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THE ECOLOGY OF SONIC SCATTERING LAYERS IN THE MONTEREY BAY AREA

BY
ERIC GEORGE BARHAM

TECHNICAL REPORT NO. 1
FEBRUARY 11, 1957

PREPARED UNDER OFFICE OF NAVAL RESEARCH CONTRACT
N6onr-25127
NATIONAL SCIENCE FOUNDATION CONTRACTS
NSFG 911 NSFG 1780

HOPKINS MARINE STATION
STANFORD UNIVERSITY
PACIFIC GROVE, CALIFORNIA

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ACKNOWLEDGMENTS

Only one name appears on the title page of this thesis, but because of the nature and scope of the problem, there have been, in a sense, many collaborators. It is this author's privilege and pleasure to acknowledge their contributions, while still assuming full responsibility for the interpretation of the data, the scientific accuracy, and matters of a controversial nature.

The program of research was made possible through the research grants made available by the Office of Naval Research (Contract N6-onr-25127) and the National Science Foundation (Contracts NSFG 911 and NSFG 1780).

Thanks are due to: Dr. Donald P. Abbott, my major professor, for his spiritual encouragement, scientific guidance, and editorial assistance which have contributed so greatly to the successful completion of the problem; to Dr. Rolf L. Bolin, director of oceanographic research at Hopkins Marine Station, without whose full confidence and encouragement this work would not have been attempted nor completed; to Dr. R. L. Blinks, Director of the Hopkins Marine Station, for his helpful encouragement and technical advice; and to Dr. Harve Carlson, acting chief scientist, Office of Naval Research, San Francisco District, who has contributed important administrative and liaison aid.

A number of scientists have generously given criticism, advice, encouragement, and factual information which have contributed to the author's conceptions of the problem. Of primary importance in this respect has been the aid received from Dr. Gordon Tucker of San Diego State College. Thanks are also due to Dr. Warren Thompson and Dr. Henry Medwin of the Navy Post-Graduate School, Monterey, California, and Mr. W. E. Batzler of the San Diego Naval Electronics Laboratory. Mr. Leonard Greenfield of the Hopkins Marine Station has rendered scholarly council and advice during the preparation of this report.

Many people have made valuable technical contributions, both large and small. Photographic help and information have been given by Mr. Richard Boolootian, Mr. Julius Phillips, and Dr. Ray Jones of the Hopkins Marine Station. The excellent negatives from which the line figures in this paper were printed, are the work of James Klingenstein, Ph. 2c. of the Monterey Auxiliary Air Field Photo Laboratory. The salinity titrations and temperature computations which provided the hydrographic data have been the work of Mr. Thomas Fast, who, along with Mr. Lee Lewis also shared in the installation of the accoustic gear aboard the "Tage." Phytoplankton samples were taken by Mr. Fast and measured in part by Mr. Robert Aughtry, Mr. Reginald Gaines, and Mr. Bernard Fink, all of the Hopkins Marine Station.

Of foremost importance has been the physical contribution of the people who have shared with the author the labors and experiences of the field work which has resulted in the accumulation of the data on which this work is based. At various times during the project the following people have participated in this work: Mr. Thomas Fast, Mr. Robert Chiason, Mr. Leonard Greenfield, and Louise McCann. The majority of the detailed biological data were obtained during the year of Mrs. McCann's sea duty. Lastly much credit for the physical success of the project should go to the captain of the "Tage," Mr. Joseph Balesteri. Not only did his ample skills in net building, navigation, and boat handling play a major part in the implementation of the field work, but his sincere interest in the problem, and good-willed cooperation made this two-year "Cruise of the Tage" a happy one.

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INTRODUCTION

At mid-depths throughout vast areas of the world's seas, observations with electronic acoustical apparatus frequently reveal one or more zones of marked sonic reverberation. Typically, these stratified zones show a diurnal shift in depth. Because they are recorded as band-like traces on the echograms of depth sounders, they have come to be known as "deep scattering layers," abbreviated DSL.

Even before World War II there had been reports of "false bottoms" from ships equipped with recording echo sounders (Lyman, 1948; Tchernia, 1952). The scientific appreciation of the phenomenon, however, awaited the wartime investigations of operational problems associated with undersea warfare. The pioneer work was done under the auspices of the University of California Division of War Research (UCDWR); their findings appear in the anonymous reports of the UCDWR (see bibliography) and in the papers of Duval and Christensen (1946), and Eyring, Christensen and Raitt (1948). Many of the results are further summarized in the National Defense Research Council Reports, Physics of Sound in the Sea and Principles of Underwater Sound, both reprinted in 1951 (Anon. 1951a, 1951b).

Essentially, the method used in the study of the DSL as an entity has consisted of generating an ultra-sonic sound pulse and directing it vertically downwards. Objects in the sound cone either reflect a part of this energy or are set in motion and create secondary sound waves which are scattered back to the receiver as numerous weak and jumbled echos. Acoustically, this is known as reverberation. Its intensity may be critically and quantitatively measured by means of an oscilloscope, magnetic tape, or qualitatively represented by the spark-burned traces of a recording echo sounder. While the latter method lacks precision, it has provided a simple and convenient method of carrying out continuous observations of the DSL. The numerous reports of such observations can be distilled into the following generalized statements.

