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Experiences in making acoustic measurements in a mesocosm with *Calanus finmarchicus*

by

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ABSTRACT

In connection with a larger study of the effects of nutrification and turbulence on primary and secondary production, acoustic measurements have been made in the water volume defined by floating, vertically oriented, cylindrical enclosures, with flexible but impermeable walls, called mesocosms. Nominal diameters and greatest depths in the tapered bottom region are 2 and 9 m, respectively. The mesocosms contain rather small quantities of zooplankton, of which *Calanus finmarchicus* is the organism of primary interest in the acoustic work. In fact, a range of scatterers were visualized, including krill, smaller organisms, and, most likely, hydrographic features as well as the wall of the mesocosm, complicating recognition and quantification of *Calanus finmarchicus*. The density of this copepod in stages I-VI, reckoned in orders of magnitude, is 10-1000 animals per cubic meter, the precise figure depending on the particular mesocosm. An attempt was made to quantify the scatterers by echo integration. Measurements were made with the SIMRAD EK500 echo sounder, with narrowband transducers operating at 119, 200, and 714 kHz. Postprocessing was accomplished with the Bergen Echo Integrator. While preliminary, limited results are not demonstrably unambiguous, the observations and associated measurement experiences may prove valuable in like future investigations.

INTRODUCTION

How does fertilization affect primary and secondary production? To what degree might this be influenced by turbulence? Can such things be measured in a limited volume under highly controlled conditions? Briefly, these were some of the questions being asked in the pilot study to the proposed European Union MAST-III project "Fertilization and pelagic production efficiency (FAPPE)".

Understandably, such a study involves many considerations, the collaboration of diverse groups, and the close coordination of tasks. To support the several activities, but in a completely subsidiary capacity and with a view to continuation or extension of the work in the future, a modest study was proposed to attempt acoustic visualization and quantification of zooplankton in so-called mesocosms. These entities consisted of cylindrical enclosures, roughly 2 m in diameter and 9 m deep, fashioned out of an impermeable, transparent fabric and suspended in the sea by floats, that were filled with sea water by pumping.

The acoustics study was initiated just prior to the experiment, 2-27 September 1996, confronting project participants with formidable logistical hurdles. Under the circumstances, the results could at best be partial. Thus, in reporting the work, greater weight is to be placed on the experiences than on the particular results, which are admittedly scarce.

It is the present aim to document the work, summarize experiences, and make recommendations for possible future applications of acoustics in mesocosms.

MATERIALS

Measurement venue and mesocosms

This pilot study was conducted at University of Bergen field station at Espegrend, 22 km south of Bergen. The station is part of the Bergen Large Scale Facility (LSF) for Marine Pelagic Food Chain Research. In the shallow bay 150 m offshore a laboratory raft was moored at a bottom depth of approximately 15 m. The bottom sediments underneath and around the raft were dominated by soft organic debris and mud.

Eight bags or enclosures made of polyethylene sheeting of thickness 0.15 mm were mounted from cylindrical floats attached to the floating laboratory. The diameter and depth of each enclosure were approximately 2 and 9.6 m, respectively (Figure 1). The interior of the bag consisted of several structures to aid the circulation of the surface water and to control and determine the degree of turbulent mixing in the uppermost 4 m of each enclosure. In the center of the mesocosm an airlift (4.1 m long and about 4 cm diameter), was positioned. Air was forced into the tube at approximately 1 m depth. The air was allowed to escape upwards through the tube, drawing water in at the lower end at 4 m depth, thus creating a main circulation cell from the surface to approximately 4 m depth. In addition, a pneumatically regulated turbulence grid, not shown in Fig. 1, covered most of the surface of each enclosure. This was driven with a vertical amplitude of +/- 20 cm about the mean depth of 1 m. A pycnocline was thus generated around 4 m depth, while the volume below was characterized by low turbulence and mixing. The boundary gradually migrated downwards to 7 m because of entrainment (J. E. Stiansen, pers. comm.). To keep the enclosures in vertical position a bucket filled with stones was placed in the center of the bottom floor of each enclosure. Each turbulence grid was divided in four quadrants, each of which was possible to open like a door to ensure that equipment and different types of instrumentation could be deployed for sampling purposes.

The mesocosms were labeled according to nutrient and mixing regimes. Two parallel experiments were run for each of the four types of treatments: low turbulence (LT-I and LT-II), high turbulence (HT-I and HT-II), high turbulence with silicate added (HTS-I and HTS-II), low turbulence with silicate added (LTS-I and LTS-II). Originally the eight mesocosms bags were filled with seawater from 4 m depth, containing "natural" populations of zooplankton and phytoplankton. In all bags nutrients were added to increase and maintain phytoplankton production. The same amount of nitrate and phosphate was added in all bags (1.5 μM nitrate and 0.1μM phosphate) per day, starting on 2 September. In all S-enclosures, or those with silicate treatment, an amount equivalent to 1.5 μM silicate was added per day.

Several other structures were also present. A sediment trap was placed at 8-m depth in all enclosures. These consisted of two tube-like sampling units of length 50 cm, positioned approximately 40 cm apart. To keep the air lift in a vertical position one or several small stones were attached to the end of the lift at 4-m depth. Periodically primary production bottles were deployed and positioned at 2- and 6-m depth, respectively. In all I-enclosures, light meters were placed at 2-m depth at a distance of 20 cm from the airlift.

Because of the shallowness of the bay itself, and the shallow depth from where seawater was pumped into the bags, very few *Calanus finmarchicus* (Gunnerus) were introduced into the mesocosms. Nonetheless, this was believed to be the dominant zooplankter, hence the main subject of the acoustical study reported here.

A post-experiment series of measurements was also performed in a new mesocosm to which zooplankton were added from catches made in the outer, deeper fjord adjoining the bay at Espegrend. These measurements complemented or otherwise supported the measurements performed during the experiment proper, but detailed results are not given.

The electricity supply on the raft was quite unstable. Especially when the pneumatically controlled turbulence-generating grids were in operation, an air-compressor ran, causing abrupt drops in the mains voltage and probably powerful transient spikes in too. Thus it was necessary to use a Uninterruptable Power Supply (UPS) system to avoid damage to computers and other instrumentation attached to the power network. Notwithstanding use of a UPS system, electrical noise was periodically present and influenced instrument performance, hence measurements too.

Acoustic instruments

The acoustic measurements were conducted using a SIMRAD EK500 scientific echo sounder (Bodholt, et al., 1989). The system was equipped with three transducers with nominal frequencies of 119, 200, and 714 kHz (Table 1).

