An Echosounder System Ground-Truthed By Towfish Data: A Method To Map Larger Nearshore Areas

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by

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Vandermeulen, H. 2011. An echosounder system ground-truthed by towfish data: A method to map larger nearshore areas. Can. Tech. Rep. Fish. Aquat. Sci. 2958: v + 21 p.

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ABSTRACT

Vandermeulen, H. 2011. An echosounder system ground-truthed by towfish data: A method to map larger nearshore areas. Can. Tech. Rep. Fish. Aquat. Sci. 2958: v + 21 p.

The specifications and design of an echosounder system are described for shallow water use. A BioSonics, Inc. DT-X digital echosounder with 210 and 430 kHz single beam transducers was custom fitted to a 22’ research vessel with a unique transducer cage. The echosounder system can be run at 4 knots, offering rapid coverage of large areas of the bottom. Towfish transects (video and sidescan) are used to ground-truth the echosounder data, creating benthic habitat classes and maps. All positional data is collected at dGPS specifications (sub-meter precision).

RÉSUMÉ

Vandermeulen, H. 2011. Un écho-sondeur à validation à l’égard de la réalité du terrain par des données d’un corps remorqué : une méthode de cartographie des zones littorales. Can. Tech. Rep. Fish. Aquat. Sci. 2958: v + 21 p.

Les spécifications et la conception d'un système écho-sondeur destiné à une utilisation en eux peu profondes sont décrites. Un écho-sondeur numérique DT-X de BioSonics Inc. muni de transducteurs à faisceau unique de 210 kHz et 430 kHz a été spécialement installé sur un bâtiment de recherche de 22 pi au moyen d'une cage de transducteurs unique. Le système peut être utilisé à une vitesse de 4 noeuds, ce qui permet de couvrir rapidement de grandes étendues du fond. Des images de section provenant d’un corps remorqué (vidéo et balayage latéral) servent à valider les données de l’écho-sondeur à l’égard de la réalité du terrain, ce qui permet de créer des classes et des cartes d’habitats benthiques. Toutes les données de positionnement sont recueillies en qualité DGPS (précision submétrique).

INTRODUCTION

Nearshore habitat mapping of marine environments has become a priority for managers over the last decade. Mapping methods and equipment development have been a core component of the author's research program since 2004. This report is part of a series describing the results of this effort.

In a previous publication, Vandermeulen (2011) described a towfish system useful for generating bottom type maps. An echosounder system was also developed at the Bedford Institute of Oceanography (BIO) as part of the same research program for mapping the nearshore. The echosounder system was built from BioSonics, Inc. hardware as described below.

2.0 MATERIALS AND METHODS

2.1 Vessel, Power and Electronics

A 22' Cape Sable style Rosborough custom wheelhouse research vessel (Figure 1) was used as described in Vandermeulen (2011). All equipment was custom fitted to this vessel. A 1 kW gas generator (Vandermeulen 2011) provided power for the electronics. The navigation computer was upgraded from Vandermeulen (2007) to Nobeltec, Inc. VNS™ Max Pro navigation software (Figure 1).

A custom hardwood shelf unit bolted to the wheelhouse wall (Vandermeulen 2011) was used to hold a notebook computer running BioSonics, Inc. data acquisition software (Visual Acquisition™ ver. 6.0) and the associated BioSonics DT-X digital echosounder surface unit (Figure 2). The surface unit communicates with the computer via an Ethernet cable.

The BioSonics, Inc. system consisted of a DT-X digital echosounder surface unit; a 210 kHz single beam digital transducer with 6° cone angle; a 430 kHz single beam digital transducer with 6° cone angle and built in heading / pitch / roll (HPR) sensor; and cables. Figure 3 provides a schematic overview of the configuration.

A large cable leads from the DT-X digital echosounder surface unit on the shelving via a port on the back wheelhouse wall to the stern working deck. The cable feeds the transducers held in a cage on a break away arm mounted on the port side of the vessel (see below).

2.2 The Transducer Cage

A transducer cage was developed with the assistance of an engineer and the machine shops at BIO (Figure 4). An aluminum frame was constructed to hold the transducers, and then faring was added to provide a smooth hydrodynamic aspect to the frame. A blunt nose was created from solid sheet aluminum, with a tapered tail section composed of perforated aircraft aluminum. The cage is supported by a metal arm which can be winched up and tied off for transport (Figure 4), or lowered into survey position (Figure 5) where a latch at the top of the arm holds it in place. The overall design leads to a very smooth laminar flow over the transducer surfaces at survey speeds (4 knots, Figure 6).

2.3 Survey Operations

Unlike the towfish system described in Vandermeulen (2011), the echosounder system is relatively simple to operate. It only takes a crew of two to run surveys with this new echosounder system, a helmsperson and a survey supervisor:

1. Helmsperson – This individual controls the navigation computer and dGPS. They are responsible for keeping the vessel on course and at the correct speed (optimally 4.0 knots) along depth contours[1] (typically 5 and 10 m) indicated by the navigation computer charts; recording the vessel track with the navigation computer, monitoring the stability of the dGPS feed, radio communications and overall vessel safety and operation.
2. Survey supervisor – This person is responsible for selecting which depth contours to run on any particular day, and tracking overall survey progress. This person is situated in the wheelhouse, next to the helmsman, and is responsible for powering up the BioSonics surface unit and raising and lowering the transducer cage as required. They call off the start and end of each track to cue the helmsperson. They face the stern of the vessel while running survey tracks, operating the Visual Acquisition™ software on the BioSonics computer, cleaning the transducer cage of debris from time to time, and monitoring the generator on the stern working deck.

The start and end sequence for each survey track is as follows:

1. The survey supervisor indicates to the helmsperson which survey track contour on the navigation computer is next, with its start position. The helmsperson then steams to the target.
2. Just before the target is reached, the helmsperson slows down the vessel to low speed (1.5 knots, 700 RPM with our vessel) and aligns to the start of the track depending upon currents and wind.
3. Once the helmsperson is satisfied with the vessel position they place the engines in neutral and the survey supervisor lowers the transducer cage into survey position and straps it in place with the ratchet strap (Figure 6).
4. The helmsperson then places the engines back in gear and begins to steam to the start of the survey track contour as indicated by the navigation computer, steering and increasing engine speed to 2200 RPM (approximately 4 knots) and correcting vessel track for wind and waves. Ultimately, the intent is to move

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[1] It is best to run the transducers along a particular depth contour for each part of the survey. This will ensure that the ensonified area of the bottom on each ping (pulse) will be approximately the same size for each set of echoes recorded. Uniform ping areas (and correspondingly uniform ping depths) will provide better precision for echo based bottom classifications performed by other software back in the laboratory.

along the survey track contour as tightly as possible with a ‘speed over ground’ of 4.0 knots.