Scattering layers are considered to be worldwide in distribution, although they may be diffuse, poorly developed or unrecordable in certain areas (Dietz, 1948; Hersey and Moore, 1948: Tchernia, 1952, Ritchie, 1954). While there is in general a main layer, multiple layers are frequently observed, and as many as five layers have been recorded (personal communication, Batzler, 1956). Typically these layers undergo diurnal migration, rising toward the surface at dusk and beginning a return to their daytime depths just before sunrise (Johnson, 1948; Dietz, 1948; Hersey and Moore, 1948; Moore, 1950; Boden, 1950a; Tucker, 1951; Tchernia, 1952; Batzler and Westerfield, 1953; Ritchie, 1954; Koczy, 1954; Kampa and Boden, 1954). However, non-migratory components have been reported, as well as layers which appear to move downward at night from shallower depths, (Dietz, 1948; Hersey and Moore, 1948; Moore, 1950, Tchernia, 1952). The daytime depths of the main layers range from about 200 to 600 meters, and tend in general to be deeper in the low latitudes (Dietz, 1948; Hersey and Moore, 1948; Batzler and Westerfield, 1953). Shallower or deeper secondary layers may be present at 75 to 900 meters (Tchernia, 1952; Ritchie, 1954). Rate of migration varies from about 0.3 to 6.0 meters per minute and appears to be related to the daytime depth (Dietz, 1948; Batzler and Westerfield, 1953). The early extrapolated computations of Moore (1950), and the recent critical measurements of Kampa and Boden (1954) conclusively demonstrate that these movements are related to changing light intensities. Moore (1950, 1952), has amassed a great deal of data which indicate that temperature may play a modifying role. Sasaki, Okami, Watanabe, and Oshiba (1955) have also considered these factors in their investigations in Japan.

Observations made with specialized instruments capable of more critical measurements modify this picture to the following extent. Deep layers with high scattering coefficients may be present which echo sounders fail to record (Tucker, 1951; Batzler and Westerfield, 1953). By using a spectrum of signal frequencies, different layers which escape resolution at one set wave length may be brought into focus (Hersey, Johnson and Davis, 1952; Kampa and Boden, 1954). The impression, provided by echo sounders, of a horizontal homogeneous layer is probably an erroneous one (Machlup and Hersey, 1955). The descriptive concept of the DSL is still in its formative stage, but the emerging picture is that of a complex, dynamic phenomenon. As further observations are made with sounding gear specifically designed or modified to record deep reverberations, additional anomalies will undoubtedly be discovered.

We now turn to the question of what causes the scattering-layer phenomenon. Theoretically, density variations which result from sudden changes in temperature or salinity gradients could reflect sound waves to such a degree as to be responsible. The UCDWR group examined the water masses at the DSL level for such gross features with negative results. Similar findings have been reported by Hersey and Moore (1948), Tchernia (1952), Batzler and Westerfield (1953), and Ritchie (1954). These results do not preclude the possible role of a physical microstructure which can not be measured by the relatively crude means at our disposal. However, to explain the observed facts it would be necessary in some cases to postulate several regions of microdiscontinuities moving vertically with changing light intensities at different rates. Such movements of physical interfaces is highly unlikely.

Martin W. Johnson, who was associated with the UCDWR group, was the first to propose a biological explanation. The fact that certain pelagic organisms undergo diurnal vertical migrations has been known since the days of the "Challenger" Expedition (1872-76), and the phenomenon has received the attention of numerous workers since that time. (An excellent review of the descriptive and experimental work on the diurnal migration of crustacea is to be found in Cushing, 1950). On this basis, Johnson theorized that if the DSL underwent a similar diurnal migration convincing evidence would be at hand to support a "biological hypothesis". His theory was borne out by extensive observations in 1945, and the diurnal vertical movement of scattering layers has been amply demonstrated since that time. This one characteristic has provided evidence enough to convince most oceanographers that the DSL is a biological phenomenon. One problem is then to discover the specific identity of the organisms which are responsible.

Marshall (1951) and Tucker (1951) have enumerated the essential characteristics which a group of organisms must exhibit in order to qualify as potential scatterers. These are considered to be: (1) well-defined acoustic properties; (2) wide geographical distribution; (3) marked diurnal migration; and (4) vertical concentration within the reported limits of the DSL. These basic criteria may serve as a convenient framework on which to arrange the available evidence.

To try to evaluate marine organisms as potential scatterers on the basis of their acoustic properties is by no means a simple or straight-forward process. First we must consider their physical nature. According to theory as expressed in <u>Principles of Underwater Sound</u> (Anon. 1951b), it can be assumed that organisms whose anatomical compressability is markedly different from sea water can be considered efficient scatterers. A high degree of sclerotization of hard parts and the presence of gas-filled cavities or associated air bubbles could drastically increase their scattering properties. The importance of the latter structures is due to resonance, the production of a sympathetically vibrating corona of water which reinforces the acoustic dimensions of the actual scattering object. Johnson (1948), Dietz (1948), Moore (1950), and Boden (1950a) eliminate many types of organisms from consideration as scatterers on the basis of physical structure. Representatives of the plant kingdom are disregarded, and medusae, ctenophores, siphonophores, chaetognaths, pelagic tunicates, or collectively Boden's "watery plankton" are eliminated.

The physical nature of marine organisms as sound scattering objects has also been treated experimentally. Anderson (1950) used a fluid-filled sphere as a hypothetical marine animal and concluded that at certain frequencies such objects would be more efficient scatterers than solid brass spheres. Machlup (1951) attempted to ascertain the effect of the exoskeleton of marine crustacea by using a model with a rigid shell. Smith (1954) mounted a frontal attack on the problem by investigating the reflectivity of dead squids, fishes, and shrimps suspended on wires below a raft bearing the sounding equipment. He concluded that all these organisms are potentially effective scatterers.

The factor of size must also be taken into consideration. Here we must differentiate between physical size (the total area which is exposed to the sound beam) and acoustic size or target strength (the amount of sound energy which is actually re-radiated by the organism). As a further complication, the size of scatterers must also be considered in terms of the length of the sound waves which impinge upon them, since this factor may drastically influence their acoustic size. This principle is known as "frequency dependence".

Consider the hypothetical case of a non-resonating balloon which is suspended in sea water by a tube inserted through its neck so that its size can be varied. A sounding apparatus operating at 24 kc frequency sprays it with sound waves approximately 3 in. long. A hydrophone picks up the reflected sound and it is amplified for measurement. When intensity of reverberation is plotted against size of the scattering object (the balloon), it is found that the points fall on a complex curve which can be divided into three characteristic regions with somewhat arbitrary limits.