Table 1. Transducer and transceiver characteristics

Center frequency (kHz)	Model	Beamwidth (degrees)	Receiver bandwith (kHz)	Pulse duration (ms)
120	ES120-7G	7.0°	Wide (12.0), Narrow (1.2)	Short (0.1), Medium (0.3), Long (1.0)
200	200-28	6.8°	Wide (20.0), Narrow (2.0)	Short (0.06), Medium (0.2), Long (0.6)
714	710-36-E	2.8°	Wide (71.0), Narrow (22.4)	Short (0.02), Medium (0.05), Long (0.2)

The absorption coefficients for the 119, 200, and 714 kHz transducers are 38, 53, and 201 dB/km, respectively.

The EK500 and display monitor were mounted in the raft laboratory. The 119- and 200-kHz transducers were connected to the echo sounder by manufacturer-supplied split-beam cables of respective lengths 100 and 75 m. The 714-kHz transducer was connected by a 20-m long single-beam cable.

Data logger and postprocessing system

Acoustic data collected with the EK500 were logged on the Bergen Echo Integrator postprocessing system (BEI) (Foote et al., 1991), running on a SUN SparcStation 10 via an Ethernet-based local area network (LAN). Geographic information, including time reference, was received from a portable GARMIN 45 geographic positioning system (GPS). Data at all three frequencies (see Table 1) were logged simultaneously.

CTD sonde

To determine temperature and salinity profiles, a Gytre Mini STD sonde model SD-202 was used (Gytre 1988). The resolution of this is determined by the sampling period, which is 5 s.

METHODS

Acoustic measurements

Acoustic measurements were performed in the mesocosms from 10 September to 2 October 1996. Only data and results from the measurements performed at 200-

and 714-kHz on 26 September are presented. Data were also acquired at 119 kHz, but these have not been processed due to problems with the transducer or the receiver card in the EK500 echo sounder.

The transducers were mounted closely together on a steel plate with weights and floats to adjust the buoyancy of the rig (Fig. 2). Between the transducers and the steel plate a 5 cm thick Divinycell HCP 90 plate of density 360 kg/m^3 was mounted to absorb any radiation from the back of the transducer. Before the measurements, the air-lift circulation system in the bags were turned off and the transducer surface washed with a suitable detergent (Zalo), to avoid air bubbles at the transducer/sea interface. The transducer rig, its mass of 30 kg supported by rope over a suspended block, was then carefully lowered into the enclosure and positioned at the half-way distance between the air-lift in the center of the bag and the inner wall of the mesocosm. A series of measurements were then performed at transducer depths 0.5, 2.5, 4.5, and 6.5 m within each enclosure. In some enclosures it was not possible to measure deeper than 6.5 m depth due to restrictions imposed by the short single-beam cable used with the 714-kHz transducer. When lowering the rig between measurement depths and back to the surface, utmost care was exercised to minimize disturbing the physical and biological environment of the enclosure and to avoid rupturing the enclosure wall. During all measurement series the transducers were pointing vertically downwards. Usually a measurement series lasted for about 3-6 minutes at each depth.

The EK500 echo sounder was operated initially with simultaneous use of all three transducers. In most measurement series a range of 0 - 5 m was used and the EK500 "simulated vessel speed" function was set to 20 knots. Thus a ping rate of approximately 1.5 pings per second was achieved. During the second experiment a range of 0 - 10 m was also used to cover the whole mesocosm from 0.5-m depth. To control the measurement depth, the rope and cables were marked at 0.5-m intervals measured from the transducer face. Accordingly the EK500 "Transducer depth" variable was set to a value corresponding to the actual depth of the transducer surface. Performance of the measurements at fixed depths and pre-selected intervals gave the possibility of vertically profiling the enclosures with high resolution and overlap too.

After each measurement series, a series of control measurements was performed in the sea outside the mesocosms. It was thus possible to discern the difference in the two scattering environments, serving as a control on the operation of the echo sounder. This was especially important because of the proximity of boundary surfaces and hydrographical structures within the enclosures, all of which produce echoes and complicate the task of visualizing zooplankton.

During the first set of measurements in the nutrient-manipulated mesocosms, the echo sounder was operated with short pulse duration and wide receiver bandwidth at all frequencies, as specified in Table 1. When the post-experiment mesocosm was established and measurements were performed on 1 - 2 October 1996, different combinations of pulse length and bandwidth were used to verify the difference between these operation modes, particularly with respect to the small target organisms constituting the zooplankton population within the enclosure.

To get information on the general noise levels of the system, both the 200- and 714-kHz transducers were operated alternately in passive and active modes. Thus it was also possible to get specific information on mutual interference.

For the selected range and number of transducers, an average ping rate of 1.3 pings per second was achieved.

Calibration of the echo sounder was performed according to the standard-sphere method (Foote et al. 1987), with use of 38.1- and 10.3-mm-diameter tungsten carbide spheres (Foote 1990). The first calibration attempt was conducted from the raft. Although the weather conditions were excellent, positioning the sphere on the beam axis was extremely difficult for want of a proper rig. This was especially true for the smaller sphere, which was used with the 2.8-deg-beamwidth transducer at 714 kHz. The calibration of the EK500 system was thus postponed until after the field measurements, when it was conducted in the cylindrical experimental tank at IMR on 2 and 3 October 1996.

Visualization

During acquisition of the acoustic data from the enclosures a colour echogram of the backscattered sound was produced and visualized simultaneously on the EK500 display monitor and on a HP PaintJet colour printer. Examples of echograms, as presented by BEI for convenience, are presented with the results.

Echo integration

The SIMRAD EK500 echo sounder system may be viewed as a preprocessor which delivers values of the volume backscattering strength S_V as a function of depth to the LAN for recording and further processing by the Bergen Echo Integrator. The noise threshold function in the echo sounder is set to zero according to recommended practice.

Echo integration is, in fact, performed in the EK500 echo sounder, but according to preselected intervals of depth and sailed distance or, in the present case, simulated sailed distance assuming a particular speed. The numerical operation of echo integration is, in a word, irrevocable. In the Bergen Echo Integrator (BEI), however, echo integration can be performed in arbitrary geometric regions of the echogram, as defined by the user, after data collection. The system operates in the following way. Values of S_V are transferred to BEI from the EK500 by means of datagrams broadcast on the LAN. These are displayed in the form of echograms on the screen of a workstation. The operator identifies regions of interest (ROIs) by means of the mouse function, associating them with a particular object class, for example, a biological species or group of species or noise. Thus reverberation noise, as due to physical structures in the mesocosm, can be separated from signal due to biological scattering, if sufficiently distinct and spatially separated in at least some regions.

When the ROIs and associated object classes are identified, the echo integration is automatically performed. Resultant values of area backscattering coefficient s_A are stored in a database with resolutions in depth and horizontal distance, or effective integration time, that are selected by the operator from a fixed number of choices. In the present case, the depth interval is 0.2 m and the simulated distance is 0.1 nautical mile. For the specified 20-knots simulated speed, about 27 pings are combined over each such simulated interval of sailed distance.

