Bol. Inst. Esp. Oceanogr. 15 (1-4). 1999: 325-336 **BOLETÍN** INSTITUTO ESPAÑOL DE OCEANOGRAFÍA
ISSN: 0074-0195

Acoustic methods for *Gelidium* seaweed detection

A. C. Molero and R. Carbó

Instituto de Acústica, CSIC. Serrano, 144. 28006 Madrid, Spain

Received September 1997. Accepted April 1998.

ABSTRACT

The reflection and absorption coefficients of a thick layer of *Gelidium sesquipedale* (Clem. Born. et Thur.) seaweed covering a sandy bottom were determined in a laboratory tank. As a result of the reduced vertical cross-section and the high water content of this seaweed, its acoustical impedance is very similar to water impedance, and the target strength of each individual seaweed frond is very weak. The usual frequency range for detection of marine life, 100-500 kHz, has been used. The average value of the bottom scattering strength was found to be between –26 dB and –34 dB in the frequency band used.

Key words: Underwater acoustics, bioacoustics, back-scattering.

RESUMEN

***Métodos acústicos para la detección de* Gelidium**

Se han realizado mediciones del coeficiente de reflexión y absorción de una capa espesa de algas de Gelidium sesquipedale *(Clem. Born. et Thur.), sobre un fondo de arena, dispuesto en un tanque de experiencias hidroacústicas. Como resultado de la reducida sección transversal acústica de cada brote del alga, y de su alto contenido de agua, su impedancia acústica tiene un valor muy próximo a la impedancia acústica del agua marina y, en consecuencia, el nivel de blanco de cada brote es muy débil. El rango de frecuencias utilizado parte de 100 kHz, alcanzando 500 kHz. El valor promedio del nivel de difusión de fondo de la capa de alga de* Gelidium *encontrado varía entre –26 dB y –34 dB en el rango de frecuencias utilizado.*

Palabras clave: *Acústica subacuática, bioacústica, retrodifusión.*

INTRODUCTION

To improve the detection possibilities of *Gelidium sesquipedale* (Clem. Born. et Thur.) seaweed in the seabed, its acoustical behaviour has been investigated under laboratory conditions, to determine the basic acoustic properties: reflectivity, absorption and acoustic impedance, in the 100-500 kHz frequency range.

G. sesquipedale is a Rodofita seaweed (figure 1) which belongs to the Rhodophyceae class, Gelidiales order, and its size varies from 2 mm to 45 cm, with a uniaxial structure. They are finally shaped into grouped clusters; from a very active rhizoid, a succession of new portions of thellus begins to grow. This rhizoid attaches to a calcareous substrate, with a predominantly organic origin, through tiny hapteron discs (Juanes and Borja, 1991).

Because of its high content in agar-agar, there is universal interest in this seaweed. Agar-agar is a very complex polysaccharide, highly valued as a thickener in the food industry. It is also used in bac-

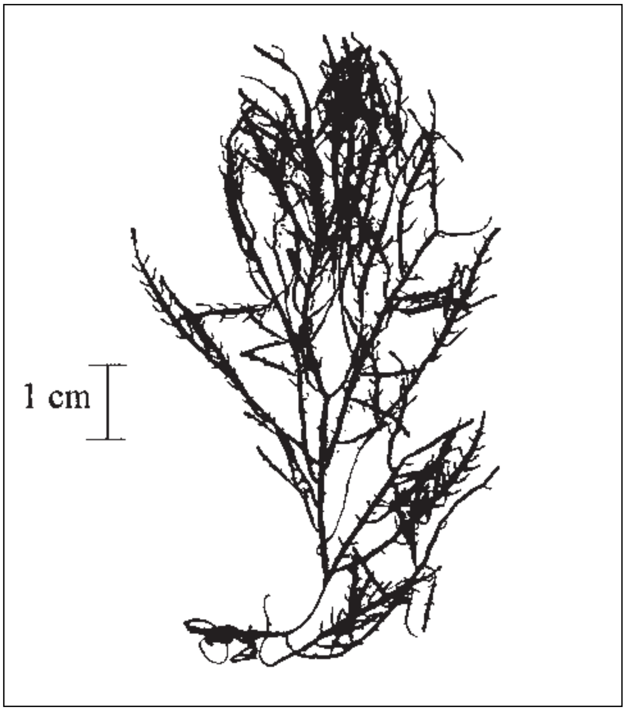


Figure 1. *Gelidium sesquipedale* seaweed

teriological synthesis, and this latter application is another source of interest in agar-agar. Still, not all agar-producing seaweed are useful in bacteriological agar production, only five of them, including *G. sesquipedale,* are able to produce agar of sufficient quality.

The increase of microbiological synthesis techniques has made agar a highly interesting product, due to the universal lack of high-quality agar-producing seaweed. Its value on the international market is growing daily as new applications and subproducts derived from agar appear continuously. Agarose, which is a sulphate-free colloid extracted from agar, commands a very high international market price.

On the Atlantic Iberian continental margin, large *Gelidium* seaweed communities can be found, especially on the Cantabrian continental shelf, from Fuenterrabía to Cabo de Peñas. There are also other major *Gelidium* seaweed populations, located on the Galician coast from Camariñas to La Guardia, and on the Portuguese shelf, especially near Porto, Setúbal and Algarve (Álvarez *et al.*, 1989; Juanes and Borja, 1991). Spain probably has the highest-density seaweed community in the world.

It is noteworthy that one of the natural forms in which *Gelidium* can be found after loosing from the seabed is known as *arribazón*. This is a seaweed mass no longer attached to a calcareous substrate, so that it can move anywhere with the currents, floating in the water column. If the wind blows towards the coast, people on the beaches can collect it easily, but whenever the wind blows in the opposite direction, the *arribazón* is transported towards low dynamic regions, remaining there until its decomposition (in about 10 days).

The application of new acoustic detection techniques (i.e. sonar) in the finding of *Gelidium* seaweed masses, would enable us to make use of the sea's natural resources, avoiding the loss of tons of *Gelidium* seaweed, whenever conditions on the continental margin are inadequate for beach collection.