If the diameter of the target is much smaller than the wave length of the signal, (e.g. 0.1 mm. in diameter) it is found that an extremely small amount of energy is reradiated. Now, if the balloon is inflated slowly by means of the supporting tube, the intensity of the scattered sound will increase by a factor proportional to the fourth power of the diameter of the scatterer. By the time the balloon has stretched to 1.0 in. in diameter, the measured reverberation has increased a thousand-fold. This extremely steep portion of the curve, where a slight change in the size of the scatterer will greatly effect reverberation intensity is predicted by Rayleigh's Law and is therefore known as the Rayleigh region. As we continue to inflate the balloon to a diameter roughly corresponding to the wave length of the signal, the second distinctive region of the curve is reached. Here the slope of the reverberation curve flattens sharply and may be quite irregular. When the balloon has stretched to a diameter several times greater than the wave length, the scattering curve enters a third region where reverberation increases directly with the first power of the diameter of the target.

The form of the target must also be considered. A thin, flat object will present a varying silhouette in the sound cone as it changes its orientation. Scattering intensity at a given wave length will vary as the object moves. Most biological targets will present varying silhouettes and, as a further complicating factor, it is probable that many of them are effective resonators at wave lengths used in echo sounders and thereby have their acoustical size increased by harmonics.

Despite these complex considerations, a general idea of the size of scatterers has been gained by field experimentation. Raitt (1948) computed acoustical size from traces of what he considered to be individual scatterers above the main scattering layer, and concluded that the major source of reverberation was scatterers between 0.1 cm.^{2} and 10 cm.^{2}. By varying the wave length of the outgoing sound signal (the converse approach of the hypothetical balloon experiment, where the size of the target was varied), Hersey, Johnson, and Davis (1952) have utilized the principles outlined for frequency dependence to estimate the maximum length of scatterers as 30 cm. While this feature was not discussed by the authors, similar data provided by Kampa and Boden (1954) indicate a larger maximum size. Hersey and Backus (1955) attribute an upward shift in peak frequencies -- hence a decrease in the acoustical size of the scatterers -- during descent of a scattering layer to the shrinkage of fishes' swim bladders under increasing hydrostatic pressure. Assuming spherical shape, they computed three bubble sizes at shallow depth, 16.7, 5.5, and 1.0 mm. All of the evidence indicates that we are very probably dealing with organisms which have an acoustic diameter comparable to the wave lengths of the standard frequencies used in observations (17 to 24 kc). Therefore results predicted for the second region of the reverberation curve, which is characterized by dynamic changes in reverberation intensity with slight changes in wave length or in the size of the dominant scatterers, are to be expected.

The population density necessary to account for the measured reverberation intensities can be considered as a third acoustical property. Raitt (1948) concluded that only one scatterer of an acoustical size greater than 1.0 $cm.^2$ was present per 10,000 $m.^3$ of water. By dropping a transducer operating on shoal scale to a position above a scattering layer, Kanwisher and Volkman (1955) were able to record traces which are remarkably in accord with Raitt's figures. Smith's (1954) work provided valuable estimates of necessary population densities for several types of organisms. Unfortunately, because of the uncertainties involved in converting acoustical size to physical size, the conclusions which can be drawn from these studies are limited. It appears, however, that population densities of the main scatterers need not be of a high order of magnitude.

Potential scatterers have been evaluated in terms of the other basic criteria (wide distribution, vertical migrations, and concentration at the depth of the DSL) by recourse to existing knowledge and experimental work. It is agreed that the bathypelagic fishes, macro-crustacea, and cephalopods best fit the requirements. The evidence for this is reviewed briefly below.

In an early publication, Hersey and Moore (1948) center attention on the euphausid shrimps as the biological agency responsible for scattering layers. Further amplification and new evidence is presented in a later paper (Moore, 1950). The essential arguments are based on a series of correlations between the nature of scattering layers at various geographical location and the available data on the density and distribution of euphausid populations. Quantitative support is given to the euphausid theory by the work of Boden (1950a), who analyzed a large series of net hauls taken simultaneously with echograms. The results showed a marked concentration of planktonic organisms, dominated by euphausids, at the scattering-layer level. The pelagic-trawl hauls of Tucker (1951) also showed a definite relationship between the upper part of the layer and euphausid populations. Very recently, Cushing and Richardson (1956) have presented convincing evidence that the intensity of shallow-level scattering is related to euphausids.

The possibility that fishes feeding on the smaller zooplankton could be acoustically responsible for the DSL had been considered at an early date by Johnson (1948).* In his plea for exploitation of the economic potential of pelagic populations, Chapman (1947) briefly proposes the same possibility. Moore (1950) emphasizes the role of euphausids as scatterers, but he concedes that fishes, particularly those which possess swim bladders, may be causative agents as well. The ubiquitous Pacific saury is mentioned as a potential scatterer by Boden (1950a). Marshall (1951) documents the possible role of bathypelagic fishes as sound scatterers with a detailed and scholarly presentation of the indirect evidence. A tabulation of the

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*This paper is an updated restatement of earlier wartime contract studies.

presence and dimensions of air bladders in such fishes is given, and the available data on distribution and behavior is summarized. It was Tucker's work (1951), however, that gave direct evidence of the role of bathypelagic fishes in sound scattering. A series of hauls with an especially designed net, taken concurrently with sound scattering records, demonstrated a relation between fishes (predominantly myctophids) and reverberations from the deeper part of the main layer and from a secondary layer below this level. A population density of one fish per 1000 cu. ft. was estimated. Haffner (1952) relates the taking of Chauliodus as well as other fishes at scattering layer depth. The acoustical evidence for fishes as sound scatterers provided by the work of Hersey and Backus (1955) has already been mentioned.

There has been less evidence to substantiate the importance of other organisms as scatterers. Johnson's closing-net hauls (1948) showed a slight increase in copepods at DSL depth. Dietz (1948) and Moore (1950) speculated on the role of copepods in scattering, but presented no new evidence. Basing their calculations on Smith's (1954) population density factors, Batzler and Westerfield (1953) computed the proportional contributions of copepods and amphipods to the volume of reverberation. Two hauls were taken through the layers. One of these indicated that large copepods contributed 3.5 per cent of the reverberation intensity; in the other, 15 per cent was due to copepods and amphipods. A 75 per cent contribution was estimated for large copepods in another haul taken below the layer recorded on the echo sounder, but in a region of reverberation picked up by means of oscilloscopic presentation.

