Fisheries Innovation Scotland

FIS004 - Slippage Mitigation and Acoustic Characterisation (SMAC). Phase I: sonar adaptation and development of data processing tools

A REPORT COMMISSIONED BY FIS
AND PREPARED BY

Kaj Daworski, Alan Fenwick and Paul Fernandes

University of Aberdeen

Published by: Fisheries Innovation Scotland (FIS)

This report is available at: http://www.fiscot.org.

Dissemination Statement

This publication may be re-used free of charge in any format or medium. It may only be reused accurately and not in a misleading context. All material must be acknowledged as FIS copyright and use of it must give the title of the source publication. Where third party copyright material has been identified, further use of that material requires permission from the copyright holders concerned.

Disclaimer

The opinions expressed in this report do not necessarily reflect the views of FIS and FIS is not liable for the accuracy of the information provided or responsible for any use of the content.

Suggested Citation:

Daworski, K., Fenwick, A., Fernandes, P. 2015. Slippage Mitigation and Acoustic Characterisation (SMAC). Phase I: sonar adaptation and development of data processing tools. A study commissioned by Fisheries Innovation Scotland (FIS) http://www.fiscot.org/

Title: Slippage Mitigation and Acoustic Characterisation (SMAC). Phase I: sonar adaptation and development of data processing tools

ISBN: 978-1-911123-03-3

First published: October 2015

© FIS 2015

Slippage Mitigation and Acoustic Characterisation (SMAC). Phase I: sonar adaptation and development of data processing tools.

FIS004: Final Report

By

Kaj Daworski, Alan Fenwick and Paul Fernandes

Institute of Biological and Environmental Sciences

University of Aberdeen

2 September 2015

EXECUTIVE SUMMARY

Mackerel is the most important pelagic species in the Scottish fishing fleet and the most valuable single species fishery in Scotland, accounting for 29% (£126 million) of the total value of Scottish landings in 2013. The species consists of one stock, known as the North East Atlantic mackerel stock, and is managed under the European Union's (EUs) Common Fisheries Policy (CFP), normally in agreement with other coastal states (Norway & the Faroe Islands). In spite of recent disputes with Iceland over catch shares, the stock is exploited sustainably. The total catch taken from this stock in 2013 was 932,000 t, which at a approximate value of over £1000.t^{-1} makes this a billion pound fishery, important to many other northern European nations such as Norway, Netherlands, Ireland, the Faroe Islands, and more recently, Iceland.

In January 2015, these northern European fleets will be the first to be subject to the new landings obligation, effectively banning the practice of discarding. In the case of the mackerel fishery, the main challenge is to avoid slippage, the practice of releasing large amounts of (mainly small) mackerel caught in the net, back into the water. The goal of this project was to develop analytical techniques to allow the size of fish to be determined prior to capture using a novel broadband sonar device and so avoid the problem of slippage. As such this project was considered as the first, now completed phase, of an envisaged sequence of projects summarised in the flow chart below (Figure 1).

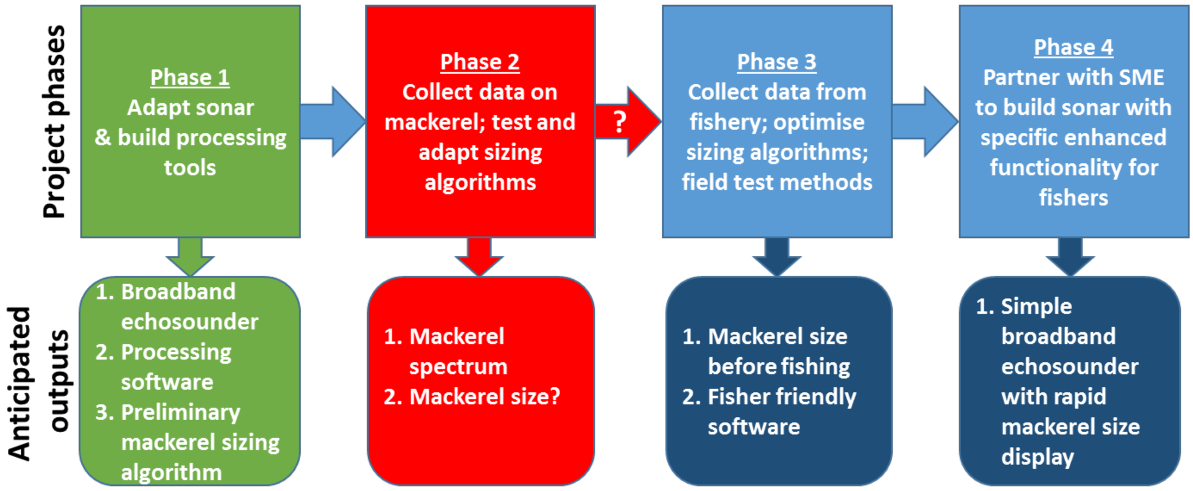

__Figure 1.__ Phased sequence of projects to deliver a system for the remote determination of mackerel size. Green boxes represent the current completed project. Red arrows and boxes indicate the critical phase: whether the broadband spectra (acoustic characteristics), collected from mackerel schools in the wild, conform to theory and allow for size to be estimated. Blue boxes represent further phases required to achieve the ultimate goal of having a system for sizing mackerel for the fishing fleet.

This project (Phase 1) involved the adaptation of an EdgeTech 3200 sub-bottom profiler (shown on the front cover) recently acquired by Marine Scotland Science (MSS) to work as a low frequency echo sounder. Concepts and computer code developed at the Woods Hole Oceanographic Institute (WHOI) were adapted to provide a set of tools to process whole water column echosounding data from the device.

This document is a technical description of the routines used to adapt the sonar (mostly to do with pulse generation); to analyse data from the device so that broadband spectra can be measured; and to size fish with a preliminary sizing algorithm. As such the document reads more like a manual. This was necessary because the manual provided with the sub-bottom profiler describes how to use it for its intended purpose – geological surveying - not for whole water column broadband echosounding.

In addition to describing methods to adapt the system for echosounding, there is an extensive suite of programmes adapted from programmes built by WHOI to process the data. The steps are described in order to obtain (i) an echogram; and (ii) broadband spectra from the 3 channels effectively providing a broadband range from 1 to 60 kHz. The complete code is not reproduced in this document: although it forms the bulk of the work, it contains over 4000 lines of computer syntax which would have little meaning to anyone not familiar with coding and acoustics. Calibration of the system is also described drawing on the experience of WHOI staff who were sub-contracted for the project.

Finally a preliminary least squares algorithm to determine mackerel size based on simulations of mackerel broadband spectra is described. Without any real data it is difficult to demonstrate its utility, hence the critical Phase 2 where real data should be collected at sea (Figure 1). A Bayesian approach was aslo tested, but the run times (over 1 hour) make it impractical for use at sea.

The document will allow MSS staff and others to operate the EdgeTech sonar as a broadband echosounder and collect broadband spectra from mackerel in future projects (Phase 2). This will allow for testing of the algorithm. If this succeeds, then this can then be field tested further in the mackerel fishery (Phase 3). Finally, commercial implentation of a stripped-down simple system could take place in Phase 4 in order to have a viable system available to the fishing industry.

TABLE OF CONTENTS

1 INTRODUCTION

Mackerel is the most important pelagic species in the Scottish fishing fleet and the most valuable single species fishery in Scotland. In 2013, it accounted for 29% (£126 million) of the total value of Scottish landings and 82% of the value of pelagic landings (Anon 2014). Scottish vessels landed 74,211 t into Scotland and a further 59,800 t abroad in 2013. The species consists of one stock, known as the North East Atlantic mackerel stock. This stock was managed under the European Union's (EUs) Common Fisheries Policy (CFP) in agreement with other coastal states (Norway & the Faroe Islands), under a management plan aiming to set an annual Total Allowable Catch (TAC), in accordance with scientific advice given by the International Council for the Exploration of the Sea (ICES). However, recent disputes (Hannesson 2013) with Iceland over catch shares have meant that recent quotas being set do not correspond with the advised TAC. Despite this, in 2014, ICES, which conducts stock assessments of mackerel, concluded that the stock was exploited sustainably, with an estimated spawning stock [adult] biomass of 4.4 million t and an average fishing mortality of 0.2 in 2013 (approximately 18% of the adult stock was removed in 2013). The total catch taken from this stock in 2013 was 932,000 t, which at a approximate value of over £1000.t^{-1} makes this a billion pound fishery. The species is therefore also important to other nations in northern Europe such as Norway, Netherlands, Ireland, the Faroe Islands, and more recently, Iceland.

In January 2015, the Scottish pelagic fleet, along with those of the European Union (EU), which is largely dependent on this species, will be the first to be subject to the new landings obligation (Borges 2013). The landings obligation is a policy requires that all fish that are caught are brought ashore and landed. This effectively bans the practice of discarding, the throwing away at sea of fish that have been caught, dead or alive (Fernandes et al. 2011). In the case of the mackerel fishery, the main challenge is to avoid slippage, the practice of releasing large amounts of (mainly small) mackerel caught in the net, back into the water. The goal of this project is to develop analytical techniques to allow the size of fish to be determined prior to capture and so avoid the problem of slippage.

Recent research has demonstrated that low frequency broadband spectra may be obtained using adapted sub-bottom profiling devices (Stanton et al. 2010, Stanton et al. 2012). These broadband spectra could be used to determine the size of mackerel in schools. This project involves the adaptation of a sub-bottom profiler recently acquired by Marine Scotland Science (MSS) to work as a low frequency echo sounder, and applying the concepts developed by Stanton et al. (2010) at the Woods Hole Oceanographic Institute (WHOI) to provide a set of analytical tools including a fish sizing algorithm. It will be a "significant advance over existing designs" as asked for in the call. The resulting tools will then be used in subsequent future projects (Figure 1) to test the new device and sizing algorithms during the mackerel fishery (e.g. in autumn 2015).

There are additional benefits to developing a broadband system to characterise various other objects in the marine environment. One of these might be to distinguish Norway pout schools from herring schools which may also help the pelagic fleet target herring. The latter feature will also help MSS in their acoustic surveys for herring and have the potential to provide an additional abundance index for Norway pout. Other potential applciations are discussed in Section 4.

1.1 Project rationale

The mackerel fishery in northern Europe targets a high value, larger size fraction of fish for human consumption. Although the minimum landing size for mackerel is 30 cm in the North Sea and 20 cm in other areas, prices are higher for larger fish of 35 cm and more. Consequently, there has previously been evidence of either: high grading, discarding of fish in the sorting systems of factory vessels (Borges et al. 2008); or slippage, discarding of fish en masse prior to being hauled in from the nets of pelagic trawlers (Huse and Vold 2010). The European Commission's forthcoming landings obligation could jeopardize the economic performance of this fleet by forcing fisheries to land mackerel of a size smaller than the higher market price of the larger individuals. This policy came into effect for this fleet in January 2015. The problem of slippage is also relevant to the industry's continued certification of its produce: in 2011 the Marine Stewardship Council certified the Mackerel Industry Northern Sustainability Alliance (MINSA, which Scotland's mackerel fishering industry is a part of) as sustainable; this has been suspended since 2012 due to the disputes with Iceland and Faroese (Hannesson 2013). With a resolution to the latter dispute in sight, the focus wil return to other aspects important to accrediatio which include slippage and its mitigation. There is, therefore, a need for the industry to be able to determine the size of individual mackerel within a fishable school. Ideally this should take place before fishing operations take place, to avoid catching fish of an inappropriate [small] size. Some of the measures currently available to fishers to determine the size of fish prior to fishing (e.g. jigging, which is an automated form of multiple line fishing) are ineffective.

1.2 Current scientific and commercial practice

The techniques currently used in surveying fish are largely based on the use of single beam, narrowband echosounders, although in the last decade or so, multifrequency methods (Korneliussen et al. 2008) have become ubiquitous, and multibeam sonars are also used extensively, if not quantitatively (Gerlotto et al. 2003, Guillard et al. 2011). The use of many (typically 3 to 6 at frequencies of e.g. 18, 28, 50, 120, 200 and 333 kHz) narrowband frequencies allows for better identification of the backscattered signal (Lavery et al. 2007), but this can be improved by the use of broad band systems which sweep throughout the frequency range. Broadband echosounder systems have been developed as bespoke systems (Simmonds et al. 1996, Zakharia et al. 1996), but until recently, have not been available as commercial products.

1.3 Theoretical basis for mackerel sizing

The next generation of Simrad echosounder, long the industry standard in fisheries acoustics, will be a broadband device: however, this is still not available, and when it arrives will be limited to the higher frequencies (greater than ~20 kHz). However, there is a system on the market, supplied by Edgetech as a sub-bottom profiler, which has been adapted for use as a broadband sonar (Stanton et al. 2010). This has the further advantage of operating to low frequencies (greater than ~1 kHz) which allows for resonance peaks of fish with swimbladders to be captured and the turning point between Rayleigh and geometric scattering to be pinpointed (see Lavery et al. 2007, their Figure 1). It is this key feature which we aim to capture in this project which is potentially indicative of mackerel (fish) size (see Figure 2).