5. At the same time, the survey supervisor prepares the echosounder system in the following sequence:
    a. BioSonics computer on, checking computer date and time
    b. BioSonics DT-X surface unit turned on
    c. Wait for computer to ‘see’ the Ethernet feed from the surface unit
    d. Start BioSonics Visual Acquisition™ software
    e. Interrogate the hardware and determine that the transducers are operating properly (with the 430 kHz transducer loaded to channel 1)
    f. Run GPS diagnostics to interrogate the dGPS (9600 BAUD) and start the GPS feed
    g. Configure the echosounder by setting[2]:
        i. pulse (ping) rate to 10 times per second (the 430 and 210 kHz transducers alternate pings, so each transducer has five pings per second)
        ii. the 430 kHz transducer to 0.1 ms pulse duration; threshold held at -130 dB; start range 0.1 m (best for shallow eelgrass)
        iii. end range (for 5 m track, set end range to 30 m; 10 m track set to 40 m – this is required to ensure that second returns are recorded, see Figure 7)[3]
        iv. environmental parameters (pH, temp and salinity) of the water column[4]
        v. the 210 kHz transducer to 0.4 ms pulse duration; start range 0.0 m; all other settings like 430 kHz transducer
6. Once the echosounder system is prepared, and the vessel is at the start of the survey track contour, the survey supervisor calls out “start recording” and the following occurs simultaneously:
    a. the helmsperson starts recoding the vessel track with the navigation computer
    b. the survey supervisor starts the record function of the Visual Acquisition™ software
7. As the vessel moves along the track contour at four knots, the survey supervisor monitors the Visual Acquisition™ software:

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[2] If working in very shallow water for eelgrass, you could also set “transmit power reduction” (-10 dB)

[3] Record the end range in the field note book along with the depth contour (e.g. 5 or 10 m)

[4] These values are to correct for the speed of sound in water; we use a YSI EC300 hand held conductivity / temperature meter, parameters recorded in the field notebook

   a. two windows will be open, one for the 430 kHz transducer and other for the 210 kHz transducer (see Figure 7 for sample outputs); any unusual features are recorded in the field notebook along with time and echo[5] numbers
   b. the echo record is logging to file[6] and the dGPS feed is solid
   c. 430 kHz window base should also show HPR data (which is automatically logged in the data file) – record in field notebook any sequences where pitch or roll go beyond 10 degrees (i.e. stormy day)

8. At the end of the survey track, the survey supervisor calls out “Stop recording”. The vessel is placed in neutral and the BioSonics and navigation recording modes are turned off[7].
9. The survey supervisor turns off the software and surface unit, and raises the transducer cage.
10. The helmsperson then moves the vessel to the next survey track contour.

2.4 Data Processing

Every day of field survey requires at least two days of data processing by a technician back at the laboratory. The echo data recorded by the BioSonics Visual Acquisition™ software is processed by two other BioSonics software packages, Visual Bottom Typer™ for the 210 kHz echo set, and EcoSAV™ for the 430 kHz echo set.

Data processing typically begins with a review of the HPR data. Files with HPR data indicating a preponderance of >10 degrees on pitch or roll are flagged. That level of pitch or roll indicates stormy conditions and the possibility of poor echo quality (echoes at an angle to the transducer surface) which may interfere with later echo classification in Visual Bottom Typer™ or EcoSAV™.

A Visual Bottom Typer™ (VBT) analysis is performed next. The data file containing the first 30 minute set of echoes along the appropriate depth contour (e.g. 5 m) is opened in a viewing window in VBT (Figure 8). The energy trace of each echo can be displayed (Figure 8 upper left), with the first return (bottom signal) highlighted in a red hatched area and the corresponding second bottom echo[8] highlighted as a red high

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[5] The term ‘echo’ is used because it is the echo of the original ping (which was only 0.1 or 0.4 ms in duration) that the transducer listens for and records.

[6] The software automatically writes a series of new files to the hard drive with date and time stamp approximately every 30 minutes, or at the user’s choice during configuration.

[7] It is possible to stop and start on the fly. Since we map on bay-wide scales, a typical survey track can last for up to four hours (limited by the run time of the generator on one tank of fuel).

[8] The second bottom echo is an artefact because it represents a sound wave which has hit the bottom and then bounced to the water surface where it returns to the bottom again, only to bounce back to the surface once again. The transducer is waiting at the surface to hear the echoes. The first return / echo (surface click to bottom and back) represents the true bottom signal; the second echo (surface to bottom cycle twice) will be heard by the transducer with a delay of approximately twice the timing of the first echo. This makes the second echo twice as ‘deep’ as the first echo. A third echo would be three

echo energy return. The program automatically selects the first bottom echo return (and corresponding second bottom echoes) based upon a peak threshold energy setting. First returns must exceed the minimum echo energy threshold (i.e. be acoustically 'loud') to be classified by the software. Echoes that do not pass peak energy threshold levels will not be processed in the later stages of the VBT analysis. The peak threshold setting can be altered by the user. It is important for VBT to have echoes with good quality first and second returns because they are a measure of bottom hardness[9].

Once the first data file of echoes has been viewed, the rest for that depth contour (5 m in our example) of the survey can be loaded and examined. If the operator is satisfied with the quality of the echoes in the data files, they can move on to the next step in the data processing – a supervised or unsupervised bottom type classification based upon all of the echoes for the depth contour.

VBT performs an unsupervised classification by developing metrics for the first and second return, plus over 20 other characteristics calculated per echo. A Principle Components Analysis (PCA) of echo characteristics is then performed. Lastly, a fuzzy cluster analysis is created to group bottom type 'signatures' from the PCA to fit the number of bottom types requested.

The results of an unsupervised classification are presented in the bottom right of Figure 8. The classification was generated automatically by the software after the operator specified the number of bottom classes for which to search (in this example, 4). Note that these are hypothetical 'bottom classes' as they actually just represent echoes of similar type. The classification is generated with associated latitude / longitude positional data which can be exported to a GIS program for mapping.

We build a MapInfo® GIS project on an external hard drive (typically 1 TB) from the survey data. The GIS project begins with a hydrographic chart background layer; we then add the VBT classification results. We have found that VBT can typically discern three to four real bottom types (mud, sand, cobble, and boulder)[10]. Figure 9 is an example classification from VBT results.

Once the bottom type classification has been performed, the EcoSAV™ assessment for submersed vegetation can begin. EcoSAV™ is a straight forward software package requiring very little parameter setting by the operator. Similar to VBT, EcoSAV™ uses echo characteristics. It provides an analysis of macrophyte presence, canopy height and percent cover. This information can be used by the operator to 'bin' different macrophyte types (mainly according to canopy height). Figure 10 is an example EcoSAV™ classification from the same survey as Figure 9.

