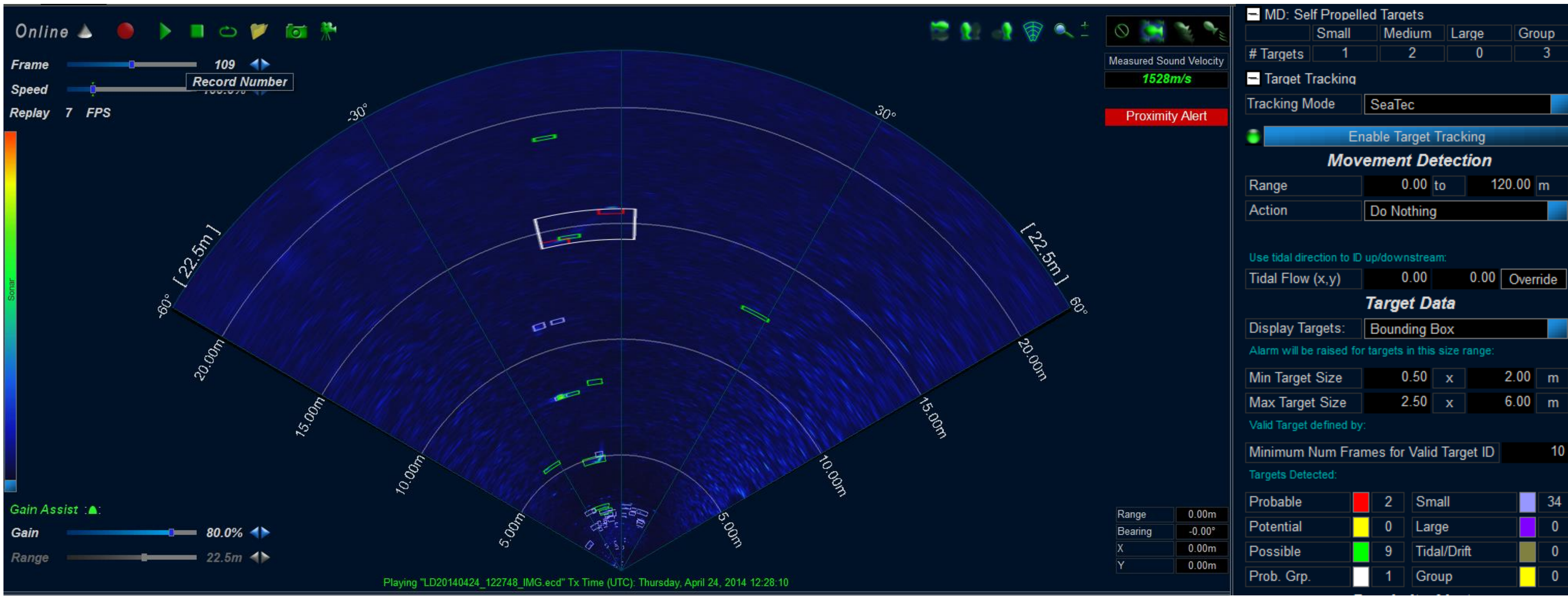
# Automatic Target Tracking

Target Size controls in the User Interface

# Size Controls



# Automatic Target Tracking

Tidal/Drift Calculations

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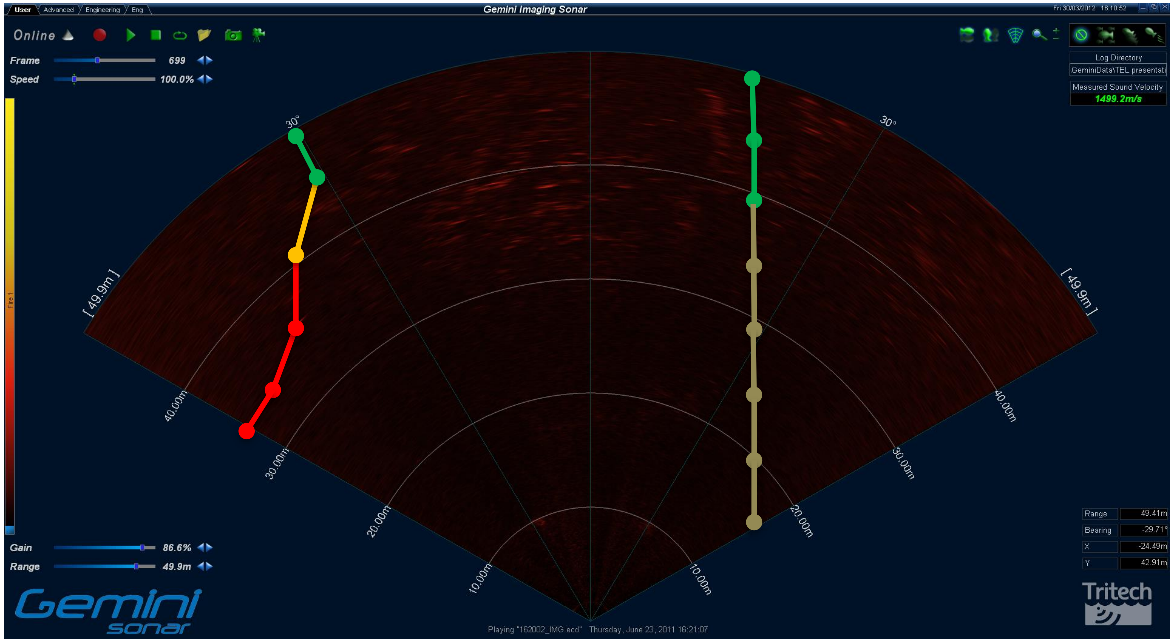
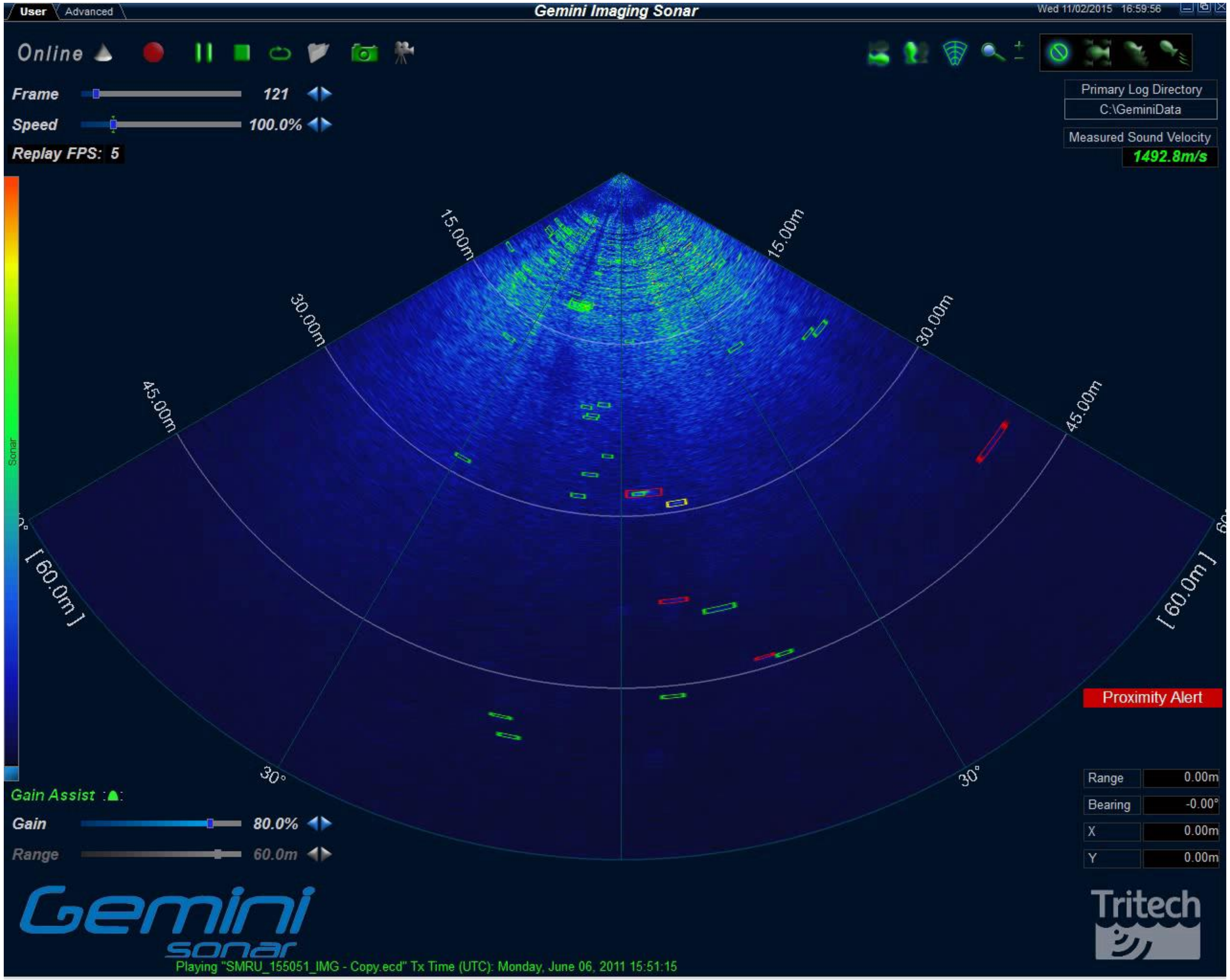
# Tidal Drift

