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Hydroacoustic detection of food waste - a method to estimate maximum food intake of fish populations in sea cages

by

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ABSTRACT

A linear relationship between echo energy and amount of salmon dry food was established. Measurements were carried out both for food batches (5-400 gram) and single pellets. For a certain amount of food, the echo energy decreased when pellet size increased. The relationships allowed hydroacoustic detection of small amounts of food waste. Maximum food intake of a salmon population was determined as the amount of food delivered by the feeder before food waste was detected.

INTRODUCTION

A competitive producer of salmon in sea cages must be able to control the feeding process to achieve rapid growth, low production costs, and a healthy environment. The complexity of factors controlling appetite makes it, however, a difficult task to predict daily feed consumption in a salmon population. Methods to study fluctuations in appetite are therefore a valuable tool in finding new ways to control the feeding process.

Food intake is one essential parameter in the study of feeding in fish, as it is the most direct measure of appetite. Methods to estimate the food intake of individual fish range from weighing the stomach content to non-destructive techniques such as mixing known quantities of radioactive or iron particles into the food and estimating food intake using a Geiger-counter or X-ray photos (Storebakken, Austreng & Steenberg 1981, Talbot & Higgins 1983). However, the sample size requiered when working with large populations of adult salmon make these methods unsuitable for long term studies of appetite fluctuations. Furthermore, the stress imposed on the population when netting out a sample may have a negative effect on appetite.

An alternative to observation on individual fish is to measure the cumulative food intake of all fish in the population. Cumulative food intake can be observed by determining when offered food is rejected. The low visbility in a sea cage excludes observation from the surface as a reliable method to determine the point of satiaton. This paper describes a method where hydroacoustic detection food pellets at the bottom of the sea cage is used as an indicator of food rejection.

Maximum food intake of a salmon population was estimated as the amount of food delivered by the feeder before food waste was detected. A precise estimate of maximum food intake was therefore depending on quantification of echo energy from small amounts of food. To quantify the echo energy, essential parameters of the acoustical instruments and the food firstly had to be determined. The next step was to establish the relationship between the amount of echo energy and amount of feed. The method was then applied in a feeding experiment.

METHODS AND RESULTS

A 200 kHz Furuno FE-881 (MK-II) echo sounder with a ping repetition frequency of 400 per minute and a pulse length of 0.3 msec was used. The echo sounder was connected to a Simrad QM (MK-II) echo integrator. The beamwidth of the two transducers, were measured in the laboratory to 4.9 and 15.6 degrees and the beam patterns were close to circular. Calibration was carried out on all gain-steps (Appendix 1) of the echo sounder, with -30 dB attenuation on the echo integrator, using a copper-sphere with a diameter of 13.7 mm and a calculated target strength of -45dB at 200kHz (Foote et al. 1987).

The echo energy from the pellets was quantified using a modified version of the echo integration method for assessing fish stocks (Dalen & Nakken 1983). The echo energy from a observation volume is expressed by the area backscattering-coefficient (s_a):

$$s_a = \sigma_p \cdot \rho_a \qquad (1)$$

where σ_p is average backscattering-crossection of a object (e.g. fish, foodpellet) and ρ_a is the area density of the objects. The accumulated echo energy, presented by the echo integration, M_0 (mm), is expressed in units of s_a by the use of the instrument constant (C_i), calculated from calibration of the instruments (Foote et al. 1987)

$$s_a = M_0 \cdot C_i \qquad (2)$$

The relationship between amount of food and amount of echo energy was established for five different sizes of commercial dry-pelleted fish feeds with only marginal differences in nutritional composition. The sinking speed of the pellets was measured using the echo sounder at high paper speed and gain 8 (Table 1). To correct for differences in sinking speed, all M-values were normalised to an observation period of one minute [s_a/min = $s_a \cdot K$ (mm/min), $K = 60/T_s$ where T_s is the time the pellet used to sink through the integrated layer of 2.0 m].

Table 1. Name (abbrevation), diameter and sinking speed (M $\pm$ SD) of the food types.

