FINAL PROJECT REPORT (v1.6)

OERA Pathway 2020 Program

Field Assessment of Multi-beam Sonar Performance in Surface Deployments

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Executive Summary

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

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

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

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

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

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

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

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

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

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

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

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Acknowledgments

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- Luna Sea Solutions
- MarineSitu
- Mi’kmaw Conservation Group
- Fundy Ocean Research Centre for Energy (a.k.a. FORCE)
- Dasco Equipment Inc.
- Tritech and Teledyne technical support staff
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1.0 Introduction

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

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

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

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

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

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

The **expected outcomes** include:

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

2.0 Methodology

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

Table 1: Multibeam imaging sonar frequency and ensonified area

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

Notes:

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

2.1 Data Collection

2.1.1 Method

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

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

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

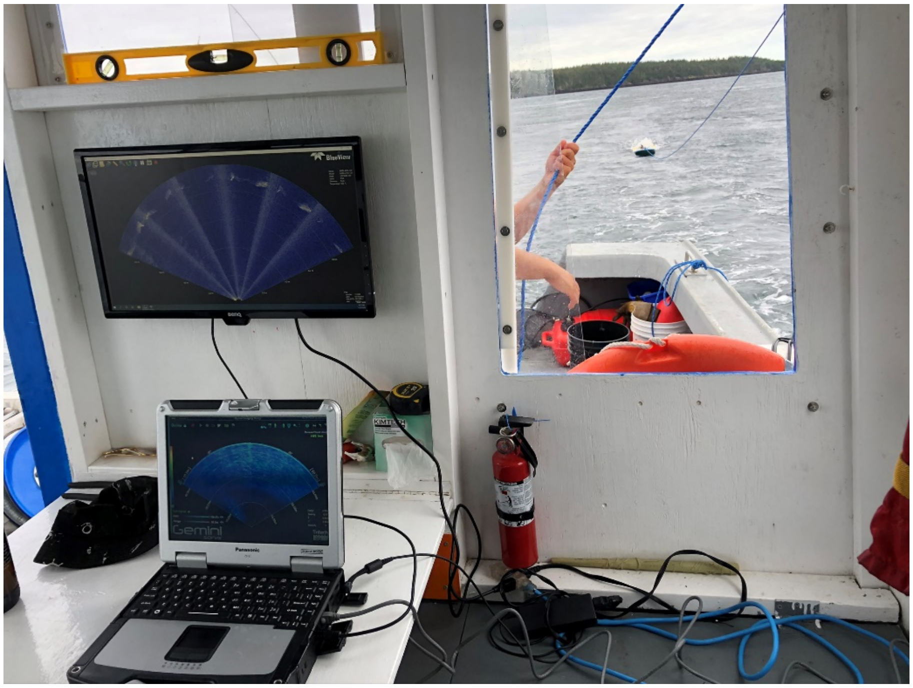


Figure 2: Data display and collection on research vessel Grand Adventure