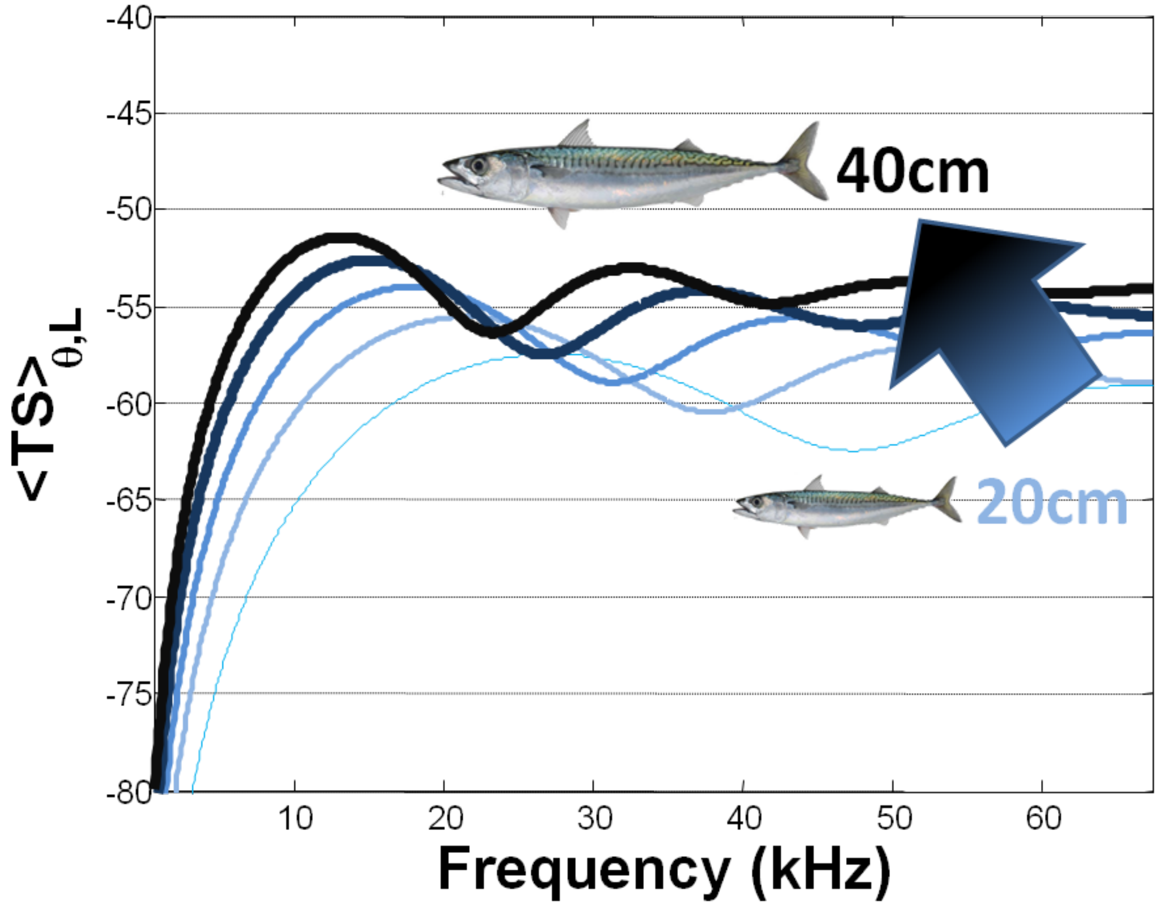

Figure 2 Backscattering (mean Target Strength, <TS> dB) at 1-70 kHz, by mackerel shaped spheroids as determined by an acoustic scattering model (DWBA). Curves represent scattering from a spheroid of average length 20, 25, 30, 35 and 40 cm (larger sizes represented by progressively darker and thicker lines), each with a coefficient of variation of length of 10%, and averaged over a 20° standard deviation in tilt angle. The feature of interest is the initial turning point on the curve (transition from Rayleigh to geometric scattering) which occurs gently (shallow slope) and peaks at 30 kHz for small fish, but rapidly (steep slope) and peaks at 15 kHz in large fish. Model code supplied by Dr Dezhang Chu, NWFSC, NOAA Fisheries, USA.

1.4 Project Objectives

The goal of the project was to develop tools to measure broadband scattering spectra at sea, for use in a potential sizing algorithm, ultimately to enable fishermen to determine the size of mackerel prior to capture. Examples of these spectra are given in Figure 2, where each line represents a spectrum from a (theoretical) assemblage of mackerel at a certain size. This goal was achieved by the following three objectives:

Objective 1. **Adaptation of the Edgetech sub-bottom profiler**

Adaptation of the Edgetech 3200 sub-bottom profiler. The raw data from this device will be interpreted to allow it to serve as a broadband echo sounder, processing whole water column echoes. This will be achieved with the assistance of the WHOI. WHOI have experience in using this device in this manner and are willing to share data processing routines (software) to transform the broadband echoes using pulse compression processing. In the early part of the project, the research team will travel to WHOI and be trained to adapt the device. The training will also cover calibration techniques (to be carried out locally in future phases, as described above) and analytical techniques (see objective 2 below).

Objective 2. **Development of analytical software.**

The WHOI software will be adapted and augmented to produce volume backscattering strengths (VBS) as a function of frequency (1.5 kHz to 60 kHz) – broadband spectra. These will also be available at any chosen narrowband frequency, and then resolved vertically according to pulse duration and frequency, and horizontally according to pulse repetition rate and vessel speed. This will produce two dimensional echograms of objects such as fish schools which scatter sound in real time with vertical resolutions of the order of a few cm to a maximum of 20 cm at 1 KHz. Crucially, the software will include facilities to produce broadband spectra of any area selected on the echogram.

Objective 3. **Development of preliminary fish sizing algorithm.**

Raw data from the sub-bottom profiler will be collected during a research cruise in October 2014 from schools of mackerel of known size. These will provide the data for tasks 1 and 2 (above). Once the above tasks are complete, then the broadband spectra from mackerel schools will be fit to theoretical scattering models to determine fish size. A distorted wave born approximation (DWBA) model will be applied using scattering model parameters fitted by a Bayesian approach to account for parameter uncertainty and to incorporate prior knowledge. This will be done on a standard PC based on programming routines in the open source software language R which UNIABDN already has.

2 ADAPTATION OF EDGETECH SYSTEM

2.1 SIGNAL GENERATION AND DATA COLLECTION

2.1.1 System description

The system to be adapted was an EdgeTech 3200 sub-bottom profiler, currently configured for seismic surveys. Its primary function by design is producing high-resolution images of the sub-bottom stratigraphy in bodies of water. The system, purchased by Marine Scotland Science (MSS) has four transducers as detailed in Table 1: henceforth this is referred to as the MSS Edgetech 3200 system. A picture of the system during a test calibration deployment at the Woods Hole Oceanographic Institute can be seen in Figure 3.

Table 1. Specifications of the transducers contained in the MSS EdgeTech 3200 system.

Manufacturer	**EdgeTech**	**EdgeTech**	**Airmar**	**Airmar**
Model Designation	KT-0504 (Shamu)	KT-424	M1192 Custom housed unit	M159 Custom housed unit
Centre frequency (nom)	3.5 kHz	10 kHz	35 kHz	50 kHz
Bandwidth (nom)	1 - 5 kHz	4 - 24 kHz	25 - 45 kHz	42 - 65 kHz
Circular Beamwidth (nom)	25 deg.	15 deg.	19 deg.	20 deg.
Transmitting response (dB re 1uPa/V) at 1m	158	160	170	166
RMS power	2 kW	2 kW	1 kW	1 kW

Figure 3. Marlab EdgeTech 3200 being hoisted from its storage box during a test calibration procedure.

The sections below describe the use of a system to analyse volume backscatter information from acoustic data of fish. They describe the entire process including signal generation, data collection and analysis. Further information on the structure of the processing programs can be found in the Appendix A, while code examples can be found in Appendix B. A data flow diagram is shown in Figure 4, showing the entire structure of the collection and processing of data.

Preparation for data collection consists of generating pulse files and downloading them to the towfish unit. When the unit is deployed EdgeTech's proprietary software (JSTAR) is used for data collection (files are stored as *.jsf). The section below on signal generation covers generating and mangling (breakup and recombination) of pulses. Subsequent sections describe the use of JSTAR for playback and recording of data files.

The processing of data involves running several scripts written in Matlab code, including a GUI and command-line input. Figure 4 shows a data flow diagram of the entire process.

2.1.2 Signal generation

Pulse generation is done through a Matlab GUI script. The steps below detail the process of generating pulse files.

<u>It is strongly advisable to make a copy of the pulses used as template. It is very easy to overwrite files using this program.</u>

1. Open matlab. Run PulseGen.p. Make sure PULSER.EXE is in the same directory as PulseGen.p. This will open a GUI interface like the one seen in Figure 5.

2. Load (press yellow "Load .ppf File" button on top line) a .ppf file. Make changes to this file and save with a different name and pulse ID[1]. By default, saves file in the directory in which the original .ppf was opened.

3. Important parameters to change and keep track of: "Center Frequency kHz or -F0" recommend use the -F0 option as start frequency in kHz (e.g. -35), "Bandwidth kHz or -Fn" recommend use the -Fn option as end frequency in kHz (e.g. -70), "length (ms)", "Pulse ID" making sure it is unique, filename (*WHOI/Pulses\A1_35_70_2ms_00* in example shown here), "Select DDC template" these parameters control the gain. The gain (independent of spherical spreading) defaults as set by EdgeTech are 290 2000 32000 10.4 which give a linearly increasing gain. This should be modified to 200 7000 7000 1, which gives a flat gain response. Another important parameter is if the signal is created in temporal or frequency space (TX Type). Toggle between options 2 and 3. For longer signals use 3: FChrp for shorter signals use 2:TChrp.

4. Once all the parameters have been entered, press the yellow "Generate Pulses" button <u>which also saves the file</u>.) This generates a .spf file and two figures with a number of subfigures showing the generated pulse. If pulse looks as desired, close the program by killing the window. The .spf file is the file to be transferred to the towed unit, unless the file is to be mangled (shared with another channel, as is the case for the two AirMar channels) at which point additional steps are necessary. See section below.

[1] Pulse ID numbers have no inherent meaning. They are embedded in the collected data files to identify the pulse used during further processing. It is advisable for the researcher to come up with and consistently use ping IDs that help to identify and keep track of them.

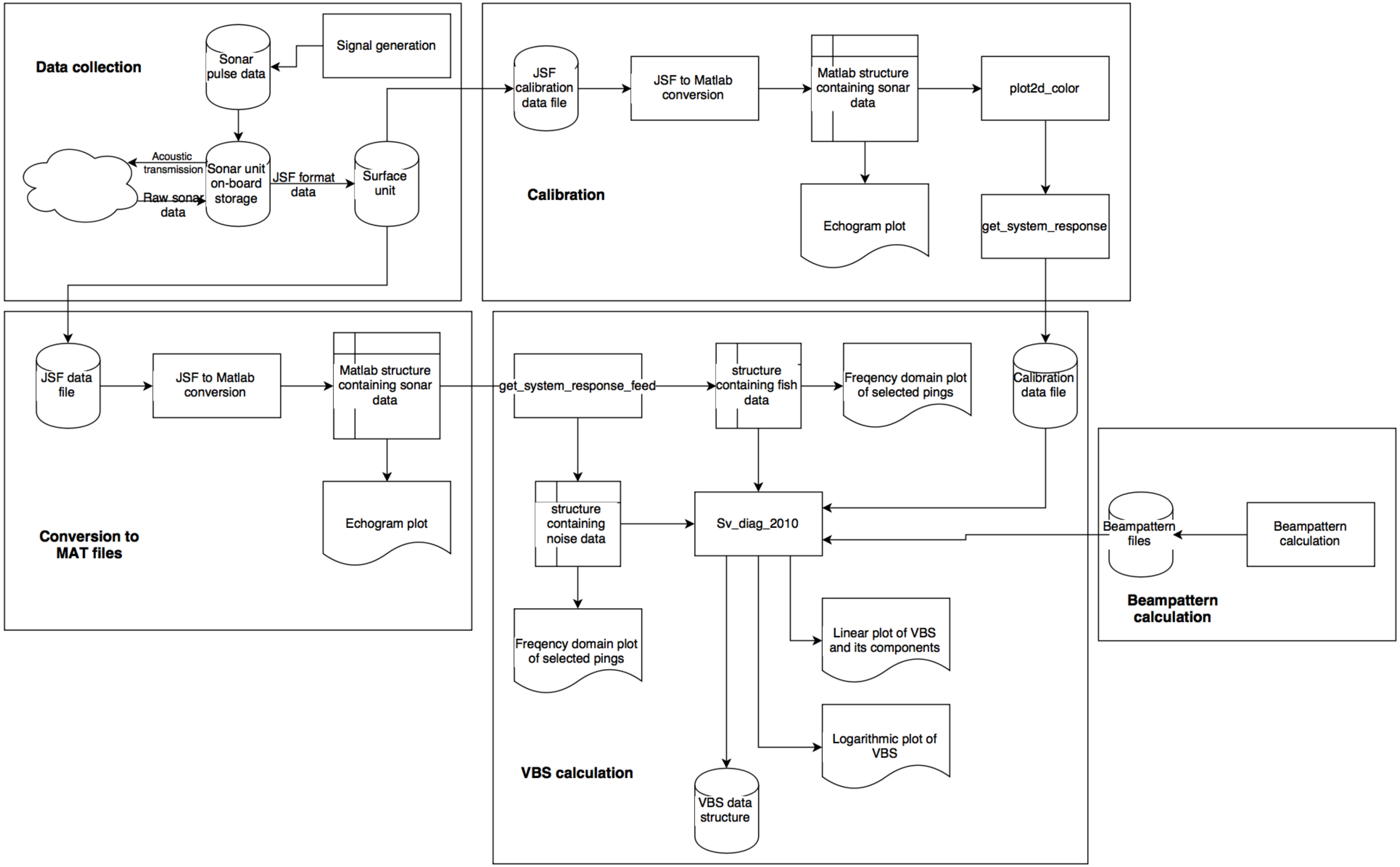

Figure 4. Data flow diagram for the EdgeTech 3200 system covering data collection and processing.