Name	Diameter (mm)	Sinking speed (cm/s)	
Tess elite pluss (TEP-5)	5	15.2$\pm$1.4	(n=20)
Ewos Miljøfor (EM-6)	6	14.7$\pm$1.3	(n=17)
Ewos Vextra (EV-9)	9	16.4$\pm$1.4	(n=8)
Tess Edel (TE-10)	10	17.9$\pm$1.4	(n=18)
Ewos Vextra (EV-12)	12	17.9$\pm$1.6	(n=11)

Food batches

The food batches was discharged through a pipe centered at the acoustic axis of the 4.9° transducer. To avoid disturbances from fish attracted to the food, all measurements were carried out inside an empty sea cage (see Figure 1). Disturbances from gas bubbles originating from decomposing organic material in the bottom sediment were eliminated by a sheet of thin plastic fastened to a wooden frame underneath the observation volume, guiding the bubbles away. The transducer was mounted in a compass-suspension, assuring that the transducer surface always was parallel with the sea surface (Figure 2).

Five parallel measurements were carried out for 9-12 different weights of foodbatches in the interval 5 - 400 gram. Food pellets were detected as grey traces on the echogram and echo energy was integrated as the pellets sank trough a 2 meter observation layer (Figure 3). The area covered by the acoustic beam in the integration layer averaged 0.63 m^2 and visual observation indicated a uniform distribution of pellets in this area.

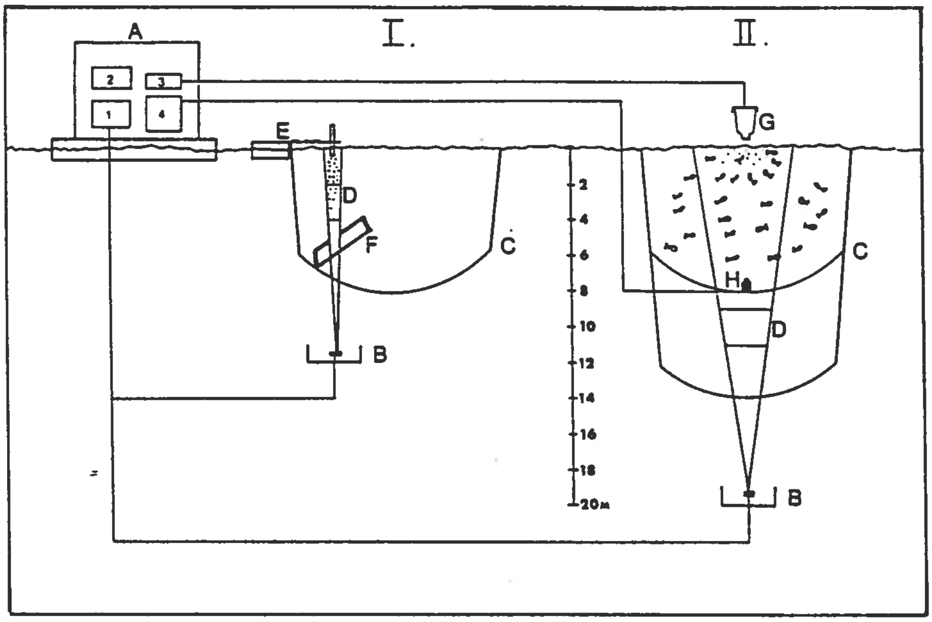

Figure 1. I. Experimental setup during echo energy measurments.
II. Experimental setup during the feeding experiment.
(A) Observation raft with echo sounder (1), echo integrator (2), feeder control (3), video monitor (4).
(B) Transducer in rig (see details Fig. 2).
(C) Sea cage.
(D) Observation volume.
(E) Calibration ramp.
(F) Bubble curtain.
(G) Feeder.
(H) Camera.

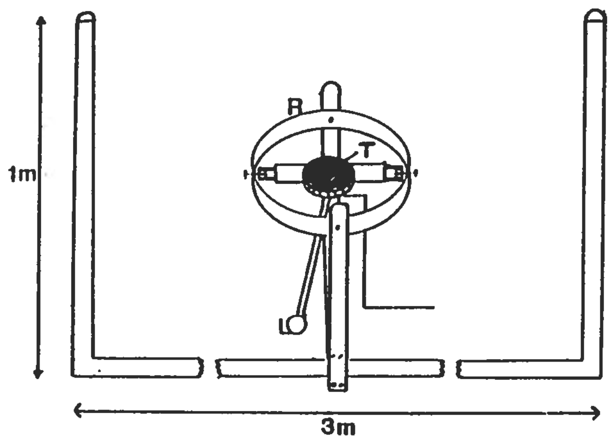

Figure 2. Tranducer (T) mounted in rig (R). The construction allows the transducer to move independetly of rig position. The lead weight (L) keeps the transducer surface parallell with the sea surface.

