ACOUSTIC ESTIMATION OF MACROPHYTES IN THE HORNSUND FJORD (THE SVALBARD ARCHIPELAGO)

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In this paper we examine the use of side scan sonar for estimation and spatial distribution of macrophytes in Arctic conditions. Acoustic observation were verified by video recordings and biological samplings. Single beam echosounder was also used. The Hornsund Fjord represents a periglacial environment with great diversity of morphodynamic processes and sensitivity for global warming changes so it is one of the most promising areas to research the influence of the climate's impact on ecosystem. Side scan sonar is a very effective and economic tool for mapping marine vegetation on the seafloor but interpretation of data still causes many problems especially in the specific conditions of the Arctic fjords (underwater rocks, postglacial sediments, steep slopes). We have created segmentation and classification algorithm based on the two-dimensional discrete wavelet decomposition of echo signals and fuzzy c-means data clustering. The algorithm was verified using biological data.

INTRODUCTION

The climate changes observed all over the world are especially visible in the Arctic environment. Long-term environmental observations and studies in the Hornsund Fjord (Fig.1) show a great intensity of morphodynamic processes and a great deal of interesting phenomena in its ecosystem. All that allows to treat Spitsbergen as a pattern natural laboratory. The fast diminishing areas of melting glaciers cause serious changes in the structure of the fjord's seabed and the configuration of its habitats. The parts of the bottom which became exposed create a new area for macroflora migration however, postglacial sediments change their life conditions (water transparency and seabed composition). Therefore, spatial distribution, species composition and biomass estimation of benthic macrophytes in Spitsbergen fjords are important indicators for monitoring and predicting global warming trends. This knowledge is significant for better understanding fjord ecosystem functioning.

On the other hand, extreme and demanding measurement conditions pose serious methodological challenges. Underwater rocks, icebergs, nebulosity and very irregular coastline create difficulties in the usage of research vessels. Airplane and satellite photography or biological sampling are expensive and time-consuming, especially when systematic and large scale studies are required. Therefore, we chose acoustic methods which are effective and suitable tools for investigating underwater habitats and describing bottom surface morphological forms. They allow quick and precise data acquisition but require efficient algorithms for image correction and data classification. There are two main approaches: an analysis of backscattering signal [1-3] and image processing methods. With respect to the first we used wavelet analysis of echo signal [4] and than fuzzy c-means clustering for estimation of spatial range of underwater meadows. Algorithm is ground-truthed by video registrations and samples of species taken *in situ*.

The research expedition took place in August-September 2005 having logistic support of the Polish Polar Station located in the Hornsund Fjord. The study areas were located in shallow waters, close to the surf zone (Fig.1). Measurements were carried out from an easily maneuverable rubber boat.

a) b)