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

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

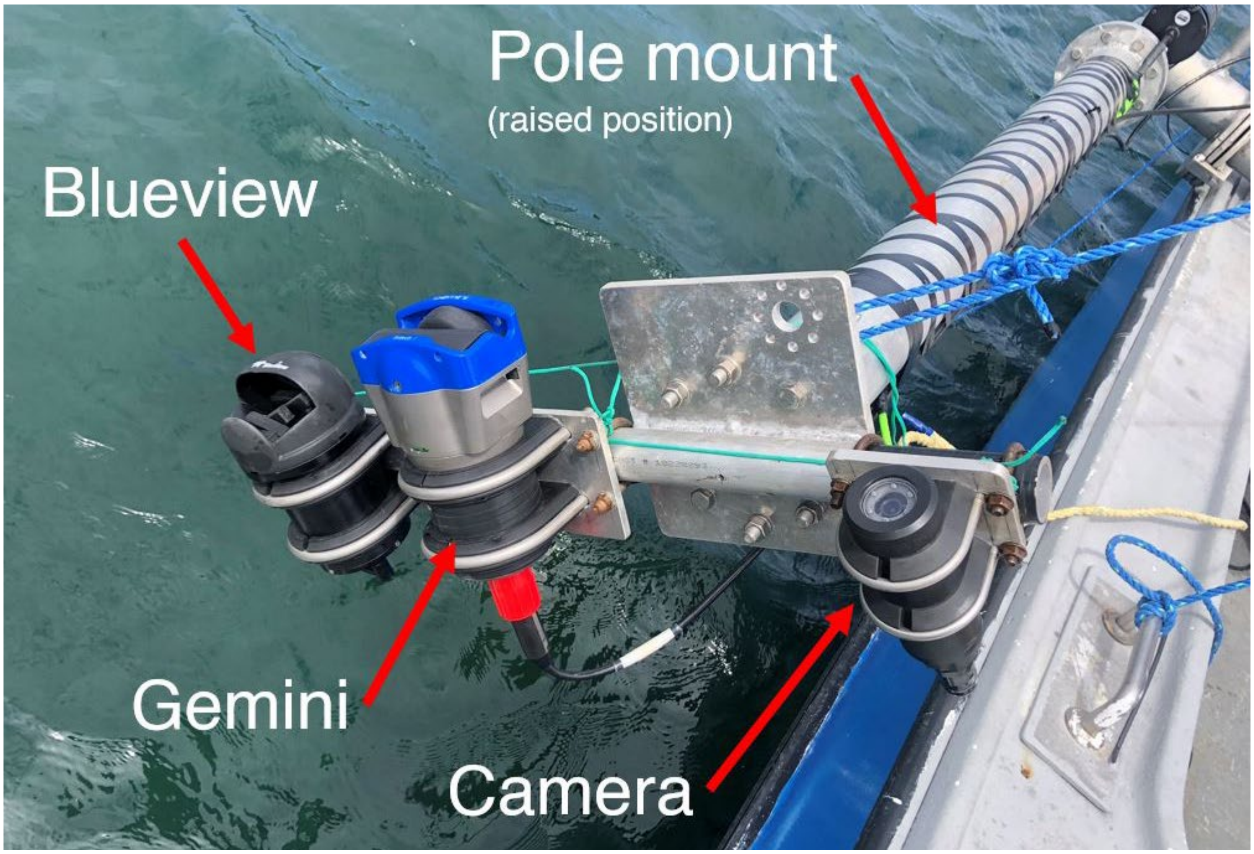


Figure 3: Pole mounted sonars and camera

Figure 4: SciBoard

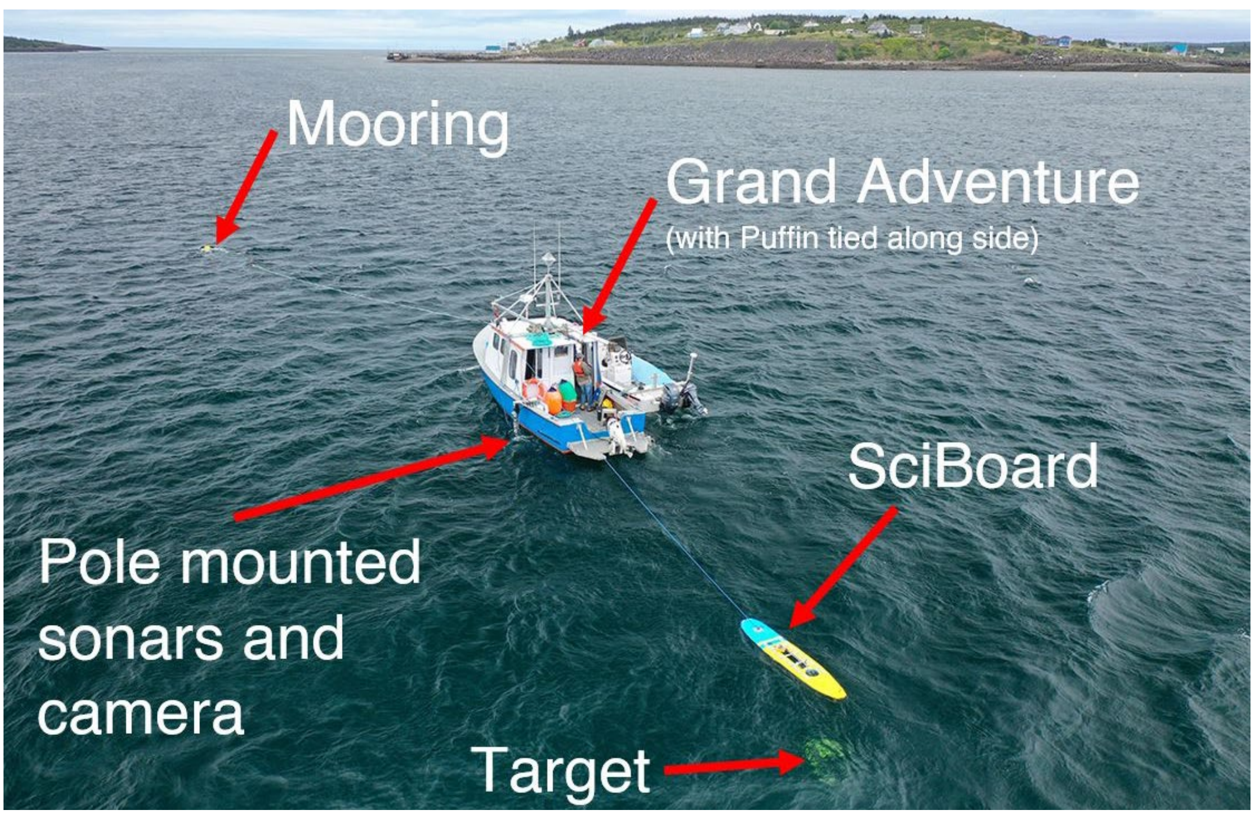


Figure 5: Aerial image of experiment layout

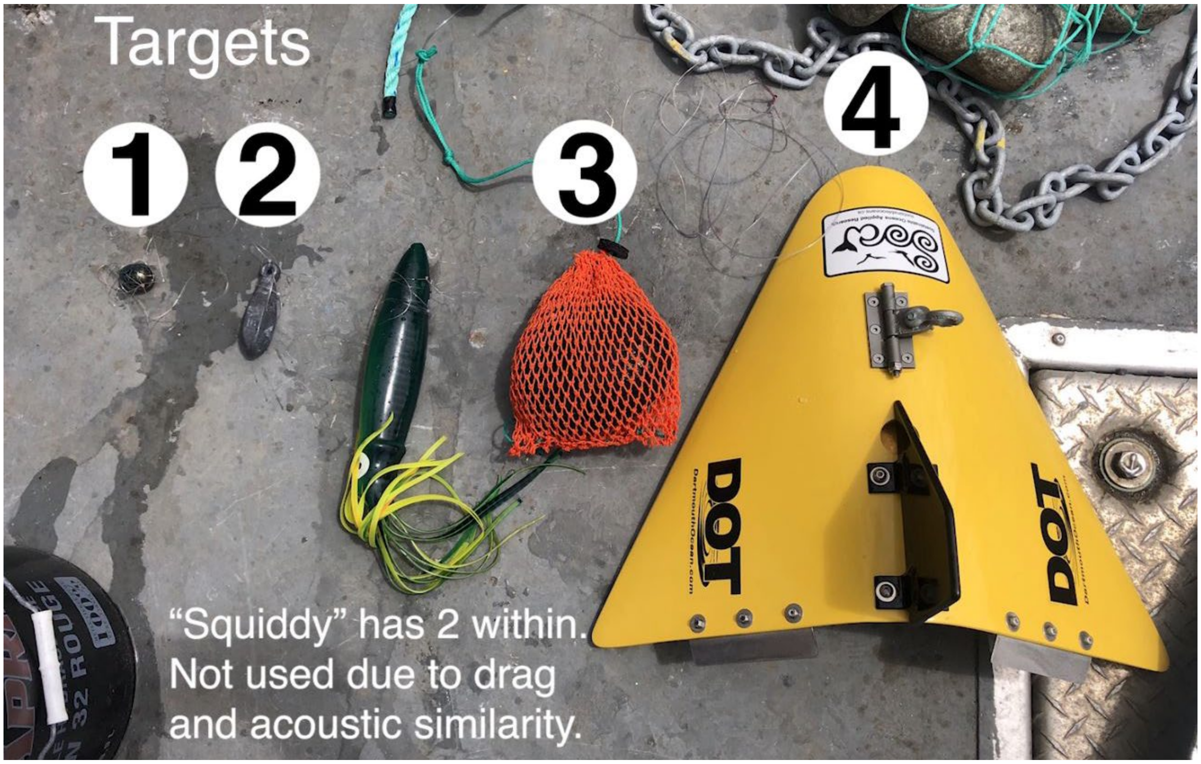


Figure 6: Targets

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

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

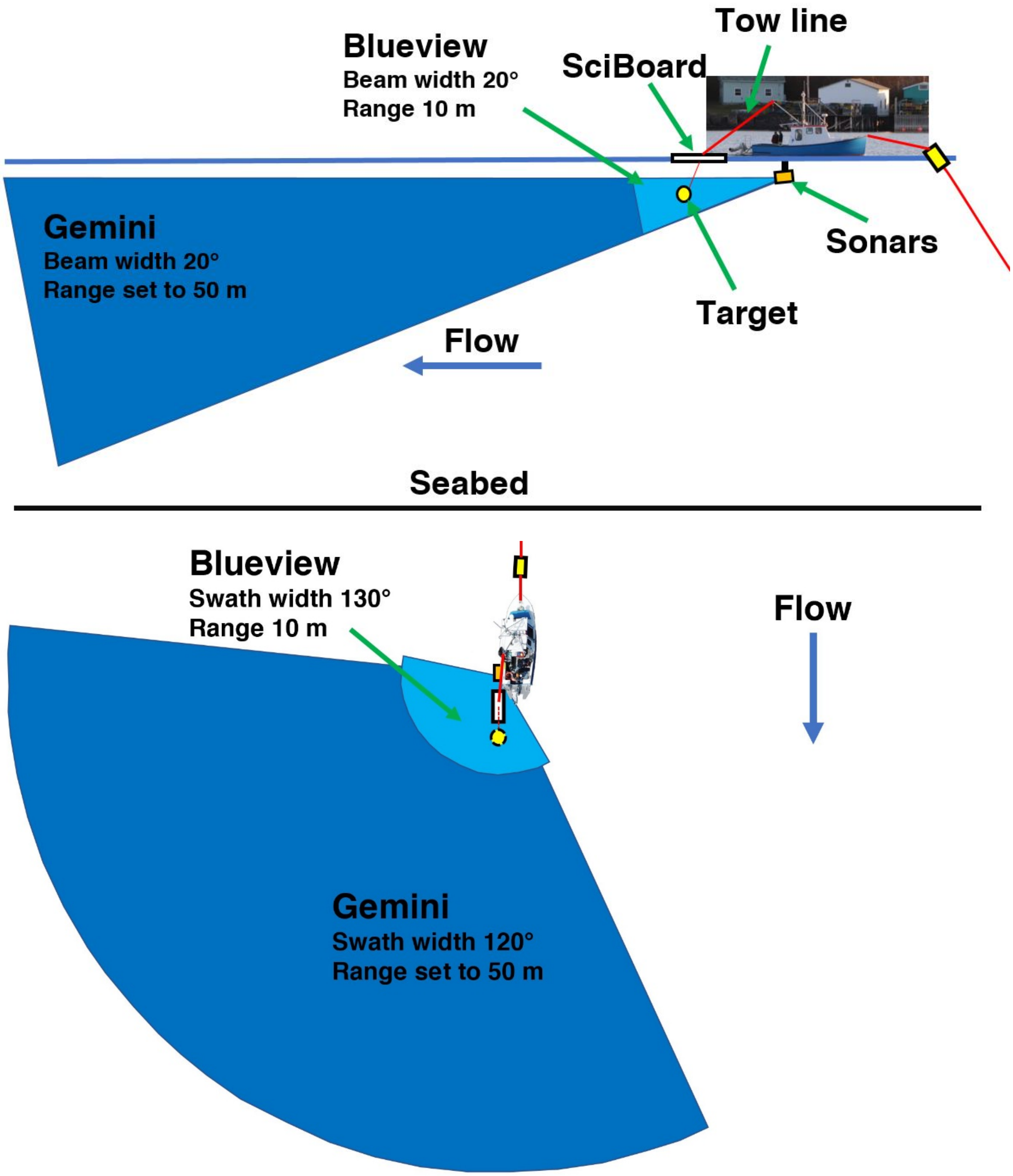


Figure 7: Schematic of experiment setup

2.1.2 Locations

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

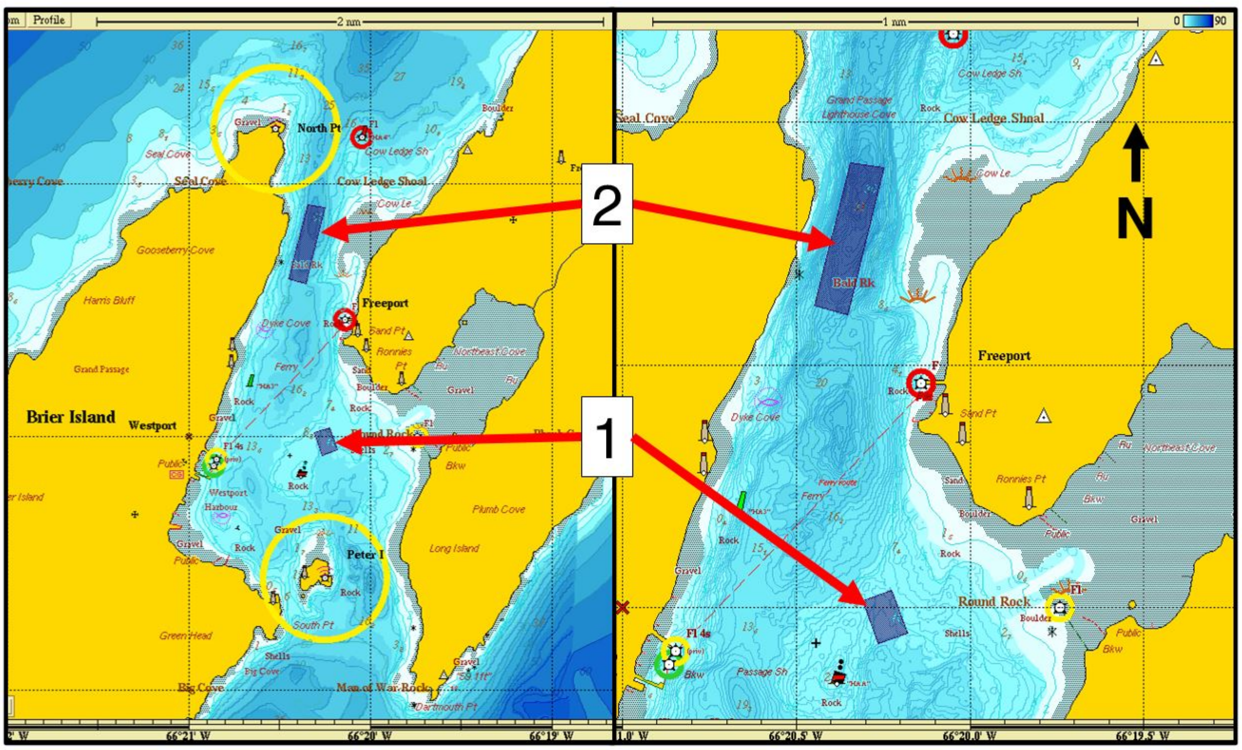


Figure 8: Data collection locations in Grand Passage