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times as long and so on. Most bottoms cause enough acoustic reflection for a second echo. Harder bottoms (rock, hard packed sand) can even create third echoes (Figure 7).

[9] We have found some very soft bottoms where a second return is not generated. VBT can still analyse this type of bottom using other methods.

[10] Unsupervised classifications of >6 classes are possible, with decreasing separation between classes (Bob McClure, pers. comm.).

Note that both VBT and EcoSAV™ create unsupervised classifications. These are hypothetical classifications and need to be validated (ground-truthed) with other data such as image data.

We ground truth the echosounder based classifications by using data from the towfish system described in Vandermeulen (2011). Figure 11 is the results of a towfish bottom classification performed during the same survey (different days) as Figures 9 & 10. We know the towfish classification is ‘real’ because of the video and sidescan imagery it creates (Vandermeulen 2011) and by SCUBA diver observations in this particular bay.

Our survey design involves running towfish transects perpendicular to shore, and then running the BioSonics system across those transects (Figure 12). The echo classifications (both bottom type and macrophyte) corresponding to pings made on a transect (30m worth of known bottom and macrophyte type) are examined carefully for both the 5 and 10m contours. If the VBT and EcoSAV™ classifications on a transect correspond well with the towfish information, then the echosounder classifications are assumed to match reality and ‘hold’ between the transects as well.

Note that the BioSonics classifications must match the towfish data where they cross on transects or else the echosounder based classification is thrown out and another data processing run (with a different number of classes requested or slightly different parameter settings) is made. If required, we perform several iterations of VBT or EcoSAV™ analyses until a good fit is found with the towfish data.

3.0 RESULTS

Table 1 presents the results of a comparison between the towfish and BioSonics classifications in our example bay. All data points from the towfish analysis were binned into bottom type and associated macrophyte class, providing a percentage of data points in each group. The BioSonics data points were then binned into the same groups. The correspondence between the towfish and BioSonics percentages of data points in each group is very good, and suggests that the BioSonics classification for the entire bay will be accurate.

Higher spatial resolution or information content could have been provided using more classification categories for the macrophytes and bottom types in this bay. However, the three level classifications provided the best correspondence between the towfish and BioSonics data.

The echosounder system is always used in conjunction with the towfish system for ground-truthing. The advantage of adding echosounder runs to a towfish survey is the extra area that the echosounder can cover between the towfish transects. Instead of having gaps of information between towfish transects which must be interpolated (Vandermeulen 2011); we now have an echosounder system to fill those gaps.

The echosounder / towfish survey combination is now routinely used for our mapping work in Bras d’Or Lake (Cape Breton). The survey design calls for transect spacing of about 700m and echosounder runs at 3, 5 and 10 m depth. The design provides enough information to produce a benthic classification for this relatively simple nearshore system, which has most macrophyte growth in the shallows (<4 m depth). For each field day of towfish work we perform one day of echosounder work. In 2010, we covered 66 km of Bras d'Or Lake shoreline in ten days.

DISCUSSION

The value of the new echosounder system is its ability to fill in gaps between towfish transects. This allows us to cover larger areas of the bottom and obtain more information in less time than using the towfish system alone – a clear improvement in mapping method and efficiency.

Note that the towfish data is primary in this analysis; it informs (ground-truths) the echosounder data. We analyze the echosounder data to match the towfish classification, not the reverse. Our methods are actually nested according to ground-truth priority as follows:

1. Direct observation by SCUBA – the primary data for ground-truth. We have hundreds of hours of SCUBA observations that confirm our next level of data collection, towfish data.
2. Towfish data – the next level of ground-truth data. Video and sidescan imagery can be reliably used to generate bottom classifications (Vandermeulen 2011).
3. Echosounder data – this level of data collection is almost completely dependent upon ground-truthing by the previous two levels[11]. Acoustic signatures of echoes need to be interpreted by other types of observations (i.e. SCUBA, or in this publication, towfish data).

The towfish / echosounder combination acts as a grid based sampling system where echosounder tracks cross towfish transects. It provides an overview of bottom types (e.g. mud, sand, cobble, and boulder) with associated macrophyte cover information (e.g. canopy height, species information) over large polygons of nearshore bottom in relatively short time frames.

ACKNOWLEDGMENTS

Peter Hurley and Ross Claytor were supportive of the echosounder work. Megan Wilson acted as the survey supervisor on some of the surveys. Megan Wilson and Brian Jones created the GIS projects.

Funding for equipment purchases came from the Oceans & Habitat Branch at BIO, many thanks to Dave Duggan! The custom cage and support arm design were provided by Glen Morton (Ocean Sciences Division). As always, the staff working in

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[11] Although good echo processing software can provide a decent bottom classification 'blind', echosounder data is one more step removed from direct observation (SCUBA or towfish data). An analogy would be using an airphoto alone for land classification, without ground based observations.

the BIO welding, machine and carpentry shops did a superb job of turning paper plans into reality.

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Vandermeulen, H. 2007. Drop and towed camera systems for ground-truthing high frequency sidescan in shallow waters. Can. Tech. Rep. Fish. Aquat. Sci. 2687: v + 17p.

Figure 1: 22’ twin engine Cape Sable style research vessel with enclosed wheelhouse. **Insert** - Navigation notebook computer at helm running Nobeltec, Inc. VNS™ Max Pro navigation software.

Figure 2: **Left** – Custom hardwood shelf on back wheelhouse wall. BioSonics data acquisition computer on top shelf; with BioSonics DT-X digital echosounder surface unit below. The white object in the foreground is a passenger seat (folded down). **Right Top** – BioSonics computer with blue Ethernet cable leading to the DT-X surface unit. **Right Bottom** – BioSonics DT-X digital echosounder surface unit strapped in place.

