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Title:	**Recommended operating guidelines (ROG) for single-beam echosounder surveying**
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Reviewed by:	Janine Guinan (MI) 07/09/07
Workgroup:	
MESH action:	Action 2
Version:	1
Date published:	15/01/2007
File name:	Recommended operating procedures for single-beam echosounder surveying.doc
Language:	English
Number of pages:	9
Summary:	This document deals with the use of single-beam echosounders for identification of underwater vegetation. It shows how post-processing of the coefficient of acoustic retrodiffusion gives an idea of the altitudinal distribution of seaweed densities.
Keywords:	kelp, sounder, echo-integration, *Zostera*
Bookmarks:	
Related information:	

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Change history		
Version:	**Date:**	**Change:**
1	15/01/07	

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Recommended operating guidelines for single-beam echosounder surveying

1. General principles of operation

Mapping underwater vegetation in the inshore subtidal zone is a difficult task owing to the various constraints encountered. While side-scan sonar and multibeam sounders have not proved efficient solutions, single-beam sounders on board light inflatable dinghies enable the detection of underwater vegetation (kelp and other seaweed and seagrasses). In the case of kelp, research is underway to also estimate their biomass.

The overall distribution of the brown algae species *Laminaria* has been selected by the French benthos monitoring network, Rebent, as an indicator of the health of macroalgal populations for the coastline of Brittany. These hard substrate seaweeds are potentially reactive to changes in coastal water quality and can therefore be used as a variation indicator.

Although exhaustive mapping cannot be contemplated using the above-mentioned tools given their low rate of coverage and the vast area concerned, they seem appropriate as monitoring tools, as a means of collecting ground-truth data for prediction models, or to validate other types of surveys (e.g. hydrographic LiDAR).

2. Surveying with single-beam echosounders

Two types of sounders were deployed: an EK60 120 KHz Simrad echosounder (along with the EK60 acquisition software) and a Kongsberg EA400 operating at both 38 and 200 kHz frequencies. Several study areas in Brittany were selected, for which a variety of bathymetric data were available (from LiDAR, Reson shallow multibeam, and single-beam sounder surveys).

Surveys took place in the summers of 2005 and 2006. Measurement data obtained with the sounders were georeferenced and time-referenced. Time references enabled subsequent re-calibration of depth data in relation to the LAT (lowest astronomical tide) level. The EK60 and EA400 sounder acquisition parameters were set in such a way as to obtain maximum resolution, of the order of 5 cm vertically. All measurements were taken at a constant speed of about 2.5 knots (4.5 km.h^{-1}), corresponding to a distance between each impulse (ping) of 5-10 cm.

EK60 surveys covered various seabed types, including bare sediment as well as various densities and types of vegetal cover. In order to try and link the

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backscatter index to the kelp biomass, EA400 surveys were focused on sub-areas with highest kelp cover which had been previously identified with the EK60 and validated by divers.

3. Data post-processing

Data post-processing was performed with the software MOVIES+, developed by Ifremer, using Excel for tabulating the data and the GIS Arcview 8.3 for map handling. The treatment procedure was as follows:

a) Post-processing with MOVIES+: file formatting, software configuration, choice of parameters:

Echo-integration is based on a layer-by-layer superimposition from the seafloor upwards. A buffer layer of 20 cm was decided on to eliminate potential errors owing to faulty interpretation of the bottom in areas where the seabed was irregular or in the presence of a steep slope. The definition of the layers (thickness, length and height) was carried out in parallel with visualisation of the echogram, and characterising the responses for each species. For the survey zones, three layers were selected: 20-70 cm, 70-110 cm and 110-200 cm from the seabed. These correspond to the maximum height of each type of algae (*Zostera*, *Cystosera* and *Laminaria* respectively). No echo that could be identifiably associated with fixed vegetation was found on the echograms over 2 m above the seabed, a fact that was confirmed by divers' observations. Therefore, this was chosen as the upper limit for echo-integration. Each echo-integration unit (ESU) has a fixed length of 100 pings (this value was lately improved to 30 pings), corresponding to a duration of around 5 seconds and a distance to the bottom of 5-10 m. The parameter *sA*, coefficient of acoustic retrodiffusion, was selected to characterise the density of algal population. This amplitude is independent of the speed of the boat and of the sounder's sampling rate, proportional to the biomass present in the volume explored. The results of the echo-integration were stored in a text file in ASCII format.