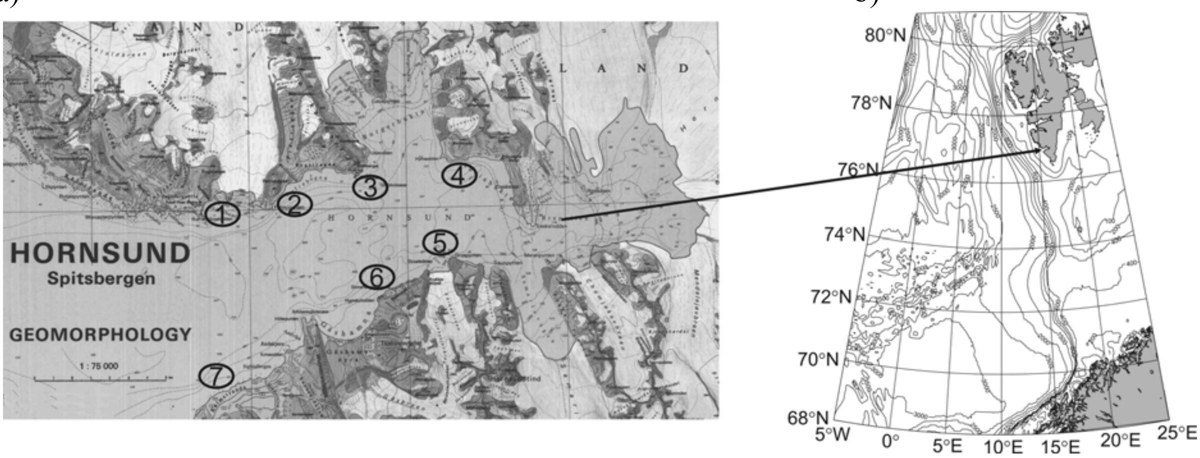

Fig.1 Location of study areas inside Hornsund fjord (a): 1) Isbjornhamna, 2) Fannypynten, 3) Gnalodden, 4) Adriabukta, 5) Gruspynten, 6) Stonecity (Rasstupet), 7) Kulmstranda and (b): map of Svalbard Archipelago

1. DATA ACQUISITION AND EXPERIMENT METHODOLOGY

Our basic equipment was Simrad EK500 single beam echosounder operating at 120kHz and EdgeTech DF-1000 side scan sonar operating at 100kHz and 500kHz. Echosounder transducer was attached to the boat and placed 1m below the sea surface. Side scan sonar towfish was towed at constant depth of about 2m. The collected acoustic data were linked with their geographic position obtained from GPS navigation system. The depths in research areas range from 2 – 50m but we took into account only those down to 30m because of the maximal euphotic zone limit. Transects were made as parallel swath lines across the measurement areas mostly perpendicular to the coastline.

Hydroacoustical methods are based on an assumption that phytobentos is acoustically visible against a bottom background what results from different backscattering properties. The aim of this work was to examine the spatial distribution of macrophytes and their bio-volume estimation extracted during processing collected data.

Biological samples collected by divers provided knowledge about qualitative and quantitative properties of examined vegetations (species, biomass, magnitudes). The position of samples was coincident with hydroacoustical transect areas. The data and video recordings allow to calibrate and verify data processing and classification algorithms.

