# Target strength of common jellyfish (Aurelia aurita: Scyphozoa): A preliminary empirical study with dual-beam acoustical system

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ABSTRACT

An experimental enclosure (Fig. 1) was designed to estimate the target strength (TS; dB) of the common jellyfish (Aurelia aurita) in the Black Sea. The hydroacoustic data-collection was made with a 120 and 200 kHz BioSonics echo sounder. Records were processed using the ESP_DB.EXE and ESPTS.EXE software packages.

Averaging TS of each ping for each size class, functional regression equations relating mean TS (dB) of jellyfish to its diameter (d, cm) and wet-weight (W, g) are as follows:

$TS=6.42\log d-74.68$ and $TS=2.48\log W-69.41$ at 120 kHz
$TS=16.3\log d-101.47$ and $TS=6.31\log W-88.07$ at 200 kHz.

Analyzing TS fluctuation within period of successive pings, the swimming harmony from -54 to -67 (dB) (individuals 15.5 cm in disc diameter) was observed for every 15-20 pings (7.5-10 sec.) at 120 kHz and from -58 to -68 (dB) (11.5 cm) for every 12-25 pings (6-12.5 sec.) at 200 kHz.

## Introduction

After the invasion of the non-indigenous species, Mnemiopsis leidyi into the Black Sea (Vinogradov et al., 1989; Zaika and

Sergeeva, 1991; Caddy, 1993; Mutlu et al, 1994), changes in the recipient ecosystem have been observed. The biotic changes concerning this study are as follows: global changes in the structure of the copepod community, a drop in maximum sustainable yield of some commercial fish stocks, structural and quantitative changes in gelatinous zooplankters Aurelia aurita, their competitor Mnemiopsis leidyi, and Pleurobrachia pileus (Zaitsev, 1992; Vinogradov et al., 1992; Anon., 1994; Mutlu et al., 1994).

At the first meeting of GESAMP (on the scientific aspects of marine pollution) on the ecosystem of the Black Sea, guidelines were offered regarding numerical abundance, vertical distribution, size composition and biomass of the jelly-like-organisms (Anon, 1994). From this point of view, the acoustical technique which minimizes comparable sampling error is a very practical and applicable tool in quantifying and sizing the population. The acoustical technique led to remarkable development in the stock assessment of fish populations (Foote, 1978, Johanesson and Mitson, 1983, Ehrenberg and Kanemori, 1987 and Stepnowski et al, 1993) and even in population by live zooplankton and micronekton displaying soundscattering in the preceding years (Pieper, 1979; Richter, 1985; Greene at al, 1989; Wiebe et al, 1990; Johnson and Griffiths, 1990 and Greene et al, 1991; Stanton, et al., 1994). It was usually the subject of studies in the biological field at the end of the 1970s (Urick, 1983; Johanesson and Mitson, 1983). Some such acoustical studies were directed towards estimating the target strengths of gelatinous forms (Wiebe et al., 1990 and Nakken, 1991, pers. comm.). In recent years, acoustics have also been involved in etiological studies on marine animals e.g. fish, dolphin, whale etc. Furthermore, acoustical methods have also been aimed at physical oceanography (Spiesberger et al, 1993, Spiesberger and Metzger, 1992 and Spiesberger, 1993).

The target strength (TS) is an acoustic element proportional to the size of target primarily associated with amount of gas bubble in the body, density and orientation of target. The term "TS" is acoustically expressed as the echo reflecting power of single target and technically as the decibel equivalent of the target's backscattering cross section (Urick, 1983; Ehrenberg, 1982). The target strength has kept its importance as a key in stock estimation of populations since TS is an alternative converter of the echo-integrator readings into absolute fish-biomass (density) estimates.

In this study, starting with the common jellyfish, Aurelia aurita, preliminary estimation of the target strength is achieved which may lead to stock assessment and size composition determination of this gelatinous population in the Black Sea at a future stage.

## Material and methods

The four day-acoustical experiment was conducted in the gulf of Beykoz of Bosphorus, (Istanbul) in January 1992. A scientific echo sounder of BioSonics equipped with 38, 120 and 200 kHz dual-beam (narrow;N and wide;W) transducers was used during the experiments. The hydroacoustical data-collection system consisted of the following components: armored transducer cables, V-fin towed body, oscilloscope, chart recorders, tape recorder interface and a digital audio tape recorder (Fig. 1). The echoes were amplified by 40 log(R) and 2 alpha(R)time-varied gains (Model 102).

In situ calibration of the echo sounder and transducers performance was carried out referring the tungsten spherical ball at the same place before starting the experiment. In Table 1, sounder calibration data and processing parameters are summarized. The pulse width was kept at 0.4 ms throughout the cage experiments. The sound velocity c required for dual-beam processing was calculated using the necessary measurements by the

CTD-Sea Bird probe in Wilson's formula (Urick, 1983).

$c = 1445 + 4.66\,T - 0.055T^2 + 1.3(S-35)$

where $T$ is temperature (°C) and $S$ is salinity (‰).