Nortek Signature 500 ADCP



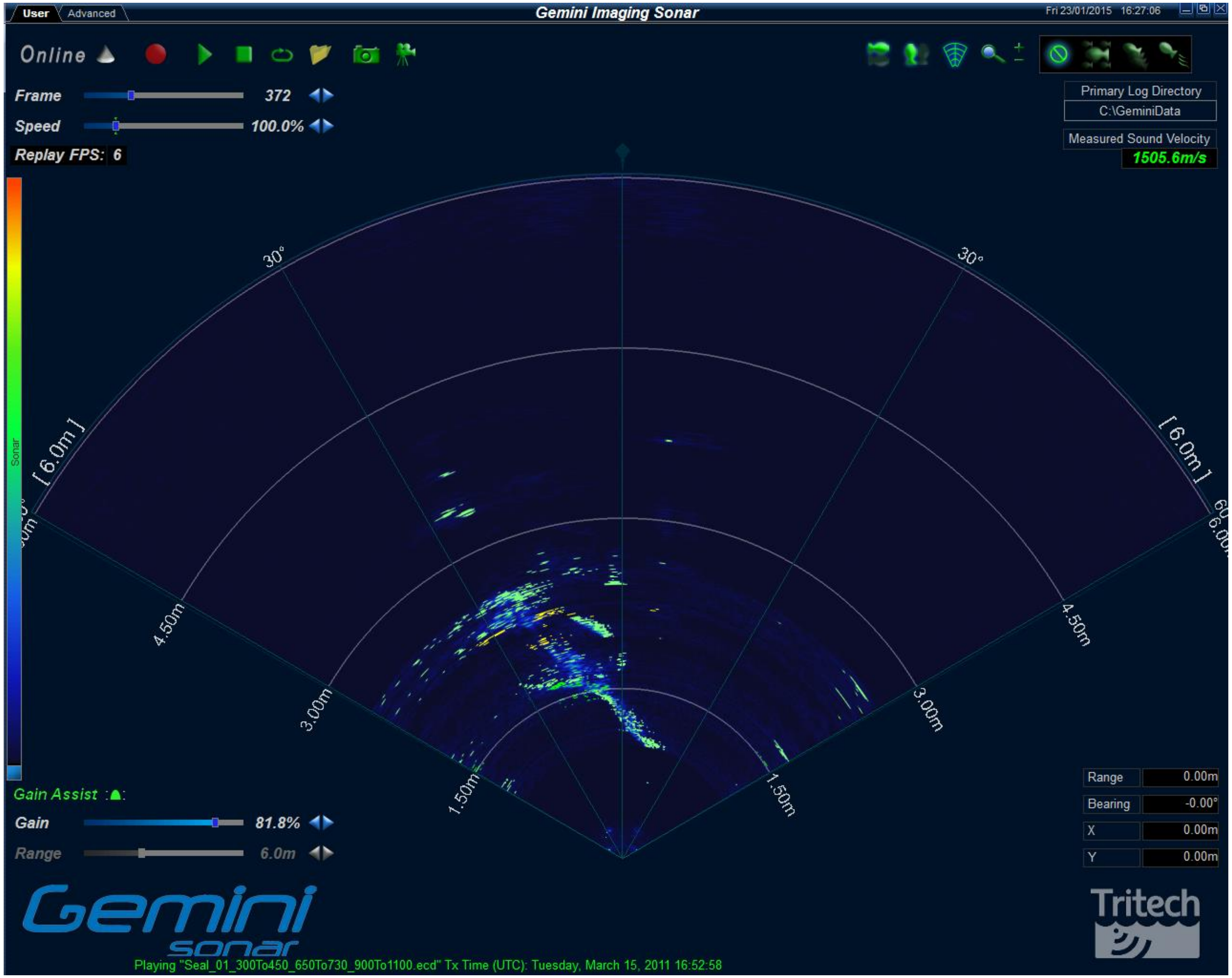

Tritech

# Tidal Drift vs. Average direction

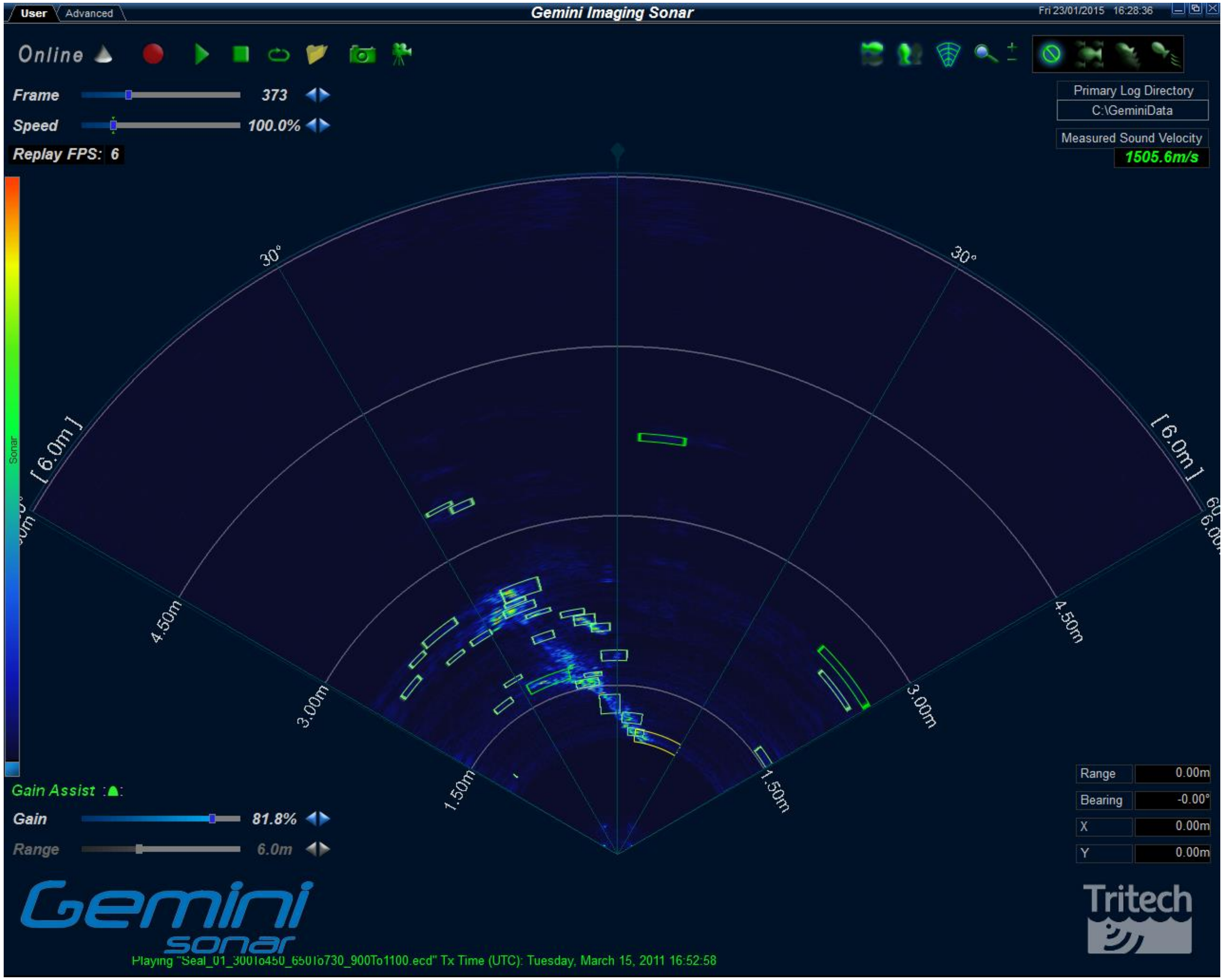


# Locate Moving Targets

## Flood Fill



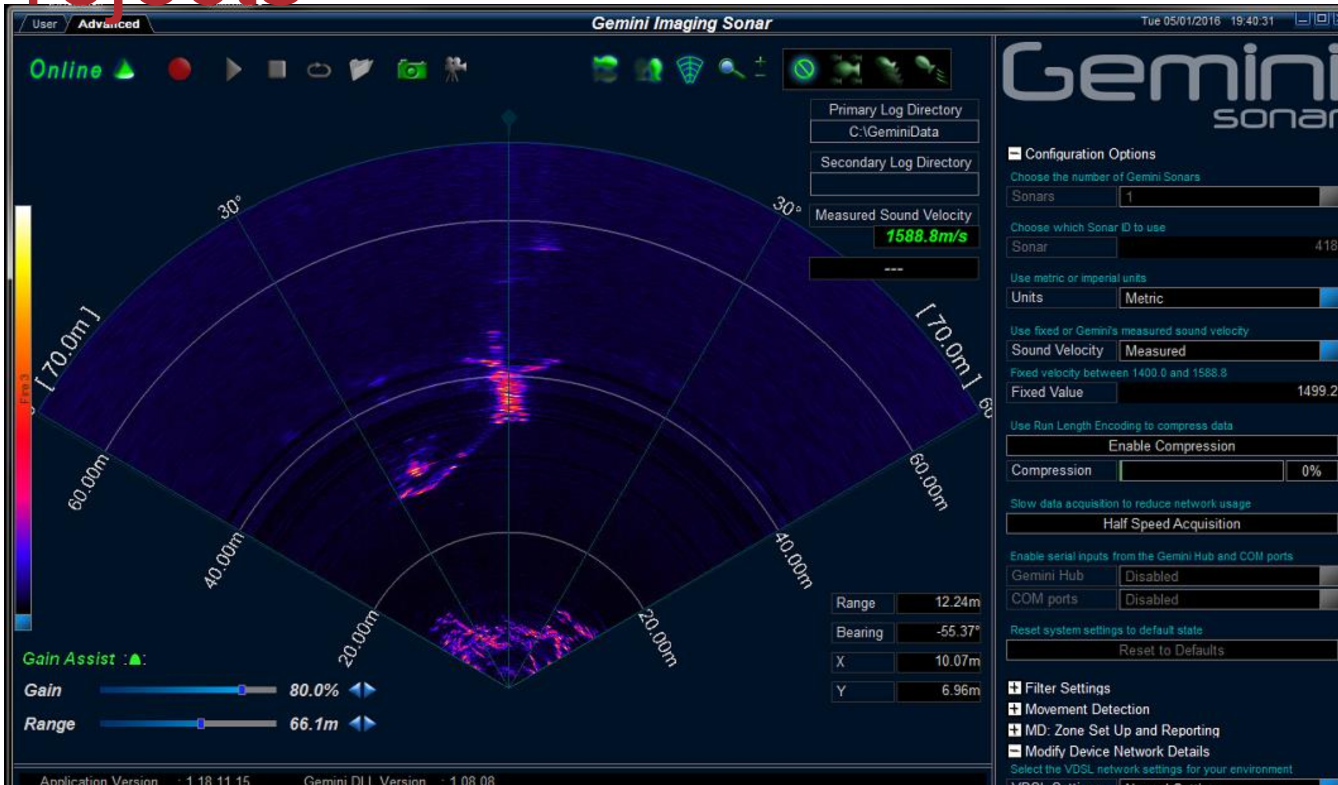
# Verify Moving Targets



# SeaTec Projects

## Tidal Energy Ltd

- **Ramsey Sound, Wales**
- **Deployed Dec 2015/Jan 2016**

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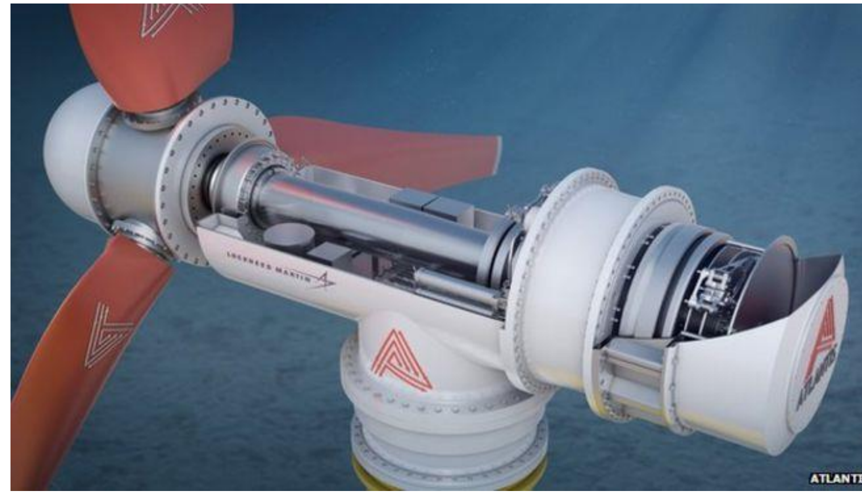
# Pentland Firth: MeyGen

## In progress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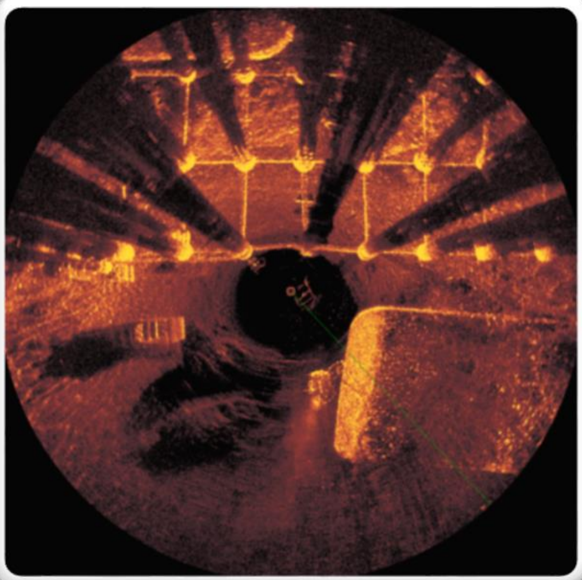
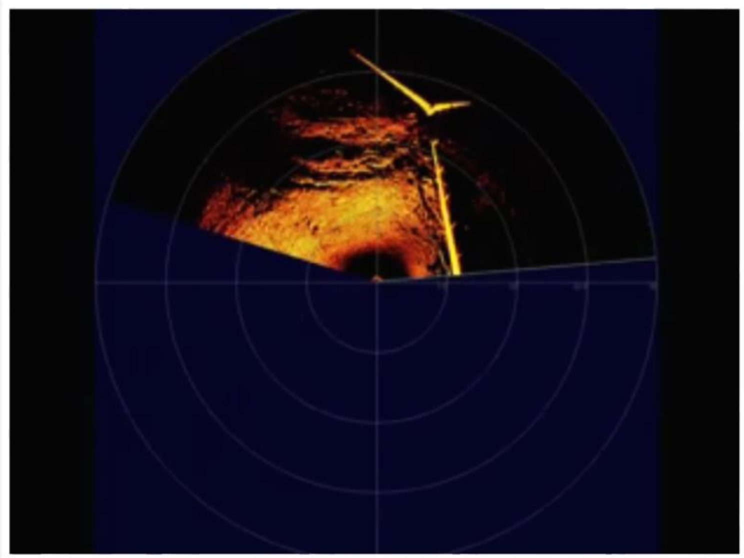
# Sonar – mechanically scanning