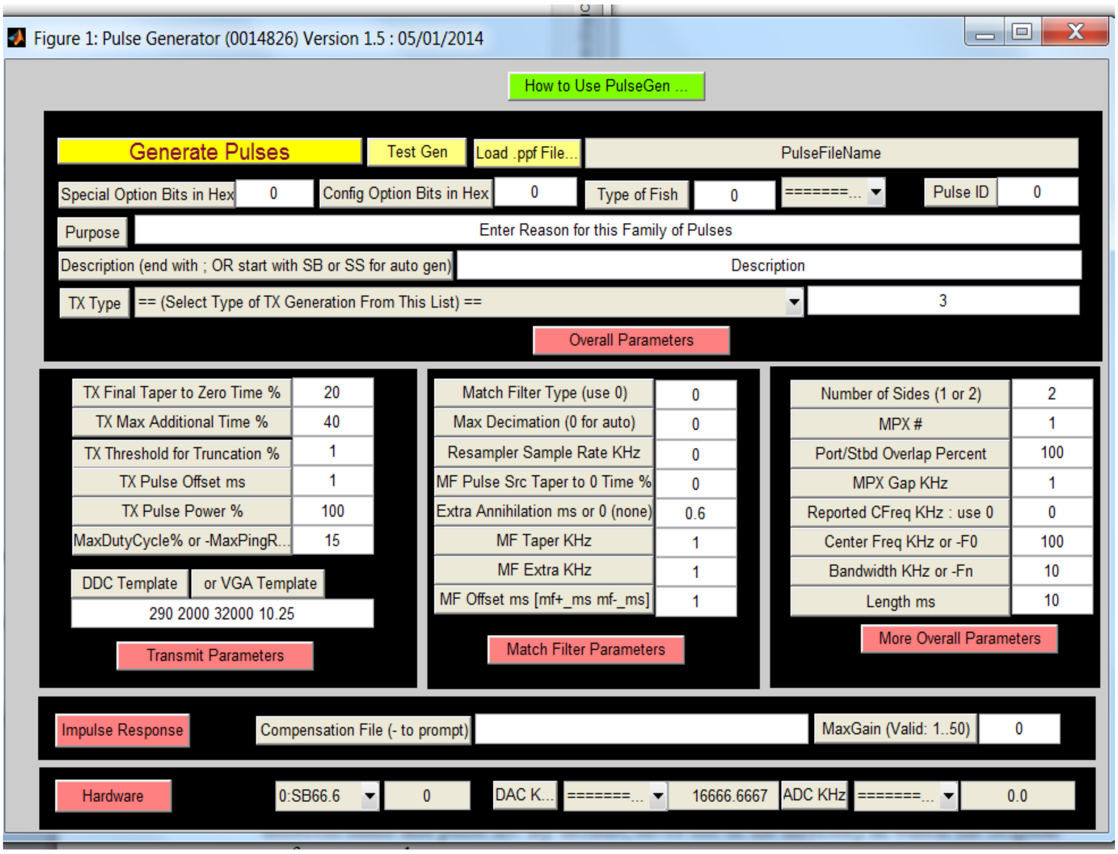

Figure 5. GUI interface of program used to generate signal files for MSS EdgeTech 3200

5. Open pulser.exe (double click on "PULSER.EXE") to generate text files that are used by the Matlab analysis code, this will bring up the interface seen in Figure 6. <u>These are not used during data collection.</u> Load the desired .spf file, and select conversion to ASCII, with headers. CONVERT. EXIT. This generates the following files: filename.pfh, filename.R0, filename.R1, filename.T0, filename.T1, filename.T2. These files will be used in further processing stages.

2.1.2.1 Mangling of pulses

'Mangling' is a term used to describe the process of combining two pulse files into a single one. This is necessarily used for the AirMar Low and AirMar High transducers. They share a single channel and only one of them is fired per ping sequence (additional details in section 2.1.3.2).

Open Matlab and run WSEpulse. This opens a window which asks you to load an existing .wse file[2]. This will populate the fields and give an example of the settings, as seen in Figure 7. You can press 'Cancel' and enter all values manually. Enter the output (mangled) file name and the two files you want to mangle. Take care to input the High/Low AirMar pulses in the correct order. You need to enter a filename even if you end up using option 0 or 1 (that is, transmit on one channel only). Press 'OK' to run the program. Run it twice to ensure Pulse ID is set correctly.

[2] These are generated by WSEpulse upon mangling, and are essentially a record of settings used in that instance.

Finally, update the PulseID_filename.txt file to reflect changes using the previous entries as a template.

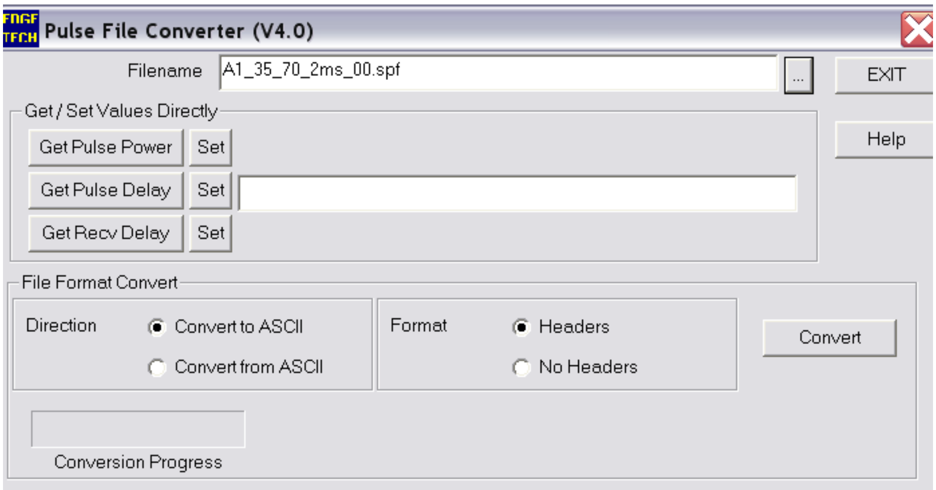

Figure 6. Pulser program used to convert EdgeTech 3200 pulse files into ones compatible with the Matlab based processing software.

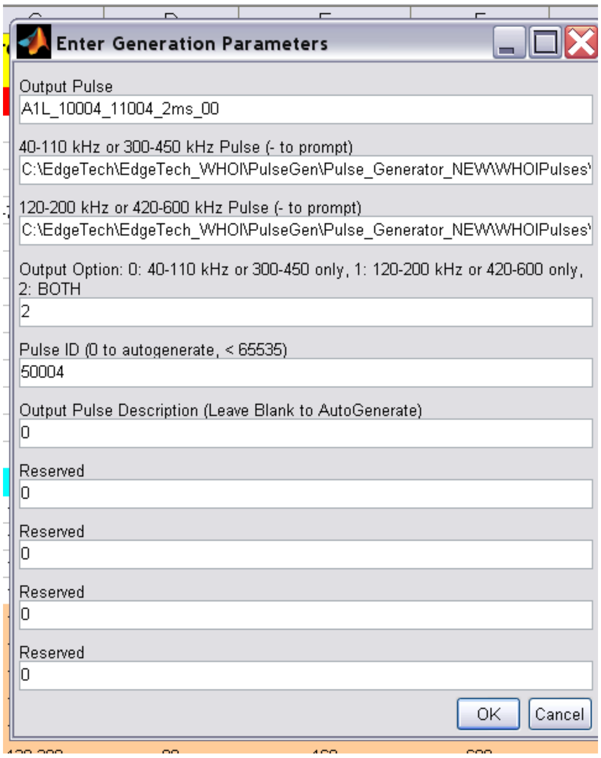

Figure 7 WSEPulse program, used for combining two AirMar pulse files into one in a process called 'mangling'.

2.1.2.2 Transfer of files to towfish

Use the remote desktop connection provided by EdgeTech: Edgetech.rdp. Copy files in appropriate folders in SSSSonar directory by dragging and dropping. You will be able to verify if this has been done correctly in JSTAR, where the files should be visible in the pulse selection menu.

2.1.3 JSTAR

2.1.3.1 Playback procedure and basic display controls

Once JSTAR is launched, open the control panel through Options -> Control Panel if it isn't already opened. Open the Disk tab, which can be seen in Figure 8. On the Playback Settings panel open a **.jsf** file, or several files (using Ctrl or Shift). Select Auto Repeat and click the Playback button in the upper right. Adjustments to the Playback Rate can be made at any time, including during playback. The above should cause the main screen to become active. The main screen can be seen in Figure 9.

In the main window, the top display should show the pitch and roll data in blue and red (Misc tab shows which is which). The controls on the right allow to zoom in and zoom out of the display.

Below are the actual data displays. By default they should correspond to the subsequent transducers. The vertical axis on the right gives the depth in meters. It can be reset by double-clicking on it, or zoomed in by dragging a box over the desired area. If the data displays are too bright or too dark, they can be adjusted using the gain settings on the top toolbar (blue arrows). Right of the depth axis is the bottom tracker panel, which is generally left unused, except as an aide during gain adjustment. Bottom tracking can be adjusted by clicking on the display, but is best done using the control panel.

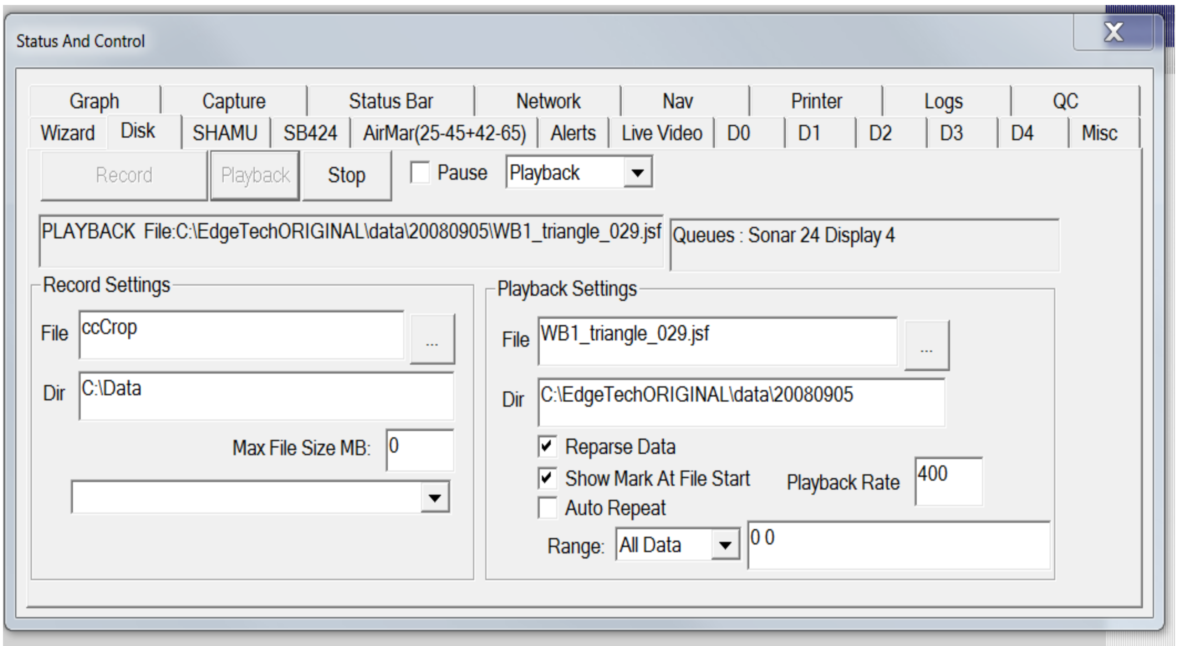

Figure 8. JSTAR control panel, Disk tab.

All the displays can be adjusted and modified using the Control Panel tabs D0 - D4, which correspond to given displays. The channel being displayed can be modified, as well as the type of colour gradient used for the display (in Advanced Options).

The Status Bar tab in the control panel controls what is being displayed on the bottom bar of the main window. Some displays on the status bar may be inactive during data playback.

2.1.3.2 Data acquisition

For data acquisition, it is necessary to have the required pulse files (uploaded to the system) and a sequence for the transducers to ping at. After switching on, the system in the fish will take a moment to boot up.

Once the system is on, JSTAR will try to connect and if it is successful, there will be green message in the bottom right corner of the main window: Network ON.

Once connected, go to each transducer's tab in the control panel, select the appropriate pulse, the desire data window size (range) and make sure the data format is set to 'Analytic'. Figure 10 shows the control tab for the SHAMU transducer.

2.1.3.3 Triggering

The transducers transmit pings in sequence. It is important to figure out a suitable timing that will allow the transmitted signal to return so as not to interfere with the transmission of the following channel. Keep in mind that as mentioned previously, the AirMar transducers share a single channel and switch between sequences. This means that an example sequence could look like this[3]:

Shamu -> 424 -> AirMar Low -> Shamu -> 424 -> AirMar High -> Shamu -> 424 -> AirMar Low …

Select the master transducer and set its triggering to "Internal", and the master to that transducer. Go to the transducer next in sequence and its triggering to "Coupled" and the master to the previously chosen transducer.

Input the delay in milliseconds. Do the same for the remaining transducers.

The ping frequency need only be set for the master transducer, settings for others will be overridden.

Note: Set Power % to 0 for all transducers before proceeding, and after acquisition is over to prevent switching them on accidentally. Running the transducers in air can damage them, especially the higher frequency ones.

To switch on the transducers, either check the "Ping On" box in the control panel (on every transducers tab), or use the main window icons in the top left corner.

[3] This also means that there are less AirMar pings in the output data files and they are numbered differently. Shamu pings numbered from 400 to 600 would be 200 to 300, which need to be taken into account during processing.