Table 1. Calibration data and processing parameters for hydroacoustic cage-experimental system (PW, pulse width).

| | Sounder parameters | | | |
|---|---|---|---|---|
| Pulse width (ms) | 0.4 | | | |
| Trigger interval (s) | 0.5 | | | |
| Speed of sound (m/s) | 1448 (assumed from Wilson's formula) | | | |
| Time-varied-gain (TVG) | 40Log(R) | | | |
| Receiving gain (db) | 0 | | | |
| Transmit power (dB) | 0 | | | |
| | **Processing criteria** | | | |
| Noise threshold (V) | 0.025 | | | |
| Single target criteria | | | | |
| Pulse search window (%) | 100 | | | |
| Wide peak search window (%) | 50 | | | |
| 1/2 amplitude pulse width (ms) | 0.32 to 0.48 (limiting) | | | |
| 1/4 amplitude pulse width (ms) | 0.24 to 0.56 (measuring) | | | |
| Frequency (kHz) | 120 | | 200 | |
| Source level (dB) | 223.51 | | 222.69 | |
| Receive sensitivities | narrow | wide | narrow | wide |
| 20Log(R) (dB) | -154.53 | -154.56 | -149.59 | -149.69 |
| 40Log(R) (dB) | -184.21 | -184.21 | -179.23 | -179.23 |
| Simultaneous (dB) | -160.51 | | -149.55 | |
| Wide beam dropoff (dB) | 1.0678 | | 1.1989 | |
| Nominal angel (N/W beams) | 7° | 18° | 6° | 15° |

Acoustical measurements were made on individual jellyfish placed in a quadrant enclosure. The mouth opening of the enclosure was 2 m x 2 m and the depth was 10 m. The cage was constructed of iron bar and tulle (1 mm mesh). Four weights were attached at each bottom corner of the cage to provide support (Fig.1). The enclosure was suspended into the sea water by means of the crane and the aperture was held at 1 m above the sea surface. The V-Fin towed body was lowered inside the enclosure at around 1 m below sea surface by means of a mechanical reel system mounted on the "R/V Bilim".

Three-size classes of jellyfish (disc diameters ;9.5, 11.5 and 15.5 cm) were used in the experiments. Five to ten individuals belonging to each size class were freely released into the cage by hand and echo recording was performed at two frequencies by individual application. The enclosure was sometimes moved up and down in order to hold jellyfish in the acoustic window. In the laboratory, the recorder data on the DAT was played back for post-processing. In the analysis of dual-beam processing, an echo must satisfy minimum and maximum pulse width criteria to be classified as a single target. 0.38-0.48 milliseconds pulse width at 1/2 of the peak amplitude was used as a limiting criteria for a single target. Reliable records of echoes were used for final processing and their results are used in this study.

Echoes returning from target specimens were processed to determine the backscattering cross section ($s_{bs}$). The target strength (TS) was then; $TS=10\log(\bar{s}_{bs})$. The TS of each ping of resultant echoes was tabulated on a worksheet with the help of VIEW.EXE* and ECHO.EXE*. Finally, the mean $\bar{s}_{bs}$ was established using successive single pings (echoes) of the target. In order to establish the empirical relation between TS of jelly fish and its umbrella-diameter and wet-weight, curve-linear simple regression was applied to the data obtained from 120 and 200 KHz.

Single jellyfish (target) swimming across the acoustical beam through the axis center projected a typical "finger-nail" trace on the echogram (Fig.3a and 3d). Aurelia aurita has limited swimming ability. It jets through the water propelled by contraction and expansion of its umbrella.The swimming harmony of Aurelia aurita was determined analyzing the TS oscillation of the successive pings obtained from the single target.

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* Commercial software package of BioSonics inc.

## Results

The preliminary relationship between the acoustical unit (TS) and size (cm in diameter) and live-weight (g) of Aurelia aurita was established for 120 and 200 kHz. For two frequencies (120; 200 Khz), acoustical identity for the sized jellyfish is given in Table 2. Mean TS varied in a range of -56 to -64 dB (Fig.2 and Table 3) and narrow peak and wide peak from 0.054 (V) to 0.108 (V) and 0.056 to 0.145 V. Figure 3 outlines echogram (a), quasi 3D-TS diagram (b), echo amplitude (c) of jellyfish 11.5 cm in diameter.

Table 2. Acoustical properties of three size classes of Aurelia aurita (PW=Pulse width).

| | Size class | | |
|---|---|---|---|
| | 9-10 cm | 11 cm | 15-16 cm |
| **120 kHz** | | | |
| Narrow peak (V) | 0.058+0.01 | | 0.079+0.04 |
| Wide peak (V) | 0.071+0.01 | | 0.099+0.03 |
| Narrow PW half (ms) | 0.461+0.02 | | 0.455+0.02 |
| Wide PW half (ms) | 0.480+0.00 | | 0.480+0.01 |
| Narrow PW quarter (ms) | 0.488+0.20 | | 0.426+0.22 |
| Wide PW quarter (ms) | 0.480+0.19 | | 0.540+0.13 |
| Backscattering ($m^2$) | 9.87E-7+2.72E-7 | | 2.20E-6+9.9E-7 |
| **200 kHz** | | | |
| Narrow peak (V) | 0.071+0.03 | 0.091+0.39 | 0.108+0.05 |
| Wide peak (V) | 0.081+0.04 | 0.099+0.04 | 0.145+0.05 |
| Narrow PW half (ms) | 0.440+0.03 | 0.464+0.03 | 0.467+0.02 |
| Wide PW half (ms) | 0.464+0.02 | 0.476+0.02 | 0.480+0.00 |
| Narrow PW quarter (ms) | 0.240+0.27 | 0.439+0.21 | 0.487+0.16 |
| Wide PW quarter (ms) | 0.288+0.24 | 0.499+0.21 | 0.580+0.02 |
| Backscattering ($m^2$) | 5.82E-7+6.9E-7 | 7.24E-7+5.03E-7 | 2.42E-6+8.40E-7 |

The overall average measurements of target strength and sizes of the free-swimming common jellyfish in the enclosure are given in Table 3.