MATERIALS AND METHODS

Underwater acoustic detection requires knowledge of seaweed's main acoustic properties, e.g. reflection coefficient, acoustic impedance and absorption.

These parameters have been quantified largely through detailed laboratory studies. The transducer projects a pulse in a directional beam. The transmitted pulse of sound propagates through the water away from the transducer. It may encounter various targets, e.g. seaweed and the sand bottom. These targets reflect or scatter the pulse, and some energy returns towards the hydrophone, being recorded and processed by an A/D converter (figure 2).

In the present experiment, *Gelidium* seaweed (in a layer 20 cm thick) was placed in a water tank (1.06 m $\times$ 0.71 m $\times$ 0.90 m), taking special care to obtain a homogeneous volume concentration throughout the entire layer. Under the seaweed layer, a sandy bottom simulated natural conditions, with a thickness of 11 cm, grain size < 2 mm and average density 2.65 g/cm^3.

Relevant parameters temperature, salinity and seaweed concentration were controlled throughout the experiments. Water in the tank with marine salt in suspension reassembled ocean water, reaching a salinity value of s = 35 ‰, and density r = = 1.024 g/cm^3. Air-bubbles attached to the seaweed were also carefully eliminated.

Three piezoelectric echo-sounders were used to cover different frequency ranges, directivity and duration of the transmitted pulse. Table I shows the essential features of the echo-sounders.

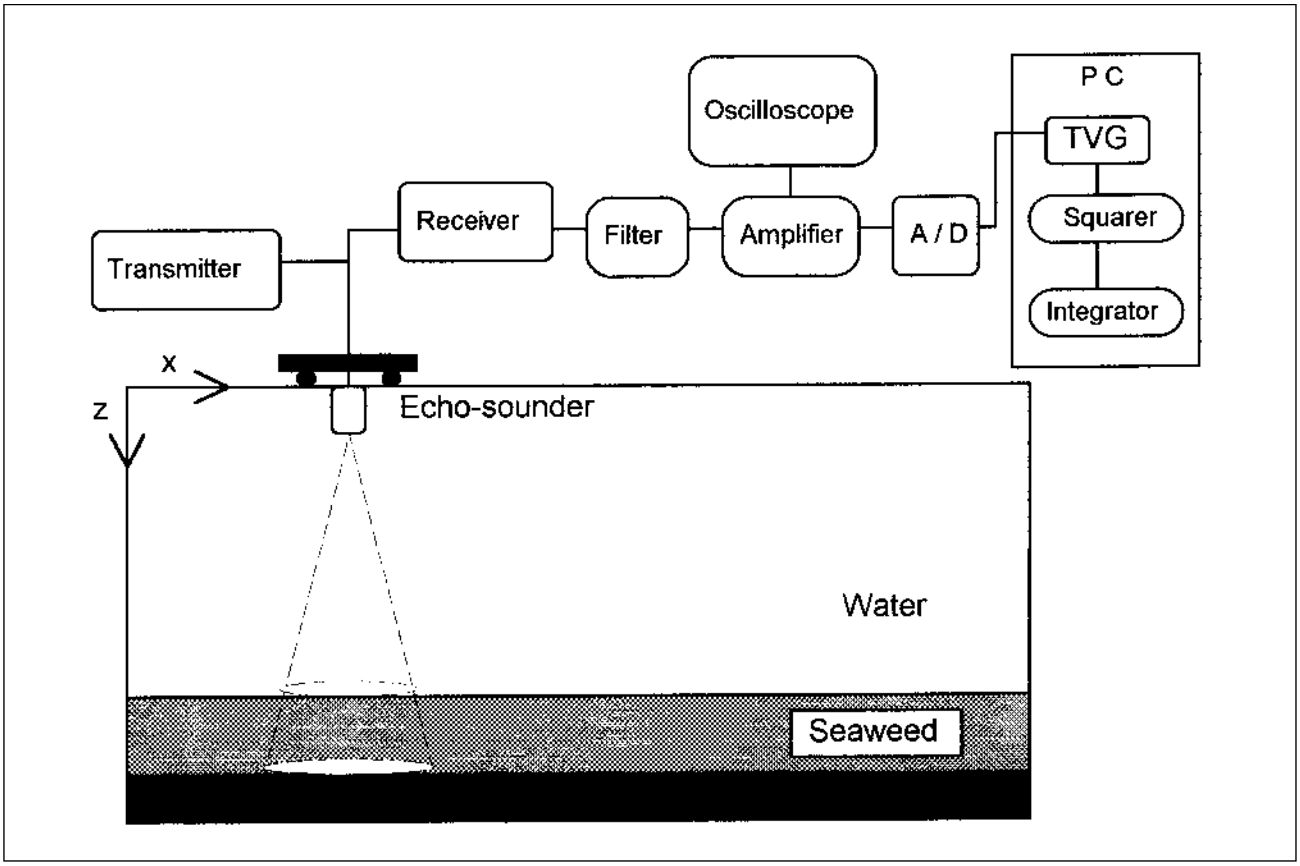


Figure 2. Experimental set-up. The combined echo-sounder/hydrophone moves along a straight line, receiving a signal every centimetre. After being filtered and amplified, this signal was converted into a digital format to be processed. Compensation for the beam-spreading (Time Variable Gain) and squared echo integration could thus be processed as the echo-sounder moves

Table I. Features of the transducers used in the experiments

Transducer	Frequency kHz	Bandwidth kHz	Source level dB re 1µPa 1 m	Directivity index dB	Beam width (1/e)	Pulse duration µs
IA-100	102	96-108	204	12	29°	50
Raytheon V700	201	198-204	211	13.3	16°	200
Ulvertech 295	527	514-539	233	18	6°	100

The directivity pattern, emitted pulse and frequency response of each transducer is shown in appendix I.

As a receiver sensor, a Brüel & Kjaer hydrophone was used, placed by the transducer, both working as a mono-static system (appendix I also includes hydrophone performances).

The combined echo-sounder/hydrophone x-y axis movement was controlled automatically, with the z axis remaining at a depth of at 2 cm deep. Three parallel trials, at y = 30 cm, y = 35 cm and y = 40 cm, with 30 acquisition points (every cm), made up a total recording network of 90 points.

