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INTRODUCTION TO SONAR SCATTERING LAYERS. (U)

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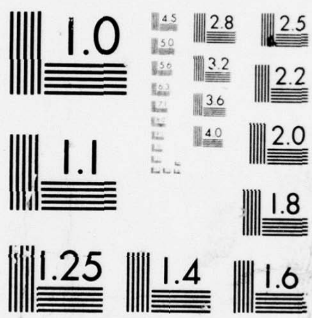

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U. S. Navy Underwater Sound Laboratory
Fort Trumbull, New London, Connecticut

(6) INTRODUCTION TO SONAR SCATTERING LAYERS.

by

(10) Harold J./Doebler

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FOREWORD

A dictionary definition of "scattering" uses such synonyms as "reflecting", "deflecting", and "wasting" to give the meaning. Indeed, these words collectively describe what happens to sonar energy transmitted through the ocean medium. Individual scattering agents can be traced on ordinary sonic depth finder paper chart recordings. Stratified congregations of scattering agents are shown as a reflecting layer. (Figures A and B)*. Scattering agents have been found everywhere in the world's oceans investigated, and have been frequently found in scattering layers. Hersey and Backus locate[1] two 12 kc/s scattering layers in the Western North Atlantic: (a) a layer 240 feet thick at an average daytime depth of 800 feet; and (b) a layer 400 feet thick at an average daytime depth of 1600 feet (where the water depth is greater than 1000 fathoms). These layers migrate toward the surface at sunset and return to depth at sunrise.

The sonic depth finder has been a useful tool for researchers studying scattering layers, but analysis of observations does not fully describe the sonar scattering problem since the depth finder's energy is transmitted predominately in the vertical direction, and the ASW sonar energy is propagated in a horizontal plane. What happens in sonar scattering can be seen from a simple visual model. Consider a lighthouse flashing a beam of light through a flock of sea gulls. Some light is reflected back or out of the beam by the birds and therefore does not reach the horizon. There are, thus, two distinct sonar problems produced by the scattering effect: (a) the acoustic energy reflected back into the receiver; and (b) the acoustic energy diverted from the sound beam. This paper will discuss the effects and nature of the scattering layers as they apply to echo ranging ASW sonar.

*Asymmetrical shapes in Figure B resulted from the echo sounder being oriented slightly out of the vertical. Personal communication from R. H. Backus.

[1] Super-scripts refer to listings in bibliography

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SONAR SCATTERING PROBLEM

Sonar Review

Sound is more effectively transmitted than light (or any other form of useful energy) through water. Systems using acoustic energy have been developed and continue to be developed, therefore, to provide for man's needs in navigation and underwater detection at sea. Near the end of the fifteenth century Leonardo da Vinci[2] placed a tube into the sea and noted that ships could be heard at great distances. Perhaps this was the first passive (listening) sonar receiver.

Active sonar differs from passive sonar in that a pulse of acoustic energy is put into the water before listening to the receiver. Energy is reflected by acoustic impedance discontinuities between the water medium and the particulate matter suspended in it. A submarine is an excellent reflector of acoustic energy, for example, because its steel hull and confined air constitute a strong acoustic impedance interface with sea water. Other denizens of the sea are also fairly good reflectors of acoustic energy.

Only a very small portion of the acoustic energy leaving the transducer reaches a particular target and only a very small portion of the reflected energy arrives back at the receiver. This reduction results from the cylindrical or spherical spreading[2] out of the acoustic energy from its source. The ratio between the outgoing pulse energy and the received echo energy is very great, perhaps more than a million to one. Other sounds, therefore, need not be very great in magnitude to interfere with the reception of the target echo.

There are three types of noise in the sonar receiver: (a) self noise (including system noise), (b) ambient noise, and (c) reverberation as explained by Horton.[2] Self noise originates with the ship and ambient noise originates in the ocean. Reverberation is the sound reflected from targets, boundary interfaces and scatterers within the ocean volume. Any of the three types of noise can be the limiting noise under actual conditions but only volume reverberation is being considered here.

The sonar figure of merit is a quantitative measure of sonar performance useful for comparing sonar systems. Numerically it is the difference (in decibels) in transmitted level and the target level that can be detected under specified conditions. The effects of scatterers on sonar figure of merit appear to become more serious as sonar ranges improve. Scattering agents reduce the figure of merit by scattering the transmitted energy out of the sonar beam and by reflecting energy into the receiver in competition with the target signal. These effects will be discussed separately.