b) Formatting and processing of the text files in Excel:

Using the echogram and land scores, the results of the echo-integration were analysed to determine the classifying criteria for the different species. Five broad ranges were defined: *Laminaria*, *Zostera*, *Cystosera*, *Indeterminate* and *Devoid of vegetation*, as a function of the type of algae present in the area and the capacities of the sounder. An algorithm was developed from the echogram and the land data. The depths were in relation to the LAT, using data from Reson multibeam.

c) Export of the data to a GIS:

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On completion of the processing stage, each of the ESUs corresponded to a point on the ground referenced in X and Y coordinates, with a depth, an *sA*, and an algal type as defined by the classification. An example of interpretation results is given in Table 1. Each line represents one point on the echo-integration. The first two columns (Y, X) record location in terms of latitude and longitude data provided by the GPS, and the next two columns record the date and time the reading was taken. The fifth column (Z) is the depth as measured by the depth finder. To be useable, this 'untreated' depth must be adjusted in relation to LAT. The next three columns (sA1, sA2 and sA3) are the *sA* results of the echo-integration for the three layers selected: at the bottom between 20 and 70 cm, between 70 and 110 cm, and between 110 and 200 cm respectively. The column 'Total' is the sum of sA1, sA2 and sA3, and the last column is the classification result following application of the algorithm.

Table 1. Classification results for each of the ESUs.

Y	X	Date	Heure	Z	sA1	sA2	sA3	Total	Classif.
48,5876833	-4,62506667	17/08/05	11:07:04	4,6	9309,5	3901,9	1193,9	14405,2	LAMINAIRE
48,5876833	-4,62513333	17/08/05	11:07:08	4,6	12377,4	3621,2	12576,1	28574,7	LAMINAIRE
48,5876833	-4,6252	17/08/05	11:07:12	3,9	7166,5	4078,7	2768,5	14013,7	LAMINAIRE
48,59145	-4,62371667	17/08/05	11:37:30	1,7	243354,5	0,0	0,0	243354,5	ZOSTERE
48,5914167	-4,6238	17/08/05	11:37:33	1,6	342455,9	0,0	0,0	342455,9	ZOSTERE
48,5914	-4,62388333	17/08/05	11:37:36	1,7	243455,5	1,4	0,0	243456,9	ZOSTERE
48,5913667	-4,62395	17/08/05	11:37:39	1,8	209439,7	1,7	0,0	209441,4	ZOSTERE
48,59225	-4,62646667	17/08/05	11:42:15	4,7	0,1	0,0	0,0	0,1	UNVEG
48,5923	-4,62656667	17/08/05	11:42:19	4,9	0,0	0,0	0,0	0,0	UNVEG
48,5924333	-4,62686667	17/08/05	11:42:31	5,4	0,2	0,3	0,0	0,5	UNVEG

Over the three study zones, and considering all the algae contained in the 20-200 cm super-layer (including the three sub-layers 20-70 cm, 70-110 cm and 110-200 cm), by tracing the *sA* as a function of depth, two compact groups of points corresponding to different types of vegetation are identifiable (Figure 1). The first group, at a height near to LAT with a Log(*sA*) of between 4 and 6 inclusive, corresponds to the *Zostera-Cystosera* ensemble. The second group of points, with a high density at a height of -15m and a Log(*sA*) between 3 and 4 inclusive, corresponds to the *Laminaria* group.