RESULTS

Echoes produced by the sandy bottom without seaweed (a), by the seaweed layer (b), and by the sandy bottom with seaweed above (c) were recorded at the three frequencies studied: 100, 200 and 500 kHz.

Figure 3 presents an example of situations b and c. The figure presents the signal taken by the hydrophone with the three different echo-sounders transmitting at 100, 200 and 500 kHz. The first pulse in each record is concerned with the direct path wave travelling in a lateral direction from the echo-sounder source to the hy-

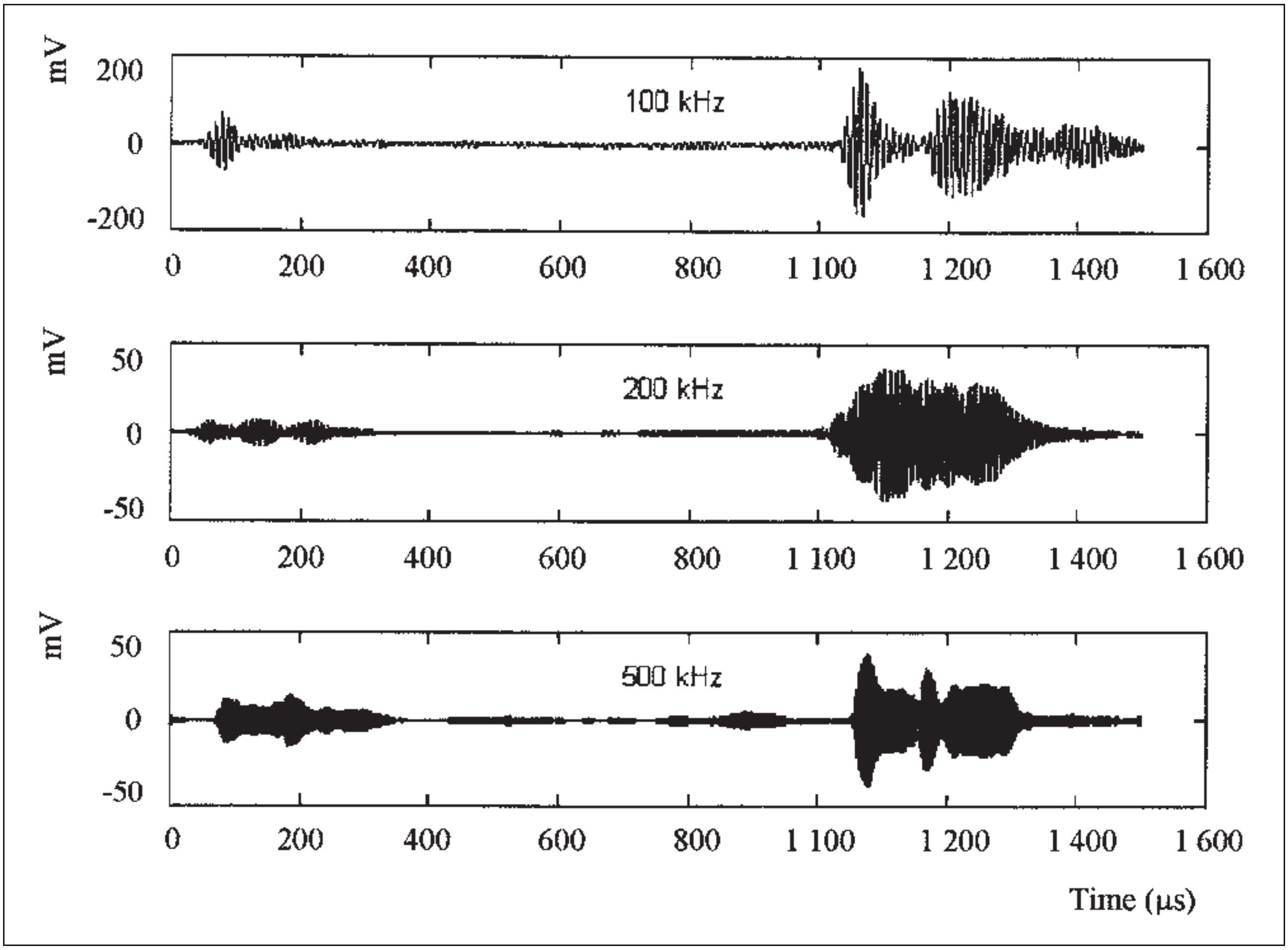


Figure 3. Sandy bottom back-scattered signal covered by a *Gelidium* seaweed layer using three different echo-sounders

drophone. A 50-μs pretrigger was set in the acquisition system.

The reflected echo produced by the sand/medium discontinuity surface reflection can be easily seen at t ≈ 1 050 μs. The echo signal shows another peak pulse that appears later (t ≈ 1 100 μs), at 100 and 500 kHz frequencies belonging to the bottom tank reflection. It is noteworthy that at 200 kHz frequency this pulse is masked, since the length of the incident pulse is longer than the sand layer thickness itself. The time arrival of these echoes does not vary significantly as the echo-sounder moves, because of the flatness of the bottom layer of sand.

A weak echo from the seaweed (700 μs) can be seen just before the strong echo corresponding to the sandy bottom (1 050 μs). In this case the incident pulse finds two targets (seaweed and the sandy layer), and both reflect or scatter acoustic energy towards the hydrophone. At first glance, the seaweed echo is not easily appreciable. Taking layer thickness into account, the arrival-time interval for seaweed echoes approaches that of sand (700-1 000 μs). Their amplitudes, as can be observed, are much smaller than those from the sandy bottom. Usually at a frequency of 500 kHz, but also sometimes at 100 kHz, the seaweed response can be appreciated, but even then the noise and reverberation sometimes mask this echo.

The 90 signal records were to create echogram plot. To improve visual detection of the seaweed, because of the weakness of its echo, a temporal window (550-1 050 μs) was processed.

The envelopes of all these signals have been computed with the Hilbert transformation (Carbó and Ranz, 1986). Graphs in figure 4 represent the 90 envelopes of scattered signals in the region where the seaweed echo arrives (570-1 070 μs). A thin, dark layer appears in the last 50 ms, caused by the sandy bottom reflection.

