Specialized Tools for Biological Assessment Using Split Beam Hydroacoustics

Eric Munday, Tim Acker, James Dawson
BioSonics, Inc.
Seattle, USA
ericmunday@gmail.com

***Abstract*— The science of fisheries acoustics and its applicability to resource management have evolved over the past several decades. The use of hydroacoustics for the assessment of fisheries resources is well established and split beam echosounders are now the standard instrument of scientific fisheries acoustics. To augment the information gained from mobile hydroacoustic surveys, researchers have developed innovative methods and devices to facilitate the use of split beam echosounders in new situations and environments. This document provides a description of three recent inventions that facilitate the use of split beam echosounders in non-conventional application; a hybrid split beam and imaging sonar system tested for defense related applications, an autonomous, submersible echosounder for long-term seafloor observation, and a towed echosounder specifically engineered for use with a self-propelled, autonomous surface vehicle.**

Keywords—Split beam, sonar, autonomous echosounder, Liquid Robotics, Wave Glider, towed body, submersible, imaging sonar, automated hydroacoustic monitoring, fisheries stock assessment.

I. Introduction

Fisheries acoustics relies on the physics of sound traveling through water to quantify the distribution of biota in the water column. By sending a signal of a given frequency through the water column and recording the time of travel and the strength of the reflected signal, it is possible to determine the size and location of fish and estimate biomass from the acoustic backscatter. A split-beam echosounder divides the transducer face into four quadrants. By comparing the arrival time differences of an echo among the four quadrants, the angle off-axis can be estimated, allowing the location of targets in three dimensions. Logistical challenges and economic factors continue to drive innovation in the field of hydroacoustics including the integration of split beam echosounders with other systems including Unmanned Underwater Vehicles (UUVs), imaging sensors, and seafloor observatory platforms. This document describes three recent inventions that facilitate the use of split beam echosounders in non-conventional applications.

II. Hybrid Split Beam and Imaging Sonar System

A. Project Overview

Split beam echosounders detect, locate, and measure individual targets at relatively long-ranges (+500m) and are largely unaffected by turbidity or light. Imaging sonar systems, such as high-frequency acoustic cameras, provide high resolution data for visual verification of fish or other targets, but are more range-limited and affected by water conditions than split beam. BioSonics, Inc. and Teledyne BlueView, Inc. have developed a prototype system that integrates split beam and imaging sonar capabilities to combine long-range detection with visual ground truthing capabilities. Such systems have been demonstrated as a highly-effective means to verify target types and reduce imaging data storage and processing efforts. Species composition data from acoustic cameras can be extrapolated across split beam datasets collected over days or weeks at a time.

Active sonar systems under consideration for security applications are designed to detect and classify specific targets by transmitting an acoustic pulse and measuring the returned energy. All such systems are subject to diminished performance due to nuisance alarms caused by physical and biological targets, such as rocks, aquatic vegetation and marine mammals, that reflect acoustic energy in a similar way when compared to an intruder. A recent experiment was conducted to characterize the acoustic signatures of physical features and biological species and to identify any acoustic signatures that would potentially cause a nuisance alarm. Data generated from the project will aid in the development of data filtering and target classification algorithms to minimize the Nuisance Alarm Rate (NAR) for active sonar systems used in security applications.

B. Experiemntal Design

Two active sonar devices were deployed and configured to run as an integrated system continuously for 3-weeks. The two devices included a BlueView P900-130-D multibeam sonar (Fig. 1) [1] and a BioSonics DT-X split beam echosounder

Fig. 1 BlueView P900 sonar

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Fig. 2 Rack-mounted BioSonics DT-X Echosounder

(Fig. 2) [2]. The two systems were aimed at an overlapping study region that measured approximately 7 m by 7 m and varied in depth from approximately 1 m at low tide to 4 m at high tide. Targets that were detected by the BioSonics system that exceeded a minimum target strength threshold and persisted for minimum duration of time, triggered an alert. A total of 10,986 alerts were generated during the 3-week study period. In post processing, video clips of the BlueView data were generated that correlated with the 10,986 alert events. These video clips were used to help assess the cause of the alerts (e.g. marine mammals, fish, or seabed features).