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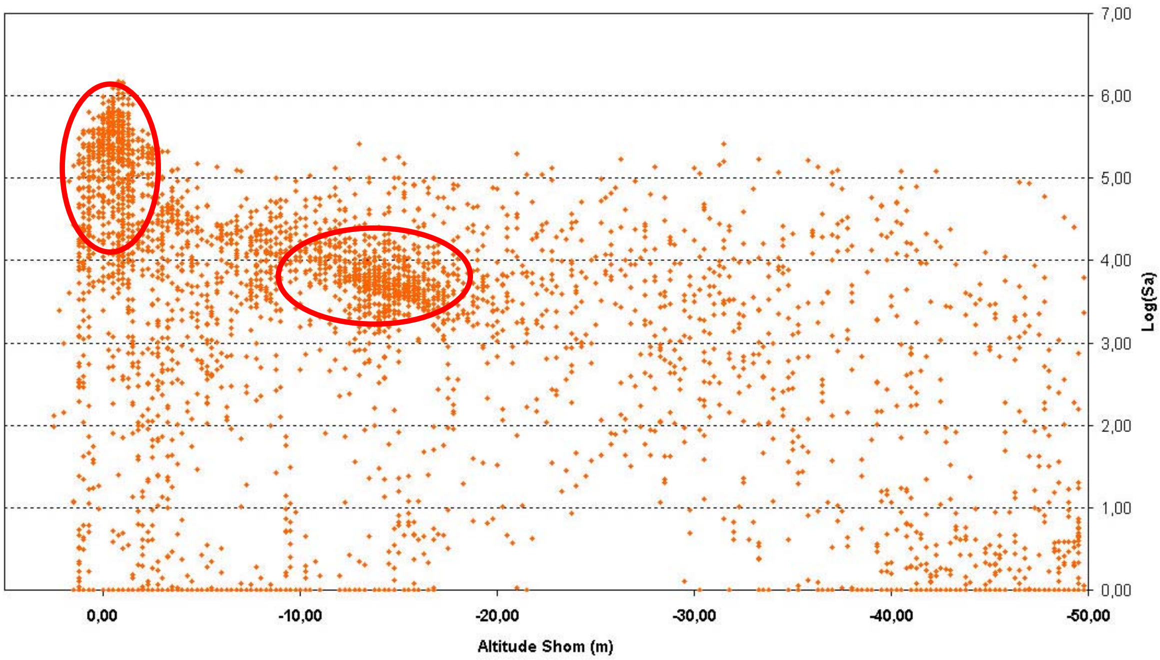

Figure 1. Results of echo-integration on the seabed (20-200 cm super-layer) as a function of depth. Two groups of distinct points are identifiable: *Zostera*-*Cystosera* at shallow depths (0 m) with a high *sA*, and *Laminaria* at an average depth of 15 m and a lower *sA*.

The results demonstrated a clear staging of the different ranges in the study zone (Figure 2). *Zostera* was found between 1.25 m and -2.75m depth, with a peak of abundance at -0.50m. *Cystosera* was proportionally less abundant than *Zostera* but at very similar water heights (between 1 m and -3.25 m, with a peak at -1 m). *Laminaria* occurred at all depths, with two clear peaks at -1.25 m and -14.25 m.

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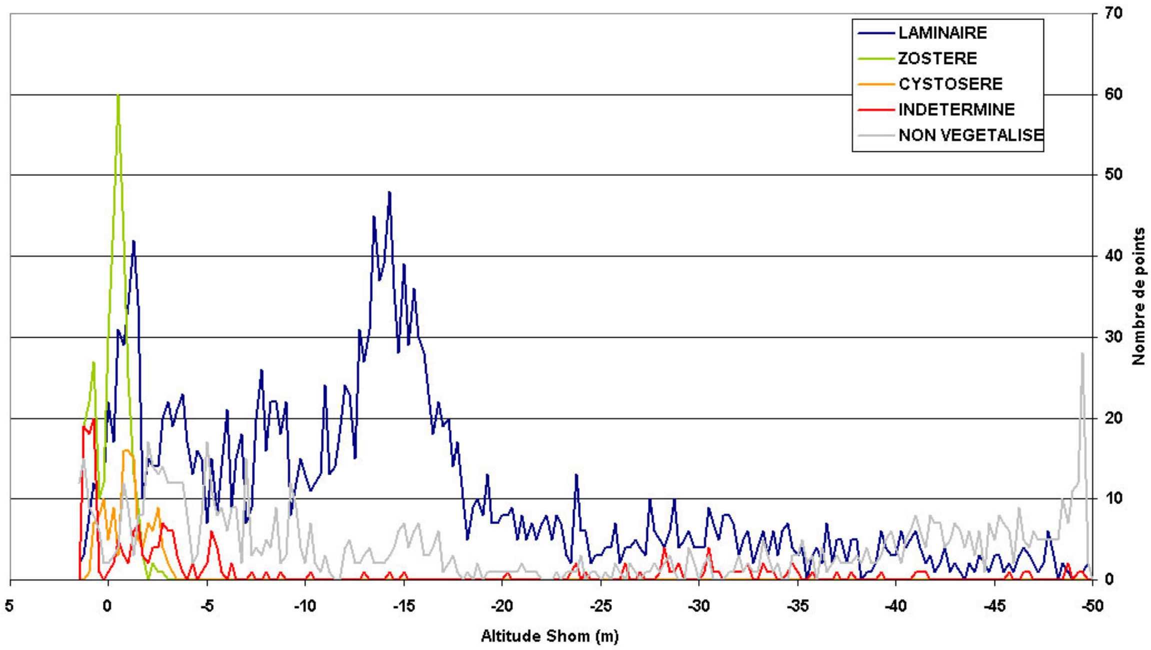