Boden (1950a) and Tucker (1951) reported mid-water prawns and mysids in their hauls taken through the DSL and Moore (1950) attributed spasmodic deep layers to the former organisms. On the basis of the number and nutritional demands of their predators, Lyman (1948) suggested squids as the organisms responsible for the DSL.

In this discussion, attention has been centered on the possible roles of individual types of organisms. However, in view of the complexity of the layers and their behavior, the concept of a scattering population made up of a mixture of animal types has frequently been suggested (Dietz, 1948; Johnson, 1948; Tucker, 1951; Tchernia, 1952).

It seems very likely from the foregoing review of the evidence that the DSL is a biological phenomenon in which the important causative organisms are bathypelagic fishes and macro-crustacea, or what Marshall (1954) terms "micronekton." In proportion to the mass of words that has been written about the scattering-layer problem, however, there is surprisingly little direct evidence to support this view. To the present time only four papers have presented quantitative results of concurrent biological samplings and echo records. Furthermore, three of these papers have been the work of one laboratory, and two have data and hauls in common. This trilogy, Boden (1950a), Tucker (1951), and Batzler and Westerfield (1953), provides the meat of the direct evidence for biological scattering, and even then, only Tucker's report is based on information obtained with collecting equipment capable of sampling the larger and more active organisms. There have been no reports which have attempted to correlate detailed chemical and physical analysis of the water masses with concurrent biological samplings and sound data. From a biological point of view, another omission, and a prime desideratum, has been the perspective of continuity.* Many observations have been intensive but taken at brief, random periods. For this reason nothing is known concerning seasonal periodicity of scattering layers. Such knowledge is a necessary prerequisite if we are to gain a predictive understanding of the DSL phenomenon.

These deficiencies have not been due to lack of appreciation of the need for more and better data on the part of investigators, but are related to the problems involved in amassing such information. Because of the expense involved in oceanic research, much scattering layer work has been done as a secondary or tertiary adjunct to the major objectives of deep sea cruises. The difficulties and uncertainties of present collecting methods, and the

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*The scattering-layer program of the University of Miami Marine Laboratory, begun in 1952, is designed to provide such information, but as yet the final results have not been published.

failure, so far, of underwater television and cameras to provide hoped-for information, have also tended to restrict the biological scope of DSL research.

It was hoped that the program undertaken by the writer would provide information in the areas outlined above.

OBJECTIVES, METHODS AND INSTRUMENTATION

Objectives and Scope.

The method of attack can be briefly defined as the direct approach with continuity in time and stability in space. Such an approach was made possible by the research program already under way at the Hopkins Marine Station. Under the sponsorship of the Office of Naval Research (Contract N6-onr-25127) and later the National Science Foundation (Contracts NSF G911 and NSF G1780), the Hopkins Marine Station was engaged in a long-term hydrobiological survey of the waters in and adjacent to Monterey Bay. As part of this program, a weekly oceanographic station was occupied over the deep waters of the Monterey Canyon, at which temperatures, water samples and plankton tows were taken at various levels from the surface to 1000 m. depth. It was evident that with the addition of appropriate sounding equipment and collecting gear, the Hopkins Marine Station's program would provide an excellent opportunity to study scattering layers at one geographical location throughout a seasonal cycle. In addition, it would be possible to gain this information, at little additional expense, and without deviating from the original objectives of the program.

It was hoped that such a project would provide information or answers to the following questions:

1. What is the morphological nature of scattering

layers in the Monterey Bay area as indicated by the NMC echo sounder?

2. Is there evidence for a physical explanation of scattering layers in this area?

3. What organisms are associated with the sonic scattering layers, and which ones appear to be the dominant scattering entities?

4. Is the recordable form of the layer constant in time, or is it dynamic in nature; is there a seasonal pattern to measurable changes?

5. If a seasonal pattern exists, can changes in the DSL be correlated with physical, chemical and biological variables?

In the broadest sense, the objectives are expressed in the title of this paper; an attempt was made to study "The Ecology of Sonic Scattering Layers in the Monterey Bay Area." The work reported here covers a two-year period, from January 1954 to January 1956. The data were obtained during the occupation of stations taken roughly a week apart at the same location, 36°42'N. 122°02'W. As can be seen in Figure 1, this position is approximately 7 miles northwest of Pt. Pinos, Monterey County, California, and lies over the Monterey Submarine Canyon in 900 fathoms of water. Due to drift and movement of the boat when hauling the net, the area of operations is best conceived as a circle, two miles in diameter, with its center at the above location.