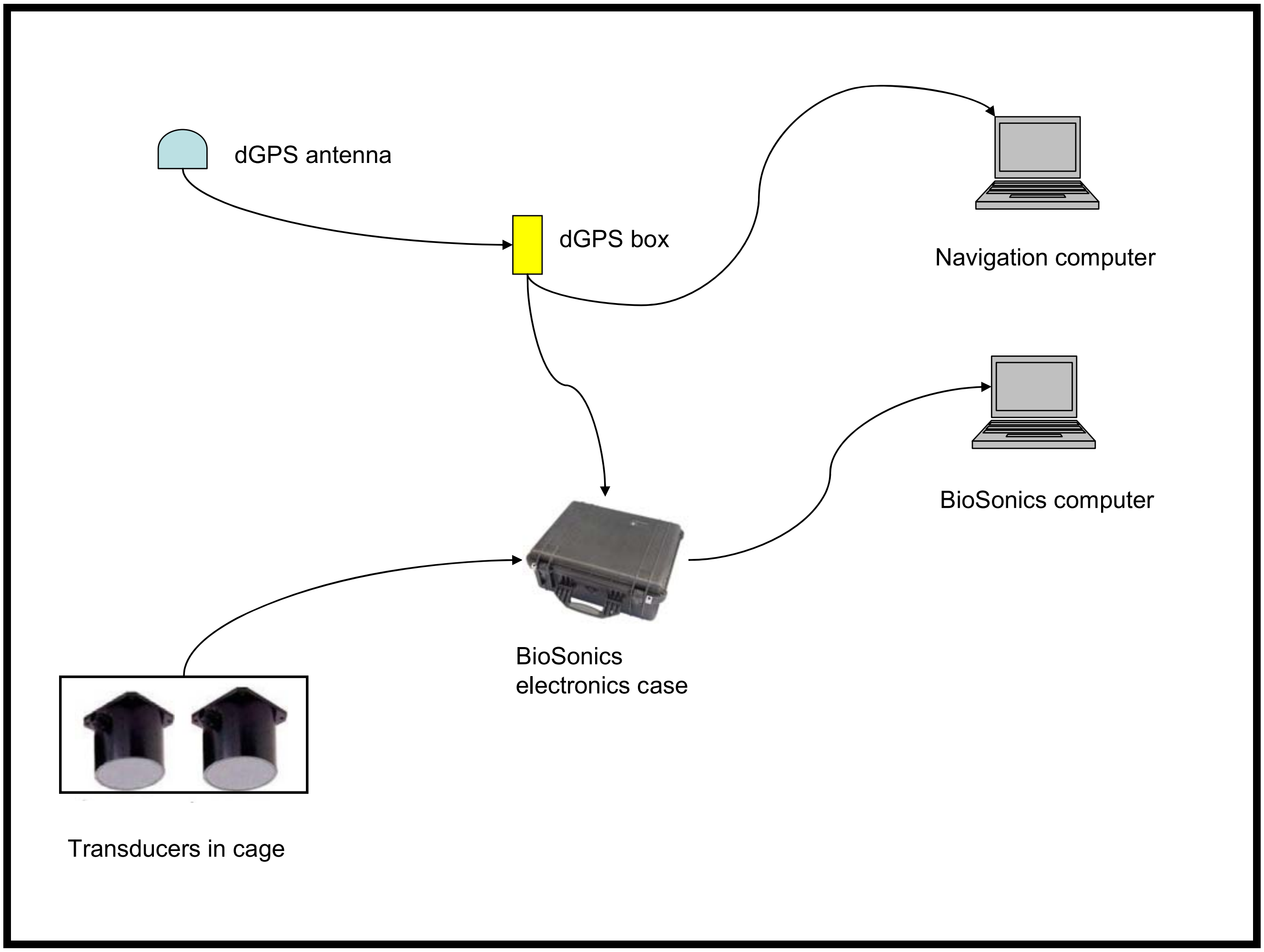


Figure 3: Schematic overview of the echosounder system. The dGPS is a Trimble® DSM™ 132 with beacon correction (Vandermeulen 2007). The 'BioSonics electronics case' refers to the DT-X digital echosounder surface unit.

Figure 4: Transducer cage raised for transport. Note tapered tail section which is ‘see through’ due to its construction from perforated aircraft aluminum. Blunt nose constructed of solid sheet aluminum. The paint can sized transducers are bolted inside the cage below its support arm in a sturdy aluminum frame (large perforations on its side). On the bottom of the cage, black plastic faring surrounds the black circular transducer surfaces, which have a mirror like smoothness.

Figure 5: Cage in survey position. Note alignment of cage support arm with davit post, and dGPS antenna on top of davit (i.e. almost directly above the transducers). Bottom of cage is higher than vessel keel, providing added protection in case of grounding. Cage support rope is removed from block during surveys.