Further data presentation and analysis

Echograms consisting of values of S_V were displayed on the BEI screen for the mentioned identification of ROIs and exclusion of noisy regions, after which integration was automatically performed. Particularly illustrative echograms were printed together with the drawn integration lines or default rectangular grid, with display of s_A-values in the upper right corner.

The corresponding s_A-values entered in the database were also extracted and stored in ASCII files. Many of these were printed in the form of tables containing ten profiles each of acoustic backscattering with time. This form of presentation facilitated identification of extraneous, non-biological structures.

Another, derived form of presentation was through averaged vertical profiles of acoustic backscattering. The associated standard error of the mean was also computed for each 0.2-m depth interval to specify a measure of variability.

CTD measurements

The physical conditions of the mesocosms were monitored every second day during the experiment, 2-27 September 1996. The larger project group was responsible for this task. During the post-experiment measurements, when *Calanus finmarchicus* and euphausiids were deliberately introduced into the single, reestablished mesocosm, vertical profiles of temperature and salinity were measured on 30 September and 1 and 2 October 1996.

Biological measurements

Each mesocosm was sampled for nutrients and phytoplankton every second day during the experimental period. The zooplankton were sampled at the beginning of the experiment at the time of filling the polyethylene bags. To define a baseline in terms of species composition and abundance, a known volume of water was pumped from exactly the filling depth and filtered through a 90-µm-mesh net but external to the bags. At the end of the experiment, the zooplankton populations in the mesocosms were sampled a second time by drawing a 54-µm-mesh net through the each mesocosm from bottom to top. The zooplankton populations were sampled a third time when the mesocosms were emptied by pumping, with filtering through a 90-µm-mesh net.

The zooplankton samples were divided into two parts, one for determination of abundance and species composition, the other for determination of dry weight. At the time of this writing, one year after the experiment, only dry-weight data are available (J. Nejstgaard, pers. comm.).

After the post-experiment measurements were concluded, the zooplankton population of the mesocosm was sampled by submersible pump at each 1-m depth from 1 to 7 m. The zooplankton were isolated by filtering with a 180-μm-mesh net, and preserved in 4% formalin for later analysis of species composition and abundance. The pumping time was 4 minutes at all depths except at 1 m where it was 2 minutes. The capacity of the pump was 3 liter/s, which gives a pumping rate of 180 liter/minute. Thus the sampled volume was calculated to be 21.2% of the total mesocosm volume of 25.5 m^3. According to Skjoldal et al. (1987), all copepodite stages of *C. finmarchicus* excepting CI are sampled without bias by a 180-μm-mesh net, while approximately 30% of CI are lost. The higher pressure exerted on the net during filtration because of the pumping might result in losses of both CI and CII, due to animals being forced through the net. However, care was taken to minimize this effect by keeping the filtering area of the net as large as possible while the water was being flushed through the net.

RESULTS AND DISCUSSION

Hydrographical conditions

Vertical profiles of salinity and temperature have been measured. These show mostly rather weak gradients. When converted to sound speed (J. E. Stiansen, pers. comm.), the maximum gradient is about 1 m/s over a 1.4 m depth interval from about 6 m. More typical gradients are of the order of 0.1 m/s per 1-4 m. This is consistent with the gradual increase of the homogeneous surface layer in the course of the experiment due to entrainment, with consequent descent of the thermocline and halocline.

It is noted that measurements of dissolved oxygen were not made.

Biological environment

As mentioned above, the only available biological data on the contents of the mesocosms are those of zooplankton dry weight (J. Nejstgaard, pers. comm.). These do not demonstrate any clear relation with fertilization or with turbulence.

Phytoplankton might also have to be considered because of their potentially high productivity in nutrient-enriched mesocosms, as well as their unknown scattering properties. However, data on these were unavailable at the time of this writting.

Acoustic observations

An echogram derived from the EK500/714-kHz echo sounder when deployed in the mesocosm HT-I, as displayed on BEI, is presented in Fig. 3. This is believed to be representative of the acoustic environments in the several mesocosms.

To be noted particularly is the presence of noise due to the 200-kHz transducer when the 714-kHz transducer was operated passively. In part A, both the 200-kHz transmit pulse and an echo at 2.2 m are registered. By inspection of Fig. 1, the echo is attributed to the upper pair of production bottles. In part B, with transducers at 2.5-m depth, a distinct echo at 6-m depth is associated with the lower pair of production bottles. This same scattering feature is registered directly on the active, 714-kHz echogram with transducer at both 2.5- and 4.5-m depths.

Also observed on the active echograms with transducer depths of 2.5 and 4.5 m is an irregular band at 1.5-2.5 and 2-3 m, respectively. It is believed that this is due to echoes from the mesocosm wall as ensonified by transducer sidelobes, which seems plausible when it is noted that the beamwidths shown in Fig. 1 are for the main lobes only, as gauged by the -3-dB levels.

Another major structure is observed with the transducer at 4.5 m at the depth 8-9 m. This can safely be attributed to the bottom weights.

Thus useful data on biological scatterers are available at 1-2-m range. These are presented in Table 2. As is the case with the measurements of dry weight, there is no clear relation with fertilization or with turbulence. Even frequency differences are indistinct in most cases, suggesting the influence of a few large scatterers, such as euphausiids, or the pervasive influence of noise. In the absence of detailed biological data, further comment here would be premature.

Sea test

The procedure used in making the acoustic measurements in the mesocosms were repeated in the sea, outside of the mesocosms, but from the same supporting raft. In Fig. 4, the registrations at 200 and 714 kHz show a relatively homogeneous distribution of small scatterers throughout the water column. When the transducers were positioned at 2.5 m depth, some larger scatterers were detected between 4 and 6.5 m depth, very likely the same small fish that were sighted at shallow depths from the raft. Otherwise, the difference in reverberation levels at the two frequencies is quite dramatic, that at 714 kHz dominating that at 200 kHz, which is consistent with frequency-dependent scattering from small organisms (Stanton 1990).

These observations are quantified through Fig. 5. The absolute levels of backscattering differ both with respect to frequency and depth owing to the observed sporadic occurrence of presumed small fish at shallow depths and differing transducer beamwidths.

INTERCOMPARISON OF RESULTS

The several series of acoustic observations are complementary in some respects but otherwise consistent. The single series of measurements made during the experiment proper, on 26 September, have suffered from the physical proximity of equipment and narrowness of the mesocosm walls. Notwithstanding the beamwidths of the two transducers, respectively 5 and 2.5 deg at 200 and 714 kHz, the mesocosm bag is simply too tight for making clean reverberation-free measurements. This is suggested by the beam outlines drawn in Fig. 1.

Table 2. Statistics of echo integrator values s_A at ranges 1-2 m from transducers after removal of apparent reverberation noise from measurements performed in six of the eight mesocosms on 26 September 1996. The code indicates low (L) or high (H) turbulence (T) and addition of silicate (S), with Roman numeral for number of mesocosm in duplicate pair, followed by transmit frequency in kilohertz and transducer depth in decimeters. The mean depth of the respective echo integration interval of thickness 0.2 m is given in meters. N denotes the number of simulated 0.1-nautical-mile intervals, with simulated speed of 20 knots, surviving the noise-removal process. This number must be at least two for inclusion. The following five quantities: minimum, maximum, mean, coefficient of variation, and standard error normalized to the mean, apply to the included s_A-value.