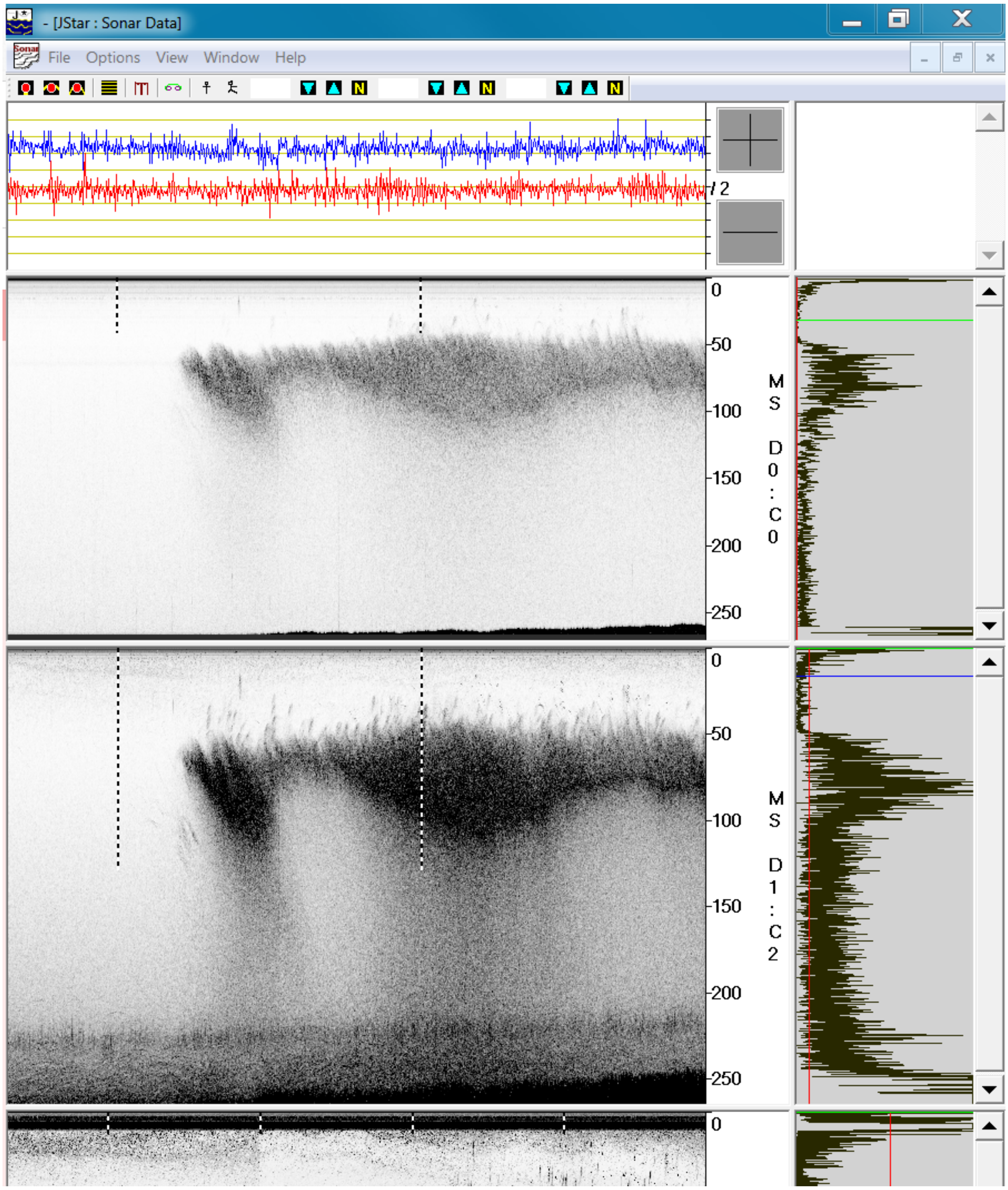

Figure 9. Main graphical display of JSTAR program used to collect and playback acoustic data from the EdgeTech 3200 system.

To start data acquisition, go to the Disk tab. Select the desired directory and filename in the left side of the panel.

Note: Using an underscore (_) at the end of a filename will make JSTAR automatically number them.

It is good to select a maximum file size, as this will prevent the generation of very large files. 100 MB is a good default value, but larger files should not pose any issues.

Ensure the format is set to "Decompressed". Press Record to start acquisition. Use Stop when enough data has been gathered.

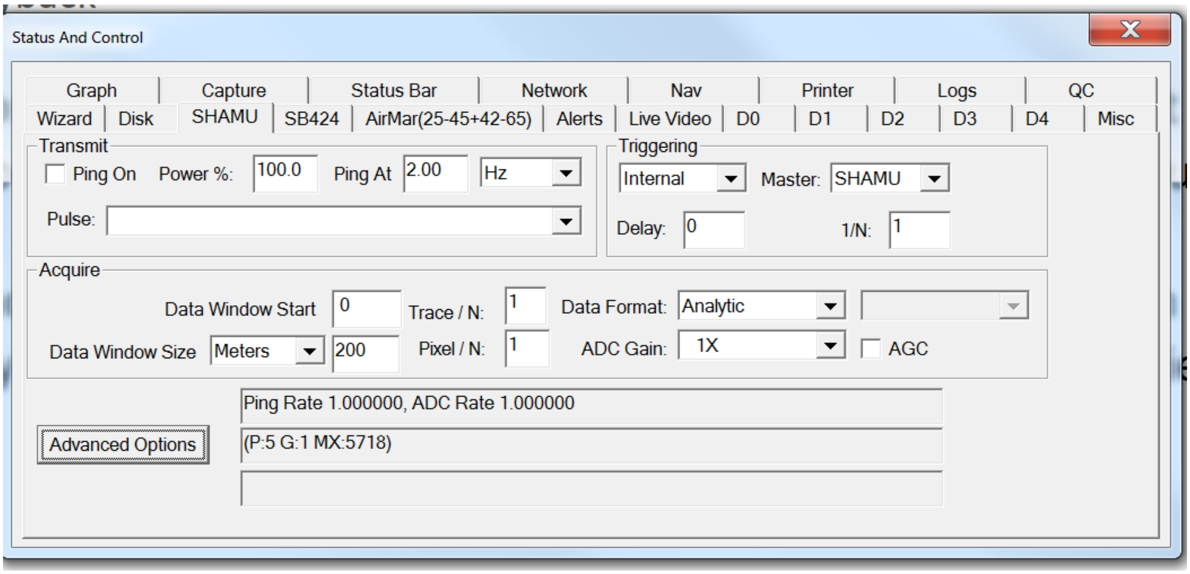

Figure 10. Control panel of JSTAR used to control the for one of the transducers (in this case SHAMU). This is where the pulse is selected, and the ping timings are set. Controls for activating the pinging are also present. Each of the transducers has its own separate set of controls.

2.2 Data Processing

This section describes the use of software used to process the data to produce volume backscatter data. For details on how the software works including data flow and file structure diagrams refer to the Appendix.

2.2.1 Overview of processing

There are two essential steps required before data can processed.

Pulses used need to be placed in the Transmit_Waveforms directory. A file called PulseID_Filename.txt needs to be modified to include the pulse ID and filename.

Line 17 in Proc_EdgeTech should be modified to point to the directory where the program is located.

Calibration curves need to be generated. The process is described in section 3.2.2 below.

The processing itself is a five stage process:

1. Run Proc_EdgeTech to convert .jsf files to .mat files
2. Run get_system_response_feed on the fish data
3. Run get_system_response_feed to generate a noise file
4. Run Sv_diag to calculate volume backscattering strengths

What follows is a more detailed description of the calibration and processing stages.

2.2.2 Overview of calibration

The calibration process is described in Stanton and Chu (2008). A solid 30cm diameter aluminium sphere is hung beneath the 3200, and a set of pings is collected. It is also necessary to collect sea bed data for calibration of the Shamu transducer at low frequencies.

Suspending the sphere is done by placing it in a woven bridle, with as small knots as possible to avoid interference. Photograph 3.2 shows the sphere as it is being attached to the Marlab EdgeTech 3200 system.

In principle, the sphere should be attached at a distance from the sonar that will ensure that there is no interference from the banding artefacts that are present in the collected data for small distances. WHOI staff recommend a distance of about 30 meters if practical, though this should factor in the depth at which the calibration measurements are taken, as adequate separation between the sphere and seafloor is required.

Collecting data for the seafloor calibration is considered the most troublesome part of the process. The data collected should be from a flat, regular section of the seafloor lacking features. Seafloor calibration data is only required for low frequenceies of the SHAMU transducer.

2.2.2.1 Processing sphere data

1. Run Proc_EdgeTech. A Graphical User Interface appears.
2. Make sure 'Tx Pulse Filename' directory is correct.
3. Change 'Ave' to 'none'
4. Select input file (Filename #1 (Cal)). Note - this is a .jsf 'data' file not a 'cal' file. More than one file can be specified, however, be careful of filling memory with too large of an array of pings! Leave memory 'space' for further processing.
5. Select subsystem – Shamu / 424 / AirMar – low / AirMar – high. Start and end frequencies change automatically
6. Select pings to use – specified (values in boxes) / all pings / File for selected pings
7. Select depth - specified (values in boxes) / Whole Range
8. Data Format - MF Analytic / Raw - generally MF Analytic
9. Ave – set to 'none'

When ready, click 'Start' in lower right of the GUI to start the processing. The following will be observed

- The name of the selected transmit file is displayed in red below the directory.
- The ping number increments.
- On completion, two plot windows are displayed.

This converts the .jsf files for use with Matlab, as well as generates an echogram of the data. The next step is done using a script called plot2d_color:

- run plot2D_color.m
- when prompted zoom into the plotted ping and click 'Yes' in the dialog box that appears
- select a 5m window beginning with the arrival of the sphere echo. This length is necessary to ensure sufficient frequency resolution.

This will select a number of pings, and circle them on the echogram plot generated during the JSF to MAT file conversion (Figure 11). It will also plot another graph showing in red the selected depths for the pings and a diagram of pitch and roll offsets of the pings with their intensity being shown by their colour (the pings selected are circled). An example of this plot is shown in

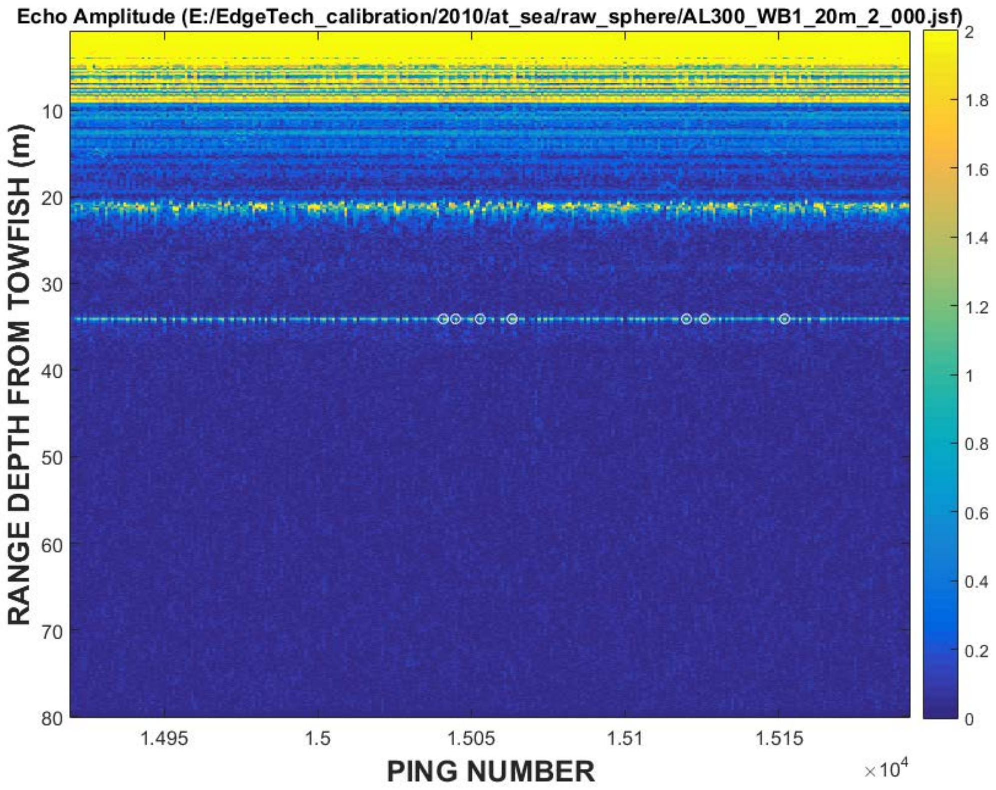

Figure 11. First output diagram obtained running the plot2d_color script during calibration. Selected pings are circled in white. It is important to know the position of the calibration sphere as noise inherently present in the system can produce confusing results (the banding seen from the 20m mark upward is such an artefact).

Figure 12. If not enough or too many pings are selected, the amp_bound variable in plot2D_color.m should be adjusted. Preferably you want as many strong pings as you can, but it has to be a number that can be comfortably handled manually in the later stages.

The absolute ping numbers are output as a variable name ping_indx. The script will also output some results to the console, including a list of selected pings with their amplitudes and detected depths. It also gives the pitch and roll of the system when the ping was taken. plot2D_color has two variables: pitch_range and roll_range that limit which pings can be selected by the script. These are generally set fairly high to prevent only extremely spurious pings from being included. If they were to be lowered, one would also have to modify the pitch0 and roll0 variables, which describe the sensor offset.

Run get_system_response with the following command:

```
>sphere_calib=get_system_response(data,ping_indx,0);
```

Where data is a structure created during the conversion from a JSF file,

This will again ask to zoom in on a ping and select the start of the echo and 5m after it, with the only difference being that it should be done more carefully in this instance. The result of this will be a red curve with, a smooth section where the pings are tightly woven (Figure 13).

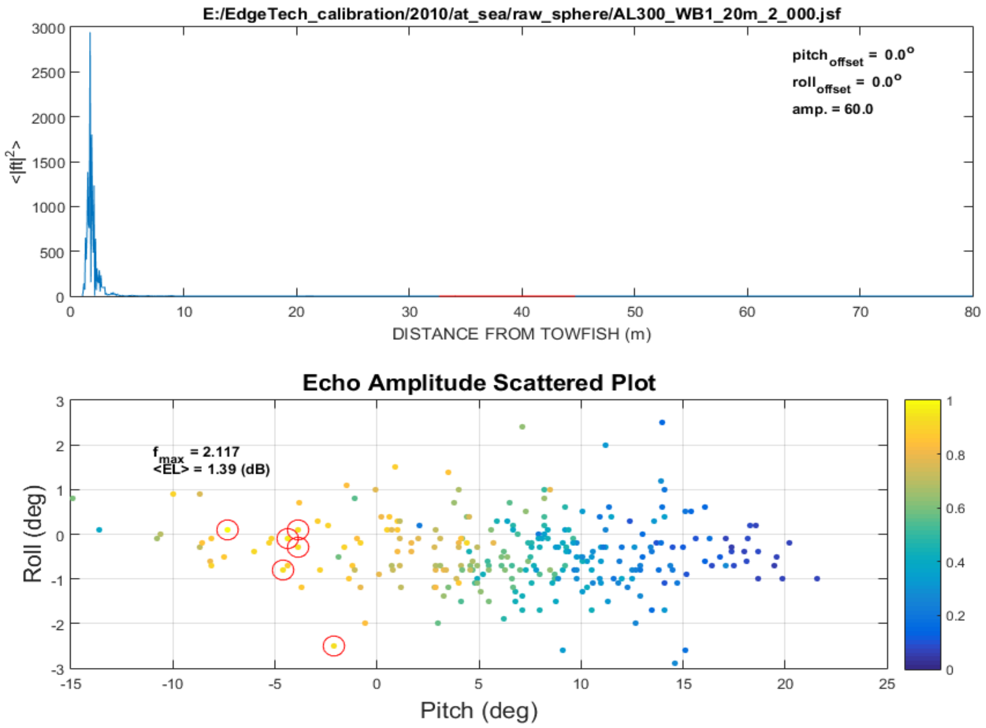

Figure 12. Second output diagram of plot2d_color script used during calibration. The top plot depicts an average ping, with the red marking signifying the data being analysed. The bottom plot show the individual pings plotted according to the pitch and roll of the system, with the colour signifying intensity of the signal. Pings selected for further processing are circled in red.