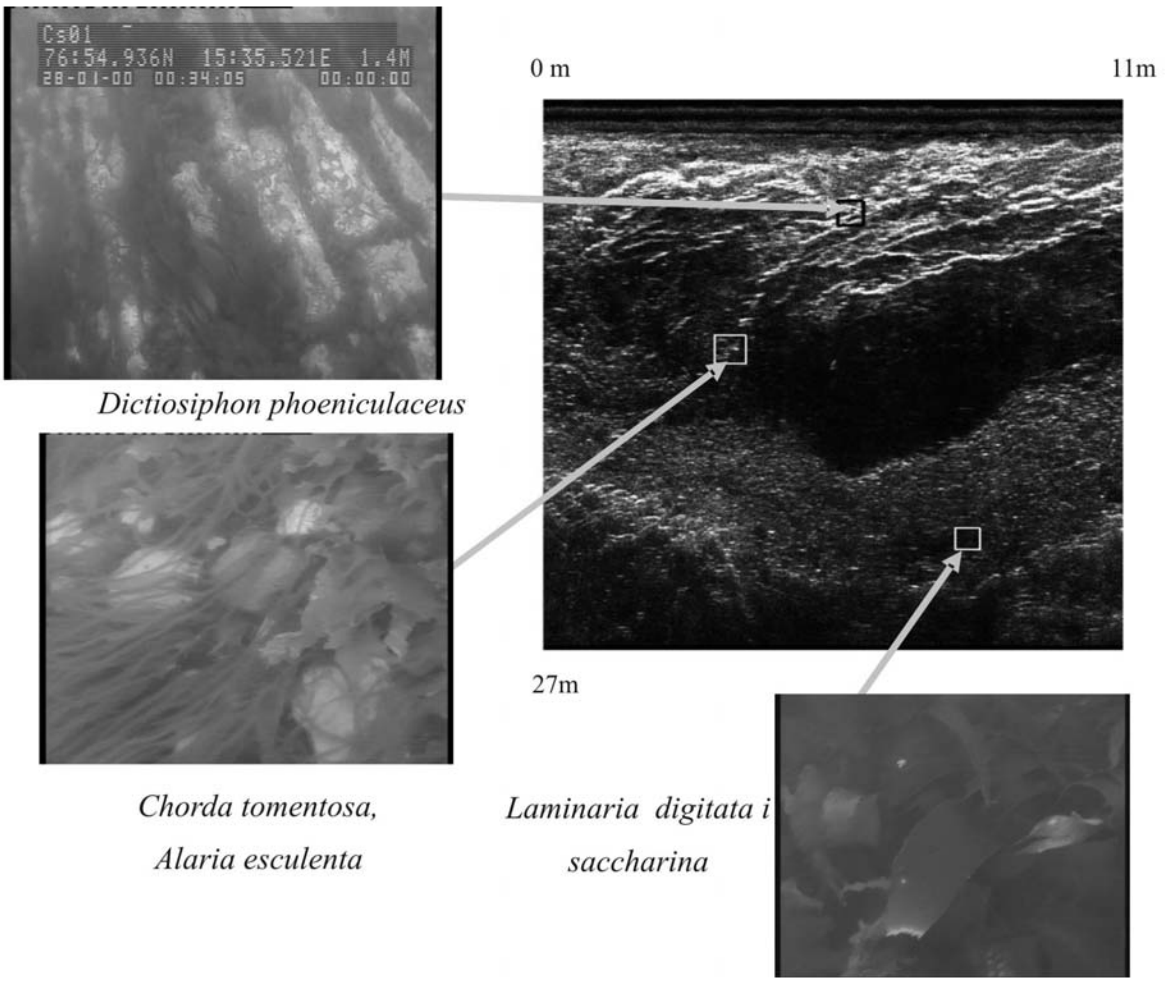

Fig.2 Kulmstranda area, the side scan sonar image, right channel 500kHz from 3-5m depth. Algae are seen as dark pixels on the stone bottom, oblong stones and rocks (light pixels). Pictures from camera contain $0.6m^2$ and are geographical coordinate with sonar

The first data analysis contains geographical orientation with maps of the Hornsund Fjord and appraisal of quality of those measurements. The sonar image is created line by line from each ping received perpendicular to the transect heading. Its range depends on ping rate and is about 14 pings/second when 50m is set. In this case number of samples used for each ping return is 1790, which secures resolution of a few centimeters. Unfortunately, sonar images are very sensitive to distortions as a result of the motion instabilities of the sonar towfish. Pitching and yawing cause geometric distortions when sonar beams scan ahead or back during stronger wind when sea surface is rough [5]. There could be also an unexpected change of speed and direction especially on a dinghy. All that may cause a displacement of the distortion of visible sonar image. These factors and steep slopes make also strong deviation from the linear relation between image intensity and backscattering strength of the bottom so we had to be careful when selecting a proper TVG for the received signal. Bearing in mind all these factors and biological specification of each area we chose, for further studies, four main places: Isbjornhamna, Gnalodden, Stonecity and Kulmstranda. The data collected using the different tools for those areas are rather complete.

2. DATA ANALYSIS AND AREAS CHARACTERISATION

Consider acoustical data we have to take a look at using the biological background of periglacial benthos life. Most common macrophytes in Spitsbergen fjords are algae. They are saltwater-dwelling, simple organisms. Distinguishing between them is based on the differences in pigment composition which causes their green, brown or red colour. Due to this adaptation we can observe stratification in their deployment on the sea floor according to depth: green algae (*Acrosiphonia sonderi*) in shallow water, brown algae (*Laminaria digitata, Laminaria Saccharina, Alaria esculetna*) deeper and red algae (*Callophylis cristita, Ptilota plumosa*) beneath [6]. The maximal length of blades was up to 150cm length and 50cm width. Some of them have gas caverns and gas bubbles located on their surface. Stronger backscattering from the bubbles does not change the observed dependence that macrophytes attenuate backscattering strength and it is weaker than the one from the bottom.

