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CERATOSCOPELUS MADERENSIS: PECULIAR SOUND-SCATTERING LAYER IDENTIFIED WITH THIS MYCTOPHID FISH

by

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with supplementary notes
by Richard H. Backus

TECHNICAL REPORT

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Approved for Distribution ________________

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ABSTRACT

A sound-scattering layer, composed of discrete hyperbolic echo-sequences and apparently restricted to the Slope Water region of the western North Atlantic, has been identified from the Deep Submergence Research Vehicle ALVIN with schools of the myctophid fish Ceratoscopelus maderensis. By diving into the layer and using ALVIN's echo-ranging sonar, we approached and visually identified the sound scatterers. The number of echo sequences observed with the surface echo-sounder (1/23.76 x 10^5 cubic meters of water) checked roughly with the number of sonar targets observed from the submarine (1/7.45 x 10^5 cubic meters). The fish schools appeared to be 5 to 10 meters thick, 10 to 100 meters in diameter, and on centers 100 to 200 meters apart. Density within schools was estimated at 10 to 15 fish per cubic meter.

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Ceratoscopelus maderensis: Peculiar Sound-Scattering Layer Identified with This Myctophid Fish

Abstract. *A sound-scattering layer, composed of discrete hyperbolic echo-sequences and apparently restricted to the Slope Water region of the western North Atlantic, has been identified from the Deep Submergence Research Vehicle* Alvin *with schools of the myctophid fish* Ceratoscopelus maderensis. *By diving into the layer and using* Alvin's *echo-ranging sonar, we approached and visually identified the sound scatterers. The number of echo sequences observed with the surface echo-sounder (1/23.76 × 10⁵ cubic meters of water) checked roughly with the number of sonar targets observed from the submarine (1/7.45 × 10⁵ cubic meters). The fish schools appeared to be 5 to 10 meters thick, 10 to 100 meters in diameter, and on centers 100 to 200 meters apart. Density within schools was estimated at 10 to 15 fish per cubic meter.*

A peculiar sound-scattering layer, apparently restricted to the Slope Water region off northeastern United States and eastern Canada (*1*) (Fig. 1), differs from typical deep scattering layers of oceanic echo-sounder records in the structure of the echo-sequences. Successive trains of echoes do not form the usual homogeneous band of reverberation such as that which results from the receipt of sound scattered by numerous objects of low target strength. Instead, they form discrete hyperbolic echo-sequences such as those which result from the receipt of sound scattered by a few objects of high target strength. The layer makes a diurnal vertical migration. Midday depth to the shallowest echo sequences on the echo-sounder record is commonly about 330 m. During the evening ascent, the layer has been traced to depths as shallow as 20 m.

The layer has been observed in all parts of the Slope Water, but is irregularly developed. A similar and possibly related sound-scattering feature has been occasionally observed east of Newfoundland. At some times and places, the layer in the Slope Water has been continuously recorded for tens of kilometers; at others, only in small patches or not at all. An examination of the broadband sound-scattering properties of the layer (*2*) during an evening ascent showed that the layer best scatters sound at progressively lower frequencies as the layer shoals. It best scattered sound at about 12 khz when near its midday depth (accounting for the high intensity of the echo-sequences on 12-khz echo-sounder records during daytime); at 30 m the layer best scattered sound at about 3 khz.

The layer was present at 39°48'N, 70°33'W, in a depth of about 1800 m

south of Woods Hole, when we began a series of exploratory dives in the mesopelagial there with DSRV *Alvin* on 3 October 1967. We dived to near the bottom of the layer, as shown by the echo-sounders of *Alvin's* tender, *Lulu*, and the support ship, R.V. *Gosnold*. There, *Alvin's* echo-ranging sonar (*3*) showed a number of sound-scattering groups nearby (Fig. 2). Turning

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out *Alvin's* lights, we chose one such group and approached it. When the sonar indicated "range zero," we turned on the lights and found we lay in the middle of a dense school of *Ceratoscopelus maderensis* (Lowe) 1839 (*4*) (Figs. 3 and 4). Driving through the school, we captured several liters of fish with a net that had been rigged on the front of the submarine.