## What it looks like

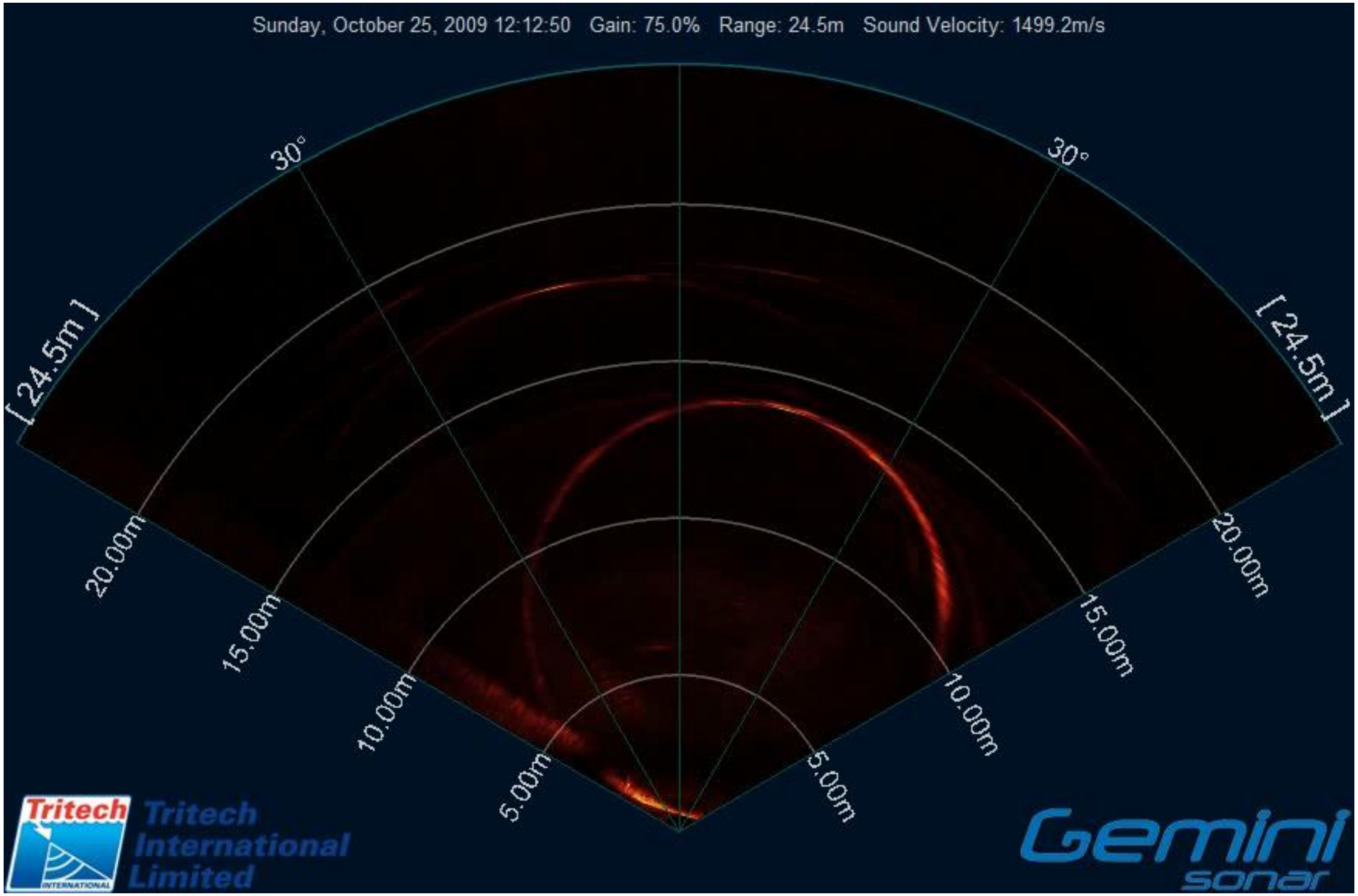

**Hammerhead** image of a pier structure, The Underwater Centre, Fort William





# Multibeam Sonar

## What it looks like

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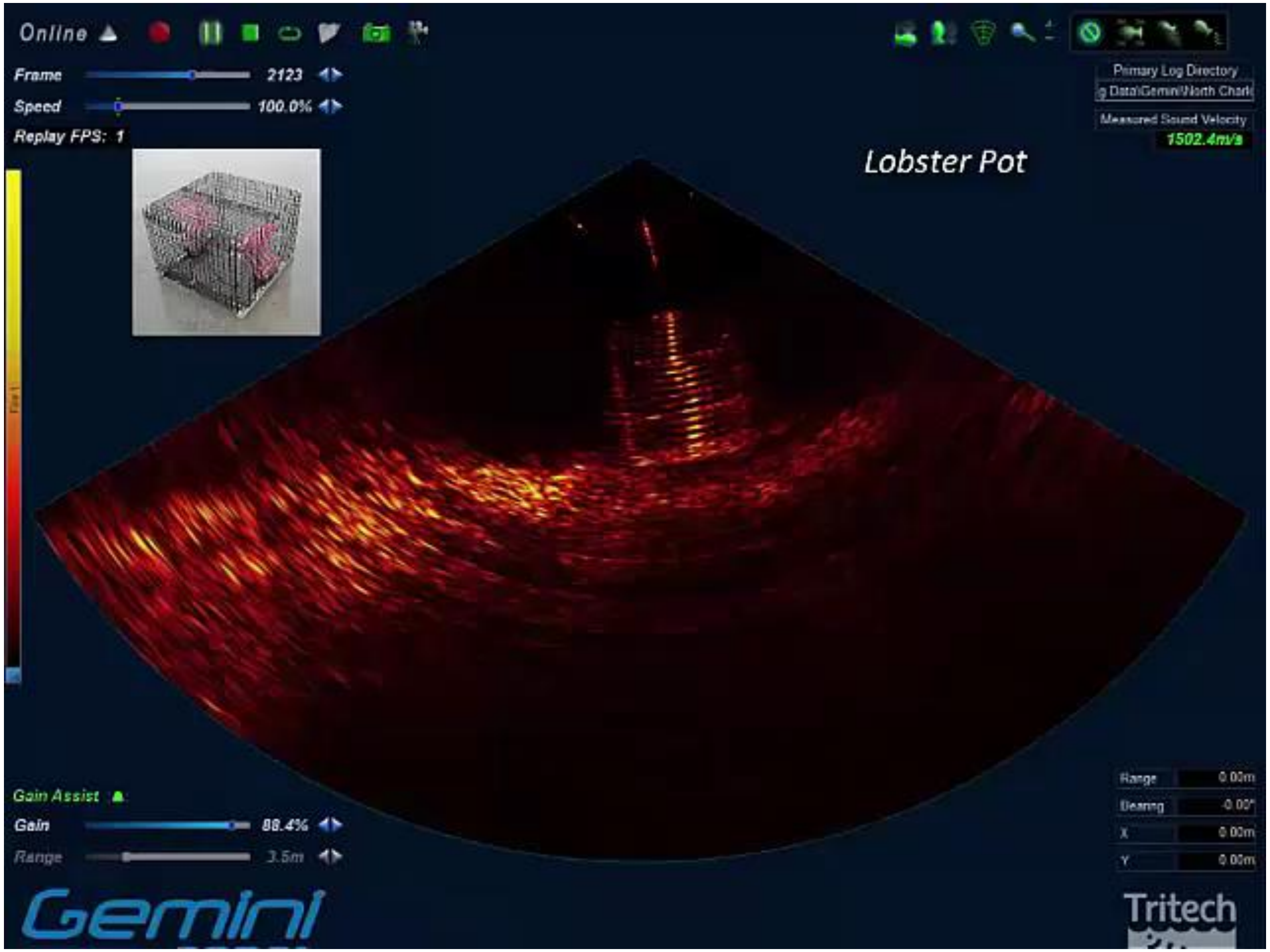
# Multibeam Sonar

