SIFIDS

Scottish Inshore Fisheries Integrated Data System

Work Package (3) Final Report

Development of a Novel, Automated Mechanism for the Collection of Scallop Stock Data

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EXECUTIVE SUMMARY

This project, aimed at the development of a novel, automated mechanism for the collection of scallop stock data was a sub-part of the Scottish Inshore Fisheries Integrated Data Systems (SIFIDS) project. The project reviewed the state-of-the-art remote sensing (geophysical and camera-based) technologies available from industry and compared these to inexpensive, off-the -shelf equipment. Sea trials were conducted on scallop dredge sites and also hand-dived scallop sites. Data was analysed manually, and tests conducted with automated processing methods.

It was concluded that geophysical acoustic technologies cannot presently detect individual scallop but the remote sensing technologies can be used for broad scale habitat mapping of scallop harvest areas. Further, the techniques allow for monitoring these areas in terms of scallop dredging impact. Camera (video and still) imagery is effective for scallop count and provide data that compares favourably with diver-based ground truth information for recording scallop density. Deployment of cameras is possible through inexpensive drop-down camera frames which it is recommended be deployed on a wide area basis for further trials. In addition, implementation of a ‘citizen science’ approach to wide area recording is suggested to increase the stock assessment across the widest possible variety of seafloor types around Scotland. Armed with such data a full, statistical analysis could be completed and data used with automated processing routines for future long-term monitoring of stock.

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1. BACKGROUND

Assessing shellfish stock, and in particular that of shellfish that can be partially or fully buried for much of their life cycle can be challenging. Previous attempts have relied on direct sampling, usually involving the dredging of the seafloor, over a limited spatial and temporal basis. The use of remote survey techniques potentially offers a way of making quantitative estimates of stock using both dedicated research platforms and also vessels of opportunity. Providing tried and tested methods is of high relevance for managing scallop stock in a cost-effective manner. A managed strategy of survey will have implications for both inshore, hand-dived stock and offshore dredge or trawl stock. It will have relevance to the protection of stock by ensuring that appropriate scientific data are available to both the shellfisheries and regulatory bodies. Furthermore, development of methods for the scallop fisheries could potentially be relevant to other commercially exploited shellfish such as *Nephrops.*

Work Package 3 (WP3) of the EMFF Scottish Inshore Fisheries Integrated Data Systems (SIFIDS) project aimed to assess the potential of novel, automated technologies for the collection of scallop stock data and was divided into three parts:

1. Desk-based review of current state-of-the-art for remote survey methods for scallop resources.
2. Limited sea-trial of methodologies that best represent the different approaches currently available for remote survey.
3. Evaluation of tests and methods with respect to industry capacity and cost effectiveness.

The project was undertaken by staff at the University of St Andrews, the Scottish Association of Marine Science, Dunstaffnage and Shearwater Geophysical. Data were requested from Marine Scotland that represent best practice for current ground truth stock assessment using remote methods but none were available to the project.

2. REVIEW OF STATE-OF THE-ART

Prior to field investigations an extensive review was undertaken of the current state-of-the-art for marine survey using remote sensing techniques that included both acoustic-based methods and visual capture methods. Both hardware and software were evaluated. The review focused on the ability of equipment to meet objectives (identification of scallops and scallop grounds), the technical performance of the equipment, their ease of implementation and cost.

The field of marine remote sensing is a highly dynamic one that is constantly evolving as commercial developments seek to meet the needs of not only the hydrocarbon industry but increasingly that of the offshore renewables market. As with many fields the constantly reducing price of computing power combined with the mass market effect created by consumer electronics impacts on the technology innovation of marine equipment in a rapid way. Therefore, what is state-of-the-art when the review was undertaken may not hold as such for long. Nonetheless, the review enabled this project to identify four three types of technology that represented methodologies with the best likelihood of addressing the dual goals of economically and systematically mapping occurrence of scallop across widely different seafloor types and measuring the density of stock. In addition to reviewing the equipment and software an evaluation was also made of deployment methods for the technology. Details of each technology reviewed, both hardware and software, are given in Appendix A and summaries are provided in section 2.1 below.

2.1. Remote Sensing Technology Types

2.1.1. Multibeam Sonar

Multibeam sonar has become the sonar method of choice for marine seafloor survey over the past decade. This methods are implemented on all the bespoke survey vessels world-wide for deep ocean to shallow water survey. Two main types of instrument currently exist, namely those based on multiple individual transducer combinations and those based on phased arrays of transducers. Both types are reviewed here as various advantages and disadvantages exist between each type. Over the past five years the reducing cost of electronics has led to the development of multibeam sonar at a low cost for fitting to non-specialist, that is non-hydrographic surveyor vessels such as the inshore fishing fleet. While the accuracy of this equipment does not meet international standards for surveying the data are nonetheless useful for evaluation of benthic habitats.

2.1.2. Sidescan Sonar

The sidescan sonar has been used in seafloor survey for over 30yrs. Modern systems use digital acquisition technology with multiple transducers allowing for synthetic aperture acquisition techniques giving seafloor resolution of centimetres. Over the past 30 years the cost of this technology has fallen dramatically and as with multibeam sonar the technology has now been adopted within non-specialist (non-surveyor) instruments that are being increasingly fitted on inshore fishing boats.

2.1.3. Still and Video Imaging

Still and video imaging are a mainstay of benthic habitat mapping and monitoring. Traditionally, cameras have been deployed on a variety of platforms from simple drop-down frames to towed sleds to remotely operated autonomous vehicles. Camera systems are both tethered with live feeds through cables to the surface and untethered but set to either video capture or timelapse still images. With the ready availability of high definition digital systems and the rise in popularity for action cameras there has never been a better time for easily acquiring underwater recording at very economic cost. A recent development in image acquisition has been the development of both 3D camera and time-of-flight camera. Both of these offer great possibilities for future development of low-cost monitoring from any type of vessel.

A summary of the advantages and disadvantages of the different systems and their deployment methods is given in table 2.1 for Sidescan sonar (SS), Multibeam sonar (MBES), Autonomous underwater vehicle (AUV), and imagery. The review of methods also took into account the deployability of equipment on small vessels, and with the provision of adequate (electrical) power it was concluded that almost all techniques can be deployed with sufficient experience.

Table 2-1 Summary of Survey Methods

Vessel/towed SS, MBES	AUV and Imagery
Strengths • Simultaneous co-located bathymetry and Sidescan for relief mapping and seabed characterization/ Angular Range Analysis • Relatively easy to deploy • Good vertical / across track resolution Weakness • Requires independent ground-truthing. • Difficult to interpret with biota / macroalgae etc. • Limited beam-spread thus coverage may be compromised in shallow water • Instrument at surface, thus resolution decreases with increasing water depth. • Poorer resolution in backscatter / swath edges compared to AUV. Opportunities • Water column data can be recorded with some systems allowing pelagic biomass estimation	Strengths • Simultaneous co-located bathymetry and Sidescan for relief mapping and seabed characterization/ Angular Range Analysis • Easy to deploy /recover from any vessel/ shore • Very stable motion • Good vertical / across track resolution • Imagery has high detectability. • Imagery allows non-independent ground-truthing Weakness • AUV not appropriate in shallow water <15m • Illumination issues/ visibility susceptible to conditions • Expensive – rental options available Opportunities • Potential to simultaneously collect Imagery with bathymetric SS • Imagery offers additional info on ecology / predator pressures etc. • Automation of scallop ID from imagery

2.2. Processing Acoustic Data

2.2.1. Bathymetry

The primary goal of sonar survey of the seafloor is to provide information on bathymetry. Processing of sonar records typically involves filtering to remove noisy data as a result of electronic interference, editing of data for navigation and motion reference inconsistency and finally interpolating point data into surface maps.

2.2.2. Sidescan (amplitude)

Processing of amplitude, sidescan sonar data has the goal of producing continuous cover images of seafloor conditions. These can be used simply as tools to "see" what is on the seafloor but also can form the basis for further processing in order to produce seafloor classification maps.

2.2.3. Seafloor Classification

A number of software packages are available for processing seafloor amplitude information and classifying this in terms of benthic habitat. Most rely on differences in amplitude corrected for offset and angle of incidence of the acoustic wave with the seafloor. All require correlation with some form of ground truth information as the Sonar Equation[1] is based only on sediment-acoustic relationships and cannot account for variation with biology. Ground truthing is typically provided by a combination of sampling, camera and video information.

2.3. Still and Video Analysis

The processing of both still images and video of the seafloor has traditionally been done manually as a very time-intensive activity. This is exacerbated with modern digital systems where there is a tendency to collect vast quantities of data. Over the past few years a number of automated approaches have been developed and trialled with images and video from benthic survey (Lacharite et al., 2018; Tang et al., 2018). The automated processing has for the most part been undertaken with singular aims such as benthic habitat classification or the counting of certain species and there is, to date, no one approach or software that has proved superior in marine data review. For WP3 a number of systems were reviewed but the amount of data collected during the limited field trials was not sufficient to train the software algorithms for statistically meaningful analysis.

2.4. Deployment Methods

The standard methods of deployment of sonar technology is from a survey vessel or vessel of opportunity. For equipment that is towed in the water, for example the sidescan sonar, there is less need for specialised vessel features in order to deploy the equipment, however, for hull mounted systems then a number of features must be provided on the vessel. Best practice typically therefore involves a dedicated survey vessel as this provides not only the requisite

[1] The "sonar equation" is a systematic way of estimating the expected signal-to-noise ratios for sonar (Sound Navigation And Ranging) systems. The signal-to-noise ratio determines whether or not a sonar will be able to detect a signal in the presence of background noise in the ocean. It takes into account the source level, sound spreading, sound absorption, reflection losses, ambient noise, and receiver characteristics. The sonar equation is used to estimate the expected signal-to-noise ratios for all types of sonar systems. Slightly different versions of the sonar equation are used for active (echo-ranging) and passive sonar systems.

additional hardware and power supply but also the bespoke mounting mechanisms for the non-towed sonar. The disadvantage of bespoke survey vessels, however, are the additional cost for surveying.

Deployment on a small vessel (sub 12m) is possible for almost all modern remote sensing survey equipment with the provision of a few basic features. All require electrical power of between 500kVa and 1500kVa. This is typically provided on small vessel by the addition of a separate generator. In-water equipment such as sidescan is deployed over the side or off the back of the vessel and is facilitated by lifting gear, however, it can usually be handled by two persons. Hull mounted sonar such as for multibeam sonar requires a bespoke bracket to be fixed to the hull either as a side mount or bow mount and typically is supplied with such mounting by the manufacturer.

A new type of recording 'vessel' has become more readily available over the past 5 years as represented by the autonomous underwater vehicles (AUVs). These allow the deployment of both sonar and camera-based technology in a mechanism that can be programmed to survey areas of the seafloor autonomously. While they represent the state-of-the-art and are commercially available, they are cost prohibitive for most surveys. The costs are falling and it was therefore considered opportune for this project to assess the potential to use the Gavia AUV that is part of the Scottish Marine Robotics Facility.

2.5. Summary of Recommended Types for Survey of Sites

For the survey of scallop sites a bathymetric sidescan (Interferrometric) sonar, the BathySwath 468 kHz and Norbit iWBMS sonar were chosen for boat-mounted instruments and a GeoAcoustis GeoSwath for implementation on the AUV. An inexpensive sidescan system, the Tritech Starfish was also deployed as a comparison to the survey grade sonar. The approximate range of equipment prices for the four systems ranges from the AUV with GeoSwath at over £500k to the Norbit at approximately £80k, the BathySwath at approximately £50k and the Tritech at under £3k. For ground truth a combination of specialised high-resolution video and camera systems were tested both onboard the AUV, within remotely operated vehicles, on drop-down camera frames and with divers together with a number of inexpensive action sport cameras. Analysis of data was carried out using the software that is provided by manufacturers with their equipment and with further statistical analysis undertaken using standard statistical packages such as the 'R Project'[2].

2 R Project is a free software environment for statistical computing and graphics.

3. FIELD TESTING

In order to test and evaluate the different acquisition and processing methods three field sites were chosen that best represented typical sites where dredge harvesting and hand-dive harvesting were practised. On each of the sties, the survey areas extended beyond the harvesting areas to include non-harvested seafloor. Two dredge sites were identified on the west coast of Scotland for survey based on a review of scallop trawling practices and after discussions with scallop fishermen in the Oban area (Figure 3-1). One site was identified in the North West near Unapool where hand-dive harvesting was practised. The sites were identified following a review of harvest records from scallop fishers known to the project team.

A detailed presentation of the survey actions at each site is given in Appendix B1 for the dredge sites and Appendix B2 for the hand-dive site. A summary is provided here.

3.1. Site 1 and 2 (West Coast dredge sites)

Two sites off Bernera with historical scallop dredging were tested. These ranged in depth from 5m to 50m with seafloor habitats including rocky reefs, gravel banks, sand with ripples to fine muds.

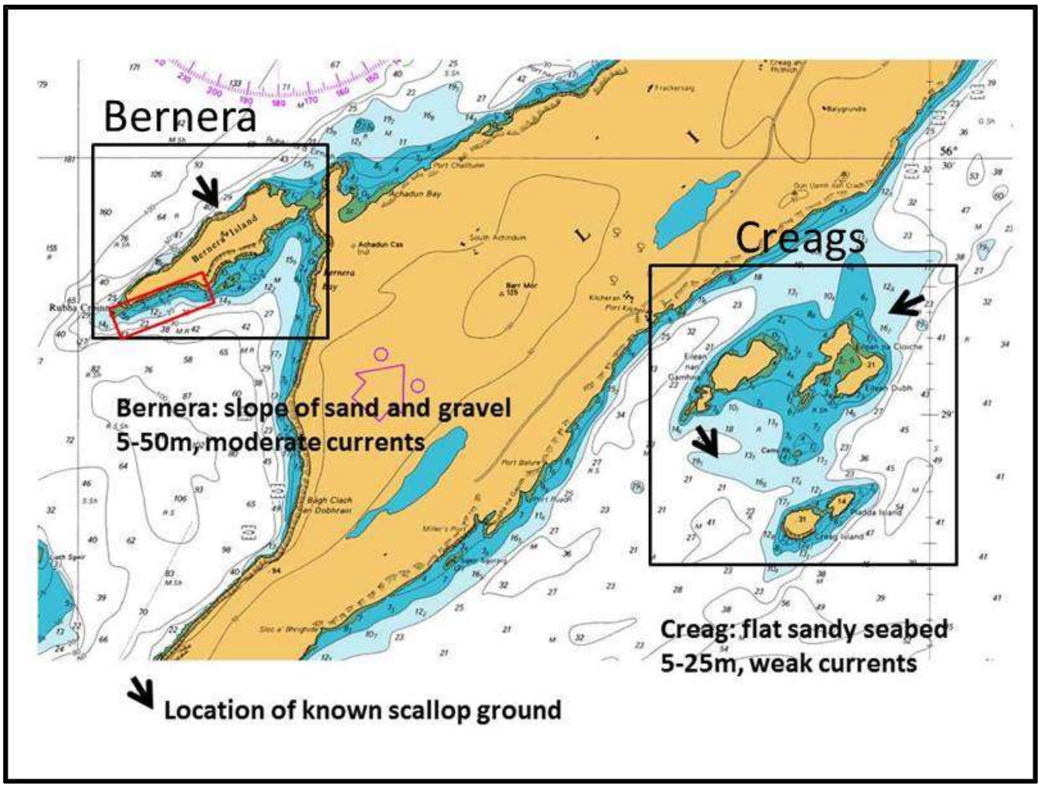


Figure 3-1 Location of target areas near Oban, Scotland.

3.1.1. <u>Acoustic Remote Sensing</u>

Remote sensing with SwathPlus (Inter) and Norbit iWBMS system were conducted along with deployment of a Gavia AUV fitted with Geoacoustics sonar (see Appendix B1). At one site extensive trawl marks were recorded (Figure 3-2). Data from both sites were of high quality such that seafloor classification maps using both manual and automated methods were achieved. The automated classification recognised seafloor favoured by scallop but ground truth data collected by divers found only minimal scallop density. The areas had clearly been heavily harvested prior to the survey and so further analysis using video techniques was not possible.

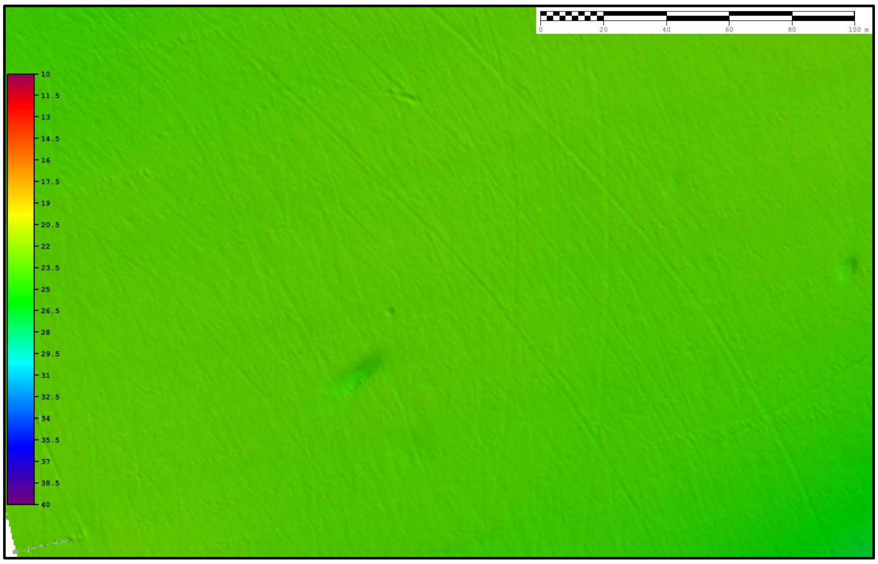


Figure 3-2 Detailed AUV bathymetry of the SW Creags site showing intensive trawling activity on the seabed below about 20 m water depth. Gridded data at 0.5 m resolution (scale=20m divisions).

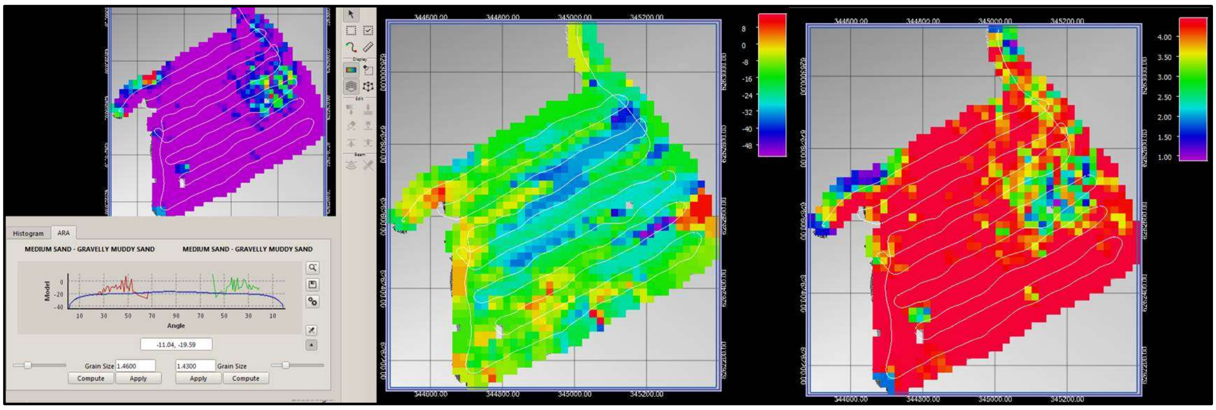


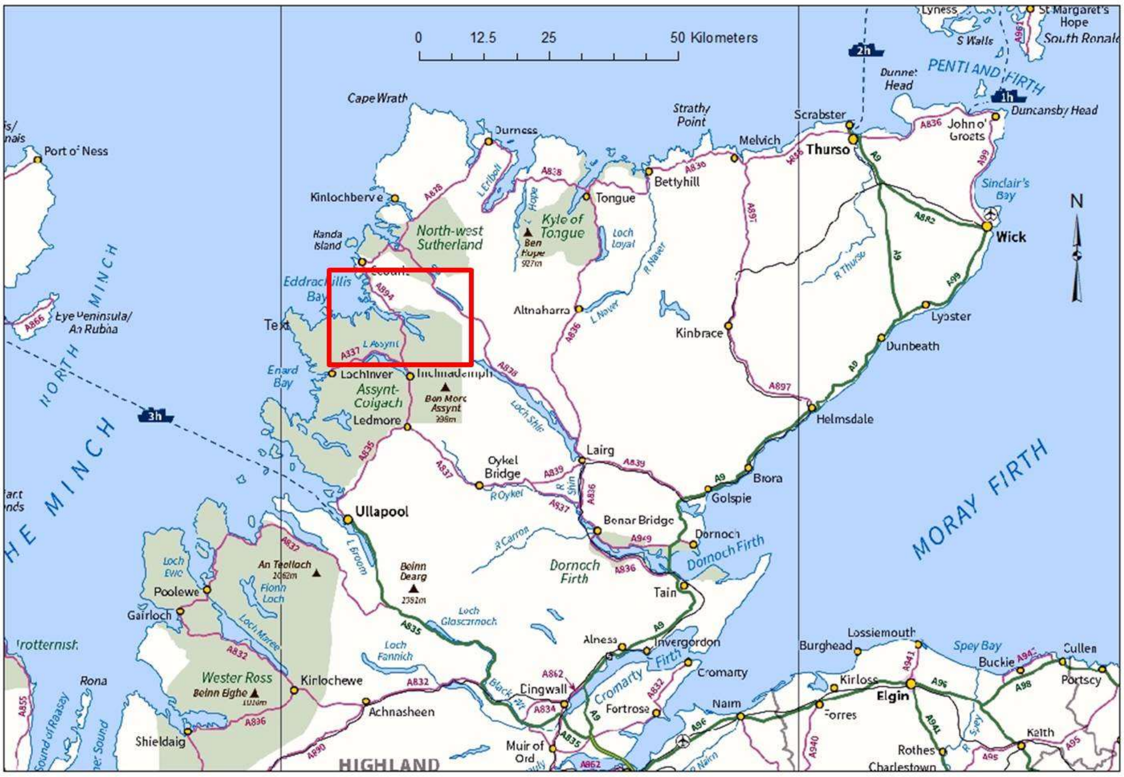
Figure 3-3 Preliminary ARA of the Creag Islands site, (left) identifies the site as being heterogeneous with a combination of muddy-sand, gravelly muddy-sand and areas with cobbles. Two further plots from the suite in ARA are shown here, Intercept and Impedance. Intercept highlights subtle gradient changes contributing to the model and Impedance (Right) is a measure of reflectivity.

3.1.2. Walkaway Velocity Analysis

At the beginning of the project there was a concern that identification of scallop habitats would be difficult where the scallops were buried or partially buried. In order to address this, a novel technique, Walkaway Velocity Analysis (WVA) was deployed at this site (see Appendix B2 for full details). This technique, developed around the concept of amplitude variations with offset practised in the Hydrocarbon Industry, uses a bespoke miniature system built by Shearwater Geophysical Co. Ltd. Field trials proved the technique for mapping seafloor type with very high resolution to a few tens of centimetres beneath the seafloor and demonstrated its potential for monitoring change in the consolidation conditions of the seafloor as a function of environmental change. However, it now requires a far more extensive programme of tests over high density scallop sites to take it from a basic prototype equipment to one that could have economic widespread use in industry.

3.2. Site 3 (Hand Dive Scallop Location)

At Site 3 an area of seafloor was chosen for study that had been seeded with scallop for the purpose of later harvesting by divers. The site is situated close to Unapool in 5-20m water depth with a mixture of course sand, pebbles through to larger rocks and boulder/slabs. Appendix B2 describes the site and results in further detail.



Crown copywright © Ordnance Survey (GB) Miniscale, Using: EDINA Digimap Ordnance Survey Service http://digimap.edina.ac.uk

Figure 3-4 Ordnance survey Miniscale map showing the location of the new site highlighted in red. The scallop sites were seeded by the fisher and due to the monetary value of these sites, their specific location is sensitive and should be kept confidential.

3.2.1. <u>Acoustic Remote Sensing</u>

The site was surveyed using a both Bathymetric sidescan and the inexpensive pole-mounted Tritech 990F Chirp sidescan sonar fish, recording at 1000kHz nominal frequency. The decision to use only a subset of remote sensing techniques at this site was made based on the results from the initial trials that indicated similar data being obtained in shallow water by all systems. It was also the intention to test methods here that might be able to be adopted by the sub-12m fishing fleet as an economic reality. Ground truth was provided by both drop down still and video photography with scallop counts made by divers harvesting along sample transects. The geophysical data were used for automated benthic classification to give different zones of seafloor type (Figure 3-5, left) with initial processing to balance the amplitude decay with increasing offset from the source. This provides a traditional-looking sidescan sonar image in grey-scale of the seafloor where rocky reefs stand out as textured areas and sand and silt as uniform grey areas. Further processing included the addition of a time variant gain before testing of attribute classifications as demonstrated by the translation of the grey-scale image to a colour discrimination chart (Figure 3-5, right). These charts form the basis for benthic habitat mapping. In Figure 3-5 the colour scheme is matched to seafloor type with automated classification picking out different sonar conditions on the seafloor. Interpretation of the colour scheme is done for each site following ground truth measurements.

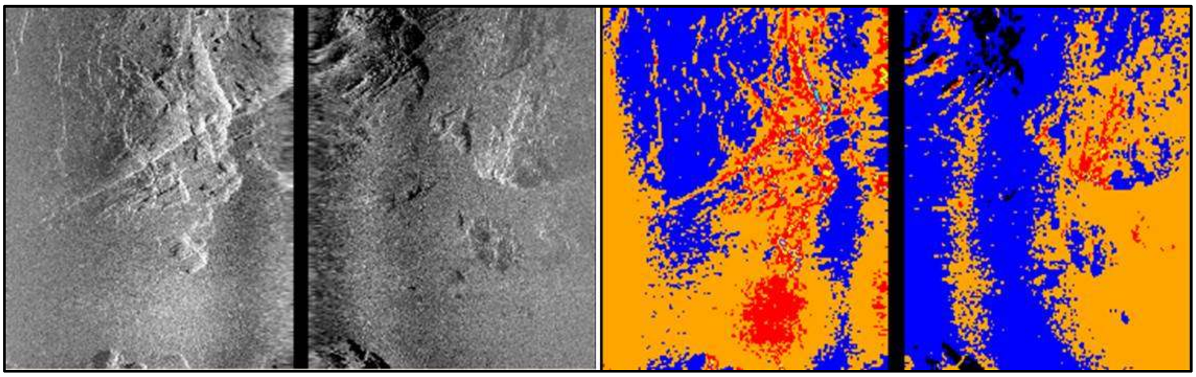


Figure 3-5 Preliminary characterisation using SonarWiz. Left is the input data, right is the applied attribute characterisation. Edge effects are more appropriately corrected for offset. White/ Red represent high intensity harder surfaces.

3.2.2. <u>Video Data</u>

Transect video (Figures 3-6 and 3-7) gave clear images of seafloor in 4-5m of visibility, however, detection of scallops when they are recessed into depressions and covered by sediment is challenging. Furthermore, when sediment load in the water column is high the quality of images rapidly declines.

Figure 3-6 Preliminary Tritech MD4000 1080p Still image extracted from video transect footage. Height above the seabed is approximately 50cm.

Figure 3-7 Preliminary Tritech MD4000 1080p Still image extracted from video transect footage. Scallops are seen here living within depressions and covered in sediment. Camera height is approximately 2m. Scallops as indicated by circles.

Figure 3-8 Preliminary Tritech MD4000 1080p Drop down. Still image extracted from video which demonstrates issues with suspended particles and light reflection.

3.2.3. Ground Truth

Both video imagery and still imagery were analysed manually for scallop count. From the ground truth diver harvest counts the mean live scallop density was recorded at 5.35 per m^2 and the estimated density from inspection of the video footage was 5.37 per m^2 and for still imagery at 5.09 per m^2 and 4.73 per m^2 with post-harvest counts based on re-survey with the camera dropping to 1.68 per m^2 and 0.36 per m^2. Summary data for the two imagery methods are presented in tables 3-1 and 3-2. Note, as mentioned earlier, this site was an area that had been specifically seeded for scallop growing and this the density of scallop might not reflect that typically encountered at non-seeded sites, however, anecdotally, the densities are ones that older scallop divers claim to have experienced in the past.

Table 3-1 Data from the diver harvested scallops per quadrat and Pre and Post-harvest data extracted from the video footage. For the latter, three pseudo-replicates were taken viewing at different times, since the video footage was difficult to interpret.

	Diver harvest data				Pre-harvest					Post-harvest		
	N live	N m^2		Video 2	live	dead	N m^2		Video 3	live	dead	N m^2
Bag 1	24	1.91		Pre-harvest	49	3	5.60		Post-harvest	14	4	1.60
Bag 2	62	4.93			45	4	5.14			14	4	1.60
Bag 3	37	2.94			47	4	5.37			16	4	1.83
Bag 4	72	5.73										
Bag 5	141	11.22										
Total	336				141					44		
Mean	67.2	5.35			47		5.37			14.67		1.68
Mean/Quadrat	13.44				transect area m^2		8.75			transect area m^2		8.75
Quadrat size m^2	12.57				(based on field of view)					(based on field of view)		

The size and shape of the field of view and quadrats can affect the sampling precision and the optimal dimensions will depend upon the dispersion of the population.