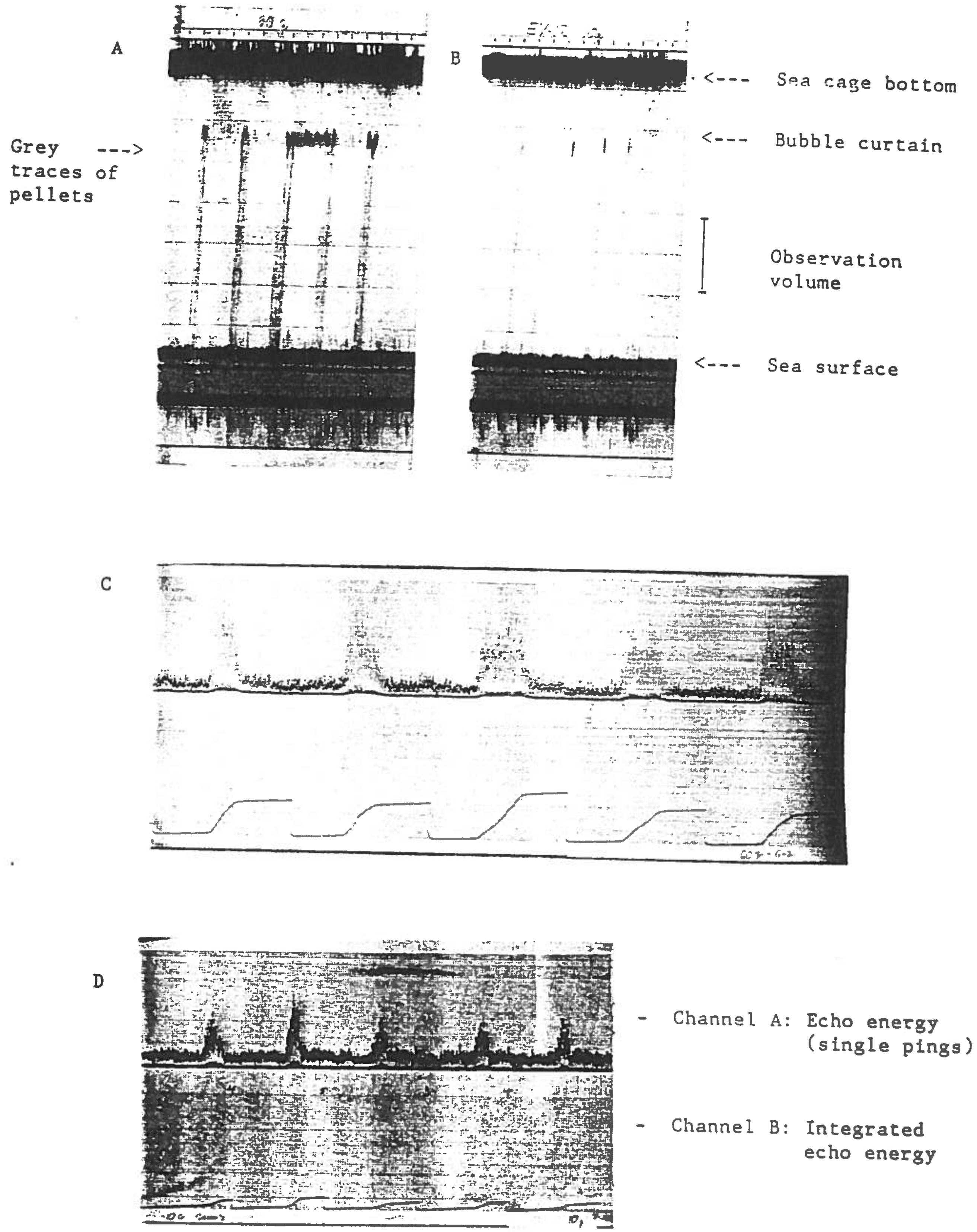

Figure 3. Echogram (A and B) and integrator output (C and D) when measuring 60 and 10 gram EV-12. The grey vertical lines on the echogram is the food sinking through the water column.