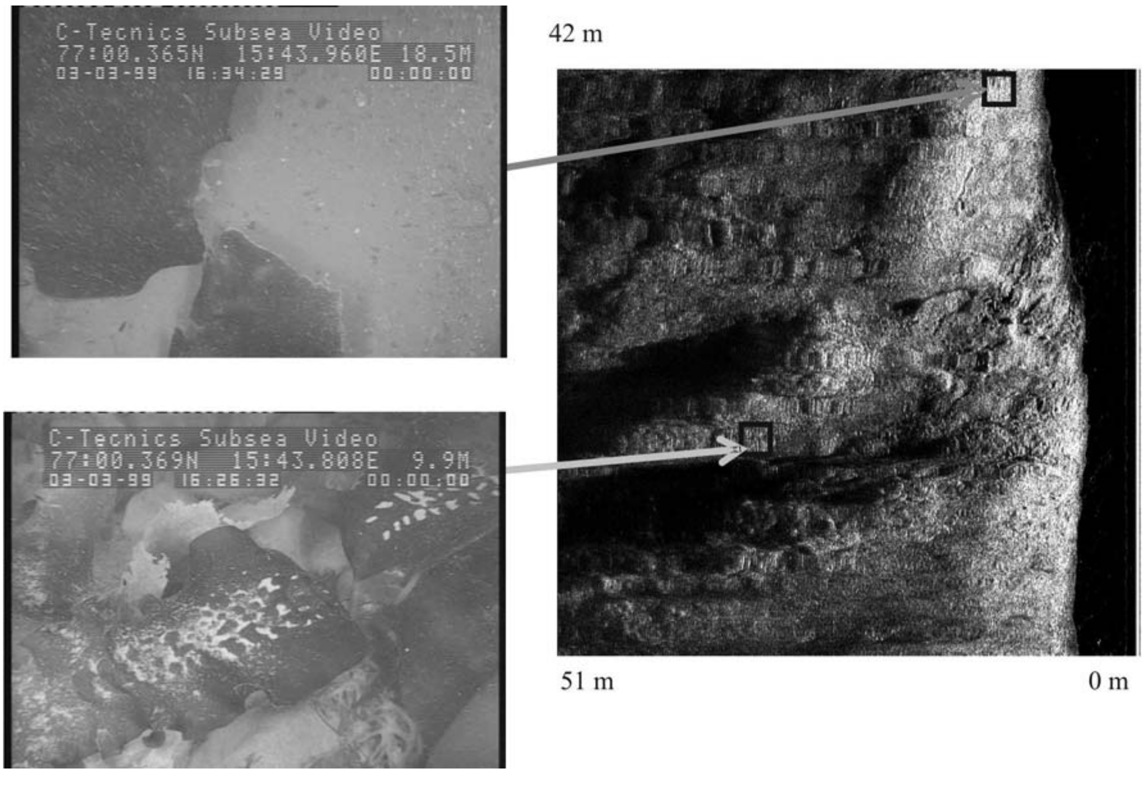

Fig.3 Gnalodden region, the side scan sonar image, left channel 500kHz from 18-22m depth. Stony and sandy (sediments from glaciers) bottom, underwater rocks. Algae occur even at 20m but mostly at about 10m. Middle density of macrophytes coverage

Algae grow mostly on stony and graveled bottom to which they have to be very well attached as protection from strong currents. As we could seen on the video algae can cover even 100% of the bottom surface but if not, the stones were acousticly visible as stronger backscattering places (light pixels). A perfect example would be Kulmstranda (Fig.2) region which is placed at the mouth of the fjord, where water transparency is high. Weaker glaciations result in rich biological diversification and algae occurrence even in shallow waters (1-6m).

Gnalodden is a quite different area placed in the fjord between postglacial bay and a rocky Sofiebogen gulf. Bottom falls softly for the first 20m depth, and afterwards there is a steep slope down more than 100m. Algae grow there not so densely (Fig.3) as in Kulmstranda and there is some suspension carrying from glacier region. Underwater rocks are rather overgrown by plants which make backscattering strength weaker than from the bare sand where macrophytes occur rarely. There are also long shadows (black pixels) which came from the rocky hillocks. This sonar image came from about 20m but we can still find there dense algae covering except for the sandy areas.