The BioSonics system has an auto-alerting function set to alert when a target of sufficient target strength enters the user-defined detection area for a specified amount of time. The time stamp of each alert can be used to automatically generate video clips from the BlueView sonar data that correlate with the split beam sonar alerts. The video clips are then used to identify targets that cause split beam sonar system alerts.

C. *Installation*

Installation and aiming validation of the two sensors were critical for achieving project goals. A study region was developed and verified where the two active acoustic beams intersected (Fig. 3). Each sonar sensor head was mounted on a dual-axis rotator, precisely installed to insure that the acoustic beam covered the entire vertical extent of the study region at all tidal cycles. The alignment of both sensor beams at the center of the study region was verified using a point-source reflector attached to a line between a float and a weight. The rotators for both sonar heads were adjusted until the reflector was positioned on each acoustic axis with both sensors ensonifying the entire study region and both pointed at its center. The coverage of the study region by both sensors was further verified by two tethered scuba divers. The divers swam to the center of the study region where they were detected by both systems. The divers then removed the reflector and swam away from the pier to a distance where they were out of the beams of both sensors, but still at the same distance from shore as the study region's center. They then swam toward a pier, held a moment, and then swam back a distance of 20 m to their starting point. The divers swam 20 replicate paths through the study region and were detected by both sensors on all 20 runs, further verifying that both sensors were adequately covering the study region's volume.

Figure 3 shows the installation points and aiming geometry of the two sensors overlaid on a tactical map. A detection range of 60 to 68 m was programmed into the BioSonics sonar to insure that target detections inside the study region were the only ones to trigger an alert. The study region was contained horizontally and vertically in the crosshatched region of the figure.

D. *Control Unit Description*

Both of the sonar systems were controlled by a BioSonics Automated Monitoring System Control Unit (AMSCU), a

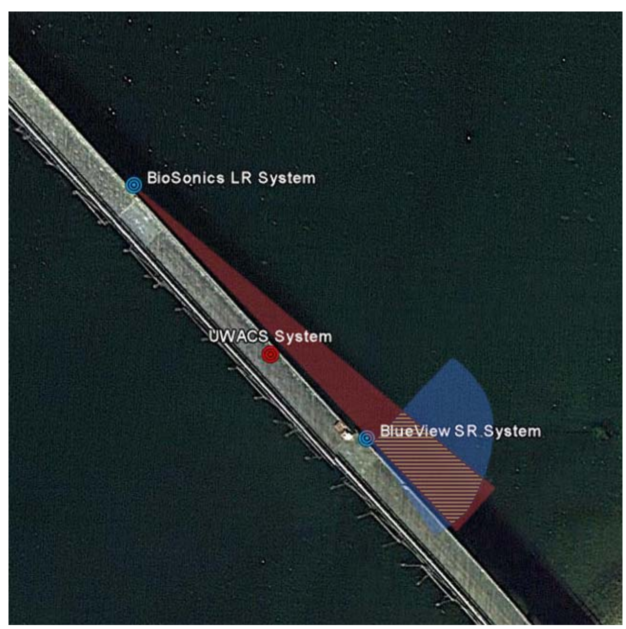

Fig. 3 Study area diagram

rack-mount electronics package consisting of a heavy-duty computer, uninterruptible power supply (UPS), broadband firewall/router, and a remote power management system (RPMS). The system was deployed in an environmental enclosure (Purcell RAC 48). Power was run to the environmental enclosure to provide 110v AC to run the control system and sonars and to provide air conditioning to the enclosure. The AMSCU utilized BioSonics System Watchdog software to monitor operational status and send daily reports to project personnel via a cellular modem internet connection. These reports included information on the operational status of each sonar system, a record of any power outages, pan and tilt aim, file sizes and alert activity. The communication system also allowed remote, real-time control of each sonar system using GoToMyPC service.

E. Data Collection and Analysis

The data for both sonar systems were recorded continuously onto RAID drives of the AMSCU. The split beam sonar system raw acoustic data files (*.RTPX) and imaging sonar system raw acoustic image files (*.SON) were date and time stamped by the system clock and placed in corresponding daily directory file folders.