Table 3. Average target strength measurements of the free-swimming common jellyfish in the experimental cage.

| Disc diameter $d$ (cm) | Wet-Weight $W$ (g) | Settling volume $V$ (ml) | Frequency 120 TS (dB) | 200 TS (dB) |
|---|---|---|---|---|
| 9.5 | 40.21 | 22.7 | -60.24 | -64.27 |
| 11.5 | 65.89 | 35.5 | | -62.48 |
| 15.5 | 142.51 | 71.1 | -57.10 | -56.47 |
| $\bar{\sigma}_{(1kg)}$ ($m^2$/kg) | | | 1.7E-05 | 1.5E-05 |

The empirical relationship of TS to the bell diameter ($d$;cm) and wet-weight ($W$; g) for *Aurelia aurita* (Fig.4 a and b) is given in Table 4.

Table 4. Functional regression equations relating mean TS to disc diameter ($d$; cm) and wet weight ($W$; g), and the relationship between the size (diameter $d$; cm) of *Aurelia aurita* to wet weight ($W$; g) and between the settling volume ($V$; ml) and size (diameter).

| 120 kHz | 200 kHz | |
|---|---|---|
| $TS=6.42 \log d-74.68$ | $TS=16.3 \log d-101.47$ | $W=0.12*d^{2.58}$ |
| $TS=2.48 \log W-69.41$ | $TS=6.31 \log W-88.07$ | $V=0.12*d^{2.33}$ |

The TS fluctuations for single individual jellyfish descending (Fig 3.e.*) in the cage are shown in Fig. 5. This dynamic range resulting from the orientation and swimming of the animal was related to the swimming period. The swimming-rhythm was repeated at each 10-30 pings equivalent to 5-15 seconds (ping interval=ping/0.5s). The mean swimming harmony from -54 to -67 (dB) (individuals 15.5 cm diameter) was observed within each 15-20 pings (7.5-10 sec.) at 120 kHz and at -58 to -68 (db) (11.5 cm) between each 12-25 (6-12.5 sec.) pings at 200 kHz.

## Discussion

For the establishment of functional regression equations between TS of jellyfish and pertinent size data (bell diameter, cm and wet-weight, g) the most striking difficulty was in bringing living individuals of free-swimming jellyfish into the acoustical window. The peak amplitude, thus, target strength of individual jellyfish, was comparatively lower than the TS of fish. This is due to the lower reflectance of the species because of high water content (>95%) in the tissue of Aurelia aurita (Zhong et al., 1988). The target strength increases slightly with size. Target strength measured was between -64 (dB) (9.5 cm in bell diameter) and -56 (15.5 cm) at 200 kHz, and -60 (9.5 cm) and -57 (15.5 cm) at 120 kHz. Estimates of target strength of some gelatinous organisms found in the literature include those of Nakken (1991, pers. comm.) for Aurelia autrans and of Wiebe et al., (1990) for the comb-jelly (Bolinopsis sp.). Nakken found a range of -54 (8 cmo) to -51.7 (16 cmo) at 38 kHz and -54.2 (8 cmo) to -50.1 (16 cmo) at 120 kHz. Target strength of ctenophoran individual (45 mm length) was only -80 (dB) at 420 kHz (Wiebe et al., 1990). Based on this information, use of the empirical formula of Love established for pisces would result in an under and/or overestimate of the actual physical size of the jellyfish. The reasons for this seem to be various. These might be:

- differences in length to volume ratios for gelatinous organisms,
- higher amount of water in body tissue (Borodkin and Korzhikova, 1991 and Zhong et al., 1988),
- Possible adhesion of small air bubbles to the tentacles during stormy weather,
- Oriented and/or unoriented swimming behavior in time.

The mean swimming harmony from -54 to -67 (dB) (individuals 15.5 cm diameter) was observed within each 15-20 pings (7.5-10 sec.) at 120 kHz and at -58 to -68 (db) (11.5 cm) between each 12-25 (6-12.5 sec.) pings at 200 kHz. In the experiments carried out, the most striking feature observed concerns the oriented and/or unoriented motion of the jellyfish. As can be seen in Fig. 3e(*) and Fig. 5 during the descending motion of a specimen varying TS's were measured. It is here by assumed that such variability arises firstly from rhythmical contraction of the umbrella, and secondly, and additionally from the orientation of the body with changing angle to a vertical position. Thirdly and finally from other sources together and/or in various combinations as listed in the previous paragraph.