Scattering from Beam

The loss of acoustic intensity from the sound beam by scattering has been considered to be a small amount by researchers. The writer raises the point, however, that perhaps the loss becomes significant over very long ranges. Let us consider the total volume of water insonified by a hypothetical search light sonar transmitting into a 9 degree cone of the sea. Nearly six million cubic yards of sea water are insonified in the first 1000 yards of pulse travel. If, as an order of magnitude, an average of one scatterer is encountered per 13,000 cubic yards of water outside the scattering layer as suggested by Kanwisher[3], the cone will contain some 460 scattering agents. Kanwisher counted the scatterers outside the scattering layer. He compared his count from sonic depth finder traces with net hauls and the work of Raitt, Backus and others, and obtained good correlation. It was not possible for him to use this technique to count the scatterers within the layer because the density of agents was so high that the individual echoes merged. The concentration within the layers may be as much as ten to fifteen times greater*, however.

At a range of 10,000 yards, 460,000 scattering agents would be insonified. It becomes increasingly inaccurate with range to calculate even an order of magnitude number because sonar beams are always refracted to some degree and scattering agents are concentrated into layers so that the position of the layers within the beam cross section is very important. Notice though, that even when assuming a seemingly sparse population of scattering agents a very great number of scatterers will be encountered by an acoustic pulse of energy in long path echo ranging.

Reverberation Level

The reverberation level will vary as a function of the operational parameters of the sonar such as frequency, pulse length, beam width, propagation path and path length. Characteristically, the reverberation level is observed to decay rapidly after transmission.

The scattering layers do not scatter all frequencies with the same effectiveness. Hersey (et al), working in the Atlantic, used a small explosive grenade to produce a high intensity broad band acoustic pulse.[4] Reverberation was received on a directional hydrophone, recorded, and then analyzed to determine the frequency distribution. The frequency range of the instrumentation was 100 c/s to 32 kc/s. Similar work in the Pacific using a spark as a broad band high intensity source was done by Anderson[5]. Intensity peaks in the frequency spectrum were found 10 db** above background levels with different frequencies peaking at

*Personal communication from R. H. Backus

**Personal communication from J. B. Hersey different depths within the scattering layers. Each depth exhibited peak scattering at only one frequency at a given time. The peak frequency was normally found to decrease with decreasing depth during migration in the manner of a migrating air bubble. A peak scattering frequency at 11 kc/s was observed to shift to 6 kc/s as the layer migrated from 1000 to 300 feet at sunset, for example. (Figure C). The reverse migration occurred at sunrise. Note however, that not all frequencies or layers migrate in the same way. Figure D shows the frequency range of one of the layers. The figure is not a reliable indication of the extent of depth* because the receiving hydrophone used is not directional at the low frequency illustrated.

The choice of pulse length, beam width and propagation path determine the volume of water (and thus the number of scatterers) being insonified at a particular instant. Using the data from the same hypothetical search light sonar, a sound velocity of 1600 yds. and a pulse length of 10 milliseconds, - a quarter of a million cubic yards and perhaps 20 scattering agents (as an order of magnitude) will be within the pulse at the instant the acoustic pulse reaches 1000 yards. At a range of 10,000 yards, 20,000 scattering agents are simultaneously insonified. Notice that as the range capability of sonar is increased, the number of scatterers insonified in the plane of the target is greatly increased. These scatterers return an echo at the same time as the target and so tend to mask the target echo with volume reverberation.

THE SCATTERER

The Case Against the Marine Animals

The depths of the principal scattering layers have been described as a focal plane of a complicated community of preying and preyed-upon animals by Hersey and Backus.[1] Although the scattering layers have been energetically studied for some twenty years, the evidence against marine animals would be described in a court of law as largely circumstantial. The cautious verdict of researchers, however, has been that the marine animals do constitute the important scattering agents within the ocean volume.

Four requirements a marine animal must fulfill to be considered part of a scattering layer have been given by N. B. Marshall:[6]

a. The organism must be widely distributed;

b. The organism must inhabit the appropriate layer depths in concentration;

*Personal communication from R. H. Backus

c. The organism must participate in the appropriate diurnal vertical migration; and

d. The organisms must reflect sound sufficiently to produce the observed reverberation levels.