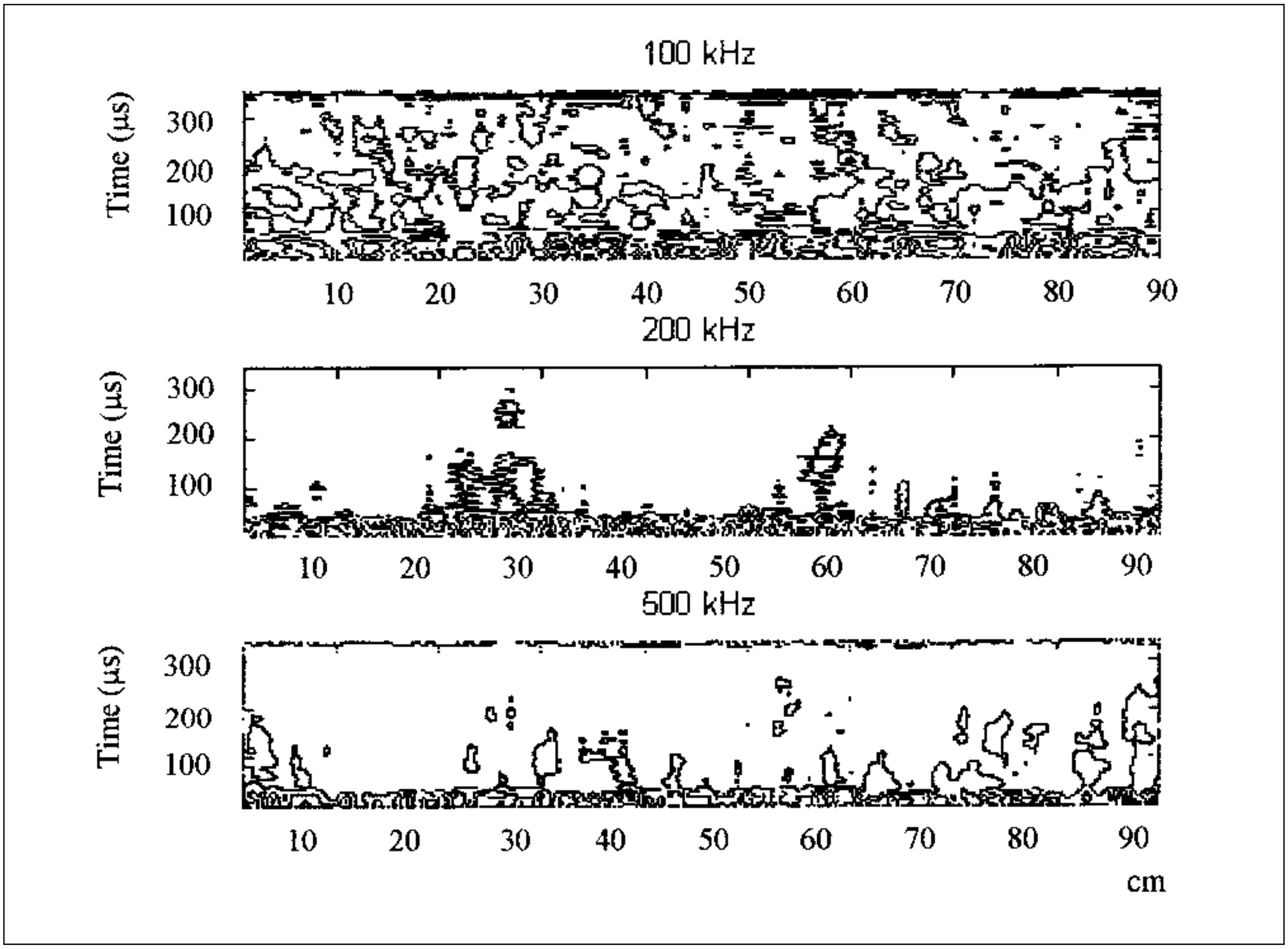


Figure 4. Echogram contour lines map of the back-scattered signal envelopes gated between 700 and 1 050 m

The graph represents a M = 25 isolines (the levels have been normalised by the maximum amplitude of all the envelopes, m = 1, 2,... M). Such plots demonstrate stronger seaweed back-scattering at 100 and 500 kHz.

To assess such visual appreciation, the following acoustic parameters have been quantified: reflection coefficient, absorption coefficient and acoustic impedance.

To detect any biomass present in the water column, e.g. seaweed, with all the difficulties inherent in an ocean survey, including bad weather conditions, it is important to previously characterise the target in the laboratory very carefully. In order to characterise a target acoustically, it is necessary to measure at least two fundamental magnitudes: reflection and absorption (expressed by the reflection coefficient and the absorption coefficient, respectively). Another parameter of great interest is acoustic impedance, as it provides an idea of the target's acoustic behaviour, when compared with water's acoustic impedance.

Therefore, two methods are proposed to detect the presence of the *Gelidium* biomass. First, by means of reflection. This method evaluates the energy from the *Gelidium* echo, in comparison with the incident wave energy, to establish a certain ratio between both sound waves energies (Eg/Eo). With this method, whenever the sonar of the ship on a survey is passing over *Gelidium* seaweed, would be found same energy ratio, and then could be said that *Gelidium* seaweed has been detected.

The second method is related to the absorption of the wave energy that propagates through the *Gelidium* seaweed layer, reflects on the sandy bottom, and again propagates through the *Gelidium* seaweed towards the receiver. Comparing the energy received at the hydrophone in two different cases, first passing through the *Gelidium* seaweed, and then when there is only sand (situation a) without seaweed, the absorption produced by the *Gelidium* layer can be evaluated.

To evaluate both detection methods it is necessary, as noted above, to determine, through very careful measurements, three main features of the target: reflection coefficient, absorption coefficient, and acoustic impedance.