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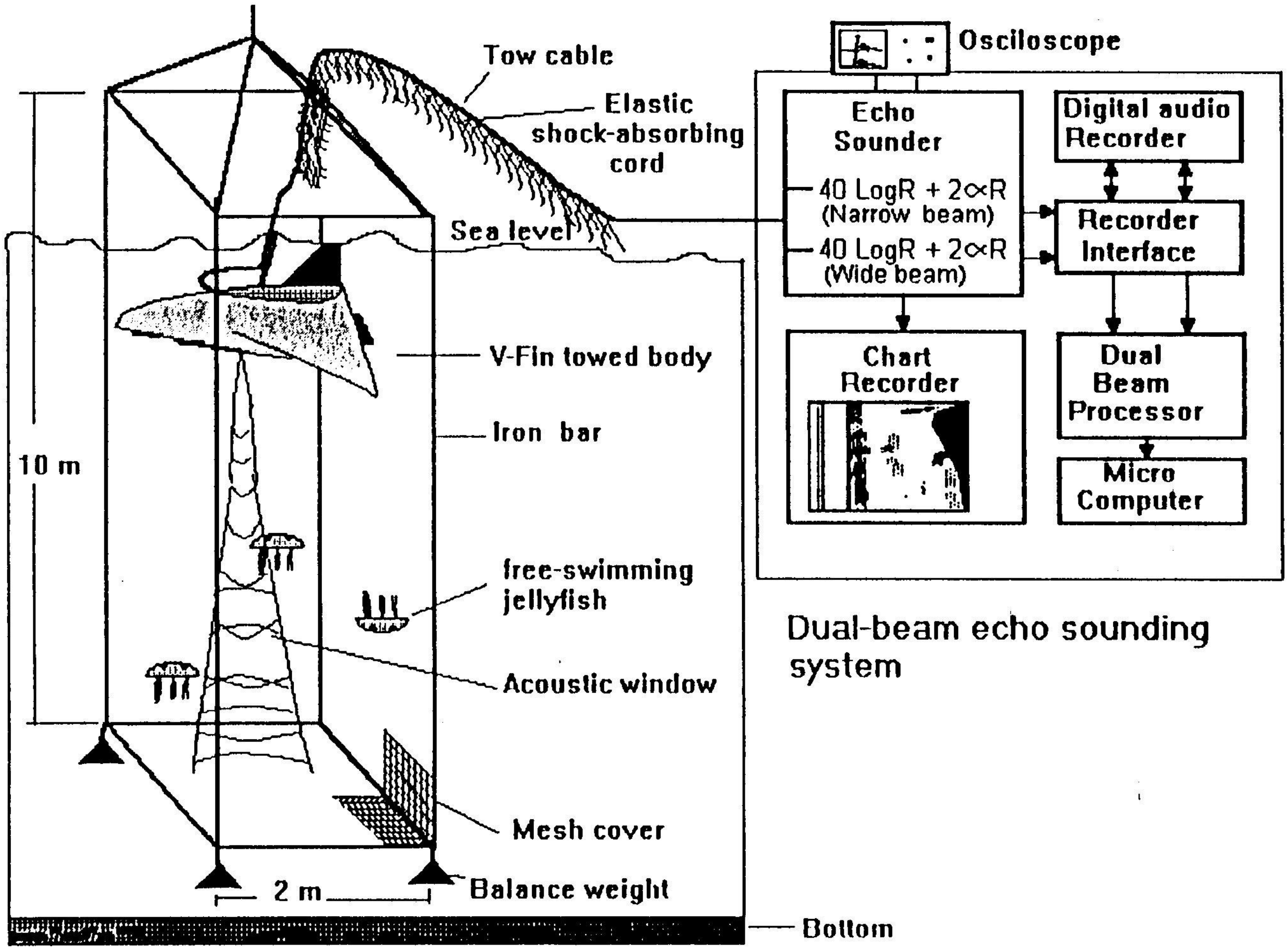
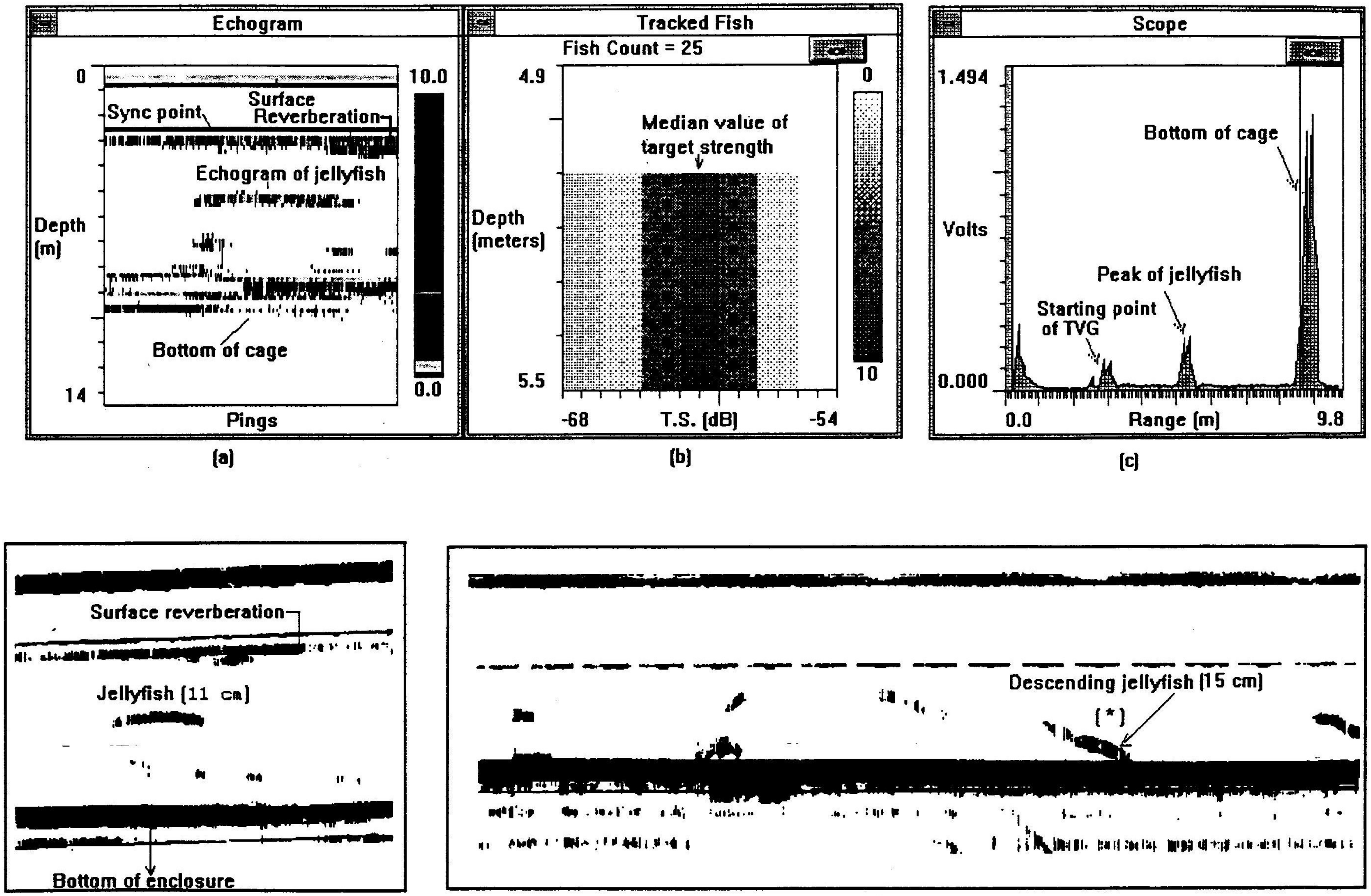
List of Figures




