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# ZOOPLANKTON AND THE DISCONTINUITY LAYER IN RELATION TO ECHO TRACES IN THE OSLOFJORD

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## INTRODUCTION

During cruises with R/V «Gunnar Knudsen» it was discovered that the echosounder nearly always recorded echoes from the depth of the thermocline. In accordance with the appearance of the traces (cf. Fig. 2) the term *echo-bands* was introduced.

The echo-bands might be caused by reflection from the border layer between two water masses (HASHIMOTO and MANIWA 1956, BANSE 1957, LENZ 1965) or from accumulated particles in this layer

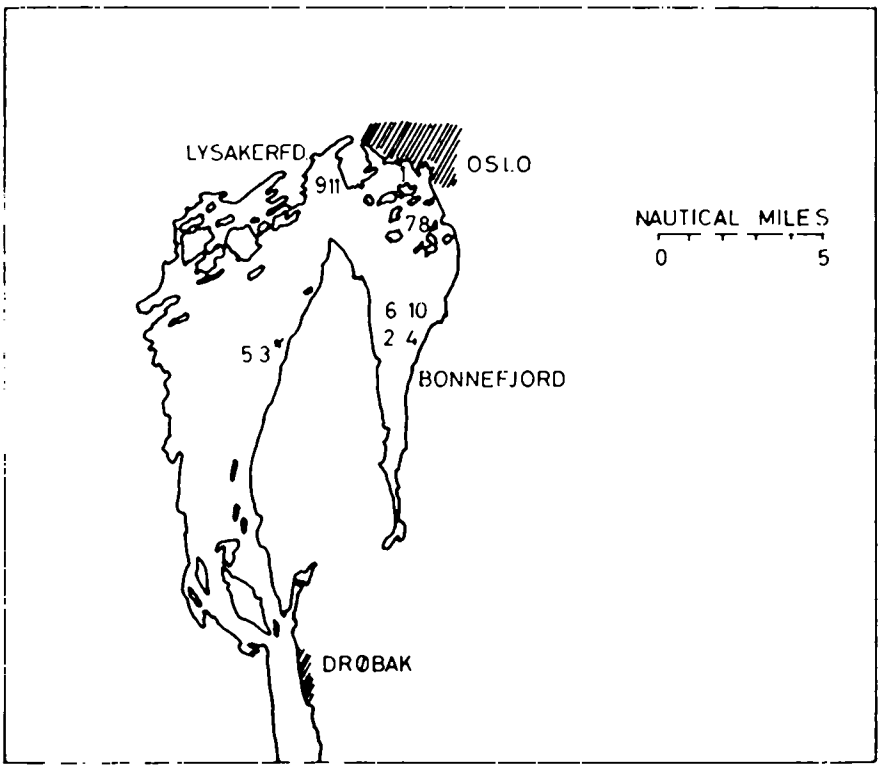


Fig. 1. The Oslofjord and observation stations.

(TROUT, LEE, RICHARDSON and HARDEN JONES 1952, CUSHING, LEE and RICHARDSON 1956, WESTON 1958, OLSEN 1960). The particles again might be living plankton concentrating in the layer or dead organisms and particles retarded in their sinking.

From June 1963 through April 1964 attempts were made to reveal the possible sources for the observed echo-bands in the Oslofjord (Fig. 1).

## METHODS

The SIMRAD echosounder used in the present investigation had a frequency of 38.5 Kc/sec. and two optional puls lengths, which were 1 and 0.1 millisecond respectively. In order to obtain distinct recordings the shortest puls length was always applied. If applying the longer puls length two narrow echo-bands might coalesce and make one broad band. The speed of the wet echosounder paper was 1.3 cm per minute. The transmitted sound impuls was constant, the source level measured as sound intensity 1 m from the transducer being 105 dB// 1 $\mu$ bar, but the the received signals could be amplified. The amplifier had 11 positions and the corresponding amplifications are given in Table 1. The lowest echo that could be recorded was — 40 dB// 1 $\mu$ bar.

Table 1. Positions of the amplifier, the corresponding amplification of a received impuls and minimum recordable signal (MRS) in dB//1 $\mu$ bar.

| Position | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Amplification: | ? | ? | 1000 | 4000 | 7500 | 10000 | 15000 | 30000 | 45000 | 80000 | 80000 |
| M R S: | | | —21 | —27 | —30 | —31 | —33 | —36 | —38 | —40 | —40 |

To find a measure of the strength of a received echo, the amplifier was turned successively down until the echo disappeared (Fig. 2) and the last position before its disappearance was used as a measure. It was not possible to distinguish echoes above 4 m since the transmitter was submerged underneath the hull 1.3 m and the receiver had a further 2—3 m blockaded area.