Code	Depth	N	Min	Max	Mean	CV	SE/Mean	Code	Depth	N	Min	Max	Mean	CV	SE/Mean
HTS_II_200_05	2.1	19	1.36	7.71	3.07	0.51	0.12	HTS_II_714_05	1.5	19	2.68	24.10	7.96	0.83	0.19
HTS_II_200_05	2.3	19	1.18	7.60	3.50	0.67	0.15	HTS_II_714_05	1.7	19	3.72	31.24	9.49	0.87	0.20
HTS_II_200_05	2.5	19	0.90	4.07	1.87	0.59	0.14	HTS_II_714_05	1.9	19	0.58	25.28	3.21	1.87	0.43
HTS_II_200_25	3.7	5	0.03	9.93	6.34	0.64	0.28	HTS_II_714_25	3.5	22	0.15	21.58	5.11	1.04	0.22
HTS_II_200_25	3.9	13	0.04	8.29	2.29	1.22	0.34	HTS_II_714_25	3.7	20	0.52	17.55	5.94	0.73	0.16
HTS_II_200_25	4.1	12	0.02	8.23	1.84	1.25	0.36	HTS_II_714_25	3.9	19	0.26	6.12	2.20	0.76	0.17
HTS_II_200_25	4.3	10	0.30	9.29	1.79	1.52	0.48	HTS_II_714_25	4.1	19	0.13	5.58	2.63	0.68	0.16
HTS_II_200_25	4.5	9	0.65	5.10	1.68	0.83	0.28	HTS_II_714_25	4.3	18	0.29	7.26	2.49	0.74	0.17
HTS_II_200_45	5.7	22	0.77	4.85	2.73	0.38	0.08	HTS_II_714_45	5.5	25	0.05	4.82	2.50	0.51	0.10
HTS_II_200_45	5.9	22	0.33	8.52	3.55	0.59	0.13	HTS_II_714_45	5.7	14	0.03	3.12	1.60	0.72	0.19
HTS_II_200_45	6.1	20	0.06	4.23	1.20	0.77	0.17	HTS_II_714_45	5.9	7	0.11	2.84	1.70	0.60	0.23
HTS_II_200_45	6.3	17	0.01	3.73	1.47	0.63	0.15	HTS_II_714_45	6.1	3	0.01	1.12	0.45	1.31	0.76
HTS_II_200_45	6.5	16	0.78	9.97	2.82	1.07	0.27								
HTS_I_200_05	2.3	17	0.27	2.02	1.40	0.27	0.07	HTS_I_714_05	1.7	10	0.43	2.24	1.63	0.32	0.10
HTS_I_200_05	2.5	17	0.84	4.16	2.43	0.37	0.09	HTS_I_714_05	1.9	10	0.11	1.24	0.56	0.60	0.19
HTS_I_200_25	4.1	35	0.20	3.50	0.70	0.85	0.14	HTS_I_714_25	3.5	35	1.68	6.77	2.66	0.43	0.07
HTS_I_200_25	4.3	35	1.09	4.05	2.44	0.30	0.05	HTS_I_714_25	3.7	35	2.36	20.69	5.38	0.69	0.12
HTS_I_200_25	4.5	35	0.64	5.15	1.89	0.41	0.07	HTS_I_714_25	3.9	33	0.66	3.64	1.38	0.58	0.10
								HTS_I_714_25	4.1	24	1.00	2.99	2.14	0.27	0.06
								HTS_I_714_25	4.3	24	3.09	10.87	5.03	0.37	0.08
								HTS_I_714_25	4.5	19	0.02	4.49	2.09	0.59	0.13
HTS_I_200_45	5.9	31	0.54	5.20	2.33	0.51	0.09	HTS_I_714_45	5.5	28	0.05	11.54	2.88	1.08	0.20
HTS_I_200_45	6.1	31	1.54	7.56	4.05	0.35	0.06	HTS_I_714_45	5.7	31	1.68	12.10	6.20	0.45	0.08
HTS_I_200_45	6.3	31	2.07	4.34	3.05	0.20	0.04	HTS_I_714_45	5.9	31	2.87	10.13	4.26	0.29	0.05
HTS_I_200_45	6.5	31	1.37	2.55	2.00	0.16	0.03	HTS_I_714_45	6.1	31	1.96	6.66	4.21	0.25	0.05
								HTS_I_714_45	6.3	24	3.10	20.44	7.49	0.46	0.09
								HTS_I_714_45	6.5	14	0.19	6.85	1.61	1.07	0.29
HT_I_200_05	1.7	11	0.08	4.33	1.58	0.99	0.30	HT_I_714_05	1.5	24	2.94	142.59	37.87	1.12	0.23
HT_I_200_05	1.9	36	3.26	79.64	14.38	1.16	0.19	HT_I_714_05	1.7	22	0.72	264.97	53.11	1.32	0.28
HT_I_200_05	2.1	20	0.05	5.25	1.26	1.23	0.28	HT_I_714_05	1.9	18	1.50	254.78	68.66	1.12	0.26
HT_I_200_05	2.3	36	4.98	56.25	15.80	0.71	0.12	HT_I_714_05	2.1	8	0.12	3.22	1.12	0.96	0.34
HT_I_200_05	2.5	35	0.04	35.47	14.44	0.59	0.10	HT_I_714_05	2.3	10	0.62	132.28	28.32	1.52	0.48
								HT_I_714_05	2.5	18	0.55	79.44	10.34	1.74	0.41
HT_I_200_25	3.9	16	0.27	4.75	1.28	0.83	0.21	HT_I_714_25	3.5	12	0.45	12.82	4.66	0.62	0.18
HT_I_200_25	4.1	16	0.92	2.47	1.88	0.18	0.05	HT_I_714_25	3.7	12	0.29	6.01	3.93	0.39	0.11
HT_I_200_25	4.3	16	0.21	1.50	1.05	0.27	0.07	HT_I_714_25	3.9	12	0.77	5.38	3.20	0.43	0.13
HT_I_200_25	4.5	16	0.32	1.97	1.49	0.25	0.06	HT_I_714_25	4.1	9	0.25	11.02	4.05	0.81	0.27
								HT_I_714_25	4.3	8	0.08	6.85	1.40	1.59	0.56
								HT_I_714_25	4.5	6	0.40	7.75	2.78	1.02	0.42
HT_I_200_45	5.9	21	0.28	3.81	1.12	0.83	0.18	HT_I_714_45	5.5	15	0.80	7.21	2.95	0.59	0.15
HT_I_200_45	6.1	21	0.13	2.94	0.94	0.68	0.15	HT_I_714_45	5.7	15	2.19	7.11	3.71	0.33	0.09
HT_I_200_45	6.3	21	0.14	2.08	0.90	0.51	0.11	HT_I_714_45	5.9	15	0.58	116.70	13.36	2.18	0.56
HT_I_200_45	6.5	21	0.13	1.88	1.10	0.44	0.10	HT_I_714_45	6.1	14	0.17	4.10	2.51	0.47	0.13
								HT_I_714_45	6.3	10	0.10	6.03	3.05	0.65	0.20
								HT_I_714_45	6.5	12	0.65	8.68	4.18	0.52	0.15

Table 2 continued.