## What it looks like

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# Multibeam Sonar

## What it looks like

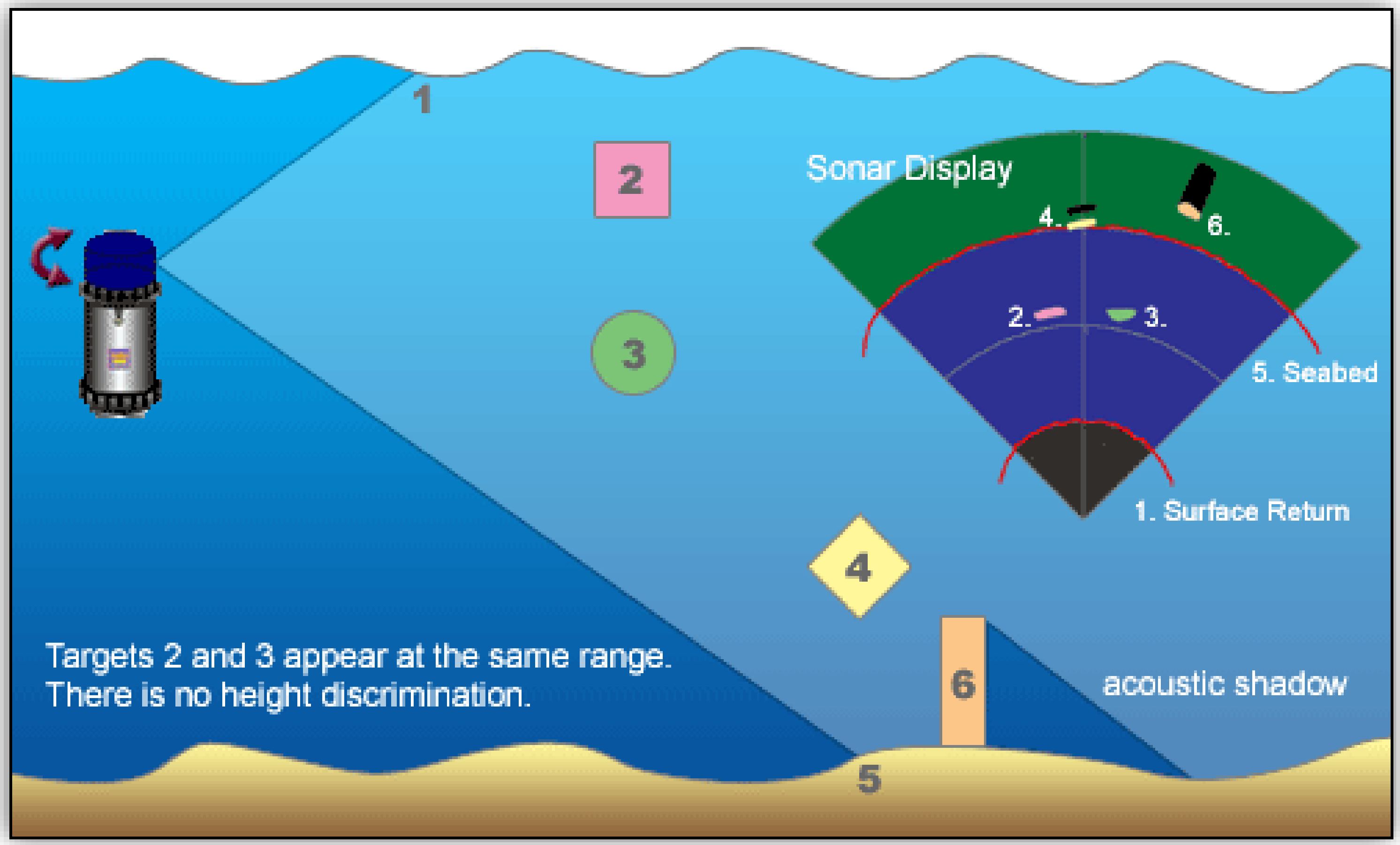

Outstanding Performance in Underwater Technology

# Sonar Technology

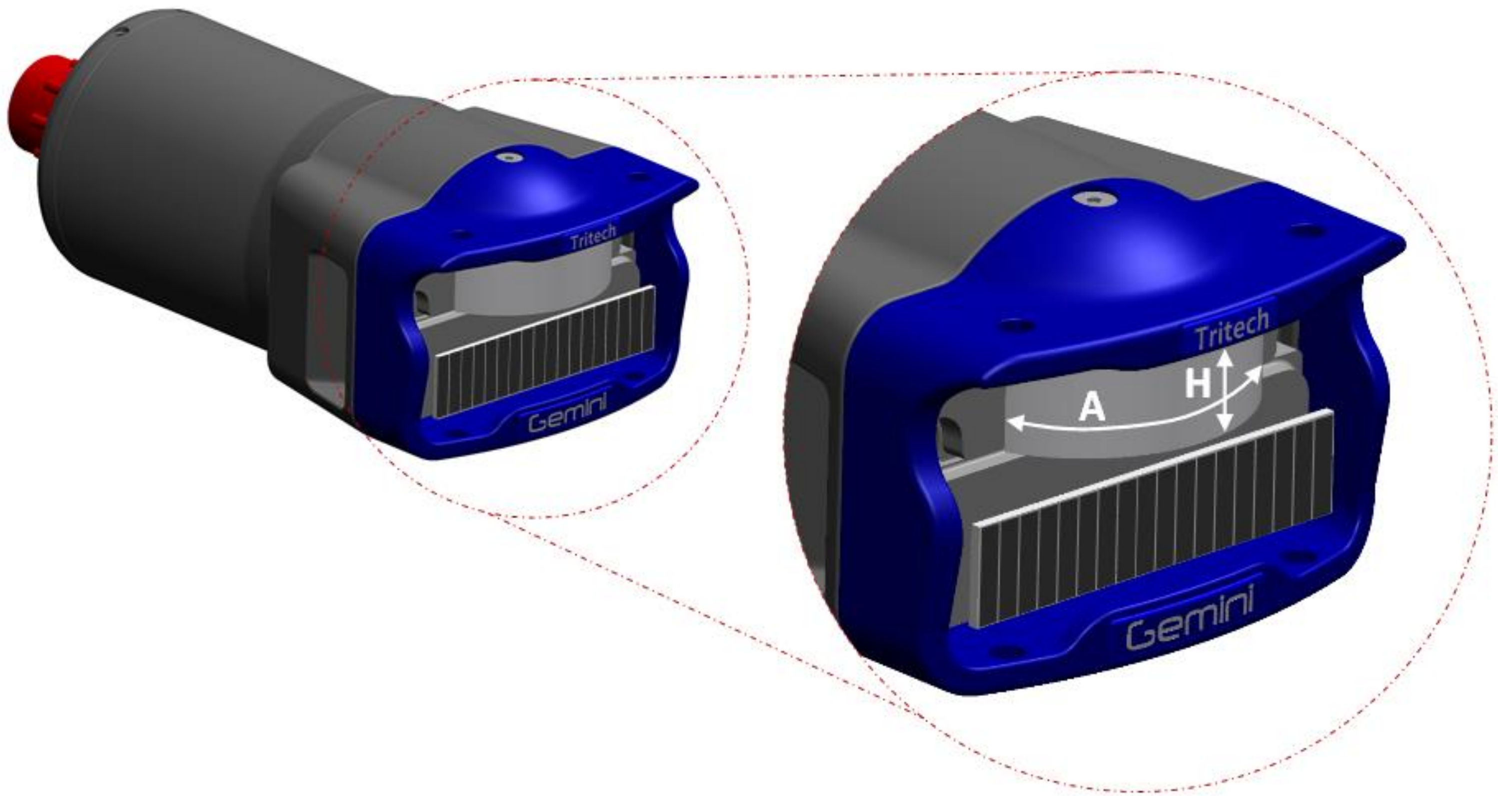
2D Representation of Data

# Sonar

## 2D Representation of Data

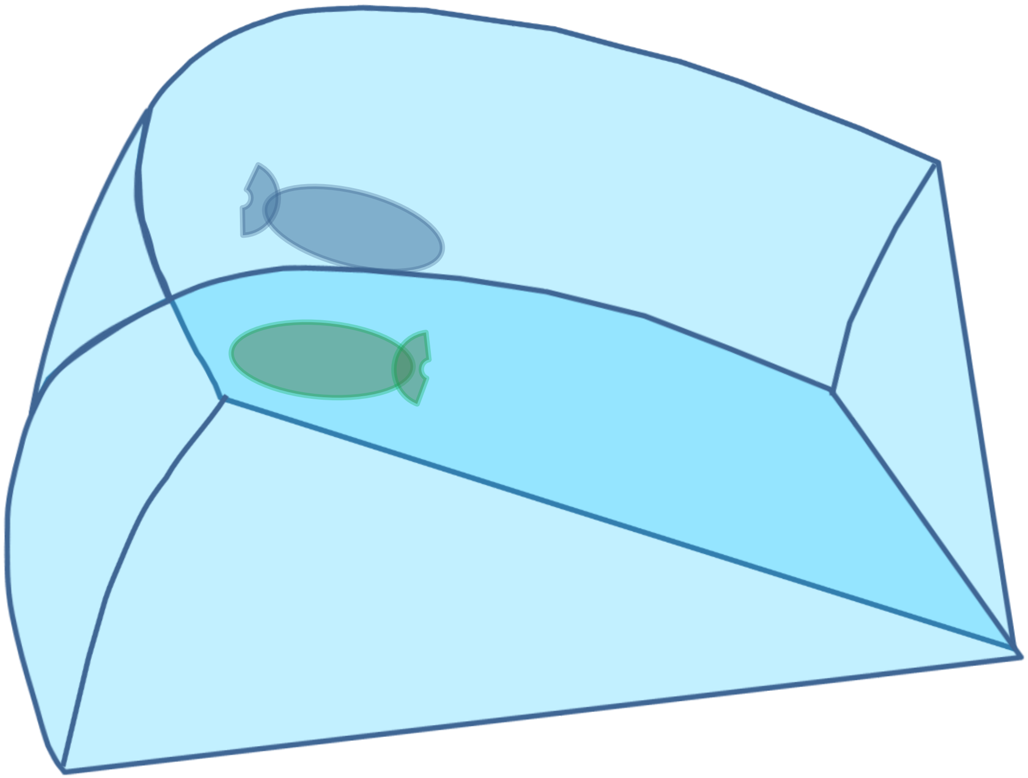


# Title



# Sonar

## 2D Representation of Data



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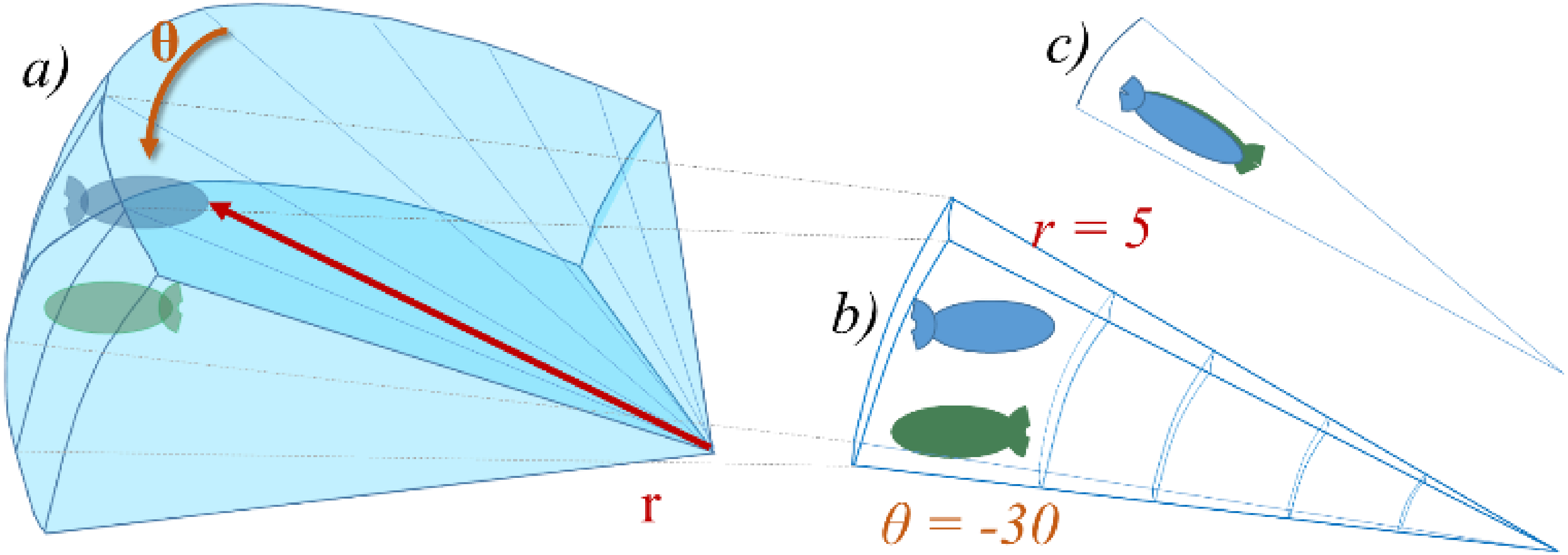
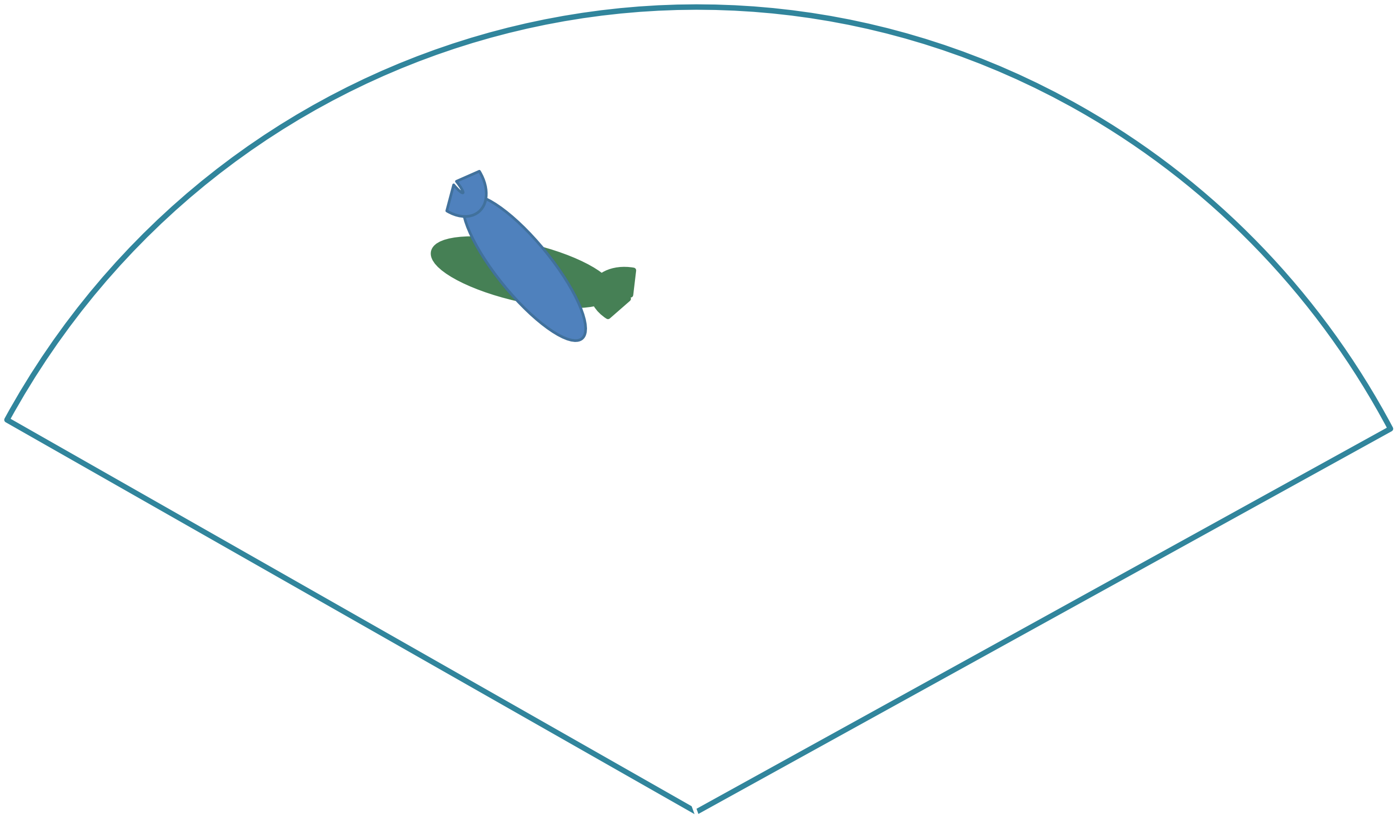