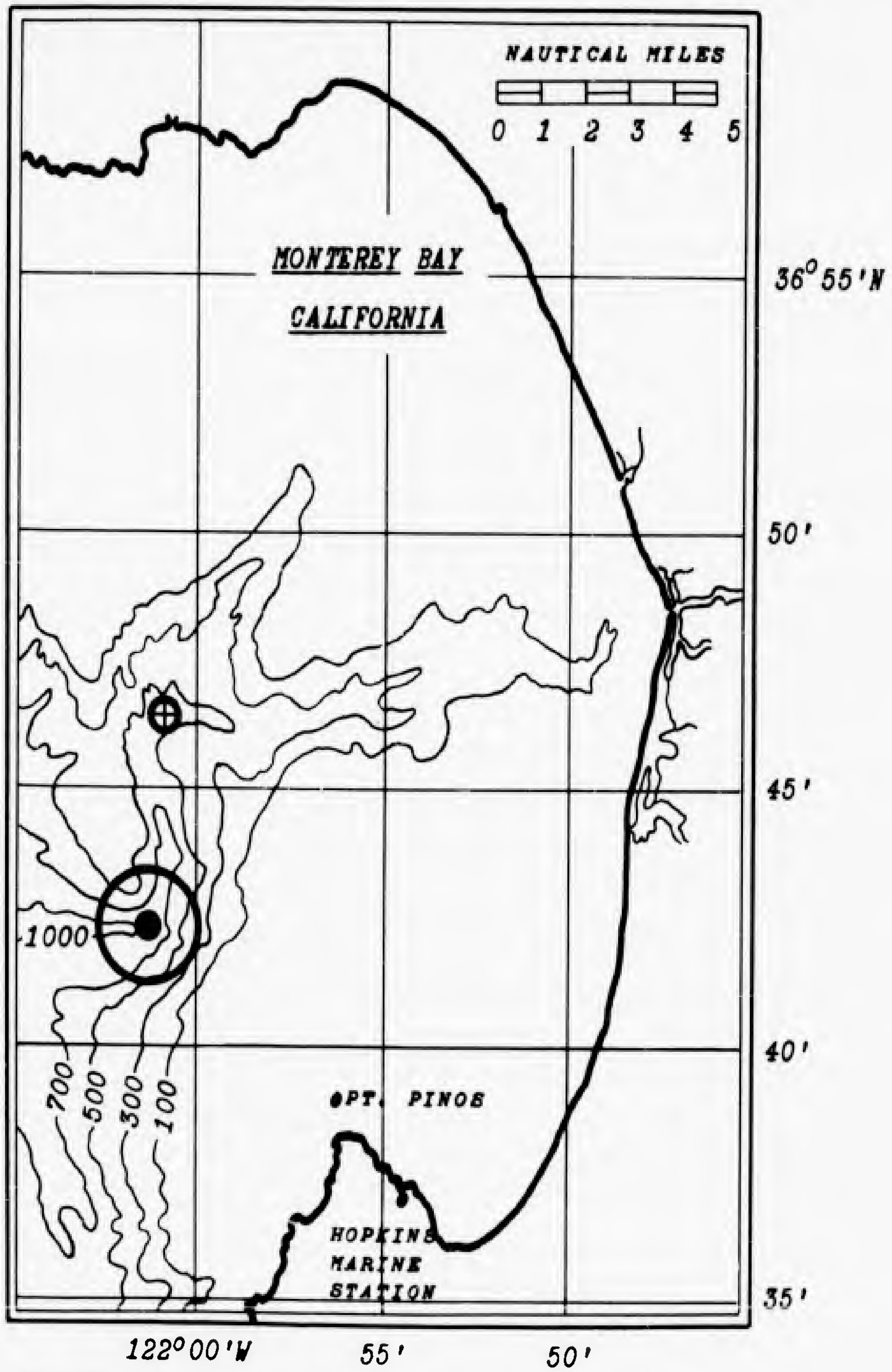

FIGURE 1. MAP OF MONTEREY BAY SHOWING AREA OF SCATTERING LAYER OBSERVATIONS MARKED BY CIRCLE. PHYTOPLANKTON STATION IS INDICATED BY A CROSS. DEPTHS IN FATHOMS.

Methods and Instrumentation.

The Boat. The Hopkins Marine Station research vessel "Tage" is a cabin motor launch, 40.5 ft. in length, of 11 ft. beam, and powered by a 185 hp. G.M. diesel engine. Mounted on the fore deck is a modified anchor winch powered by a take-off from the main engine. The winch normally holds 1300 m. of dual purpose, 0.25 in. stainless steel wire used for hydrographic casts and net towing. During operations this wire passes over a meter-block suspended from a stern-mounted A-frame (Fig. 2). A Captain-Engineer, and two-man scientific party make up her normal compliment for deep-sea work. The size of the vessel and her cramped working area aft limit the type of gear which may be successfully utilized.

Echo Sounder. All of the acoustic observations and the echograms presented in this paper were made with a Navy Model NMC echo sounder operating at 17-18 kc. The nature of the installation, indicated in Figs. 3 and 4, was determined by the danger and expense involved in mounting the large transducers in the recommended through-hull position. Essentially, the method adopted consisted of enclosing the transducers in machined bells to which an eight foot section of four inch pipe was threaded. These bell-pipe assemblies were affixed to the transom of the boat by means of fabricated oak blocks and metal shoes. The shoes could be loosened to allow the transducers to be

FIGURE 2. THE "TAGE" AT HER MOORING IN MONTEREY BAY. THE WINCH (A) CAN BE SEEN ON THE FOREDECK WITH THE TOWING WIRE RUNNING OVER A SHEAVE (B) MOUNTED ON THE PEAK OF THE CABIN AND OVER THE METER BLOCK (C) SUSPENDED FROM THE A-FRAME AT THE STERN.

FIGURE 3. A VIEW OF THE STERN OF THE "TAGE" SHOWING THE SHALLOW RANGE TRANDUCER (A) IN THE RAISED POSITION. BLOCK-AND-TACKLE SYSTEMS (C) ARE INBOARD. THE OUTBOARD CHAIN (D) SERVES AS A SAFTETY STOP.