Let us consider the evidence briefly, point by point.

The ocean's volume, indeed, abounds with zoo-plankton, fish, swimming invertebrates, and mammals in great numbers and varieties. Samples of the marine fauna can be found widely distributed throughout the length, breadth and depth of the oceans.

Careful net hauls by many researchers have shown good correlation between scattering densities and catch densities. The difficulties however, which exist in making net hauls should be mentioned. Great skill and attention must be taken in the hauling of the nets at exactly the desired depths and in the prevention of contamination from shallower depths during the streaming and recovery process. Nets which are efficient for capturing small organisms are not as effective for large organisms, and the inverse also applies. Some organisms are better able to avoid the nets than others. Net hauls are, therefore, not a completely reliable measure of the relative abundance of species at specified depths.

It is appropriate to recall the success of the world's fishing fleets, however, in searching for their catch with the use of the fathometer. The pioneering work of Captain Ronald Balls, a British fisherman, has been recorded.[1] As early as 1930, he installed an echo sounder in his herring drifter and set his nets on the basis of mid-depth echoes which he correctly attributed to the herring schools.

Diurnal vertical migration of marine organisms has been extensively studied and been found to be the normal behavior of many organisms. The reasons for the daily migrations of several hundred to several thousand body lengths is discussed later but may not yet be completely understood to the satisfaction of all observers. Moore[7] reports that euphausids (zoo-plankton) follow isoillumination levels up and down. Hersey and Backus[1] correlated the location of a scattering layer with the concentration of mytophid fish (Figure E), for example. A great many more examples as well could be selected. The layer migration rates of 15 to 25 feet per minute are within the abilities of many of the organisms studied.

What mechanism do marine animals have for scattering acoustic energy? There are actually several different acoustic impedance discontinuities present in marine organisms. There are the hard parts such as scales, bones, skull, cartilage or shell. There is also the soft parts or flesh of the organism. But the most important is the buoyancy control mechanism such as the oil, fat and particularly the air bladder found in many organisms. Smith[8] measured the scattering strengths of several different types of organisms and computed the density of the organism required to produce the observed levels _in situ_. Good correlation was obtained between computed and observed population densities. The target strength of an air bladder was found to be much greater than other scattering mechanisms.

Other Scattering Agents

Weston[9] examined a scattering layer at a very sharp thermocline (15°F. negative within 13 feet) 80 feet deep in water 40 fathoms deep with a 20 kc/s echo sounder. The measurements were made at tidal nodes in the North Sea during August 1954. He calculated the impedance discontinuity of the thermocline itself and found it to be considerably below that required for the observed scattering. Net hauls were made capturing zooplankton at the thermocline. It has been observed that migrating organisms may be slowed or stopped by a thermocline because of a preference for a temperature, the need to adjust buoyancy, or the availability of its planktonic food also arrested there. Weston and several others have concluded from independent work that the scattering was not from the physical discontinuity at the thermocline itself but from agents within the thermocline. Floating sea weeds also possess the mechanisms for scattering sound but have not been found in sufficient abundance to be an important source of scattering. Air bubbles stirred into the water during high sea states will increase back scattering. The effect, however, is rapidly lost with increasing depth and after the sea state subsides. It can be considered with boundary reverberation.

Phytoplankton has not been directly associated with scattering layers but constitutes the primary food production of the sea and therefore has an indirect effect, at least, on the herbivores of the scattering layer. Because of its need for sunlight for photosynthesis, phytoplankton is limited to the upper 100 fathoms of the ocean. Scripps Institution is currently studying what effects phytoplankton may have on the attenuation of underwater sound.

Identification

A great deal of effort by many has gone into identifying the specific organisms associated with the scattering layers. Direct observations have been made by Piccard and Dietz during bathyscaphe descents. An increase of bioluminescence at the scattering depths was noted. Heavy stratified concentration of copepods and other zooplankton have been seen. It is suspected, however, that the larger and more mobile marine forms were frightened away from the vehicle.