Dual-beam echo sounding system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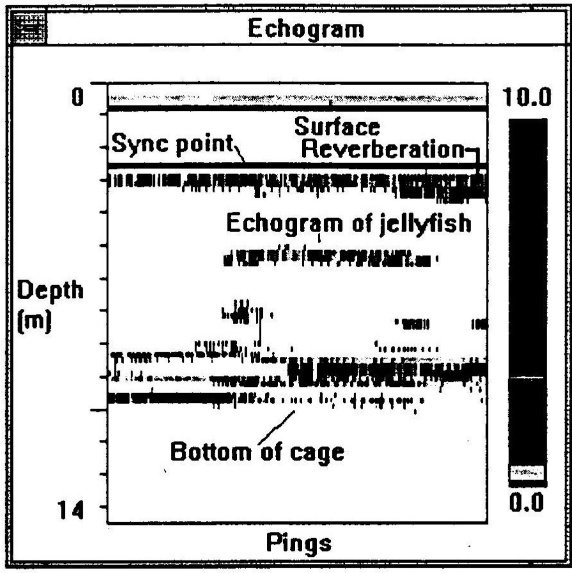
10.0
Surface
Reverberation
Sync point
Echogram of jellyfish
Depth
(m)
Bottom of cage
14
0.0
Pings
Tracked Fish
Fish Count = 25
4.9
0
Median value of
target strength
Depth
(meters)
5.5
10
-68
T.S. (dB)
-54
Scope
1.494
Bottom of cage
Volts
Peak of jellyfish
Starting point
of TVG
0.000
0.0
Range (m)
9.8
Surface reverberation
Jellyfish (11 cm)
Bottom of enclosure
Descending jellyfish (15 cm)
(*)

(a) (b) (c) (d) (e)


Echogram
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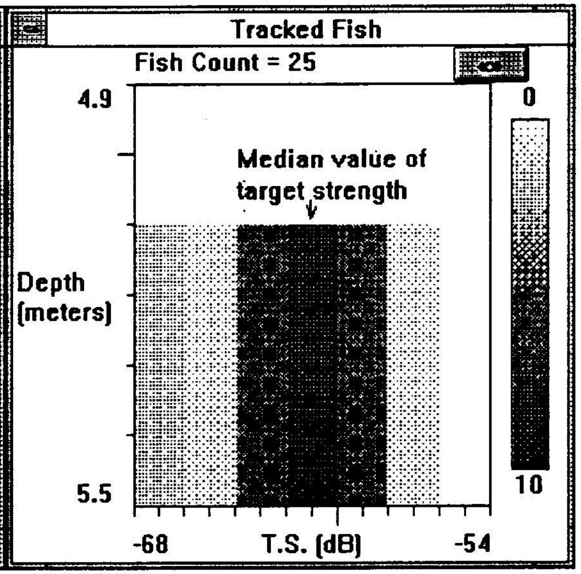
Reverberation
Echogram of jellyfish
Depth
(m)
Bottom of cage
14
0.0
Pings

