DEVELOPMENT OF ACOUSTIC DOPPLER FISH MONITORING FOR APPLICATIONS IN HIGH-ENERGY TIDAL CHANNELS

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Abstract: *Acoustic Doppler profiler systems (ADCPs) are the standard instrument used to monitor ocean currents. These instruments also detect signals scattered by fish, but these signals are normally treated as noise and rejected by ADCP data processing techniques. Those rejected signals do however contain information on fish movement providing an opportunity to extend the application of ADCP technology. The added capability of the ADCP provides a monitoring tool for fish activity and presence in areas that may be impacted by future in-stream hydro energy development projects. We explore this capability through a 37-day deployment of a self-contained bottom-mounted frame equipped with a 600 kHz RD Instruments Workhorse ADCP alongside a 120 kHz BioSonics DTX Submersible Split Beam Echo Sounder system. The deployment took place in Grand Passage, Nova Scotia, at a depth of 25m, where the tidal range is ~5m, and the currents are up to 2.5m/s. We chose this site because it is located in a tidal channel that is identified as having the potential for in-stream tidal generation. Anticipating possible interference, we selected different frequencies and regulated the duty cycles to overlap for half of the total sampling time to assure the collection of uncontaminated data. The split-beam echo sounder shows plumes of scatterers, presumably bubbles, emanating from the surface. Discrete targets are detected throughout the water column within fish schools and as individuals. The corresponding ADCP data detects the same fish schools by using coinciding instances of high intensity and high correlation. The ADCP signal has a lower range resolution but shows less contamination from surface bubbles and weaker scatterers. We present observations for both instruments and contrast their capabilities.*

Keywords: *Renewable energy, acoustic Doppler current profiler, fish detectability*

1. INTRODUCTION

Signals received by ADCPs contain backscatter from a variety of objects in the water column, including fish, zooplankton, sediments, bubbles and the surface or bottom. As the instrument is used for water velocity measurements, typically all signals that differ significantly in echo intensity between the four beams are rejected to reduce fish bias in velocity data [1]. Efforts to use Doppler sonar for fish velocity measurements before the 2000s used low frequency, long pulses and narrow bandwidths [2]. Though Doppler shift methods were said to, theoretically, be promising in gathering information for fish behaviour, the techniques and instruments had not been developed adequately for this purpose. Demer (2000) suggested that ADCPs need to achieve higher velocity and range resolution and showed that a higher frequency and autocorrelation for the detection of pulse shifts wouldaccomplish that. Demer also identified a need to modify parameters and data processing as well as carefully selecting survey sites with fish schools matched to the size of the processing bins [3].

Zedel and Cyr-Racine (2009) presented an alternative approach to analyzing Doppler sonar data using a least-squares based algorithm which analyzes each acoustic beam individually to extract both fish and water velocities, even when fish are intermittently present [4]. Even with a suitable processing algorithm, the challenge remains to identify the presence of fish in ADCP data accurately. The need for such an evaluation motivates this study which uses the opportunity presented by the need to monitor fish presence and behaviour in regions of in-stream tidal energy generation. Such areas are inherently difficult for sampling when using conventional boat mounted acoustic surveys.

This paper reports on a month-long deployment of a collocated bottom-mounted ADCP and split-beam echosounder to evaluate fish detectability in ADCP data.