Skinner mounted a camera and a high resolution sonar (with fields of view in coincidence) in the bow of the USS ALBACORE (AGSS-569)[10]. The camera (and flash illumination) were triggered when the sonar indicated a scatterer at the proper range. Nearly 5,000 pictures were obtained at various depths between 30 and 400 feet and at both medium and low latitudes in the Atlantic. Very few pictures had no visible objects at all in them but identification of the organisms was difficult where possible and inconclusive.

Tucker concluded[11] that deep and more intense scattering came from myctophids and shallow and weaker scattering came from zooplankton such as euphausids.

Recent observations from bathyscaphe dives by Barham[12] in the San Diego trough revealed very close spatial relation between siphonophores and the scattering layer in the 800 to 1500 foot depth range on a precision depth sounder. The body of the jelly fish was considered to be nearly acoustically transparent. Small bubbles used for depth control in the animal were of resonant size, however, for the frequency (12 kc/s) of the depth sounder. Siphonophores have not been netted in great abundance at the layer but this could be due to the technique used and the frail body of this animal.

ENVIRONMENTAL FACTORS

Illumination

The intensity of the sun's illumination at depth in the ocean varies as a function of the clearness of the atmosphere, and to a greater extent on the lucidity of the sea water. Other variables as altitude of the sun, sea state, and the particular wave length of the light also affect intensity at depth. The depth of an isolume and a scattering layer will be the greatest on a clear, bright day in clear water at local apparent noon where the declination of the sun is the same as the latitude and where the sea has been sufficiently roughened to minimize the albedo of the surface. The frequency of light with the greatest penetration in clear sea water is a blue green (of a wave length about 480 milli-microns).[13]

The intensity of light is reduced to 1 per cent of its surface value in a depth of 300 to 600 feet in clear sea water. The lower limit for the effective photosynthesis process of phytoplankton is within this depth range. Herbivorous zooplankton avoid the intensity levels required by the phytoplankton in order to escape actinic poisoning and predators which hunt by sight. Herbivores migrate upward into the phytoplankton crop to graze in relative safety at night. The predators of the herbivores evidently migrate upward also, perhaps for the same reasons.

Temperature

Temperature variation affects vertical distribution as well as horizontal distribution of particular organisms. A temperature dependence has been found to modify a strict adherence to an isolume by a scattering layer. One form of temperature dependence - the slowing of a migration through a thermocline - has already been mentioned. Hersey and Moore[14] report a distinct limiting of the downward migration in respect to an isolume during the middle of the day. Low temperature at depth was suggested as the barrier to further downward migration from echo sounder observations made while crossing and re-crossing the Gulf Stream. The scattering layer (believed to be euphausids in this case) was relatively deeper and more diffuse in depth on the Gulf Stream (warmer) side of the current boundary.

The diurnal migrations of organisms brings them into two widely different temperature environments twice each day. Both temperatures experienced by the organism must be sufficiently within the tolerance of the animal that it can successfully continue its life processes in the area. Moore[15] suggests that there are two different temperature optima, one associated with the day depth and the other associated with the night depth.

Distribution Gradients

Moore lists[17] two principal gradients in classifying marine environments; they are, latitude and depth. When a positive identification of the organisms involved in the scattering of specific ASW sonar frequencies is made these gradients can become useful in predicting volume reverberations. Sonar system performance can then be given as a function of area, season, and time of day.

These gradients are modified by many but often predictable physical characteristics. The distribution of insolation and thus surface temperatures decreases from the equator toward the poles. The surface circulation of the waters in the Northern Hemisphere is clockwise and the circulation in the Southern Hemisphere is counterclockwise which distorts a strict distribution of surface temperatures by latitude. The greatest seasonal variation in surface temperatures is found near the 40 degree latitude line (in the western North Atlantic). The temperature gradient in depth is greatest near the equator and least near the poles because bottom temperatures are nearly uniform everywhere.

The extreme variance of seasonal insolation at high latitudes has a marked effect on primary food production there and the organisms which depend on this food chain. The phytoplankton production also varies with the concentration of nutrient salts, and temperature stability. Upwelling and land drainage increase the nutrient salts. Temperature stability reduces deep (out of the illuminated zone) mixing which improves primary production.

Other factors

There are two minor environmental factors the writer can discuss from his own experience. The first is internal waves. The scattering layers are vertically displaced by internal waves. This fact can be shown from the sonic depth finder chart recordings of scattering layers. The writer has occasionally seen what appears to be scattering from the crests of internal waves on a sonar video presentation. The waves appeared as parallel lines of brightening on the scope at a range closer than the sea bottom. An increase of audio noise level attended the brightening.