Except for the collection of specimens, this procedure was repeated about 25 times in the course of eight 3- to 4-hour dives during 3 to 6 October, and always gave the same result. Each time that a target was chosen from *Alvin*'s sonarscope and approached, a *Ceratoscopelus* school was viewed. The vertical distribution of the sound-scattering groups seen by the surface echo-sounder corresponded closely with the vertical distribution of those seen from the submarine. Although it seems evident that the sonar targets seen by both are the *Ceratoscopelus* schools, we have attempted to check this by comparing the number of targets per unit volume of water registered by the two systems.

Assuming a 15° vertical beam width, we counted targets on photographs of *Alvin*'s sonarscope at times when the whole sonar beam was within the layer. Using six sonarscope photographs made on three different days and at various depths, we calculated an average water volume per target of 7.45×10^5 m^3.

Using echo-sounder records made by *Lulu* (Gifft Depth Recorder) and *Gosnold* (Litton Precision Depth Recorder), we noted the number of hyperbolic echo-sequences that intersected a single sweep of the echo-sounder stylus. We computed the radial thickness of the figure containing the targets by taking the minimum soundings to the shallowest and deepest targets counted, even though these soundings generally did not occur at the instant of the count. A beam width of 60° was used (*5*). Thirty calculations gave an average water volume per target of 23.76×10^5 m^3. Undoubtedly, the

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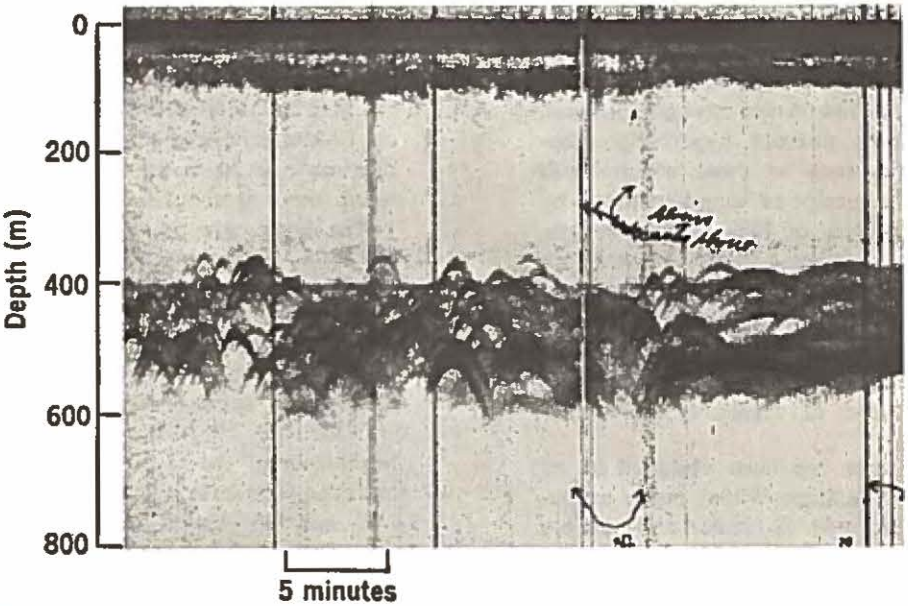

Fig. 1. Portion of 12-khz echo-sounder record made from R.V. *Gosnold* with Litton PDR near 39°48'N, 70°33'W late in the morning of 6 October 1967.

Fig. 2. Photograph of *Alvin's* sonarscope [500-yard scale (457-m)] made near 39°48'N, 70°33'W late in the afternoon of 5 October 1967 at a depth of about 300 m.

Fig. 3. Photograph of *Ceratoscopelus maderensis* school made from *Alvin* near 39°48'N, 70°33'W on the morning of 3 October 1967 at a depth of about 600 m.