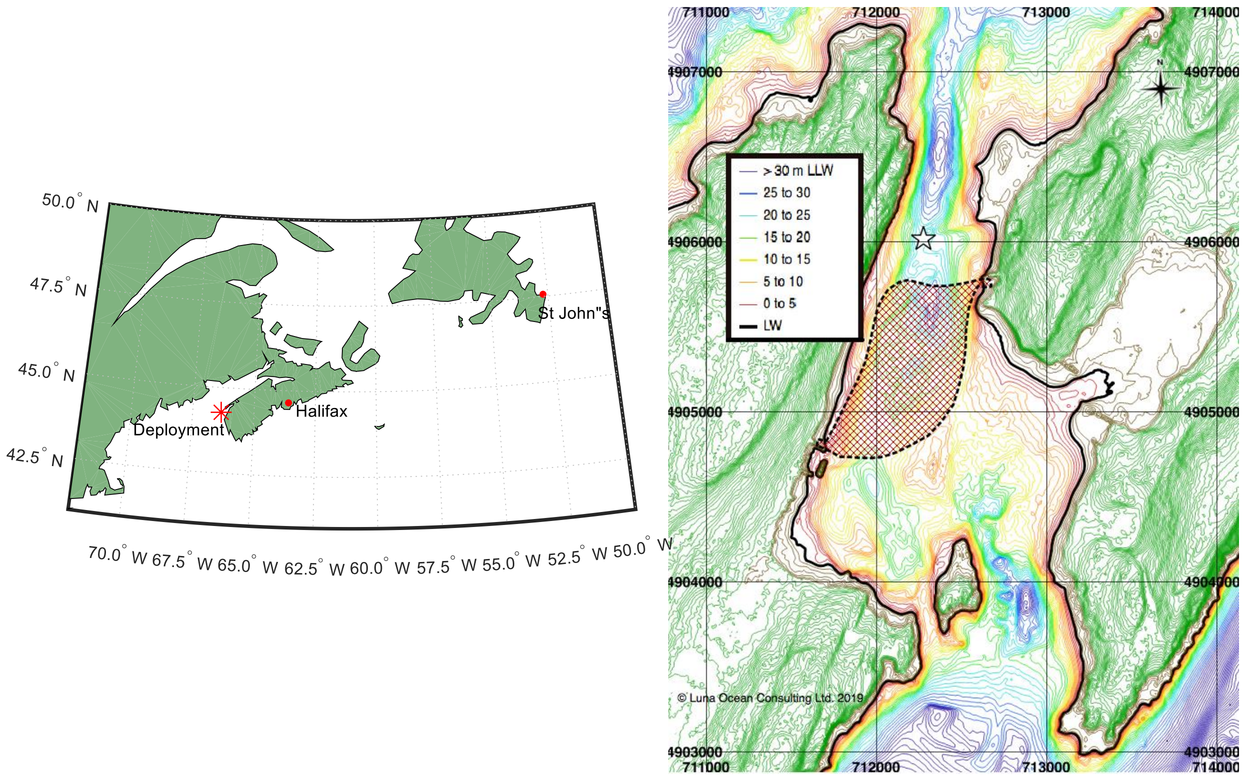

Fig.1: Experimental site. Left: location of the deployment in Nova Scotia. Right: deployment location in Grand Passage (STAR), (extent of the ferry route is the chequered red area).

2. METHODOLOGY

2.1 Experimental Site & Deployment

Grand Passage is a tidal channel in Nova Scotia, Canada that is identified as having the potential for in-stream tidal developments. Prior studies of fish presence in high-energy tidal channels have identified common survey challenges to be acoustic scattering from near-surface bubbles. The study by Melvin & Cochrane (2014) recommends deploying “an autonomous, stationary, bottom-mounted echo-sounder” to overcome these challenges [5]. This experimental site further motivates that approach because it has frequent boat and ferry traffic. A long-term bottom-deployment also allows for inter-survey data which can validate the “snapshot” measurements from conventional surveys and separate the diurnal and tidally induced fish behaviour. The bottom-mounted self-contained frame was deployed at 25m depth and positioned, as shown in Figure 1; note the location selected to avoid interference from the ferry traffic.

The frame was mounted with an RD Instruments 600kHz acoustic Doppler current profiler and a BioSonicsDTX Submersible system with 120kHz split-beam echosounder, as shown in Figure 2. The system was deployed for 37 days, from September 21st, 2018 14:30 to October 29th, 2018 13:54. The acoustic instruments were installed as close as possible to facilitate direct comparison between both datasets.

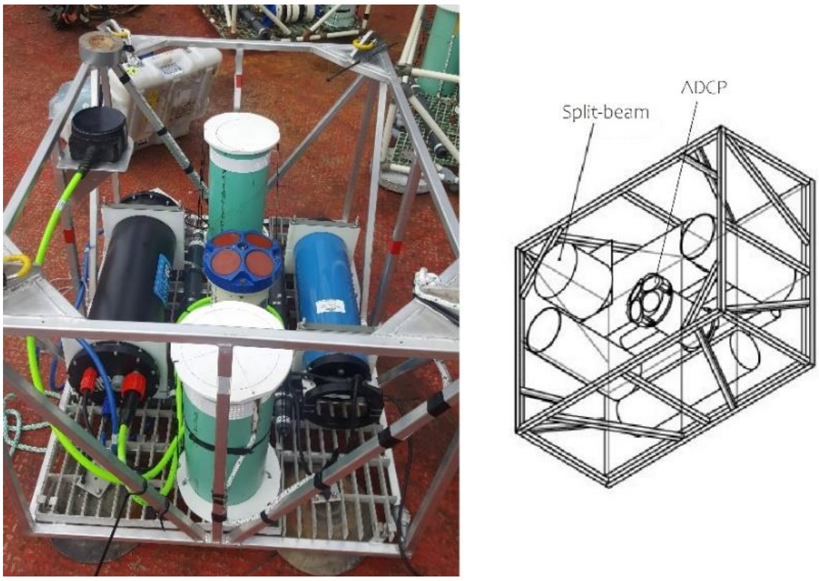

Fig.2: Left: A picture of the frame before the deployment. Right: Sketch of the frame.