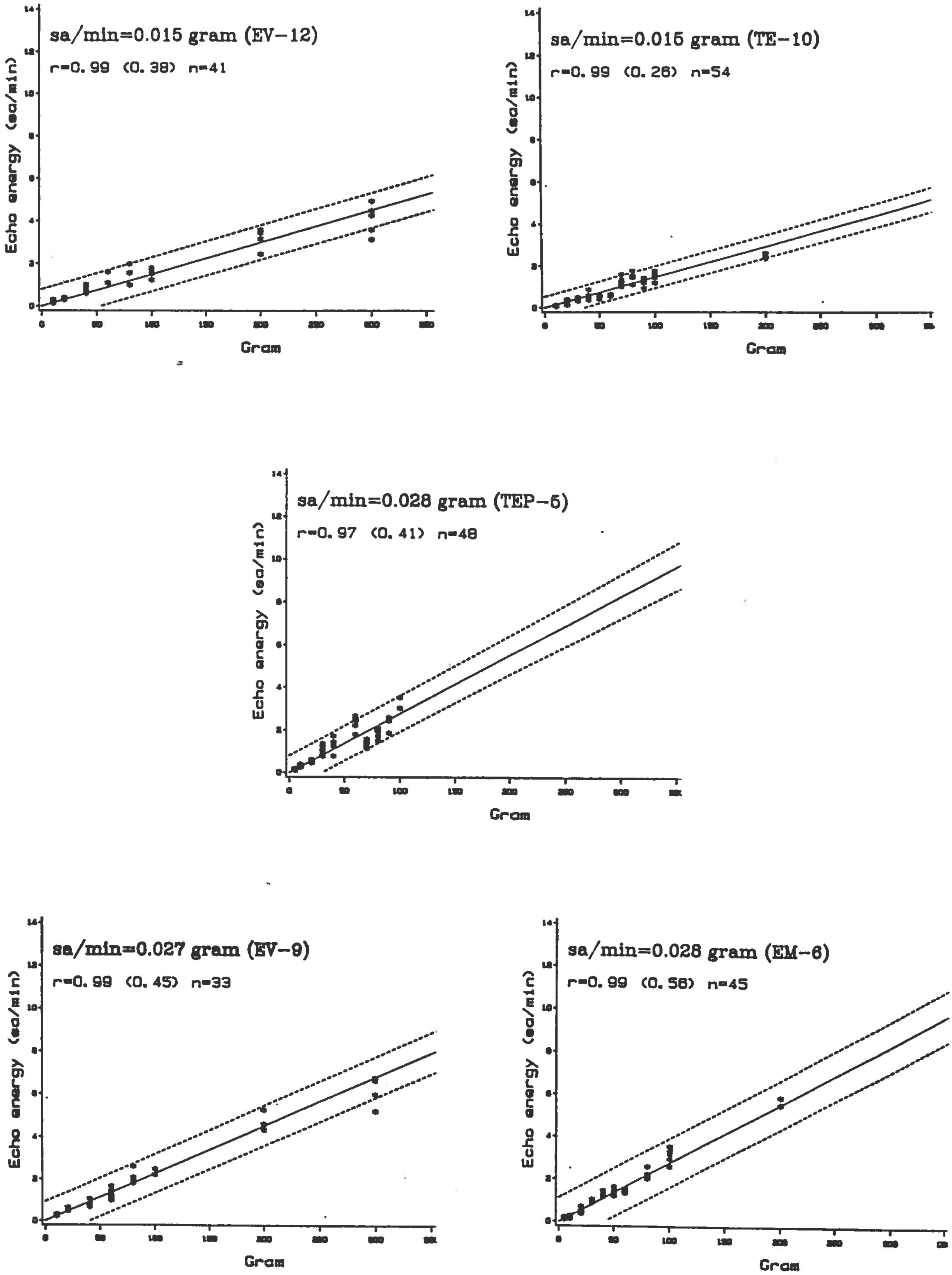

Figure 4. Regression lines showing the relation between echo energy and weight of food for five commercial salmon feeds.

Figure 4 shows a good linear relationship between the amount of food and echo energy for all pellet types (r = 0.97 - 0.99, Zar 1984). A multiple regression (Anon. 1986) including measurements of all pellet types showed that the echo energy also is negativly dependent of pellet diameter (Table 2).