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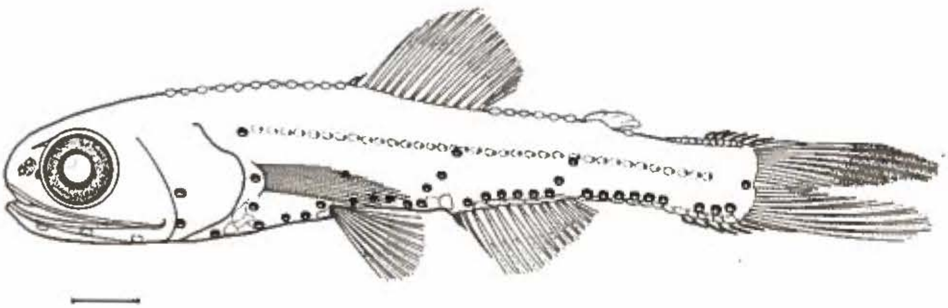

Fig. 4. *Ceratoscopelus maderensis*, a 54-mm male collected by *Alvin* on 3 October 1967 near 39°48'N, 70°33'W at a depth of about 600 m. [Drawing by Martha Howbert].

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continuously recording surface echo-sounder gives a better estimate of water volume per target than the instantaneous sonarscope photos do. There is no chance of confusing signal with noise in the first, but this is unavoidable in the latter. This fact probably accounts for the smaller average water volume per target computed from the sonarscope photos.

When *Alvin* approached a *Ceratoscopelus* school and turned on her lights, the fish reacted in a characteristic way, swimming vigorously for a few strokes, coasting for about an equal period, and, alternating thus, rapidly moving down and away from the submarine. Schools deep in the layer appeared to react more slowly and less vigorously to the submarine than shallower schools. The submarine's lights appeared to be her most disturbing element. Using flashlights, we made some observations in schools with the submarine's lights out. These and observations made immediately after the submarine's lights were turned on showed that the fish in the schools were at rest. They hung motionlessly in the water, sometimes horizontally, but often a little obliquely. They appeared to be neutrally buoyant. They were pointed in random directions, unoriented with respect to one another. Although this species is well fitted with light organs, no bioluminescence was observed save from specimens in the net, which emitted blue flashes from an undetermined source. The dusky dorsal lobe of the caudal fin was prominent and is a useful field mark. There was very little variation in the size of fish in the schools. The 774 specimens collected by *Alvin* from 3 to 6 October and measured to the nearest millimeter had a mean length of 62.4 mm, a standard deviation of 2.9 mm, and a range of 52 to 73 mm.

We estimated the density of fish in little-disturbed schools to be from 10 to 15 per cubic meter of water. There was considerable variation in the diameter of schools. We tended to pick large sonar targets for examination and approached some schools whose diameter was as great as 100 m. A common diameter of the targets displayed on the sonarscope was about 25 m. Some of the targets seen may not have been *Ceratoscopelus* schools, of course, although all targets approached were, including a few deliberately chosen for their small diameter (about 10 m). We could make neither visual nor sonar estimates from *Alvin* of the vertical dimension of schools. Surface echo-sounder observations indicate that they were commonly from 5 to 10 m thick. Thus, the schools appeared to be disk-shaped.

It was also difficult to estimate the distance between schools. We often noted upon seeking another target, having made observations of one, that the nearest was about 200 m away. However, some observations indicated that the lighted submarine was repellent to the schools out to about this radius. Furthermore, a school as near to the submarine as 100 m need only have been 25 m deeper or shallower than the submarine to have been outside the purview of the sonar. Because of the nature of the sonar beam, the separations shown in the sonarscope photos cannot be taken at face value. Perhaps the best estimates of the mean distance between schools are the ones derivable from the water volumes per school estimated above. A sphere whose volume is 23.76×10^5 m^3 has a diameter of 166 m; one whose volume is 7.45×10^5 m^3, a diameter of 112 m. Other estimates of school separation do not violently disagree with these.

Why do these aggregations of *Ceratoscopelus maderensis* form? No feeding activity was observed, nor did there seem to be any concentration of food organisms within the schools. No spawning activity was observed; the gonads of 71 specimens collected by *Alvin* were examined and found to be little developed. The ratio of males to females in these 71 fish was about 3.4 to 1. It has been suggested that schooling, in some fishes at least, minimizes predation; individuals are less often found by predators when aggregated than when dispersed (*6*). Perhaps it is for this reason that *C. maderensis* schools. We observed no predators feeding in the schools, although squids (*Loligo* or *Ommastrephes* sp.) on a few occasions seized individuals close to the submarine's lights.