Reflection coefficient

Marine acousticians often treat the integral of the squared acoustic pressure in a temporal window as if the sound was reflected at the bottom. The process is called *specular scatter,* because it describes scattering measurements in the specular direction. Using the image reflection equation as a model (Clay and Medwin, 1977), the mean square reflection coefficient (R^2) is:

$$>R^2< = \frac{(\int p^2\,dt)\ z^2}{R_0^2\,D^2 \int p_0^2\,dt} \qquad [1]$$

where p is the peak-to-peak amplitude of the echo, p_o is the peak to peak amplitude of the transmitted signal at the distance R_0, z is the layer depth and D is the source directivity which is a measure of the directional properties of the transducer.

The measurements of the echo amplitude for scenario *a*, only sand without seaweed, obtained in the laboratory experiments, were applied at the above equation to compute the reflection coefficient of the sandy bottom (R_s). Because of the sandy bottom's echo arrival time, the temporal window used in the aforesaid integral was (1 000-1 120 μs).

The same process was applied to computing the average reflection coefficient of the *Gelidium* seaweed layer (R_g) with the algae in the water tank lying above the sandy bottom (scenario b). The temporal window corresponding to the seaweed echo arrival, ranges from 700 to 1 000 μs.

To compute the reflection coefficient of the sandy bottom in the presence of Gelidium seaweed (R_{s+g}), scenario c, we estimated the ratio of the sand echo pressure amplitude in the presence of Gelidium, to that of sand without seaweed. Table II shows the average of all the 90 values of the reflection coefficients coming from the three different situations already described: a, b and c, and for the three frequencies studied.

Table II. Sand, *G. sesquipedale,* and sand with *G. sesquipedale* reflection coefficients

	Frequency		
Reflection coeff.	100 kHz	200 kHz	500 kHz
R_s	0.677	0.429	0.402
R_g	0.053	0.025	0.045
R_{s+g}	0.620	0.425	0.461

As can be seen in table II, the values of the seaweed reflection coefficient are much smaller than the sandy bottom reflection coefficient; approximately 10 times smaller. The influence of the *Gelidium* seaweed layer it is not very important, as can be seen comparing R_{s+g} with R_s, meaning that in this frequency range and with the thickness studied, the seaweed layer is almost transparent to sound waves.

Acoustic impedance

The ratio between target impedance and water impedance gives an idea of how different, in acoustic terms, the target is compared with water. If the ratio is small, it means that the behaviour of the target with regard to the incident sound wave does not differ greatly from the surrounding medium. It would be hard to distinguish such a target from water, acoustically.

The opposite happens if the impedance ratio between both target and water is large enough. In that case it would be possible, by reflective or absorptive means, to detect the target submerged in water.

In scenario a, there is a discontinuity surface between the water and the sand. Using the reflection coefficient of such a discontinuity surface, the sand impedance can be computed in relation to acoustic water impedance.

Water impedance is defined by:

$$Z_w = \rho_w c_w \qquad [2]$$

Analogically, the sandy bottom acoustic impedance becomes:

$$Z_s = \rho_s c_s \qquad [3]$$

It is important to note that, instead of this, sand impedance can be computed as a function of water impedance and the reflection coefficient. Thus, sand impedance is obtained with a non-intrusive method, very useful in cases where it would not be easy to take samples from the bottom (deep waters).

$$\frac{Z_s}{Z_w} = \frac{1 + R_s}{1 - R_s} \qquad [4]$$

For scenarios b and c there are two different discontinuity layers, one corresponding to the discontinuity between *Gelidium* seaweed and water, and the other separating the sand and *Gelidium* seaweed. The reflection coefficient produced at the first discontinuity (seaweed/water), makes it possible to compute the acoustic impedance of *Gelidium* seaweed (Z_g):

$$\frac{Z_g}{Z_w} = \frac{1 + R_g}{1 - R_g} \qquad [5]$$

Table III shows the average values of the acoustic impedance of the sand and the seaweed at the three different frequencies used.

Table III. Sand/*G. sesquipedale* and water/*G. sesquipedale* impedance ratios

	Frequency		
Ac. impedance	100 kHz	200 kHz	500 kHz
Z_s/Z_w	4.242	2.665	2.356
Z_g/Z_w	1.069	1.029	1.101

The fact that Zg/Zw is close to one reveals the similarity between water and seaweed impedance.

Absorption coefficient

In scenarios b and c, it has to be considered that the echo produced by the seaweed/water discontinuity surface and received by the hydrophone has passed twice (forwards and backwards) through the *Gelidium* seaweed layer, suffering an absorption expressed by the quantity $e^{-2\alpha d}$, where α is the absorption coefficient (Np/m) of the *Gelidium* layer, and d is the thickness of the layer.

The absorption coefficient can be computed through a relationship (appendix II) between the pressure amplitudes of the sand echoes in scenarios a and c (with and without seaweed), and the reflection coefficients shown above. The absorption coefficient can be expressed by the equation:

$$\alpha = \frac{1}{2d}\, ln \left[\frac{P_g}{P_{gs}} (1 - R_g^2) \frac{R_{s+g}}{R_g} \right] \qquad [6]$$

The α values shown in table IV have been computed this way. In underwater acoustics, absorption is usually expressed as dB/m, and Np/m is converted to dB/m by multiplying α (Np/m) by 8.67.

Table IV. *G. sesquipedale*, water and sand absorption coefficients

Absorpt.		Frequency	
Coef. (dB/m)	100 kHz	200 kHz	500 kHz
Gelidium s.	1.60	1.22	3.23
Water	0.031	0.059	0.125
Sand	35	70	175

This table also includes values of the absorption coefficient for sand (Hamilton, 1987) and water (Fisher and Simmons, 1977) given by other authors, so that they can be compared with the ones obtained in the present paper.

DISCUSSION

The frequency range chosen is in good agreement with Clay's biomass pyramid (Clay and Medwin, 1977). For marine plants and animals with dimensions between 2 cm and 20 cm, the effective frequency detection band varies from 25 kHz to 250 kHz.