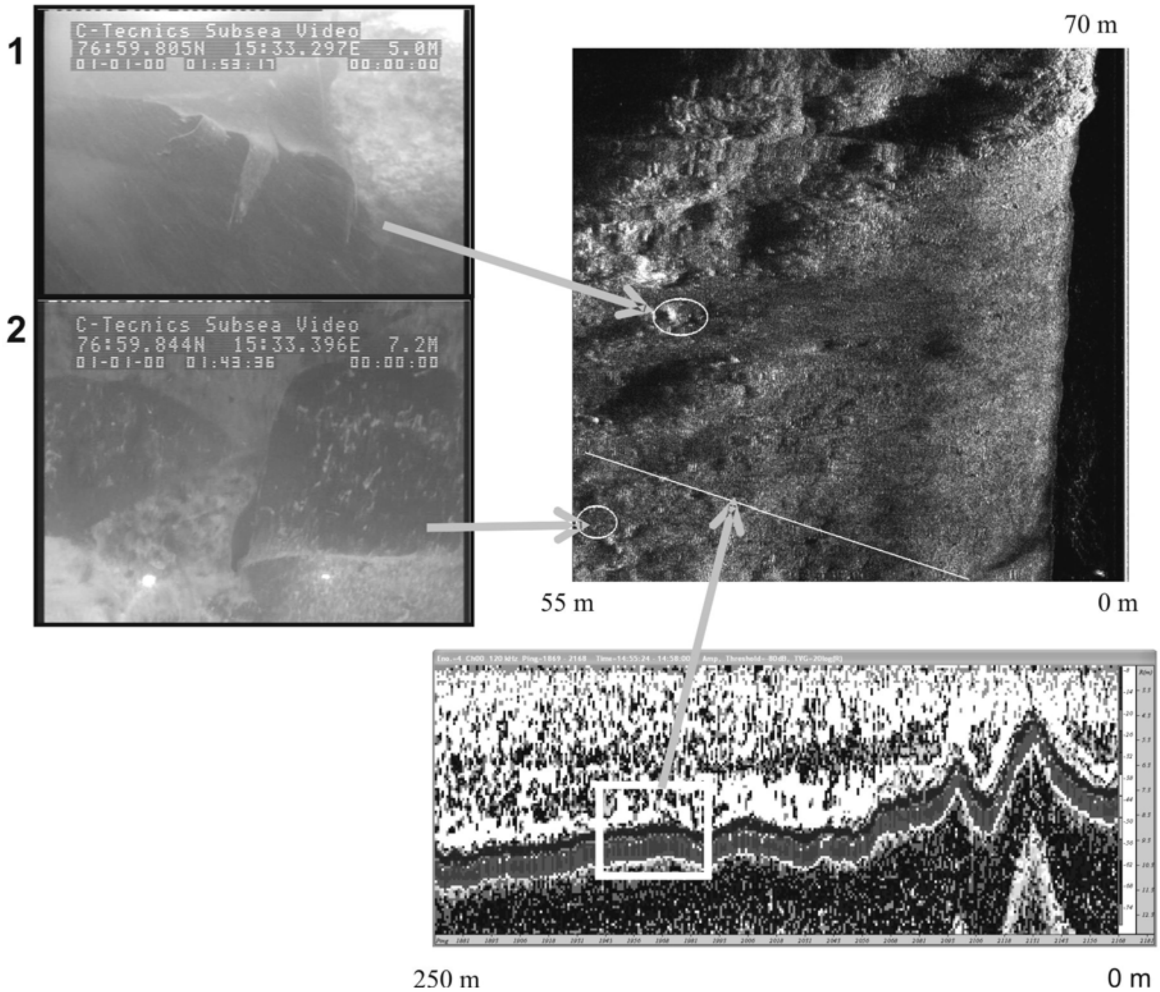

Fig.4 The image register by side scan sonar at 500kHz (upper right picture) in Isbjornhamna area at depth varying from 5m to 9m. Light pixels mean strong backscattering (from the stone bottom) and dark one weaker (from algae), black means acoustic shadows. Each camera picture covers about 0.6m^2 area and is referred to geographical coordinates to ground-truth the acoustical classification: 1) stony bottom with algae, 2) gravel bottom with algae covered by clay sediment. Beneath, echogram from single beam echosounder with 44m long transect connected with sonar image