Table 3-2 Data from the diver harvested scallops per quadrat and Pre and Post-harvest data extracted from the action camera still imagery. Pass 1 and Pass 2 are pseudo-replicates, however, the transect rope did move slightly between the two transect runs.

	Diver harvest data			Pre-harvest				Pre-harvest				Post-harvest		
Actual	N live	N m^2	Pass 1	live	dead	N m^2	Pass2	live	dead	N m^2	Pass 3	live	dead	N m^2
Bag 1	24	1.91	Q1	0		0.00	Q1	0		0.00	Q1	0		0.00
Bag 2	62	4.93	Q2	2		3.64	Q2	4		7.27	Q2	0		0.00
Bag 3	37	2.94	Q3	1		1.82	Q3	1		1.82	Q3	0		0.00
Bag 4	72	5.73	Q4	5		9.09	Q4	3		5.45	Q4	0		0.00
Bag 5	141	11.22	Q5	6		10.91	Q5	5		9.09	Q5	1		1.82
Total	336			14				13				1		
Mean	67.2	5.35		2.8		5.09		2.6		4.73		0.2		0.36
Mean/Quadrat	13.44			view area m^2		0.55		view area m^2		0.55		view area m^2		0.225
Quadrat size m^2	12.566													

A second deployment of still image photography with the drop-down frame was conducted on the site using action cameras at 30 locations across the seeded area. The action camera was used in time lapse mode for still images which gave approximate footprints of 1.570m^2 (calculated using the transect rope dimensions with markings and Image J software).

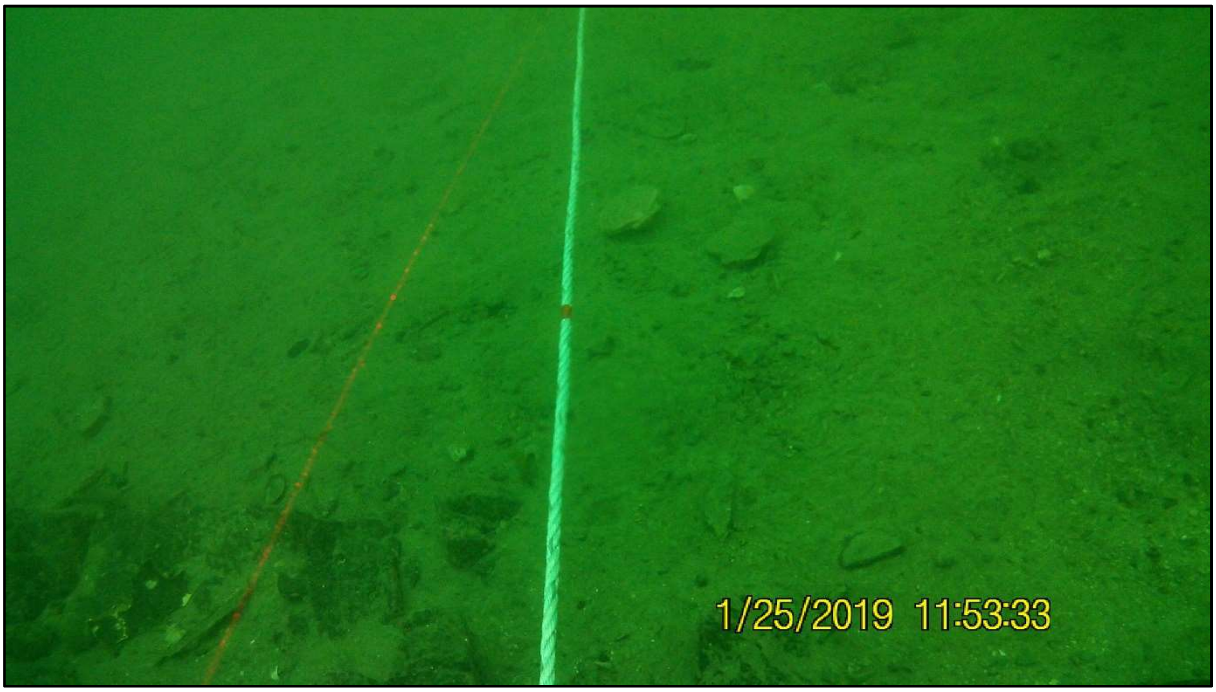


Figure 3-9 Still camera with red laser (left of rope) and scallop shells.

A total of 58 live scallops were seen over the 30 random dropdown locations which spanned the sandy shelf area through which the transect ran. A mean of 1.23 scallops per m^2 was estimated which closely reflects the actual counts observed over this transect.

Overall the video footage provided a closer estimate of the expected population, which was likely due to sample area covered by the images. With improved field of view by using either a second camera or a 360º camera, it is likely that the estimation of scallop abundance would be much improved.

4. CAMERA TESTING

The use of scientific video and still camera for acquiring data as opposed to the use of more readily available and cheaper camera options was tested at the seeded scallop site (Site 3). Results showed that very high-quality images and video of the seafloor can be obtained by inexpensive camera systems, especially when mounted on lightweight frames that cause minimal disturbance of the seafloor. In order to fully evaluate this further sea trails were conducted using action cameras and a 360º camera with the aim of not only reproducing high quality images but also with the aim of developing a drop-down or towed system that could be cheaply built and easily deployed by non-expert users from small vessels. Finally, the visual data were also tested with respect to the various automated processing software solutions that are currently available for marine data.

4.1. Dropdown Frame for Action Cameras and 360º Camera

The aim of these trials was to test options for point sampling drop down mounts for the previously used action camera and also additional options for using a 360º Ricoh Theta V camera. Figure 4-1 illustrates the drop-down frame developed for this purpose.

Figure 4-1 Drop down camera frame for action camera and 360º camera.

The dropdown camera frame was designed to be both light weight and cheaply constructed using materials readily available from any hardware and marine chandlery store. The frame consists of a folding tripod base with lead weights on each of the legs. Tension is maintained to the vertical central pole using guy cords. The legs can be painted in 10cm units to give bottom scale to the camera images. The action camera or 360º camera is mounted on the central pole at 1m from the seafloor. The total cost of construction of the frame is less than £100 and that of an action camera depth rated to 30m is typically less than £50. Both stills (see Figure 4-2) and video recording were tested for the 360º camera. Appendix C provides further specifications for the system and test results.

Figure 4-2 Uncorrected 360º image from the Ricoh Theta.

4.2. Towed Systems

A towed camera system designed for quantifying razor clams in shallow waters (Fox, 2017, 2018) was deployed across Site 1 and 2 near Bernera. The camera rig comprised a 2 m wide sled mounting three downward facing Sony 12V VN37CSHR cameras aligned with overlapping fields of view so that a swath of approximately 1.5 m width is captured (Figure 5-5). Video feeds were monitored live and recorded using a digital video recorder (Hawk D1/960H AHD RF3089, RF Concepts, Belfast UK). Captured video was reviewed manually in 15s segments using the frame-stepping function in Solveig VideoSplitter (Solveig Multimedia, Tomsk, Russia) and the size of any scallops observed was estimated based on the pixel to real-world calibrations described in Fox (2018).

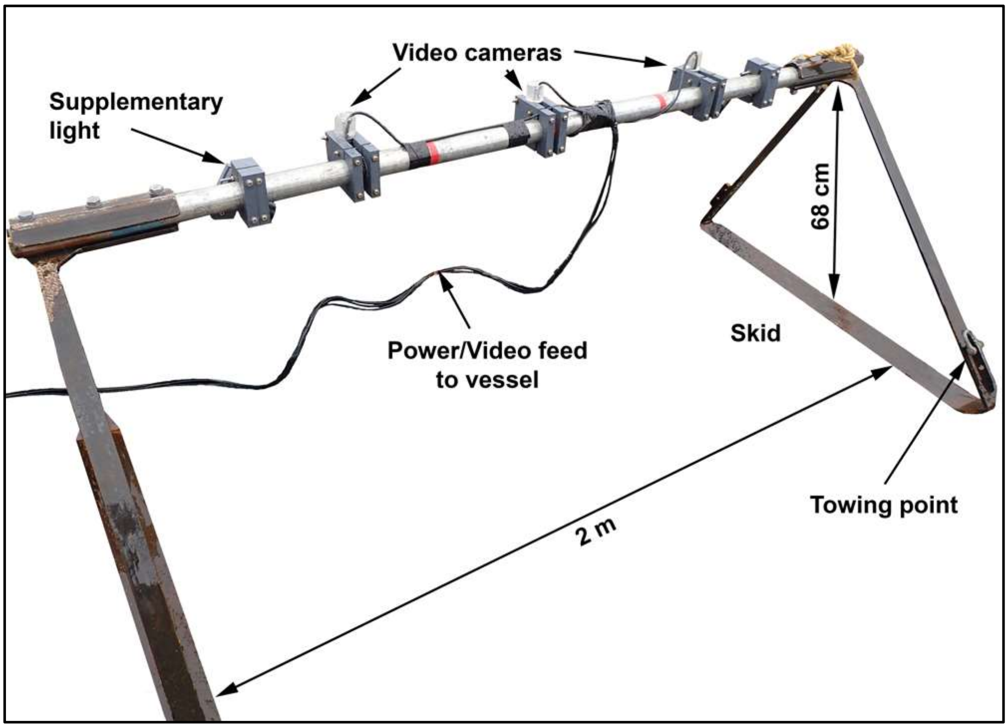


Figure 4-3 Towed system frame for video camera mounts.

Figure 4-4 Live scallop partially obscured by algae, shell width approx. 127mm. Dead shell (open and un-moving on surface) with width estiamte of 48mm.

The seabed at Bernera consisted of fine muddy-sand (Figure 4-4) that was easily disturbed when towing the camera sled leading to poor images. The sparsity of scallop at the site meant that only four individuals were observed on the images. Although very few scallops or scallop shells were seen it was demonstrated that the system images the seabed with sufficient resolution for scallops as small as 48 mm in width to be identified at depths down to 25 m. An advantage of the sled system compared with conventional drop-down cameras is the relatively large area of seabed imaged with the swath under the cameras being 1.5 m in width, meaning that several hundred square metres are covered in a typical tow. This can be advantageous when densities of target organisms are low. On the other hand, survey designs can be easier to implement using drop-down cameras because point-based randomised designs can be applied – see Boulcott et al. (2018) for an example of such a scallop survey.

A further issue is that the camera sled can only be operated across relatively flat areas of seabed so it would not be possible to deploy in areas with larger rocks or other obstructions and the system also requires a larger vessel with lifting capability.

The present system was relatively cheap with a total construction cost in the region of £2000. However, the use of cheap cameras means that the present system is limited to a maximum operating depth of 50 m. Extending this range to greater depths would involve investment in more costly cameras, additional cabling and adding auxiliary illumination (Boulcott et al., 2018).

4.3. Automated Video/Still Image Processing

The volume of data acquired with both video systems and underwater cameras using timelapse shooting creates a significant data processing challenge if it is to be conducted manually. To address this issue, systems for the automatic recognition and classification of seafloor type have been developed and tested on many different seafloor conditions globally. Fishruler by Video and Image Analytics for the Marine Environment (VIAME)[3] attempt to measure fish from video and BenthosDetect detects benthic type and fish/organisms. An early attempt at automated detection of scallops has been made by Prasanna et al. (2013), and Dawkins et al. (2017) developed a system initially for use with HABCAM II at Woods hole Oceanographic Institute with NOAA.

4.3.1. Preliminary Testing of 'Scallop Finder'

Samples of the acquired imagery from the seeded scallop Site 3 were used to test options in ScallopFinder software for scallop recognition. This software package is an open-source platform for underwater image and video analytics by Kitware, (VIAME) released on github (Dawkins et al. 2017). The comprehensive software package has several detector algorithms including 'ScallopFinder'.

Two different detector algorithms were run at low detection thresholds giving results using the pre-trained detection models (Figures 4-4 and 4-5) that showed promise. In the YOLO[4] case (Figure 4-4, right) the true detections had approximately double the probabilities of the false positives. In the second image (Figure 4-5) the probabilities were about the same (true positives and false positives). The results when using Scallop-TK (Figure 4-4, left) were similar to those using Scallop-Yolo.

These detection models were trained on the HabCam data (https://habcam.whoi.edu/gallery/) from a North American scallop fishery. This data, and likely the scallop type, was quite different to the data from Scotland and thus it is highly likely that with more appropriate data significant improvement in detection could be achieved.

3 http://www.viametoolkit.org/

4 YOLO is an extremely fast real time multi object detection algorithm. YOLO stands for "You Only Look Once". This is the link to the original paper : https://pjreddie.com/media/files/papers/YOLOv3.pdf. The algorithm applies a neural network to an entire image.

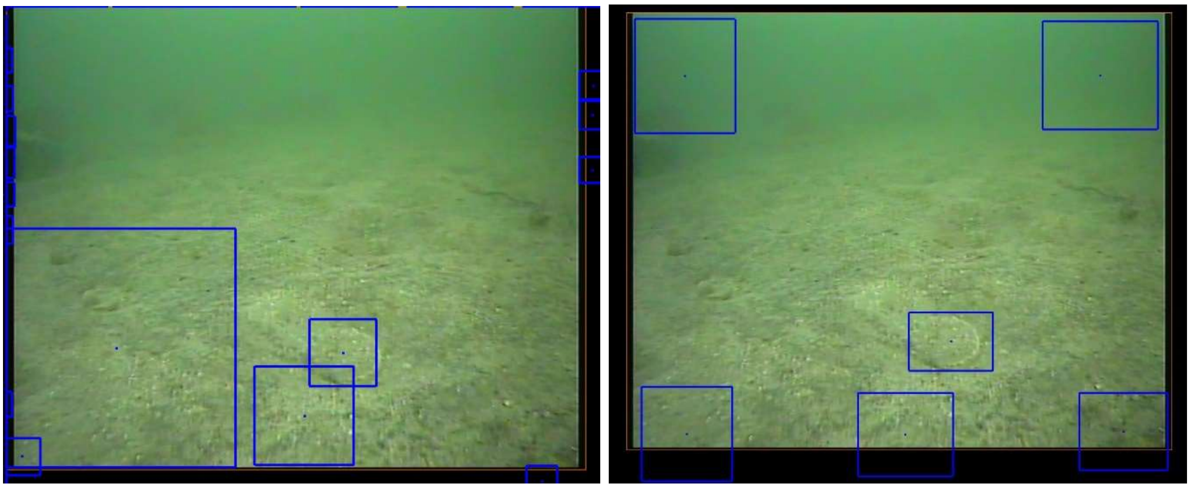


Figure 4-4 Left Output from VIAME SCALLOP_TK detector, right output from VIAME YOLO_V2 detector test 1.

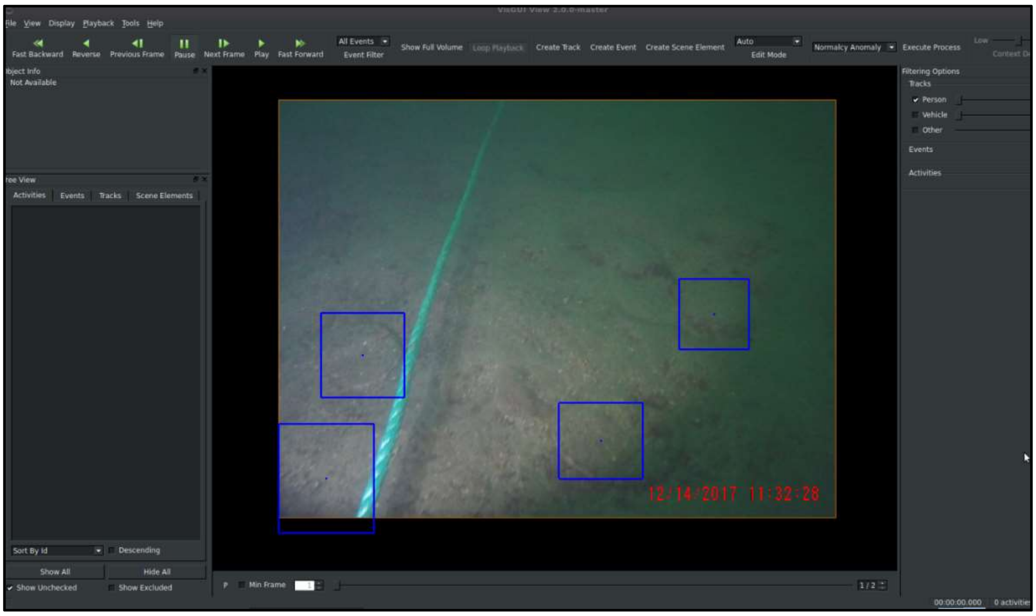


Figure 4-5 VIAME YOLO_V2 detector test 2.

Initial tests with this software are promising, however, much work is required in terms of training the software to fully test its capabilities for this species of scallop on the habitats found in Scottish waters. For this project insufficient training data were amassed to fully verify the use of this technique. Drop down camera image data from scallop surveys conducted 6/11/2010 and 22/10/2014 were also provided by Marine Scotland Science (Boulcott). However, the scallop densities in these image sets were also insufficient to establish a robust training set for the YOLO algorithm.

5. SUMMARY

The project reviewed the latest remote sensing technologies for possible detection and mapping of scallops. These ranged from inexpensive hardware to the state-of-the-art hardware and software. Following the desk-top review a representative range of equipment was tested on both dredge and hand-dived scallop sites. In addition to testing the latest equipment, experimental research methods were tested on the dredged scallop site. It was noted that the survey industry and equipment manufacturers of both hardware and software are continually developing new methods of seafloor evaluation and mapping, thus this review only forms a snapshot in time.

At the beginning of the project it was hoped that the results from new systems (both hardware and software) could be tested against data obtained from Marine Scotland in the form of video images or still images during routine stock assessment. The SIFIDS programme manager contacted MSS (Phil Boulcott) early in the project and data were provided for analysis, however, this was not focused on the seafloor and therefore could not provide the necessary information for evaluation.

The current state of art for mapping and characterising seafloor can be met by both bathymetric sidescan sonar and multibeam sonar. Seafloor classification can be accomplished effectively to map general areas of favourable conditions for scallop using software that is part of manufacturer's hardware, such as with the Norbit System, or is part of bespoke software such as with Quincy/Fledermaus or SonarWiz. Seafloor classification can also be achieved using software built into many of the Geographic Information Packages that are in widespread use in the industry. For example, ESRI ArcMap now has plug-in modules for Benthic Terrain Modeller, a widely used package originally developed at Oregon State University by Dawn Wright (Wright et al., 2005) that allows for classification of the seafloor. The use of benthic habitat mapping and classification software will be necessary for widespread seafloor mapping but can only be fully tested for scallop assessment when both a larger range of seafloor types have been surveyed and over much larger areas.

For habitat mapping a standard approach is thus routinely available and can be systematically applied for assessing the general state of scallop harvest areas. In particular, it is noted that with the resolution now possible for seafloor mapping (cm to 10s cm) features such as trawl or dredge marks can be readily identified and thus the impact on the seafloor from harvesting can be routinely monitored in situations where sediment movement is minimal. This has implications for fisheries monitoring and management.

Identification of individual scallops using remote sonar techniques was not achieved with the systems available for this project. However, as noted above, the state-of-the-art is constantly changing and new systems based on the principles of the parametric sonar are being tested currently for engineering purposes. Preliminary results are encouraging and these give hope for future quantification of buried shell concentration. For this project, mapping individual shells with remote sensing techniques thus concentrated on the use of different video and still camera options.

Bespoke video and still cameras typically used in the marine survey industry were tested and compared to low cost sport/action cameras. These were deployed using a variety of platforms from diver to towed sled, drop down camera frame, remotely operated vehicle and autonomous underwater vehicle. The latter, while providing very high-resolution imagery of the sea floor, represents an expensive option that it is unlikely to be available for widespread survey in the near future. At the other end of the economic spectrum the use of action cameras, especially those when deployed on inexpensive frames offered surprisingly high-quality images that were sufficient for scientific analysis including demonstrating that the images could be used for automatic processing. Basic statistical analysis from diver-based survey and the images demonstrated the potential of these systems for calculating scallop density. Combining this approach and information with wide area habitat mapping provides a potential powerful solution for mapping and monitoring scallop harvest sites.

All camera systems suffer from the challenging conditions posed by much of the field conditions in waters surrounding Scotland. That is, low light levels, high degree of suspended sediments and deployment conditions that are often far from favourable. Low light can be compensated for by using lights but this can cause issues when suspended sediment load is high due to excessive backscatter from the sediment. Many reports and academic papers have attempted to address these problems with the use of different styles of drop-down frames, towed sleds and by changing the lighting angles with respect to the cameras (e.g. Sutherland et al., 2019; Bicknell et al., 2016). The results from this project suggest that the simplest approach may well be the most prudent for obtaining quality images in quantities that can be ultimately useful for stock assessment. This would enable the deployment of systems on a very wide basis across a reference fleet that would allow coverage in a variety of different seafloor habitats and over a sufficiently long time to yield a statistically meaningful data set.

The use of action cameras that are wifi enabled also provides the possibility of integration with the smart boxes fitted to a reference fleet. That is, after deployment of the camera, the images that are recorded could be uploaded through wifi and thus the exact locations of where they are acquired would be recorded using a comparison of time stamps on the image records with the Global Navigation Satellite System(GNSS) record.

The increasing availability of low-cost 360º cameras represent a further development in the industry that could prove of great value in low cost marine survey in shallow water. Various manufacturers make housings for deployment in water depths to 30m where much of the inshore scallop stock is located for diver harvesting. A new type of camera system has recently come to the market and is being tested for its underwater capability known as Structured Light or Time of Flight camera systems (e.g. Answer et al., 2016). These systems allow for direct measure, or the reconstruction in 3D, of objects such as shell that may be partially buried. While early results show promise in clear water, issues with turbidity and lighting may again prove to be too challenging for most applications.

6. RECOMMENDATIONS

During this project we were unable to test the deployment of cameras and remote survey techniques over a number of different seabed types and therefore complete and rigorous statistical analysis of data was not possible. It is recommended that the combined methods of remote sensing and image capture should be rolled out across a wide area effort on different types of scallop site in order to record shell densities in other regions. To achieve this we recommend the following approach for future development:

Review of Current Stock Areas

A review current scallop information for harvesting across a range of Scottish seafloor habitats should be undertaken in order to evaluate the diversity of seafloor conditions (habitats) on which scallop are harvest and using what particular methods. The review would include already designated areas such as SPAs but also non-designated areas. From the review key sites should be chosen for further analysis and include examples from the west coast (mainland and islands), from the northern Isles (sheltered and exposed coast), in sheltered sea lochs and from further offshore areas. The subset would include a range of fisheries with different types of harvesting practice to include different dredges as well as hand-dived fisheries.

Baseline

For each of the identified areas a baseline should be established to include data for habitats as noted in a desktop survey together with the acquisition of new data using remote geophysical survey methods and visual imagery. The data sampling should also include a record of scallop stock and harvest figures together with an indication of the use of the areas by other marine parties.

Onsite Monitoring

For each site new monitoring equipment to include the dropdown camera systems would be built and distributed to either a reference fleet, the diver-based scallop harvest units or if appropriate to one of the many voluntary marine conservation groups that are established around the coast of Scotland. Examples of potential interested third parties/conservation groups could include the St Abbs Head and Eyemouth Voluntary Marine Reserve and the Community of Arran Seabed Trust through the Coastal Communities Network (Scotland), These groups would be trained in the use of equipment, in the storing of data and in the upload of data to a national database. Records would be acquired initially over a 1-2 year period. The exact survey plan for each site would be determined after the initial baseline survey but could include at least 30 deployment locations per site.

Data Processing and Review

The data collected from deployments would be uploaded for scientific analysis and processing in order to obtain quantitative assessment of change in different sites. The public (fishermen and interested public) would have access to see the results of the project in terms of habitats and if managed the harvest vs. recovery rates for managed sites.

A review of the new data would be made together with the harvest information currently collected by Marine Scotland with recommendations made for the fisheries future. The follow-on actions from WP3 would have benefit to the management of scallop stock throughout Scotland and could provide a blueprint for some shellfish stock assessment elsewhere or stock assessment of different shell types. If enacted it would have implications for policy with respect to the inshore fleet and future of the coastal seas of Scotland.

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8. APPENDIX A – REVIEW OF HARDWARE AND SOFTWARE

Review of available software

software package	license	open source	Acquisition/Processing	Supported Sensors / Acquisition Systems	Application	Processing Supported Formats /systems	Extracted Parameters	output formats	notes
CleanSweep (OIC)	x		P		Batch interactive processing of data from Sidescan sonars, multibeam echosounders and swath interferometric systems	Sidescan sonars, multibeam echosounders and swath interferometric systems. OIC, XTF,SDF,MB41, SIMRAD and others		GeoTIFF, XML & HTML, Raster/ Vector S-57,DNC,BSB, GeoTIFF,DXF, ShapeFile, ASCII,NetCDF Grid, VPF.	
Class (OIC)	x		P		Bathymetric and Sidescan Image analysis/ classification software	OIC, XTF, QMIPS, MSTL, SDF, CMAX, S81, Hypack and others		GeoTiff	
Delph for Sonar / Seismic/Mag (iXBlue)	x		A&P	Most side-scan sonars Separate packages for magnetometers, gradiometers, sub-bottom profilers, and seismic systems using XTF or SEG-Y). Single and dual frequency support. Easy interfacing to navigation data. Raw data logging to XTF format	Acquisition & Processing Seabed Mapping Suite - Geophysical exploration, Geotechnical investigation, Structural geology, Cable route survey, Hydrographic survey, Habitat mapping, Pipeline inspection, Unexploded ordnance survey, Marine archaeology			SS mosaic - geoTIFF, KMZ. Processed data- XTF, SHP,KML. Targets- geoTIFF, CSV.	