The reflection factors in Table 3 are calculated from the formula:

$$\frac{I_r}{I_i} = \frac{((\varrho c)_2 - (\varrho c)_1)^2}{((\varrho c)_2 + (\varrho c)_1)^2} \quad \text{(HORTON 1957).}$$

$I_r$ is the acoustic intensity of the reflected wave and $I_i$ the acoustic intensity of the incident wave, $(\varrho c)_1$ is the specific acoustic impedance in the medium on the side containing the sound source and $(\varrho c)_2$ the specific

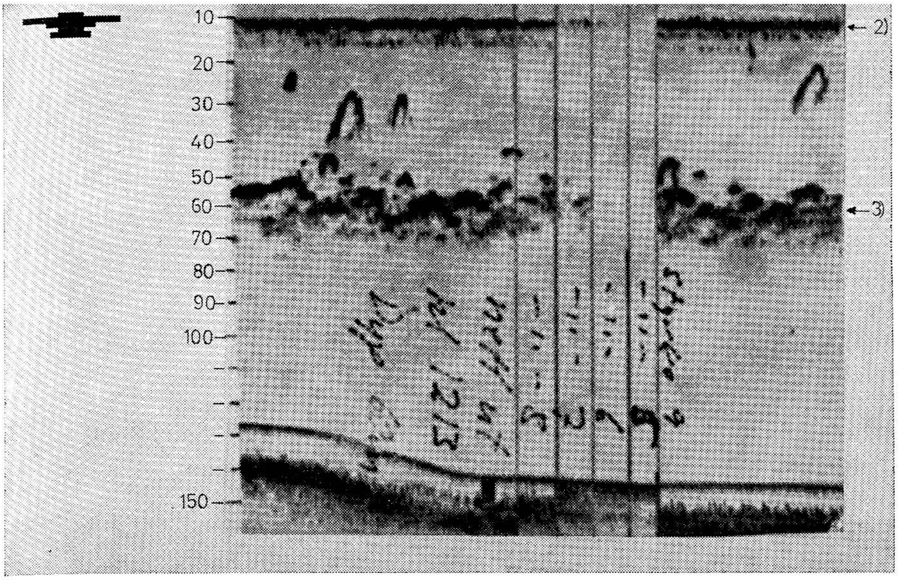


Fig. 2. Example of echo-bands reproduced in Fig. 4. 1) transmitter depth, 2) echo-band, 3) supposed herring and(or) sprat recordings.

acoustic impedance on the other side of the boundary plane. $\varrho$ is the density and c the sound velocity in the respective media. The formula is based on the assumption that normal incident sound waves are reflected from an ideal plane surface separating two ideal fluid media which are incapable of exerting shear stresses. The acoustic pressure of the wave in the second medium must equal the acoustic pressure of the wave in the first medium, both pressures being taken immediately adjacent to the boundary plane. The component of volume velocity normal to the plane with which fluid from one side approaches it, must for an infinitesimally short distance equal the component of volume velocity normal to the plane with which fluid on the other side moves away.

The sound velocities are calculated from the formula given by MIDTTUN (1964):

$$v_{t,s,p} = 1400 + 4.9\,t - 0.044\,t^2 + \left(1.32 - \frac{t}{100}\right) S + 0.018 \left(1 - \frac{t}{100}\right) p$$

$v_{t,s,p}$ is the sound velocity in m/sec. at the temperature t° C, salinity S $^0/_{00}$ and the pressure p in decibar (or metre).

Plankton samples were taken by means of a horizontally towed net. The net had a square opening 1 m by 1 m with the mesh size 1 mm by 1 mm. There was no wire in front of the opening, and the net was kept down by means of a canvas depressor. Towing time was half an hour from the net had reached the wanted depth till heaving was started. The speed of the vessel was 1.5—2.0 knots, implying that the net was towed 1300 to 1800 m in the proper depth. The percentage of plankton caught during lowering and heaving the net was assumed to be very low compared with plankton caught in the proper depth. The towing depth was determined from measuring the length and the angle of the wire. Attempts were made to sample from the strongest echo-band or the strongest part of it. The net was also towed under and over these layers.