The most important thing for our research was to find proper places for teaching and testing of classification algorithms. It means that it should be sonar data of good quality and with a correct connection to other samples, especially from the echosounder and camera. As we can see at Isbjornhamna (Wilczek) area image (Fig.4) these conditions are met. The picture from the echosounder helps to realize that there was dense suspension in water column. It came from nearby Hans glacier and was carried away by currents. Underwater investigations showed clearly that the stone and gravel bottom and also algae blades are locally covered by mud which makes classification more difficult and requires a more sensitive distinguishing algorithm.

3. ACOUSTICAL DATA PROCESSING AND CLASSIFICATION ALGORITHM

After preprocessing of data according to literature results [2,7] we decided to use parametrical method for data segmentation and estimation of bio-density of macrophytobentos [3]. There are many statistical and physical parameters of the echo envelope, which are sensitive to different forms of seabed surface shapes and properties: spectral parameters as spectral width, moments, skewness, fractal parameters, wavelet transformation parameters and more. After carrying out multiple tests we chose wavelet analysis as a very powerful and effective method. We have used their coefficients as input parameters in fuzzy logic clustering algorithm, which gave us good and fast results of classification.

Wavelets are special finite functions which have given scale and shift. When analyzing the sonar signal (image) we compare a two-dimensional wavelet function with a part of this signal, and calculate correlation coefficients, in turn shifting this function sample by sample and changing scales. Larger scales are sensitive to low frequency and small scales are sensitive to high. This way we get some new images (coefficients collection) emphasizing characteristic signal features. An important advantage of this transformation is that it keeps information about spatial location of signal disturbance, not only spectrum analysis as in Fourier transform.

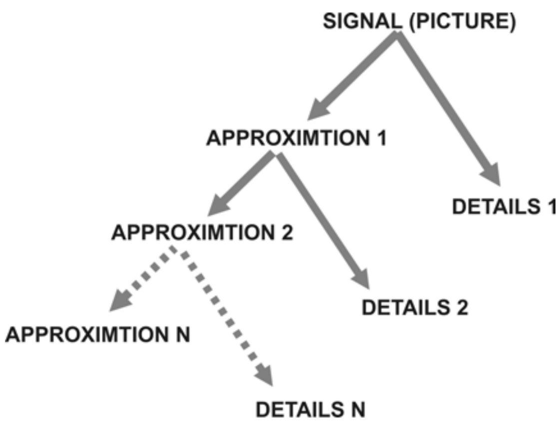

Fig.5 Wavelet decomposition of input signal, details coefficients contain diagonal, vertical and horizontal details, numbers represents changing scales in turn

Our method is more precisely based on dyadic discrete wavelet transformation of echo signal (Fig.5). It results in a decomposition of input signal in approximation coefficients (large scale wavelets) and the details (small scale wavelets) in three orientations (horizontal, vertical and diagonal). In our fuzzy c-means data clustering [8] method (FCM) we used approximation and diagonal coefficients as input parameters, which provided good results.

We also tried to use Kohonen’s self-organizing neural networks however, this is a time consuming method and its results are comparable with FCM. When using this segmentation procedure we get image divided into areas containing different features related with vegetation and seafloor morphology. As a result of the previous research region analysis we decided to distinguish three or four classes of habitats.

In the Isbjornhamna example we needed segmentation for four classes (Fig.6) for proper dividing of image areas. This is because of sediments from glaciers. As it is shown on the camera picture below algae grow there not only on stony bottom, but also a bit covering by suspensions and it was difficult to distinguish a bare bottom from bottom with macrophytes, because their backscattering strength was similar.