Code	Depth	N	Min	Max	Mean	CV	SE/Mean	Code	Depth	N	Min	Max	Mean	CV	SE/Mean
LTS_I_200_05	1.5	24	1.13	12.82	4.64	0.57	0.12	**LTS_I_714_05**	1.5	23	0.17	36.63	9.83	1.06	0.22
LTS_I_200_05	1.7	20	0.39	36.00	10.96	0.90	0.20	**LTS_I_714_05**	1.7	23	0.35	30.86	6.75	1.00	0.21
LTS_I_200_05	1.9	18	1.48	27.35	7.11	1.00	0.23	**LTS_I_714_05**	1.9	17	0.05	31.07	5.15	1.71	0.41
LTS_I_200_05	2.1	8	1.27	15.72	7.14	0.81	0.29	**LTS_I_714_05**	2.1	15	0.42	21.93	3.95	1.37	0.35
LTS_I_200_05	2.3	14	0.47	18.94	8.26	0.56	0.15	**LTS_I_714_05**	2.3	16	0.03	7.06	3.27	0.66	0.17
								LTS_I_714_05	2.5	12	2.10	7.65	3.80	0.50	0.15
LTS_I_200_25	3.5	16	0.12	22.26	5.00	1.10	0.27	**LTS_I_714_25**	3.5	15	0.03	7.47	2.40	1.03	0.27
LTS_I_200_25	3.7	21	0.38	9.84	3.52	0.85	0.19	**LTS_I_714_25**	3.7	20	0.17	8.92	2.40	0.87	0.19
LTS_I_200_25	3.9	14	0.39	12.68	2.83	1.24	0.33	**LTS_I_714_25**	3.9	21	0.06	22.72	5.08	1.04	0.23
LTS_I_200_25	4.1	13	0.09	5.13	1.77	0.93	0.26	**LTS_I_714_25**	4.1	26	0.00	54.97	6.66	1.70	0.33
								LTS_I_714_25	4.3	28	0.11	27.52	6.21	1.20	0.23
								LTS_I_714_25	4.5	27	0.72	155.01	13.30	2.34	0.45
LTS_I_200_45	5.7	5	0.82	13.20	4.10	1.28	0.57	**LTS_I_714_45**	5.5	19	0.41	6.27	2.79	0.60	0.14
LTS_I_200_45	5.9	5	0.20	3.96	1.52	0.95	0.43	**LTS_I_714_45**	5.7	17	0.20	46.55	6.03	1.87	0.45
LTS_I_200_45	6.1	3	1.06	20.56	7.89	1.39	0.80	**LTS_I_714_45**	5.9	20	0.07	9.67	1.92	1.05	0.23
LTS_I_200_45	6.3	3	0.61	78.87	27.06	1.66	0.96	**LTS_I_714_45**	6.1	21	0.01	5.96	1.37	1.04	0.23
LTS_I_200_45	6.5	3	0.81	53.11	18.91	1.57	0.90	**LTS_I_714_45**	6.3	13	0.66	2.73	1.60	0.45	0.13
								LTS_I_714_45	6.5	13	0.48	3.52	1.20	0.74	0.21
LTS_II_200_05	1.9	31	2.03	13.40	4.35	0.57	0.10	**LTS_II_714_05**	1.5	25	1.84	402.01	24.32	3.27	0.65
LTS_II_200_05	2.1	31	0.22	1.20	0.46	0.49	0.09	**LTS_II_714_05**	1.7	25	0.93	12.19	3.59	0.81	0.16
LTS_II_200_05	2.3	31	2.44	10.75	5.71	0.41	0.07	**LTS_II_714_05**	1.9	12	0.54	42.36	8.04	1.82	0.53
LTS_II_200_05	2.5	31	1.76	5.59	3.48	0.33	0.06	**LTS_II_714_05**	2.5	18	0.11	8.28	1.85	1.08	0.25
LTS_II_200_25	3.9	2	0.01	0.19	0.10	1.23	0.87	**LTS_II_714_25**	3.5	30	0.00	247.43	16.59	2.82	0.51
LTS_II_200_25	4.1	29	0.04	2.33	0.83	0.52	0.10	**LTS_II_714_25**	3.7	29	0.00	95.41	14.62	1.85	0.34
LTS_II_200_25	4.3	27	0.25	2.33	1.09	0.41	0.08	**LTS_II_714_25**	3.9	13	0.00	23.14	3.61	1.83	0.51
LTS_II_200_25	4.5	26	0.21	1.46	0.89	0.30	0.06	**LTS_II_714_25**	4.1	6	0.19	7.78	2.91	0.99	0.40
								LTS_II_714_25	4.3	7	0.62	6.56	2.17	1.00	0.38
								LTS_II_714_25	4.5	4	0.83	2.92	1.86	0.50	0.25
LTS_II_200_45	5.9	24	0.08	0.76	0.41	0.49	0.10	**LTS_II_714_45**	5.5	16	0.00	18.76	3.19	1.34	0.33
LTS_II_200_45	6.1	22	0.00	0.84	0.42	0.52	0.11	**LTS_II_714_45**	5.7	16	0.00	5.81	2.64	0.64	0.16
LTS_II_200_45	6.3	19	0.13	0.73	0.41	0.38	0.09	**LTS_II_714_45**	5.9	15	0.01	7.86	1.65	1.21	0.31
LTS_II_200_45	6.5	19	0.04	1.04	0.46	0.57	0.13	**LTS_II_714_45**	6.1	11	0.01	3.05	1.56	0.66	0.20
								LTS_II_714_45	6.3	9	0.01	2.79	1.42	0.79	0.26
								LTS_II_714_45	6.5	8	0.02	2.50	1.31	0.83	0.29
LT_II_200_25	3.9	4	0.31	0.78	0.46	0.47	0.23	**LT_II_714_25**	3.5	16	0.06	10.88	4.08	0.81	0.20
LT_II_200_25	4.1	22	0.75	2.78	1.51	0.33	0.07	**LT_II_714_25**	3.7	15	0.39	14.52	4.72	0.86	0.22
LT_II_200_25	4.3	22	1.18	3.83	2.37	0.24	0.05	**LT_II_714_25**	3.9	17	0.19	40.96	7.52	1.34	0.33
LT_II_200_25	4.5	20	0.07	3.17	1.48	0.51	0.11	**LT_II_714_25**	4.1	17	0.74	8.28	3.55	0.46	0.11
								LT_II_714_25	4.3	17	0.57	54.31	6.50	1.95	0.47
								LT_II_714_25	4.5	10	0.30	65.71	9.66	2.08	0.66
LT_II_200_45	5.9	24	0.12	8.72	1.42	1.71	0.35	**LT_II_714_45**	5.5	20	0.33	16.31	3.80	0.95	0.21
LT_II_200_45	6.1	23	0.05	1.70	0.84	0.52	0.11	**LT_II_714_45**	5.7	17	0.07	8.46	2.29	0.91	0.22
LT_II_200_45	6.3	22	0.09	1.65	1.10	0.34	0.07	**LT_II_714_45**	5.9	19	0.09	47.66	4.07	2.62	0.60
LT_II_200_45	6.5	19	0.36	1.72	1.11	0.32	0.07	**LT_II_714_45**	6.1	23	0.31	18.70	4.14	1.12	0.23
								LT_II_714_45	6.3	24	0.94	27.31	4.18	1.26	0.26
								LT_II_714_45	6.5	24	0.02	20.10	4.31	1.08	0.22