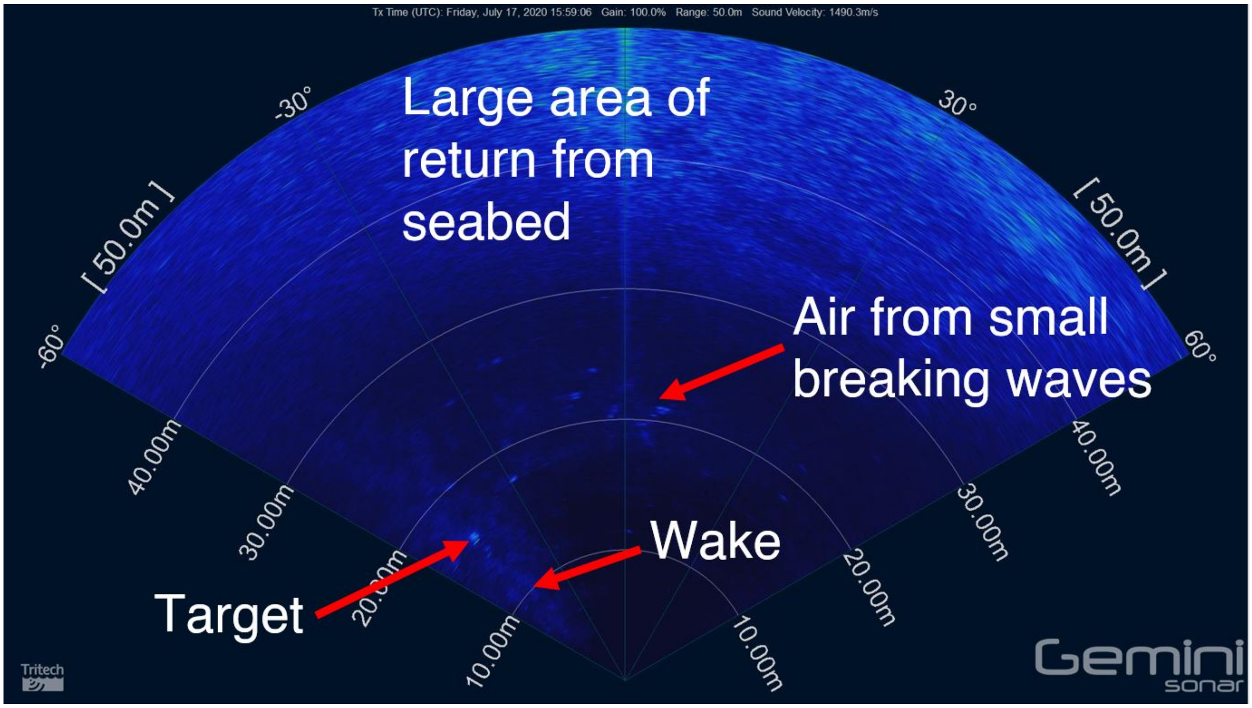


Figure 9: Example of seabed returns, wake, and air from waves on the Gemini

2.1.3 Acoustic Interference

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

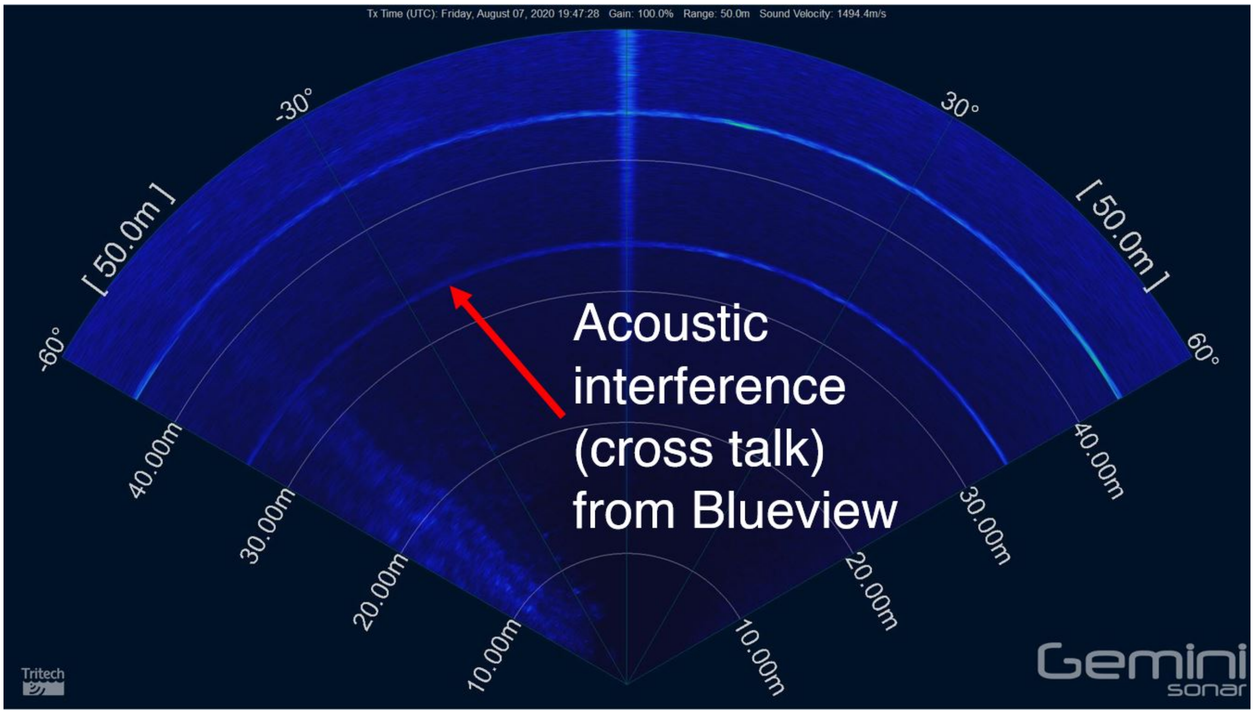


Figure 10: Example of acoustic interference for the Gemini

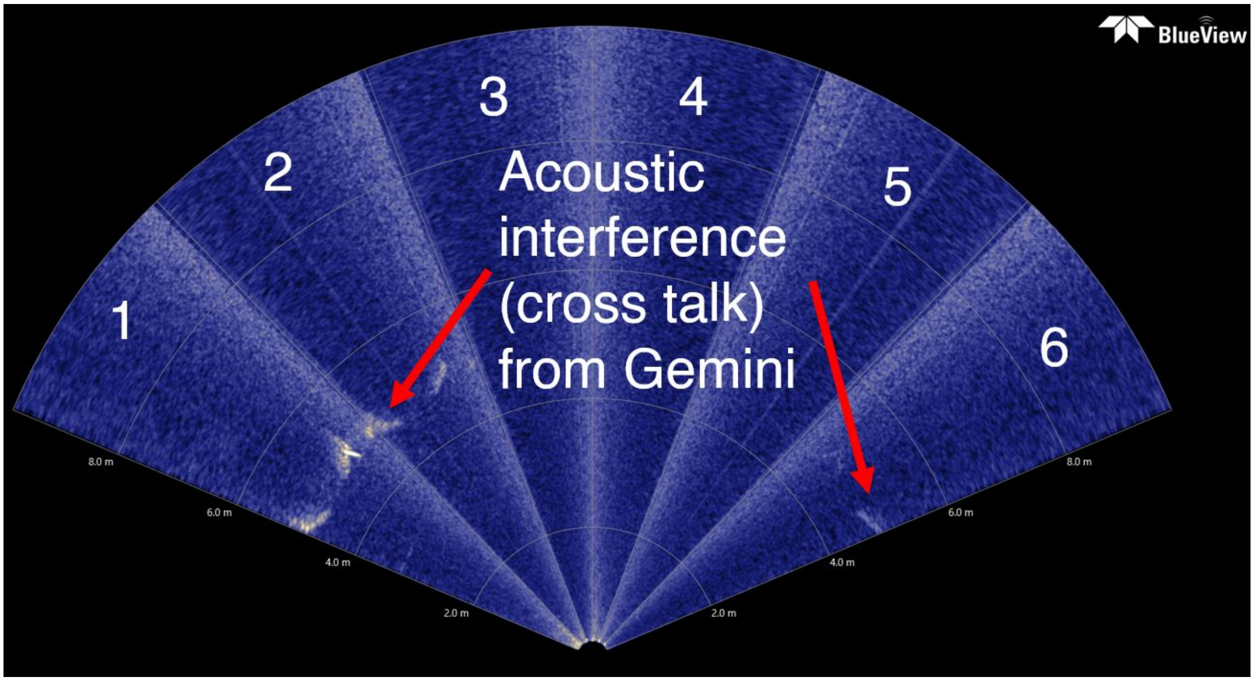


Figure 11: Example of acoustic interference for the Blueview

2.2 Data analysis

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

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

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

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

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

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