Echoview	x		P		Detect, analyze and classify the bottom substrate in single and split beam data for seabed characterization and habitat mapping purposes	Simrad (including EK60, ES70, EK80 and ME70. BioSonics (including DT-X). HTI (including model 241 and 244). Sound Metrics (DIDSON and ARIS). Kongsberg Mesotech (including M3,SM20 and the EM series). Reson (including the SeaBat T20, 6K,7K and 8K series). Furuno (FQ80, ETR-30N and FCV-30). BlueView (2D imaging sonars). RDI ADCP (Workhorse series). ASL AZFP.		Export data to QTC IMPACT and EchoIMPACT seabed classification products	
EchoviewR (CRAN)		x	P		Interface with Echoview 6.1 for automated processing for water column biomass extimations	Any data type accomodated in Echoview			https://github.com/AustralianAntarcticDivision/EchoviewR http://journal.frontiersin.org/article/10.3389/fmars.2015.00015/full
GeoDas (OIC)	x		A	Supports sidescan, single-beam, multibeam, sub-bottom, magnetometer, interferometric, and optical sensors	Realtime mosaics of sidescans, backscatter, bathymetry, magnetometry, or seabed type			OIC,XTF and other formats	
GeoSwath Plus (Kongsberg)	x	A		GeoSwath Plus MBES data and xtf SSS	acquisition /processing & display Option for sediment classification software (GeoTexture)				
GeoTexture (Kongsberg)	x		P		Normalisation and image classification of side scan data for bottom classification; feature extraction and habitat mapping.	GeoSwath Plus MBES data and xtf SSS		XTF, .kml, ASCII GeoTiff; data image; classified image and characterised textures; jpg; mod mosaic; mof GeoSwath	

								Plus mosaic file	
Hypack Office (Hypack)	x		P	Single Beam Echosounders, Side Scan Sonar, Subbottom ADCP, Pipe and Cable Trackers, Magnetometers, GPS, Motion Sensors, etc.	Hydrographic and dredging surveys.	RAW, HSX, XYZ, XTF, IMG, CM2, JSF, XSE, GPX, GSF, .83P, .D1P, .81S, .ALL, .MST, .S7K, .SXI, .SXP, .TDY, .SDF, LAS, ASCII,		XYZ, XTF, TIFF/GeoTIFF, ASCII, DXF, BMP, KML, Screen Captures, AVI.	
Impulse 15 (Maritime Scientific)	x		P		Seabed Classification software	All major brands of Single-beam sonars.	Positional coordinates, time, bathemetry, echo back-scatter, hardware configuratio n and paramenter s	*.grd *.xyz *.shp *.tif *.kmz *.png *jpeg *.btm	
MBARI - MB system		x	P	Sea Beam, Hydrosweep, Simrad, Hawaii, ELAC, Reson Seabat, Furuno, Edgetech, Imagenex & Odom Multibeam Sonars, interferometric sonars and sub-bottom profilers.	Seafloor Mapping - Processing & display of bathymetric & backscatter from multibeam systems.			MB-system produces Postscript based graphic outputs	Linux terminal based with additional GUI's
python PyHum code		x	P	Humminbird	Reading and processing data from a Humminbird low-cost sidescan sonar. Rudimentary radiometric corrections to data, and classification of bed texture. classify bed texture	.SON, .IDX and .DAT files	Roughness (E1), Hardness (E2),peak signal	KML. XYZ point cloud data, ASCII	PyHum - for Humminbird /Poseidon Linux https://github.com/dbuscombe-usgs/PyHum
QPS QINSy	x		A	SBES, MBES, Laser, SSS, Mag, and others	Navigation, Positioning, Mobile Maping, Acquisition & Editing for SBES, MBES, SSS, Seismic & Magnetometer				

QPS FMGT	x		P			QPS QINSy project; Kongsberg raw.all; XTF; GSF; L-3 Klein SDF; RESON S7K		XTF UKOOA ASCII DTM S-57 ENC geoTIFF	
QPS Fledermaus Geocoder	x		P		Used in habitat mapping; site investigation and geologic surveys to generate fully corrected backscatter mosaics and calculated statistics; and to characterize the seabed from analysis of the backscatter angular response.	QPS QINSy project; Kongsberg raw.all; XTF; GSF; L-3 Klein SDF; RESON S7K	Mean grain size; acoustic classes via statistical processing of backscatter; geo acoustic parameters; geological features	DXF; GeoTiff; XY-class ascii; Fledermaus draped backscatter files and ArcGIS grids.	
ReefMaster	x		P	Humminbird / Lawrence	Sidescan mosaic, mapping , Bottom composition.		Roughness (E1), Hardness (E2),peak signal	PNG image, Google Earth, MBTiles, Navico AT5	humminbird & lawrence
Silas Processing Ultra (Stema Systems)	x		A&P	Hypack, Qinsy,PDS2000, Hydromap,Dredgeview, ODOM, RESON, INNOMAR SES, BOOMER and SPARKER systems	Ultra High Resolution seismic process and interpretation software : Density levels for nautical depth studies, Classification of sub-bottom data, Subbottom contact detection (pipeline/cable/object)	SILAS format SEI, SEGY (Rev1, Stratabox, Coda, Edgetech3100p, Atlas Parastore, Generic), Multibeam grid (PTS), Ground Penetrating Radar (SEGY), GeoTIFF, DXF, CPT (Wison), Borehole/Vibrocore logs, Density/Yield stress profiles (Tune SDP), Navitracker/DART densitylevels	Impedance, Absorption, Velocity, Densitylevel , Depth	XYZ for each indicated class / layer, ASCII, HTML, JPEG, Bitmap	
SonarPro (Klein)	x		A&P						
SonarWiz 7 (Chesapeake Technology)	x		A&P	CMAX, Edgetech, Geoacoustics,Geomag, Humminbird, Imagenex, Klein, Knudsen, Kongsberg, Marine Magnetics, Marine Sonic,Odom, PingDSP, R2Sonic, RESON, SyQwest, Teledyne-Benthos,	Acquisition & Processing Software : Pipeline survey - Hydrographic survey - Commercial survey - Marine archaeological survey - Educational hydrography - Search and Recovery	XTF, SEG*, JSF,7K, RAW,SDF, SXR M39,SL2, COD,IMG, DAT and many more		GeoPDF GeoTIFF ECW JPEG ASCII KML CAD - more !	

				and Teledyne-Hugin. HUGIN IVER GAVIA	- Coastal Management - Biological habitat survey				
Teledyne CARIS HIPS SIPS Professional	x		P		HIPS and SIPS product is a comprehensive bathymetric, seafloor imagery and water column data processing software. HIPS and SIPS enables you to process simultaneously multibeam, backscatter, side scan sonar, LiDAR and single beam.	Atlas SDA/ASD/ACF, Chirpscan 3D BRF, CMAX CMX/CM2, Coda, Edgetech Midas/JSF, EIVA SBD, Elac XSE, Furuno, GeoAcoustics RDF, GSF, Hawkeye, Hypack RAW/HSX/HS2, Imagenex D1P/83P/83M, Kraken TIL, LADS CAF, LAS, MarineSonics MST, ProSAS IMG, QMIPS DAT, Teledyne Reson S7K/PDS, Scripps, Klein SDF, Seabeam, Seafalcon, SEGY Singlebeam, SHOALS OUT/HOF/TOF, Kongsberg ALL/OUT/RAW/DEPTH, SPAWAR DAT, Swathplus SXP/SXR/SXI, Teledyne TDY, UNB MERGED, Winfrog RAW, XTF		Raster formats BSB, GeoTIFF, HCRF, ECW, TFW, CARIS IGA and JPEG2000. Vector formats S-57 ENC, DWG/DXF, SHAPE and CARIS Vector Map. Plots export to TIFF or Geospatial PDF	live processing on the run similar to Qinsy - http://www.video.teledynemarine.com/video/10780721/autonomous-on-board-data-collection-and-processing
Teledyne CARIS HIPS SIPS Essential	x		P		Subset of the Professional suite for processing Sidescan & Multibeam Imargery and Single & Multibeam Bathymetry	industry standard formats including; Atlas, CMAX, Coda, EdgeTech, Elac, Furuno, GeoAcoustics, GSF, Hypack, SDF, Seabeam , SHOALS, Simrad, Swathplus and XTF.		Raster formats BSB, GeoTIFF, HCRF, ECW, TFW, CARIS IGA and JPEG2000. Vector formats S-57 ENC, DWG/DXF,	

								SHAPE and CARIS Vector Map. Plots export to TIFF or Geospatial PDF	
Teledyne PDS	x		A&P	MBES: Teledyne BlueView, Coda, Elac, Imagenex, Kongsberg, Norbit, Teledyne Odom, Teledyne RESON, Simrad / SBE: CDL, Deso, Elac, ESP, Imagenex, Innerspace, MiniBath, Navisound, Odec, Odom, PDR, SeaKing, Simrad, SonarMite, Syqwest, Tracs, Tritech, TSS, Ulvertech, Valeport, Yokogawa, Generic, NMEA, SSS: Edgetech, Elac, Klein, Marine Sonic, Odom, RESON, SwathPlus/ MAG:ECG, Elsec, Gem, Geometrix, Marine Magnetics, SeaSPY, Teratem, Tracs/ ADCP :NavQuest, RDI, ZRDoppler / Imaging: Teledyne BlueView, Teledyne Odom, Teledyne RESON	seafloor sediment classification.	PDS, Excel, Simrad EM, CSV, Multibeam points (ASCII), XTF, S7K, Sz, Magnetometer, FAU, GSF, Backscatter points (ASCII), UKOOA P1/90	Backscatter, the intensity of the reflection from the seafloor; Impedance, the absorption in the seafloor; Roughness, the irregularity of the seafloor; Phi, the actual bottom classificatio n; Volume, the volume backscatter, the intensity of the reflection in the seafloor; FLT factor, the fluid factor; Intercept	PDS, Excel, Simrad EM, CSV, Multibeam points (ASCII), XTF, S7K, Sz, Magnetomete r, FAU, GSF, Backscatter points (ASCII), UKOOA P1/90	
TeXAn (university of Bath) Matlab; IDL	x		P		Seafloor characterisation of sidescan (and now multibeam) imagery. See GoogleScholar and ResearcherID for references.		Sidescan and multibeam backscatter data	GeoTiff; XY-class ASCII and others	http://people.bath.ac.uk/pyspb/research/selected_publications/ocean s98.pdf http://opus.bath.ac.uk/29249/1/CSR-S-11-00338.pdf
VIAME- Video and Image Analytics for a Marine Environment		x	P		Automated Image analysis software- with plugin architecture.	HABCAM - images with embeded metadata.	Under developmen t, Scallopfinde r algorithm uses circle fitting		http://www.viametoolkit.org/ https://github.com/Kitware/VIAME http://ieeexplore.ieee.org/document/7926688/#full-text-section 2017

(KitwareNOAA)							routine & also looks for objects spectrally distinct from the benthic substrate ambience.		

http://hydrography.geo-matching.com/

http://www.oicinc.com/geodasMB.html

Preliminary review of available acoustic systems

sonars	Model	Year	mount	type	freq/ range per side	integrated sensors	waterdepth	Application	backscatter	sidescan	bathy	sub	snippets	res across track /depth	acquisition software	o/p
edgetech	6205	2014	vessel	dual MPES	230khz/225m, 550kHz/125m & 550kHz/125, 1600kHz/35m Bathy 250/230 kHz	SVP	shallow	near shore hydrographic IHO SP-44 NOAA USACE spec		y	y			bathy/ SSS range & vert 230kHz/3cm, 500kHz/1cm and SSS 1600kHz0.6cm	EdgeTech DISCOVER Hypack, Caris, Chesapeake, Qinsy,	Native JSF or XTF
edgetech	4125	2008	fish	dual chirp	400kHz/150m , 900kHz/75m & 600kHz/120m, 1600kHz/35m	roll/pitch/heading/depth	shallow -200m	Hydro / geo inspection SAR		y				400 kHz: 2.3 cm, 900 kHz: 1.5 cm, 600 kHz: 1.5 cm, 1600 kHz: 0.6 cm	EdgeTech DISCOVER	Native JSF or XTF
edgetech	2000 subbottom /SSS	2011	fish	dual chirp	100kHz/500m, 400kHz/150m Sub 2-16kHz	roll/pitch/heading/depth	shallow / deep	Archaeol/ Geophys sed class scour etc		y		y		100/6.3cm 400kHz/1.8cm Sub 6-10cm (6m-80m penetration)	EdgeTech DISCOVER	Native JSF or XTF for side scan, SEG-Y for sub-bottom
edgetech	4200	2004	fish	dual chirp	100kHz/500m, 400kHz/150m or 300kHz/230m, 600kHz/120m	roll/pitch/heading/depth	shallow / deep	IHO & NOAA spec geo/archaeo		y				100 kHz: 8 cm, 300 kHz: 3 cm, 400 kHz: 2 cm, 600 kHz: 1.5 cm, 900 kHz: 1 cm	EdgeTech DISCOVER	Native JSF or XTF
Falmouth	HMS-624	2017	fish	dual chirp & CW	100kHz 600m/400kHz 200m /side	roll/pitch/heading/ optional depth	max 2000m	hydrographic		y				2cm	compatible with OIC GeoDAS, Triton ISIS	optional XTF output
Falmouth	HMS-1400	2013	fish	single/dual	100/400 400/900 400/1250 or 400/ 150m or 1250/37.5m single	roll/pitch/heading/ optional depth	max 100m	REA SAR Small vessel surveys		y				at 400 2-15cm at 1250 .75-3.75cm	GeoDAS	optional XTF output
Humminbird	Solix 12 410400 side & down imaging	2017	vessel	dual chirp	455kHz/120m 1.2MHz/38m	temp	max 400m	mapping		y				N/A	Humminbird Sonar Recording	
klein Multibeam	5900	2010	fish	(CW,FM)chirp	600kHz/150m 20 beams per side	roll/pitch/heading/depth	max 750m	hydrographic military		y	y			3.75cm	Klein SonarPro	SDF
klein Multibeam	5000V2	2008	fish	single chirp	400kHz/250m 5 beams per side (1 bathy)	roll/pitch/heading/depth	max 500m (200m Bathy)	hydro geo Security		y	y			3.75cm	Klein SonarPro	GSF XYZ

klein	4900	2015	fish	dual chirp	455kHz/200m, 900kHz75m	roll/pitch/heading/depth	max 300m	Hydro Archaeo BOEM S&R		y				2.4 cm @ 455 kHz, 1.2 cm @ 900 kHz	Klein SonarPro	SDF XTF
klein	3900	2007	fish	dual chirp	selectable 445kHz/200m, 900kHz/75m	roll/pitch/heading/depth	200m	Seabed Target Id Geoloical mapping Geophys		y				7.5cm	Klein SonarPro	SDF XTF
klein	S3000	2002	fish	simultaneous dual chirp	100kHz/600m, 500kHz/150m	roll/pitch/heading/depth	max 1500m	shallow hydrographic		y				2.5cm	Klein SonarPro	SDF XTF
klein	3310 Subbottom (with 3000 SSS)	2009	fish	chirp	SSS 100kHz/600m, 500kHz/150m SUB 2-6kHz	roll/pitch/heading	max 600m	Geophys/Geol surveys Sediment classification Dredging Hazzards		y		y		2.5cm (5-50m penetration)	Klein SonarPro	SDF XTF & Sub bottom SEG-Y
Klein (on Gavia)	UUV-3500	2010	UAV	simultaneous dual chirp	SSS 455kHz/150m, 900kHz/75m & Bathy 455kHz/125m/side	roll/pitch/heading/depth	max 600m	hydro /geophys Env survey		y	y			2.4cm	Klein SonarPro	SDF, GSF,XYZ
Klein	HydroChart 3500	2002	vessel	single	SSS 455kHz/150m, 900kHz/75m Bathy 455	opt. SVP	max 150m	Habmap/ hydro /geo		y	y			5cm bathy 1.5cm SSS	Klein SonarPro	SDF, GSF & XYZ
Klein	HydroChart 5000	2008	vessel	(FM)single chirp	455kHz/250m	opt. SvVP	50m	Habmap/ hydro /geo (IHO SP-44)		y	y			3.75cm	Klein SonarPro	SDF, GSF & XYZ
Klein	4000	2016	fish	dual simultaneous	100/400kHz	roll/pitch/heading	max 2000m	Archaeol/ Geophys Hydro		y				8.0 cm @ 100 kHz, 1.75 cm @ 400 kHz	Klein SonarPro	SDF (Sonar Data Format) or XTF
Seatronics R2 sonic MBES	2024	2009	vessel	selectable wide band (60kHz)	170-450kHz max160m (opt. 700kHz)	SVP	max 400m	Archaeological Pipeline Bathy mapping	y	y	optional			vertical res 12.5cm	Hypack, QINSy, EIVA, Triton, Starfix, Fledermaus, CARIS	XTF
Kongsberg GeoAcoustics	GeoSwath Plus	2010	vessel	single PDBS	125kHz/780m, 250kHz/390m or 500kHz/190m	n	200m/100m/50m	Bathy /habitat mapping		y	y			125kHz/6mm, 250kHz/3mm, 500kHz/1.5mm	GeoSwath Plus	XTF XYZ Surfer & Cube compliant
norbit MBES	iWBMS	2013	vessel	(FM & CW) chirp	360-440kHz	y	max 275m	hydrographic & Bathymetric surveys		y	y		y	10mm vertical	3rd Party Software (QINSy, Hypack, PDS2000, etc.	Norbit Native s7K
norbit MBES	iWBMSh	2015	vessel	(FM & CW) chirp	200-700kHz 400nominal	y	max 275m	hydrographic & Bathymetric surveys		y	y		y	10mm vertical	3rd Party Software (QINSy, Hypack, PDS2000, etc.	Norbit Native s7K
Systems Engineering & Assessment	SWATHplus	2006	vessel	single	117kHz/400m/234/468 kHz	n	max 1000m	Bathymetric/Geophysical surveys Habitat mapping	y		y			117/5cm, 234/2cm,468 1cm	Bathyswath	

Teledyne MBES	MB1	2012	vessel	selectable	170-220kHz	GPS Motion &SVP optional	max 240m	Harbour & shallow water surveysDredging Bathy mapping	H20 column	y	y		y	3.6cm	Teledyne PDS, QINSY, HYPACK, EIVA.	s7K
Teledyne MBES	MB2	2012	vessel	selectable	200-460kHz	GPS Motion &SVP optional	max 200m	Harbour & shallow water surveysDredging Bathy mapping	H20 column	y	y		y	2cm	Teledyne PDS, QINSY, HYPACK, EIVA.	s7K
Teledyne Reson SeaBat MB	7125	2007	vessel	single/dual	200kHz or 400kHz	SVP optional	max 475m	hydrographic & bathymetric maping geophysical surveys, water column imaging	H20 column	y	y		y	6mm Vertical	Teledyne PDS, QINSY, HYPACK, EIVA.	s7K
Teledyne Reson SeaBat MBES	8125	2010	vessel	single	455kHz	SVP	max 110m	hydrographic & bathymetric maping geophysical & piepline surveys, water column imaging	H20 column	y	y		y	6mm Vertical	Teledyne PDS, QINSY, HYPACK, EIVA.	s7K
Tritech Starfish	452F	2010	fish	single chirp	450 kHz/100m	n	50m	environmental /geological		y				2.5cm	Scanline Hypack Sonarwiz	XTF
Tritech Starfish	990F	2010	fish	chirp	1MHz /35m	n	50m	SAR Target ID mapping		y				1cm	Scanline Hypack Sonarwiz	XTF
Tritech Starfish	450H	2007	vessel	chirp	450 kHz/200m	n	50m	SAR Archaeological Engineering		y				2.5cm	Scanline Hypack Sonarwiz	XTF

[1]Waterdepth – Shallow refers generally to less than 50m

http://hydrography.geo-matching.com/

http://www.oicinc.com/geodasMB.html

chirp - acronym for compressed High Intensity Radar Pulse

REA - Rapid Environmental Survey

SAR - Search & Rescue

9. APPENDIX B1 - SITE 1 AND 2, WEST COAST

The two sites were known to staff at SAMS and had the advantage of survey within relatively easy reach of the SAMS laboratories. The sites were sheltered with a range of depth from 5m to 50m and a range of seafloor habitats including rocky reefs, gravel banks, sand with ripples to fine muds. Currents in the area were generally less than 2kts.

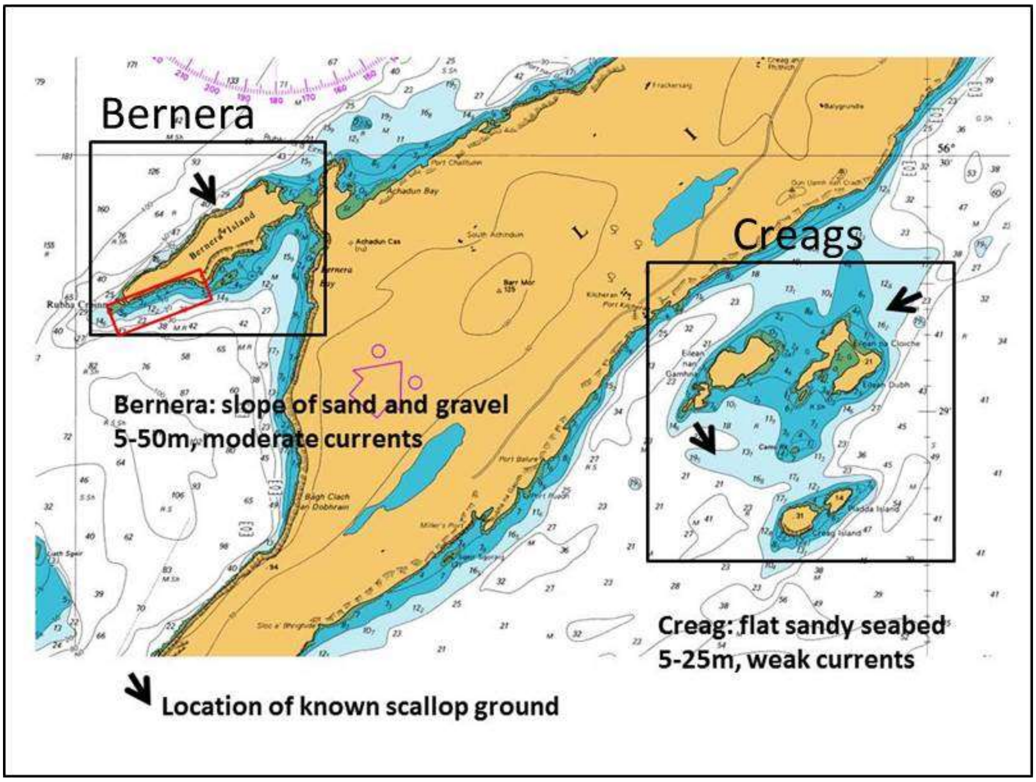

Figure B-1 Location of target areas near Oban, Scotland

9.1. Test Sites Surveyed using BathySwath & Norbit iWBMS Sonar

The priority sites were surveyed using the latest bathymetric sidescan and multibeam sonar equipment, namely the BathySwath sonar and Norbit iWBMS system. Each instrument was capable of recording both bathymetry and sidescan (amplitude) data. The BathySwath recorded at 468kHz frequency and the Norbit was recorded at two frequencies, 400kHz and 700kHz. Motion reference information was provided by Applenix WaveMaster with position using a Topcon RTK GNSS solution (Figure B-2). Both were deployed on the dedicated survey vessel *Swordsman*.

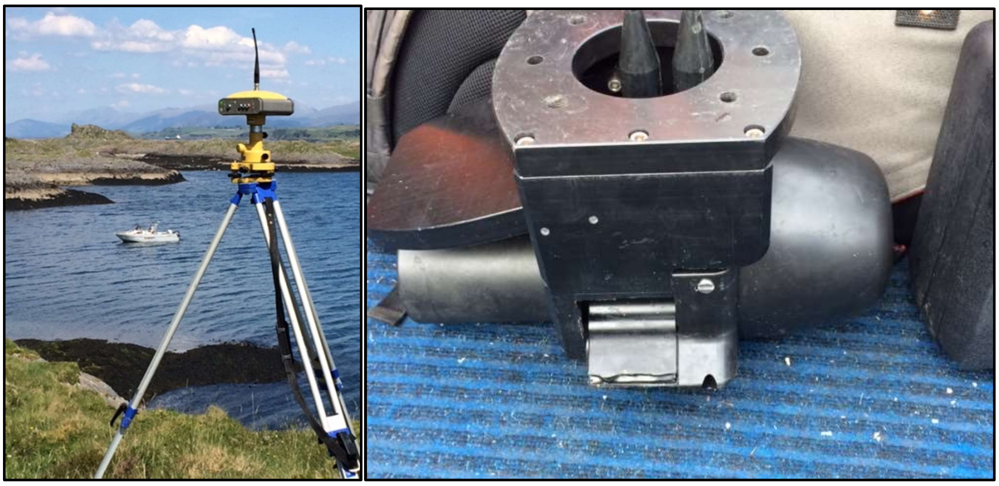

Figure B-2 Left: Topcon base station providing RTK navigation to the equipment on the Swordsman survey boat. **Right:** Norbit iWBMS integrated Wide Beam Multi-beam Sonar.

The Bernera site bathymetry was processed using QPS Qinsy, Qimera software and displayed in Fledermaus (Figure B-3). Rock outcrop features are clearly visible on the sloping seafloor at water depths down to ~20m. No obvious trawl marks were seen on the Norbit recorded bathymetry.

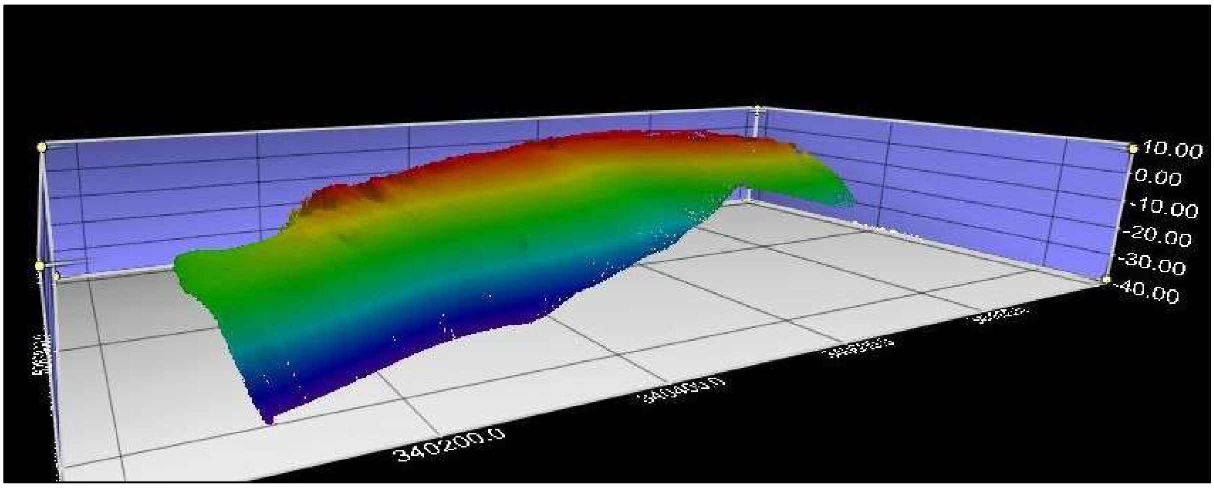

Figure B-3 3D perspective view of the Norbit bathymetry of the Bernera site (ED50). Sun illumination from the NE. Gridded at 0.5 m resolution. Vertical exaggeration is x3. Water depths extend from 0 m (red) to -40 m (blue)

The bathymetry of the Creags site (Figure B-4) reveals a much gentler sloping seafloor. The rock pinnacle seen at the north end of the AUV survey is seen here between the 5m and 10m contour. The shallower area to the north of the pinnacle, in and around the rocks show evidence of anchor drag marks and possible trawling scars.

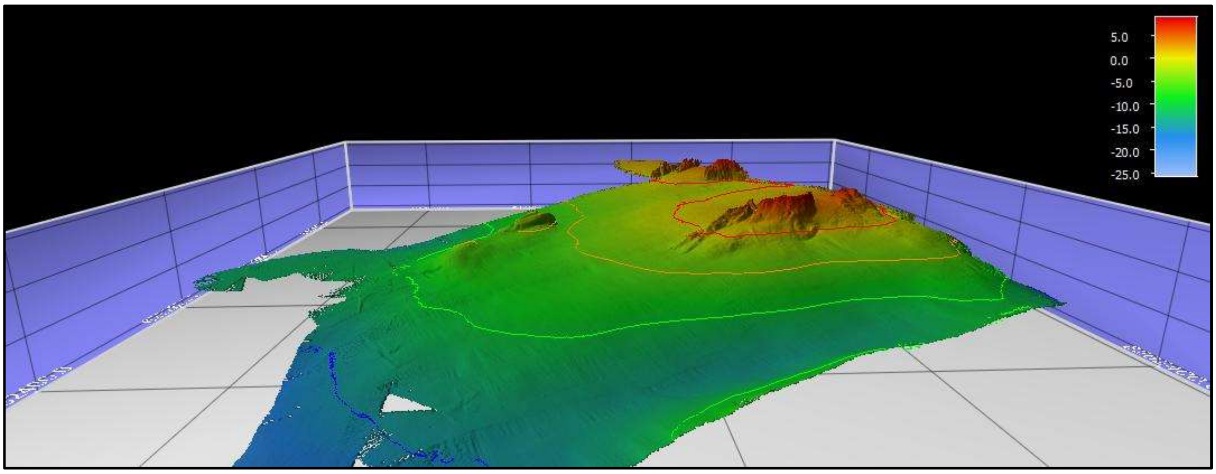

Figure B-4 3D perspective of the Norbit bathymetry of the Creags site (ED50). Sun illumination from the SW, vertical exaggeration x3. Gridded data at 1m resolution. Contours are 0 to -15m at 5m intervals.

Sidescan data (Figure B-5), acquired using the BathSwath, clearly shows areas of higher and lower backscatter which correspond to differing seafloor character. Creags (Figure B-5, left) has more distinct higher backscatter on the shallower gently sloping area, inferring more course sediments, and changing to low backscatter into the basin to the SW, inferring finer smoother sediments. The Bernera site is more heterogeneous, showing high backscatter along the rocky shore, graduating to lower backscatter sloping to the SE.

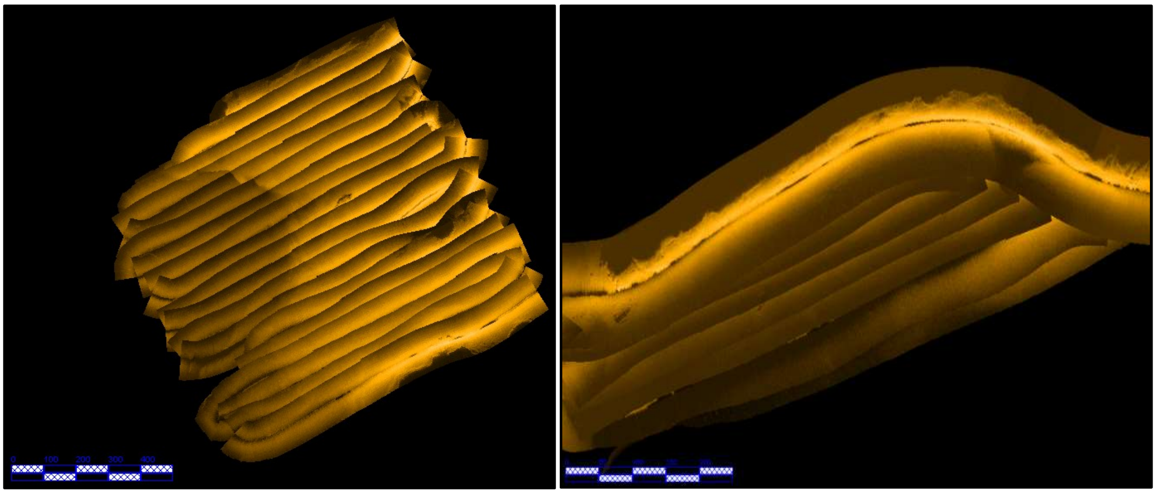

Figure B-5 Left: preliminary sidescan mosaic BathySwath (468Khz) of the Creags. Low backscatter (dark) corresponds to softer finer sediments (scale bar=50m divisions. **Right:** preliminary sidescan mosaic of the Bernera site. Rocky shoreline to the north showing as high backscatter.

The Norbit 400kHz sidescan data were investigated through Angular Range Analysis (ARA), using Fledermaus FMGT software suite, to characterize the seafloor. Conventional sidescan data are normally processed using an angle varied gain and thus lose some of the subtleties which can be picked up through ARA. Figure B-6 shows an example of the Bernera preliminary analysis.