The findings of our laboratory experiments lead us to conclude that the reflection coefficient of *Gelidium* seaweed is very weak, approximately 10 times smaller than the sand reflection coefficient, and at the frequency range studied a significant dependence on frequency has not been found. This result is in accordance with the plankton echogram presented by MacLennan (MacLennan and Simmonds, 1992), where the diffuse background traces are often seen on the echogram, caused by the echoes from dense concentrations of small creatures, e.g. plankton and micronekton. Although the individual plankters are small or even microscopic, the overlapping echoes from a dense concentration produce signals comparable to the ones given by individual fish.

We also found that there is not a major difference between the energy reflected by sand when there is *Gelidium* covering it, and when there is water only. The acoustic impedance of seaweed and water are very similar. The acoustic absorption of seaweed increases with frequency, being greater than that of water, but smaller than the acoustic absorption of sand.

Once both methods proposed have been analysed, it can be concluded that seaweed detection using sonar is quite difficult. First, because of its very weak reflection coefficient, since the ratio between energies, reflected and incident, is so small that it does not allow detection by means of reflection. Second, because the absorption produced by *Gelidium* algae is very low, making the seaweed layer an acoustically transparent biomass, so that it is difficult to detect it by the reduction of the sand echo energy whenever seaweed is present.

However, it should be pointed out here that, since the amount of power *Gelidium* diverts from the original wave varies with the layer thickness, the ratio 'sand echo pressure/sand with *Gelidium* echo pressure', formulated as $\left[\frac{P_g}{P_{gs}} \alpha\ e^{2\alpha d}\right]$, should increase whenever *d* increases. With a sufficient thickness of the *Gelidium* seaweed layer, it could be possible to detect a significant reduction of the energy reflected from the sandy bottom, and consequently, to detect the seaweed layer.

APPENDIX I

Transducers and hydrophone performances

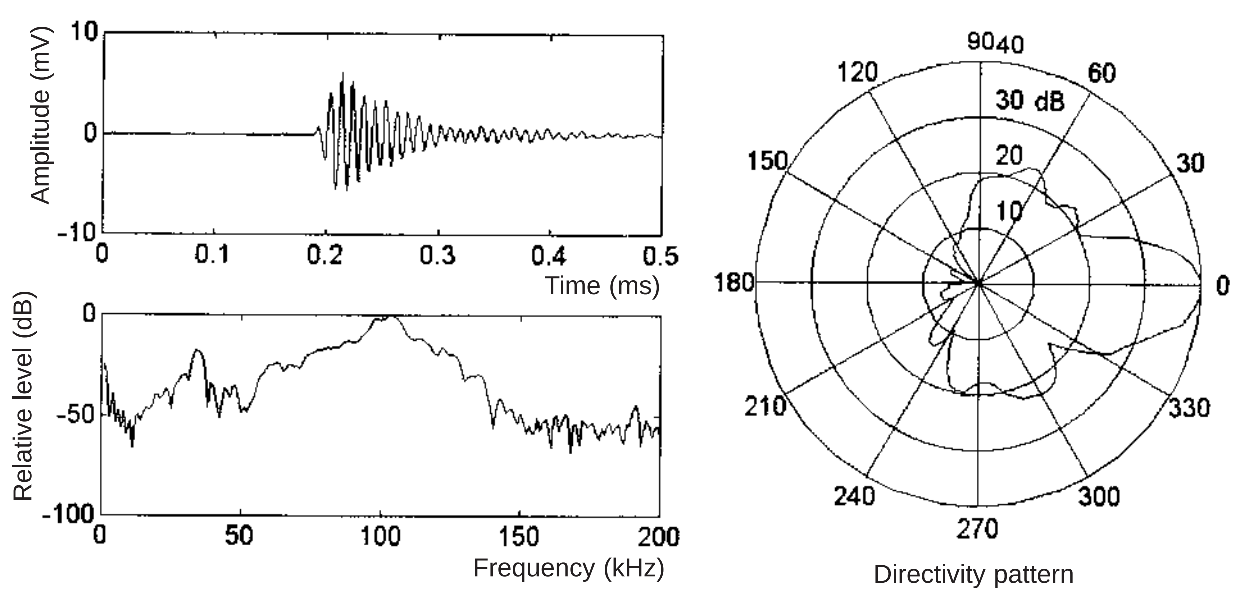


Figure 5. Emitted pulse, frequency response and directivity pattern of transducer IA-100