2.2 Instrument configuration and calibration

A common problem when operating two nearby acoustic instruments is interference between the two instruments. We chose widely separated frequencies to mitigate this problem (120kHz for split-beam and 600kHz for the ADCP). Nevertheless, we observed contamination in the split-beam sonar data during lab tests. Therefore, in addition to the separate frequencies, we staggered the duty cycle to ensure the collection of both individual uncontaminated data as well as simultaneous measurements. The ADCP was set to collect at one ping per second with 1m bins with no averaging of the profile data; the sampling duty cycle was 20 minutes on and 20 minutes off. The split-beam sonar was configured to transmit four pings per seconds at a 0.1ms pulse duration. The staggered duty cycle was set up by an initial 10 minutes lag relative to the ADCP and a 20 minutes on and 40 minutes off duty cycle.

The ADCP compass was calibrated the day before the deployment using the conventional rotation of the mounted frame [6]. The ADCP backscatter calibration coefficients were taken from a January 2018 laboratory calibration. The split-beam was calibrated with a 33.2mm diameter tungsten carbide sphere in the days immediately following the retrieval of the frame; the calculated offset of 1.1dB was applied to the dataset.

2.3 Data Processing

2.3.1 Acoustic Doppler current profiler

Backscatter data were corrected to volume backscatter coefficients using the procedure outlined by Deines (1999) [7]. The presence of fish in the Doppler sonar data can be indicated by volume backscatter levels exceeding a specified threshold, but properties unique to the broadband Doppler system allow discrimination of discrete targets as opposed to volume backscatter. Broadband Doppler systems transmit pulse pairs with a known lag; the phase of the received echoes is used to extract velocity. The magnitude of the autocorrelation of the received pulses is a measure of the quality of the signal. When coincident with high volume backscatter signal, a strong correlation suggests an acoustically discrete target, distinct from the median value correlation characteristic of a cloud of bubbles or a more extensive school of fish [8]

The volume backscatter and correlation thresholds, -45dB and 135 counts respectively, are applied to each beam individually for fish detection; an example is shown in Figure 3. To place the correlation threshold into context, normal volume backscatter data would have an average correlation of 128. Conversely; water targets are identified as signals below either the intensity or correlation thresholds. Note in particular the clear agreement in backscatter structure when comparing the Doppler sonar data (Fig 3a) with the split-beam data (Fig 3c).

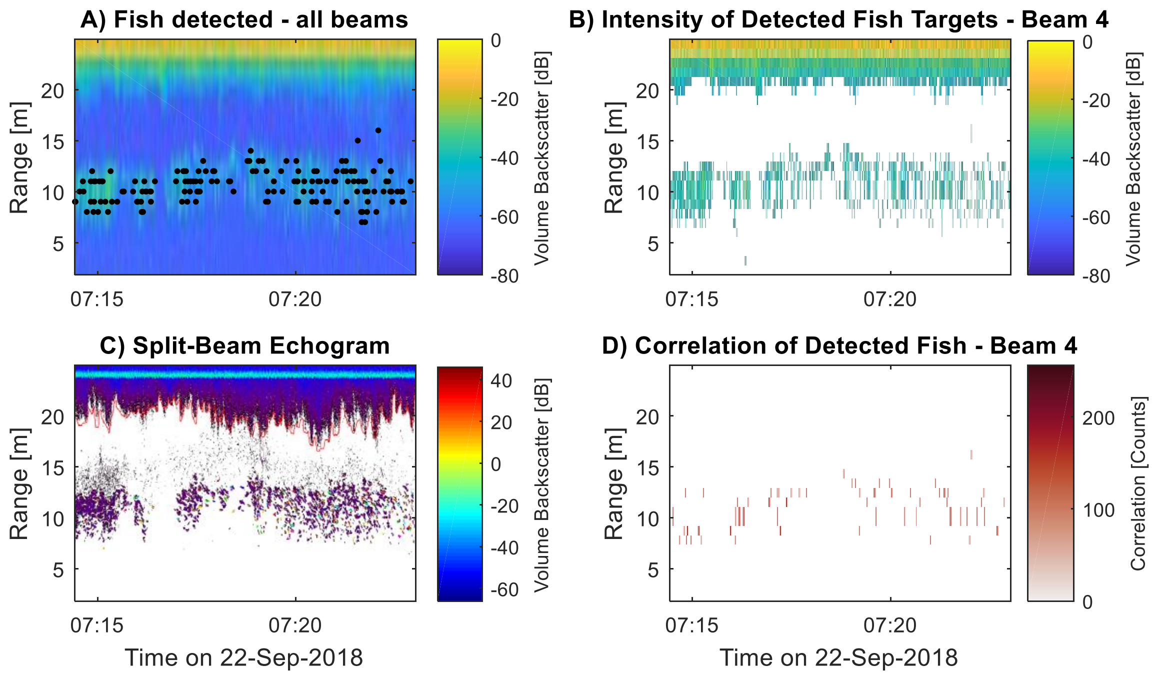

Fig.3: a) A volume backscatter echogram for a fish school from the ADCP with the identified fish targets (.) from all four beams b) identifies the remaining data after the backscatter threshold (-45dB) is applied, c) the corresponding split-beam signal and d) identifies the remaining data after the backscatter and correlation thresholds (135 counts).