In the course of a dozen years of intensive exploration with the echo-sounder in most parts of the oceanic North Atlantic, we have observed deep scattering layers composed of hyperbolic echo-sequences only in the Slope Water region and in the waters east of Newfoundland (*7*). The principal question that arises from the identification of *Ceratoscopelus maderensis* with such a deep-scattering layer, then, is this: Why are such layers so restricted geographically? Not only does *C. maderensis* inhabit a wide range in the northern North Atlantic, but some, at least, of the dozens of other species in the ubiquitous oceanic family Myctophidae (including the abundant, widespread *Ceratoscopelus townsendi*) might well be expected to cause similar acoustic effects in many or all parts of the world's deep ocean.

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References and Notes

1. This region extends from the edge of the continental shelf to the northern edge of the Gulf Stream between Cape Hatteras and the tail of the Grand Banks. The Slope Water has been defined and described by C. O'D. Iselin, *Pap. Phys. Oceanogr. Meteorol.* 4, 12 (1936).
2. Following in general the methods described by J. B. Hersey, R. H. Backus, J. D. Hellwig, *Deep-Sea Res.* 8, 196 (1962). The observations were made at 38°45'N, 68°58'W on 15 May 1961.
3. Straza Industries Model 500 Continuous Transmitting Frequency Modulated Scanning and Navigation Sonar, which operates over the band from 87 to 72 khz. The horizontal beam width is 2° (between half-power points), and the vertical beam width is 15°. The sonar sweeps through a 270° sector centered on the fore and aft axis of the submarine and is not trainable in the vertical plane.

4. *Ceratoscopelus maderensis* has a well-developed, gas-filled swimbladder. In a 61.1-mm male examined by us, the relaxed organ measured 5.7 by 1.9 by 1.3 mm. The structure of the swimbladder in the congener *C. townsendi* has been described by N. B. Marshall [*Discovery Rep.* 31, 41 (1960)].
5. This is not the value ordinarily assumed for the transducer used, the UQN-1b, whose beam width between half-power points is 30°, but was calculated from our records from the minimum and maximum soundings recorded from single hyperbolic echo-sequences.
6. C. M. Breder, Jr., *Zoologica (N.Y.)* 52, 25 (1967).
7. To judge from the literature, such layers are extremely rare for the world ocean as a whole. One has been reported from off Lower California by E. G. Barham and I. E. Davies, *Naval Electron. Lab. Rep.* 1368, 9 (1966) (Confidential). This layer has a median midday depth of about 200 m and has been associated with the Pacific hake, *Merluccius productus*. Another such sound-scattering feature has been observed off the coast of South Arabia, *International Indian Ocean Expedition, Cruise Report, Cruise 1 RRS Discovery* (Royal Society, London, 1963), p. 16. No organism was associated with this layer, whose midday depth was about 300 m.
8. This paper is Contribution No. 2061 from the Woods Hole Oceanographic Institution. Supported in part by contracts Nonr-3484(00) and Nonr-4029(00) and by NSF grant GB-4431. We thank the many shipmates who have helped us, particularly *Alvin* pilots W. O. Rainnie, M. J. McCamis, and E. L. Bland, Jr.

8 January 1968; revised 14 February 1968

SUPPLEMENTARY NOTES

The scattering layer described in the enclosed paper is the one that has been known at WHOI for some years as "Alexander's Acres". The layer is characterized not only by the teepee-like structure of the echo sequences, but also by various behavioral properties such as the depths occupied by day and by night. Scattering layers composed of teepee-like echo sequences are rare in the deep ocean, but are common over the continental shelves. None of the shallow-water layers should be confused with Alexander's Acres. The fish responsible for the latter, Ceratoscopelus maderensis, is never found in water shallower than 100 or 200 fathoms except by accident.

Not too much is known yet about the acoustic properties of Alexander's Acres. However, a set of observations using explosions as sound sources showed that the layer when at a midday depth of about 150 fathoms scattered sound best at a frequency near 12 kHz. When the layer moved up close to the surface at night, the frequency at which it best scattered sound dropped to near 3 kHz. Because 3 kHz is close to the operating frequency of modern high-power sonars and because the fish causing the layer can be very abundant, it is easy to see that when this layer is present night-time operation may well be difficult.