In fact, the indicated beam regions are shown at the farfield -3-dB levels, inside of which the one-way loss in directivity is less than 3 dB, or one-half maximum power or sensitivity on-axis. Outside of the demarcations, there is still substantial acoustic energy distributed over a wide angular sector.

Repetition of the acoustic observations in the post-experiment mesocosm on 1 and 2 October support the first findings. This new mesocosm was indeed narrow, but without internal structures, and the reverberation was much weaker if not negligible. Still, the walls apparently gave reflections, again at about 2 m, which can be imagined to be due to echoes from the walls when ensonified by sidelobes.

Observation of temporal structure in the reverberation suggests movement of transducer or mesocosm walls or both. Given that the measurements were made in a tidal basin and that the platform for the measurements was a raft to which eight mesocosms were attached, which is also a workplace for researchers including those making the acoustic measurements, it is easy to imagine that small relative movements between transducer rig and mesocosm are unavoidable and are generally present.

The so-called sea test, described above, is important for demonstrating the general functioning of the two transducers used for the measurements reported here. This test showed that a variety of scatterers, including small fish and probably much smaller organisms, could be visualized and quantified too, although the data scarcely warrant development for want of controls, namely, sufficient identification of the scatterers, as by capture.

SUMMARY WITH RECOMMENDATIONS FOR FUTURE WORK

An attempt has been made to visualize and quantify zooplankton in a mesocosm experiment. Formidable logistical hurdles were overcome just to be able to make any measurement at all before termination of the month-long experiment.

The acoustic measurements were performed as a collaborative venture, with the intention of supporting the larger experimental goals. In particular, it was hoped that visualization and quantification of zooplankton in the mesocosm might give insight into the effects of the two applied treatments, those of fertilization and turbulence.

In the event, the acoustic measurements were plagued by reverberation from physical structures in the mesocosm and, apparently, the mesocosm walls themselves. This remains an inference, if plausible. Nonetheless, a set of measurements has been compiled, in Table 2, for six of the eight mesocosms at a late stage in the experiment, just before their emptying with sampling of zooplankton. The measurements are arranged as series of partial vertical profiles of the mesocosm water columns.

While the acoustic measurements show no clear pattern, neither do the provisional dry-weight measurements, which are admittedly incomplete at the time of this writing. A further, consolidated analysis of acoustic and biological results may be entertained, but outside of this pilot study.

Results from the sea test conducted outside the mesocosm on 26 September witness to the imaging power of acoustics. In addition, the possibility of quantifying the visual record, as through application of the echo integration method, is evident. Table 2 may serve as a reminder of this capacity, if with unrealized potential here.

For future experimental work, the present experiences suggest the following:

(1) Mesocosms should be designed with regard to dimensions and placement of equipment so that the physical volume is accessible to acoustic sampling.

(2) The mesocosm environment should be monitored with respect to temperature, salinity, and oxygen content vis-a-vis saturation.

(3) The starting time for acoustic measurements which follow equipment operation that affects the mesocosm environment, as in aeration or turbulence generation, should be chosen on the basis of prior measurement.

(4) Phytoplankton abundance and species composition should be monitored. Particular attention should be paid to groups or species which might influence the reverberation environment of the mesocosm.

(5) Both tilt angle and bearing of the transducer rig should be recorded during deployment.

(6) An underwater video camera should be used occasionally to detect possible movements of the mesocosm wall.

(7) A separate mesocosm should be established and reserved for performance of concurrent measurements in support of the actual mesocosm measurements.

(8) Collateral acoustic measurements should be performed in the sea outside of the mesocosm, with both environmental and biological sampling, in order to establish a baseline.

On the purely management side of the business of conducting a pilot study, it should be clear that greater lead time contributes to better preparation, and that commitment of manpower resources to data analysis immediately following the measurements can result in more timely reporting.

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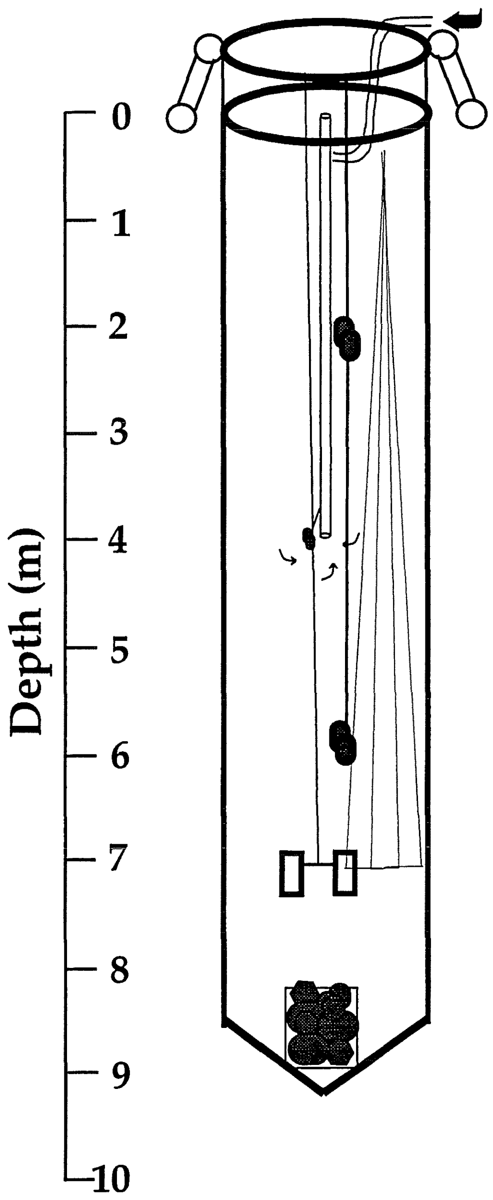

Fig. 1. Schematic diagram of a mesocosm, showing air-lift system with central pipe and small weights, with water intake at bottom end; two pairs of production bottles; sediment trap; and stabilizing weights at the bottom of the mesocosm.