Marine animals in general seem to take little notice of the man-made noises in the sea.[16] An exception the writer has noted is the porpoise. Many hours have been spent next to an underwater telephone listening to the "conversations" of the porpoises riding the ship's bow wave, when no sonar transmitting was being conducted. The relatively low power output of the telephone does not seem to annoy these animals; many persons including the writer have even heard them imitating the telephone transmissions. The writer has never detected the presence of the porpoise near a ship during high power sonar echo ranging, however.

SUMMARY

Conclusions

The presence of the scattering layers has been noted as increased volume reverberation in a sonar receiver. Other ways the scattering layers may affect the sonar figure of merit are not definitely known. The writer believes the significant points from the ideas discussed in this paper can be listed as follows:

1. Scattering layers exist over wide geographic areas at usually predictable depths.

2. The important scattering agents are marine animals with air bladders.

3. The effective scattering cross section is generally small compared to the acoustic wave lengths in common use but resonant scattering occurs.

4. The scattering strength is highly frequency dependent; the frequency is depth and organism dependent; and the organism is area dependent.

5. A relatively great number of scattering organisms are insonified in long path echo ranging.

6. How the scattering layers affect active sonar over an assortment of frequencies, scattering layer depths, and path lengths is not fully understood because of a lack of sufficient empirical data.

Recommendation

Volume reverberation might be reduced by selecting a particular frequency or by having a shorter pulse and more narrow beam than used in the examples given in this paper. While such equipment parameters might be feasible, within the state of the art, they may not be at all compatible with other important considerations of sonar performance. It is recommended, therefore, that a program be initiated to obtain the empriical data necessary to the better understanding of the scattering layer effects, particularly on long path echo ranging ASW sonar performance.

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Electronic Engineer

NOTE: This paper was prepared as part of the requirements for a course in Biological Oceanography in a graduate level study program supported by USL.

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Distribution List

EXTERNAL

BuShips (Code 688)
BuShips (Code 688E) (2)
BuShips (Code 689C)
DESDEVGRUTWO (CDR Fridge)
SUBDEVGRU TWO (Lt. J.F. Sousae)

INTERNAL

Code 100
101
900
900A
900C
910
153
R. Welsh
S. Slavtcheff
932
H. J. Doebler (3)
930
930S (3)
902
904.2 (5)
913
905

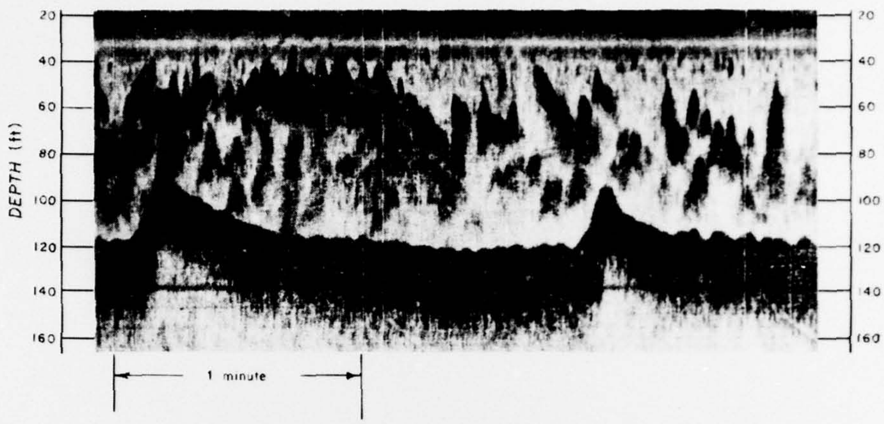

Fig. 1. Scattering groups in shallow water in the region of Nantucket Shoals recorded by a 12 kc/s echo-sounder. The conspicuous bottom features are sand waves.