Alexander's Acres has been observed with certainty only in the Slope Water region of the western North Atlantic (densely stippled area of Fig. A). On the other hand, the fish responsible for the layer is known to have a much wider distribution (cross-hatched area of Fig. A). Why the layer is not to be found wherever the fish is to be found is an intriguing question, but the several possible answers need not be explored here. A sound-scattering feature similar if not identical with Alexander's Acres has been seen now and again on echo-sounder records made between Newfoundland and Ireland (lightly stippled area of Fig. A), and this may also be caused by Ceratoscopelus.

Naval vessels operating in the Slope Water region or in the wide area between Newfoundland and Ireland can determine whether such layers are present by operating their UQN or other deep water echo-sounder during

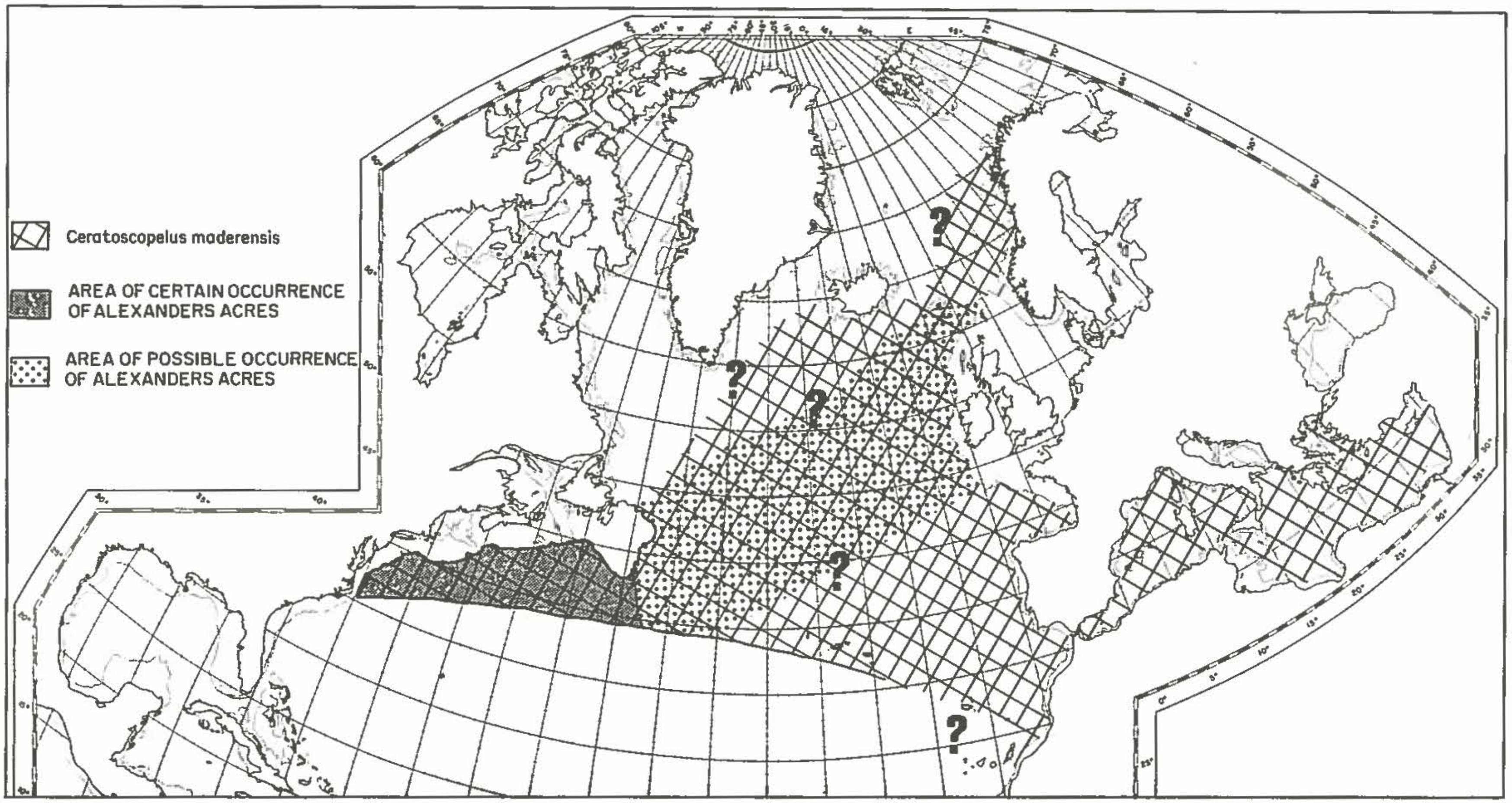

Fig. A. Distribution of Alexander's Acres and of the fish responsible for the layer, Ceratoscopelus maderensis. The wavy margins and question marks indicate where the boundaries are most open to question.

daylight hours[1]. (During the night the layer is so close to the surface as to be indistinguishable from other near-surface sound-scattering.) One might, then, on the basis of daytime echo-sounder observations better choose the area for a certain operation on the basis of the presence or absence of the layer. At the very least the presence of the layer during hours of daylight would tell the operator that during the coming night active sonar operations at frequencies in the neighborhood of 3 kHz will be more than normally difficult. (It must be remembered, of course, that the layer can be very sporadically developed. In such a case, sonar conditions can change drastically with a relatively small change in ship's position.)

Considerable variation in the density of the layer has been observed. At times as many as 15 or 20 schools may be within the cone of the echo-sounder all returning echoes during a single sweep of the recorder. At other times only one or two schools are present. Obviously reverberation levels will be much higher in the first case.

This report can be summarized as follows:

1) Nighttime reverberation levels in the band around 3 kcps will be considerably higher than usual when the scattering layer called Alexander's Acres is present.