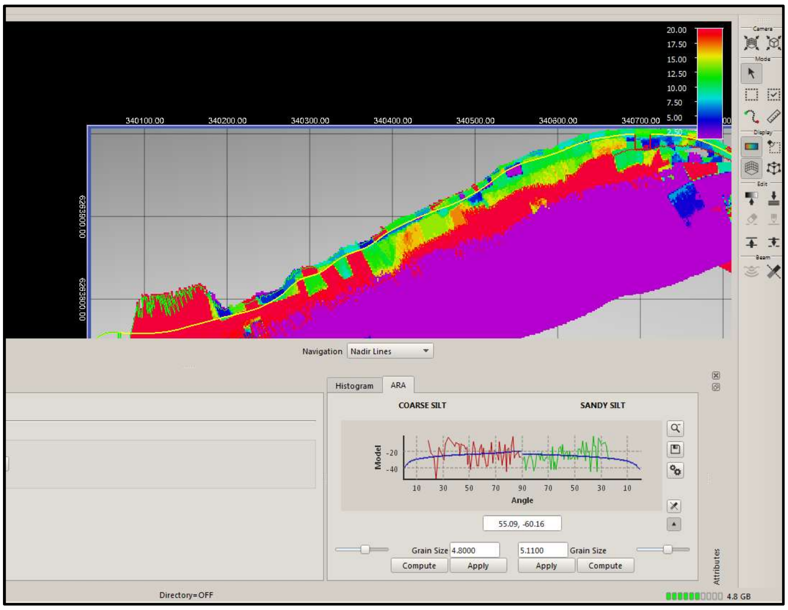

Figure B-6 Preliminary ARA of the Bernera site. Run using 0.10m sidescan mosaic. The variation in backscatter strength being a function of grazing angle, representing an inherent property of the seafloor. Low backscatter to high backscatter is displayed as pink to red respectively.

Figure B-7 is an example of the Creag Island site preliminary ARA analysis. The ARA characterization (left) identifies the site as being heterogeneous with a combination of muddy-sand, gravelly muddy-sand and areas with cobbles. Two further plots from the suite in ARA are shown here, Intercept and Impedance. Intercept highlights subtle gradient changes contributing to the model and Impedance (Right) is a measure of reflectivity.

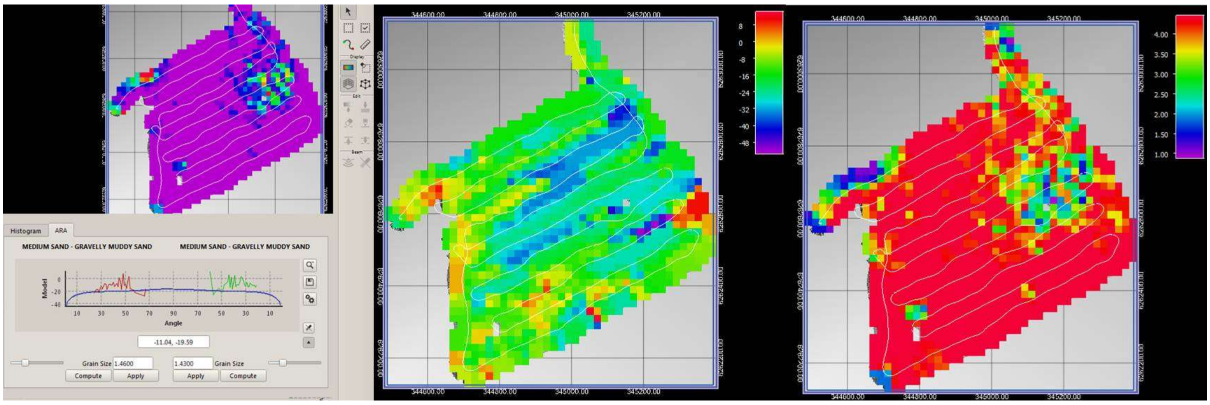

Figure B-7 Preliminary ARA of the Creag Islands site. Run using 1m sidescan mosaic. Left is the characterization, Centre is a plot of intercept angles and Right is a plot of Impedance.

While these analyses are proprietary to the Norbit system they follow common application of the Sonar Equation as is commonly applied in most marine sonar processing packages.

9.2. Test Sites Surveyed using Gavia AUV

Both sites were surveyed using a Gavia Offshore Surveyor autonomous underwater vehicle. This AUV carried a Kongsberg GeoAcoustics 500kHz GeoSwath^{+} interferometric sonar, with a Grasshopper benthic camera strobe. The AUV collected concurrent bathymetry and sidescan data and re-flew for photographic imagery.

Preliminary AUV bathymetry data from the two sites are displayed in Figure B-8. Bernera moderately slopes (~30 deg) from a rocky shore southwards, and as noted in the data acquired with boat-based instruments are characterized by silty-mud, sand and cobbles. Small rock outcrops are found in shallow water near the shore.

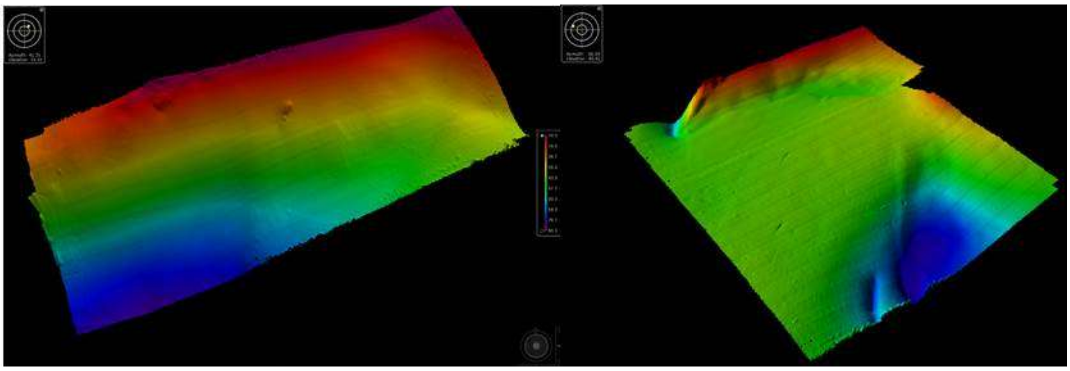

Figure B-8 Left: 3D perspective view of the AUV bathymetry of the Bernera site. Sun illumination from the NE. Gridded at 0.5 m resolution. Vertical exaggeration is x3. Water depths extend from 11 m (red) to 83 m (purple). **Right:** 3D perspective of the AUV bathymetry of the Creags site. Sun illumination from the NW, vertical exaggeration x3. Gridded data at 0.5 m resolution.

The Creag Island site gently slopes from the rock pinnacle (~12m) in the north towards a deeper basin (~37m) in the south. This area is included within a Marine Protection Area but has permissions for *Nephrops norvegicus* trawling. Form the very high resolution bathymetry mapping intensive trawl marks were evident on the bathymetry (Figure B-9) and sidescan data (Figure B-10).

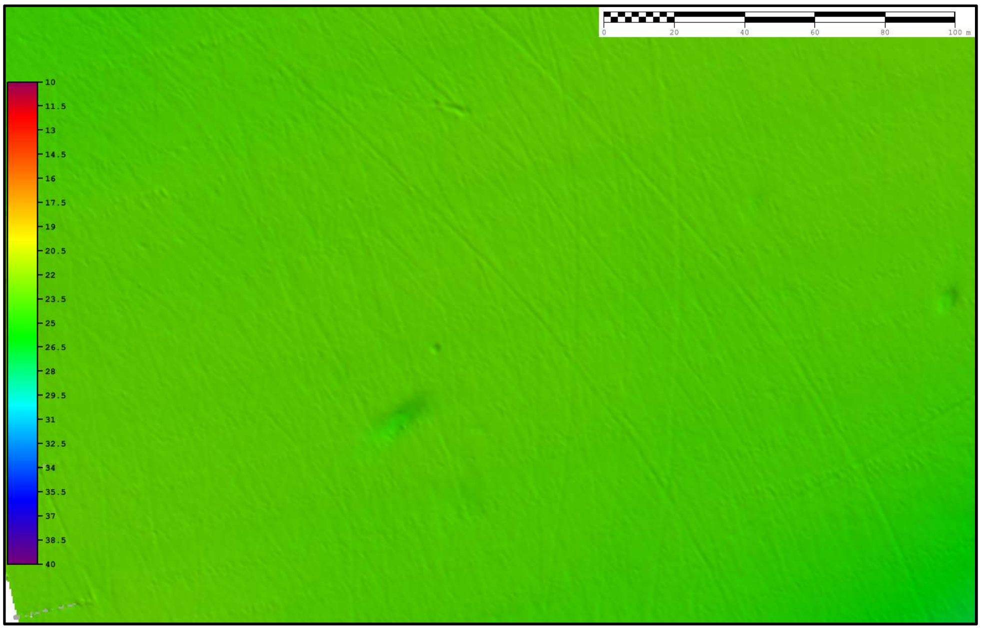

Figure B-9 Detailed AUV bathymetry of the SW Creags site showing intensive trawling activity on the seabed below about 20 m water depth. Gridded data at 0.5 m resolution (scale=20m divisions).

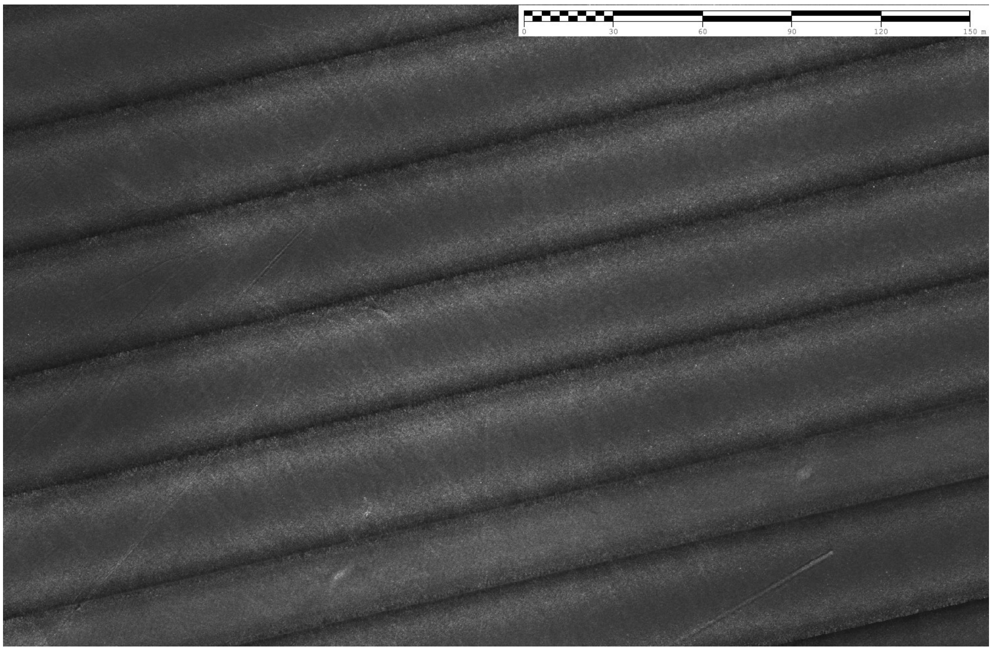

Figure B-10 Detailed AUV SSS mosaic of the Creags site showing intensive trawl activity SW of the site. Low backscatter (dark) corresponds to soft burrowed mud (scale=30m divisions).

Photographic imagery provided ground truthing, particularly for the interpretation of sidescan data. Approximately 11,000 photographs were collected from Bernera and approximately 10,000 from Creags. Both sites were recognized to EUNIS[5] level 3, and where diagnostic epifauna were present to EUNIS level 4. No scallops were identified from the seabed images at either location. Examples photographs are given in Figure B-11 and Figure B-12 with a mosaic of photographs shown in Figure B-13.

5 The EUNIS habitat classification is a comprehensive pan-European system to facilitate the harmonised description and collection of data across Europe through the use of criteria for habitat identification. EUNIS can be accessed through https://eunis.eea.europa.eu/

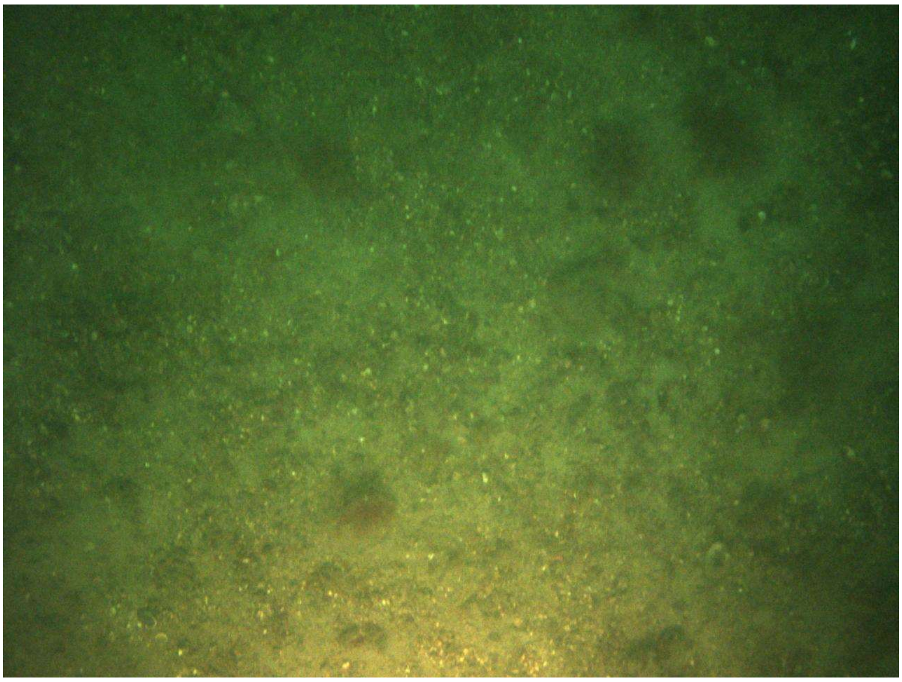

Figure B-11 Unprocessed, seabed AUV photograph from Creag Islands from ~12 m water depth showing a seabed composed of mixed sediment. Approximate scale is 1 m horizontal and 2 m vertical.

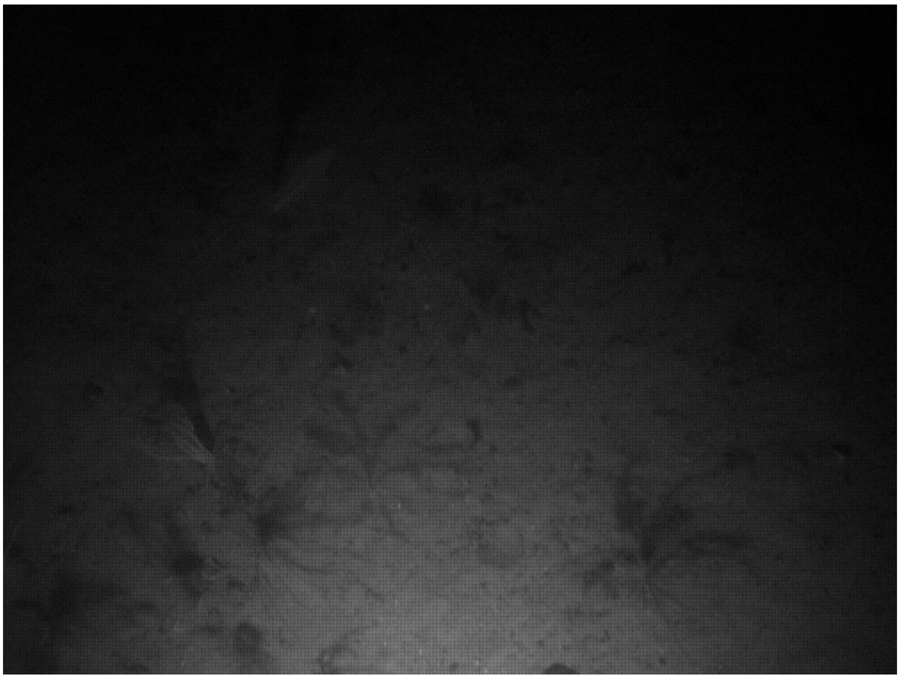

Figure B-12 Unprocessed black white seabed AUV photograph from Bernera in ~60m water depth showing soft burrowed sandy-mud with abundant feather stars. Approximate scale is 1 m horizontal and 2.5 m vertical.

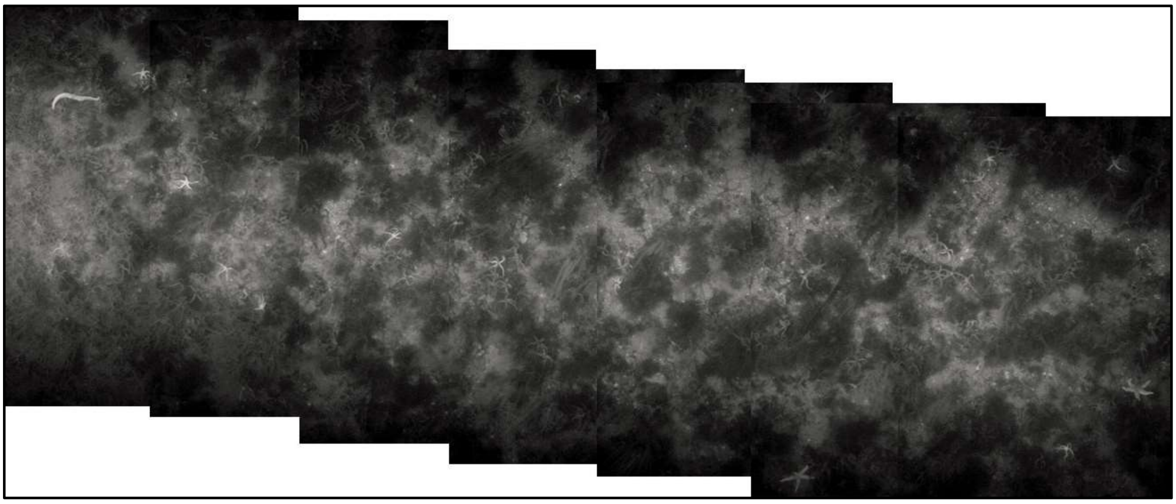

Figure B-13 An example of a short (~5 m) unprocessed photomosaic of the seabed in ~20 m water depth from the mixed sediment slope of the Bernera site. Abundant brittle star beds dominated by the common brittle stars Ophiothrix fragilis and Ophiocomina nigra. The abundance of these species masks the sea bed, and prevents easy observation of potential scallops in this location.

9.3. Test Site Creag Islands Surveyed using Walkway Velocity Analysis (WVA)

9.3.1. Detection of Buried and Partially Buried Scallop

At the beginning of the project there was a concern that identification of scallop habitats would be difficult where the scallops were buried or partially buried. Mapping these types of habitat, and further estimating the density of shell within them, would therefore require a method that could penetrate the sediment to a few centimetres and allow the characterisation of the sediment using the acoustic wave signature. Sonar systems are commonly available from industry to record sub-bottom information but these are typically aimed at penetrating tens of centimetre for engineering purposes to kilometres for hydrocarbon exploration. No system was therefore available as an off-the-shelf method of recording conditions of very shallow shell burial. However, an experimental system was available for evaluation based on the tried and tested methods of amplitude analysis as a function of incidence angle (AVA) and from vertical seismic profiling (VSP) as typically used in the hydrocarbon industry. The system tested was built by Shearwater Geophysical Co. Ltd who have been designing miniaturised systems for walkaway velocity analysis (WVA) and VSP for high resolution applications over the past 5 years. In summary, the primary objective of these tests was to evaluate the sonar wave amplitude variation as a result of partially buried scallop shells using a Walkaway Velocity Analysis technique. Tests were conducted at the Creag site in order to evaluate this method. Figure B-14 shows the equipment at the site.

Figure B-14 WVA instrument prior to deployment and in free navigation mode at the site.

9.3.2. Background to Method

The principles of the method rely on the natural variation response of the seafloor to acoustic waves at different offset angles. Amplitude response vs reflection angle can either be accomplished in a shot-profile fashion (de Bruin et al, 1990) or in a shot-geophone migration (Prucha et al., 1999). In both cases the angular data (gathers) are analysed using slant stacks on the wavefield prior to imaging.

9.3.3. Survey Layout

All sea trials were conducted at the Creag site with the intention of covering seafloor that contained buried and partially buried scallop in fine to medium sand. Sea-state was variable during the survey. Two types of test were designed, namely a corridor stack to simulate survey along a line transect through a scallop ground and a stationary survey where one instrument remained static at the centre of the site while the second instrument autonomously navigated around the site. The aim of the surveys was to test not only the ability of WVA to measure seafloor condition and hopefully to detect scallop but also to assess the repeatability of this survey method for long-term monitoring.

9.3.4. Results

In Figure B-15 the nominal survey line is coloured green and the corridor around it is coloured in blue. The red line represents the position of an autonomous unit during one acquisition period. Large scale displacements are related to support vessel positioning (i.e. the unit being on the back deck of the support vessel). Finer scale displacements observed in and around the blue box are due to the autonomous movement of the unit as it moves up and down the nominal survey line.

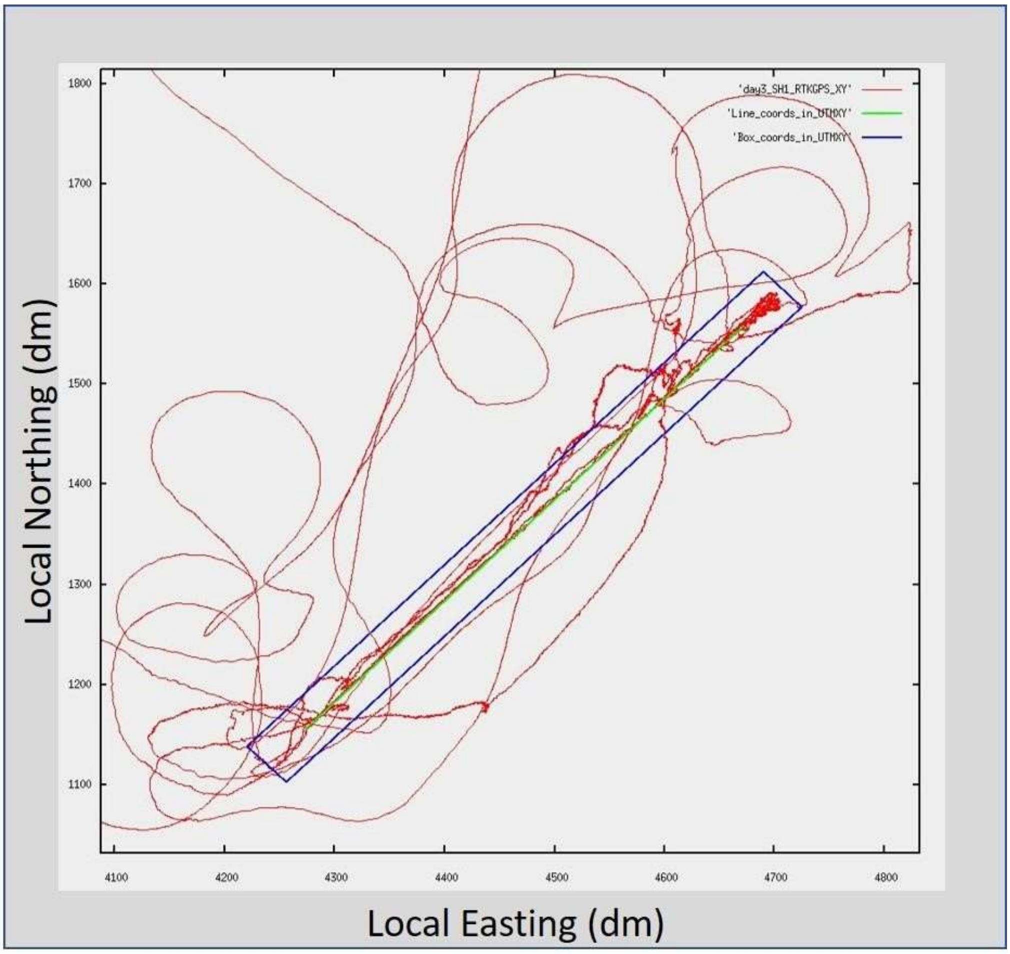

Figure B-15 Day 3 Shot Pattern.

Figure B-16 is a zoom in on the tracks associated with Lines 002, 003 and 004 and demonstrates the ability of the autonomous unit to hold line under different sea states.

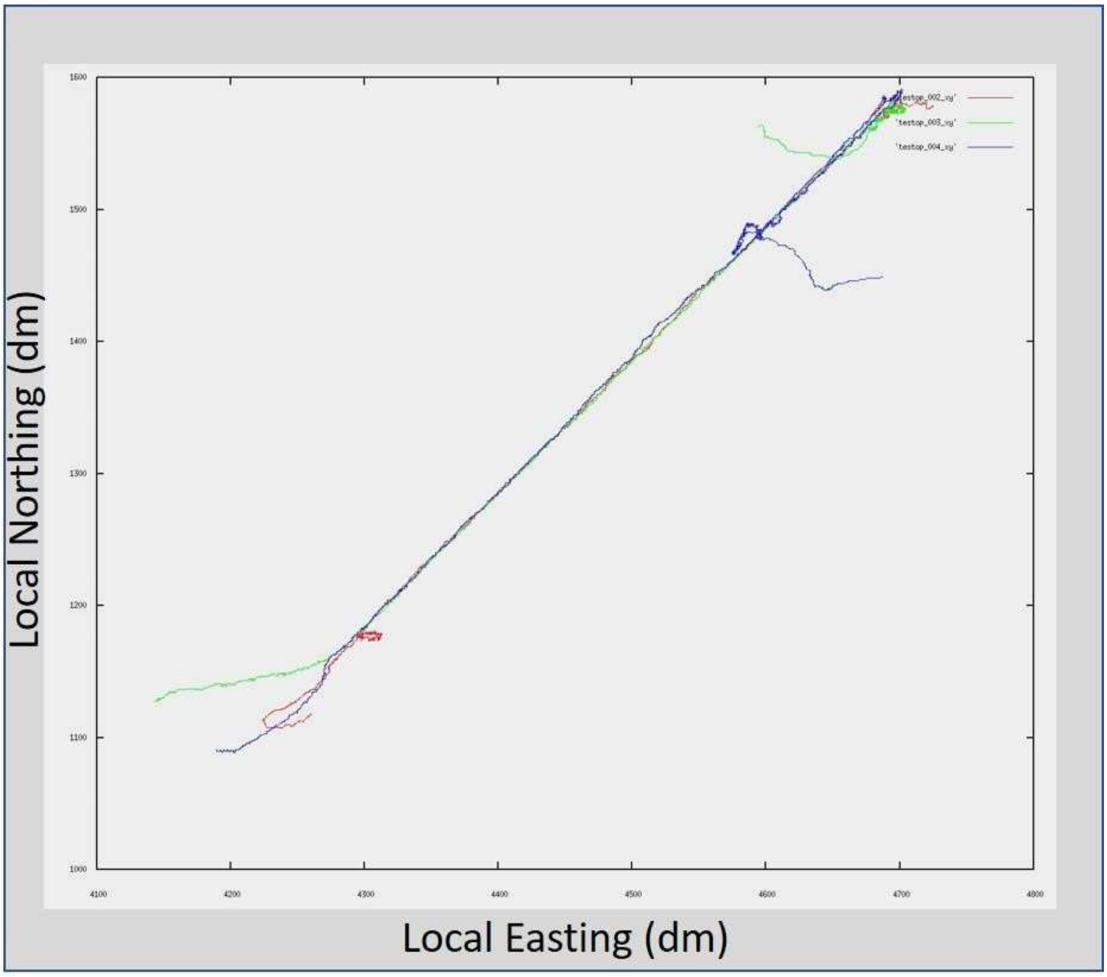

Figure B-16 shot positions for lines 002 (red), 003 (green) and 004 (blue).

9.3.5. Seismic Measurements

Source Parameters

Using one WVA instrument as the rover unit it was programmed to emit a coded signal at regular intervals using a 0.5-20kHz sweep signal (Figure B-17). The reflected signal was recorded on both the source (rover) and receiver (static) unit with resultant signals observed in real time for on-site quality control.

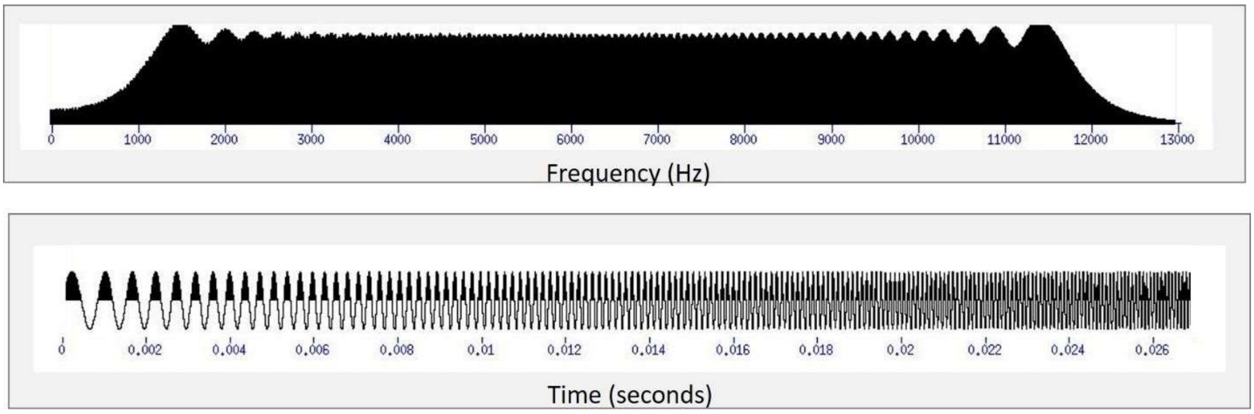

Figure B-17 Time series (top figure) and fast fourier transform of the signal shown (bottom figure) of the sweep-signal used in the field.

An example of the recorded source-wavelet after pulse-compression is shown in Figure B-18.