# Sonar

## 2D Representation of Data



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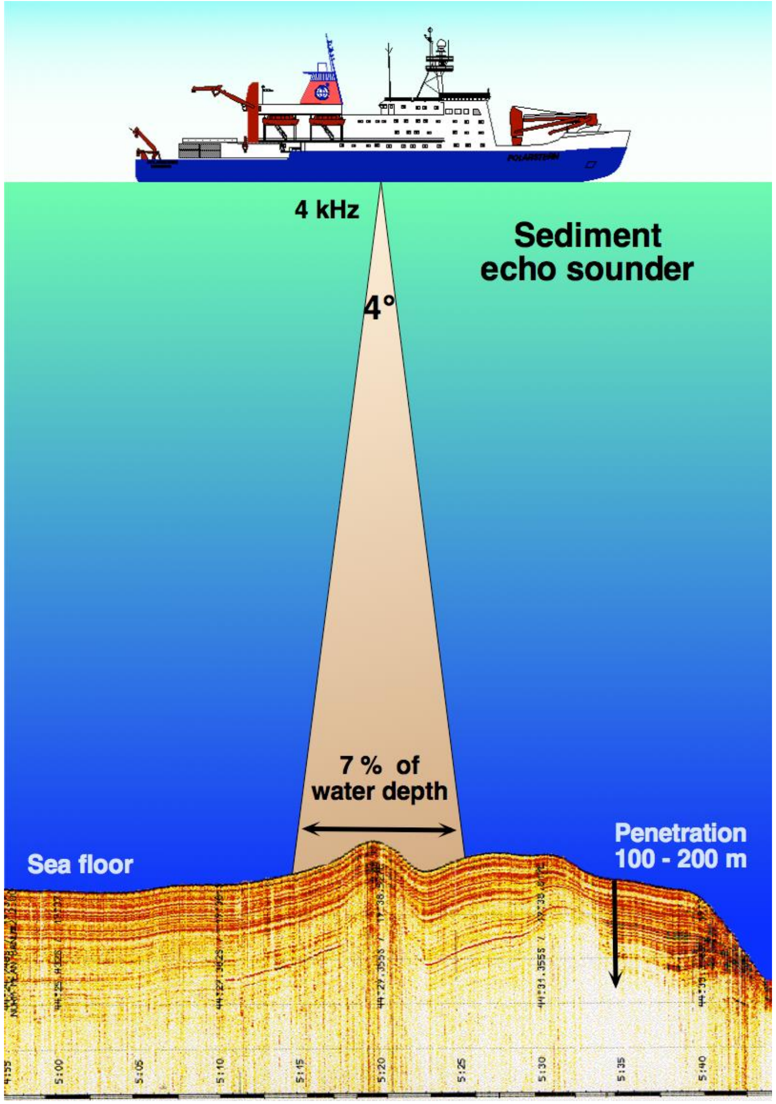
# Sonar

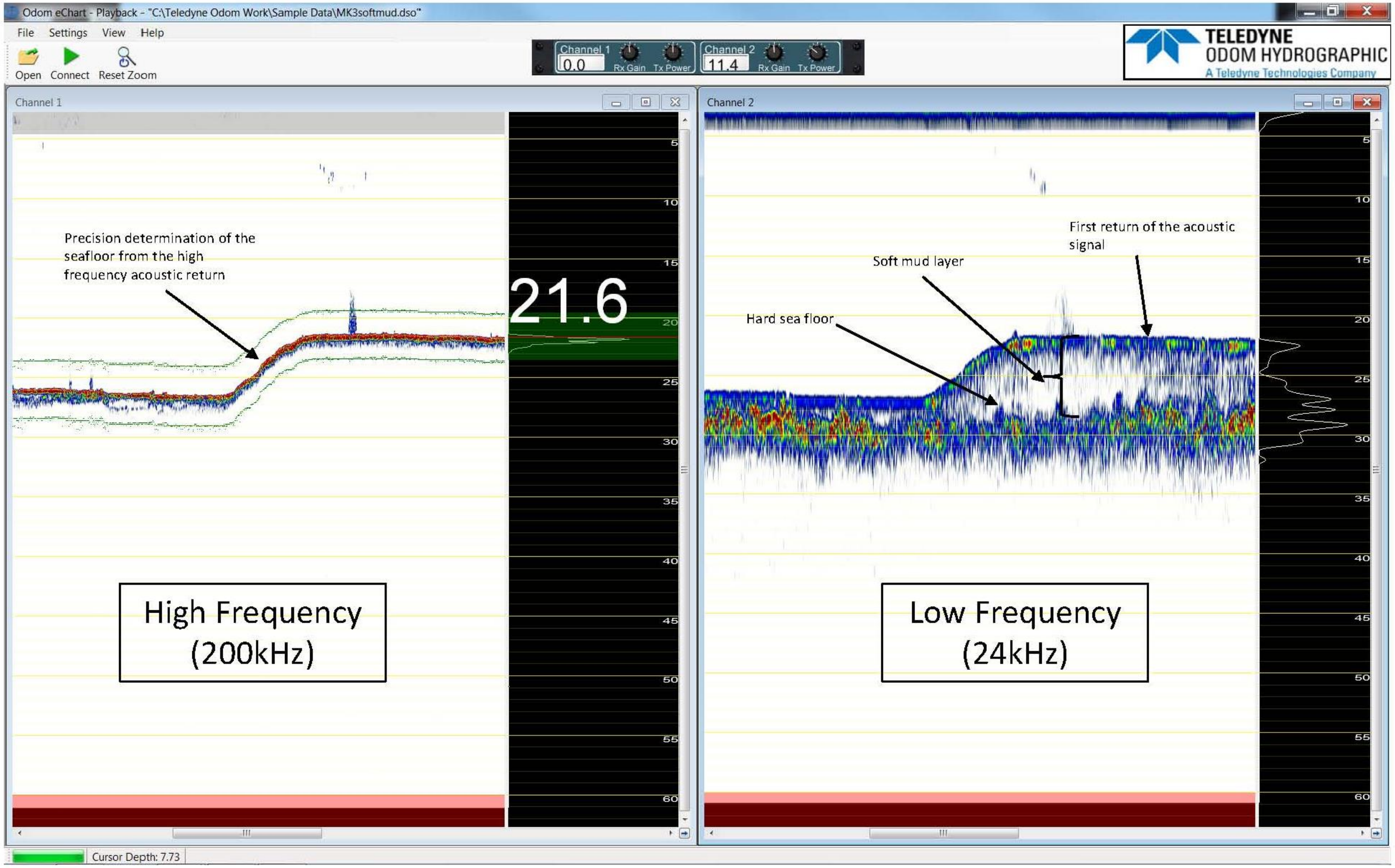
## 2D Representation of Data

# Frequency

4kHz



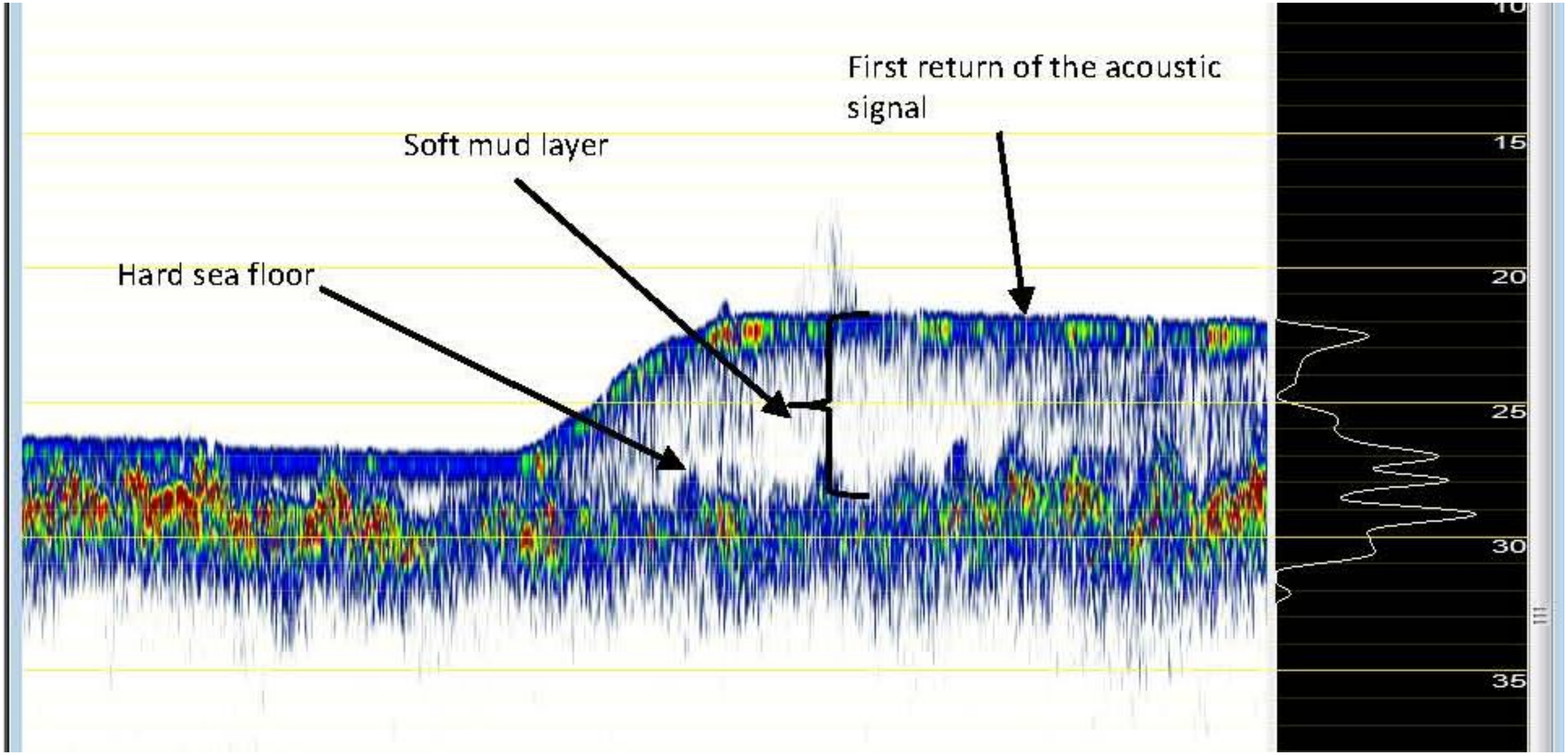
# Frequency




Example of a digital screengrab of dual frequency singlebeam echo sounder traces
By Mredmayne (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