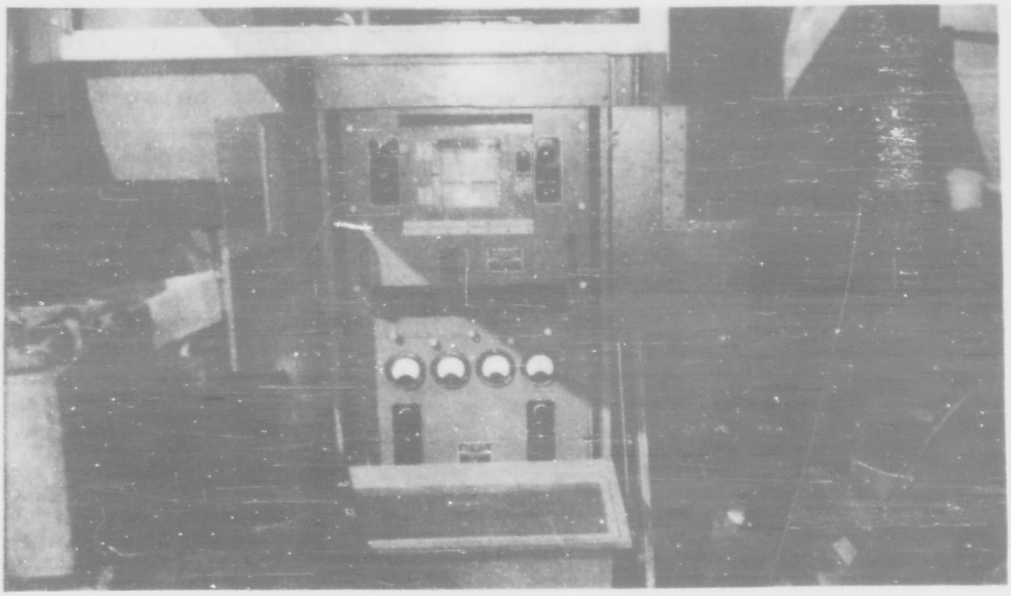

FIGURE 4. THE NMC ECHO SOUNDER UNITS WITHIN THEIR PROTECTIVE CABINET WHICH IS MOUNTED ON THE DECK OF THE COCKPIT. LUCITE PORTS IN THE CABINET'S DOORS ALLOW OBSERVATION WHEN THEY ARE SECURED.

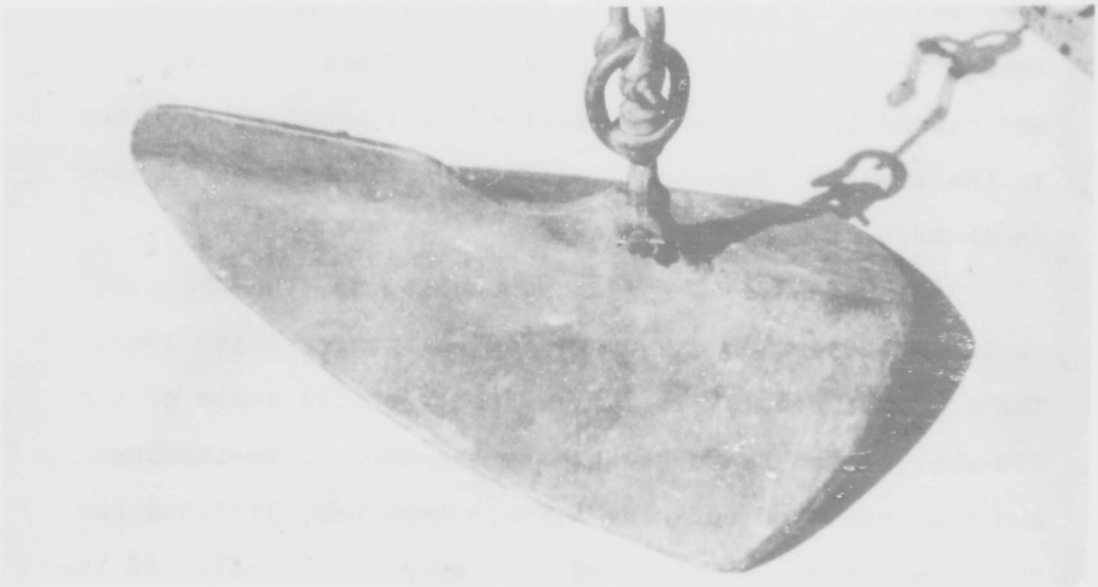

FIGURE 5. THE "HOMOGENEOUS DEPRESSOR" USED AS A WEIGHT ON THE NETS.

lowered or raised by a block and tackle. In the lowered position the transducer head was about 4.5 ft. below the sea surface (Fig. 3). The amplifier, receiver, and recorder units were protected from spray by housing them in a cabinet mounted in the cockpit (Fig. 4). Power was provided by a 110 volt, 600 watt, Briggs-Stratton gas-driven generator mounted below deck and originally adjusted to 60 cycles with the aid of a cathode ray oscilloscope. The echo sounder's performance while hove to or running at very slow speeds was good to excellent. Unfortunately, due to the juxtaposition of the transducer to the boat's screw, when the propeller revolutions were increased above a critical rate the resultant turbulence and bubbles of cavitation completely jammed the signals. At times the vessel's electrical equipment, or the slosh of bilge water over the boat's ground plate, also caused jamming which tended to obliterate the recordings. These two last sources of trouble were alleviated to a great extent late in the study by degaussing all of the vessel's metal parts in contact with the sea water.

Even under ideal operating conditions, the NMC echo sounder has certain drawbacks for scattering-layer work. The major difficulty is the limited vertical scale of the recorder, which tends to squeeze the zone of scattering and the region of outgoing signals together, limiting the detail which can be recorded and reducing the value of the echograms for reproduction. This is particularly true in

Monterey Bay, since shallow layers are frequently present and the regions of signal and echo may overlap on the recording. Further, in evaluating the presented echograms, one must bear in mind that, regardless of type, an echo sounder is not a precise method of establishing the vertical zonation and intensity of reverberations. Critical data can be obtained only through the application of refined, brief-signal, high energy techniques, which were not available for this work. The analogous situation of trying to read a newspaper with ill-fitting glasses might apply here. The large type is clear enough, but the fine print is only a blur. Like such glasses, our instrument has allowed us to read the headlines, but the details remain unknown.

Intrinsic changes in the sounding gear must be considered as an important factor in evaluating the scattering conditions recorded. The duration or length of the outgoing signal (ping-length) is an important instrumental variable which can affect the results. The recording of deep scattering layers is enhanced by long, high-energy sound pulses, but these tend to mask zones of reverberation in the upper layers. Furthermore, the longer the duration of the outgoing signal, the longer the timespan during which reverberations will be returning from the layer, and therefore the thicker the recorded zone of reverberations will be. Since there is no external adjustment control for ping-length on an NMC echo sounder, this factor has been held fairly constant. The length of signal can be altered only by adjusting the internal, factory-set, keying mechanism. This setting was changed slightly during the first year of observations in a successful effort to obtain clearer recordings. The influence of this change in ping-length has been considered in interpreting the results. Providing the ping-length is adequate to allow for full response of the transducer, the strength of the outgoing signal is an instrumental constant. As the sound rays diverge from the point of origin, however, the signal will decay roughly according to the inverse square law (Principles of Underwater Sound, 1951).