Smaller plankton animals were collected with a two inch rotary pump (capacity 100 l/min.) equipped with an armed two inch rubber intake hose. 300 litres of water were filtered trough a fine mesh plankton net (125 $\mu$).

The samples were preserved on bord in 4 % formaldehyde in water, and the organisms were counted in the laboratory, as a rule in subsamples of one or two tenths of the entire sample. Subsamples were obtained by means of the plankton divider described by WIBORG (1951).

The bathythermograms were adjusted to the thermometer readings from the Nansen water bottles. Some samples for salinity determinations were taken from the water bottles, but the majority of the salinity determinations were made on water obtained through the pump. The intake of the hose was mounted between two horizontal circular plates with a diameter of 42 cm and a distance between the plates of 8 cm in order to as far as possible get the water from the measured depth. Comparable samples taken with water bottles and the plankton pump gave a difference in salinity corresponding to about 1 m difference in sampling depth, the water bottle always sampling above the pump. BANSE (1955) similarly found a difference of 1.5 m. It was assumed that the figures here obtained from the pump were correct, and these figures were therefore applied when available.

## RESULTS

Several observations during night cruises showed that artificial light did not affect the echo-bands implying that reflections were not caused by phototactic organisms, the fact that the echo-bands were found in the same depth both day and night indicated the same. In some cases

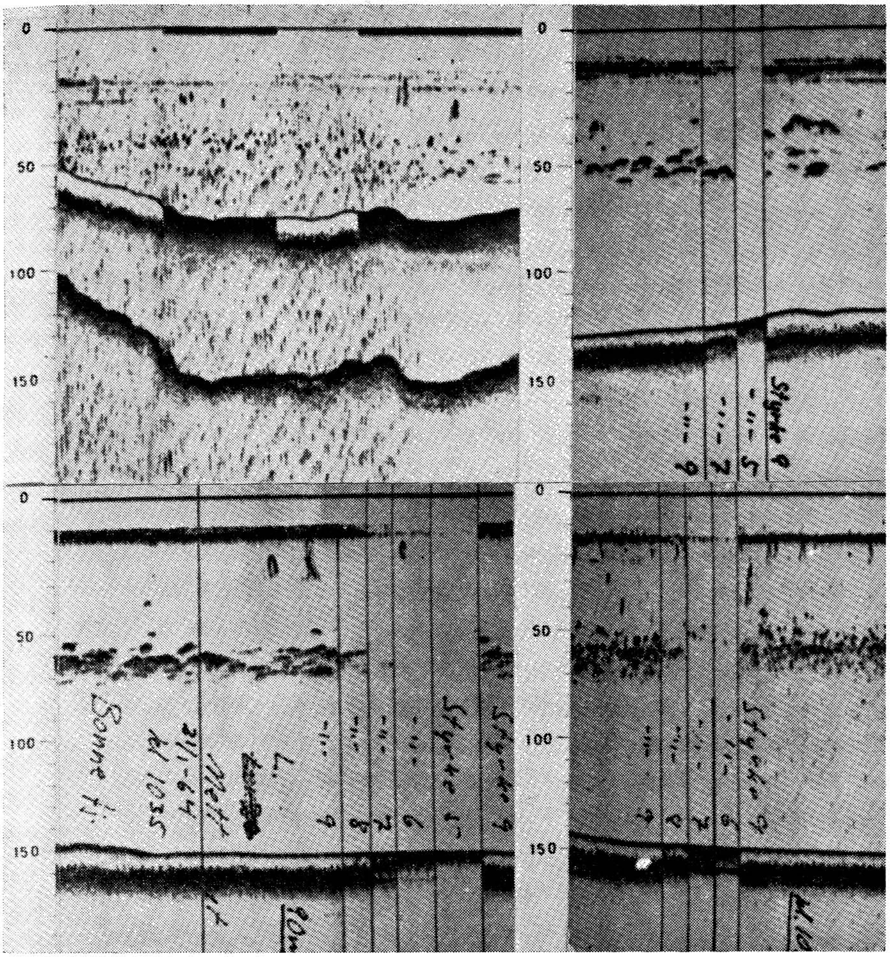


Fig. 3. Different types of echo-bands observed.

only one single echo-band was recorded, in other cases there were several ones, up to five, one just underneath the other (Fig. 3).