(a)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Depth
(meters)
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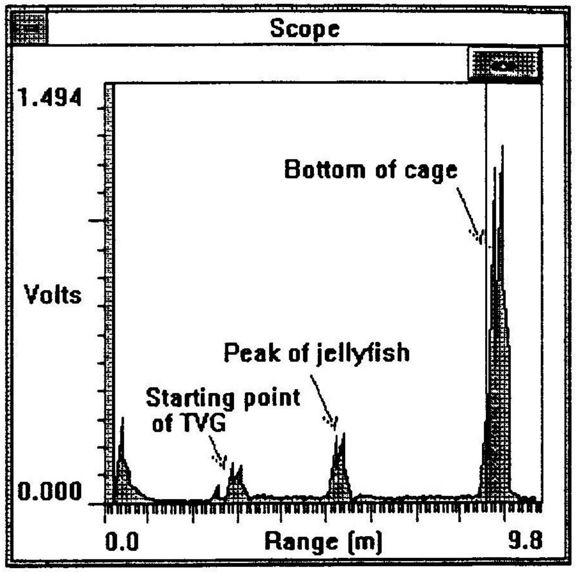
10
-68
T.S. (dB)
-54

(b)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Volts
Peak of jellyfish
Starting point
of TVG
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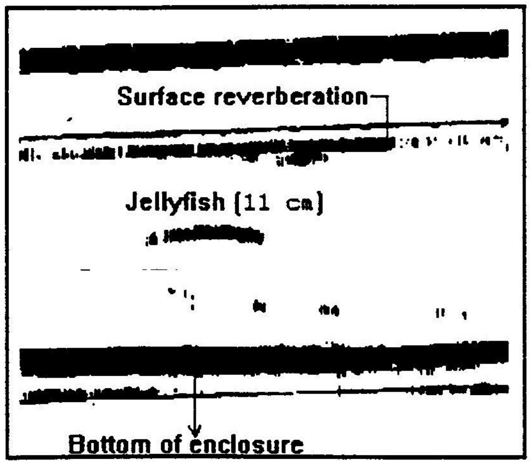
Range (m)
9.8

(c)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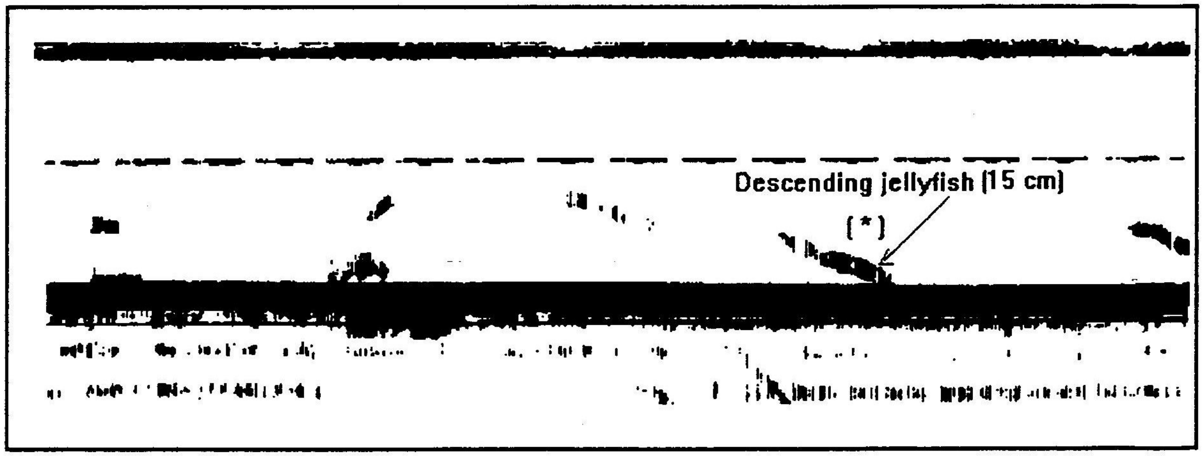
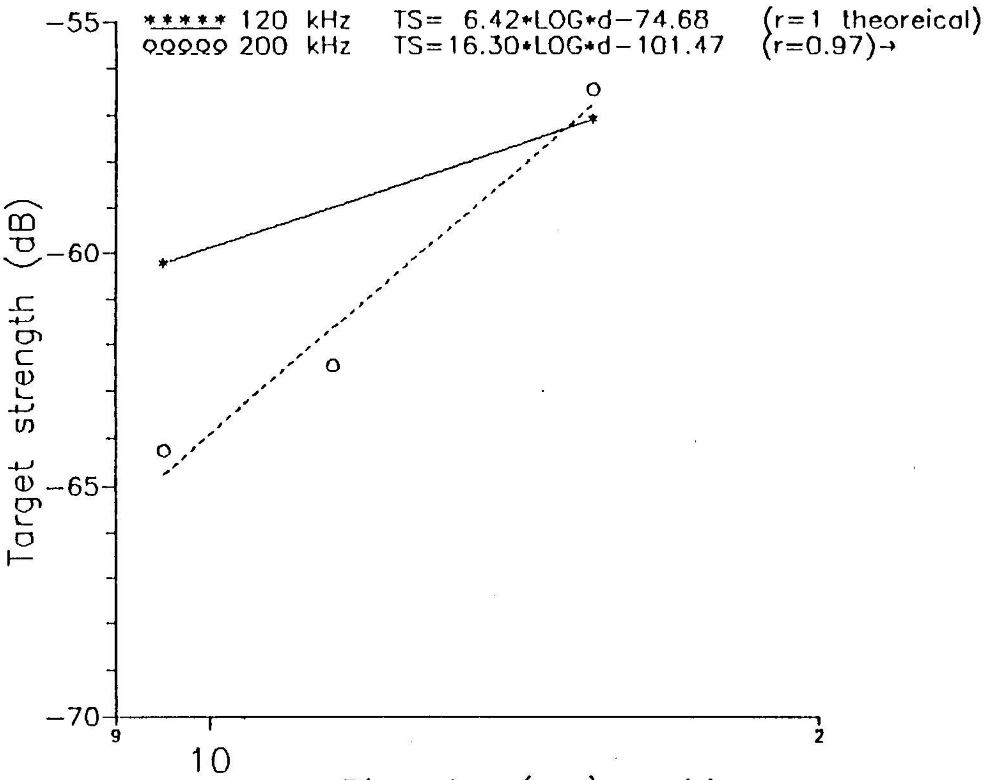
Jellyfish (11 cm)
Bottom of enclosure