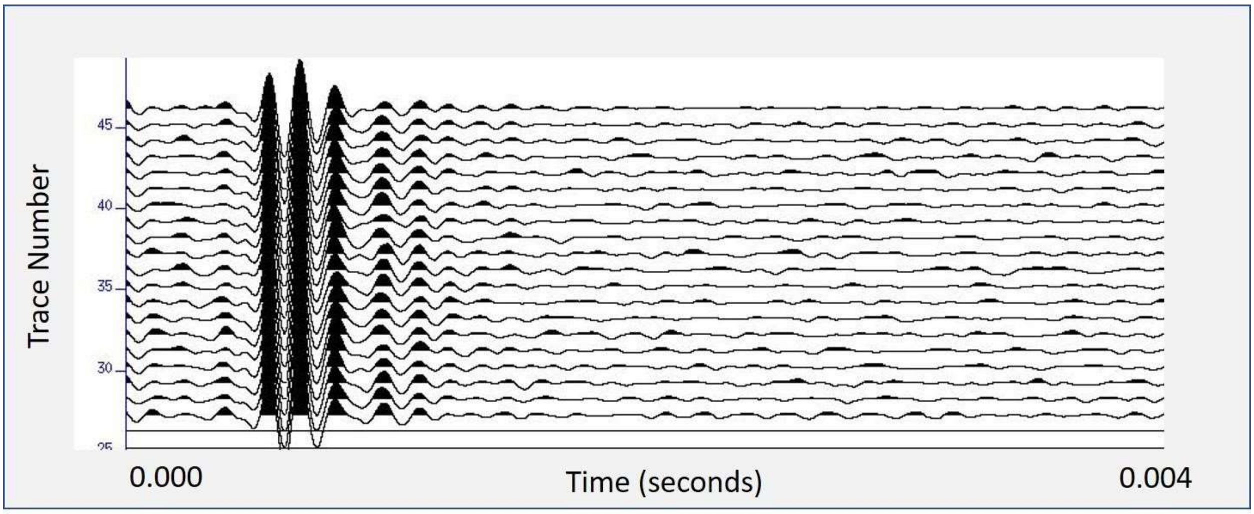

Figure B-18 Recorded source-wavelet.

Once recorded the then following processing sequence was undertaken:

9.3.6. Denoise

Initial processing involved coherent-noise attenuation in order to target the effects of swell motion and mechano-acoustic resonances from both the WVA motors and the support vessel. The severity of the noise varied as a function of the amount of effort needed to keep the autonomous devices on-track in the presence of changing swell, current and wind conditions.

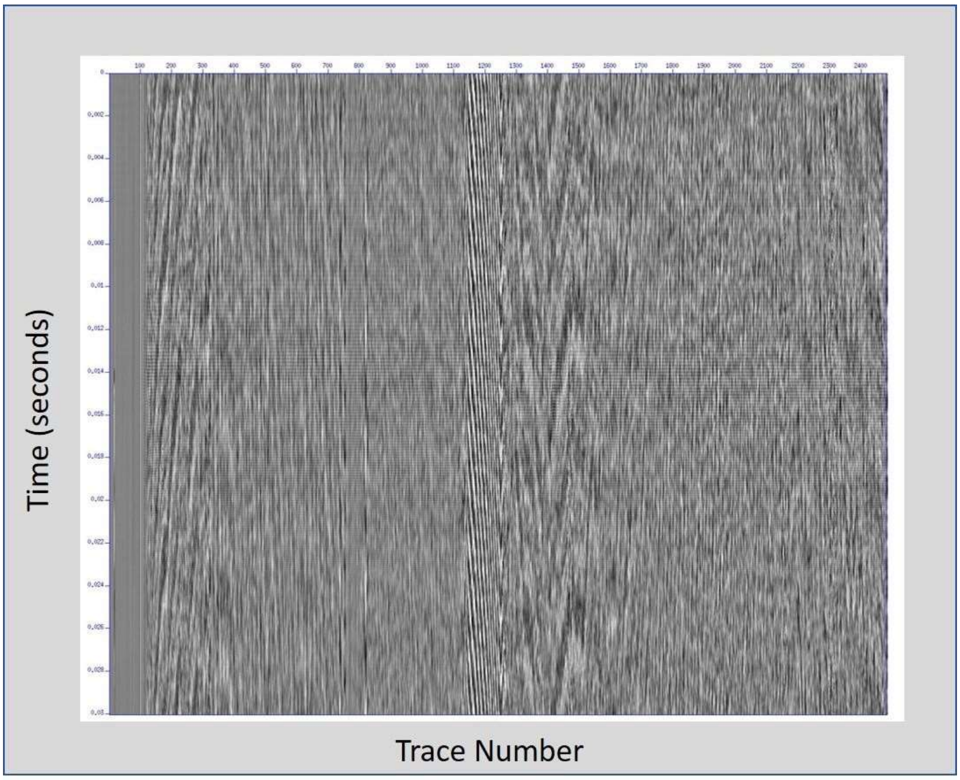

Figure B-19a Selection of raw traces before the de-noise process**.**

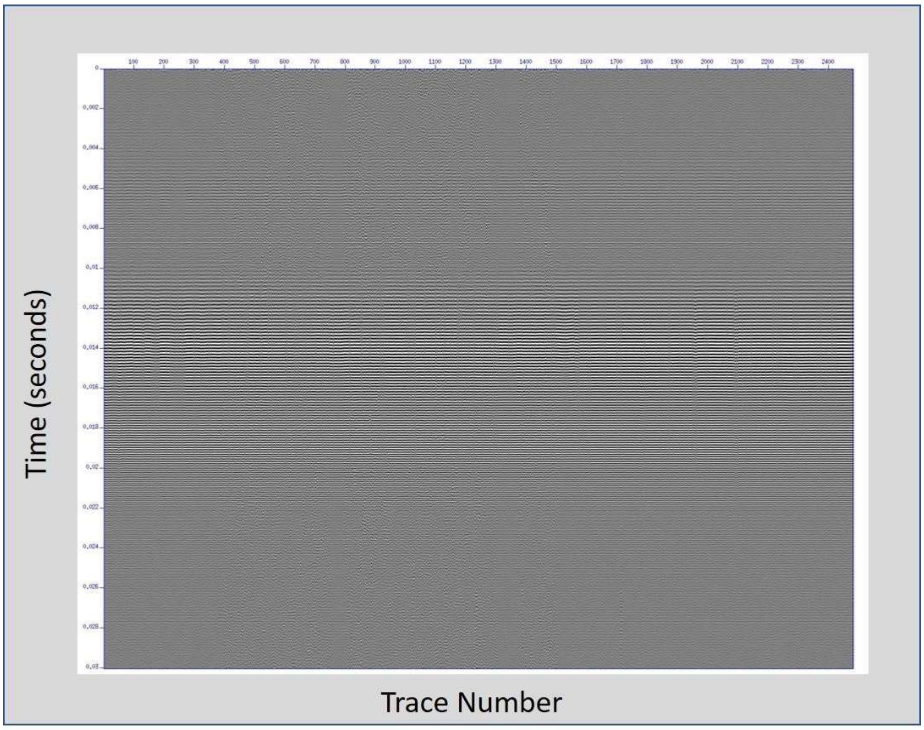

Figure B-19b Selection of raw traces after the de-noise process.

Figure B-19 shows an example selection of recorded traces from Line 002 a) raw, b) after the application of denoise processing. The former contains a variety of noise phases, in accordance with the prevailing sea-state and the different rig movements needed to counteract the sea-state motions. The latter reveals the sweep signals that, originally buried under the noise, represent emitted and reflected seismic energy.

As a further QC, a process was applied to both sections in order to collapse the sweep signals and to replicate the resultant source wavelet. Figure B-20 is a zoom of a selection of traces showing the impact of the coherent-noise attenuation on the shape and repeatability of the source-wavelet. Note the refinement in the shape of the initial onset in the upper section of traces (after denoise), together with an overall improvement in signal-to-noise as a result of the process.

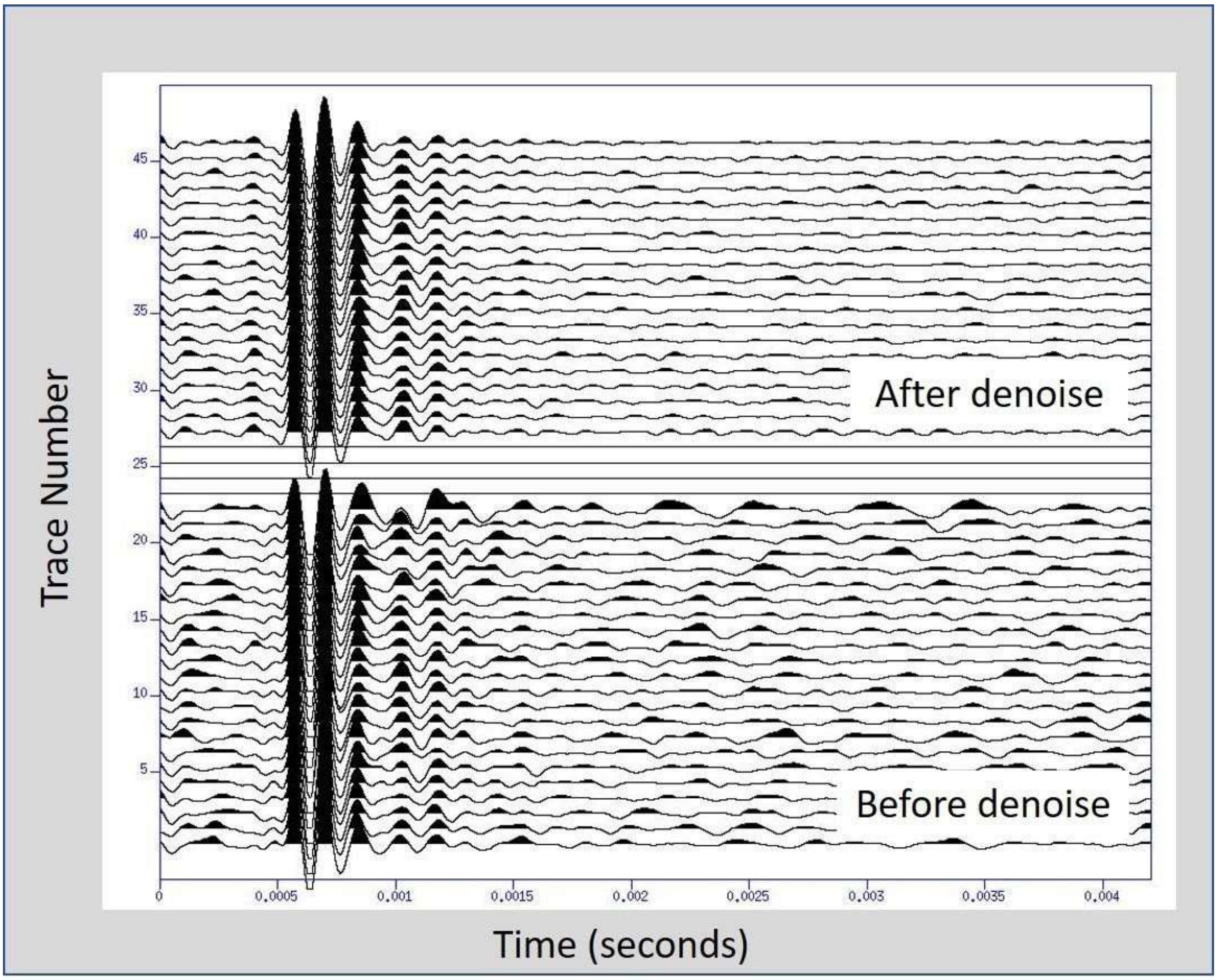

Figure B-20 Source wavelet observed at random shot positions along Line 002. Lower section has no de-noise, upper section is de-noised.

9.3.7. Sweep-Compression

The sweep-signal used during sweep-compression, is illustrated and described in Figure B-20. Sweep compression was applied to the traces output from the denoise processing (see previous paragraph). Figure B-21 is a zoomed section over a portion of Line 002 data, that demonstrates the impact of the process. It can be seen that the seismic reflection events at and below 18ms two way travel time are bright and have good stand-out. Note the oscillatory appearance of the reflection-events (as a function of trace-number or, rather, elapsed time). This is due to rapid change in elevation, associated with swell-motion at the sea surface.

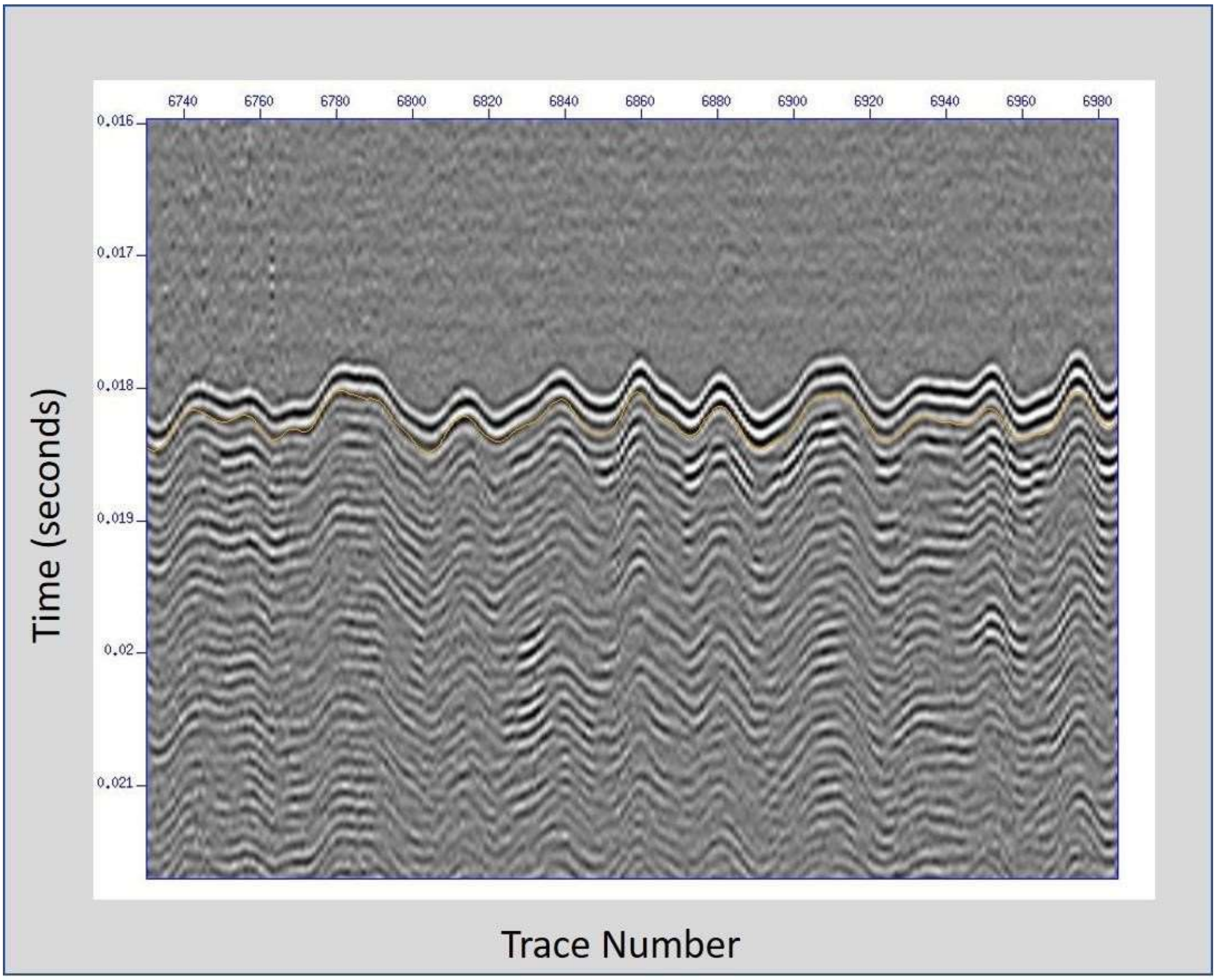

Figure B-21 Traces from Line 002 after the application of sweep-compression.

9.3.8. Re-datuming

The amplitude and wavelength of the sea/swell components imparted significant elevation change, and hence time-shift, to the recorded seismic wave-field. The shorter the wavelength (and greater the amplitude), the more difficult it can be to follow coherent phases between traces. In order to address this issue, a correction was applied to the recorded wave-field such that the transducers are shifted to a theoretical datum. Figure B-22 illustrates this process. Note the dramatic improvement in continuity of the seafloor and sub-seafloor reflectors in Figure B-22b compared to the input section in Figure B-22a.

9.3.9. Stack

Subsequent to redatuming, the data from each survey line were binned in a 3D sense (inline cell-size = 10cm; xline cell-size = 10cm). The traces within each bin were then stacked to produce the stack-sections shown in Figure B-23. Note, this is a vertical concatenation of Lines 002, 003, 004 and 005. Essentially, it spans the entire 66m corridor. While a lot of commonality exists in terms of the structure of the seafloor and sub-seafloor, one can see differences. For example, the noise-content in Line 002 seems to be higher than on the other three lines; Line 005 is missing illumination in places (due to lack of multiple overlapping data).

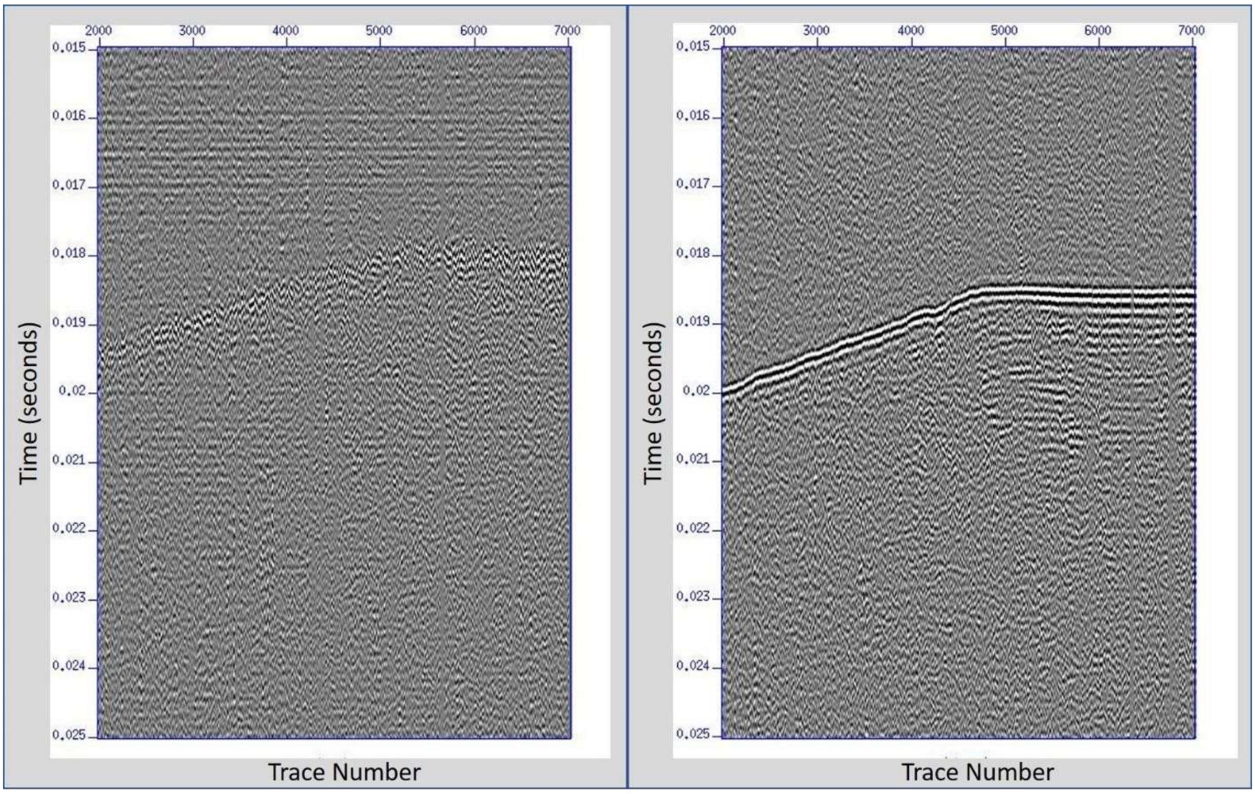

Figure B-22 Prestack traces after the application of a) sweep-compression (left), b) sweep-compression and redatuming (right) **.**

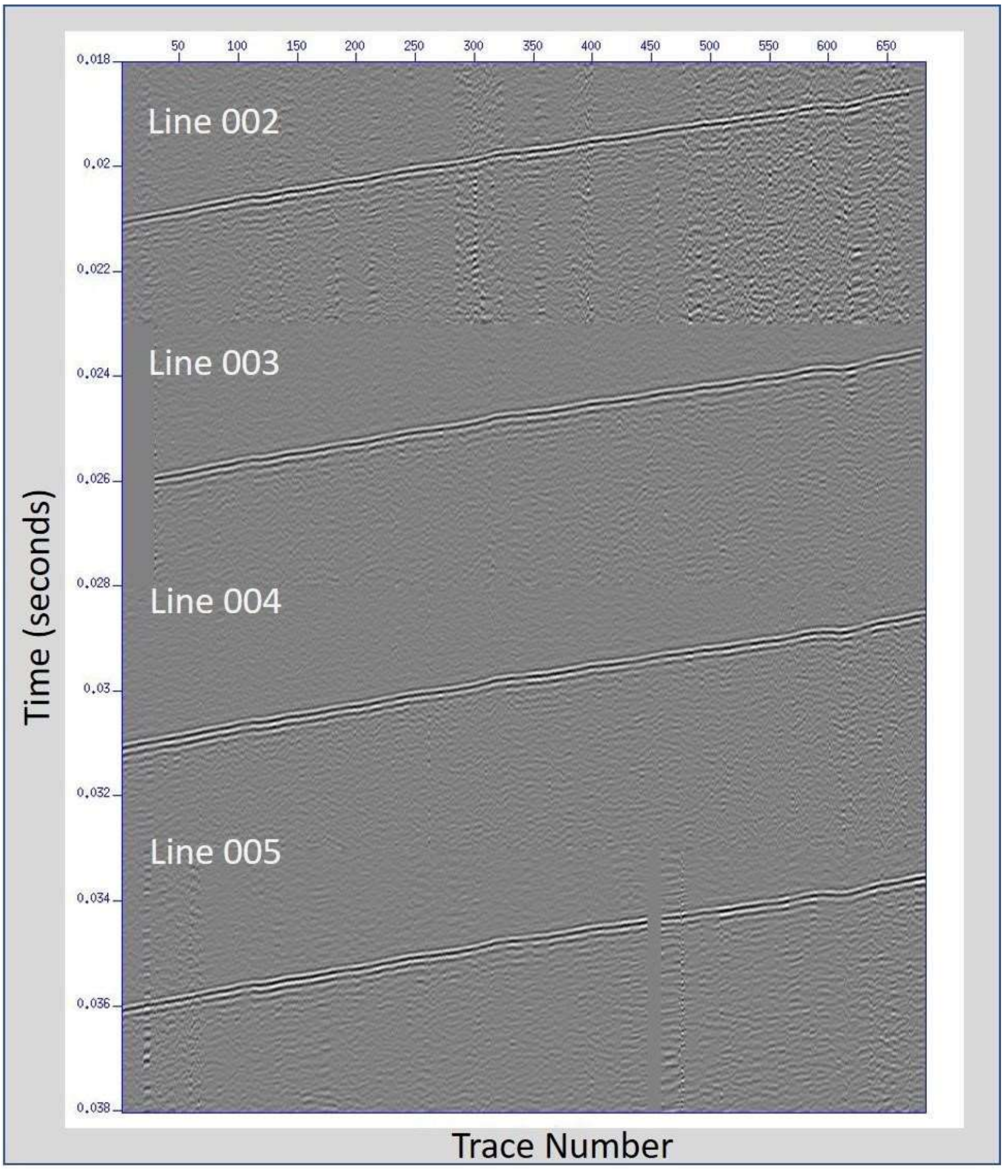

Figure B-23 Stack-sections for Lines 002, 003, 004 and 005, spanning approximately 66m of subsurface.

9.3.10. Interpretation

In order to assess repeatability, Lines 002, 003 and 004 were analysed over a line segment that had the highest degree of continuous, common bin-coverage. Line 005 was rejected from further analysis on the basis of these criteria. The line segment covered about 40m of the total 66m corridor. Prior to analysis, the pre-stack traces within each cell were time-lapse harmonized to ensure commonality between the different survey lines. The traces within each bin were then re-stacked for input to repeatability analysis. Repeatability is essentially a measure of how similar two traces (acquired at different times but existing within a given common-reflection-point bin) resemble each other. In order to assess this, two types of seismic attribute were considered namely, root mean square of amplitude and instantaneous amplitude.

9.3.11. Root Mean Square (RMS) Amplitude

Using a gated time-window in the range of 18-23ms, the RMS amplitude was calculated for each trace associated with the stacks shown in Figure B-23. These attributes are plotted in Figure B-24. Though relative amplitude fluctuations between the three lines show a ±6% variability (probably related to noise), the trends are remarkably similar suggesting a high degree of repeatability in the data.

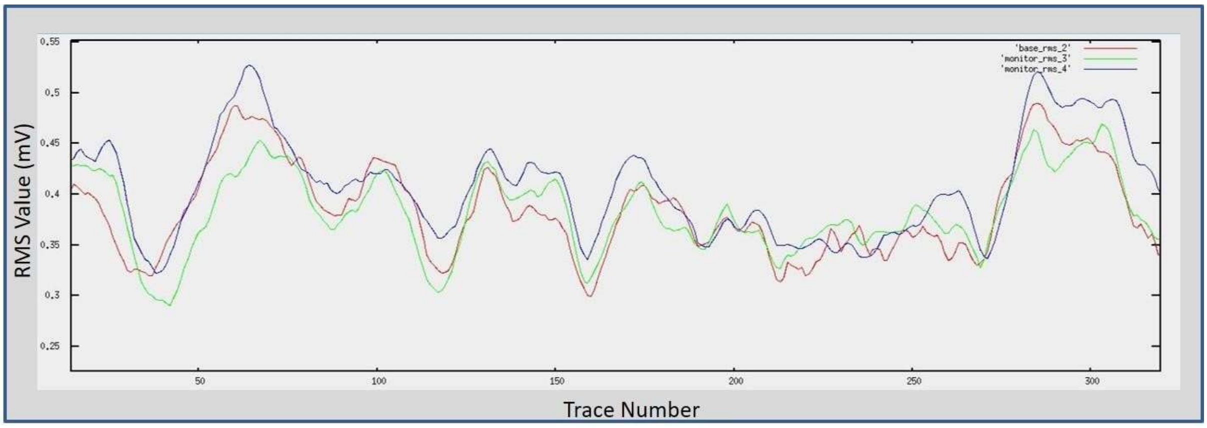

Figure B-24 RMS amplitude attributes extracted from the stacks of Line 002 (red), Line003 (green) and Line 004 (blue)

9.3.12. Instantaneous Amplitude

The RMS attribute can only provide a single number associated with a given trace (at a particular common-reflection-point location), however, the instantaneous amplitude allows a more comprehensive view of how similar the seismic stacks are, in terms of both lateral and vertical changes. Figure 3-25a shows a vertical ensemble of this attribute derived from the three line segments. To a first order, the similarity is striking. Figure 3-25b shows an interpretation of “reflectivity-compartments” based on common lateral and vertical trends observed in the attribute distributions. Note how the amplitudes within each compartment exhibit a dim-bright-dim trend.

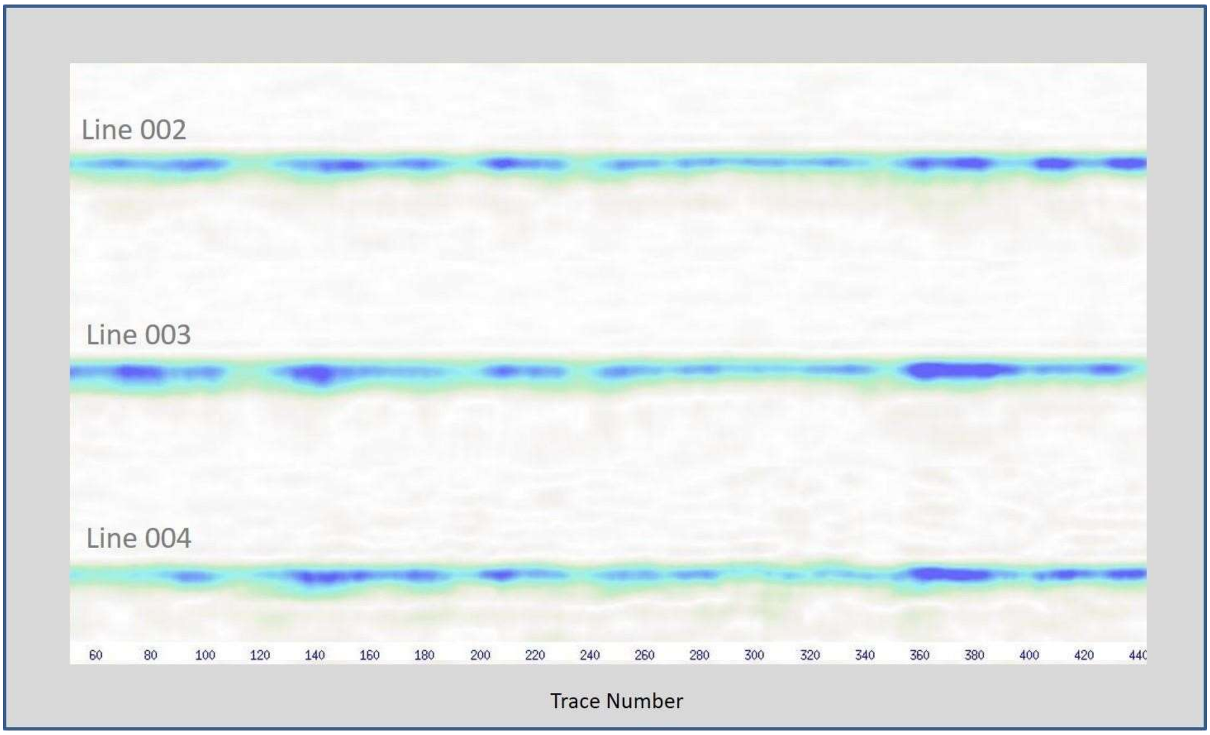

Figure B-25a Vertical concatenation of instantaneous amplitudes extracted from the harmonized stack sections, for Lines 002, 003 and 004.