Fig. A*

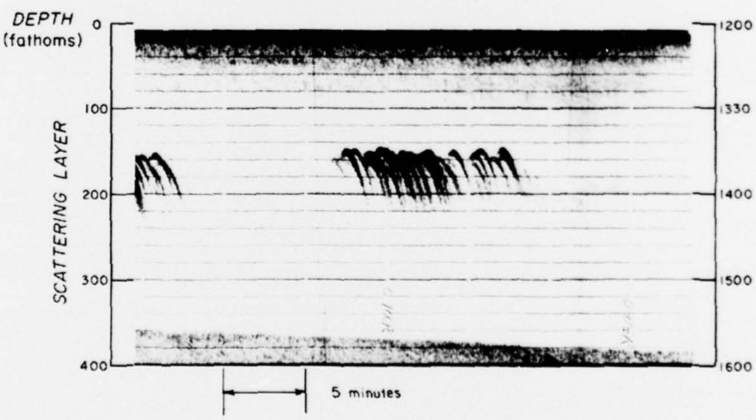

Fig. 2. Scattering groups in deep water south of New England recorded by a 12 kc/s echo-sounder. An ordinary deep-scattering layer is faintly shown at a depth of about 200 fathoms.

Fig. B*

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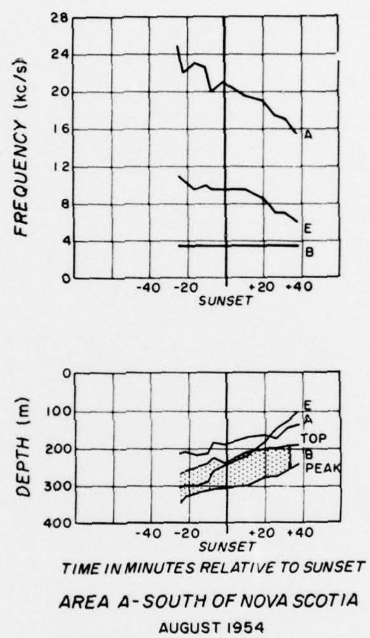

Fig. 18. Depth and peak frequency versus time of observation relative to sunset of the principal scattering layers in area A of Fig. 14 (cf. Figs. 16 and 17). For the low-frequency layer (B), the figure shows the depth of the greatest intensity of scattering ("peak") and the apparent depth where scattering begins ("top").

Fig. C*

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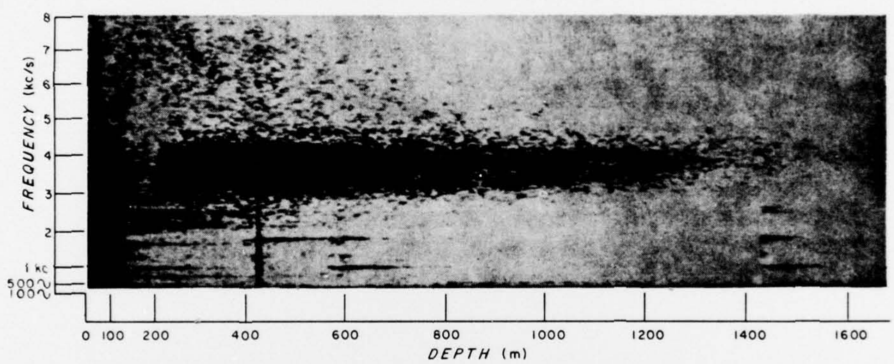

Fig. 16. Typical Sonagraph record of sound-scattering in the low-frequency range. The vertical line at about 420 m and the extended straight horizontal lines are artifacts. The low-frequency layer is represented by the pronounced blackening between 3 and 4 kc/s which starts at about 200 m (cf. Fig. 17).

Fig. D*

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Official Photograph

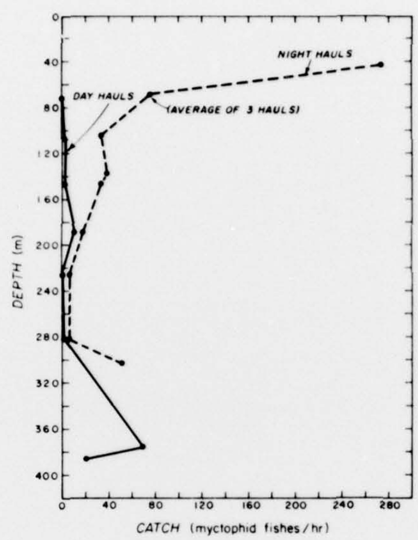

Fig. 9. Vertical distribution of myctophid fishes in number of fish per hour's haul for day and night catches in deep water south of New England (see text).

Fig. E*

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