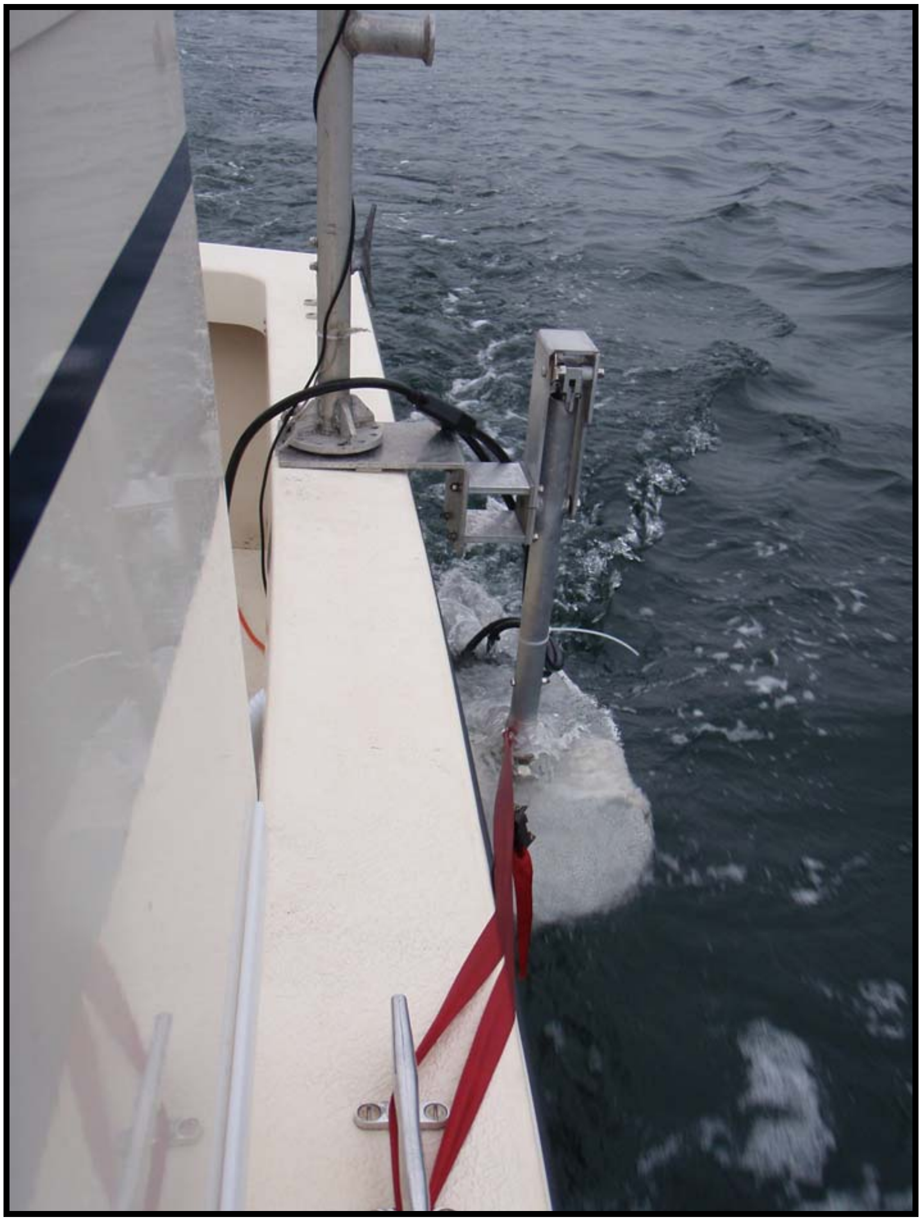


Figure 6: Transducer cage in place while running a survey. A red ratchet strap holds the bottom of the cage support arm in position, preventing the water pressure at 4 knots from popping the support arm latch (device at the top of the arm). The top of the cage is just below the water surface. Note how the blunt nose of the cage creates a small standing wave which then falls into the perforated tail section. This creates a very smooth flow of water around the cage, and laminar flow over the transducer surfaces.

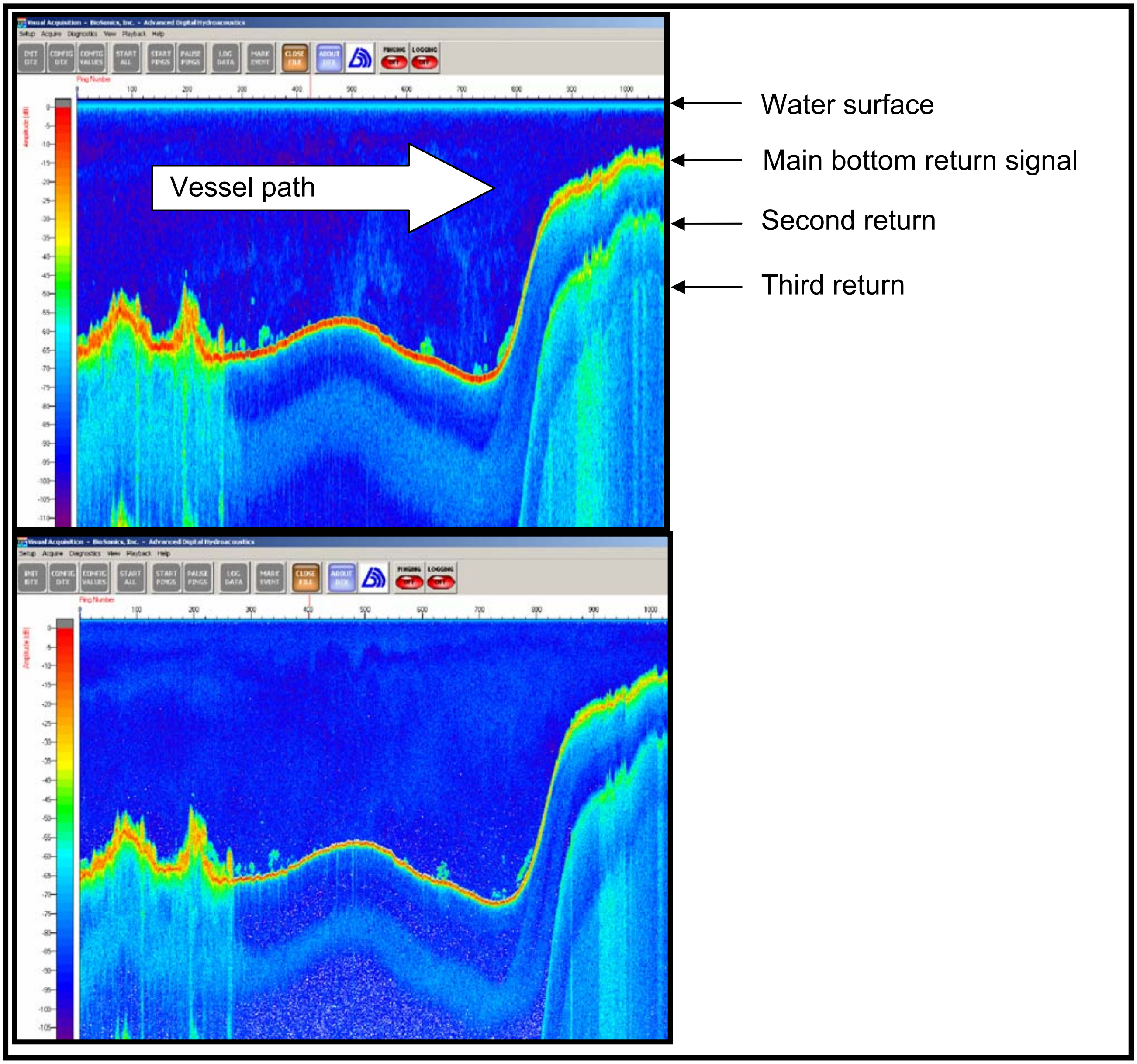
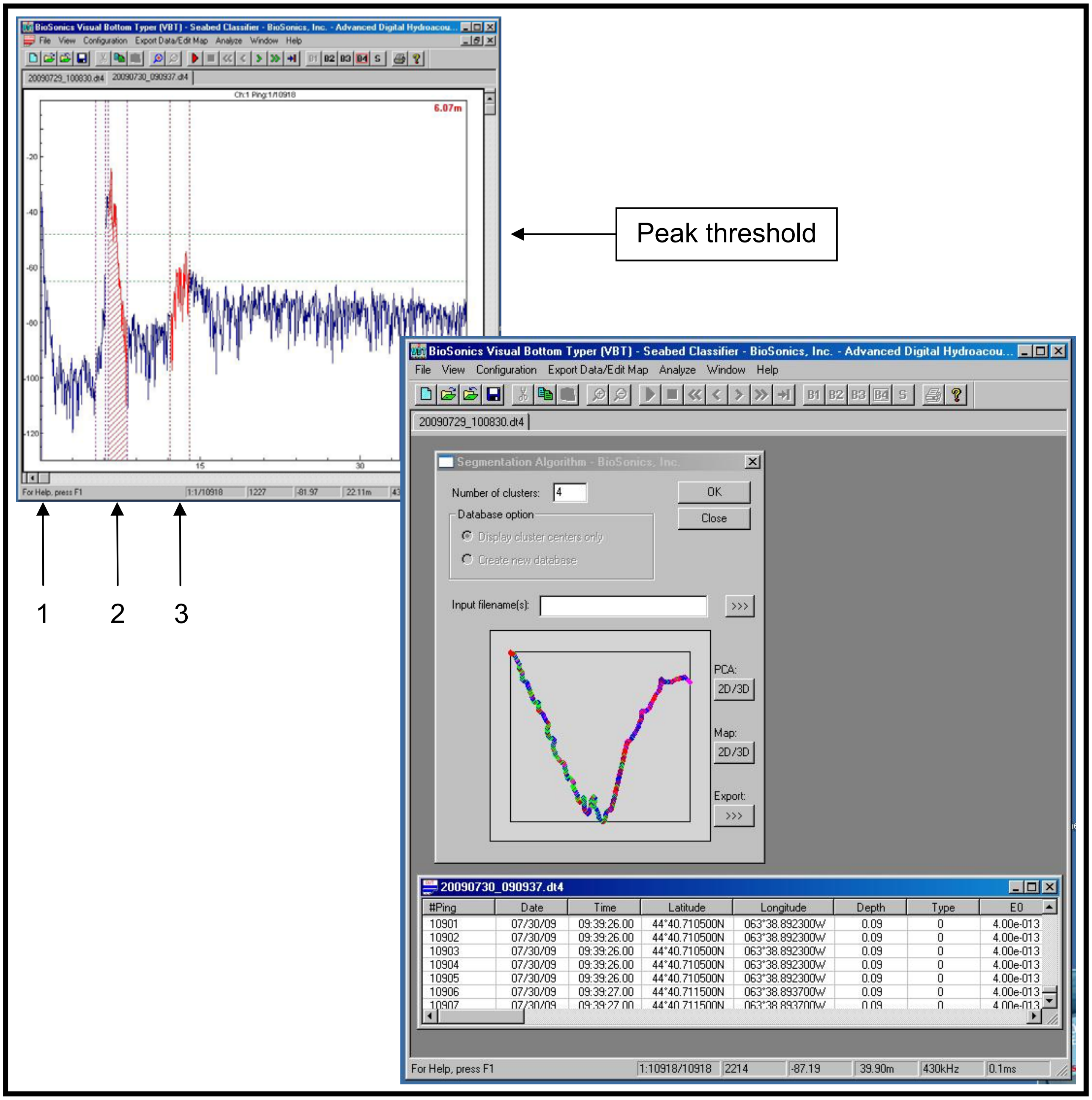