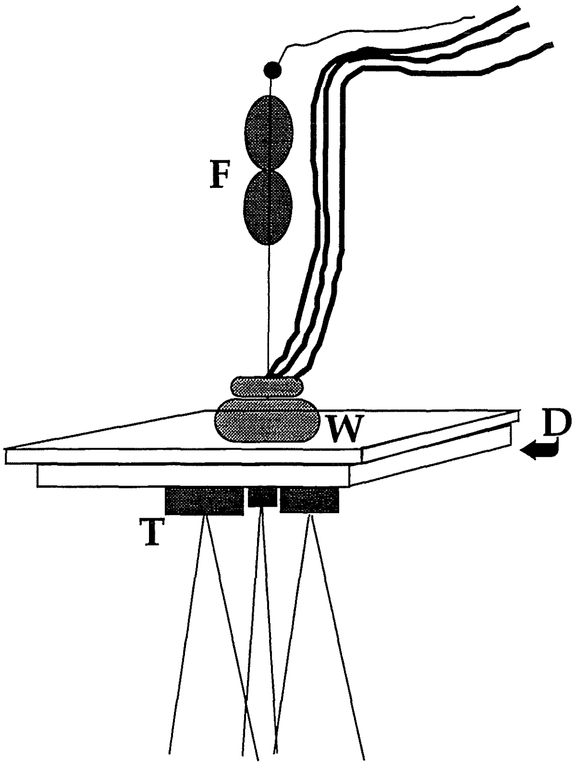

Fig. 2. Transducer rig, showing three transducers T, damping material D, weights W, and buoyancy floats F.

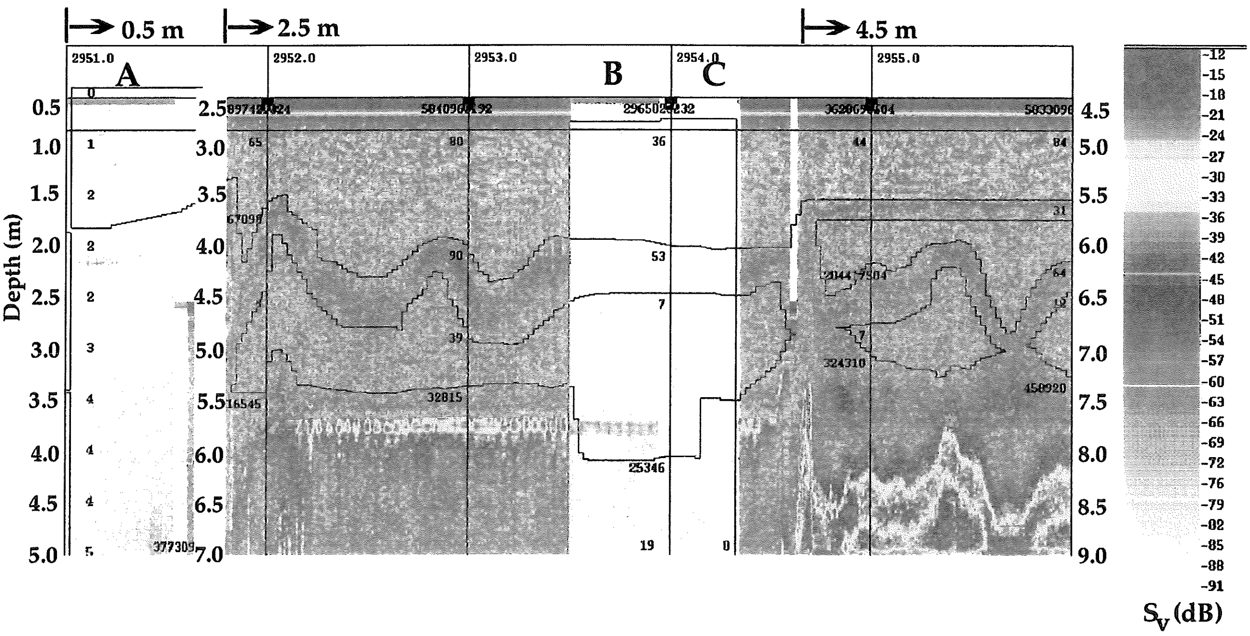

Fig. 3. Echogram derived from the EK500/714-kHz echo sounder system, deployed in mesocosm HT-I on 26 September 1996, as displayed by BEI. The transducer depth was successively 0.5, 2.5, and 4.5 m. The bar to the right associates colors with absolute values of the volume backscattering strength S_V. A&B: The 714-kHz transducers was operated in passive mode while the 200-kHz transducer was operated in active mode. C: Both transducers in passive mode.