The split beam sonar system data files are represented visually as an echogram, with the time along the X-axis and range from the face of the transducer on the Y-axis (Fig.4). The color scale in the echogram represents the intensity of the individual echoes. The split beam sonar system detection alert is set to trigger when echoes exceed an intensity threshold for a consecutive number of pings at a particular range. The system then changes its alert status from “Green” to “Red” (Fig. 5) and the information (Time, range, bearing, latitude and longitude, depth, speed, and direction of travel) about the echoes that generated the alert are recorded in a track list. In post-processing, the software copies a section of raw split beam sonar data extending from 10 seconds before the alert to 10 seconds after. The time stamp from this section of raw data is used to find and make a video clip of the corresponding imaging sonar data (Fig. 6). These video clips provide a means to verify the cause of the alerts.

III. AUTONOMOUS PROGRAMMABLE SPLIT BEAM ECHOSOUNDER

A. Project Overview

Repeated mobile hydroacoustic surveys conducted within a general area at varied time intervals have demonstrated the variability in fish and other biological organism distribution and abundance as a function of short-term (daily, monthly) variation in behavior. This variation may be due to cryptic behavior to avoid predation, migration between resting and feeding areas, pursuit of food, territorial activities, spawning activities, response to weather and physical changes (e.g. tidal activity) or other influencing variables. These highly-variable biological activities are important to understand for siting and operation of tidal energy generation facilities.

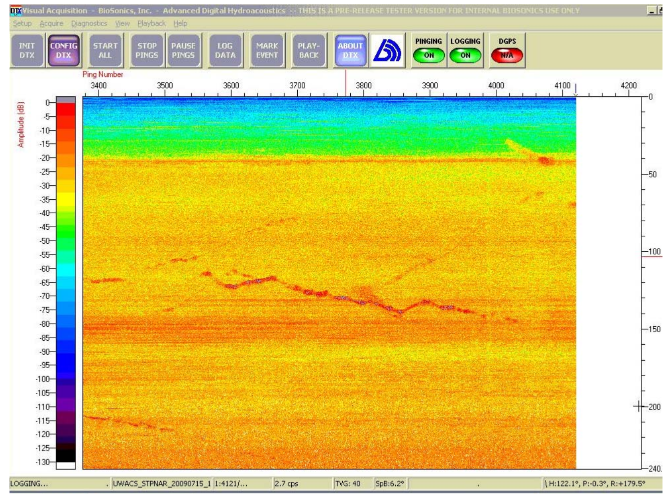

Fig. 4. DT-X echogram from side-looking echosounder showing large target at range of 110 to 150 m.

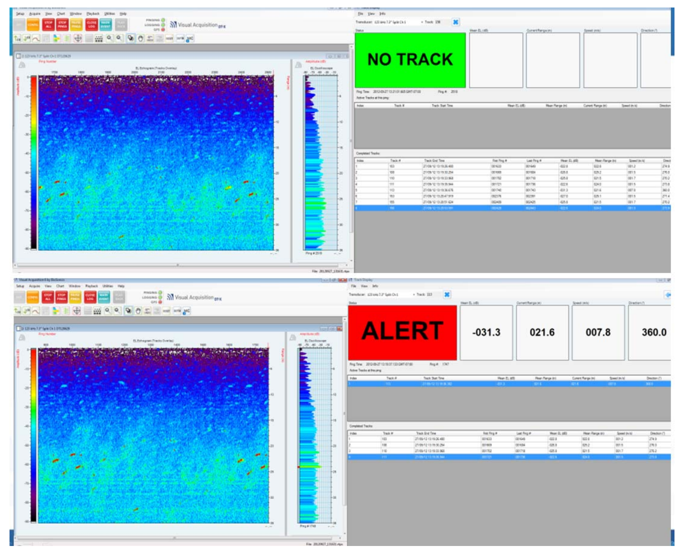

Fig. 5. BioSonics AMSCU data acquisition software showing auto-alert function with red/green indicators.