The results from the tow net are given in Table 2. All these samples were taken during daylight. The greatest displacement volume of plankton was found below the echo-bands at all the four stations. Correspondingly the numbers of organisms were highest below the layer except at Søndre Steilesand where a great number of fish eggs occurred. Fish eggs, when present, had always the maximum in the scattering layer, *Pleurobrachia pileus* (O. F. Müller) also showed maximum abundance there at the stations 3 and 4, but had a different distribution pattern at the stations 1 and 2 (Table 2). The big jellyfishes *Cyanea capillata* (L.) and

Table 2. Plankton animals caught with the horizontally towed plankton net. Numbers and displacement volumes of the samples above, in, and below the scattering layer.

Station 1. Vippetangen, 26. June 1963, 1130—1700 hours.
Echo-bands at 10 and 12 m, strength 7.

| Depth in m | 5 | 9.5 | 14 |
|---|---|---|---|
| *Rathkea octopunctata* | 0 | 0 | 1 854 |
| *Lensia conoidea* | 0 | 6 | 481 |
| *Aurelia aurita* | 4 | 6 | 2 |
| *Pleurobrachia pileus* | 1 | 9 | 72 |
| Other organisms | 3 | 10 | 267 |
| Total | 8 | 31 | 2 676 |
| Displacement volume ml.[1]) | 1 | 1 | 18 |

Station 2. Bonnefjorden, 1. July. 1963, 1200—1600 hours.
Echo-band at 11 m, strength 9.

| Depth in m | 3.5 | 10 | 20 |
|---|---|---|---|
| *Rathkea octopunctata* | 0 | 0 | 2 180 |
| *Eutonina indicans* | 0 | 66 | 10 |
| *Lensia conoidea* | 5 | 74 | 6 340 |
| *Aurelia aurita* | 6 | 15 | 0 |
| *Cyanea capillata* | 0 | 10 | 0 |
| *Pleurobrachia pileus* | 3 | 61 | many[2]) |
| Fish eggs | 5 | 18 | 10 |
| Other organisms | 29 | 46 | 150 |
| Total | 43 | 272 | 8 680 |
| Displacement volume ml.[1]) | 1 | 43 | 100 |

Station 3. Søndre Steilesand 2. and 3. July 1963, 1000—1500 hours. Two to four echo-bands at 8—16 m, strength 9—5.

| Depth in m | 4 | 11 | 18 |
|---|---|---|---|
| *Eutonina indicans* | 0 | 1 | 73 |
| *Lensia conoidea* | 0 | 1 | 3 |
| *Aurelia aurita* | 2 | 1 | 0 |
| *Cyanea capillata* | 1 | 4 | 6 |
| *Pleurobrachia pileus* | 0 | 36 | 25 |
| Fish eggs | 3 | 316 | 179 |
| Other organisms | 11 | 70 | 104 |
| Total | 15 | 393 | 365 |
| Displacement volume ml.[1]) | 1 | 4 | 64 |

cont.

Table 2 cont.

Station 4. Bonnefjorden, 21. Jan. 1964, 1000 -1400 hours.
One echo-band at 8 - 14 m, maximum strength 5
at 11 m. Mesh size in this case 10 mm.

| Depth in m | 5 | 10 | 35 |
|---|---|---|---|
| *Lensia conoidea* | 0 | 17 | 236 |
| *Pleurobrachia pileus* | 0 | 23 | 1 |
| *Sagitta elegans* | 0 | 0 | 4 |
| Other organisms | 0 | 3 | 11 |
| Total | 0 | 43 | 252 |
| Displacement volume ml.[1]) | 0 | 2 | 14 |

[1]) In the displacement volume *A. aurita* and *C. capillata* are not included.
[2]) A great number of *P. pileus* disintegrated because of unsuited formalin concentration.

*Aurelia aurita* (L.) also sometimes occurred in greater numbers in the echo-band layer. Large jellyfishes may give echo-traces, but not with the appearance of an echo-band (BEYER, verbal information). The greatest concentrations of the other species were as a rule found below the level of the echo-band. Macroplankters thus seem not to present a probable source of sound scattering in the present cases.

Fig. 4 shows the distribution of smaller plankton animals taken with the pump. It appears that the observed maxima correspond fairly well with the echo-bands at the stations 6, 7 and 10. The total number of smaller plankton at the other stations have either no distinct maxima or the maxima are not in the depths of the echo-bands.

Regarding the single species, the larvae of the polychaet *Polydora ciliata* (JOHNSTON) had a very distinct maximum in the scattering layers both at St. 6 and 7, but at St. 8, taken at night, the maximum was clearly above the layer. Some other species had their maxima in the scattering layer, but never in such amounts that they could explain the echo-bands.