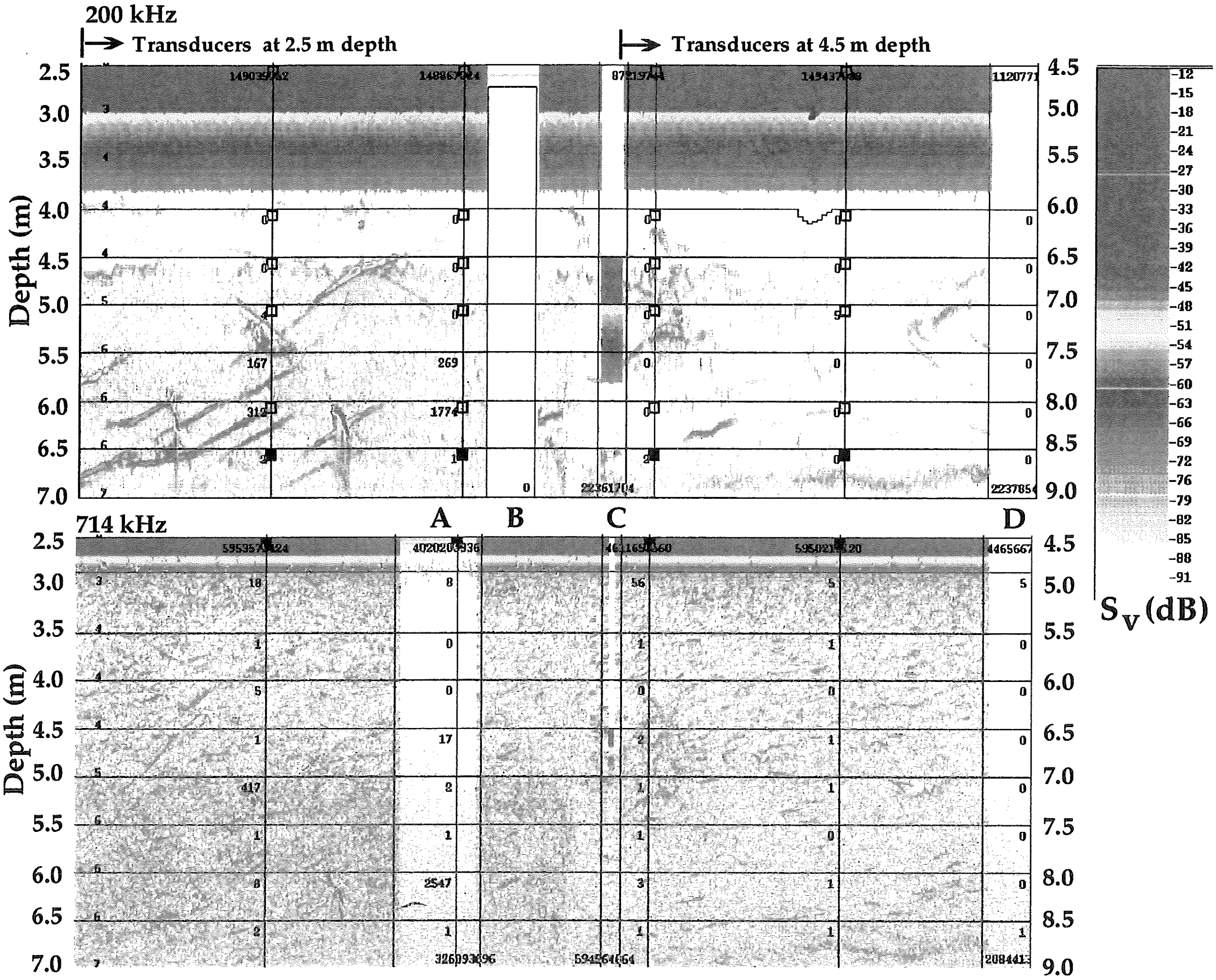

Fig. 4. Echograms derived simultaneously from the EK500/200- and 714-kHz system, which was deployed in the sea outside the mesocosms on 26 September 1996, as displayed by BEI. Each of two transducer depths is shown, 2.5 and 4.5 m. A: The 714-kHz transducer is operated in passive mode while the 200-kHz transducer is operated in active mode. B: 200-kHz in passive mode and 714-kHz in active mode. C: Lowering transducers to 4.5-m depth. D: Both transducers in passive mode. Horizontal lines indicate echo integration channels. Numbers in the upper right corners of boxes indicate the result of echo integration in the respective box. These are given in units of area backscattering coefficient s_A. The bar to the right associates colors with absolute values of S_V.

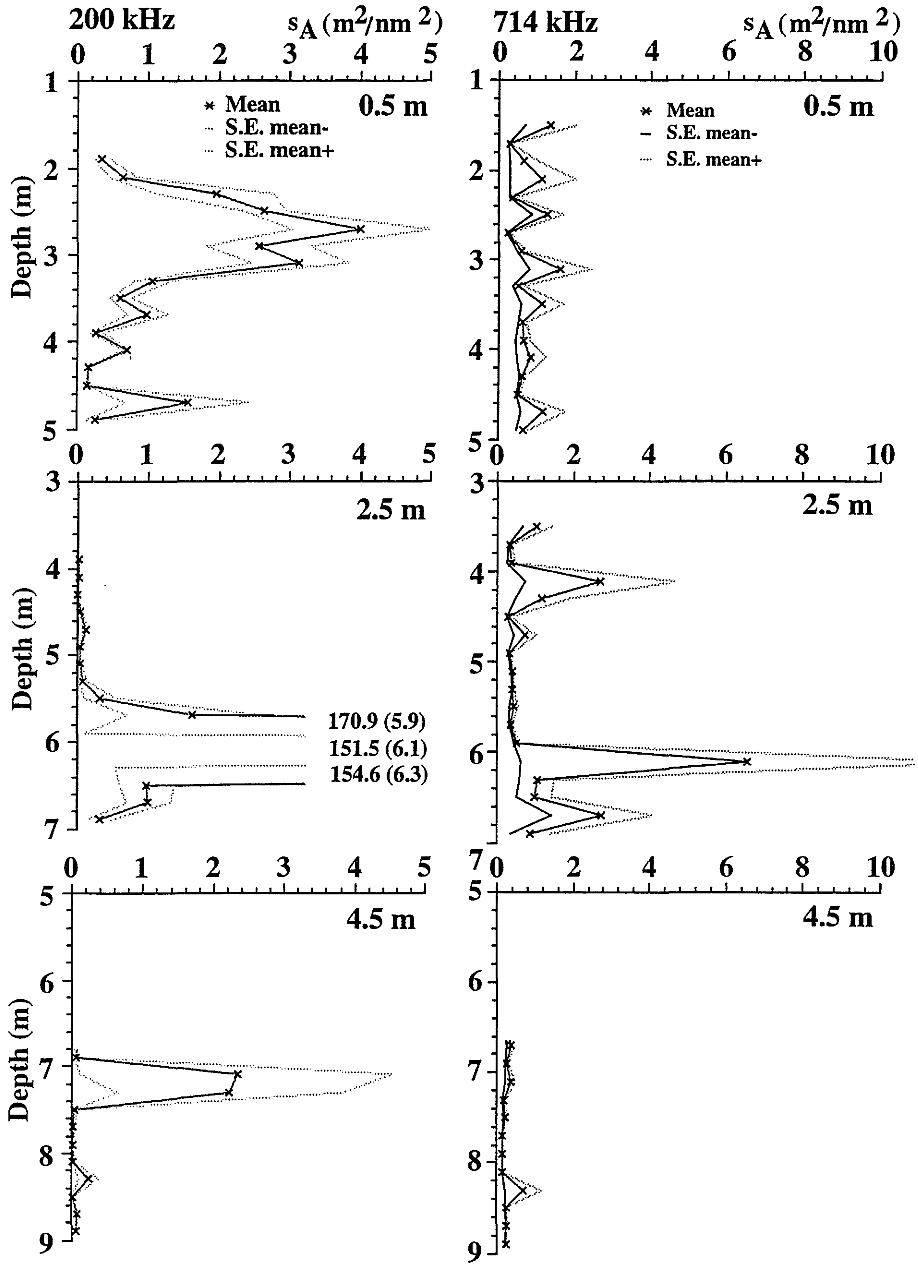

Fig. 5. Vertical profiles of acoustic backscattering at 200 and 714 kHz at each of three transducer depths, 0.5, 2.5, and 4.5 m, derived from the EK500 system deployed in the sea outside the mesocosms on 26 September 1996. Each profile is the result of averaging s_A-values over ten simulated 0.1-nautical-mile intervals. The envelope about each solid line is defined by one standard error. In a single case, 200 kHz at 2.5 m, the maximum values are indicated but not shown in order to maintain similar scales.