Figure 7: Screen shots of waterfall display from BioSonics computer during a survey (Visual Acquisition™ software). Rocky reef with kelp on left, middle is hard sand / pebble with drift algae, right is sand with an eelgrass signal on top. **Top –** Feed from 210 kHz transducer. Note how this transducer emphasizes the bottom return (bright red / orange line) and the second and third 'ghost returns' (green / yellow lines below the main bottom return). This data is used to determine bottom type. **Bottom -** Feed from 430 kHz transducer. This transducer emphasizes the difference between the bottom signal (orange line) and the macrophyte signal (green / blue pixels above bottom signal). This data is used to determine macrophyte canopy height and percent cover.



Number of clusters: 4

20090730_090937.dt4

#Ping	Date	Time	Latitude	Longitude	Depth	Type	E0
10901	07/30/09	09:39:26.00	44°40.710500N	063°38.892300W	0.09	0	4.00e-013
10902	07/30/09	09:39:26.00	44°40.710500N	063°38.892300W	0.09	0	4.00e-013
10903	07/30/09	09:39:26.00	44°40.710500N	063°38.892300W	0.09	0	4.00e-013
10904	07/30/09	09:39:26.00	44°40.710500N	063°38.892300W	0.09	0	4.00e-013
10905	07/30/09	09:39:26.00	44°40.710500N	063°38.892300W	0.09	0	4.00e-013
10906	07/30/09	09:39:27.00	44°40.711500N	063°38.893700W	0.09	0	4.00e-013
10907	07/30/09	09:39:27.00	44°40.711500N	063°38.893700W	0.09	0	4.00e-013

Figure 8: Screen shots from BioSonics Visual Bottom Typer™ (VBT) data processing software. **Upper left –** Echo processing window. Each echo (horizontal axis in Fig. 7) is analyzed. The echo is placed in its 'side' where 1 = water surface, 2 = energy envelope of first return (bottom signal), 3 = second echo return. Peak threshold can be adjusted to select first returns of a particular energy level. Bottom right – the software then compares all echoes in the dataset against a number of metrics (including energy level of first return against second return) and bins them into classes (in this case four of them). The color coded classes (corresponding to different bottom types) are then plotted along the vessel track – which has a V shape in this example.