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

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

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

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

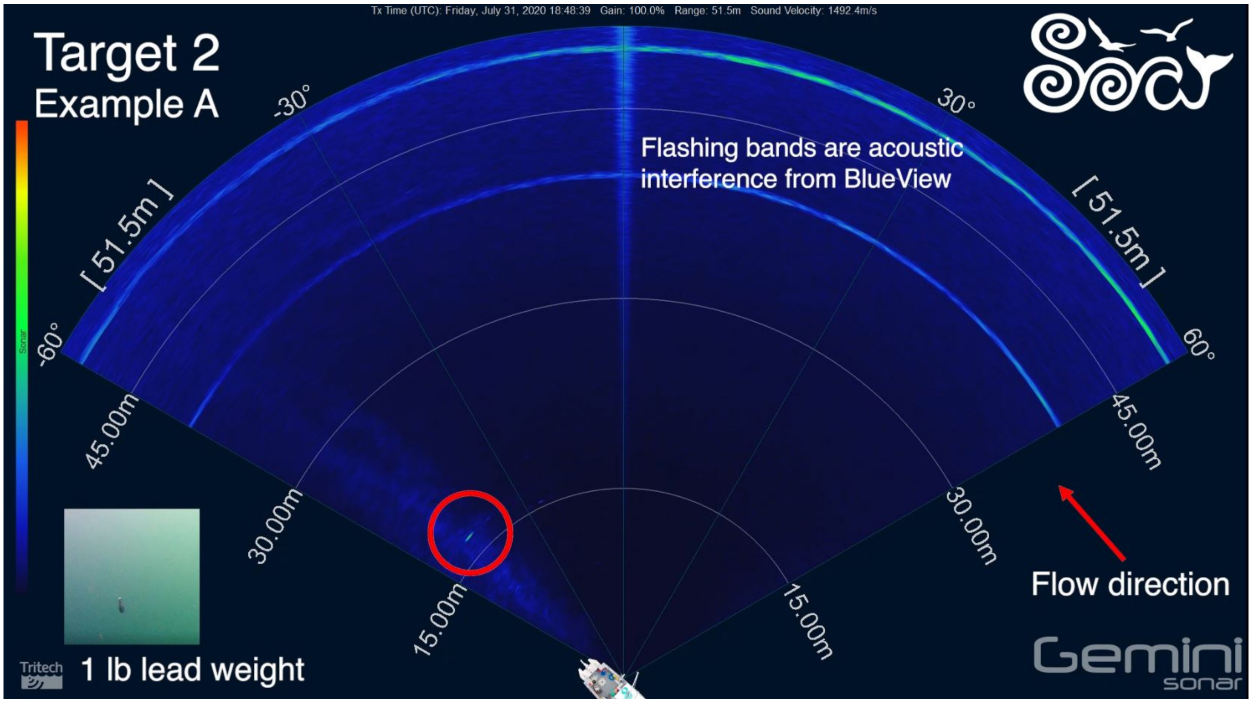


Figure 12: Example from training data - Gemini - 50m range - Target 2

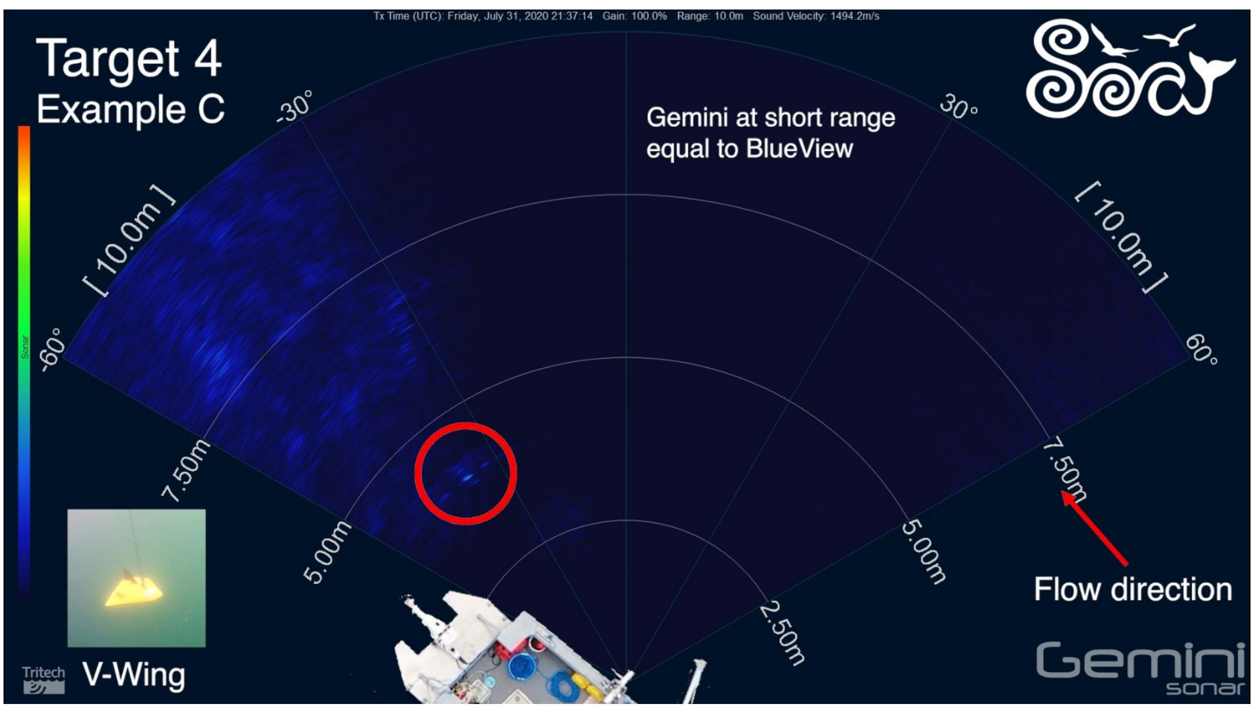


Figure 13: Example from training data - Gemini - 10m range - Target 4

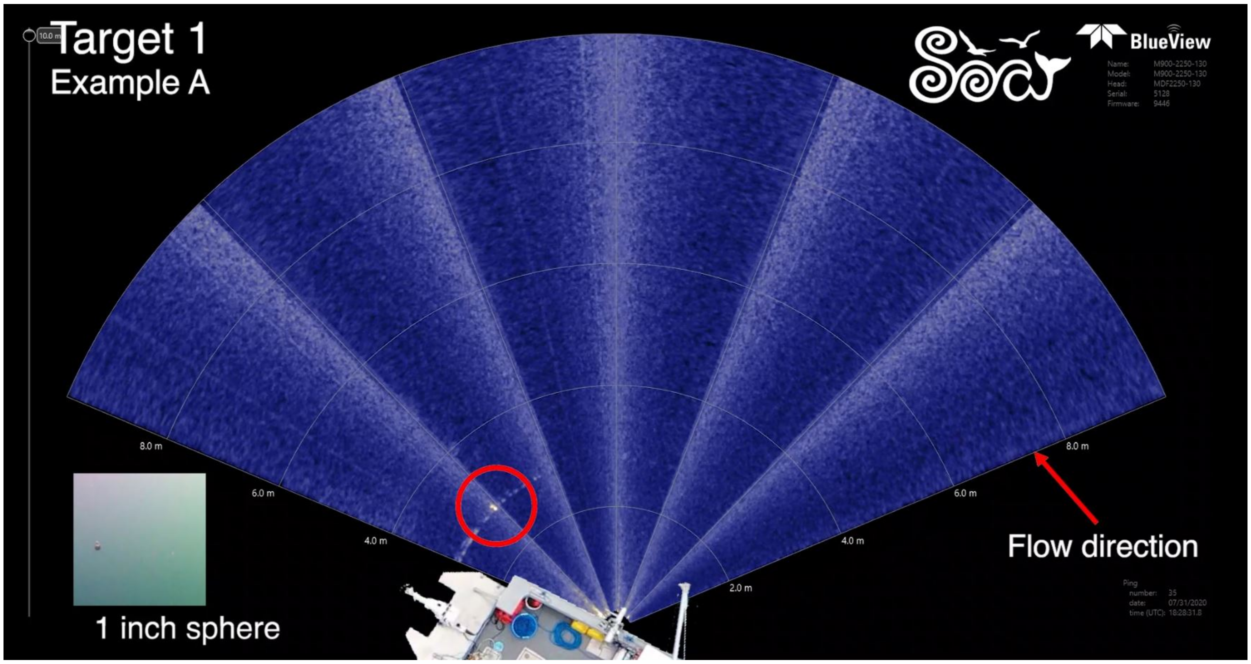


Figure 14: Example from training data - Blueview - 10m range - Target 1

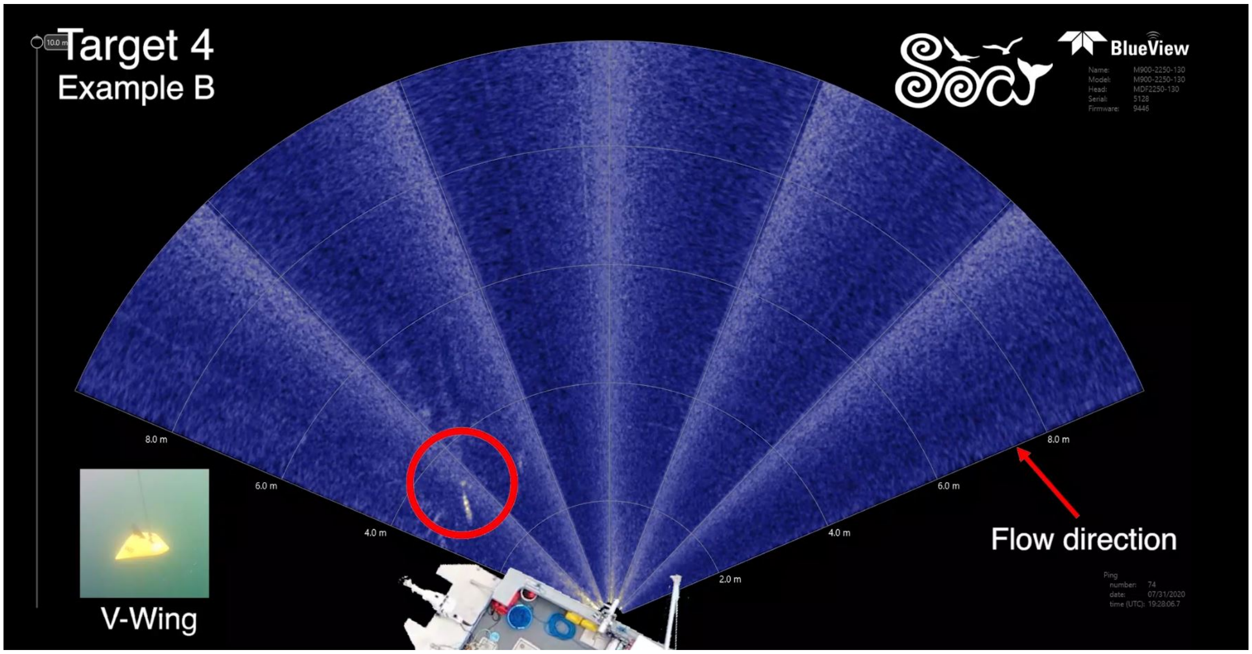


Figure 15: Example from training data - Blueview - 10m range - Target 4

3.0 Results

3.1 Detection, identification, and tracking