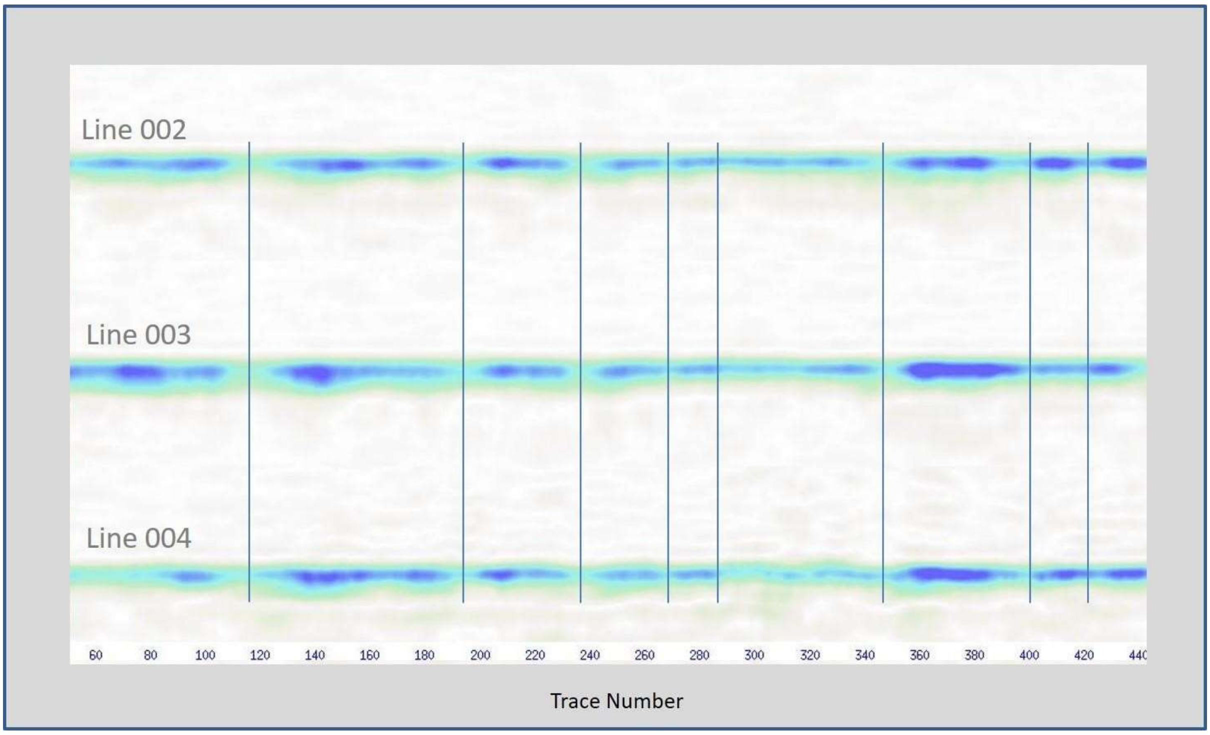

Figure B-25b Vertical **concatenation of instantaneous amplitudes extracted from the harmonized stack sections, together with interpreted reflectivity compartments**

Even though the seismic data show deeper reflection events elsewhere in the survey area, these results indicate a thin veneer of soft sediment overlying a much stiffer sediment/bedrock. Further, that the dim-bright-dim amplitude variations arise from changes in the local reflectivity at the seafloor (over a 5-50cm depth range), with 'dims' occurring where the soft sediment is relatively thicker, and the reflectivity 'brights' where the stiffer/harder sediment is closer to the seabed interface. These 'brights' could also be associated with buried or partially buried shells. Unfortunately, as noted in the main body of the report, the density of scallops reported by the divers after the remote surveys were made, was not sufficient to allow for a full evaluation of the WVA method.

9.3.13. Conclusions and Recommendations

Significant noise (both from mechano-acoustics and the sea-state turbulence) was present in the recorded data, however, despite this and the challenges posed for processing, repeatable acoustic data were obtained using the WVA method. Changes in seabed state (texture) as a result of the sediment condition types were mapped using the technique and thus the method holds promise for mapping changes in acoustic property as a result of shell burial. More sea trials are recommended especially at sites where control of scallop density is achievable.

9.4. Ground Truth Data

At each of the sites ground truth information was obtained by a scientific dive team from Heriot Watt University. The dive team was experienced in benthic mapping and in particular in making underwater observations that could be used for statistically rigorous analysis of shell stock.

A brief summary extract from the dive log is shown in Tables B-2 and B-3. Table B-2 has information on dive transects within the priority areas of Creag Islands with the summary extract from the log presented in table B-3. Across all areas low densities of scallop were present especially within the areas where extensive trawl marks were observed in the sonar records.

Table B-2 Dive transect log extract from the two priority sites.

Location	Depth (m)		Transect bearing	Scallop count	Scallop Length (cm)					Substrate
	Transect start	Transect end			1	2	3	4	5	
Bernera	11.6	12	115	1	7					First 9m of transect, boulders with common Echinus esculantus and Saccharina latissima. 9m to 25m on transect, Sandy mud and shell gravel, large shell fragments and pebbles rare.
Bernera	9.7	11.7	120	1	15					First 10m of transect mud with coarse sand, pebbles and 5 -15cm rocks. 10 - 25 mud
Bernera	15.4	15.1	285	0						Sandy mud. Surface gravel, pebbles & shell of <2 cm size - <5% cover; >2cm size <<1% cover.
Bernera	14.6	14.6	235	1	11					Sandy mud with shell grit (~20%). A few dead shells.
Creags	10.8	11.4	245	5	13	13	13	12	12	Cobbles, pebbles mixed coarse gravel with muddy sand, red algal turf on the pebbles and cobbles
Creags	14.4	14.3	250	4	10	11	13	1.5		Sandy mud with shell grit (~20%). A few dead shells and pebbles. Occasional 5 - 15cm cobbles.
Creags	10	10.7	220	4	14	15	13	14		Surface gravel (~2-4 mm) ~90% cover with silty sand infill. Dead venerid shell 10-20% cover.
Creags	12.3	13.3	240	0						Surface gravel ~2mm about 70% on muddy sand. Red algal turf (Trailliella) 80%. Dredge tracks evident (not very recent).

Table B-3 Extract from exploratory search dives.

North (Y)	West (X)	Dive Time	Dive depth	Scallop density	Substrate	Notes
56.48245	-5.5298	09:29	16.5	1-9 per 10 x 10m (1 seen in ~25 m2 area)	Muddy sand with 30-40% surface gravel and 5-10% pebbles & cobbles.	Depart shot line station at 6 min dive time swimming ~90deg. At 12 min dive time depth unchanged, sediment sandier & with more gravel. Small (~5-10 m wide) patches of cobbles encountered en-route. Scallops remain sparse (1-9 per 10 x 10m; 4 seen).
56.4827667	-5.52782	09:47	15.2	1-9 per 10 x 10m	Silty sand with ~90% surface shell gravel. Pebbles & cobbles 5-10%, small boulders 5-10%.	Depart station at 21 min dive time swimming ~45deg (inshore). At 23 min dive time, depth ~14 m, meet slope of large boulders at the base of bedrock outcrop. Resume bearing ~90 deg on sediment plain. Sediment becoming coarser and less silty. Patches of cobbles with Saccharina latissima. Scallops remain sparse.
56.4834	-5.52547	10:04	12.8	0	Sand with ~90% surface shell gravel. Pebbles & cobbles 5-10%. Saccharina latissima 10-20%.	Depart station at 40 min dive time swimming ~90deg. At 41 min dive time enter area with ~50 small boulders & cobbles. One restricted patch with scallops 1-9 per 3m by 3m but elsewhere sparse or absent. At 44 min dive time move out of rocky area onto the gravelly sand sediment.
56.4837	-5.52302	10:20	13	1-9 per 10 x 10m (1 seen in ~25 m2 area)	Sand with ~90% surface shell gravel. Pebbles & cobbles 5-10%. Venerid bivalve shells 5-10%. Saccharina latissima 20-30%.	Depart for surface at ~55 min dive time.
56.4787167	-5.51005	10:47	13.8	1-9 per 30 x 30m	Muddy sand with shell fragments	
56.4783667	-5.51195	10:55	12.7	1-9 per 30 x 30m	Coarse sand with shell fragments.	Vigularia mirabilis present
56.4842333	-5.5137	11:47	7.3	0	Gravel, coarse sand, shell sand	Saccharina latissima 70%, Desmerestia aculeata and red algae turf, Asterius rubens common
56.48355	-5.5123	12:02	9.3	0	Coarse sand some gravel and stones	Saccharina latissima 50% , and kape form Saccharina latissima and reds
56.48375	-5.51033	12:15	11	1-9 per 10 x 10m	Stones coarse shell sand, dead shells	Saccharina latissima 40% and red algal turf
56.48375	-5.5098	12:22	13.9	1-9 per 10 x 10m	Coarse shell sand, muddy, patchy stones	Saccharina latissima 10%, little other algae
56.4887167	-5.5023	12:57	23.2	0	Soft burrowed mud	Nephrops norvegicus and Vigularia mirabilis present
56.4880167	-5.50418	13:07	22.7	0	Pebbles on shelly sandy mud, occasional cobbles	
56.4872833	-5.50588	13:19	11.3	0	Sand and shelly gravel with occasional pebbles and larger dead shells (Pectin, Artica, Modiolus)	Swimming on a bearing of 225, after shallowing to 8m dense banks of Saccharina latissima encountered
56.4917	-5.5072	13:56	13.8	0	Muddy sand with 10-20% surface pebbles. Mixed foliose red algal turf 50-60%.	Depart shot line station at 5 min dive time swimming ~225deg. At ~11 min dive time, depth ~10 m the substrate becoming more rocky with increased density of Saccharina latissima.
56.4908	-5.50798	14:08	9.9	1-9 per 10 x 10m (2 seen in ~25 m2 area)	Muddy sand with 10-20% small boulders and 20-30% cobbles & pebbles. Saccharina latissima ~40%.	Depart station at 19 min dive time swimming ~225deg. Area ~60-70% covered in dense Saccharina latissima. Scallop density estimated at 1-9 per 30 x 30m (2 seen) but obscured by kelp.
56.4898333	-5.509	14:26	6.8	0	Silty sand with 5-10% small boulders and 10-20% cobbles & pebbles. Saccharina latissima ~80%.	Depart for surface
56.4894333	-5.51983	14:49	9	0	Muddy sand with gravel and shells. Short algae turf with occasional Saccharina latissima	
56.4895667	-5.51853	15:07	11.4	0	Muddy sand with gravel and shells. Abundant Saccharina latissima + filamentous red	
56.48955	-5.50602	15:40	14.6	0	Stones (30%) on sandy mud	Vigularia mirabilis x1; hydroids and red algal turf 1-5%; Bispira volutacornis x1; Asterias rubens and Echinus esculentus present.
56.48955	-5.50843	15:56	7	0	Muddy sand, some stones	Saccharina latissima 50%; Plocamium cartilagineum + red algal turfs 30%; Hyas araneus and Asterias rubens present.
56.4938167	-5.50748	16:21	14.2	0	Pebbles on shelly sandy mud, red algal turf	
56.4924667	-5.50918	16:32	8.6	1-9 per 30 x 30m	Sandy mud and gravel, occasional pebble	Saccharina latissima 10 %, algal turf 80%
56.4925833	-5.51012	16:39	6.6	0	Large boulders, cobbles and pebbles over sandy shelly gravel	Saccharina latissima and Laminaria digitata 80%

It can be seen from the dive information that the number of scallops recorded during the dive surveys was too small to enable any statistically meaningful analysis.

9.5. Conclusions and Recommendations from Initial Field Trials

The initial field trials were disappointing with respect to testing methods for mapping different densities of scallops due to the lack of scallops following what must clearly have been a period of heavy dredge harvesting. This was manifest by the lack of scallops and high density of trawl marks across all the sites. It was therefore decided to seek out a site where high density of scallops could be guaranteed.

10. APPENDIX B2 – SITE 3 (HAND DIVE SCALLOP LOCATION)

Whilst acoustic techniques have proven useful for the larger *Pecten* species, the king scallop proves more difficult to detect acoustically, often living partially buried in a depression in the sediment, it therefore has a reduced acoustic footprint and becomes almost indistinguishable from the surrounding sediment. Our original trials did highlight the value of acoustic methods for habitat classification and coupled with imagery there is potential for a robust detection technique. The imagery also provides valuable ground truth and additional ecological information. However, in order to test further the methods a site was needed where abundant scallops were known to be both on the seafloor and partially buried within the seafloor. It was also useful to have both dead and live scallop.

A new test site (Figure B-26 and B27) was selected based on the advice from Alasdair Hughson, Keltic Seafare (Scotland). The site is situated close to Unapool; forming a shallow relatively flat (approx. 9 deg) shelf which drops away more sharply towards the outer edge of the cove. The seabed is a mixture of course sand, pebbles through to larger rocks and boulder/slabs, intermittently covered with macroalgae.

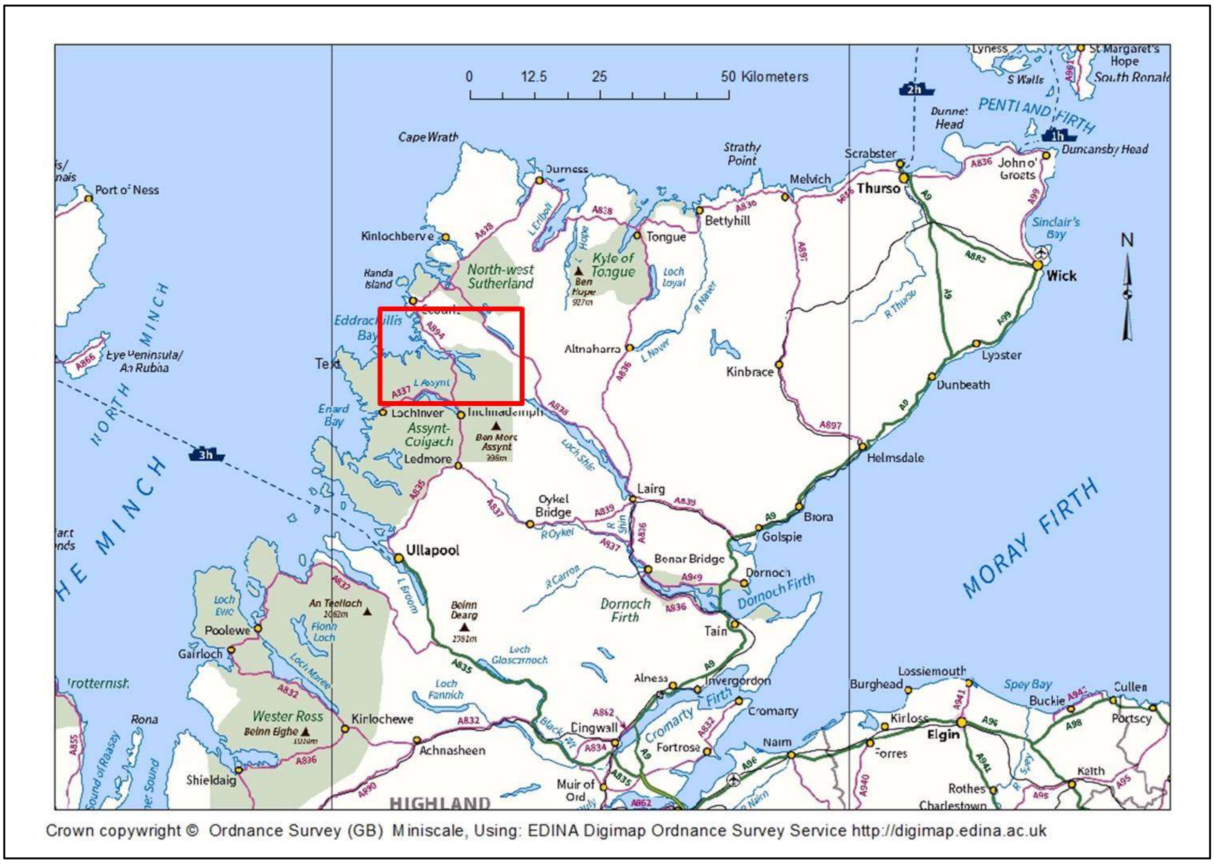

Figure B-25 Ordnance survey Miniscale map showing the location of the new site highlighted in red. The scallop sites are seeded by Alasdair and due to the monetary value of these sites, their specific location is sensitive and should be kept confidential.

The new site had been seeded with scallops which were grown in tanks and subsequently placed in locations in the near shore that were naturally high in nutrient, to increase their size naturally before harvesting once fully mature. Due to the commercial sensitivity of these sites, the specific location is not given.

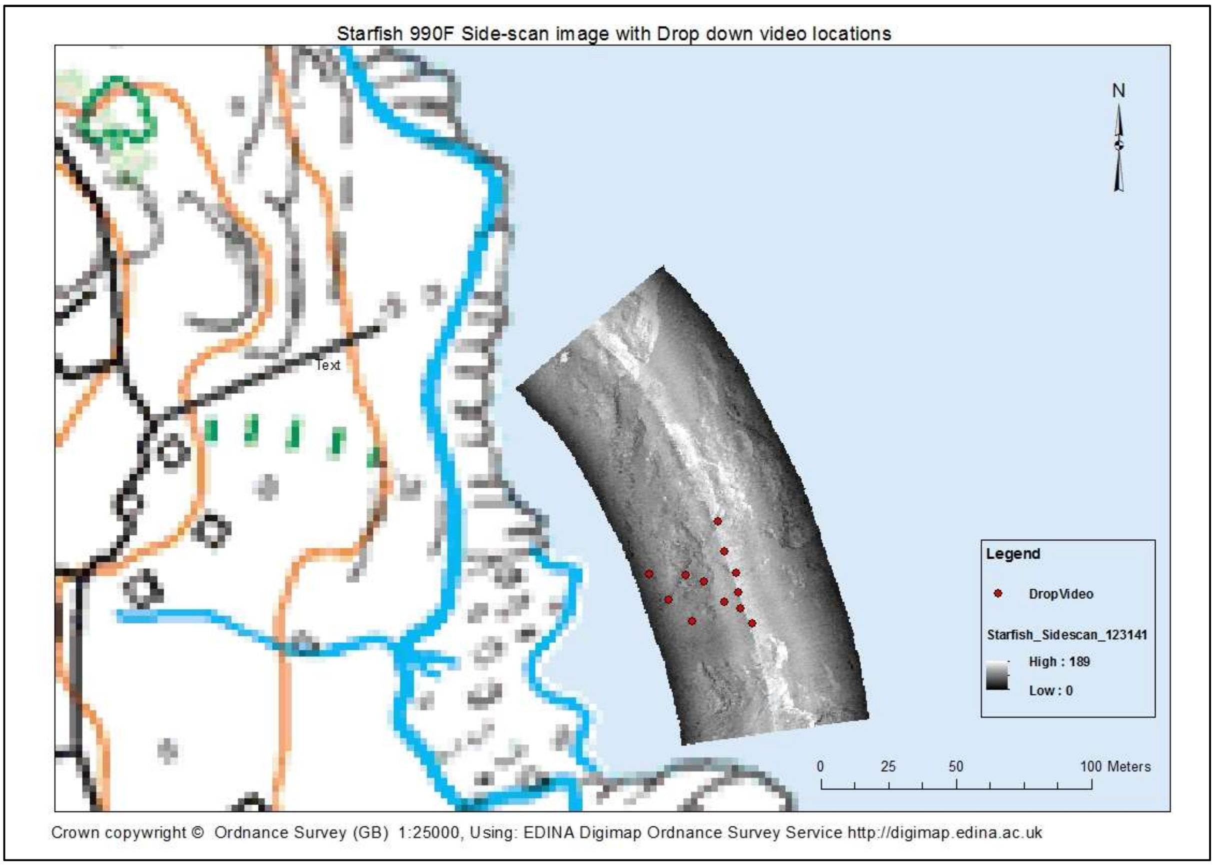

Figure B-26. Ordnance Survey 1:25,000 backdrop map showing sidescan data from a single raw edited line. Low backscatter (darker) represents softer sediment or shadow in signal return, higher backscatter (light) represents denser/ harder sediments. Edge effects (darker margin) are due to under correction of amplitude drop of with offset.

10.1. Survey

The new site was trial surveyed using a pole mounted Tritech 990F Chirp sidescan sonar fish, recording at 1000kHz nominal frequency and with the BathySwath (Figure B-27). The latter was used to be able to complete a cross-comparison with previous surveys and the former used as it represented the most affordable solution for non-scientific survey. The Tritech sonar has a 1m to 35m range, enabling a total coverage of 70m with a 1cm optimal resolution. Positional information was provided by the Starfish's dedicated GPS and data acquired using Tritech Scanline Software. Data were subsequently processed using licensed Chesapeake Technology SonarWiz version 6. Imagery data were collected as colour HD 1080p video via a Tritech MD4000 camera and additionally using a VideoRay ROV. Both imagery systems used their integrated LED lighting. Video data were acquired using Ulead Video Studio via EasyCap USB adapter.

Figure B-27 Left: Starfish 990F side scan sonar, **Centre:** Tritech MD4000 HD video, **right:** VideoRay ROV with integrated HD video camera

The Tritech MD400 high resolution camera was initially tested collecting a land to seaward transect approximately 25m length, then subsequently by spot sampling attached to a sledge as random video drops. The sledge was lowered onto the seabed and footage was recorded for approximately 3-4 minutes whilst disturbed sediment settled.

10.1.1. Sonar Results

Sidescan data were collected over the area of the site; the line shown in Figure B-28 crosses the zone where the random video drops were undertaken (also shown Figure B-26). Outcrops of rock are clearly visible in this display as dark areas, which are exposed through the sands. This line was used to test the classification software option within SonarWiz (Figures B-28 to B-30).

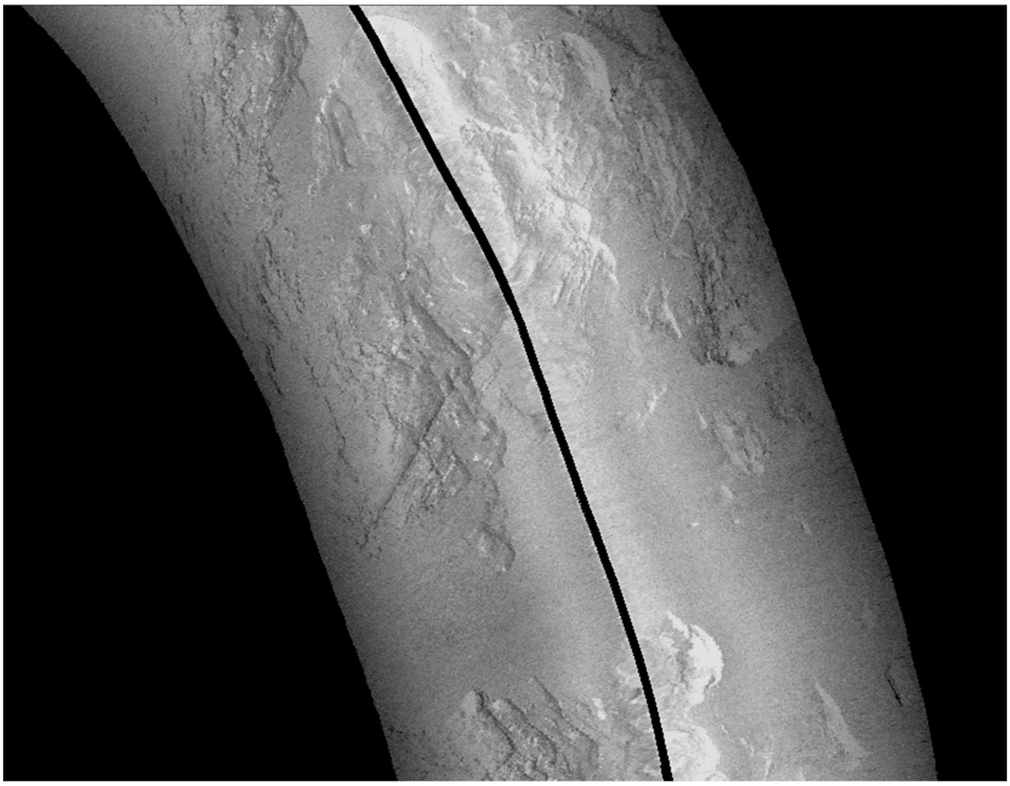

Figure B-28 Preliminary processed sidescan (1000Khz) of a line crossing the zone in which the drop down video footage was recorded. No gain corrections are added. In this display, Low backscatter (lighter) corresponds to softer sediments or shadow (lack of return). Scale: swath trimmed to 35m on each channel. The site slopes gradually towards the east (right of the plot).

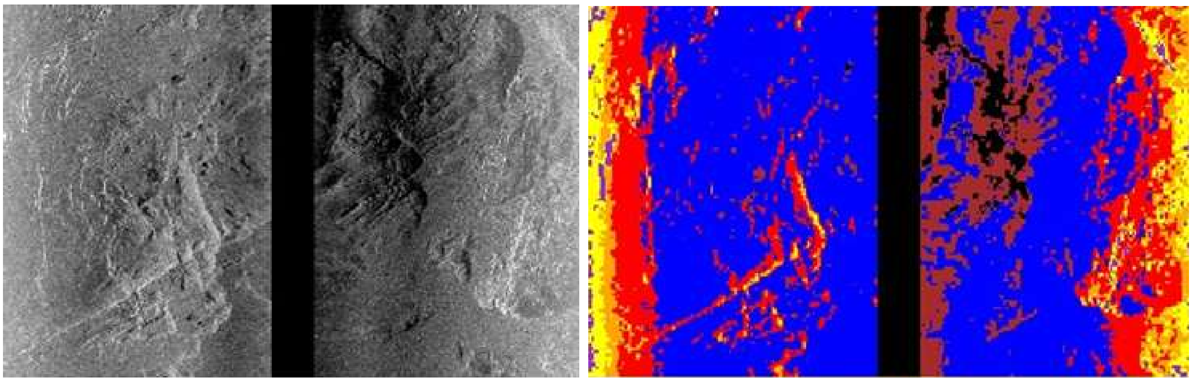

Figure B-29 Preliminary characterisation using SonarWiz version6. Left are the input data, right is the applied attribute characterisation. Edge effects are due to the offset-gain being poorly corrected.

Initial processing is required to balance the amplitude decay with increasing offset from the source (Figure B-28). A time variant gain (TVG) was applied (Figure B-29) and several attributes tested as classification methods. The optimum attributes for Classification were by entropy and intensity.

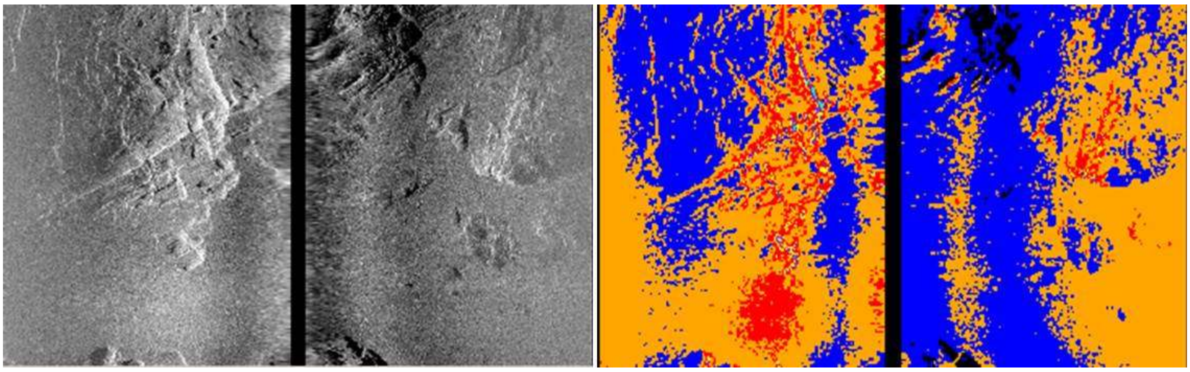

Figure B-30 Preliminary characterisation using SonarWiz. Left are the input data, right is the applied attribute characterisation. Edge effects are more appropriately corrected for offset. White/ Red represent high intensity harder surfaces.

Following optimisation of the TVG, training of the characterisation software allows a preview of applied settings (Figure B-30), after which full characterisation of the input dataset can be run with the production of an output shape overlay (Figure B-31).