(d)

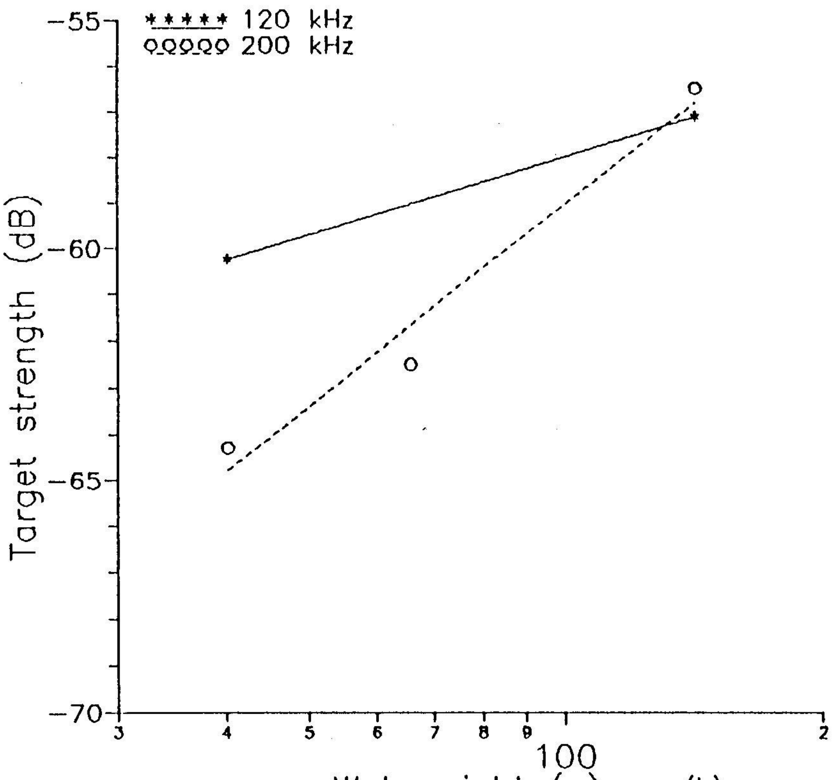

Descending jellyfish (15 cm)
(*)

(e)



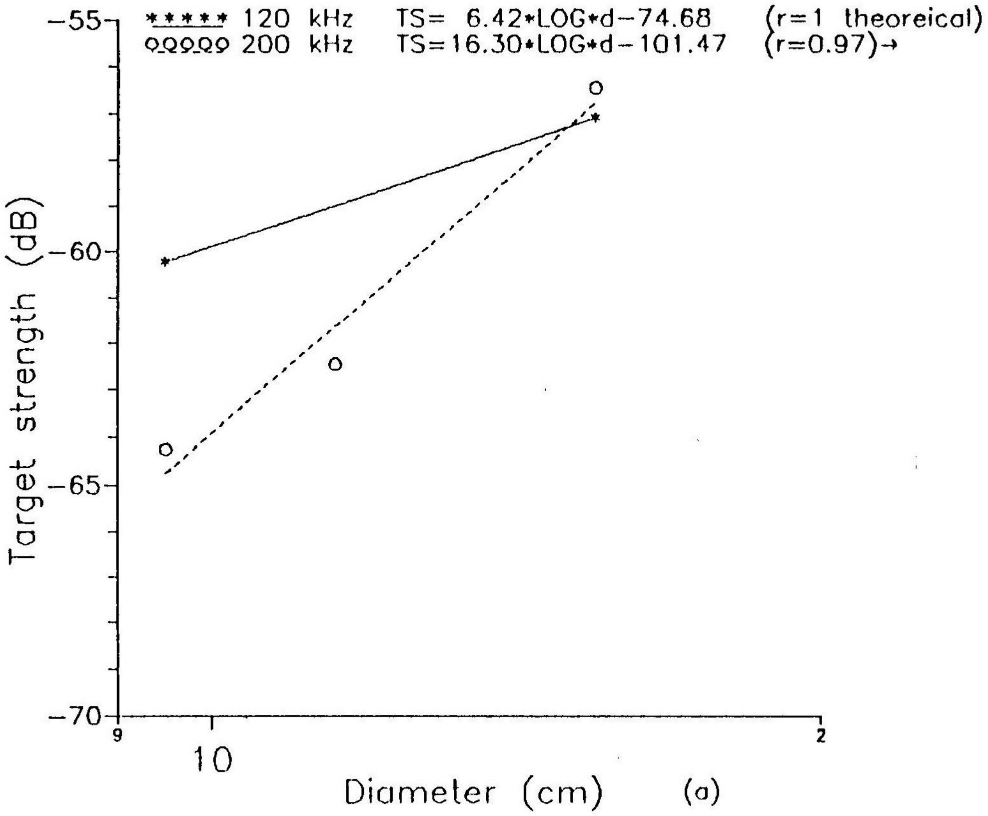
*****  120 kHz   TS= 6.42*LOG*d-74.68   (r=1 theoreical)
ooooo  200 kHz   TS=16.30*LOG*d-101.47   (r=0.97)→
Target strength (dB)
-55
-60
-65
-70
9
10
2
Diameter (cm)