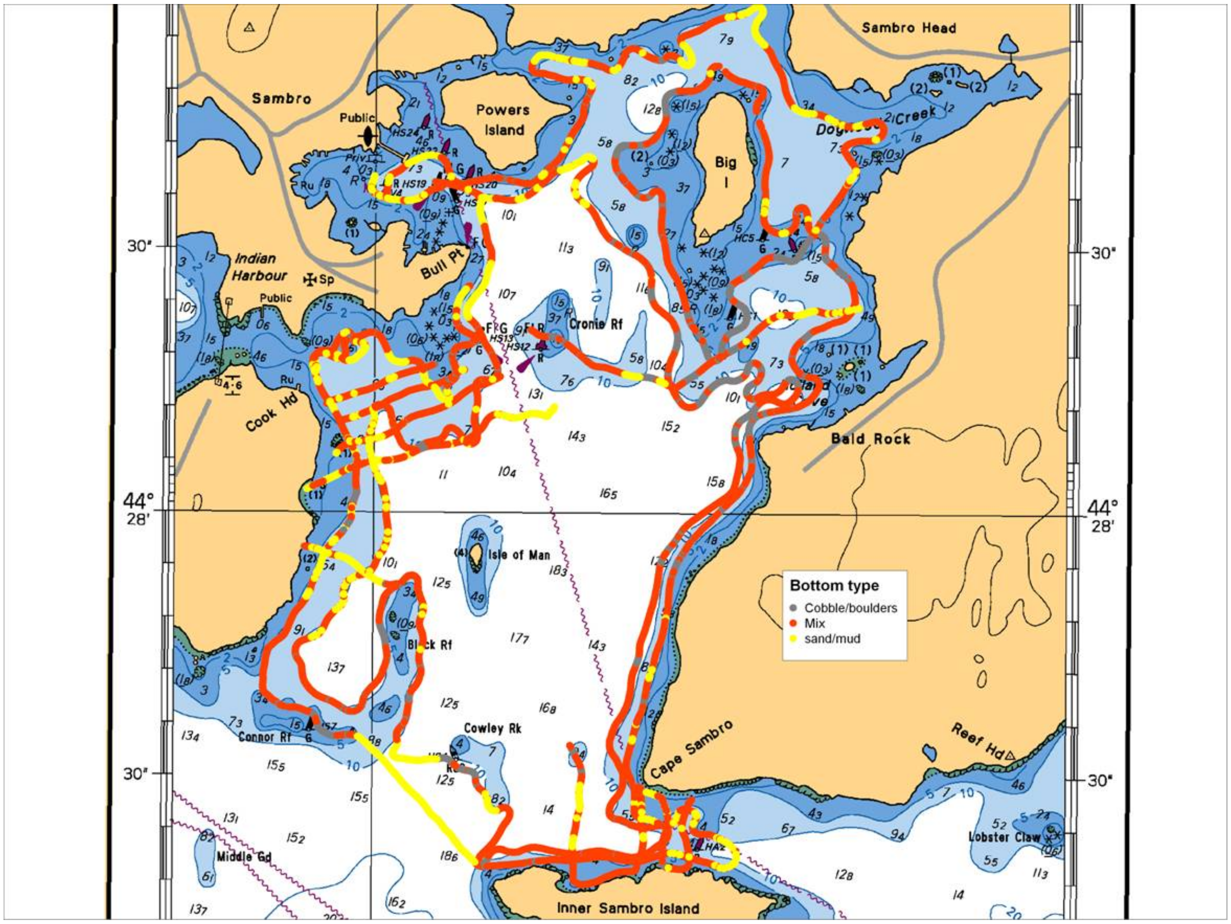


Figure 9: Screen shot of a typical bottom type classification in MapInfo® GIS made from VBT results (i.e. data from the 210 kHz transducer). The survey was performed primarily along the 5 and 10 m contours of the bay.

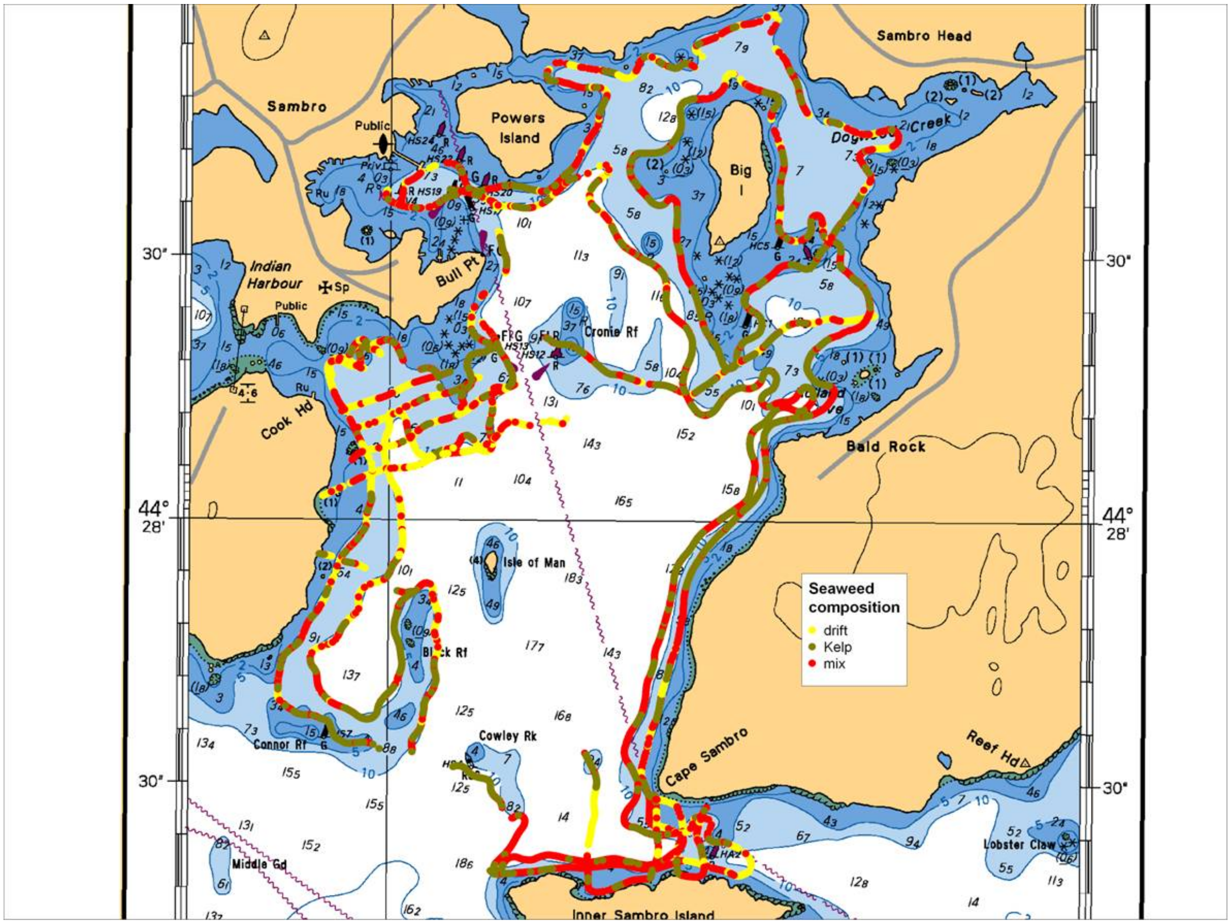


Figure 10: Screen shot of a typical macrophyte classification in MapInfo® GIS made from EcoSAV™ results (i.e. 430 kHz transducer data) for the same bay at the same time as Figure 9.