Degree of amplification of the returned reverberations can be modified by increasing the "gain" or sensitivity setting (S.S.). This factor may be extremely important in controlling the type of scattering pattern recorded. At a low gain an upper zone of reverberations may be separated from the outgoing signal on the echogram, but any deeper scattering layer will not be recorded. Increasing the gain will pick up the deeper layers, but will also extend the vertical dimensions of the upper scattering layer so that this tends to fuse with the outgoing signal on the recording. Therefore, throughout the operation the practice has been to use the lowest gain at which it was possible to resolve all layers capable of being recorded on the instrument.

The variable resistance adjustment controlling the amount of energy passing through the stylus will affect the intensity of the markings recorded on the iodized paper, but this adjustment was kept constant throughout all the work. Condition of the steel RCA phonograph needles used as styli is also important. If these are blunt or worn they will not record the detail of resolved layers, but will give a heavy, burned trace. Trouble from this source was eliminated by frequent changing of styli. Jamming of the recorder from various sources can also modify the intensity of the tracings. Fading or fluctuation of the power input may be another modifying factor. Not only will this affect the intensity of the sound pulse, but the resultant shift in cycles will distort the spatial relationships of recorded scattering layers by affecting the timing mechanism controlling stylus movement. Aboard the "Tage" the only precaution possible was to monitor the generator, making proper adjustments when necessary.

All the above factors have been taken into consideration in interpreting each individual echogram. It is possible that they may account for occasional variations in scattering patterns recorded. Further, they may sometimes cause apparent small changes in position and thickness of recorded layers. However, in the great majority of cases the echograms are considered to be crude but reasonably accurate recordings of the nature, dimensions, and position of underwater zones of reverberation in the upper 400 m. in Monterey Bay.

Hydrographic Data. As part of the general hydrobiological research program, water samples and temperatures were obtained during the course of the DSL investigations by means of conventional Nansen water bottles and reversing thermometers at the following depths: 0, 10, 20, 30, 50, 75, 100, 150, 200m. and every 100 m. thereafter to 900 m. Analysis of these samples for salinity, dissolved oxygen and phosphate content was carried out according to the methods outlined by Wooster (1950). Silicate content was estimated by the technique described by Phelps (1937).

Description of Nets Used. The primary objectives in attempting to study the DSL with biological collecting gear are twofold. (1) To selectively sample a given stratum of water without contamination from organisms present in water levels above or below. (2) To obtain adequate quantitative samples of the potential scattering organisms. Conventional closing plankton nets can be used to fulfill the first objective, but these fail to sample adequately the larger and more active organisms. The latter objective can be better achieved through the use of large, horizontally towed gear. However with such gear, towed from a small boat, it is difficult or impossible to critically sample only the desired level. During the course of the project the first objective has been partially sacrificed to achieve the second. Inaccuracies in sampling depth can be compensated for by a comparative study of many hauls, whereas a thousand non-representative samples are still meaningless. For this reason the majority of the biological data used in this study were obtained by using a net similar to the gear developed by Tucker (1951) to sample what are probably the larger and more active components of the DSL.

In basic design the Tucker net (T-net) is a square, 6 x 6 ft. mouth-frame hung with 30 ft. of webbing diminishing in size toward the cod-end. The top and bottom of the mouth-frame are formed by iron pipe while the sides consist of sections of rope. Towing strain is taken from the top bar by means of a short bridle, while a similar bridle suspends a weight from the bottom bar. This arrangement not only results in an unobstructed mouth opening, but, since the mouth is collapsible, the net can be handled in the cramped working space aboard the "Tage." In our gear, Tucker's specifications were retained with minor modifications in mesh size determined by availability of materials. A silk gauze or stramin cod-end, canvas collar and cod-end bucket were also added to limit abrasive damage to the collected specimens, many of which were used in detailed taxonomic and anatomical studies. Due to premature failure of scavenged netting, it was necessary to employ three bags of slightly varying mesh-size and dimensions. A good idea of the construction of the T-net's mouth-frame can be gained from Fig. 6. The specifications of the bags are listed below.