If we compare the echo-bands with the corresponding hydrographic condition, the echo-bands were in most cases found at depths where great gradients in salinity and(or) temperature occurred (Fig. 4).

There is no good correlation between the theoretic calculated echoes and the strengths at which they are recorded (Table 3), but the two lowest calculated echoes had corresponding echo-bands which only were recorded at strength 10 and 9.

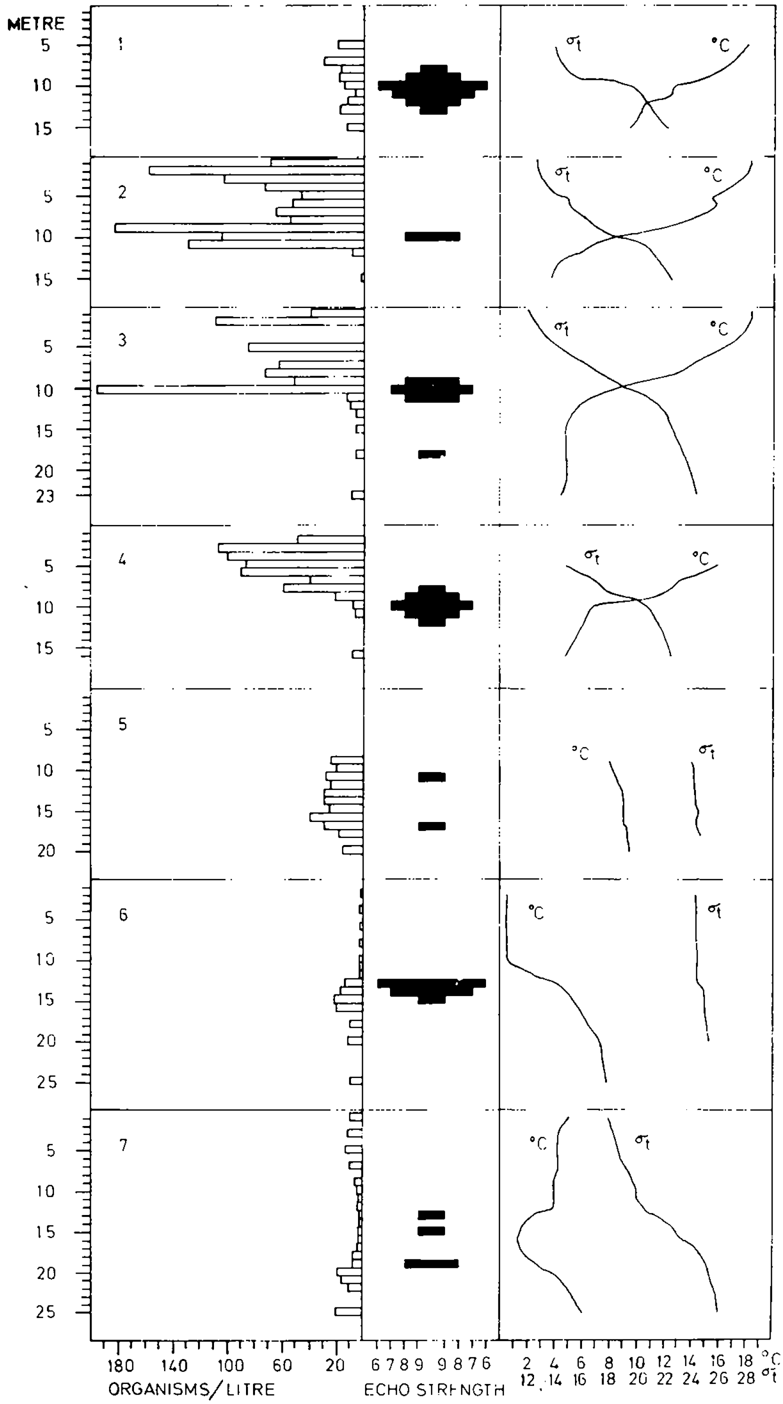
METRE
1
2
3
4
5
6
7
σt
°C
180 140 100 60 20
ORGANISMS/LITRE
6 7 8 9 9 8 7 6
ECHO STRENGTH
2 4 6 8 10 12 14 16 18 °C
12 14 16 18 20 22 24 26 28 σt

Table 3. Strength and properties of echoes from the scattering layers where water was sampled with one metre depth intervals. The calculations are made from two successive observations in the layer where the largest difference was recorded.