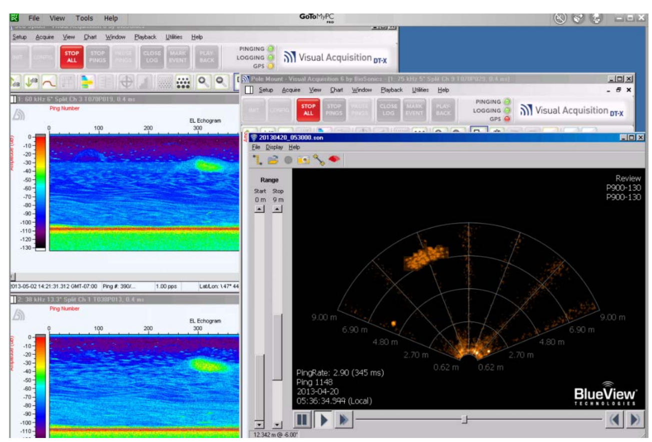

Fig. 6.Integration of BioSonics DT-X echogram and BlueView video data

A better understanding of biological distribution and behavior can be obtained through single-site measurements from fixed locations over a period of weeks or months, with data transmitted and recorded at a shore-based site. This type of fixed-station hydroacoustic monitoring involves the collection and analysis of water column backscatter data utilizing an upward or side-looking echosounder over an extended period of time.

Data transmission and configuration of conventional split beam echosounders is accomplished via a continuous communication link (typically Ethernet) with a computer running specialized data acquisition and echosounder configuration software. Installation of a communication tether cable to the surface can be impractical or even impossible in deep water, remote, and offshore projects. Therefore, fixed-station deployments of split beam echosounders in these conditions were not previously possible. Recent invention of a programmable, autonomous, split beam system (BioSonics DT-X SUB) allows for untethered deployments and long-term data collection in remote or deep-water environments. This submersible echosounder system is capable of collecting and logging data from one or more split beam transducers over an extended period of time.

University of Washington and the Northwest National Marine Renewable Energy Center (NNMERC) working with BioSonics, successfully deployed a DT-X SUB echosounder [3] in Admiralty Inlet, Puget Sound for 5-weeks. The study location is a proposed Snohomish Public Utility District tidal energy demonstration project site. Information gained is useful to project developers in identifying locations where there is long-term potential for hydrokinetic commercial facilities.

B. DT-X SUB Deployment Methods

The DT-X SUB was deployed on a seafloor observatory system as part of an array of oceanographic and biological monitoring sensors powered by deep-cycle batteries affixed to a Sea Spider tripod mount (Fig. 7). The system was completely autonomous and required no surface tether. Configuration and duty cycle were programmed at the surface. The echosounder was programmed to collect data for twelve minutes every other hour in a 10% operational duty cycle alternating between active pinging and sleep modes. This duty cycle maximized temporal coverage and extended battery life for the duration of the deployment. An integrated orientation sensor recorded the aiming angle of the transducer for accurate water column volume and fish target angle calculations. The system was retrieved using acoustic releases and the data files were downloaded for processing of fish abundance, distribution, and behavior information. The DT-X SUB scientific echosounder system was configured as follows:

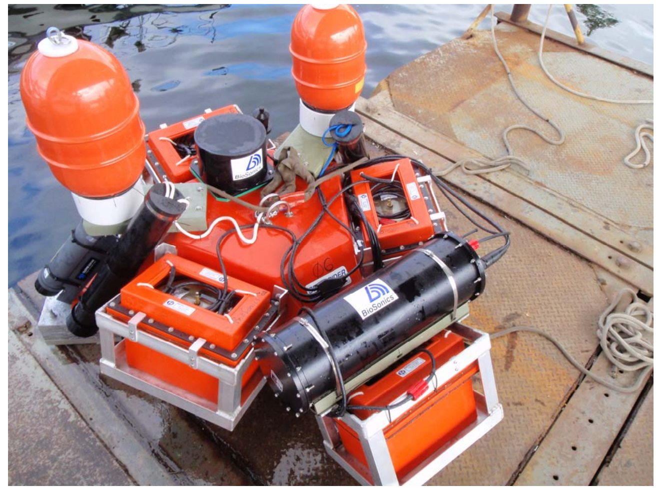

Fig. 7 Sea Spider configured with DT-X SUB autonomous echosounder and other sensors