Table 2. Multipple regression using all food types [Echo energy = a + b(pellet diameter) + c(amount)]. Regression- and correlation coefficients with standard errors. p-values for variance analyses and t-test of b = 0 and c = 0 are also given.

Coefficients	Standard error	p-values
r = 0.93	0.83	0.000
a = 1.31	-	-
b = 0.02	4.7E-4	0.000
c = -0.14	2.1E-2	0.000

Single pellets

The second approach to establish the relationship between the amount of food and echo energy was to measure echo energy from single pellets and then estimate echo energy for larger amounts of food.

Measurements were carried out for the pellet types EV-9 and EV-12. Pellets were suspended into the observation volume on the acoustical axis (±5cm) by a 0.15 mm nylon gut with a lead weight at the end, outside the observation volume, assuring the pellet position in the beam. The integrator output from the pellet (M_p), and the noise level including the rigging was measured for one minute.

Echo energy from single objects is often expressed as target stength (TS). The target strength of the pellet (TS_p), was calculated by direct comparison with the target strength (TS_{sp}) of the copper sphere used during calibration:

$$TS_p = 10 \log(M_p/M_{sp}) + TS_{sp}$$

where M_p and M_{sp} is the integrator output from one minutes measurement of pellet and copper sphere, respectively .

The target strength of single pellets, estimated target strength per kilo and the signal/noise ratio are given in Table 3. The largest pellet (EV-12) had the highest target strength, but the variation was considerable.

Table 3. Target strength of single pellet (TS_p), estimated target strength per kilo (TS_{kg}) and signal/noise ratio (S/R).

Food type	TS_p (dB)	TS_{kg} (dB)	S/R
EV-12	-55.3±4.2	-27.3	1.65
EV-9	-56.6±2.4	-25.9	1.76

The target strength was used to estimate echo energy for larger amount of food using (1). The backscattering cross-section (σ_p) in (1) is calculated from the target strength using

$$TS_p = 10 \log(\sigma_p/4\pi) \qquad \text{(Urick 1967)}$$

The area backscattering coefficient (s_a) was then estimated for different area densities (δ_a) of pellet.

The estimated area backscattering using single pellet measurements is compared with the food batch measurements in Figure 5. For comparision the food batch measurements was converted from gram to area density by counting the number of pellet in 100 gram (EV-12 = 63 $\pm$ 2, EV-9 = 118 $\pm$ 2, n = 10).