The ultimate goal is to ensure that the section is as smooth as possible. To do that, individual pings have to be removed and the results checked. This is best done in a new window, by creating a new figure and using:

```
>figure
>plot(data.out1.freq, sphere_calib.Fsys);
```

where "sphere_calib" is the name of the output structure of GSR. Eliminate columns from sphere_calib.Fsys until you get the desired result, taking note of the ping numbers along the way. Remove the ping numbers from ping_indx and re-run get_system_response. Save the result as a .mat file.

2.2.2.2 Processing sea floor data

The processing is essentially identical as for sphere data. The difference is that the depth window begins 5 meters before the seafloor echo and runs until just after the first peak. The primary difficulty is finding a long enough sequence of data with a smooth and flat sea floor.

2.2.3 Processing collected data

The first stage of calculating the volume backscatter spectrum, is identical to the first step of the calibration process. JSF files ned to be converted to Matlab-compatible data structures using the GUI launched using Proc_EdgeTech.m.

The next step involves get_system_response_feed.m The two functions - 'get_system_response' and 'get_system_response_feed' are very similar . They are run from the command line. The first is used during calibration, while the latter is used when processing the data. GSRF is also used to produce noise files used later in the processing.

The inputs for GSRF:

- data – data structure from the GUI
- input_pings – ping numbers of data to be processed (these are relative ping numbers)
- ave_opt – sets averaging display (set to '0')
- dind – depth indices, can be set numerically, eg. [40 60] or using the alternate method below.
- dopt – if set to 2, uses indices above. If set to 1, the depths can be input by the user by clicking on the desired depths which uses 'ginput'

The output of GSRF should be saved as a variable or file, eg.

```
>noise=get_system_response_feed(data,1:10,0,[40 60],2);
>fish=get_system_response_feed(data,1:10,0,[40 60],2);
```

GSRF will draw a white rectangle on the echogram, which is one of the two figures produced by the GUI (as can be seen in Fig. 14). It will generate two figures (Fig. 13): a single ping (with the selected depths lined in red), the average ping, and a frequency spectrum of the selected pings. Figure 15 shows the system response within the frequencies specified in the GUI.

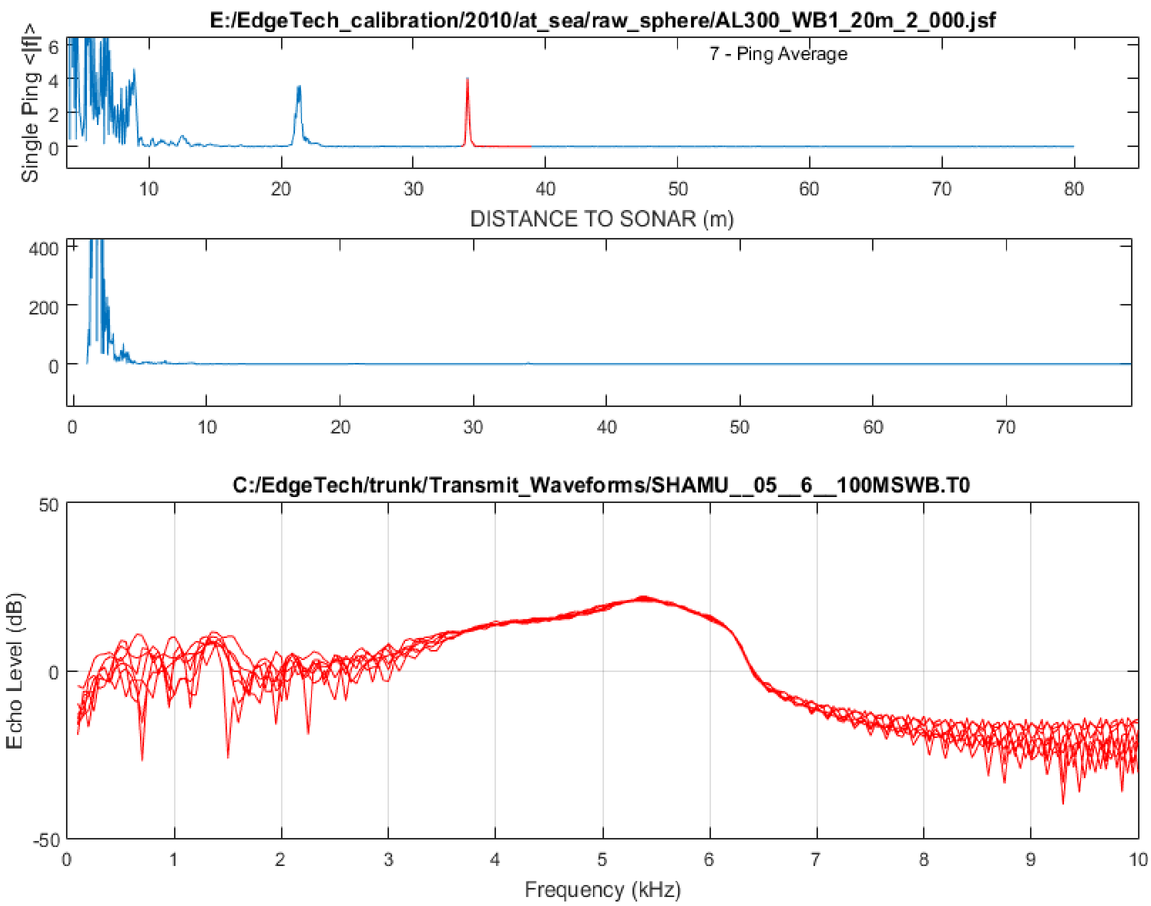

Figure 13. Output of get_system_response, final stage of calibration. The top plots show a single and averaged pings respectively (from the ones chosen by plot2d_color), with the first one being magnified. The bottom show a frequency-domain plot of the selected pings. Of primary interest is the tight grouping of pings between 3.5 kHz and 6.5 kHz – the aim of the final selection is to get this as smooth as possible.

GSR is used in the calibration and its use will be described in section 3.

2.2.3.1 Setting up a noise reference file with GSRF

A section of the echogram where there are no fish is found. The sonar must be at the same depth as the fish data. The range to the sea floor may be different but this is corrected for in the VBS processing. A noise window is selected which is equal to or larger than the fish data window and the same depths. *Insert a echogram with a white box.*

The noise pings are averaged as are the fish pings.

2.2.3.2 Volume backscatter calculation - Sv_diag

Sv_diag calculates the volume backscattering of the area selected through GSRF. It requires calibration data (for a given tow depth from GSR), fish data (from GSRF), and noise data (from GSRF). There are four Sv_diag files, each corresponding to a transducer (Sv_diag_Shamu, Sv_diag_424 etc.). Use the appropriate Sv_diag script for the data you are processing (transducer selection is done during JSF -> MAT conversion). For example:

Run Sv_diag_shamu with the following command:

```
>[Sv]=Sv_diag_2010(ppfish, dep_in);
```

if using the example commands from the start of section 2.2.3

```
>[Sv]=Sv_diag_2010(fish, noise);
```

where [Sv] – is the name of the output structure
Ppfish – is the name of the output structure from GSRF containing fish data
Dep_in – is the name of the structure containing noise data output from GSRF

Depending on the transducer, the script will brind up one or two consecutive prompts asking for a file input. As labelled, you should select an appropriate calibration file(s). **All** transducers require a sphere calibration file. **Shamu** additionally requires a seafloor calibration file.

The result of Sv_diag processing are two plot windows (Figures 13 and 14). The first (Fig. 13) is a complex diagram with numerous curves. The second (Fig. 14) contains only the VBS with the frequencies plotted on a logarithmic scale. The various curves are identified on the legend of the first window, and are as described below:

- sphere(data) – calibration data from sphere
- seafloor(shift=x) – seafloor calibration data, shifted by x to fit calibration curve
- hybrid/seafloor – the part of the seafloor calibration that is actually used to compliment the sphere data
- TS(sphere pred.) – theoretical target strength of sphere
- Sph-TS – sphere data minus TS
- hybrid+PSI – complete calibration data with beampattern (see below)
- fish9320 – raw fish data. 9320 indicates the first ping number
- noise – noise used by Sv_diag
- PSI – beam pattern of transducer
- fac_r – spreading factor
- fish-hybrid – fish data with calibration applied
- Sv(fish-hybrid-PSI+fac_r) – volume backscattering strength, the final result

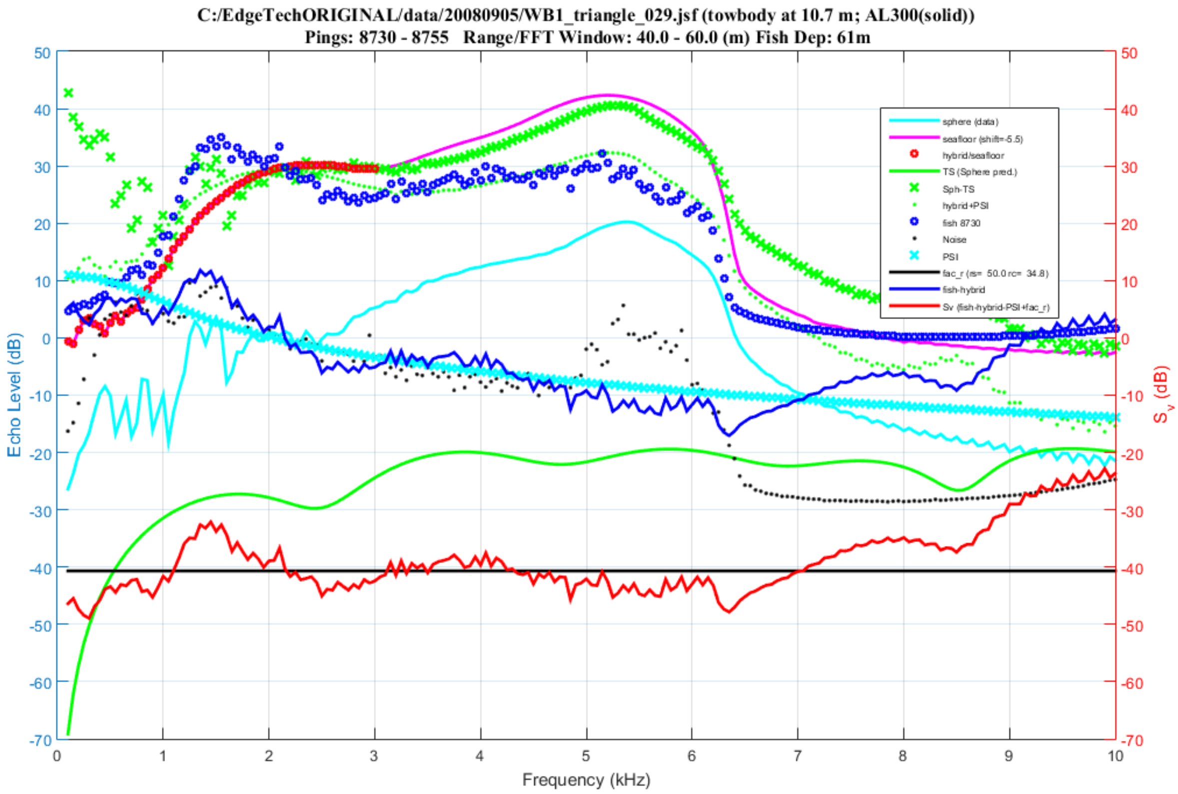

Figure 14. First output of Sv_diag_2010. This plot shows details of the various component elements that go into the final VBS result. The VBS result itself is the solid red line.

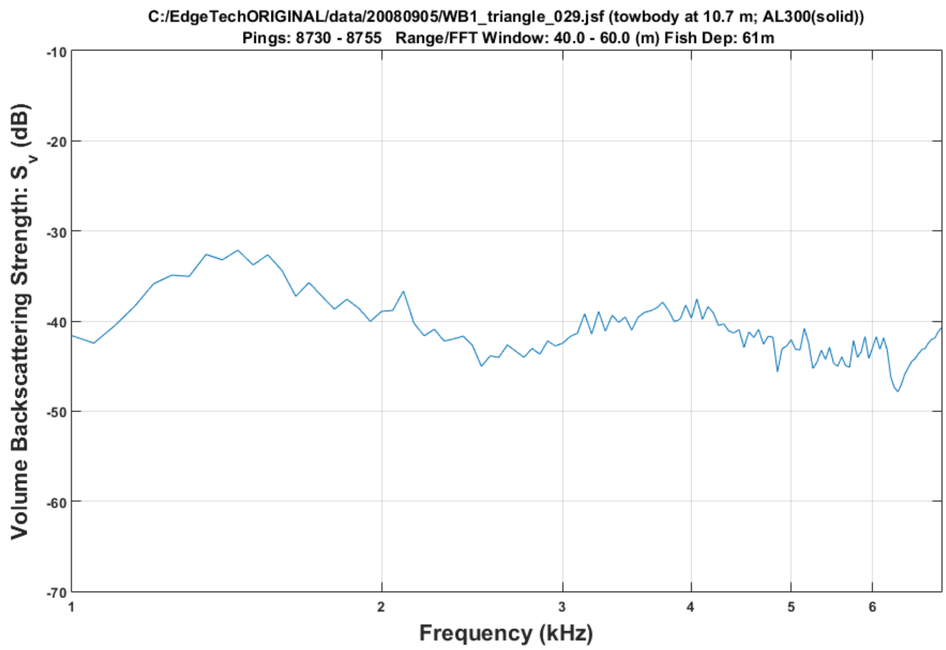

Figure 15. Second output diagram of Sv_diag_2010. Plot of VBS fopr the selected region for one channel.