(a)

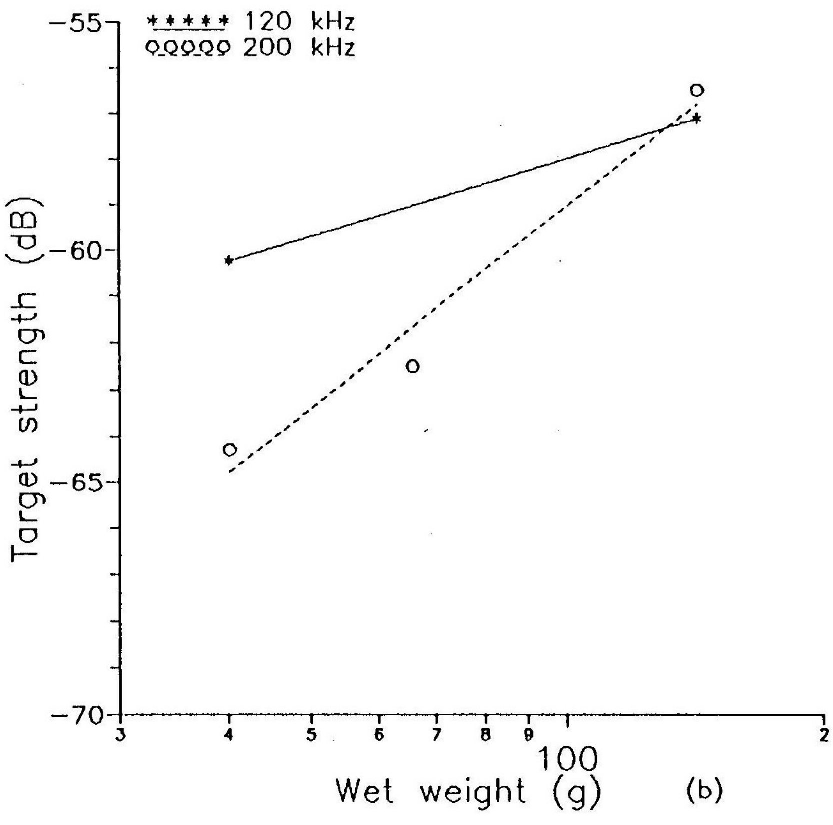


*****  120 kHz
ooooo  200 kHz
Target strength (dB)
-55
-60
-65
-70
3
4
5
6
7
8
9
100
2
Wet weight (g)

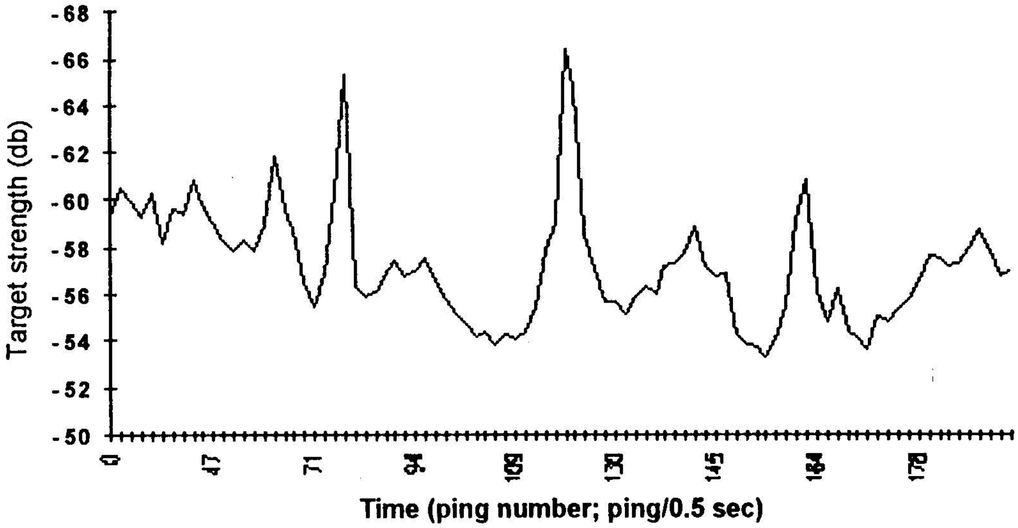

(b)



***** 120 kHz TS= 6.42*LOG*d-74.68 (r=1 theoreical)
ooooo 200 kHz TS=16.30*LOG*d-101.47 (r=0.97)→
-55
-60
-65
-70
Target strength (dB)
9
10
2
Diameter (cm)
(a)

***** 120 kHz
ooooo 200 kHz
-55
-60
-65
-70
Target strength (dB)
3
4
5
6
7
8
9
100
2
Wet weight (g)
(b)



Target strength (db)
-68
-66
-64
-62
-60
-58
-56
-54
-52
-50
0
47
71
94
109
130
145
164
178
Time (ping number; ping/0.5 sec)