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

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

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

Table 2: Summary of results by sonar

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

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

Table 3: Summary of results by sonar and target type

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

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

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

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

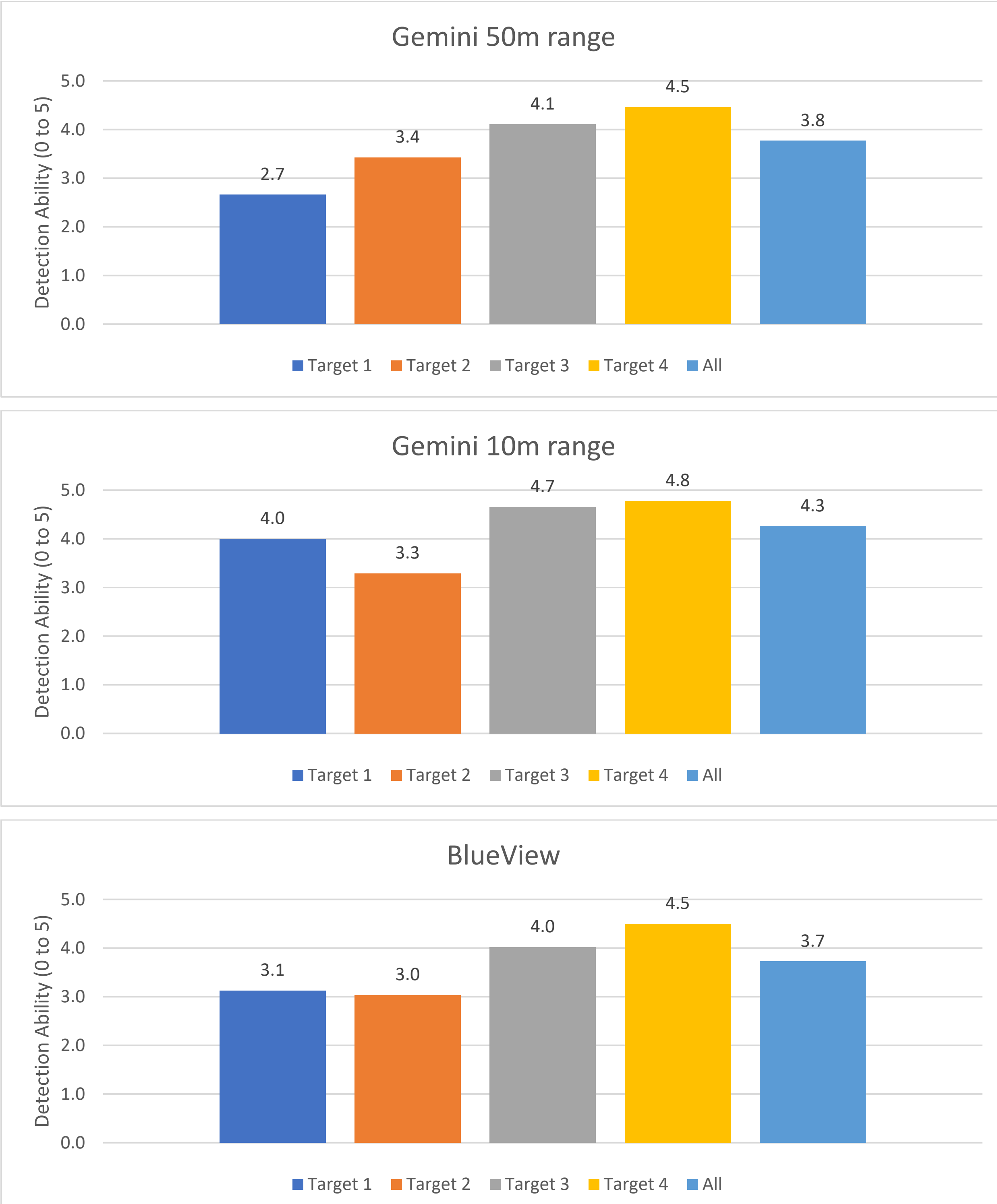
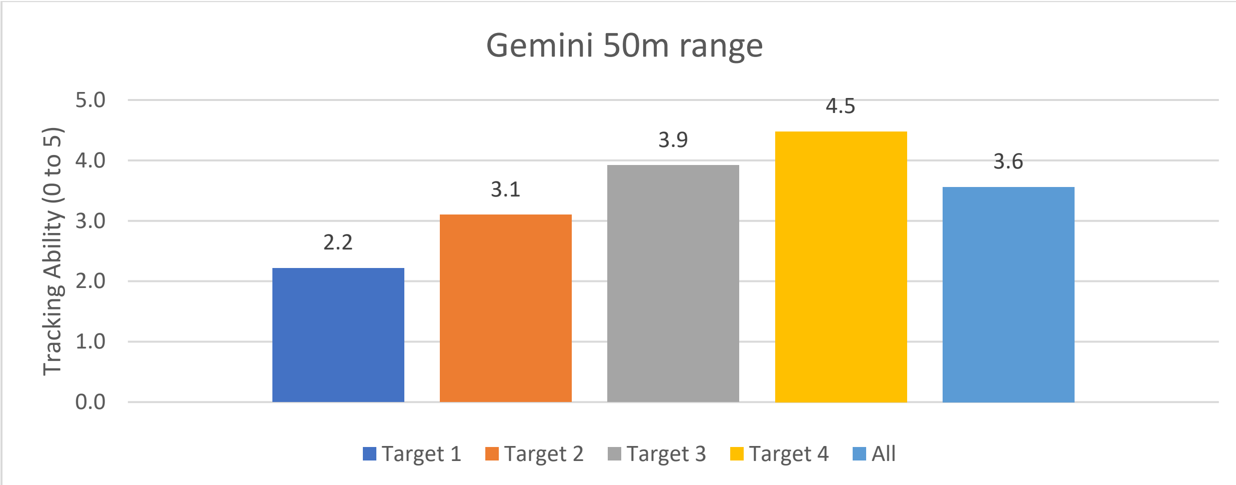
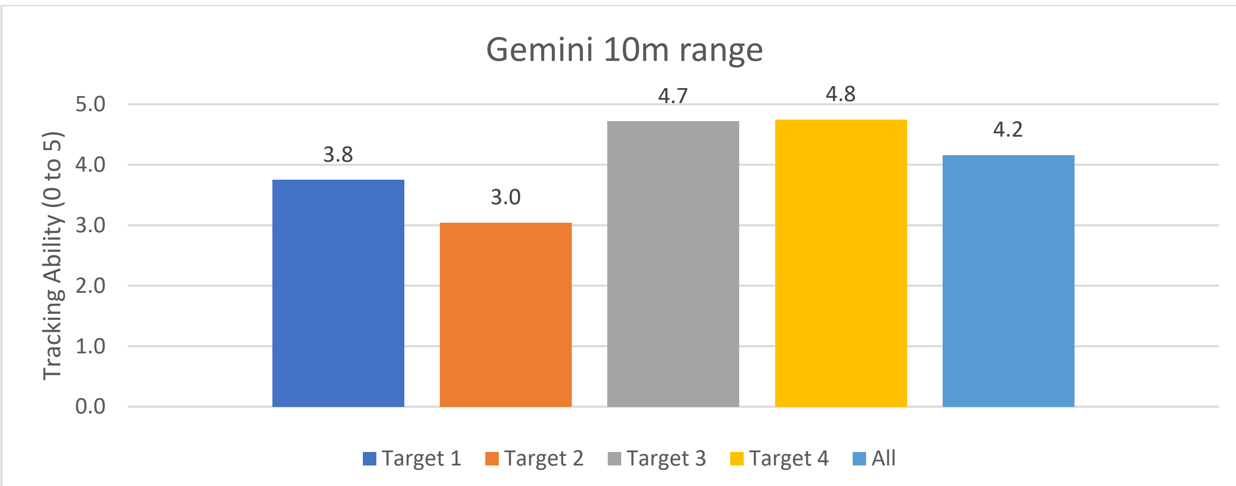