2.2.4 Producing a full spectrum volume backscatter diagram

The current software setup is optimized for single-channel usage. It has been developed with this mindset from its inception. Furthermore, almost all changes made to it throughout the years were focused on using the Shamu transducer specifically. This means that a significant amount of work would be required for it to process all channels in an efficient manner, including reworking data structures used, code and modifying the currently used GUI.

Despite this, it is possible to obtain a full-spectrum VBS result. Figure 16 below shows an echogram made using data shared by WHOI. The two white boxes indicate areas used for analysis. The left one is used to estimate noise present in the system at the specified distances from the towbody. The right one encompasses the fish data to be analysed.

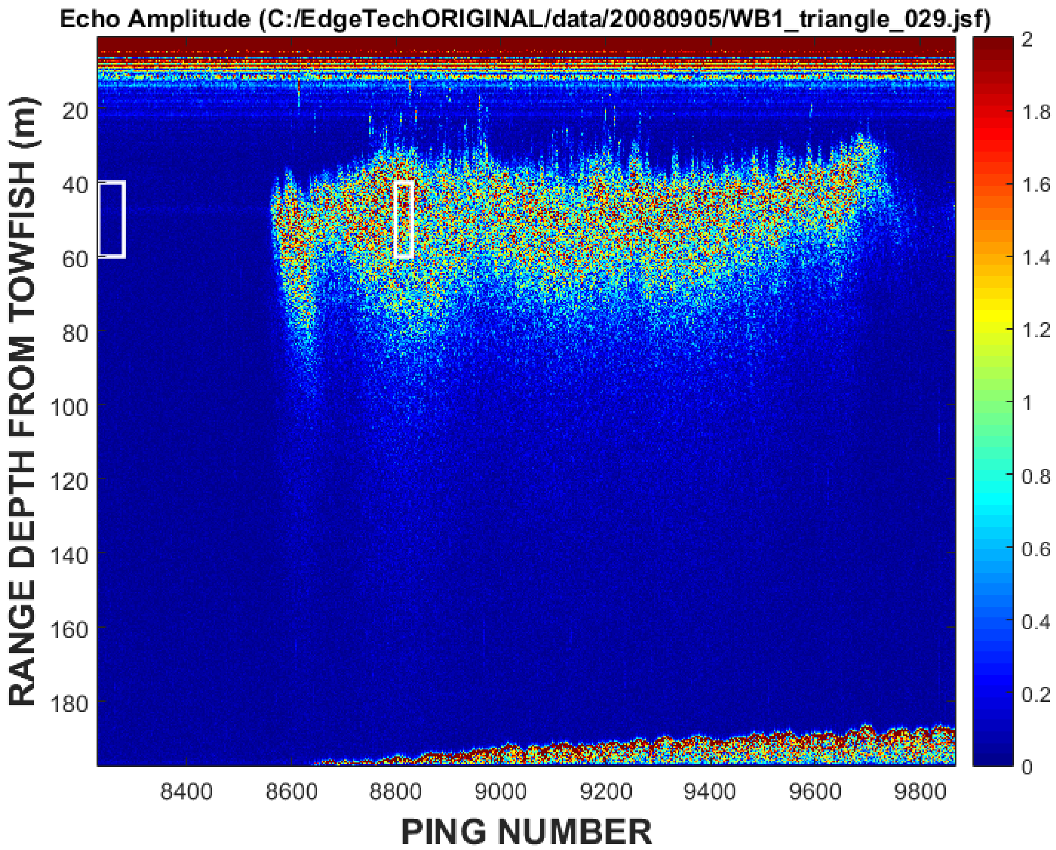

Figure 16 Echogram of a fish school. The white boxes signify data chosen for analysis, with the left one being the source of noise data, and the right one providing fish data.

Figure 17 shows the output result VBS spectra for the four transducers. This is the preferred way of displaying data from multiple channels in this instance. The WHOI system from which the data is taken has a frequency gap between 17 kHz and 30 kHz, while the two upper channels have a significant frequency overlap which makes a continuous line plot not as clear. Figure 18 shows a continuous spectrum plot of data for all four transducers.

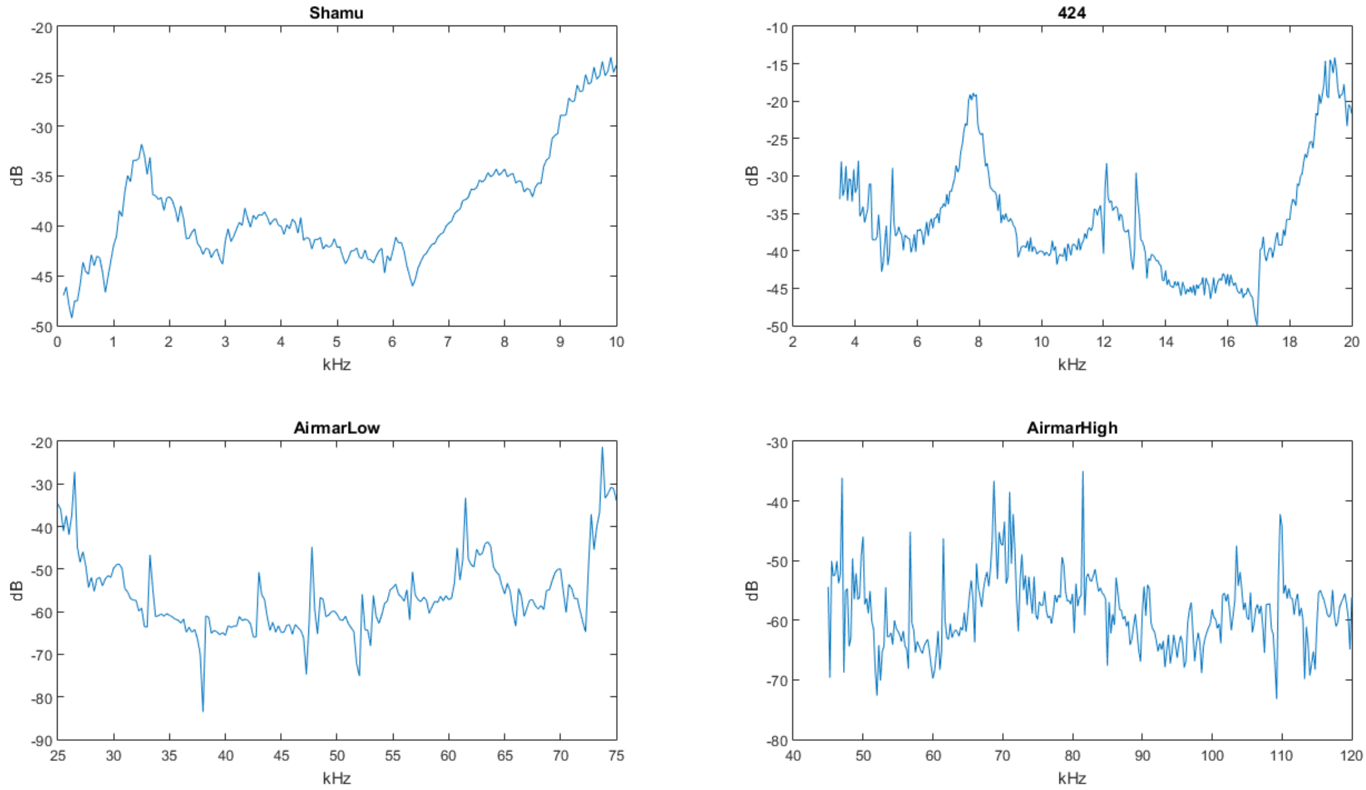

Figure 17 Volume backscatter spectra for all four transducers. Data from a dense school of fish, as collected by WHOI.

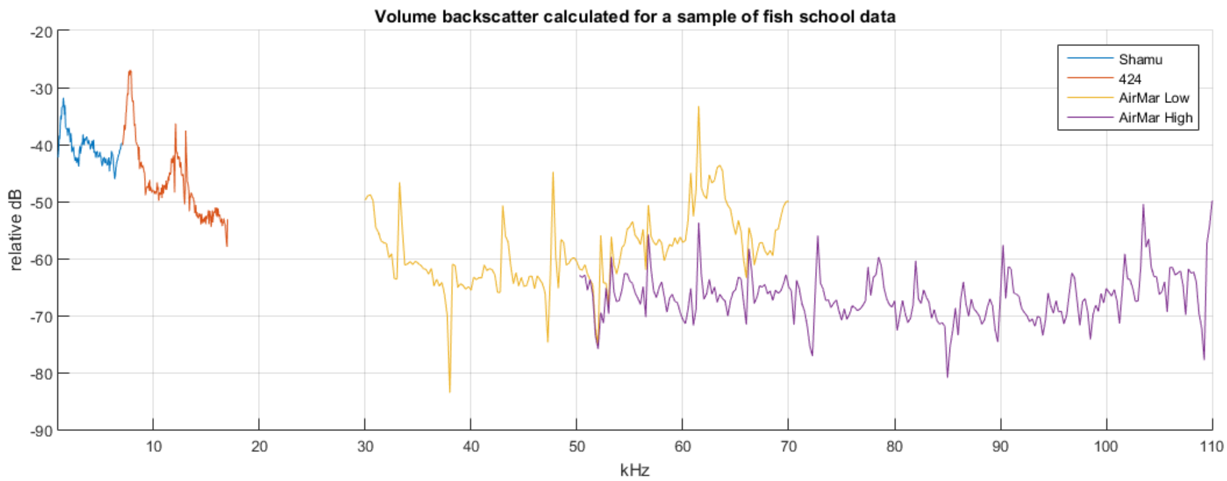

Figure 18 Continuous VBS spectrum for fish school data, taken from the white box on the right in Figure 16.

These graphs serve to demonstrate that it is possible to obtain frequency-response information from acoustic data from all of the transducers used in the system using the currently available techniques. As mentioned previously, there is more work to be done to make this process efficient and user-friendly. There is also a need for further testing of the processing at higher frequencies, since the current software, data collection and calibration procedures have only been extensively tested with the Shamu transducer.

3 SIZE ESTIMATION ALGORITHM

3.1 BACKGROUND

The data collection and processing stages outlined in the previous chapters produce measured data comprising the average backscattering strength in the selected volume as a function of frequency (Fig. 18). Size is estimated by inverting this measurement using the scattering model to simulate scattering spectra. Figure 2 and Figure 19 show simulated spectra for different sizes of fish.

Two inversion methods - least squares fitting and Bayesian inference using the MCMC (Markov Chain Monte Carlo) algorithm - were applied to simulated data. Simulated data were used in the absence of any data collected on mackerel (the fishery operates in January and October, which were outside the time period of this project). The first inversion method gives a single value for each parameter being varied. The second takes account of prior information about variables in the optimisation and produces probabilities for a range of values of the parameters. Both processes are iterative, starting from initial assumptions. It was found that runs of the MCMC algorithm were time consuming but that the least squares algorithm converged very quickly. Both converged from inaccurate initial estimates. The least squares algorithm was robust to differences between assumed values for parameters in the model and in the fitting.

3.2 SIMULATING BACKSCATTER SPECTRA

The simulation for the acoustic backscatter uses the DWBA model to calculate the scatter from a school of fish with randomly distributed lengths and tilt angles. Mackerel are represented as prolate spheroids with density and speed of sound close to those of water. Acoustic scattering is dependent on aspect angle, but the assumption about shape limits the variation due to angle. Only tilt needs to be considered for an echo sounder. The distributions of lengths and tilt angles were modelled by Gaussian distributions. Recent measurements of the lengths of Atlantic mackerel caught with trawl and rod and line show that the distribution is symmetrical about a single peak (Scoulding *pers. comm.* IMARES, University of Wenningen) and the Gaussian assumption is reasonable. Video measurements of tilt angles show wide variation in mean angle and distribution (Fernandes et al. submitted). The Gaussian assumption has been used in previous studies (Gorska et al. 2005).

The assumed parameters to generate simulated data are given in Table 2. The simulated curves are shown in Figure 19.