Figure 2. Classification results with LAT height reference.

This distribution of the various species needs to be considered in relation to the topography of the study zones. Indeed, the average altitudes recorded are close to the two above-mentioned distribution peaks (roughly LAT and -15m). These peaks are therefore only the reflection of the number of measurements and not of the real depth distribution of species.

In order to remove this bias it is necessary to weight these results by the number of samples taken at each altitude. In Figure 3 the two peaks observed for *Zostera* and *Cystosera* are still present, although the density peak for *Laminaria* is much less clear, maximum density occurring between -10 m and -20 m. The decrease in *Laminaria* beyond -20 m could also be a bias explained by the parallel increase in the number of indeterminate points. The chaotic nature of the seabed at this depth could be responsible for a faulty classification of the points analysed. Beyond -40 m, a substrate without vegetation predominates.

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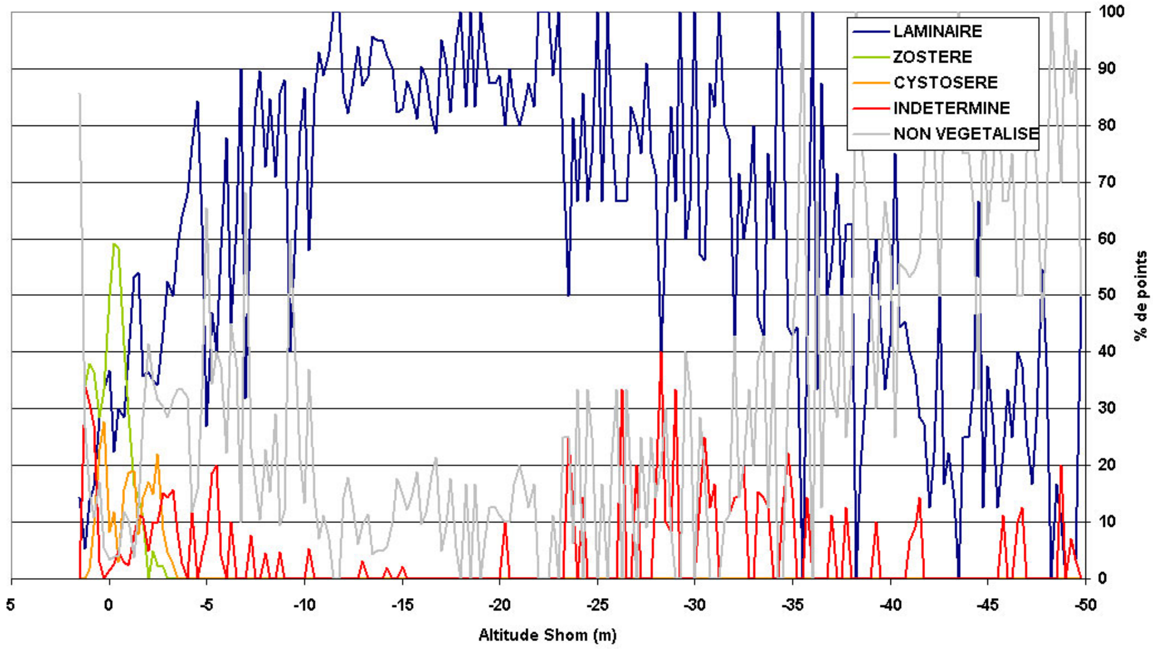

Figure 3. Results weighted by the number of samples at each altitude.