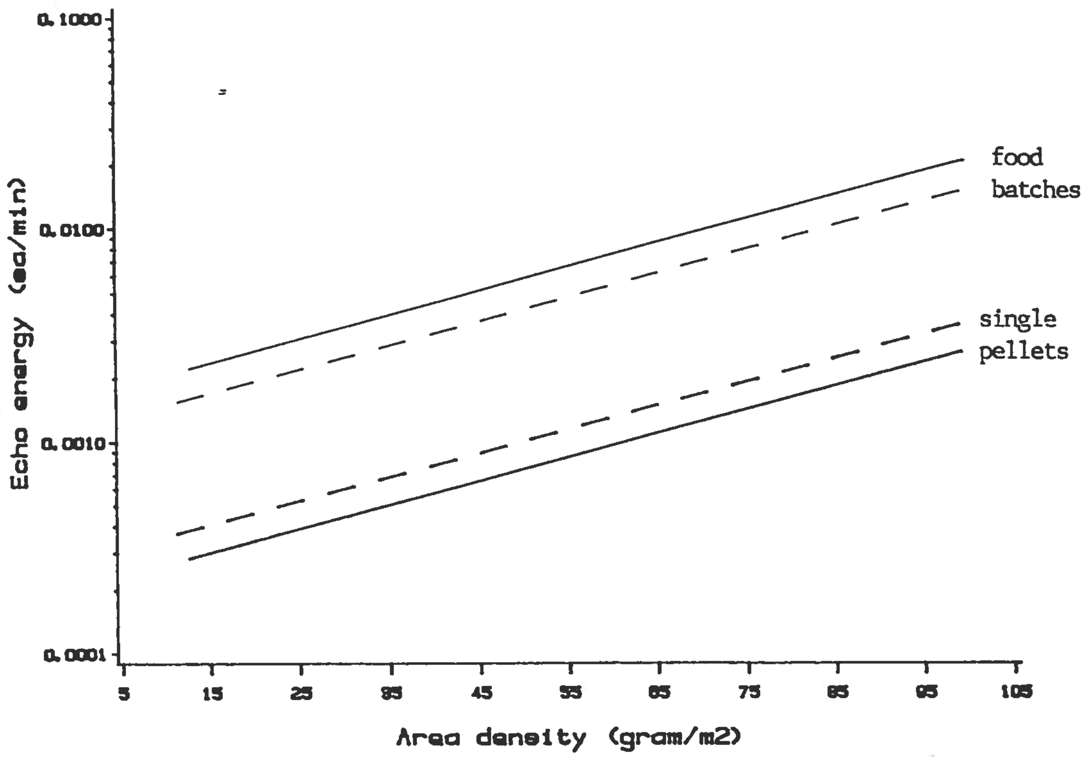

Figure 5. Estimated echo energy for different area densities of EV-9 (——) and EV-12 (---) based on food batch and single pellet measurements.

Detection of food waste to estimate maximum food intake

When a salmon population becomes satiated, the food is no longer eaten at the surface and some of the food will sink through the bottom of the sea cage. The principle of the present method is to determine when this happens by acoustic detection of these small amounts of food waste.

The method was used in 150-200 feedings over a 3 month period, observing the food intake of a salmon population of about 3000 individuals given 2-8 meals pr. day. A commercial feeder delivering 0.5 ± 0.1 kg every 20 seconds was turned off when a increase in integrator output indicated arrival of uneaten pellets at the bottom of the sea cage. The maximum food intake would then approximately equal the food delivered.

The wide beam transducer was used in order to increase the observation volume. The observation volume was shielded from noise by a empty sea cage (see Figure 1). A underwater camera (Osprey, OE-1336), positionted at the bottom of the sea cage directly underneath the feeder, was used to check the hydroacoustical observations.

Food intake in one meal ranged from 1.5 to 81 kg. The lowest representing the last of 8 meals in a day and the highest the first meal after 66 hours of food deprivation. The amount of food waste sinking trough the observation volume was calculated from the integrator output and relationships established earlier, correcting for background noise. The echo energy from food waste, measured in all feedings, averaged 30.0 gram (0.46 s_A/min). This corresponds to less than 10% of the amount the feeder delivered every 20 second and less than 5% of the lowest food intake in one meal.

DISCUSSION

The acoustic reflection properties of any object depends on its density contrast to sea water. The low water content, uniform size and solid consistency of the food types used in this work make them more suitable as acoustical targets than soft or wet fish food. The porosity of the dry pellet or small gas bubbles attached to the surface of pellet may contribute to variation in echo energy estimates. However, the echo energy measurements demonstrate that it is possible to register amounts as small as 5-10 gram of typical salmon dry food.

The echo energy was proportional to the pellet size and consequently to the number of pellets in a batch. This is explained by the increased surface/weight ratio when the size of the pellet decreases as the total backscattering surface mainly determines the amount of echo energy. Both the food batch and the single pellet measurements confirm this. As a consequence a single EV-12 pellet reflects more energy than the smaller EV-9, but one kilo EV-12 reflects less than a kilo EV-9. This is in acccordance with target strenght measurements of different sized fish (Edwards & Armstrong 1982).

The low signal/noise ratio during single pellet measurements may explain the lower estimate of area density compared to food batch measurements. A biased distribution of pellets towards the center of the beam during the food batch measurements could also have contributed to the divergence, as an accurate estimate of the backscattering coeffisient is based on the assumption of a uniform distribution of targets in the beam.

Thus, the theoretical assumptions underlying any use of acoustical measuring techniques set limitations to the accuracy in the estimate of food waste. However, the small amounts of food needed for hydroacoustic detection compared to the food intake of a salmon population make the food intake estimate reliable. In practice the method proved to be a valuable tool to get a precise etimate of the cumulative food intake of the population during a meal.

The feeding rate of the population at the start of a meal will influence the rate of food waste. If the appetite is very low, the feeding intensity of the feeder will exceed the inital feeding rate of the population. This will cause food waste to start at a high level instead of increase slowly as the population get satiated.