Table 2: Parameters for simulating acoustic backscatter from a school of mackerel

Parameter	Symbol	Value
Density contrast	g	1.04
Speed of sound contrast	h	1.04
Length to height ratio	lhratio	8.5
Speed of sound in water (m/s)	cw	1444
Tilt average (deg)		0
Tilt standard deviation (deg)		20
Number of random samples		100
Average length (cm)	l	20,30,40
Length standard deviation (cm)		2,3,4
Number of random samples		100
Frequency (kHz)	*f*	0.65 to 67.5
Number of bins		1000

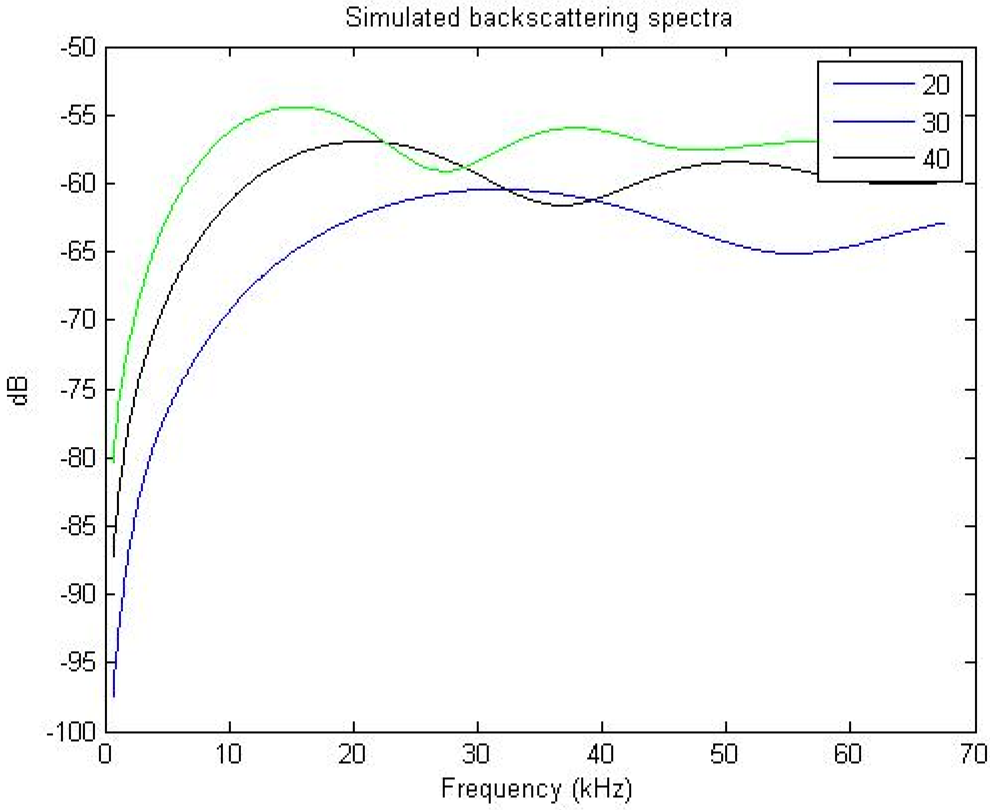

Figure 18. Simulated backscattering spectra for schools of mackerel with average lengths 20, 30 and 40 cm

3.3 Optimisation Algorithms

The least squares optimisation calculates a spectrum with the assumed parameter values and compares it with the measured spectrum by finding the square root of the sum of the squares of the differences between the curves. It adjusts the assumed value according to a search scheme and continues until the curves are sufficiently close. The MatLab function fminsearch was used. This implements the Nelder-Mead simplex direct search algorithm.

The Bayesian approach requires the calculation of the posterior probability that a given set of conditions is in force if a set of data is observed. It uses Bayes theorem which expresses knowledge about the behaviour of the parameters deduced from measurements and past experience. Past experience is expressed both by the prior probability of a set of parameters and a model for the dependence of the data on the parameters. If A represents a set of parameter values and B represents a set of measurements, the probability P(A) of A occurring is known as the prior probability. The probability P(B|A) of taking a particular set of measurements B if the actual conditions A are known is the likelihood. It can be calculated from a model for the physical and measurement processes, in which B is the output and A is the input. Bayes theorem relates these probabilities by:

$$P(A|B) = P(B|A)P(A) / P(B)$$

where P(B) is the probability of a set of measurements no matter what the conditions.

A Markov Chain Monte Carlo (MCMC) simulation with the random walk Metropolis algorithm was used to sample P(A|B) as per (Fässler et al. 2009). The probability P(B) is found as a normalisation constant. A new value is found from the current value by generating a random perturbation whose probability density function (pdf) is the prior distribution.

3.4 COMPUTE HARDWARE AND CODING

The code was written in MatLab. MatLab executes more quickly than 'R' and has the potential for faster execution using parallel processing on a multi-core processor. Using MatLab allowed software developed at Woods Hole Oceanographic Institution to be modified more easily. This is the DWBA calculation which is used by both optimisation methods. The computer was a Toshiba laptop with Intel i3-2350 CPU running at 2.3 GHZ with Windows 7 and 4 Gbytes of RAM.

Preliminary runs showed that the least squares process converged very quickly and parallel processing was not necessary. On closer examination it was found that neither algorithm can be parallelised. For parallel operation, a calculation must not depend on updating previously calculated values inside a loop – the essence of an iterative process.

3.5 TEST RESULTS

Sets of runs were conducted with each algorithm assuming the same values for the stray parameters as for the modelled data. The execution times for the MCMC algorithm were in excess of an hour whereas the least squares fitting algorithm converged in less than a minute. It was found that both converged to the correct value with both poor and accurate initial estimates. No further runs were conducted with the MCMC algorithm. Sets of runs were conducted using the least squares algorithm but assuming different tilt distributions. For these, the initial value for length was taken as 35 cm as the mean length for a school of mackerel.

3.5.1 Least squares

The results for the least squares runs including those with different assumptions for the stray parameters are shown in Table 3.

Table 3: Length estimation by least squares fitting

Starting value for length = 35cm							
True length (cm)	Length std	Tilt pdf	Average tilt (deg)	Tilt std (deg)	Estimate (cm)	Number of iterations	Time (s)
20	0.2	normal	0	20	20	24	35
30	0.3	normal	0	20	30	21	28
40	0.4	normal	0	20	40	21	26
20	0.2	normal	7.5	30	20.004	24	36
30	0.3	normal	7.5	30	30.016	21	29
40	0.4	normal	7.5	30	40.022	21	27

3.5.2 MCMC

Figure 19 shows the MCMC algorithm converging on the true length of 30 cm from an initial estimate of 35 cm The parameter values are as in the first three rows of Table 2. The run time for 6000 iterations was 5 hrs 32 min and an estimate for the time to converge is approximately 1 hour 20 mi.

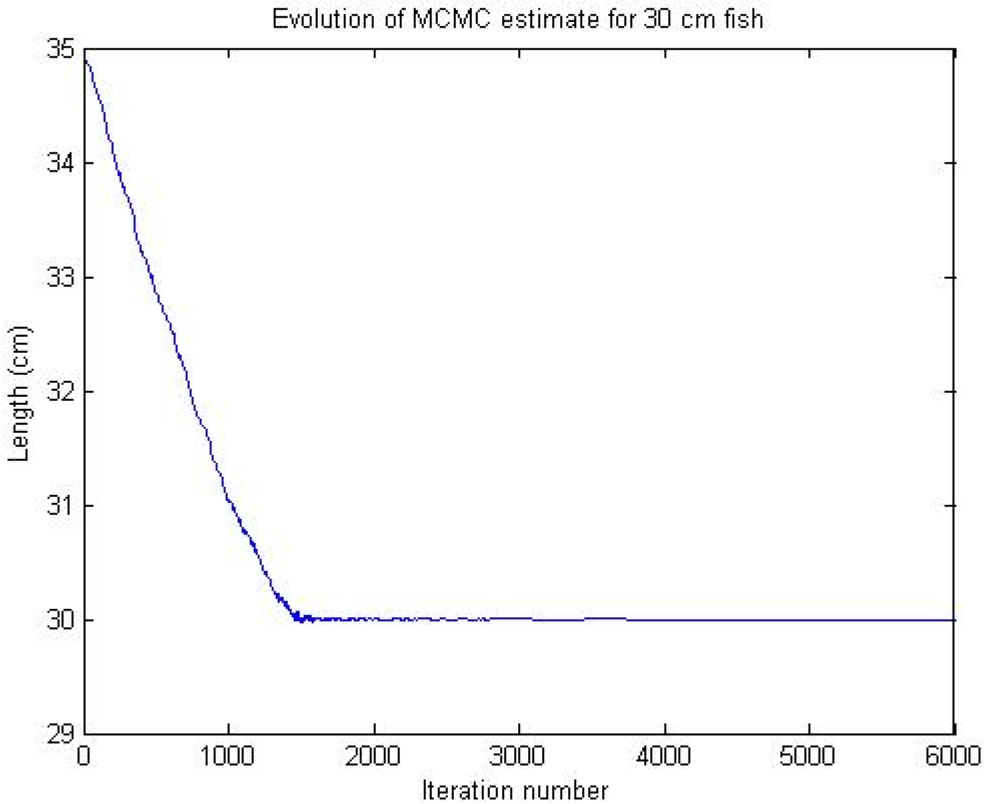

Figure 19. Estimates of the length of a 30 cm mackerel from simulated data using an MCMC sampling strategy .

3.6 Scope for further investigation

The values given for mackerel characteristics in Table 3 are those generally assumed, but in some cases no definitive measurements are available. The effect of varying these parameters needs to be investigated. It has been noted that measured tilt angle distributions are not normal. The sensitivity of the results to the shape of the distribution will provide information about the practical usefulness of the scheme. It was found that changing the mean and standard deviation of a normal distribution model for tilt did not have a significant impact on the results.

4 TOPICS FOR FURTHER RESEARCH

This project was the first stepp in the process of identifiying a potential means to determine the size of mackerel remotely prior to fishing. Clearly the next phase of this project, as originally envisaged, would be to collected some real data from mackerel schools at sea, using the methods outlined in Chapter 2 and then apply the sizing algorithms described in Chapter 3. The timing of the current FiS call meant that by the time the project had started (February) the Q1 mackerel fishery had ceased; by its end (August) the Q3 (October) mackerel fishery has yet to begin. We invisage three further phases conditional on the critical next one (Phase 2). Ideally, phase 2 would start immediately after the current project, to prepare for the October fishery and obtain data. Other funding opportunities have therefore been sought to make measurements at sea. Research vessel time has been provided by Marine Scotland Science to enable Phase 2. Phase 2 will therefore collect broadband data from mackerel schools and apply the algorithms to see if the esimated size coincides with the true size as determined by capture (using a pelagic trawl and rod and line). This is a critical phase as it is not known what from the data from mackerel schools will take. If successful, then Phase 3 would be to collect some additional data from pelagic fishing vessels during the fishing season under normal fishing operations.

The following phase of work, phase 4, would then consider the design of an integrated simple system for fishermen to use at sea. Some slimmed down version of the EdgeTech 3200 would be required with limited functionality using the routines described here, presented in a simple graphical User interface. A local sonar manufacturer may be able to build a system that may be tailored to needs. Calibration may be an issue to address but once the system was on the keel, or ideally a dropped keel, then this could be done in the various periods down time the pelagic fleet experience.

Notwithstanding the critical outcome of Phase 2, the equipment and post processing routines describe dhere may have many other applications. Broadband sonar at the frequencies of the device employed here has many other potential applications including: sizing of resonant structures (fish with swimbladders); high resolution target detection; and other species identification. The sizing of resonant structures (Holliday 1972) has several applications. In surveys of aquatic resources, such as herring, this could serve to distinguish small schooling fish (likely to be Norway pout) from larger ones (herring), improving the precision of the survey. There may also be scope to determine the size of herring from the acoustic resonance peak which would improve the precision of the abundance at age estimates.

The higher resolution afforded by broadband systems could also enable better single target discrimination and may, therefore, allow for detection, identification and sizing of demersal fish close to the seabed. This may prove useful in discard mitigation and has the potential for enabling acoustic surveys of demersal fish, particularly when combined with trawl sampling (Jakobsen et al. 1997) to estimate density in the acoustic dead zone (Ona and Mitson 1996). Finally, the unique broadband spectra generated by the system may allow for a host of other targets to be examined and possibly identified (Stanton et al. 2010), including myctophiids (Scoulding et al. 2015), ocean turbulence (Lavery et al. 2003), and the scaterring layers of unknown composition which are prevalent in northern temperate waters during the summer (Mair et al. 2005).

ACKNOWLEDGEMENTS

This work was funded by Fisheries Innovation Scotland under the grant code FiS004. P. Fernandes received funding from the Marine Alliance for Science and Technology for Scotland (MASTS) pooling initiative and their support is gratefully acknowledged. MASTS is funded by the Scottish Funding Council (grant reference HR09011) and contributing institutions.

REFERENCES

Anon (2014). *Scottish Sea Fisheries Statistics 2013*. Edinburgh, Scottish Government.

Borges, L. (2013). "The evolution of a discard policy in Europe." *Fish and Fisheries*: n/a-n/a.

Borges, L., O. A. Van Keeken, A. T. Van Helmond, B. Couperus and M. Dickey-Collas (2008). "What do pelagic freezer-trawlers discard?" *ICES Journal of Marine Science: Journal du Conseil* **65**(4): 605-611.

Fässler, S. M. M., A. S. Brierley and P. G. Fernandes (2009). "A Bayesian approach to estimating target strength." *ICES Journal of Marine Science* **66**: 1197-1204.

Fernandes, P. G., P. Copland, R. Garcia, T. Nicosevici and B. Scoulding (submitted). "“Alternative evidence” techniques for fisheries acoustics, not strictly ground truth." *ICES J Mar Sci*.

Fernandes, P. G., K. Coull, C. Davis, P. Clark, R. Catarino, N. Bailey, R. Fryer, et al. (2011). "Observations of discards in the Scottish mixed demersal trawl fishery." *ICES Journal of Marine Science* **68**: 1734–1742.

Gerlotto, F., P. A. Brehmer, P. G. Fernandes, D. G. Reid, P. Copland, S. Georgeakarakos and J. Paramo (2003). "Application of multibeam sonar in marine ecology and fisheries research: New fields and limitations." *Journal of the Acoustical Society of America* **114**(4): 2299.

Gorska, N., E. Ona and R. Korneliussen (2005). "Acoustic backscattering by Atlantic mackerel as being representative of fish that lack a swimbladder. Backscattering by individual fish." *ICES Journal of Marine Science* **62**: 984-995.

Guillard, J., P. G. Fernandes, T. Laloë and P. A. Brehmer (2011). "Three-dimensional internal spatial structure of young-of-the-year pelagic freshwater fish provides evidence for the identification of fish school species." *Limnology and Oceanography: Methods* **9**(7): 322-328.

Hannesson, R. (2013). "Sharing the Northeast Atlantic mackerel." *ICES Journal of Marine Science: Journal du Conseil* **70**(2): 259-269.

Holliday, D. V. (1972). "Resonance structure in echoes from schooled pelagic fish." *Journal of the Acoustic Society of America* **51**: 1322-1332.

Huse, I. and A. Vold (2010). "Mortality of mackerel (Scomber scombrus L.) after pursing and slipping from a purse seine." *Fisheries Research* **106**(1): 54-59.

Jakobsen, T., K. Korsbrekke, S. Mehl and O. Nakken (1997). Norwegian combined acoustic and bottom trawl surveys for demersal fish in the Barents Sea during winter, ICES. **17**.