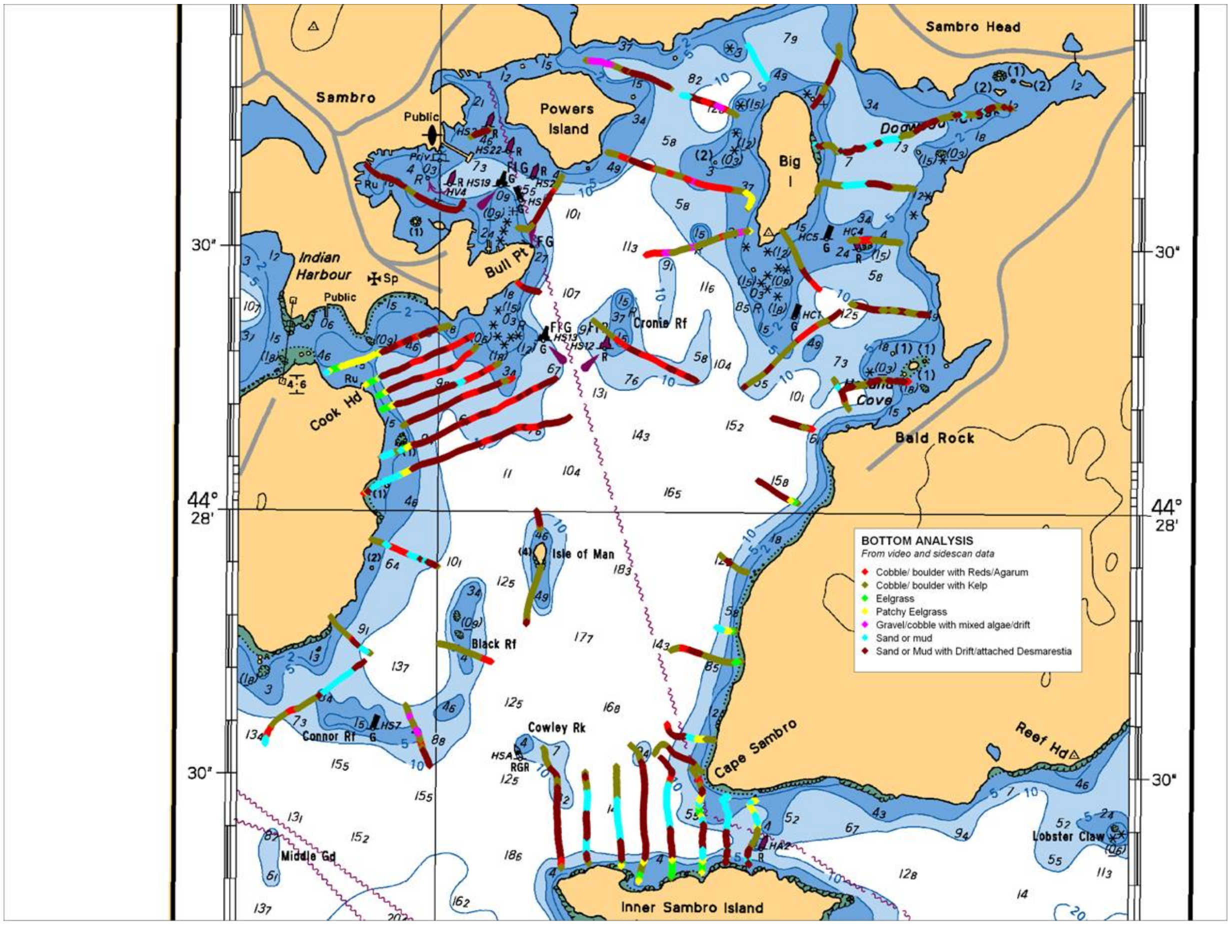


Figure 11: Screen shot from the same MapInfo® GIS project as Figures 9 & 10 showing bottom classification from towfish transects.

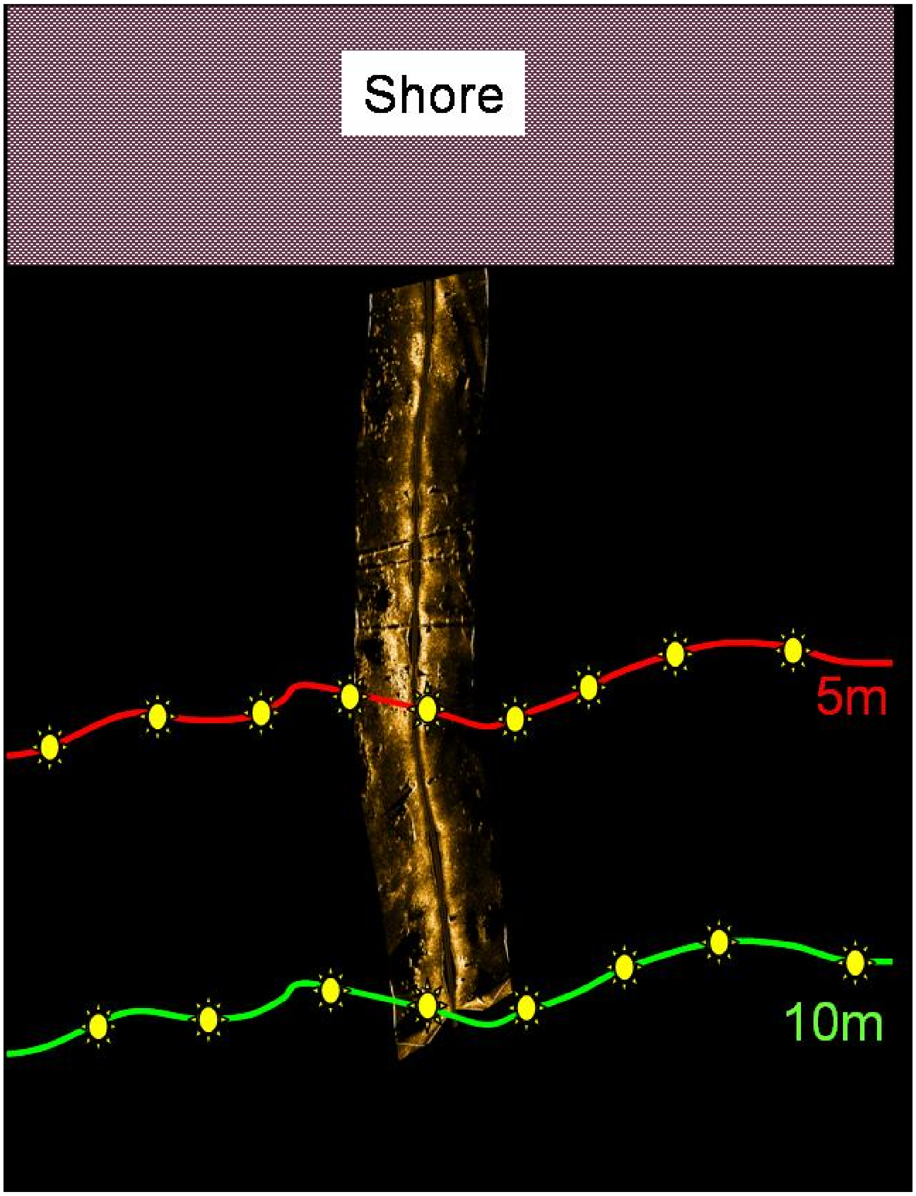


Figure 12: The BioSonics classifications are compared to towfish data where BioSonics pings cross towfish transects. In the previous figures, one can see that the BioSonics data came from running the vessel along the 5 and 10 m depth contours. Those tracks are shown here symbolically as the red and green lines, the yellow dots representing groups of echo sounder echoes along the tracks. A number of these echoes fall along a towfish track - represented here by a 30 m wide sidescan image taken from towfish data. The towfish track started at the 10 m depth contour and ran perpendicular into shore. The towfish data ground truths the echosounder echo data associated with the towfish track (i.e. a 30 m wide swath of known bottom type).

Comparison of towfish & BioSonics

Bottom type	Macrophyte type	Towfish analysis (% of data points†)	BioSonics analysis (% of data points†)
mud / sand	none (bare)	12	16
mixed	mixed	61	62
boulder / cobble	kelp	27	22

† classified point data associated with a lat / long position

Table 1: Comparison of results from towfish and BioSonics systems from previous figures.