To use the method sucsessfully, feeding experiments should be carried out at locations with low or predictable water currents to assure that food waste sink trough the observation volume. Furthermore, a properly shielding of the observation volume is important to avoid fish disturbing the measurements. The instrumentation used in this work is expensive and developed for other purposes. The applicability of the method would be greatly enhanced by using transducer and signal prosessing technology specially designed for this purpose.

Food waste from fish farms is both an economical and an ecologial problem. Much effort has been invested to solve this problem, like finding methods to collect food waste or moving farms to more exposed locations. However, these approaches only remove the ecologial symptoms. The core of the problem is to feed populations of salmon in accordance with their fluctuating appetite. A food waste detector controlling the feeding could be a solution to this problem.

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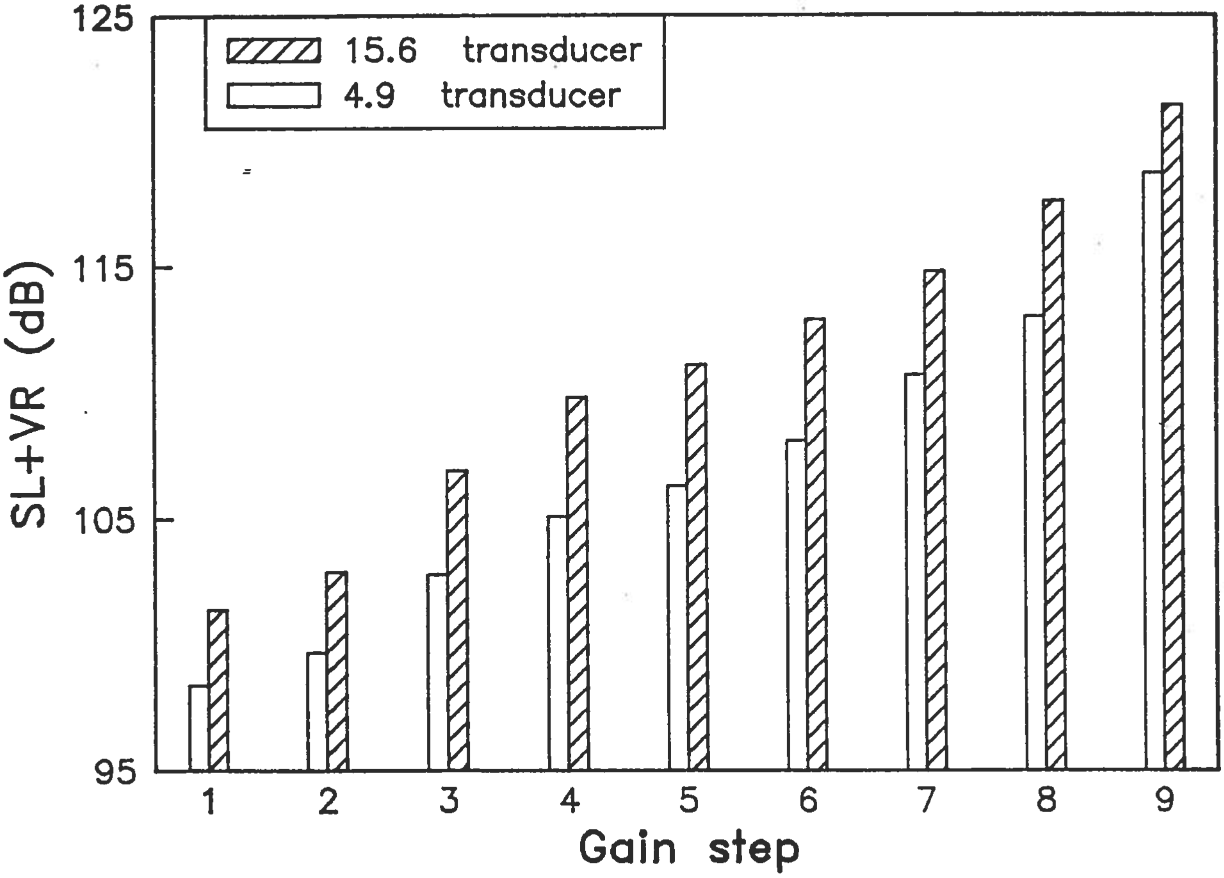

The sum of source level and voltage respons (SL + VR) at different gain steps of the echo sounder with the two transducers used.