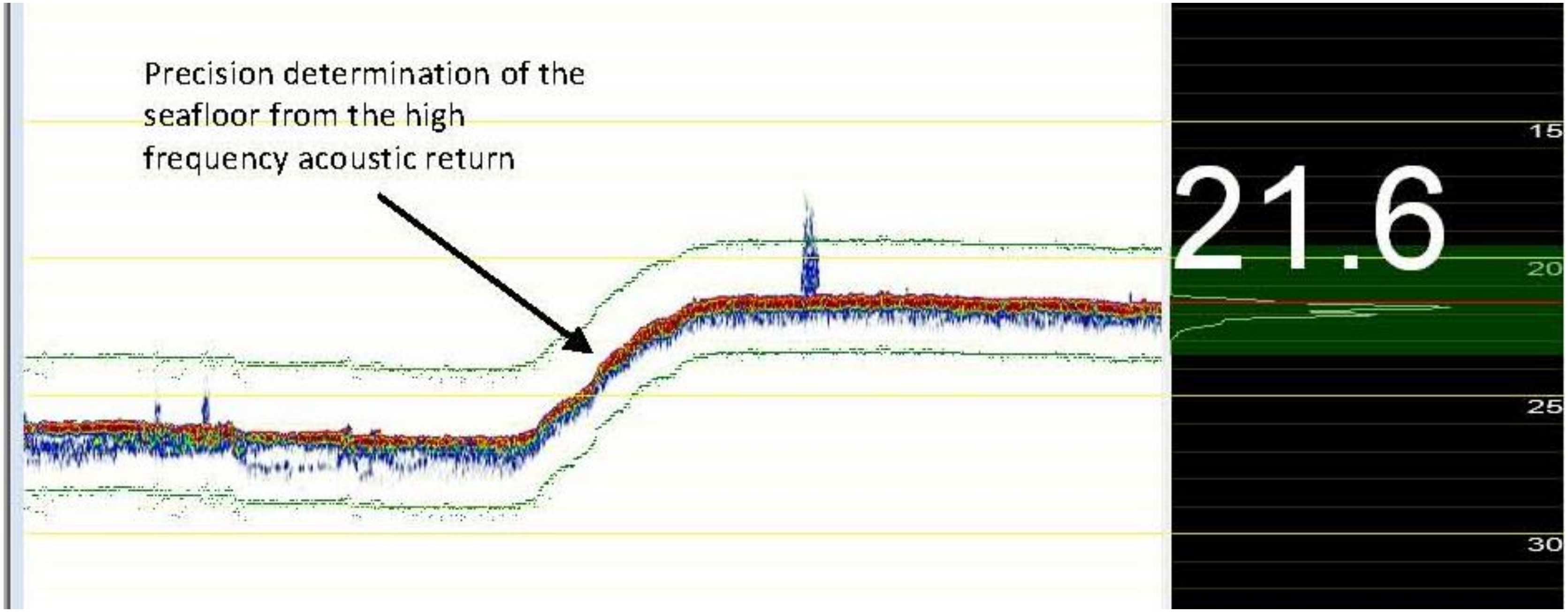
# Frequency

24 kHz

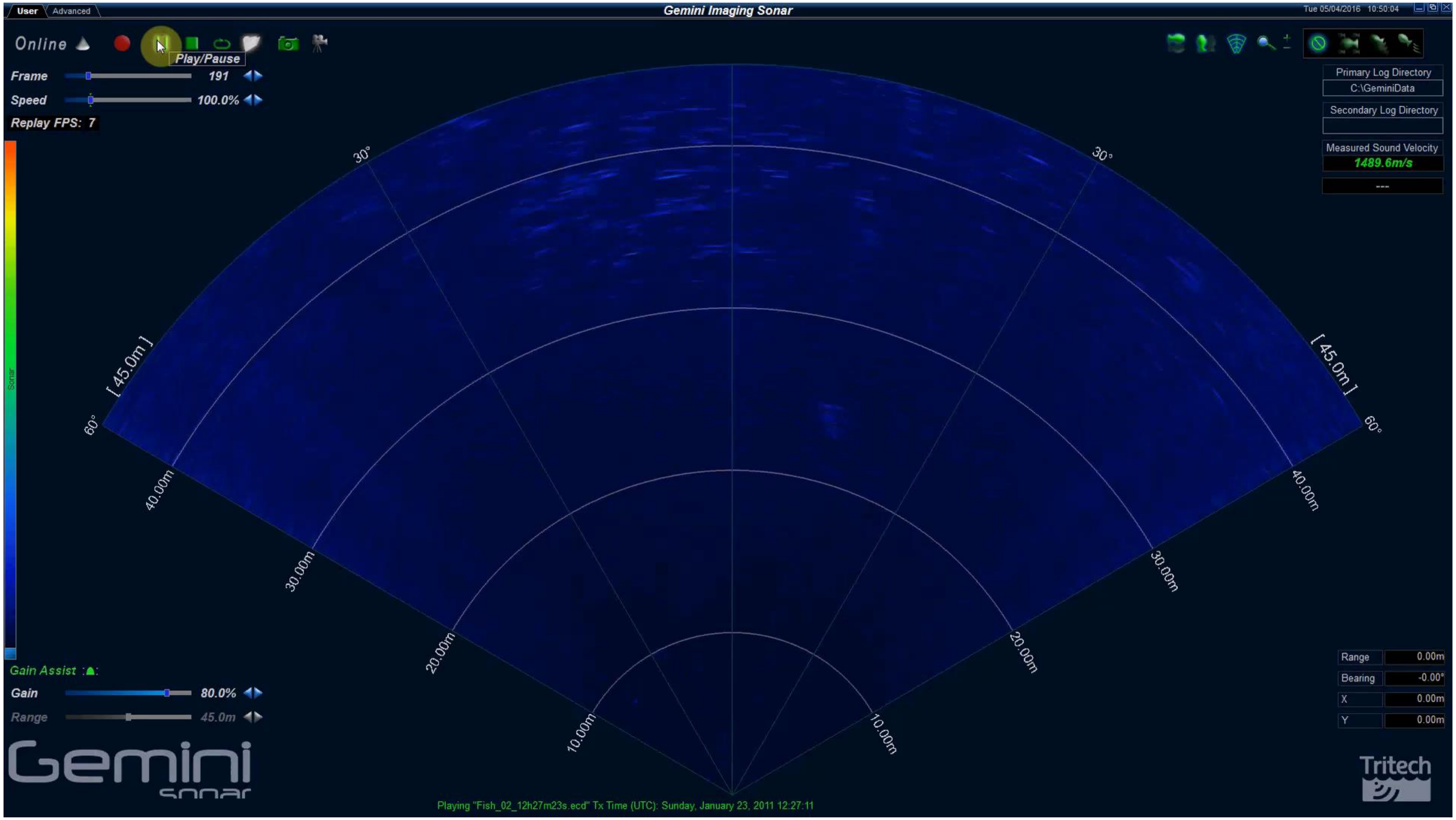


# Frequency

## 200 kHz



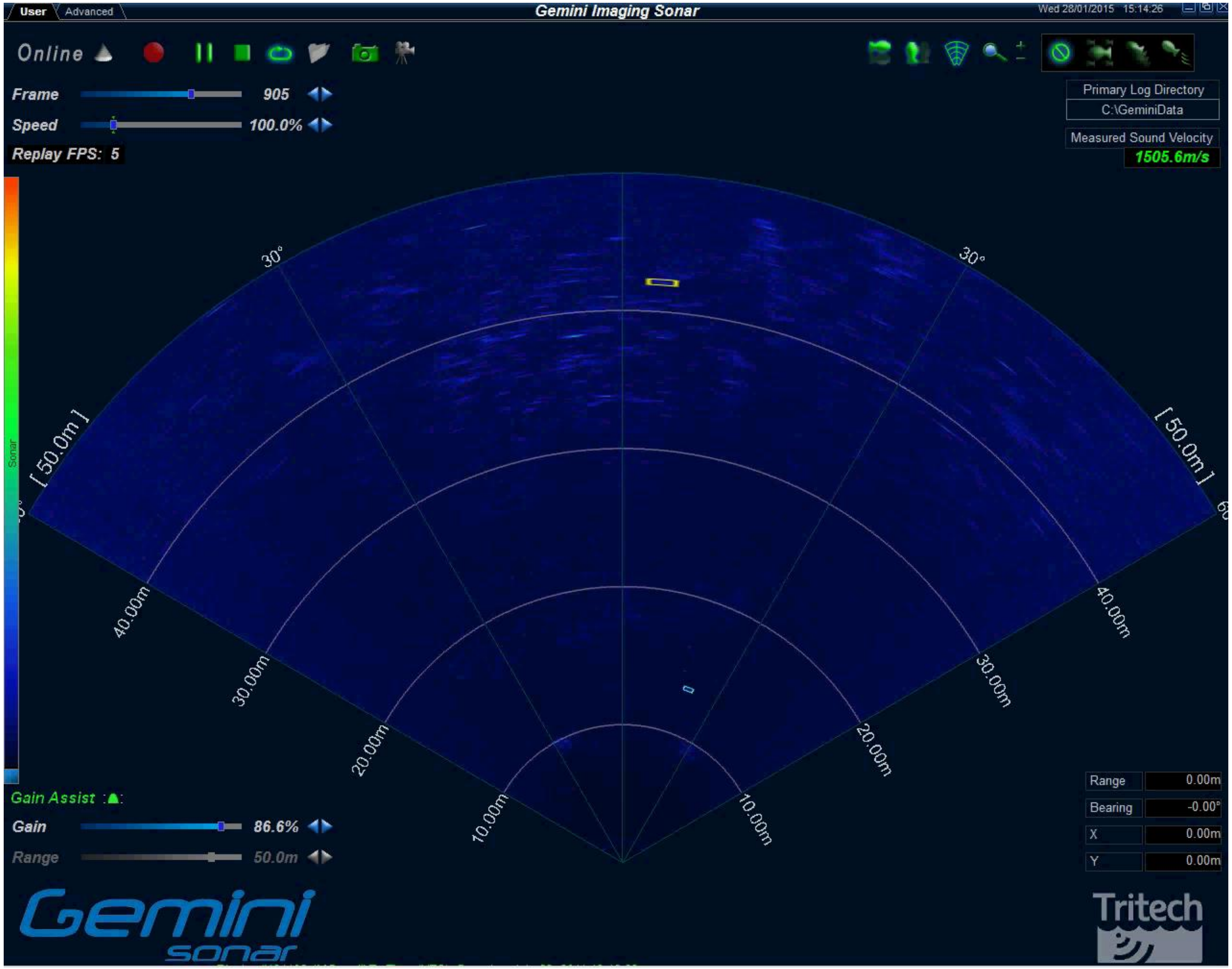
# Results: Strangford



# Targets

## How they move

What they look like → How to find them → How they move