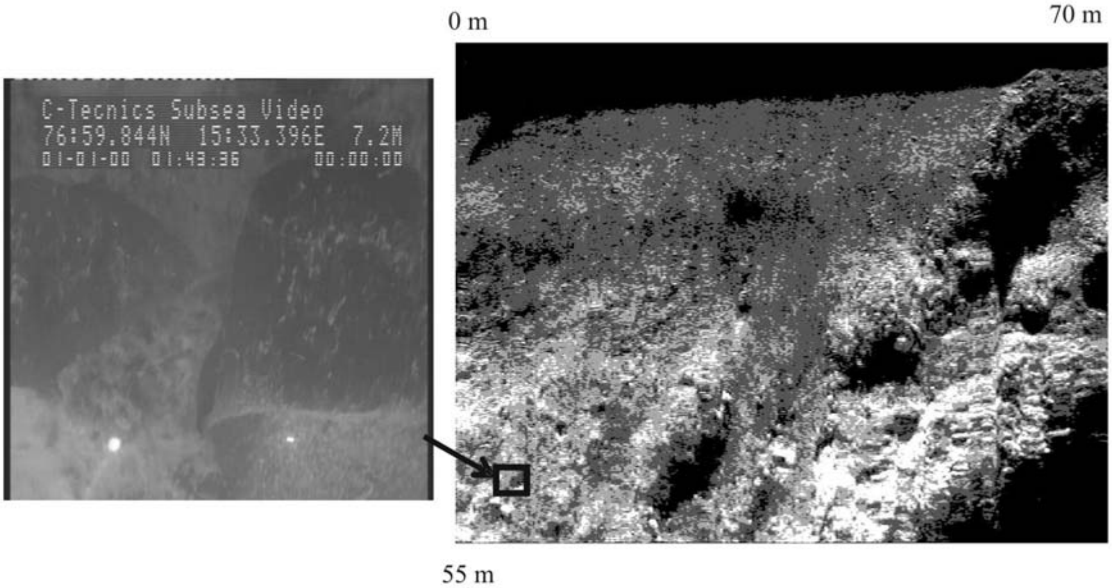

Fig.6 Results of image segmentation based on the two-dimensional wavelet decomposition of sonar echo signal from one channel and fuzzy logic clustering method. Black pixels depict acoustical shadows and reflections from the water column, dark gray - muddy bottom, gray - vegetation occurrences and white - strong backscattering from rocks and stones. The camera picture covers area about $0.1 m^2$ and verify accuracy of classification

As we could calculate from classification algorithm, estimated algae area is about $811 m^2$ what represents 23% of the presented image. According to biological and video observation this is a quite good value. The algae and muddy bottom shown on the camera image (Fig.6) correspond with classification results on the segmented sonar picture.

In Kulmstranda where the water was pure we needed only three classes: acoustic shadows, macrophytes and stony or sandy bottom, and it brought good results of estimation. It proves that the sonar data should not be analyzed fully automatically, even should we have an effective recognition algorithm.

Sonar data processing contains multiple challenges linked with image distortions: geometrical and intensity result from data acquisition, towfish motion instabilities or boat course and speed changing. All those problems can be resolved using mathematical models of these distortions. In our work we chose parametrical methods, although texture analysis is also very promising area for farther investigation.

4. CONCLUSIONS

The preliminary results presented in this article on biomass estimation of macrophytobentos in the Arctic (Svalbard) fjords demonstrated that the proposed method of side-scan sonar data analyzing using wavelet transformation and fuzzy logic clustering provide proper recognition of areas covered with vegetation what is confirmed with single beam echosounder registration, video recording and biological probing. The proposed image segmentation is a fast and effective method of classification which makes it a very promising algorithm for large amount of sonar data interpretation. The side scan sonar is a good tool for the systematic collection of data from a wide area, however it requires more investigations into data processing and recognition algorithms.

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