| St | Date | Echo strength | Depth | $t_2$—$t_1$ | $\sigma t_2$— $\sigma t_1$ | $(\varrho c)_2$— $(\varrho c)_1$ | Geometric spreading loss dB | Reflection factor dB | Theoretic echo received. dB// 1 $\mu$ bar |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 13 08 63 | 6 | 8—12 | —2.00 | 2.88 | 1.17 | 36 | —67 | 2 |
| 6 | 14 08 63 | 8 | 10 | —3.00 | 1.71 | —7.09 | 36 | —52 | 17 |
| 7 | 15 08 63 | 7 | 9—11 | —2.25 | 0.95 | —5.51 | 36 | —55 | 14 |
| 8 | 16 08 63 | 7 | 8—12 | —4.25 | 1.08 | —14.37 | 36 | —47 | 22 |
| 9 | 05 12 63 | 9 | 10 | 0.25 | 0.32 | 2.10 | 36 | —63 | 6 |
| 9 | | 9 | 17—18 | 0.00 | 0.20 | 0.64 | 48 | —74 | —17 |
| 10 | 28 01 64 | 6 | 13—15 | 1.50 | 0.39 | 8.18 | 43 | —51 | 11 |
| 11 | 22 04 64 | 9 | 13 | —1.75 | 1.08 | —4.56 | 41 | —57 | 7 |
| 11 | | 9 | 15 | —0.25 | 0.40 | 0.18 | 45 | —84 | —24 |
| 11 | | 8 | 19 | 0.75 | 0.27 | 4.23 | 49 | —57 | — 1 |

## DISCUSSION AND CONCLUSION

If only the geometric spreading of the sound wave is considered as transmission loss, the theoretical calculated echoes should lie between 22 and — 24 dB// 1 $\mu$ bar, implying that all calculated echoes have higher intensity than minimum recordable signal for the present echo sounder, — 40 dB// 1 $\mu$ bar. In fact most of the echo-bands should have been recorded with far less amplification than they were. However, the ideal conditions required to give correct results with the formula for reflection factors are surely not fullfilled. The calculations are made from observations taken with one metre interval, and the difference between the two observations are considered to take place somewhere within this metre without having any vertical dimention. The vertical distributions of some echo-bands show that this is not the case, the sound must have been reflected from more than one plane. Hence the reflected sound waves are surely of lower intensity than calculated. However,

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Fig. 4. Total number of plankton taken in the pump and the corresponding echo-bands, temperature and density. 1) station 5, Aug. 13, 1963, 1130—1600 hours, 2) station 6, Aug. 14, 1963, 1000—1500 hours, 3) station 7, Aug. 15, 1963, 1000—1600 hours, 4) station 8, Aug. 16—17, 1963, 2100—0030 hours (dark), 5) station 9, Dec. 5, 1963, 1330—1600 hours, 6) station 10, Jan. 28, 1964, 1000—1500 hours, 7) station 11, Apr. 22, 1964, 1030—1600 hours.

there is room for relative great reductions till the minimum recordable signal for the SIMRAD echosounder is reached. More exact conclusions will require both better acoustical equipment and more accurate hydrographical measurements.

The echograms are affected by both the situation in the sea and the electronics of the echosounder. It is, therefore, difficult to compare results obtained from different echosounders. BARRY, BARRACLOUGH and HERLINVEAUX (1962)got different recordings of the same scattering layer with a 12 Kc/sec. and a 30 Kc/sec. echosounder.

NORTHCOTE (1964) recorded 9—12 mm long Chaobourus (gnat) larvae when using a 200 Kc/sec. echosounder.

From the present investigation it is concluded that zooplankton is not responsible for the echobands, similar to what LENZ (1965) found using a 30 Kc/sec. echosounder. The strong echobands recorded during the winter, when the water was clear and contained comparatively little phytoplankton and detritus also support LENZ's findings that the phytoplankton and detritus do not cause echo-bands. The material indicates, however, that the physical border between two water masses might be the real cause of the echo-bands in the Oslofjord.

## SUMMARY

1. Using high amplification on the 38.5 Kc/sec. echosounder echoes from the depth of the discontinuity layer in the inner Oslofjord were mostly observable.
2. The distribution of zooplankton was analysed from samples taken with a plankton pump and tow nets.
3. The vertical distribution of zooplankton, biomass, total number and number of the different species demostrated that such organisms were not responsible for the echoes.
4. Calculations made from hydrographic data are the bases for assuming that these special echo traces are caused by the border layer between two water masses.

## ACKNOWLEDGMENTS

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