Outstanding Performance in Underwater Technology

# Targets

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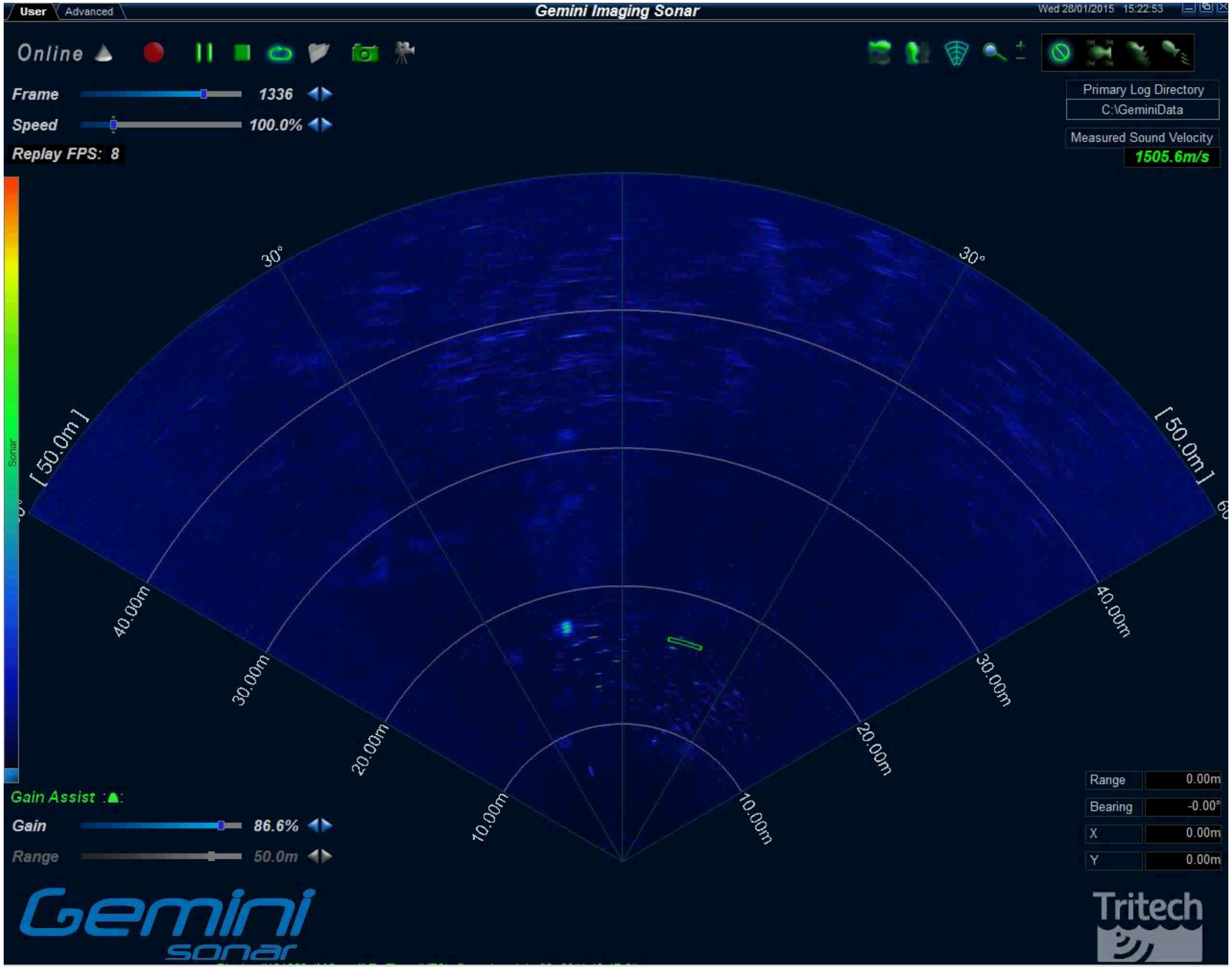
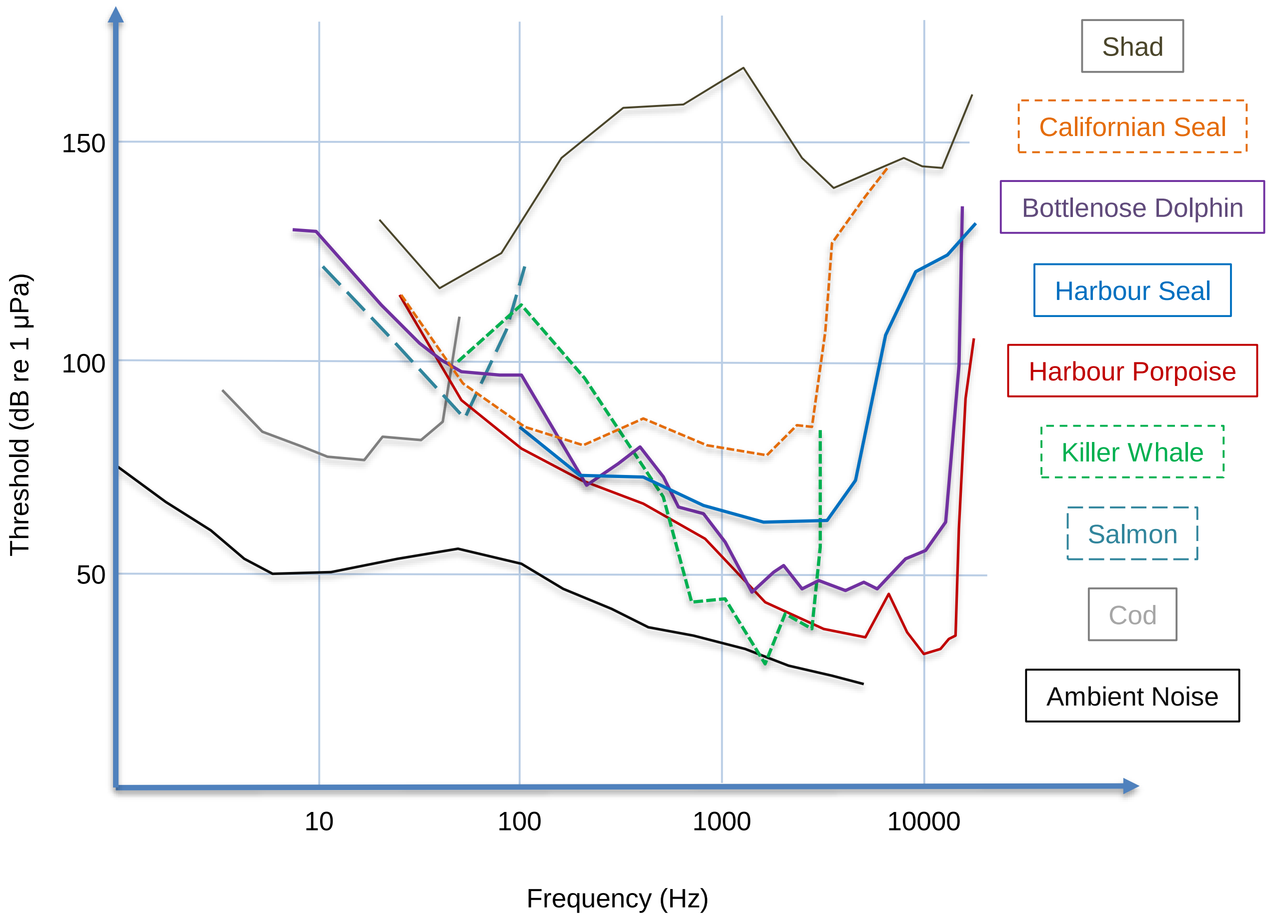
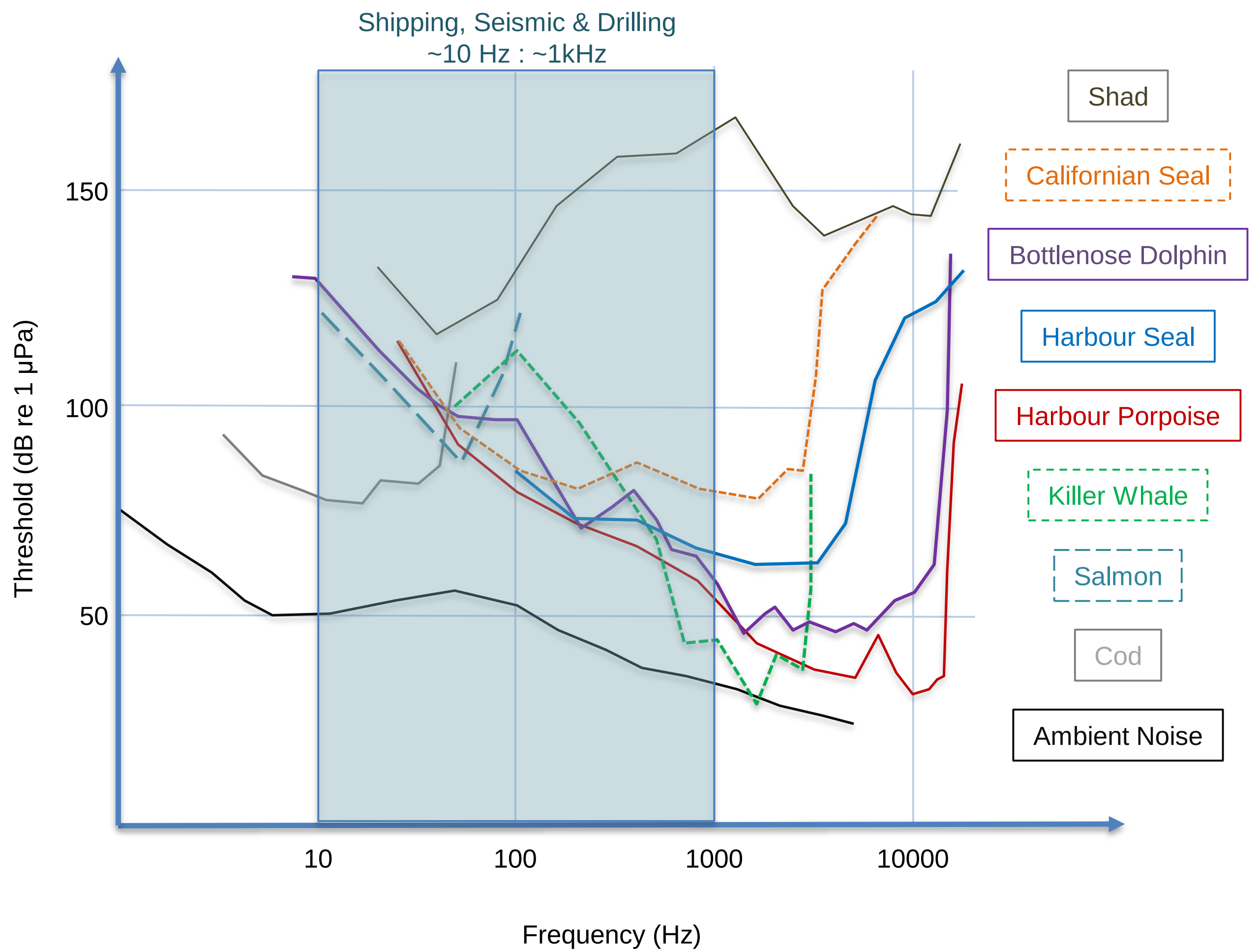