- PREVCO A811SS TB pressure housing containing a DT-X split beam echosounder, an embedded processor running Linux SBC.
- A 200 kHz split beam digital transducer with internal orientation sensor
- Electronics and specialized software for onboard automated operation and data handling/storage.
- A power monitoring system with automated system shutdown/restart capability
- Four 24v deep-cycle batteries manufactured by Deep Sea Power and Light [4]

C. Results from Admirakty Inlet DT-X SUB Deployement

Hydroacoustic data verified the expected biomass density distributions across time and space. Overall, NNMREC concluded that is possible to adapt existing acoustic instrumentation for autonomous deployments in high-flow environments [5]. However, it was also noted that while data storage capacity is not an issue, limited power availability restrict sampling density and therefore it is important to ensure that power supplies meet sample design requirements. Researchers also concluded that more pre-deployment testing to optimize echosounder data collection parameter settings would have improved data quality.

IV. Wave Glider Towed Split Beam Fisheries Echosounder

A. Concept Origin and Overview

Rising costs of ship time have reduced fisheries survey efforts by government agencies and compromised their value to fisheries managers. Autonomous vehicles are now used to carry split beam sonar systems and collect data in environments not before possible and at a reduced cost compared with traditional ship-borne missions. A hybrid machine conceived by Dr. Charles Greene of Cornell University, was co-developed by Liquid Robotics Inc. (LRI) and BioSonics, Inc. The device combines an LRI Wave Glider [7] with a BioSonics DT-X SUB scientific echosounder housed in a purpose-built, missile-shaped tow vehicle (Fig. 8). The tow body is attached to the submerged glider unit of a Wave Glider with a compliant tow cable to provide mechanical isolation from the surging motion of the Wave Glider propulsion system. This "Fisheries Glider" requires fewer man hours than typical shipboard acoustic surveys, uses no fuel, and thereby operates at a reduced cost.

B. System Description

The Wave Glider is a hybrid sea-surface and underwater vehicle comprising a submerged glider tethered to a surface float. The vehicle is propelled by the conversion of ocean wave energy into forward thrust, independent of wave direction. The wave energy propulsion system is purely mechanical; electrical power is neither generated nor consumed by the propulsion mechanism. There is substantial power available in ocean waves, and the Wave Glider harnesses this power to maintain an average forward speed of about 1m/s (1.5 knots) in seas with 0.5m - 1m wave height. The system uses solar panels and 650 Watt hours of battery capacity to power on board sensors and payloads. The Wave Glider vehicle has been designed to withstand large open-ocean waves and strong winds with its low-profile surface float, high-strength tether and robust submerged glider.

The DT-X SUB is a programmable split beam echosounder in a submersible housing engineered for deployments in seafloor observatories, UUVs, and other applications where a cable to the surface is not practical. The DT-X SUB echosounder can be configured with a range of transducer frequencies and is capable of detecting objects as small as several millimeters in size. The echosounder provides acoustic data which can be analyzed for various information including: bathymetric measurements, substrate classification, sizing distribution and abundance estimates of fish and other organisms, and location of boundary layers in the water column. Raw hydroacoustic data are logged on storage drives within the DT-X SUB and downloaded upon recovery of the vehicle. Real-time data summaries can be retrieved via satellite connection while the vehicle is deployed.

The DT-X SUB echosounder features programmable duty cycling to reduce power consumption by up to 90% and dramatically extend battery life and operation time. The echosounder can be operated continuously for approximately