A representation of the algal density as a function of depth can be obtained by tracing the average *sA* for each species for each altitude (Figure **4**). For *Zostera*, we note an increase and then a rapid decrease in density between 1.5 m and -2 m, with a peak and maximal value around -1 m. The *Cystoseras* curve has a different form, taking the shape of a kind of hole, with a plateau between 1 m and -3 m. In the zones of presence, the density in *Cystocera* seems to be constant as a function of depth. For *Laminaria*, the *sA* values are much lower, but after some higher values between 1 m and -2 m, they seem constant as a function of depth.

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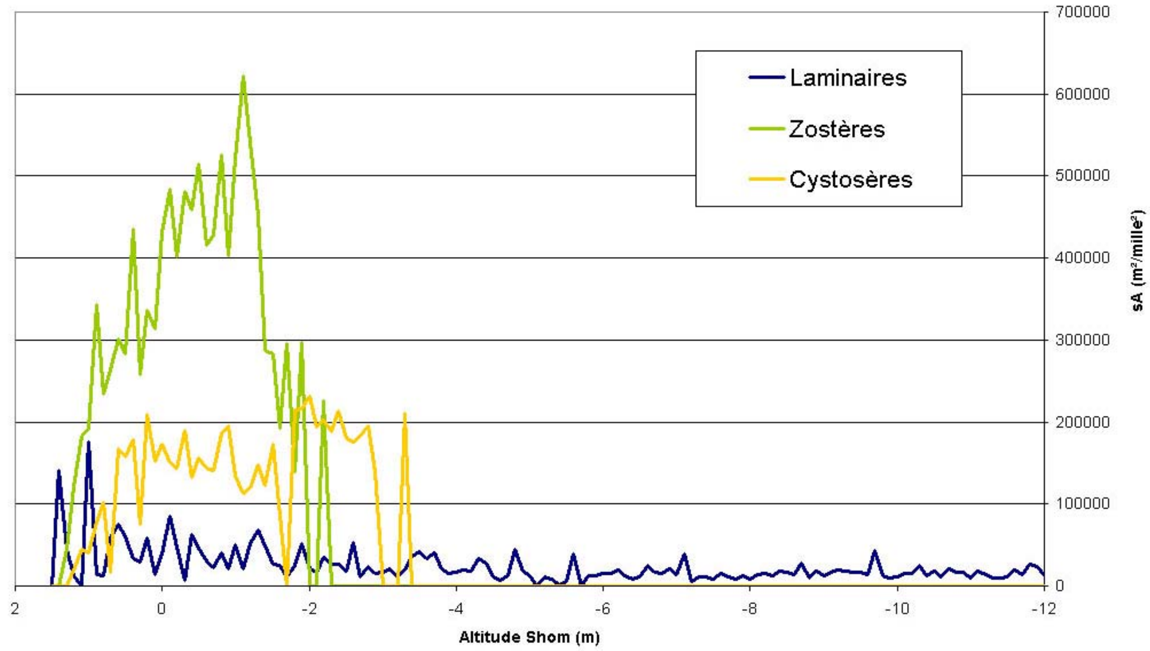

Figure 4. For each range, the average *sA* is traced as a function of depth. Being proportional to the biomass, this gives an idea of the altitudinal distribution of algal densities.

4. Conclusions

Investigations have shown that single-beam echosounders are a useful detection tool for mapping underwater algae beds, with comparable precision to classical diving methods for typical formations such as *Laminaria* and *Zostera*. The accumulation of data should enable the classification criteria to be refined and so improve discrimination of species. Attempts to link the backscatter index to biomass are promising. A calibration exercise would be necessary to link *sA* and real biomass in the field for each of the species studied.

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