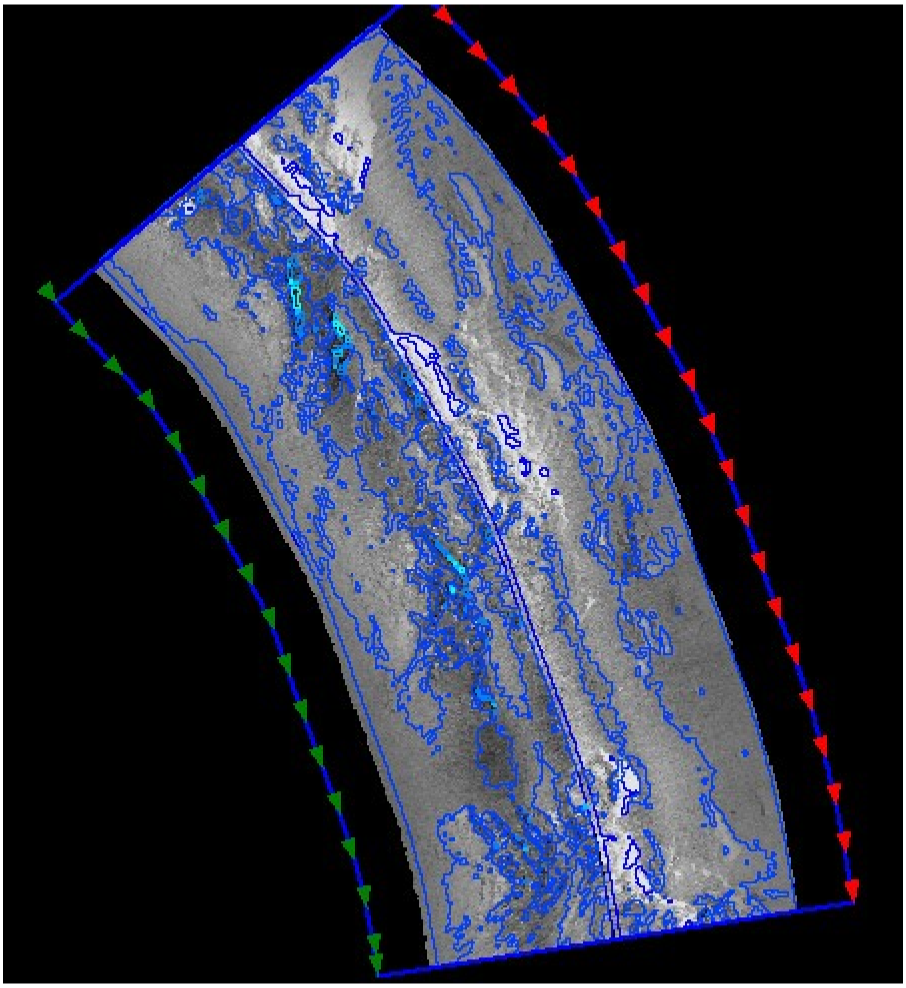

Figure B-31 Preliminary characterisation overlay using SonarWiz version6.

10.1.2. Ground Truth Results – Imagery

Mixed results were obtained from the initial trials. The transect video (Figures B-32 and B-33) gave good clear images, though height above the seabed requires refinement. Off-vertical clear images of the upper valve are desired because oblique angles make it difficult for object detection applications to identify the scallop based only on shape. Figure B-33 demonstrates how difficult it may be to detect the scallops when they are recessed into depressions and covered by sediment. Ecological information and identification of macroflora and fauna could easily be extracted from the imagery.

The method for deploying the drop down sledge could be improved to reduce sediment disturbance. Towards the later drop down samples, there was an increased volume of suspended particles which interfered with the ambient lighting, not only causing light to be reflected back to the camera but also causing the camera to focus on the particles (Figure B-34).

Figure B-32 Preliminary Tritech MD4000 1080p Still image extracted from video transect footage. Height above the seabed is approximately 50cm.

The ROV imagery was recorded after the drop down spot sampling. Lighting was lowered (Figure B-35) to reduce the reflection from suspended particles caused from the disturbance, however, the resulting images have little contrast which might be an issue for automated processing but still allows for manual identification of the scallop and therefore counting. The imagery was not clear enough at these lighting levels to allow approximate visual classification of the substrate.

Figure B-33 Preliminary Tritech MD4000 1080p Still image extracted from video transect footage. Scallops are seen here living within depressions and covered in sediment. Camera height is approximately 2m.

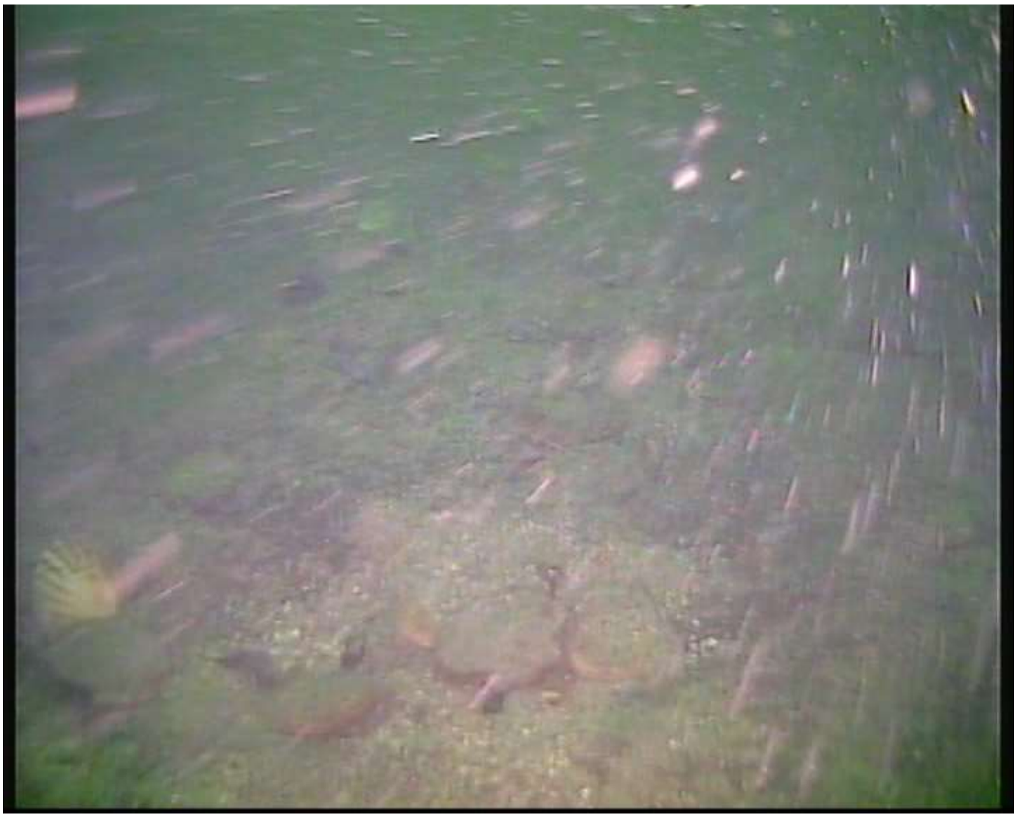

Figure B-34 Preliminary Tritech MD4000 1080p Drop down. Still image extracted from video which demonstrates issues with suspended particles and light reflection.

Figure B-35 Preliminary ROV imagery. Still image extracted from video footage. Lighting has been reduced to reduce reflection.

10.2. Summary Results and Recommendations from Field Trial

Following this initial set of tests it was clear that this site contained sufficient abundance of scallops to allow for a full test of the acoustic and visual methods. Furthermore, with the aid of the scallop divers it would also be possible to conduct ground truth sampling in a controlled manner to allow calibration of the detection equipment across sediment/ habitat classes, following a method which was statistically robust.

10.3. Site 3 Resurvey

Initial test trials on Site 3 highlighted the value of acoustic methods for habitat classification. Coupled with appropriate imagery there is a high potential for a robust combined scallop detection technique. The imagery additionally provides valuable ground truth and ecological information including site condition. The second survey at the seeded site aimed to further calibrate the sonar results and to use the divers to provide ground truth data for number of scallops at specific locations for comparison with the remote sensing data.

10.3.1. Revised Methodology

A 25m rope transect was laid over the seabed in an approximately NNW to SSE direction. The start point was attached to an anchor on the seabed and the far end was staked into the sediment and anchored to a large rock. At the surface two buoys marked either ends of the transect line. Sample locations were marked along the transect rope at 5m intervals by red cord which would be easily visible on the imagery. The line was first surveyed by sonar and then by imagery detection methods in the same direction. Once surveyed by the two methods, a diver team collected all scallops from within the marked quadrat locations before repeating the detection methods, with the aim of quantifying the change in population. At each marked location a 2m cord was attached to the transect rope, such that the diver could swim in a circle ($12.57m^2$) to collect the scallops, which were bagged for counting. Here the shape of the quadrat was based on ease of use for the divers. Optimal size is yet to be determined.

A pole mounted Tritech 990F Chirp sidescan sonar fish was used for the main sonar survey. Recording at 1000kHz nominal frequency, the sonar has a 1m to 35m range enabling a total coverage of 70m with a 1cm optimal resolution. Positional information was provided by the Starfish's dedicated GPS and data acquired using Tritech Scanline Software (Figure B-36). Data were subsequently processed using Chesapeake Technology SonarWiz version 6. Additionally, a SwathPlus bathymetric sonar system (combined bathymetry and backscatter) was used to survey the wider area of the test site, for a more general characterisation of the habitat. The system was pole mounted on a smaller support vessel with navigation provided by a Trimble differential GPS (Figure B-37). The system has a nominal 468kHz frequency and an optimal resolution detection limit of 1.5 cm, with a range approximately 8 times the water depth. Data were acquired and processed using Bathyswath Swath processing software.

Imagery data were collected as colour HD 1080p video via a Tritech MD4000 camera and additionally using a low cost action camera for time lapse stills. Both imagery systems used the integrated LED lighting from the Tritech MD4000 (Figure B-36). Video data were acquired using Ulead Video Studio via EasyCap USB adapter. Still images from both systems were loaded into ImageJ software and using the 12mm transect rope to calibrate the scale (which was also marked in metre sections), the footprint for the imagery was estimated. A further open source night vision Raspberry Pi camera was intended to be tested, however, the waterproof housing failed and no data were collected.

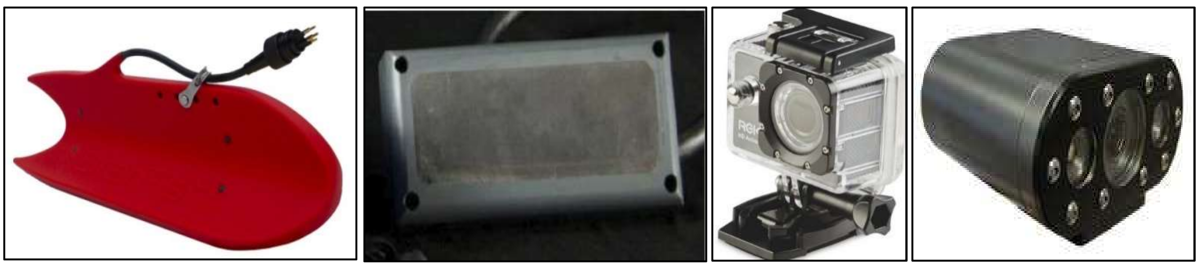

Figure B-36 Detection equipment Left Starfish 990F side scan sonar, Centre left Bathyswath 468 transducer (one per channel), Centre right Action HD stills camera and right Tritech MD4000 HD video camera.

Figure B-37 Left: Bathyswath system, bow mounted with differential GPS. **Right:** The boat used to survey Starfish Sonar & Imagery.

10.3.2. <u>Results</u>

Sidescan data were collected along and in the direction of the transect line using the Starfish high resolution sonar (Figure B-38). The target zone was close to the Nadir, falling on the centre side of the starboard channel. The presence of the scallops is not obvious in these data but other seafloor features such as anchor drag marks are visible at the beginning of the line on the port channel.

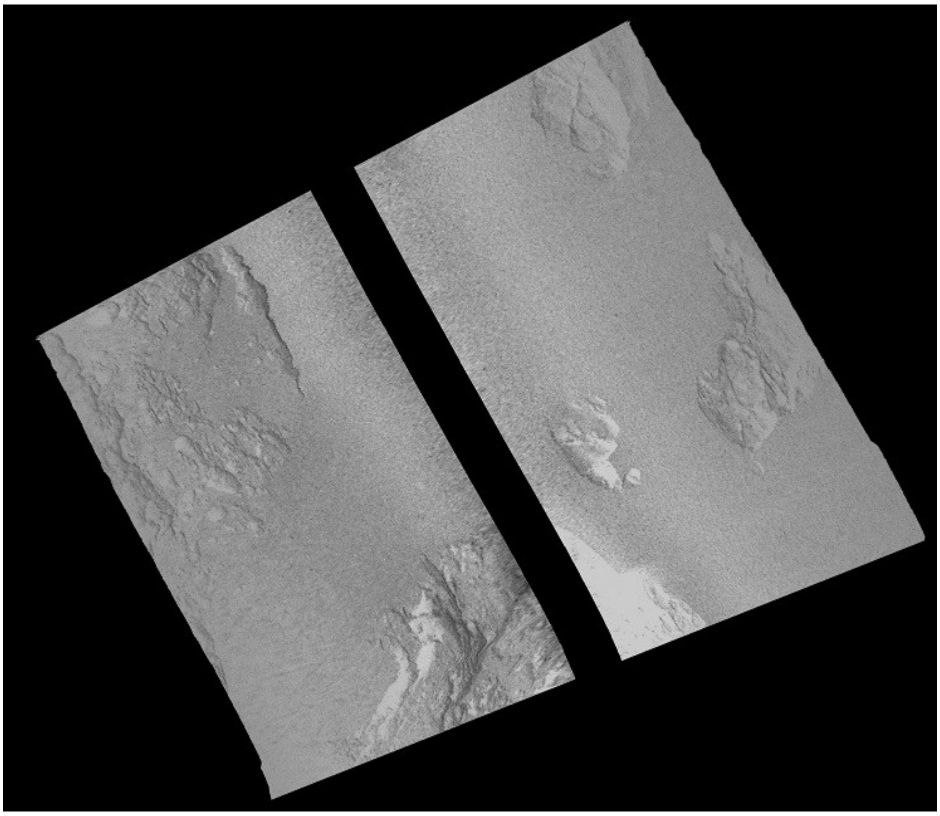

Figure B-38 High resolution preliminary processed Starfish 990F side scan sonar data. The line was shot in a NNW direction. Low backscatter (lighter) corresponds to softer sediments or shadow (lack of return). Scale: the overall swath range is 54m.

Further investigation of the sidescan data using the classification tool (Figure B-39) within Sonarwiz v7 required initial processing to balance the amplitude decay with increasing offset from the source. A time variant gain (TVG) was applied and several attributes tested as classification methods. The optimum attributes for Classification were by standard deviation, entropy and intensity. There are, however, issues with this latest version of the software which need to be resolved before further progress can be made Ground truthing is required to assign the substrates to the identified classes.

The classification identifies distinct rocky outcrops exposed through the sand and a band of denser material between the outcrops on the port channel. However, over the target zone the substrate appears fairly homogeneous.

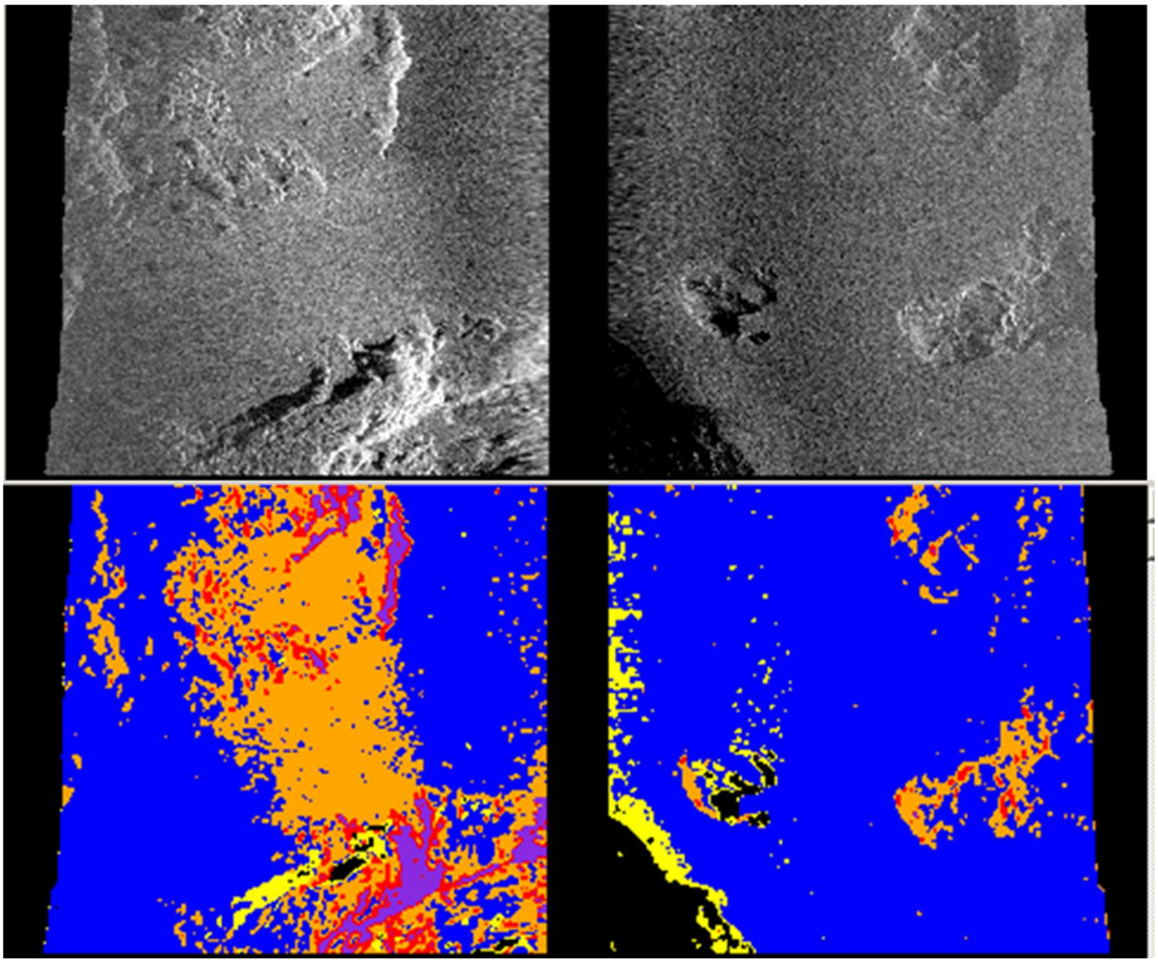

Figure B-39 Preliminary characterisation using SonarWiz version7.00020. Above are the input sidescan data (lighter represents harder/ denser), Below is the applied attribute characterisation.

Similarly, from the backscatter data of the Bathyswath system it is not immediately obvious where there are individual scallops. However, where scallops exist at highest density the backscatter shows a response with darker banding. Overall, the data identify potential habitats that may be occupied by scallops and hence target sampling areas.

The bathymetry data from the Bathyswath system (Figures B-40 and B-41) provide a high resolution contextual overview of the survey site and coupled with the backscatter data, is important in the design of an appropriate sampling strategy for new survey locations.

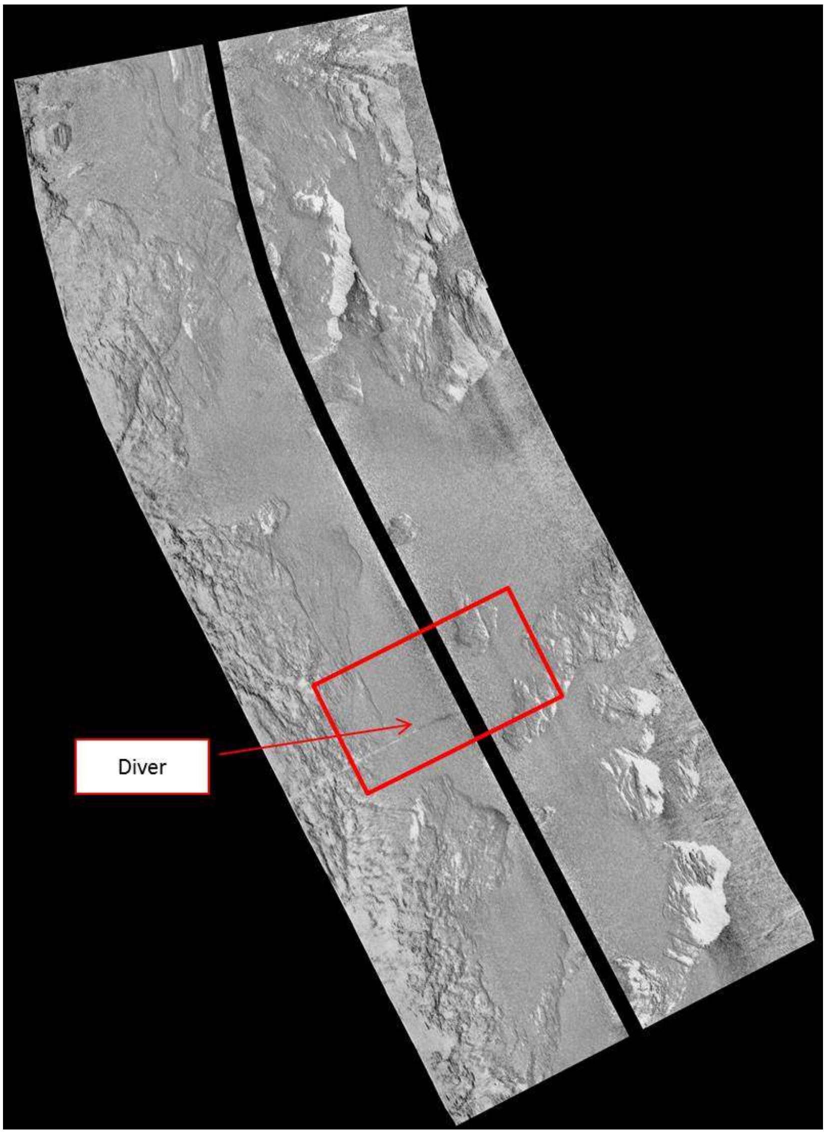

Figure B-40 Preliminary processed backscatter (Bathyswath 468Khz) of line 5 crossing over the transect area (marked as red box). TVG gain corrections are added. In this display, Low backscatter (lighter) corresponds to softer sediments or shadow (lack of return). Scale: the overall swath range is 100m. The site slopes gradually towards the east (right of the plot).

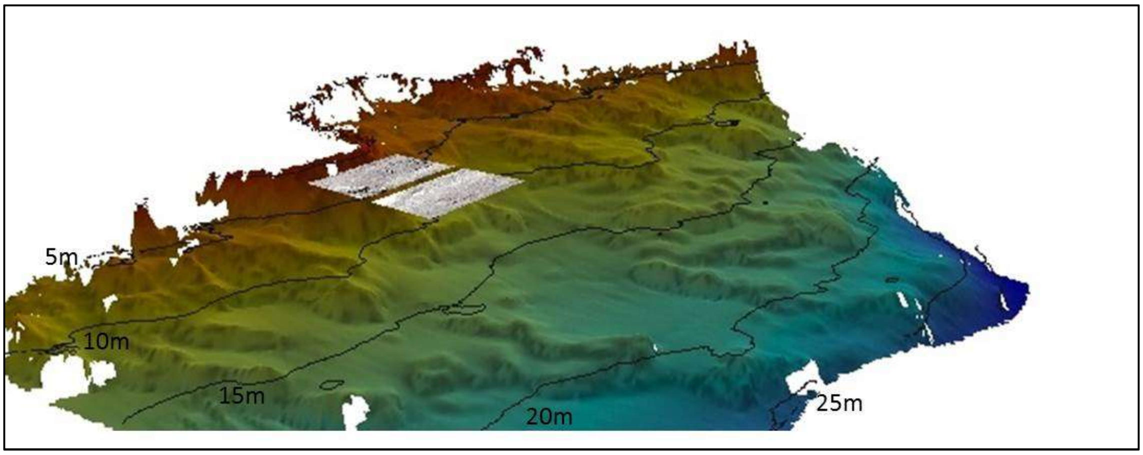

Figure B-41 Preliminary processed bathymetry data from the Bathyswath 468Khz system, with the Starfish sidescan data (45m line) displayed above. Vertical exaggeration is x2.5.

The transect video (Figure B-42) provided clear imagery from which live and dead scallop counts were possible. Ecological information and recognition of macroflora and fauna could easily be identified from the imagery. As evident from Figure B-42, there were issues with light reflecting off suspended sediment particles which added to the difficulty and time required for counting individuals.

Figure B-42 Top left and right: Examples of the visibility issues encountered with the video transect imagery. Suspended particles are illuminated by the in-line Tritech MD4000 HD video camera lighting. **Bottom left and right**: Examples demonstrating additional macro faunal species may also be recognised.

The stills imagery was not affected by the suspended sediment due to the positioning of the camera relative to the light source. However, despite being generally clearer images, it was sometimes quite difficult to identify scallops in the images due to their behaviour. Figure B-43 demonstrates the difficulty in detecting scallops when they are partially buried or are lying in depressions where they become covered by sediment. In these situations, it is not only difficult to recognise the scallops manually but it also proves challenging for any of the automated software recognition programmes to identify the scallops

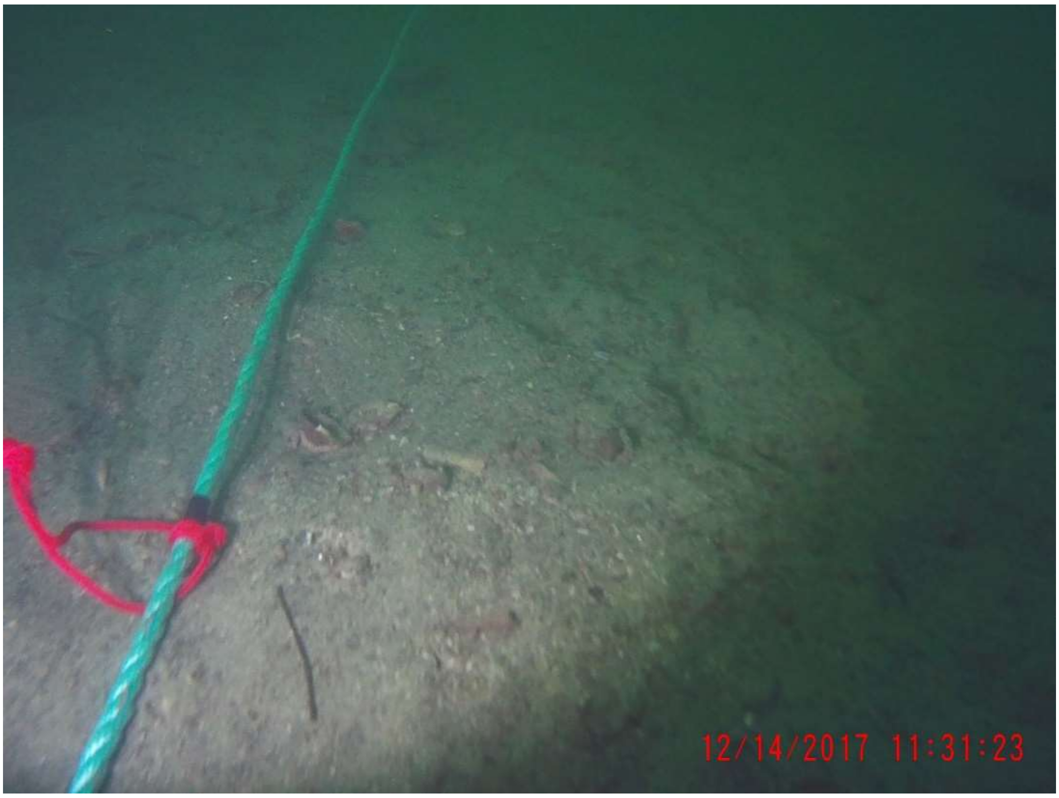

Figure B-43 Action Camera stills image pre-harvest (Scallops present just above the red quadrat marker rope). The 1m marker black tape can be seen by the quadrat marker and also just going out of view at the top of the picture.

10.4. Summary of Results

Overall the imagery was much clearer on the action camera time lapse stills, largely due to the lighting being out of plane with the camera. The video footage was difficult to interpret due to the suspended sediment and also because the scallops were partially covered at times. Although the stills imagery was much clearer to interpret, the field of view was smaller. Ideally a second camera is required to widen the field of view and if calibrated correctly will enhance the depth perception allowing quantitative morphometrics to be taken. Alternatively, a wide-angle lens camera might be effectively deployed. It was also concluded that quantitative morphometric data would benefit from the addition of lasers spaced at a known distance either side of the camera. Although the red and violet ends of the spectrum are attenuated more strongly than blue or green in seawater, a red laser is likely to be more easily visible against the blue-green background of the seawater on the imagery.

From the ground truth diver harvest counts the mean live scallop density was 5.35 per m^2, the estimated density from the video footage was fractionally higher at 5.37 per m^2 with post-harvest counts dropping to 1.68 per m^2. In percentage terms of what area of the transect had been cleared of scallops, the expected number of individuals remaining would be approximately 16. Summary data for the two imagery methods are presented in tables B-4 and B-5.

Table B-4 Data from the diver harvested scallops per quadrat and Pre and Post-harvest data extracted from the video footage. For the latter, three pseudo-replicates were taken viewing at different times, since the video footage was difficult to interpret.