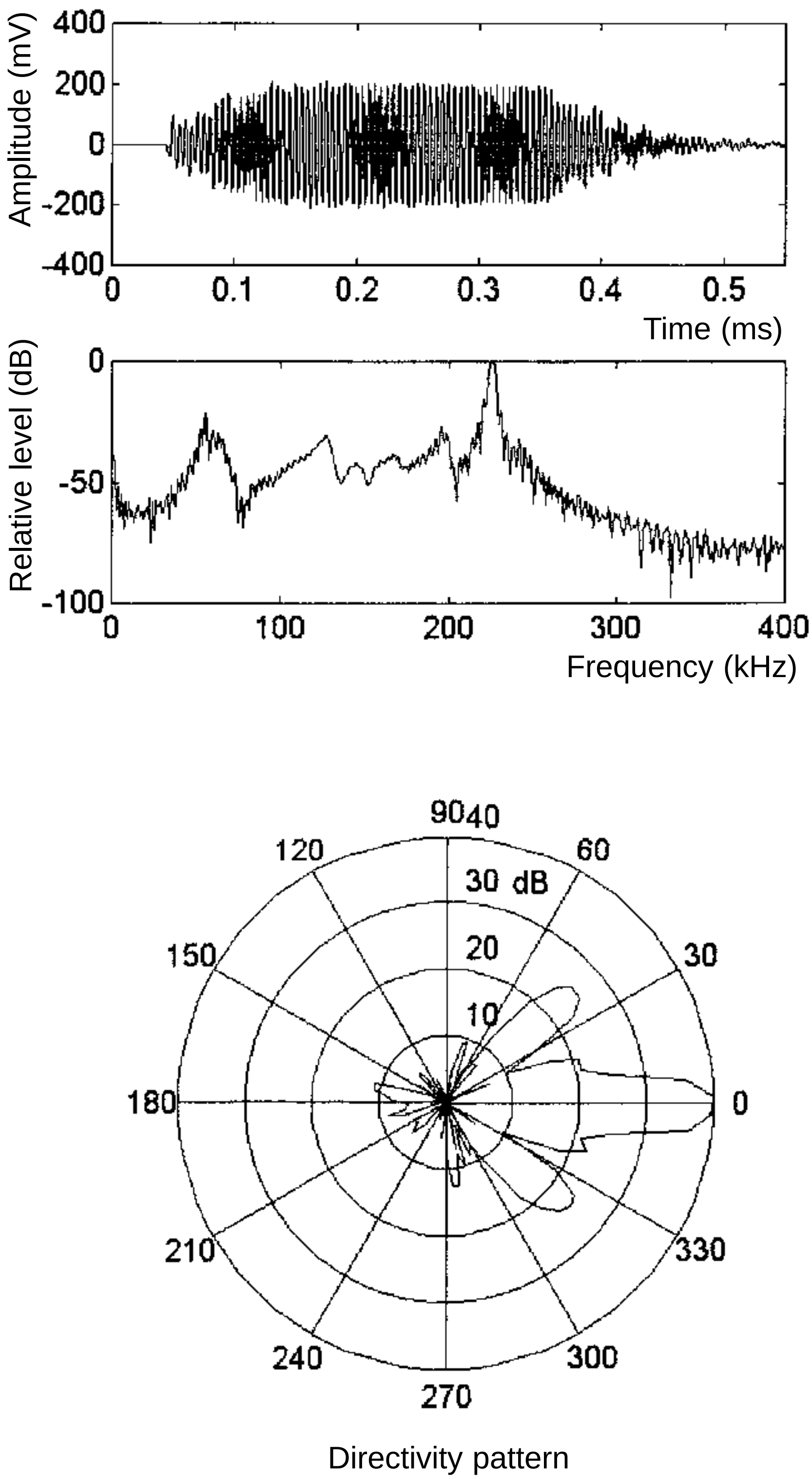


Figure 6. Emitted pulse, frequency response and directivity pattern of the Raytheon V-700 transducer

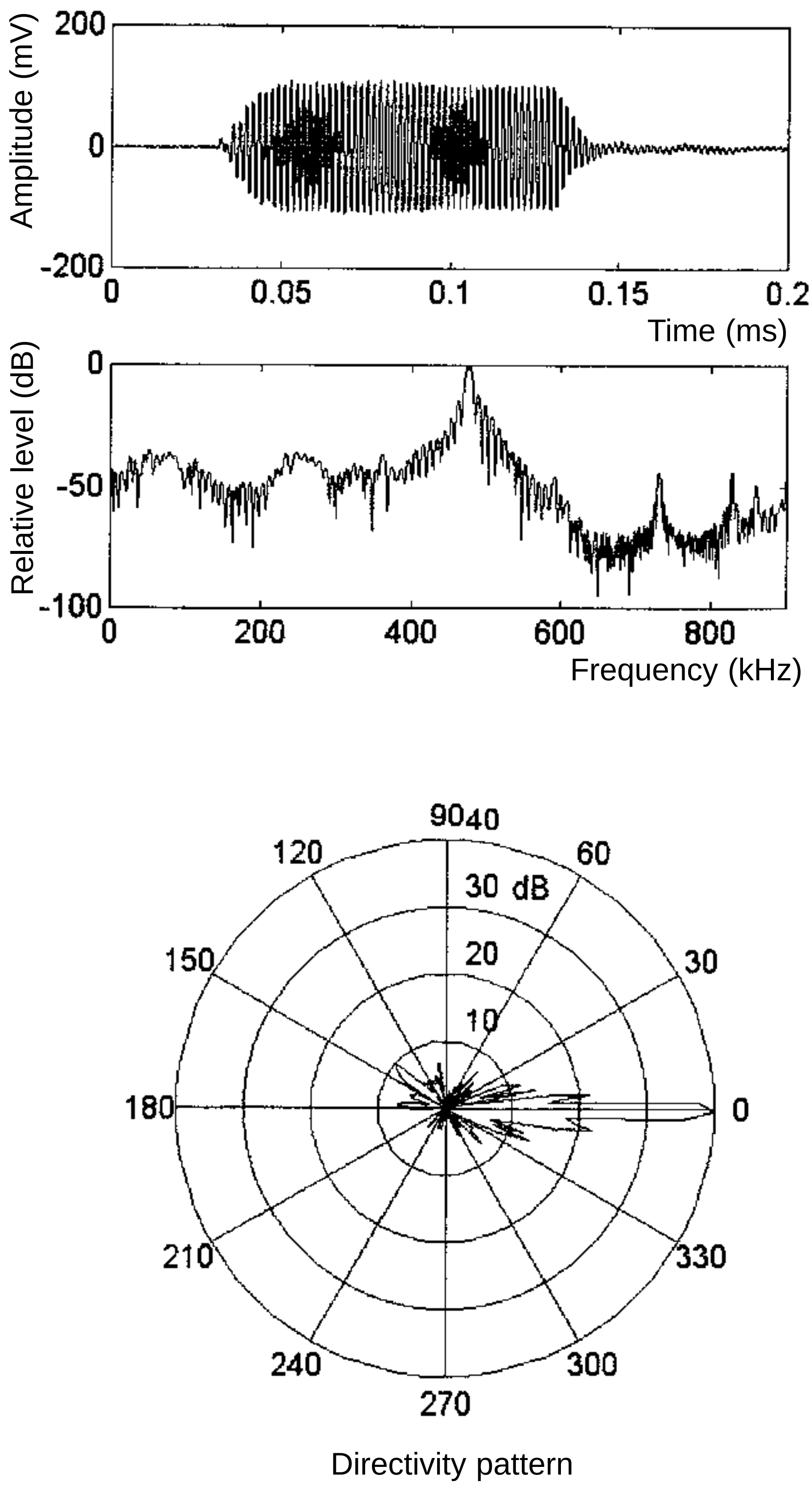
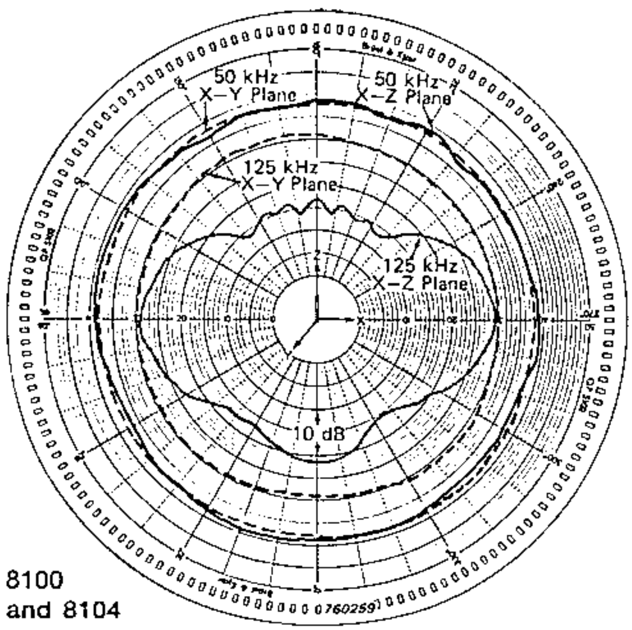