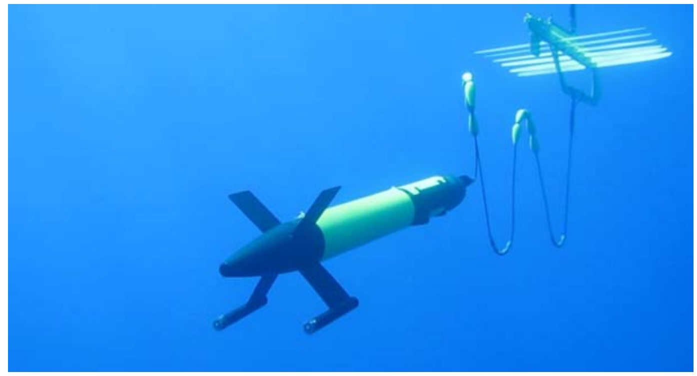

Fig. 8. Wave Glider and DT-X SUB echosounder towed body

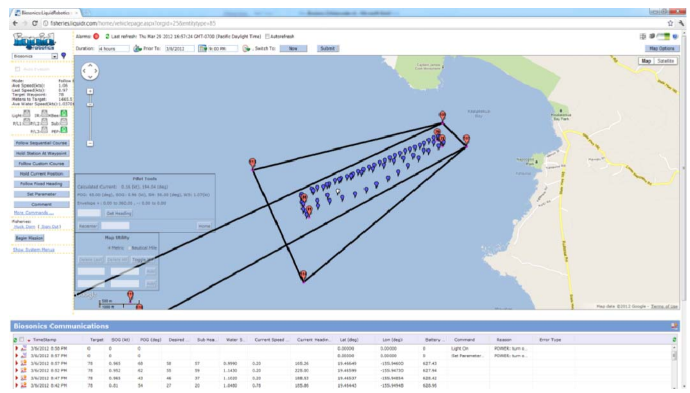

Fig. 9. Screenshot of LRI's WGMS during trials in Hawaii.

10 hours before the Wave Glider's 650 Watt-hours battery capacity must be recharged with the on-board solar panels.

The system is monitored and controlled using LRIs Wave Glider Management System (WGMS) as shown in Figure 9. WGMS uses the Iridium satellite network to communicate with Wave Gliders, allowing user control from any internet enabled terminal. WGMS provides the ability to turn payloads on and off, command the vehicle to travel to desired locations, monitor vehicle status, and much more. The operational status of the echosounder, as well as low-resolution previews of the acoustic data, can be monitored via WGMS, allowing remote confirmation of system performance.

C. Test Description

Recent testing has demonstrated the device provides high-quality acoustic data and an efficient means to catalog the global fisheries resource. Liquid Robotics conducted a series of tests in Kealakekua Bay, Hawaii, during March 2012 to evaluate the ability of the system to detect and observe the migration of the mesopelagic boundary community (MBC). The system proved to be an effective platform for collecting acoustic data and studying patterns in the distribution and migration of marine organisms.

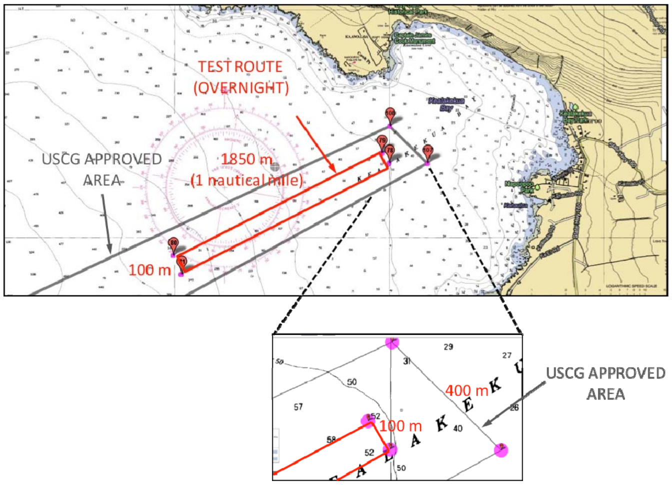

Fig. 10. Screenshot of LRI's WGMS during trials in Hawaii.

The system tested in Hawaii included a Wave Glider, a compliant tow cable and towed echosounder. The tow body contained a BioSonics dual frequency echosounder with 70kHz and 200kHz single-beam transducers and on-board computer. The Wave Glider was equipped with a custom umbilical cable and payload box to provide power and communications capabilities to the tow body. Testing was performed in Kealakekua Bay off the west coast of Hawaii Island during March 2012. A Coast Guard-approved operational test area of 1 nautical mile x 100 m was configured with four waypoints (Fig. 10). The Wave Glider was instructed to continuously run the operational box, with the transducers alternating pings in both active and passive mode. The speed through water of the Wave Glider pulling the tow body during this test was approximately 1.2 knots in a moderate sea state.