2) This layer is composed of teepee-like echo sequences, generally has a midday depth to the top of the layer of 150-200 fathoms, and moves up to near the sea surface at night.

3) The layer occurs in the Slope Water region and possibly in the waters between Newfoundland and Ireland, but is sporadically developed.

4) Whenever it is useful to anticipate the extra nighttime increase in volume reverberation, a vessel can determine the presence or absence of the layer by operating its echo-sounder during daylight hours.

[1] Operators using the echo-sounder for examining the midwater sound scattering should remember to operate the sounder at a much higher gain than is necessary simply to make a good recording of the bottom.

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CERATOSCOPELUS MADERENSIS: PECULIAR SOUND-SCATTERING LAYER IDENTIFIED WITH THIS MYCTOPHID FISH by R.H. Backus, J.E. Craddock, R.L. Haedrich, D.L. Shores, J.M. Teal, A. S. Wing, G.W. Mead and W.D. Clarke. Volume 160. Pp. 991-993. September 1968. Contract Nonr-3484(00), NR 260-107 and Nonr-4029(00), NR 260-101. NSF Grant GB-4431.

A sound-scattering layer, composed of discrete hyperbolic echo-sequences and apparently restricted to the Slope Water region of the western North Atlantic, has been identified from the Deep Submergence Research Vehicle ALVIN with schools of the myctophid fish Ceratoscopelus maderensis. By diving into the layer and using ALVIN's echo-ranging sonar, we approached and visually identified the sound scatterers. The number of echo sequences observed with the surface echo-sounder (1/23.76 x 10^5 cubic meters of water) checked roughly with the number of sonar targets observed from the submarine (1/7.45 x 10^5 cubic meters). The fish schools appeared to be 5 to 10 meters thick, 10 to 100 meters in diameter, and on centers 100 to 200 meters apart. Density within schools was estimated at 10 to 15 fish per cubic meter.

1. Sound-scattering
2. Myctophid Fish
3. Ceratoscopelus maderensis

I. Backus, R. H. V. Teal, J. M.
II. Craddock, J. E. VI. Wing, A. S.
III. Haedrich, R. L. VII. Mead, G. W.
IV. Shores, D. L. VIII. Clarke, W. D.

IX. Nonr-3484(00), NR 260-107
X. Nonr-4029(00), NR 260-101
XI. GB-4431

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