Figure 16: Detection ability for each sonar by target type





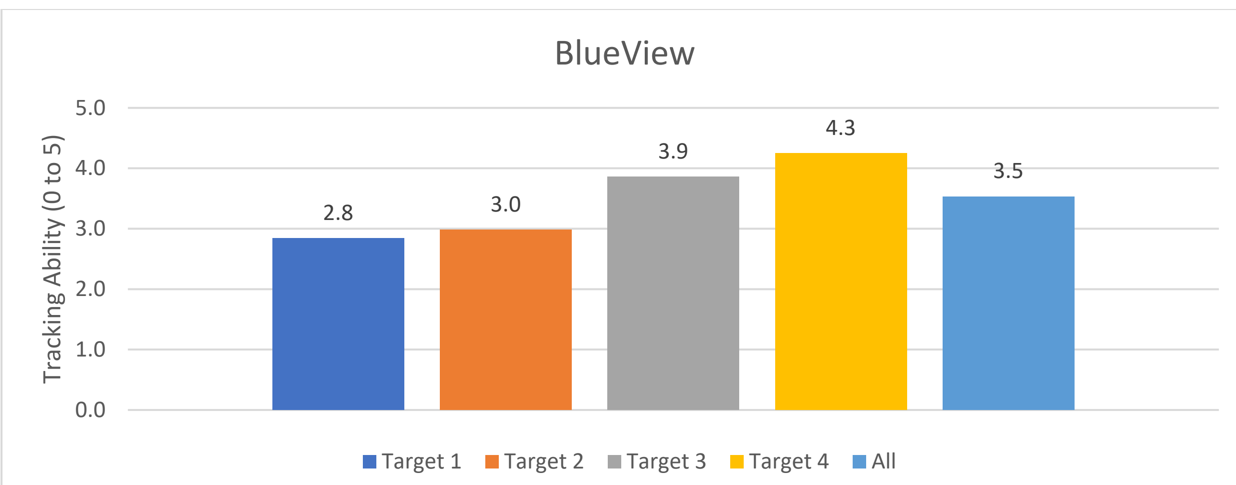


Figure 17: Tracking ability for each sonar by target type

3.2 Effect of Flow Speed

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

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

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

3.2 Hardware Limitations

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

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

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

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

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

3.3 Acoustic Interference

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

Table 5: Effect of acoustic interference

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

4.0 Conclusions

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

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

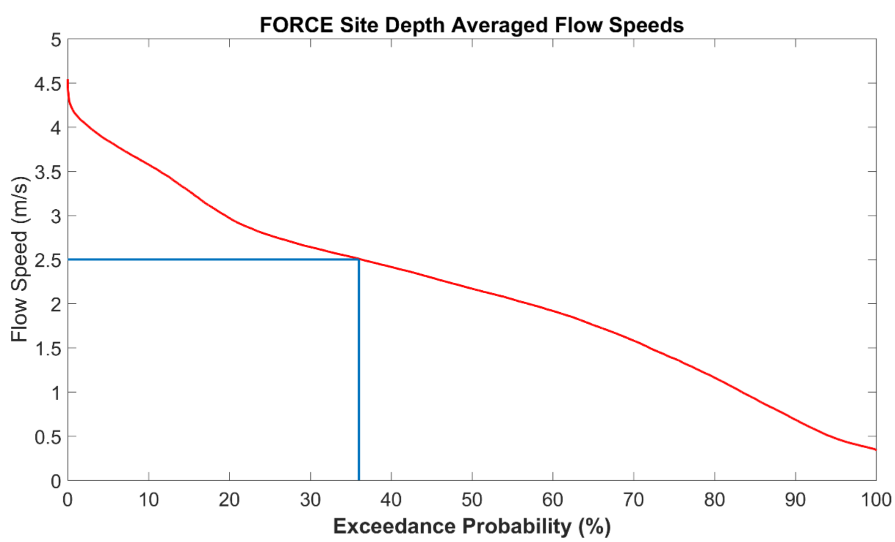


Figure 18: FORCE Site flow speed exceedance curve

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

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

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

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

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

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

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

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

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

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

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

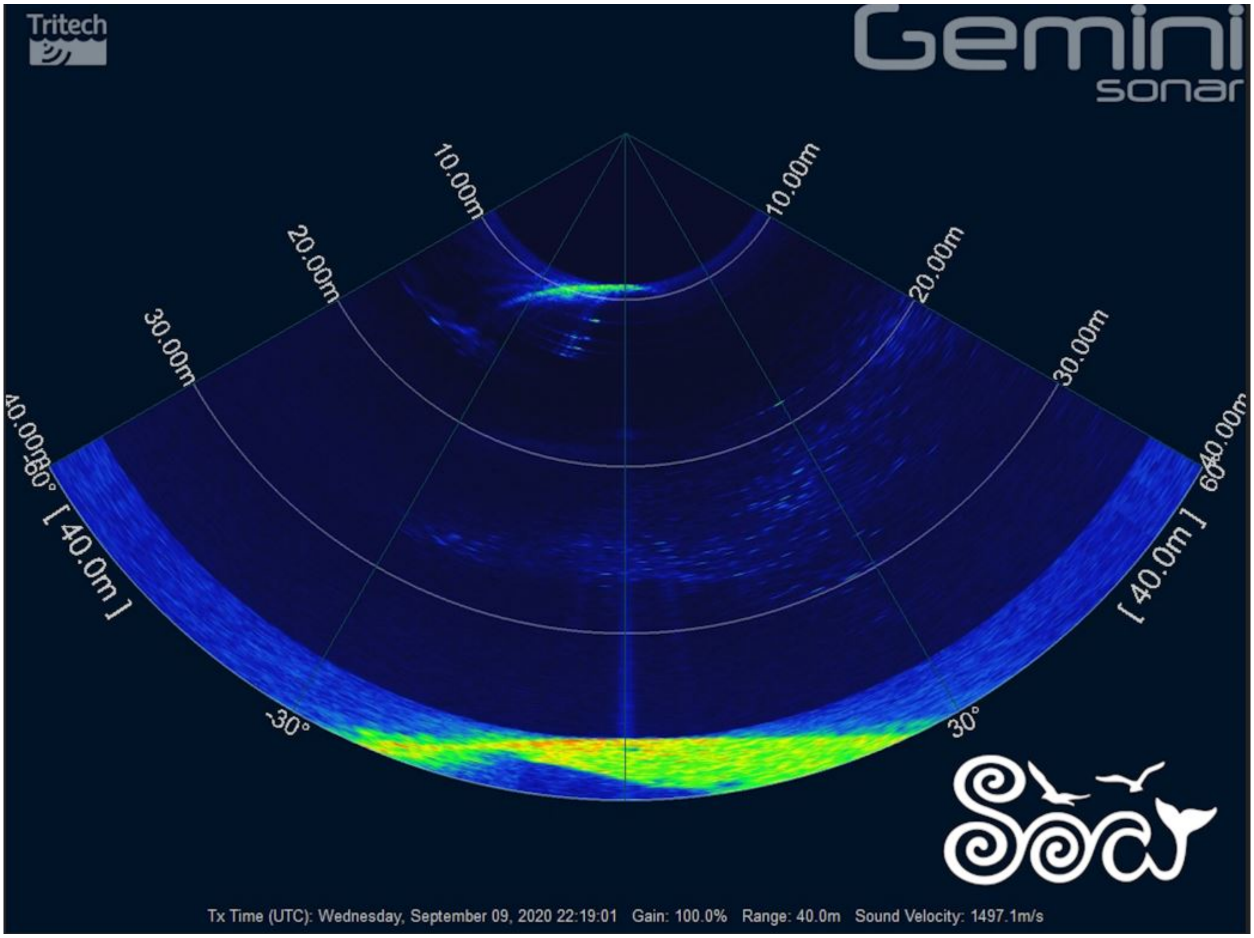


Figure 19: Gemini example of Humpback whale and school of fish

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