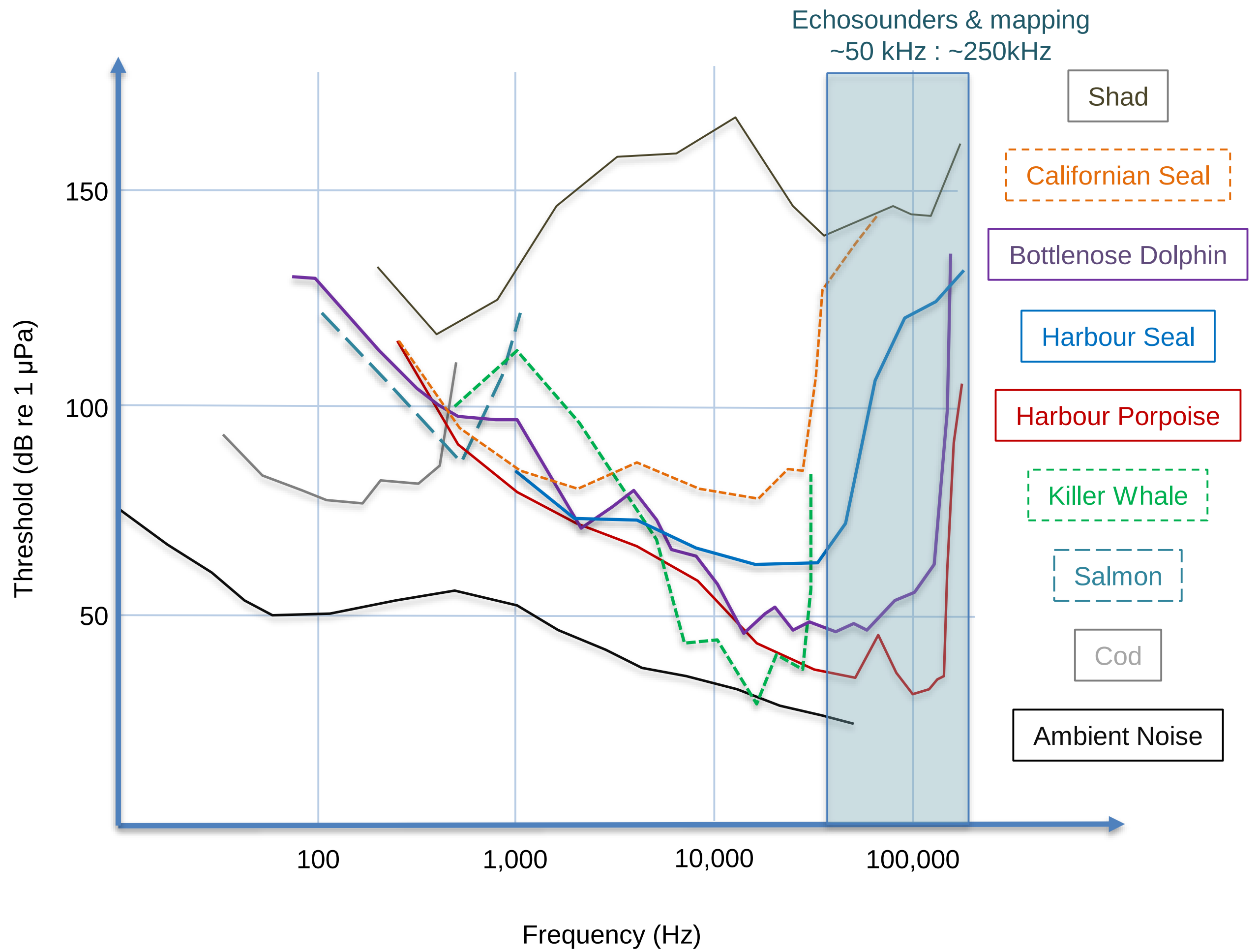
# Frequency considerations



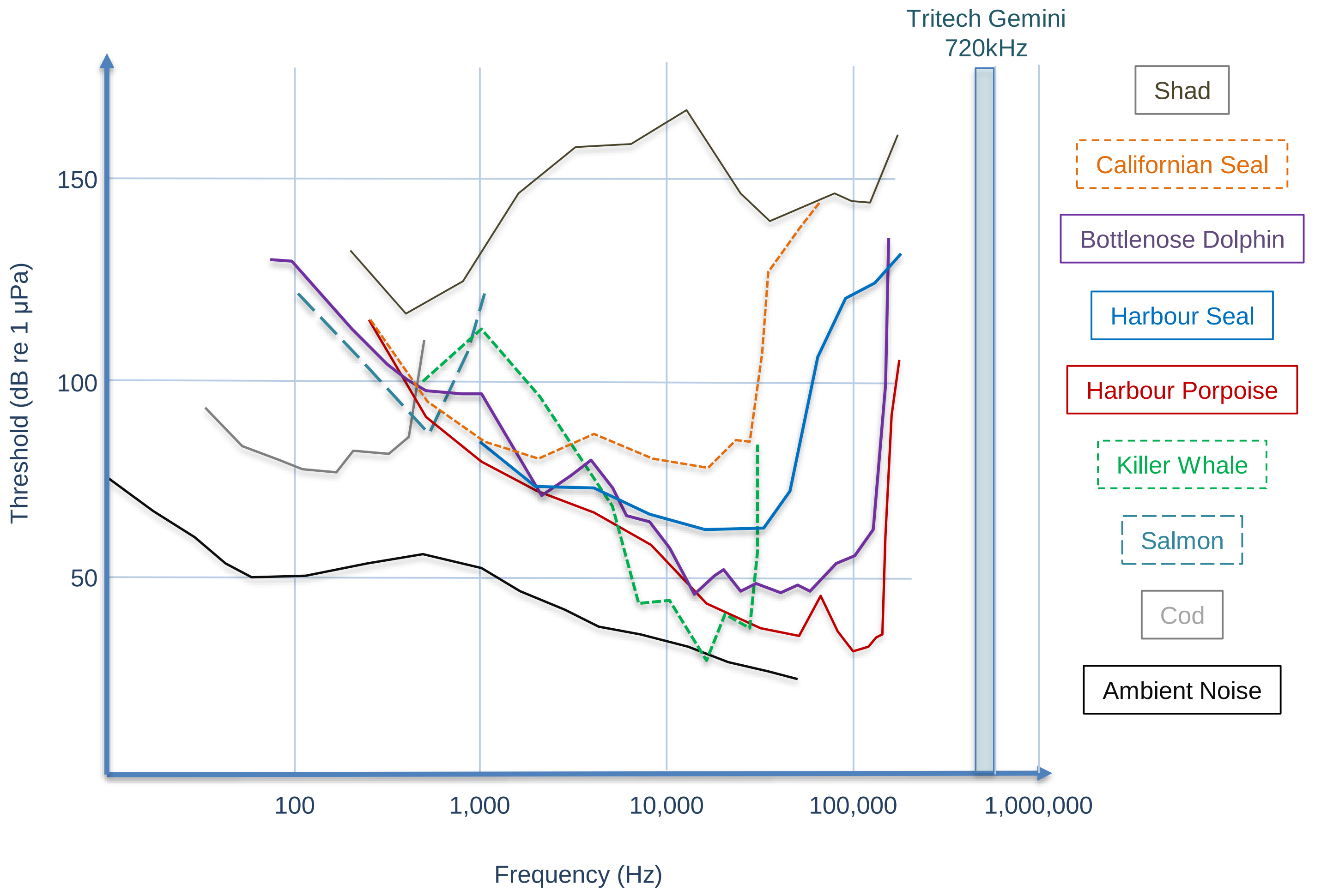
# Frequency considerations



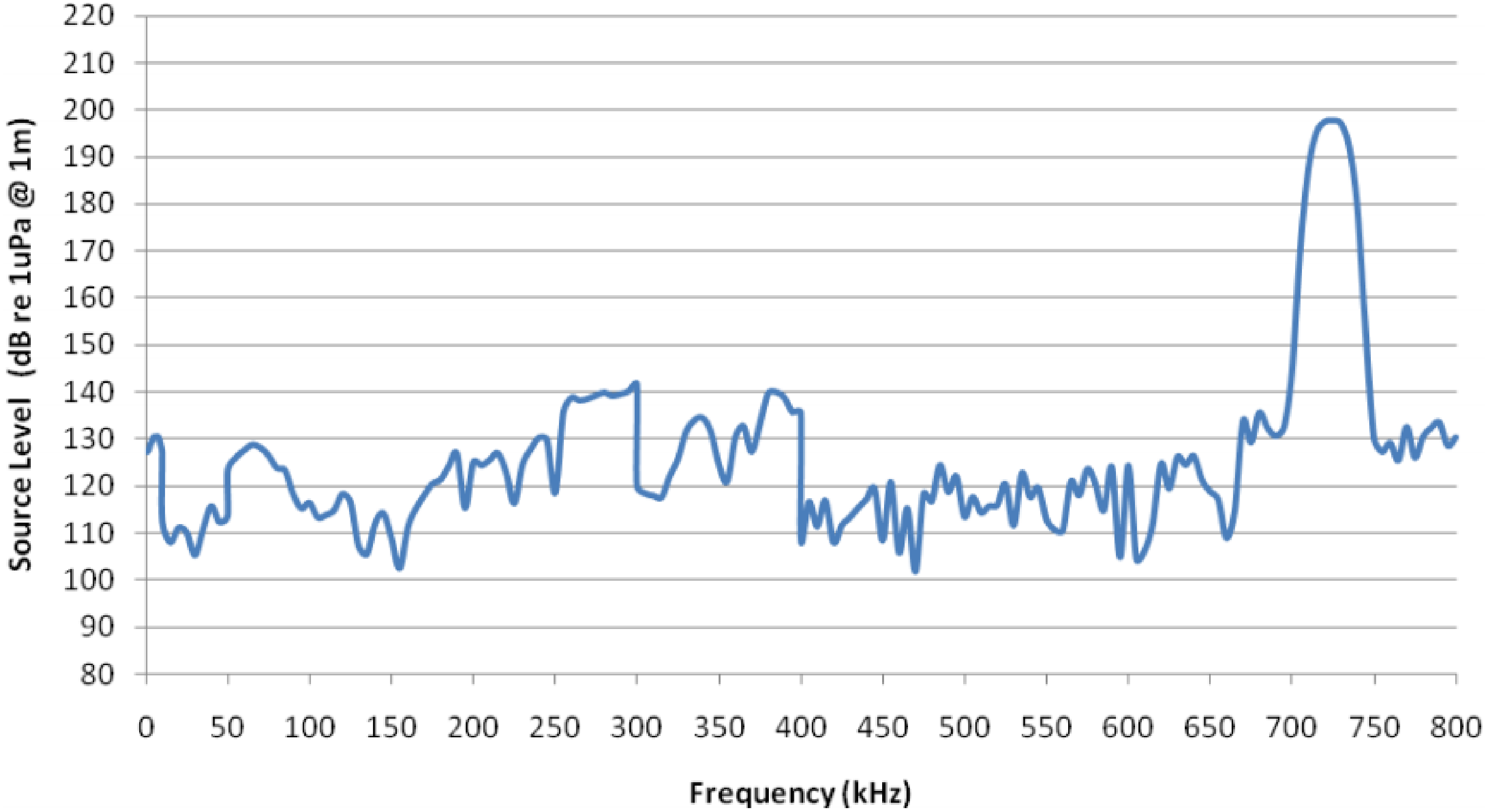
# Frequency considerations



# Frequency considerations



# Frequency considerations




Spectrum of the transmit signal of the Gemini; the signal exhibits a peak of around 198 dB re1 µPa at 1m at 720 kHz and ranges between 105 and 129 dB re1 µPa at 1m at frequencies between 30 and 110 kHz.

# Automatic Target Tracking

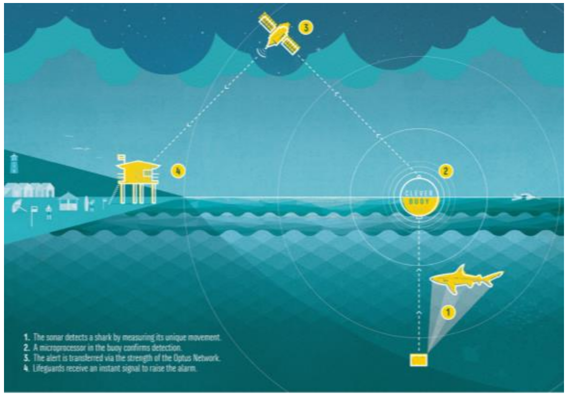
Real time considerations

# Real-time vs. Post-hoc analysis

MCT @ Strangford Lough

TEL @ Ramsey Sound

Clever Buoy Beach Protection

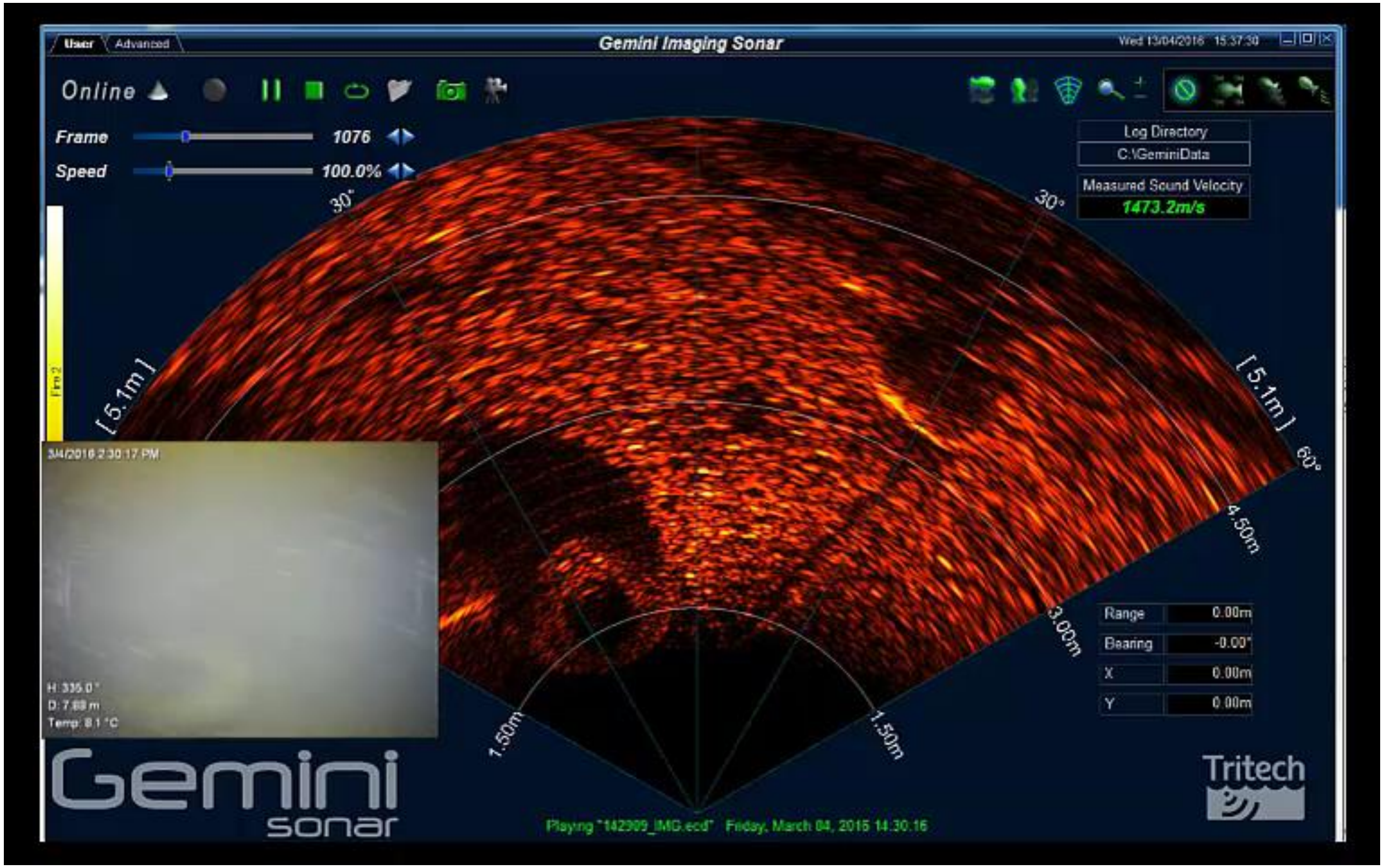



MeyGen @ Pentland Firth

# Sonar Technology

Outstanding Performance in Underwater Technology

# Sonar visibility



# Multibeam Sonar

## What it looks like