Due to the risk of collision with fishing vessels, the system was sent in for nighttime operations starting at 7pm and sent back out to an offshore loiter box to recharge the system batteries starting at 5am. The operations lasted two nights to test and validate the system's ability to collect stable, high-quality acoustic data.

D. Results

Echograms of the 200-kHz data can be seen in figure 11 below. The ocean bottom can be seen at a depth of 100 m as a red line. Significant biological backscatter is visible all along the ocean bottom at a depth of 70 to 90 m, as well as a likely aggregation of fish at approximately 30 to 50 m.

The compliant cable allowed for the tow body to maintain a horizontal orientation suitable for the collection of high-quality acoustic data. Biological backscatter was clearly detected by the echo sounder at ranges in excess of 100m and observed to vertically ascend over time (Fig 11). The tow body contained an orientation sensor logging positional data approximately 9 times per second. The pitch of the tow body typically stayed within a range of +/- 7 degrees and roll within +/- 2 degrees, a vast improvement from previous tow-body designs not employing the compliant cable. This improvement also allowed the echo sounder to collect a reliable bathymetric profile.

The Wave Glider with its compliant cable was able to effectively tow the echo sounder tow body and maintain an averaged 90% of the velocity of a nearby, un-encumbered Wave Glider.

Sources of noise were identified during transmission of echo integration reports and from the mechanical rudder on the sub-surface glider. The amount of system noise relative to biological backscatter was deemed negligible however, and the testing demonstrated that acoustic data collected from the Fisheries Glider are suitable for quantitative analysis. In the future, shielding the transducers from communication signals and reducing rudder noise would mitigate system noise and

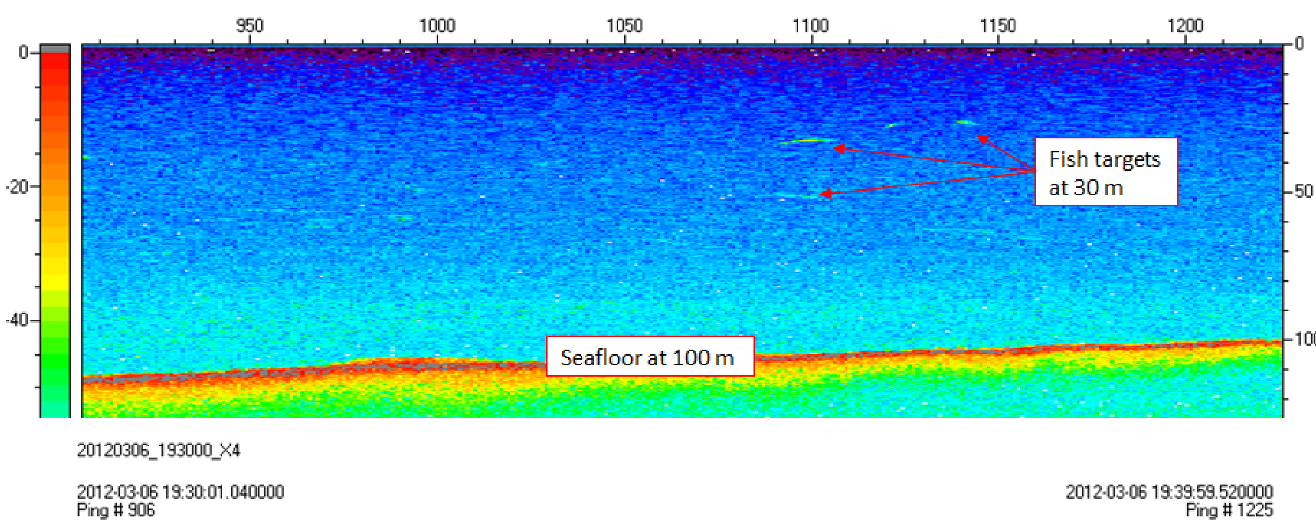

Fig. 11. Echogram from towed DT-X SUB 70 kHz transducer

extend the depth range of quantitative analyses at each frequency. Overall, the system proved suitable and highly efficient for observing fish, zooplankton, and other aquatic organisms in the water column over extended periods of time.

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