	Diver harvest data				Pre-harvest					Post-harvest		
	N live	N m²		Video 2	live	dead	N m²		Video 3	live	dead	N m²
Bag 1	24	1.91		Pre-harvest	49	3	5.60		Post-harvest	14	4	1.60
Bag 2	62	4.93			45	4	5.14			14	4	1.60
Bag 3	37	2.94			47	4	5.37			16	4	1.83
Bag 4	72	5.73										
Bag 5	141	11.22										
Total	336				141					44		
Mean	67.2	5.35			47		5.37			14.67		1.68
Mean/Quadrat	13.44				transect area m²		8.75			transect area m²		8.75
Quadrat size m²	12.57				(based on field of view)					(based on field of view)		

Table B-5 presents the stills imagery data. Again from the ground truth diver harvest counts the mean live scallop density was 5.35 per m^2, the estimated density from the pre-harvest stills imagery is fractionally lower at 5.09 per m^2 and 4.73 per m^2 for the two pseudo replicates respectively. Post-harvest dropping to 0.36 per m^2. The size and shape of the field of view & quadrats can affect the sampling precision and the optimal dimensions will depend upon the dispersion of the population. This is demonstrated by the data from the stills imagery and particularly for the post-harvest stills data when, unfortunately there is a reduction in the visible camera footprint (Figure B-44) resulting in an underestimate of the Post-harvest mean Nm^2.

Table B-5 Data from the diver harvested scallops per quadrat and Pre and Post-harvest data extracted from the action camera still imagery. Pass 1 and Pass 2 are pseudo-replicates, however the transect rope did move slightly between the two transect runs**.**

	Diver harvest data				Pre-harvest					Pre-harvest					Post-harvest		
Actual	N live	N m²		Pass 1	live	dead	N m²		Pass2	live	dead	N m²		Pass 3	live	dead	N m²
Bag 1	24	1.91		Q1	0		0.00		Q1	0		0.00		Q1	0		0.00
Bag 2	62	4.93		Q2	2		3.64		Q2	4		7.27		Q2	0		0.00
Bag 3	37	2.94		Q3	1		1.82		Q3	1		1.82		Q3	0		0.00
Bag 4	72	5.73		Q4	5		9.09		Q4	3		5.45		Q4	0		0.00
Bag 5	141	11.22		Q5	6		10.91		Q5	5		9.09		Q5	1		1.82
Total	336				14					13					1		
Mean	67.2	5.35			2.8		5.09			2.6		4.73			0.2		0.36
Mean/Quadrat	13.44				view area m²		0.55			view area m²		0.55			view area m²		0.225
Quadrat size m²	12.566																

Overall the video footage more accurately estimated the expected population, which was likely due to sample area. Having a live feed video is also useful to confirm the site is an appropriate survey location. With improved field of view by using a second still camera it is likely that the accuracy in estimating abundance will be much improved.

Figure B-44 Action camera stills image demonstrating that for the post-harvest imagery, the field of view was compromised.

10.5. Test Site 3 Final Survey

Following lessons learned through the development of the dropdown action camera frame Site 3 was revisited in January 2019 with the aim of repeating the ground truth harvesting exercise but with data recorded using only the dropdown camera frame together with video from diver. The site had already had significant harvesting but still contained large numbers of scallop. The same 50m transect rope was initially deployed across the site for the divers to video along and then collect scallops at 5m intervals. In addition to the video recording and dropdown deployment along the line 30 sites were surveyed with the dropdown camera as shown in Figure B-45.

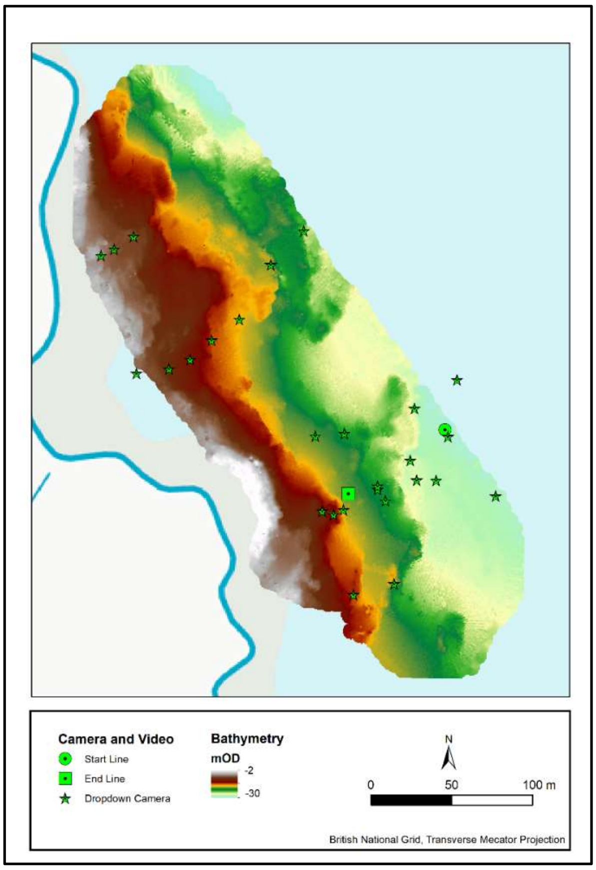

Figure B-45 Site 3 sampling.

10.5.1. <u>Video</u>

Calibration of the footprint was based upon the markings of the transect rope. The 11mm polypropylene rope was marked out in 1m intervals, and every 5m a loop of cord was inserted as the centre point of each of the 5 quadrats. Using 'Image J' software the approximate footprint could them be calculated.

On the first video pass the lighting was focused on too small an area. However, scallops and other prey fauna (whelk) can be easily seen. Live (red highlight) versus dead (black highlight) scallops could easily be determined (Figure B-46).

Figure B-46 Still image taken from video action camera.

10.5.2. <u>Qualitative Statistical Analysis</u>

Table B-6 Data from final ground truth

Diver Harvested data

Actual	N live	N m²
Bag 1	5	0.40
Bag 2	7	0.56
Bag 3	0	0.00
Bag 4	8	0.64
Bag 5	58	4.62
Total	78	
Mean	15.6	1.24
Mean/ Quadrat	3.12	
Quadrat size m²	12.57	

Pre Harvest

Pass1	N live	N m²
Q1	4	0.85
Q2	2	0.43
Q3	1	0.21
Q4	8	1.71
Q5	34	7.25
	49	
	9.8	2.09
	1.96	
View area m²		4.69

Pre Harvest

Pass2	N live	N m²
Q1	5	1.07
Q2	2	0.43
Q3	1	0.21
Q4	9	1.92
Q5	36	7.68
	53	
	10.6	2.26
	2.12	
View area m²		4.69

Post Harvest

Pass1	N live	N m²
Q1	1	0.21
Q2	0	0.00
Q3	4	0.85
Q4	2	0.43
Q5	3	0.64
	10	
	2	0.43
	0.4	
View area m²		4.69

expected numbers after harvest based on % transect harvested 0.43 /m²

The video quadrat data over-estimate the population density, this may be due to the low replicate number or inappropriate footprint size. The expected number of scallops to be found post-harvest, based upon the percentage area of the transect harvested is as expected, thus it is likely that with increased replicates the population estimate would be closer to the true density per m².

10.5.3. <u>Drop Down Action Camera</u>

The drop-down tripod with action camera was used across the site at 30 locations. The action camera was used in time lapse mode for still images which gave approximate footprints of 1.570m² (calculated using the transect rope and Image J software).

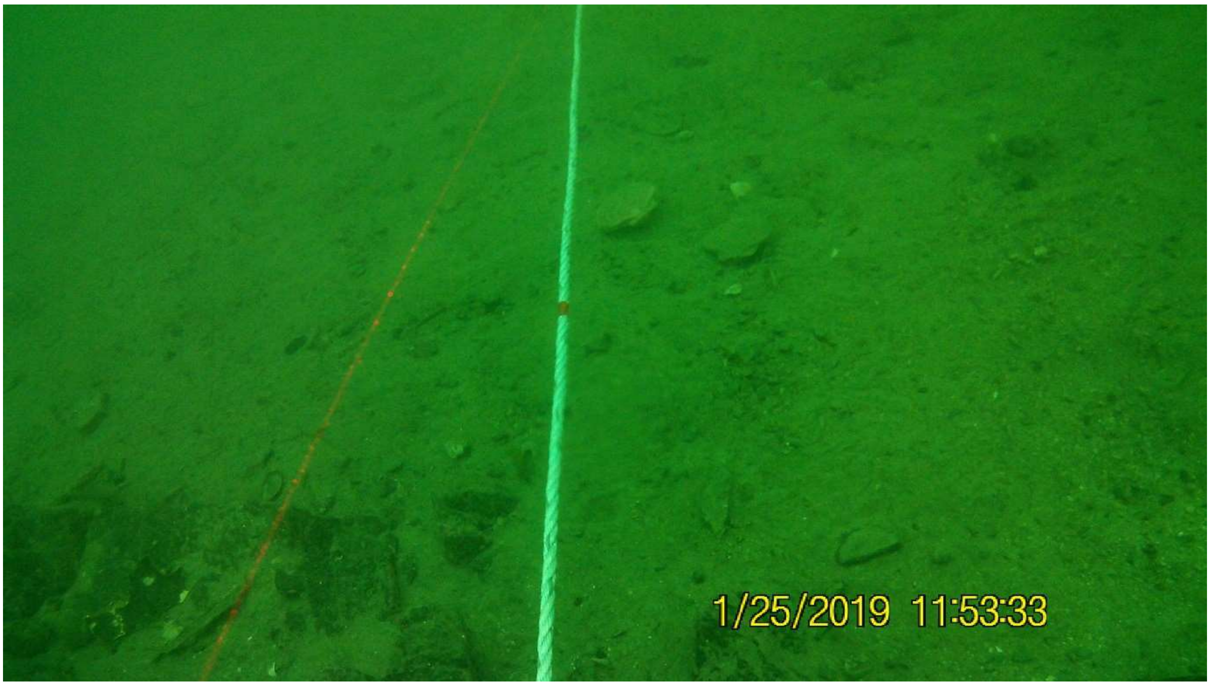

Figure B-47 Still camera with red laser (left of rope) and green laser (right of rope)

A total of 58 live scallops were seen over the 30 random drop down locations which spanned the sandy shelf area through which the transect ran. A mean of 1.93 scallops per drop image were seen equating to 1.23 scallops per m^2, this value more closely reflects the actual counts observed over the transect.

Both red and green lasers were used on the drop down camera, however, the latter were not visible due to issues with water clarity (Figure B-47). For calibration purposes a single laser is sufficient as the width of the beam can be used in Image J to calculate dimensions across the rest of the image.

Table B-7 Ground Truth Data.

Diver Harvested data

Actual	N live	N m^2
Bag 1	5	0.397899
Bag 2	7	0.557059
Bag 3	0	0
Bag 4	8	0.636639
Bag 5	58	4.615629
Total	78	
Mean	15.6	1.241445
Quadrat size		
m^2	12.566	

Pre Harvest

Pass1	N live	N m^2
Q1	4	1.183432
Q2	2	0.591716
Q3	8	2.366864
Q4	15	4.43787
Q5	21	6.213018
	50	
	10	2.95858
	2	
View area m^2		3.38

Post Harvest

Pass1	N live	N m^2
Q1	1	0.295858
Q2	0	0
Q3	4	1.183432
Q4	2	0.591716
Q5	3	0.887574
	10	
	2	0.591716
	0.4	
View area m^2		3.38

11. APPENDIX C1 - STILL AND VIDEO CAMERA DROP-DOWN

The use of scientific video and still camera for acquiring scientific data as opposed to the use of more readily available and cheaper camera options was tested at the seeded scallop site (Site 3). Results showed that very high-quality images and video of the seafloor can be obtained by inexpensive camera systems. In order to fully evaluate this further sea trails were conducted using action cameras and a 360º camera with the aim of not only reproducing high quality images but also with the aim of developing a drop-down or towed system that could be cheaply built and easily deployed by non-expert users. Finally, the visual data were also tested with respect to the various automated processing software solutions that are currently available for marine data.

11.1. Mounting Systems for Action Cameras and 360º Ricoh Theta V Camera

The aim of these trials was to test options for point sampling drop down mounts for the previously used action camera and also additional options for using a 360º camera. Figure C-1 and C-2 illustrate the drop-down frame developed for this purpose. Both stills and video recording were tested for the 360º camera.

Figure C-1 Dropdown camera frame

The camera records 4K/2K video with a maximum video time per recording of 5 minutes/25 minutes respectively and overall total of 40/130 minutes respectively. A ten-minute video used approximately 4GB of memory. Stills resolution is 14.5MP and the maximum number of images which may be recorded is approximately 4800. Battery life is perhaps the most limiting, being internal, allowing approximately 300 stills and 80 minutes of video. The camera may be recharged via micro USB2.0 cable.

Figure C-2 Drop down camera mount options for the Ricoh 360º camera. Left, the 'lander' option ready for deploy on survey boat, and right the weighted rope option. Both mounts had additional lighting if required.

The mounting method for both cameras employed an inexpensive collapsible frame constructed from readily available materials from non-specialist hardware store. The frame is shown with cameras in Figure C-1. The frame consists of a folding tripod base with lead weights on each of the legs. Each leg is 1m long and tension is maintained to the vertical central pole using rope guy cords. The legs can be painted in 10cm units to give bottom scale to the camera images. The action camera or 360º camera is mounted on the 1m long central pole which consists of a readily available threaded bar. The camera platform mount is constructed of a single piece of the leg bar and this can be adjusted up and down the length of the central bar at varying heights up to 1m from the seafloor. Additional platforms can be added for lights and adjusted to be either at the same height as the camera or at lower or higher distances from camera and seafloor. The total cost of construction to the frame is less than £100 and that of an action camera depth rated to 30m is typically less than £50.

The 'lander' drop-down mount worked very well with the action camera and 360º video causing very little disturbance on soft sediment.

Overall the imagery from the Ricoh was clear (Figure C-3); the images can be loaded into the Rich Theta App (for Android and Desktop) allowing the image to be viewed in full VR mode (Figure C-4). The camera would be good for initial habitat assessment however careful calibration would be required for morphometric uses.

Figure C-3 Uncorrected 360º image from the Ricoh Theta.

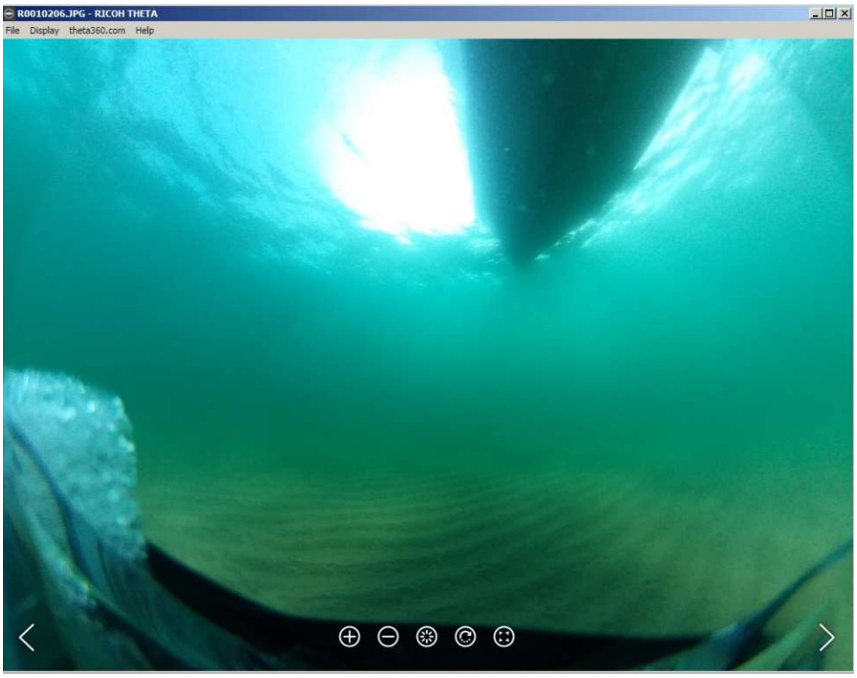

Figure C-4 Ricoh desktop App image in VR mode. Ripple marks are easily visible.

Figure C-5 Action camera still image taken from video recorded whilst attached to the ‘lander drop down mount

12. APPENDIX C2 – TOWED CAMERA SYSTEMS

A towed camera rig previously successfully used for quantifying razor clams in shallow waters (Fox 2017, 2018) was deployed at Bernera and the Creags, with the aim of evaluating whether the system could detect scallops and to summarise its strengths and weaknesses compared with other scallop survey approaches.

The camera rig comprised a 2 m wide sled mounting three downward facing Sony 12V VN37CSHR cameras aligned with overlapping fields of view so that a swath of approximately 1.5 m width is captured (Figure C-6). Video feeds were monitored live and recorded using a digital video recorder (Hawk D1/960H AHD RF3089, RF Concepts, Belfast UK). The rig was towed as slowly as practical using the SAMS RV Seol Mara for two tows of around 15-40 mins at each site (Figures C-7 and C-8). Captured video was subsequently processed to correct for camera lens distortion as described in Fox (2017). The composite videos were reviewed manually in 15s segments using the frame-stepping function in Solveig VideoSplitter (Solveig Multimedia, Tomsk, Russia). The size of any scallops observed was estimated based on the pixel to real-world calibrations described in Fox (2018).

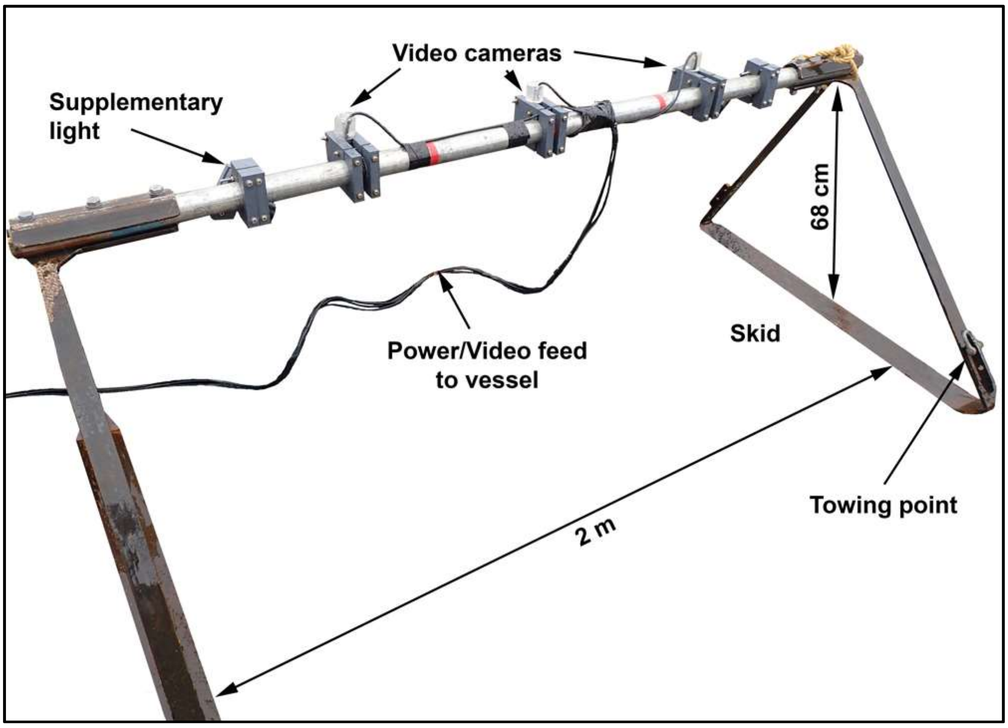

Figure C-6 Towed camera system design.

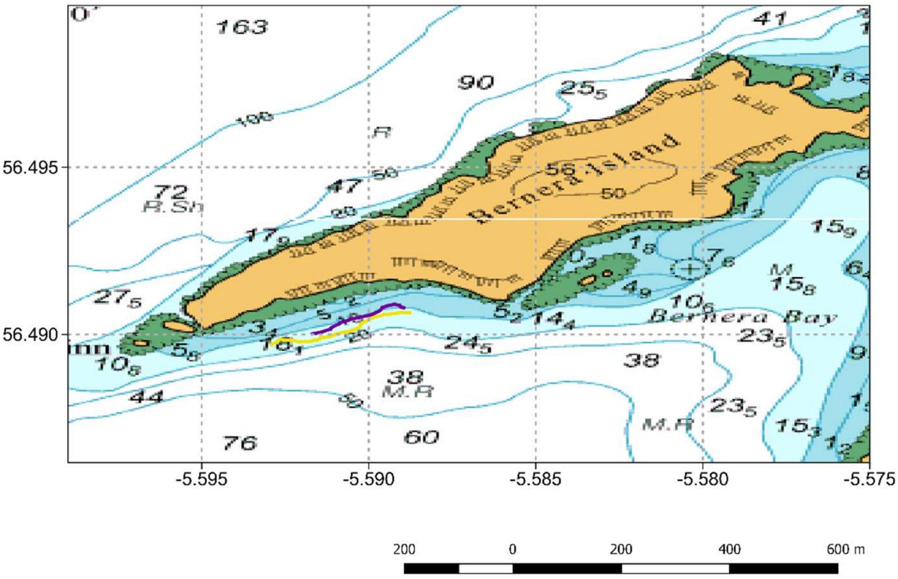

Figure C-7 Tows undertaken at Bernera. Tow directions were east to west. Purple line - tow 1; Yellow line - tow 2.

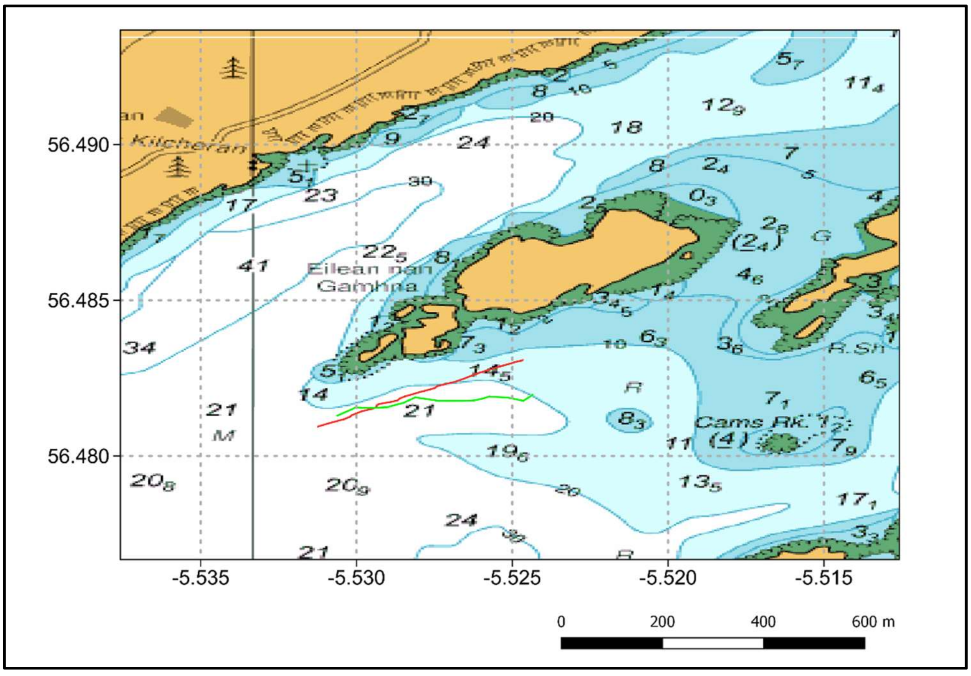

Figure C-8 Tows undertaken at the Creags. Tow directions were west to east. Red line - tow 3; Green line - tow 4. Underlying charts © Crown Copyright/HR Wallingford Ltd. 2017. All Rights Reserved. Licence No. L012017.0001. Not to be Used for Navigation.

Tow details are shown in **Error! Reference source not found.**. Total estimated tow lengths were between 204 and 479 m meaning that swept areas were between 302 and 713 m^2. Taking into account the estimated percentage of obscured seabed in each 15 s video fragment reduced the effective observed areas to between 124 and 677 m^2.

The seabed at Bernera consisted of fine muddy-sand (Figure C-9) that was easily disturbed when towing the camera sled. This was a particular problem on the first tow, but better control of the towing speed improved visual coverage on the second tow. The quality of video captured by one of the downward facing cameras is shown in Figure C-10. Overall, four scallops were seen at Bernera although only one of these was definitely alive (Figures C-11 and C-12). The widths of the shells ranged from 48 to 127 mm. Large numbers of *Turritella* and burying anemones were observed on the video (Figure C-9). Other organisms seen on the videos included crabs (probably *C. maenas*), squat lobsters, starfish and occasional small fish (likely gobies). Bryozoans and kelp debris were present across much of the seabed.

Figure C-9 Appearance of seabed at Bernera (Tow 1) from forward facing camera

Figure C-10 Typical seabed captured by the towed camera sled – Bernera (56.491^{o}N 5.589^{o}W) – a burrowing anemone is on the left-hand side of the frame

Figure C-11 Live scallop partially obscured by algae - Bernera. Shell width was estimated at around 127 mm

Figure C-12 Scallop – almost certainly a dead shell - Bernera. Shell width was estimated to be 48 mm

The seabed at the Creags was burrowed fine mud and sandy-mud towards the west becoming firmer and grading to gravelly-sand and gravel moving eastwards. Red and brown algae were growing on the stony areas and kelp debris was present at some parts of the tows (Figure C-13). Other organisms seen on the videos included common sunstar (Figure C-14) and urchins (Figure C-15). No scallops were seen at the Creags site.

Figure C-13 Appearance of seabed at Creags (Tow 3) from forward facing camera.

Figure C-14 Common sunstar (Crossaster papossus) - Creags

Figure C-15 Urchin (Echinus sp.) - Creags

Although the video was sufficiently clear to identify scallops and other organisms across much of the tows (**Error! Reference source not found.**), re-suspended sediment was problematic, especially for Tow 1 at Bernera. The presence of kelp also blocked clear views of the seabed on occasions. Re-suspension was caused by a change in the method of towing the sled compared with previous uses for surveying razor clams combined with areas of soft sediment at both sites. The speed of towing also caused the sled to bounce in stony areas at the Creags, although the video was still useable. In previous work the towing vessel was slowly warped towards an anchor meaning that the sled moves slowly across the seabed (typically < 3 m min^{-1}) greatly reducing any tendency to kick-up sediment. In the present application towing in this manner from RV Seol Mara was not possible, although it could be arranged in future with some re-arrangement of the vessel winches.

There was also insufficient time to align the cameras prior to this test. One of the cameras had become rotated in its housing meaning that the swath overlaying was less well aligned than in previous razor clam surveys.

Although very few scallops or scallop shells were seen it was demonstrated that the system images the seabed with sufficient resolution for scallops as small as 48 mm in width to be identified at depths down to 25 m. However, the results could be much improved by reducing the towing speed to prevent sediment re-suspension and by ensuring the cameras are correctly aligned before deployment.

An advantage of the sled system compared with conventional drop-down cameras is the relatively large area of seabed imaged with the swathe under the cameras being 1.5 m in width, meaning that several hundred square meters are covered in a typical tow. This can be advantageous when densities of target organisms are low. On the other hand, survey designs can be easier to implement using drop-down cameras because point-based randomised designs can be applied – see Boulcott et al. (2018) for an example of such a scallop survey.

A further issue is that the camera sled can only be operated across relatively flat areas of seabed so it would not be possible to deploy in areas with larger rocks or other obstructions and the system also requires a larger vessel with lifting capability. The original sled was designed for imaging razor clams which are only found in sandy sediments which tend to be relatively flat. In rocky areas, drop-down cameras may be more appropriate for scallop surveys, for example see the Lamlash Bay study by Boulcott et al. (2018).

Because of the size and weight of the camera sled it is not suitable for deployment from very small vessels, such as RIBs, but can be operated by larger vessels used for shellfish diving, as demonstrated in previous deployments using razor clam fishing vessels (Fox 2017, Fox 2018).

The present system was relatively cheap with a total construction cost in the region of £2000. However, the use of cheap cameras means that the present system is limited to a maximum operating depth of 50 m. Extending this range to greater depths would involve investment in more costly cameras, additional cabling and adding auxiliary illumination (Boulcott et al. 2018).

Obscuration of the seabed by macroalgae was noted on some occasions, which could lead to under-estimation of scallop abundance. However, the sled movement tended to cause fronds to be disturbed which can reveal organisms hidden underneath. This problem will also be common to any camera-based system.

Because so few scallops were seen it was not possible to evaluate the degree to which the passage of the sled or towing ropes might disturb the animals and cause them to move out of the camera field of view. This could be assessed on other sites with further work by comparing counts in the downward-looking cameras with the forward-looking camera.

Table C-1 Tow details

Tow details													
Site	Tow	Time		Position				Tow	Tow	Swept	Seabed	Effective	Scallops
		Start	End	Start		End		duration	length	area	clear	observed	
				Lat	Lon	Lat	Lon					area	
								(mins)	(m)	(m^2)	(%)	(m^2)	
Bernera	1	11:00	11:24	56.491	-5.589	56.490	-5.592	39	204	302	41	124	0
Bernera	2	11:32	12:05	56.490	-5.593	56.491	-5.589	33	300	450	88	396	4
Creags	3	13:04	13:50	56.481	-5.531	56.483	-5.525	46	479	713	95	677	0
Creags	4	13:58	14:15	56.481	-5.531	56.482	-5.524	17	423	635	96	610	0

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