2.3.2 Split-beam echo sounder

Sonar5-Pro [9], a post-processing tool for echosounder data was used to process the split-beam data. A surface exclusion line is determined by using the bottom detection algorithm but generally requires manual adjustment for areas of combined fish and bubbles signals. The Cross-Filter Detector algorithm was used to identify the SED (single echo detections) and to combine them into fish tracks. This algorithm is composed of two filters: a foreground filter that smooths over the stronger signal with a running mean and a background filter that smooths the weaker signal and adds an offset to minimize the intensity of the weaker signal even further. The combination of these filters isolates the targets into SEDs. These targets are then combined into fish tracks, using the automatic fish tracking algorithm, based on proximity of targets, and length, speed and path of tracks. Only the SEDs included in tracks, and the whole tracks themselves were used to compare with the fish targets identified in the ADCP data.

3. RESULTS

A total of 37h of simultaneous data were collected between September 21st and October 1st in 10 minutes intervals. The accepted fish detections for both instruments were averaged over 2-hour time bins and 2m depth bins to make a comparison.

A particular challenge in strong tidal flows is the occurrence of near-surface bubble plumes [5] which are often hard to distinguish from fish (or plankton) targets. With the Doppler sonar, we used the requirement of high signal correlations to distinguish discrete targets from bubble clouds. The capability is demonstrated through the data present in Figure 3, note the difference between Fig 3b and 3d, where the correlation threshold effectively removes the bubble plumes. For split-beam sonar data, most bubbles were avoided by using the surface exclusion line algorithm. That algorithm is not always correct and requires a user to review areas of spread bubble plumes or regions where fish and bubbles are mixed. In these areas, it becomes a somewhat arbitrary delineation to distinguish desirable data from bubble clouds. This process is irreproducible and time-consuming.

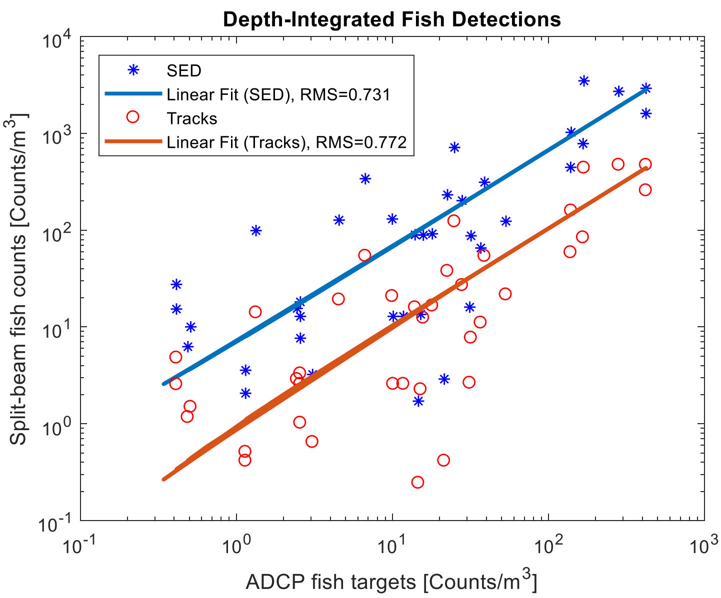

Fig.4: Linear regression analysis for comparison of ADCP fish targets dataset to split-beam fish track counts and SED within fish tracks count.

The ADCP and the split-beam sonar were evaluated by comparing depth-integrated counts over 2h time intervals. A linear regression model (Figure 4) between the two data sets has a slope of 1.04 ± 0.03 for the fish tracks and 6.7 ± 0.2 for the SED. The SEDs and fish track comparison show that there are on average seven single echo detections per track. The fish tracks are a slightly better representation of fish targets in the ADCP data and more representative of fish counts. Overall, the tracks provide a strong agreement with a cross-correlation of 0.881. Discrepancies in counts between the instruments would be expected due to differences in sampling volumes, operating frequency, and measured product.

4. FURTHER WORK

This data demonstrates that ADCP can detect fish in providing agreement with the industry standard, split-beam echosounder, for the conditions sample in Grand Passage. The ADCP also provides an alternative processing approach for dealing with near-surface bubbles that eliminates the need for the more operator intensive process of determining an exclusion line. Further work will focus on extracting fish velocity from the targets in the ADCP data and comparing those with velocities from fish tracks in split-beam data.

5. ACKNOWLEDGEMENTS

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