Korneliussen, R. J., N. Diner, E. Ona, L. Berger and P. G. Fernandes (2008). "Proposals for the collection of multifrequency acoustic data." *ICES Journal of Marine Science* **65**: 982-994.

Lavery, A. C., R. W. Schmitt and T. K. Stanton (2003). "High-frequency acoustic scattering from turbulent oceanic microstructure: the importance of density fluctuations." *The Journal of the Acoustical Society of America* **114**(5): 2685-2697.

Lavery, A. C., P. H. Wiebe, T. K. Stanton, G. L. Lawson, M. C. Benfield and N. Copley (2007). "Determining dominant scatterers of sound in mixed zooplankton populations." *Journal of the Acoustic Society of America* **122**(6): 3304-3326.

Mair, A. M., P. G. Fernandes, A. Lebourges-Dhaussy and A. Brierley (2005). "An investigation into the zooplankton composition of a prominent 38-kHz scattering layer in the North Sea." *Journal of Plankton Research* **27**(7): 623-633.

Ona, E. and R. Mitson (1996). "Acoustic sampling and signal processing near the seabed: the deadzone revisited." *ICES Journal of Marine Science: Journal du Conseil* **53**(4): 677-690.
Scoulding, B., D. Chu, E. Ona and P. G. Fernandes (2015). "Target strengths of two abundant mesopelagic fish species." *The Journal of the Acoustical Society of America* **137**(2): 989-1000.
Simmonds, E. J., F. Armstrong and P. J. Copland (1996). "Species identification using wideband backscatter with neural network and discriminant analysis." *ICES Journal of Marine Science* **53**: 189-195.
Stanton, T. K., D. Chu, J. M. Jech and J. D. Irish (2010). "New broadband methods for resonance classification and high-resolution imagery of fish with swimbladders using a modified commercial broadband echosounder." *ICES Journal of Marine Science* **67**: 365–378.
Stanton, T. K., C. J. Sellers and J. M. Jech (2012). "Resonance classification of mixed assemblages of fish with swimbladders using a modified commercial broadband acoustic echosounder at 1–6 kHz." *Canadian Journal of Fisheries and Aquatic Sciences* **69**(5): 854-868.
Zakharia, M. E., F. Magand, F. Hetroit and N. Diner (1996). "Wideband sounder for fish species identification at sea." *ICES Journal of Marine Science* **53**: 230-208.

APPENDIX A

PROGRAMS TO OPERATE THE EDGETECH HARDWARE

Program	**Source**	**Use**
Jstar.exe	EdgeTech	Data collection and playback
Pulse_Generator_NEW.zip	WHOI (Lavery)	Pulse generation and mangling software
PULSER.exe	EdgeTech	Files conversion (for Matlab processing)
JSFFileViewer.exe	EdgeTech	Examine contents of .jsf file

The root directory is ..\EdgeTech. EdgeTech software is written in 'C'. The WHOI pulse generator is written in MatLab.

DATA ANALYSIS PROGRAMS

Program	**Use**
Proc_EdgeTech.m	Transcribe data and create echograms using a GUI
get_system_response_feed.m	compute spectrum of fish data
Sv_diag.m	compute Volume Backscattering Strength

The diagram in Figure 20 gives a tree diagram of tructure of functions called by Proc_EdgeTech.

EXAMPLE OUTPUT DATA STRUCTURES

The tables below show some of the data structures created in the course of processing. While the list is not exhaustive, it gives a comprehensive overview of the different structures that the software creates and operates on.

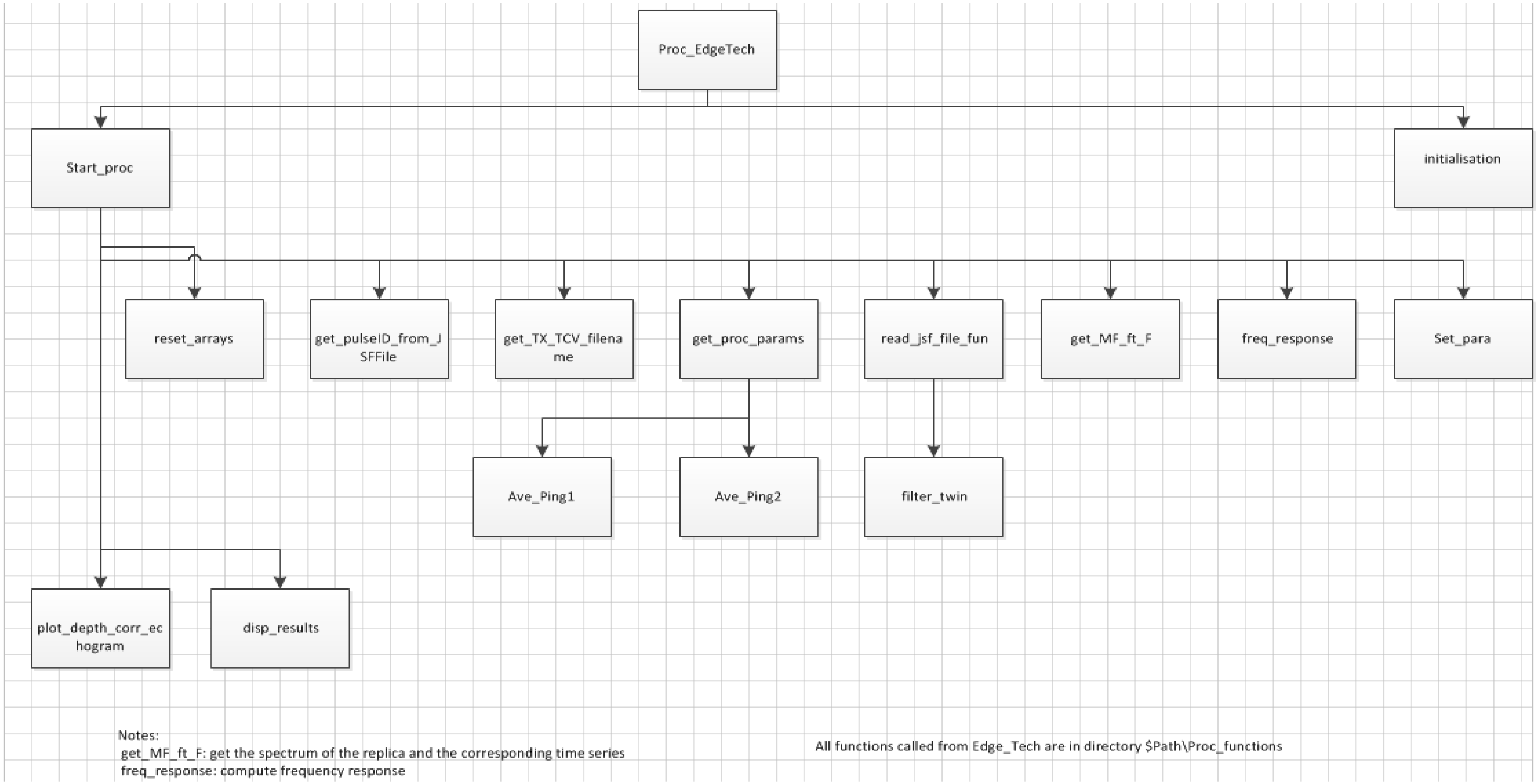

Figure 20. Tree diagram showing structure of functions called by Proc_EdgeTech, which initiates the GUI used for conversion of files from JSF to MAT format.

Table 4. The main data structure created upon conversion of JSF data files to MAT files. This is the primary data structure used throughout the processing stage.

Data	structure	data1.in data1.out	Set by	Notes	Used in
Output	from first step:				
'data'	structure:				
data	=				
	in1:	[1x1 struct]		see below	
	in2:	[1x1 struct]		not used	
	sub_system:	0	GUI	popupmenu_SubSystem.m	
	start_freq0:	1000	GUI		
	end_freq0:	10000	GUI		
	df:	10	GUI		
	chan:	0	GUI		
	start_freq:	500	GUI		
	end_freq:	6000	GUI		
	out1:	[1x1 struct]		see below	
	TX_RCV_file_dir:	$path/Transmit_Waveforms	GUI	pushbutton_TX_RCV_PulseDir.m	
	tx0:	[1x1 struct]		get_xmit_rcv_waveforms_para.m	Transmit Waveform info – see below
	filename_r0:	$path/Transmit_Waveforms/*transmitFile*.R0			
	rc0:	[1x1 struct]		get_xmit_rcv_waveforms_para.m	Receive Waveform info – see below
	sub_system_name				"Shamu","424", etc

Table 5. The structure of data.in1. This structure contains data pulled from the JSF file. Beyond converting from JSF to MAT files, no further processing is done to these data.

Data	structure	data1.in data1.out	Set by	Notes	Used in
data.in1	file_path:	%path/data/date			
	file_record_type:	p	initialisation	popupmenu_SubSystem	data.chan
	data_format:	0		popupmenu_dataformat1	flag for raw/MF
	ave_ping_no:	10		proc_functions_Ave_Ping1	number of pings to average(if used)
	special_proc_indx:	1		proc_functions_get_proc_params	do depth correction or not
	special_proc_string:	{'No Depth Correction'}		proc_functions_get_proc_params	
	filename:	$path/data/date/*runSerialNumber*.jsf			1st raw data file to process
	ping_number:	[1x273 double]			array of ping numbers
	findx:	[]			index of the specified frequency window
	depth:	[1x2879 double]			array of depths in time series
	t:	[1x2879 double]			array of times (s) corr to depths
	freq:	[]			
	lat:	[1x273 double]		latitude in degrees from bytes 73-76	data per ping
	lon:	[1x273 double]		longitude in degrees from bytes 77-80	"
	Lat:	[1x273 double]		latitude in degrees from bytes 81-84	"
	Lon:	[1x273 double]		longitude in degrees from bytes 85-88	"
	pitch:	[1x273 double]			"
	roll:	[1x273 double]			" up = +ve

Data	structure	data1.in data1.out	Set by	Notes	Used in
data.in1	year:	[1x273 double]		Bytes 198-199	"
	day:	[1x273 double]		Bytes 196-197	" day number
	hours:	[]		Bytes 186-187	always blank in our data
	mins:	[]		Bytes 188-189	always blank in our data
	secs:	[]		Bytes 190-191	always blank in our data
	pressure:	[1x8717 double]			CTD at sample rate of device
	sonar_dep:	[1x8717 double]			" press converted to depth
	temp:	[1x8717 double]			"
	sal:	[]			Salinity is in the '2060' record, but these bytes are not converted in our code
	cw:	[1x8717 double]			speed of sound (from CTD - in raw data spec)
	cond:	[]			Conductivity is in the '2060' record, but these bytes are not converted in our code
	ScaleFactor:	[]			I think this is not used CJS (see scaleFactor below)
	ft:	[]			I think this is not used CJS – see data.out1.ft
	PulseID:	10032			from raw data file
	SR:	1.09E+04			sampling rate
	n0:	2894			nt+time_win_indx(0)
	nt:	2879			length of time series
	power:	60			internal gain in JSTAR
	day_secs:	[1x273 double]			time in seconds since midnight
	time_str:	{1x273 cell}			hh:mm:ss
	heading:	[1x273 double]			fish heading
	scaleFactor:	[1x273 double]		bytes 169-170 in raw data	Signed Weighting Factor for scaling ImpuleData(sonar data) values – see JSF file pdf document

Table 6. The structure of data.out1.

Data	structure	data1.in data1.out	Set by	Notes	Used in
data.out1:					
	freq_filter:	[1x1 struct]	hard wired in get_proc_parameters.m		start and end frequencies
	ft:	[273x2879 double]			time series from each ping
	F:	[1x16612 double]			spectrum
	depth:	[1x2879 double]			same as data.in1.depth
	t:	[1x2879 double]			same as data.in1.t
	freq:	[1x16612 double]			frequency in kHz
	time_win_indx:	[1x2879 double]		filt_twin (Proc_Funs)	windowed data
	ft0:	[1x273 double]		read_JSF_file_fun	filtered
	fmod:	[]			
	bp_low:	[]			
	bp_mid:	[]			
	bp_hl:	[]			
	bp_hh:	[]			
	BP_Low:	[]			
	BP_Mid:	[]			
	BP_HL:	[]			
	BP_HH:	[]			
	findx:	[1x16612 double]			indices of transformed data
	nt:	32768			# pts in FFT
	data_format:	0			see data.in1
	pitch_raw:	[1x11165			reduced rate data
	roll_raw:	[1x11165			"
	ping:	[1x1 struct]			point of CTD data for each ping

Table 7. An example output structure of a get_system_response file. Output structures generated by get_system_resonse_feed are essentially identical.

Data	structure	data1.in	data1.out	Set by
get_system_response	output data structure = P			
	target_indx:	3		
	signal_indx:	[1x74	double]	
	PS_c:	[199x1	double]	
	cnt:	1		
	freq:	[1x27181	double]	
	ft_c_sgl:	[74x2	double]	
	nt:	217		
	PS:	[2x199	double]	
	np:	2		
	depth:	[1x2919	double]	
	twin_indx:	[1x74	double]	
	depth_win:	[1x74	double]	
	pitch_range:	[-8.2947	6.8994]	
	roll_range:	[-1.3953	0]	
	pitch_cal:	0		
	roll_cal:	0		
	fft_size:	217		
	rc0:	[1x1	struct]	
	filename:	$path/data/date/*serialNumber*.jsf'		
	ping_number:	[1x688	double]	
	data_format:	0		
	pings:	[553	555]	
	TS:	[1x199	double]	
	Fsys:	[2x27181	double]	
	Fsys_m:	[1x27181	double]	
	Pr:	[1x27181	double]	
	Psys_m:	[1x27181	double]	
	freq_ts:	[1x199	double]	

Fisheries Innovation Scotland

Scottish Charity Number SC045119

Company Number SC477579

FIS MEMBER ORGANISATIONS

marine scotland

The Scottish Government

SFF SERVICES LIMITED

SWFPA The Scottish White Fish Producers Association Ltd

Scottish Natural Heritage Dualchas Nàdair na h-Alba

SEAFISH the authority on seafood

Young's Seafood Limited

Sainsbury's