Figure 7. Emitted pulse, frequency response and directivity pattern of the Ulvertech 295 transducer

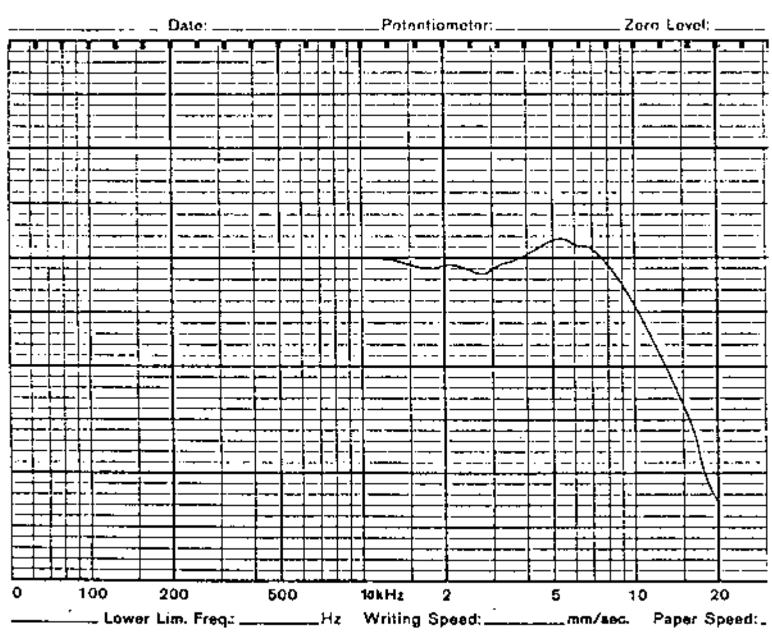
Bruel & Kjaer 8104 Hydrophone

Frequency kHz	Sensitivity at reception μV per Pascal
100	30.2
200	3.8
500	0.9



8100 and 8104

Directivity pattern



Reception answer vs frequency of the hydrophone

Figure 8. Frequency response and directivity pattern of the Brüel and Kjaer 8104 hydrophone

APPENDIX II

Absorption coefficient theoretical model

The transmitted pulse of sound propagates through water, encountering a few discontinuity surfaces (water/seaweed, seaweed/sand). These surfaces reflect or transmit the pulse, and a portion of the incident energy, proportional to the reflection/transmission coefficient, returns to the hydrophone. The pressure amplitude of such a pulse, after been transmitted and reflected can be expressed by the equation:

$$P_{s+g} = T_{wg} R_{s+g} T_{gw} e^{-2\alpha d} P_o \quad [7]$$

where T_{wg} is the transmission coefficient of the water/seaweed discontinuity, T_{gw} is the transmission coefficient of the seaweed/water discontinuity, $e^{-2\alpha d}$ express the absorption, and P_o is the incident pressure amplitude.

The coefficient transmission multiplication is:

$$T_{wg} T_{gw} = 1 - R_{wg}{}^2 \quad [8]$$

And the incident pressure amplitude is related with the reflection coefficient by the expression:

$$P_g = R_g P_o \quad [9]$$

Combining the three equations, an analytical expression for the absorption coefficient can be obtained:

$$\alpha = (1/2d)\ ln\ (P_g/P_{gs})\ (1 - R_g^2)\ (R_{s+g}/R_g)$$

ACKNOWLEDGEMENTS

This research was financially supported by the Comisión Interministerial de Ciencia y Tecnología (CICYT) National R&D Plan, project PTR94-0158. The authors thank Dr J. Rey, E. Pérez (Esgemar, S.A.), Dr P. Siljeström and A. Moreno (IRNASE, CSIC) for their assistance and helpful comments.

REFERENCES

Álvarez, J., E. M. Llera, A. Vizcaíno, S. González, I. Olivella, J. L. Catoira, X. M. Romaris, A. Borja, J. M. Salinas and S. Revenga. 1989. *Programa de orientación plurianual sobre macroalgas (1989-1991).* Junta Asesora de Cultivos Marinos (JACUMAR): 94 pp.

Carbó Fité, R. and C. Ranz Guerra. 1986. Discrimination temporelle d'échos impulsifs qui se chevauchent. *Traitement du Signal* 13: 145-151.

Clay, C. and H. Medwin. 1977. Acoustical Oceanography. John Wiley & Sons. New York.

Fisher, F. H. and V. P. Simmons. 1977. Sound absorption in sea water. *J. Acoust. Soc. Am.* 62: 528-564.

Hamilton, E. 1987. Acoustic properties of sediments. In: *Acoustic and Ocean Bottom.* A. Lara, C. Ranz and R. Carbó (eds.): 3-58. CSIC. Madrid, Spain.

Juanes, J. and A. Borja. 1991. Biological criteria for the exploitation of the commercially important species of *Gelidium* in Spain. *Hydrobiology* 221: 45-54.

MacLennan, D. N. and E. J. Simmonds. 1992. *Fisheries Acoustics.* Chapman & Hall. London: 325 pp.