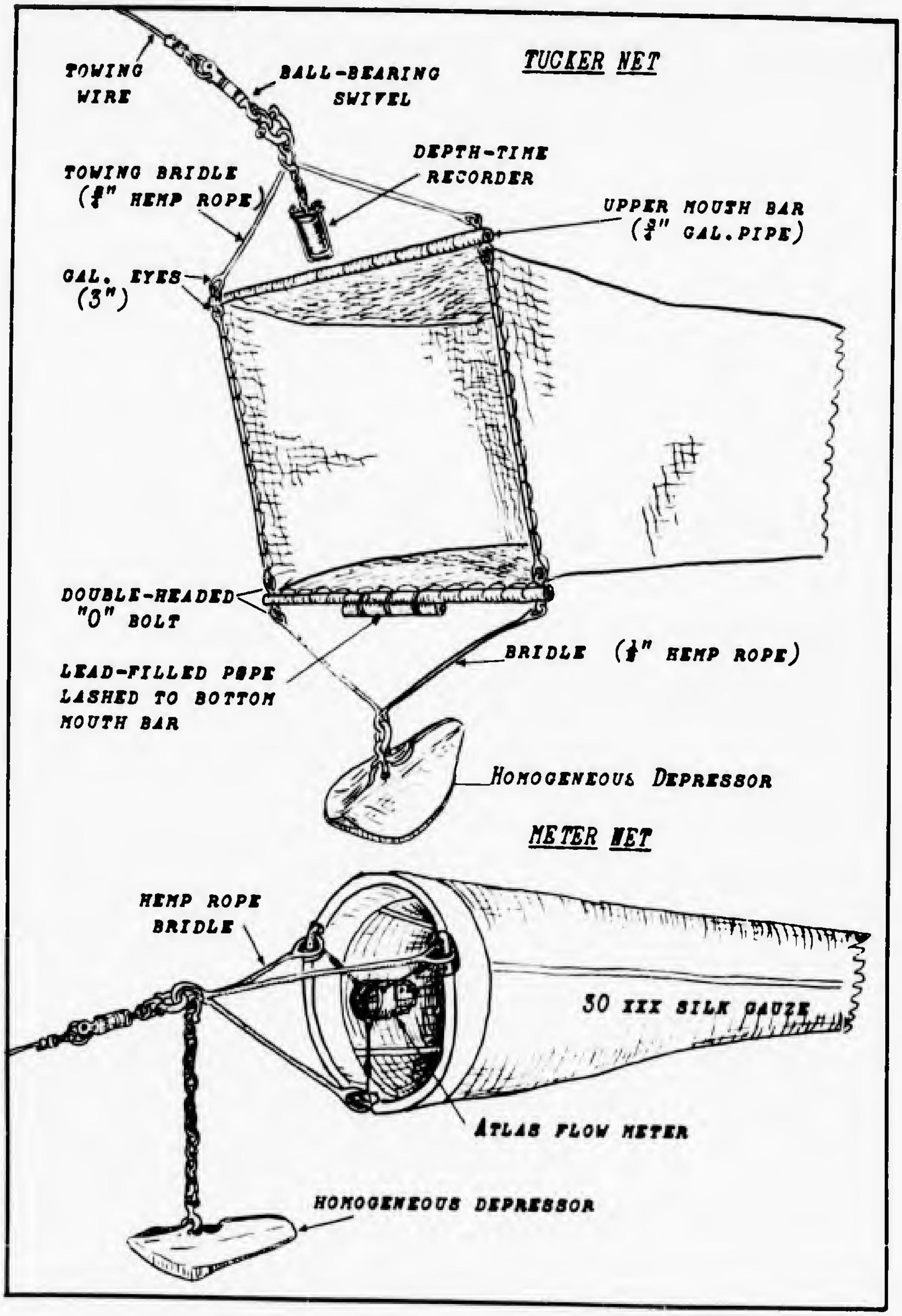

FIGURE 6. An illustration of the Tucker Net and the Meter Net showing relative differences in mouth size and method of attachment to the towing wire.

T-NET	MESH SIZE (measured at stretch, knot to knot)
1	Leading section consisted of 15 ft. of 10 in. mesh, followed by 15 ft. of 0.5 in. mesh, then 5.0 ft. of 30XXX grit gauze, terminated by a 1.0 ft. canvas sleeve. This bag was cut to taper to an 8.0 in. diameter at the cod-end.
2	Leading section consisted of 6.0 ft. of 1.25 in. mesh, followed by 12 ft. of 0.75 in. mesh, then 12 ft. of 0.5 in. mesh, terminated with 6.0 ft. of 30XXX grit gauze and a 1.5 ft. canvas sleeve. This bag was tapered by hanging the various sections knot to knot.
3	Leading section consisted of 5.0 ft. of 1.5 in. mesh, followed by a short 1.0 ft. section of 7/8 in. mesh, then 6.0 ft. of 0.75 in. mesh, 5.0 ft. of 5/8 in. mesh, 7.5 ft. of 0.5 in. mesh, then 6.0 ft. of 3/8 in. mesh, terminated with a cod-end of stramin and a 15 in. canvas sleeve. This bag was tapered by hanging the various sections of mesh knot to knot.

The weight attached to the bottom mouth-bar of the T-net was a bronze homogeneous depressor (Fig. 5), developed at Scripps Institution of Oceanography and described in The California Cooperative Sardine Research Progress Report for 1950. This device is similar in design and action to the streamlined hydrodynamic cable depressor described by Reed and Stewart (1949), and even at slow hauling speeds develops considerably greater pull than its actual 43 pounds. A lead-filled section of brass pipe weighing 12 pounds was lashed to the bottom mouth-bar of the T-net as a further aid in holding the mouth open.

No practical method was at hand to open and close the mouth of the T-net. Therefore, contamination from organisms captured at undesired depths as the net dropped down and was recovered was always a possibility. By setting and recovering the gear as rapidly as possible, however, the amount of contamination was held to a minimum. The fact that the T-net's towing strain is taken from the top mouth-bar, so that the mouth opening is tangential to the line of pull and is partially obscured by the collapsed and trailing net when it is retrieved, also reduces contamination. The effectiveness with which a given stratum can be selectively sampled will be evident from the data on individual stations presented later.

A second type of collecting device employed was a conventional meter net (M-net), essentially the same as that described in Sverdrup, Johnson, and Fleming (1942) and hung with 30XXX grit gauze (Fig. 6).

Establishing the Path of the Net in Fishing. The path followed by the net in each haul was established by means of a depth-time recorder manufactured by the Woods Hole

Oceanographic Institution (Fig. 7). This device consists of a bourdon pressure element and a clockwork contained in a water-tight case sealed by rubber O-rings. A pressure activated stylus traces a continuous record of depth on a smoked paper disk turned by the clockwork. On return to the laboratory this can be converted to a more practical graphic form by measuring the distance between the zero line and stylus trace at key intervals with draftsman's dividers, reading it against a calibration table, and plotting the depths on graph paper as a function of time. The possible measurement error in converting the depths from the stylus trace to graph paper is no more than plus or minus 10 m. Calibration of the instrument was carefully checked both by the manufacturers and at the Hopkins Marine Station.

Unfortunately it was possible to accurately establish the stratum of sampling by this method only <u>after</u> recovery of the gear. In an attempt to determine the depth of the net while it was actually being fished, it was necessary to resort to the conventional wire-angle method. This method is based on two measurements and one assumption. The amount of towing wire payed out and the angle of inclination of the cable are measured. Assuming the cable to form a straight line between boat and net, the net depth is calculated as the vertical leg of a right angled triangle of which the angles and the length of the hypotenuse are known. The amount of wire out was measured by passing the

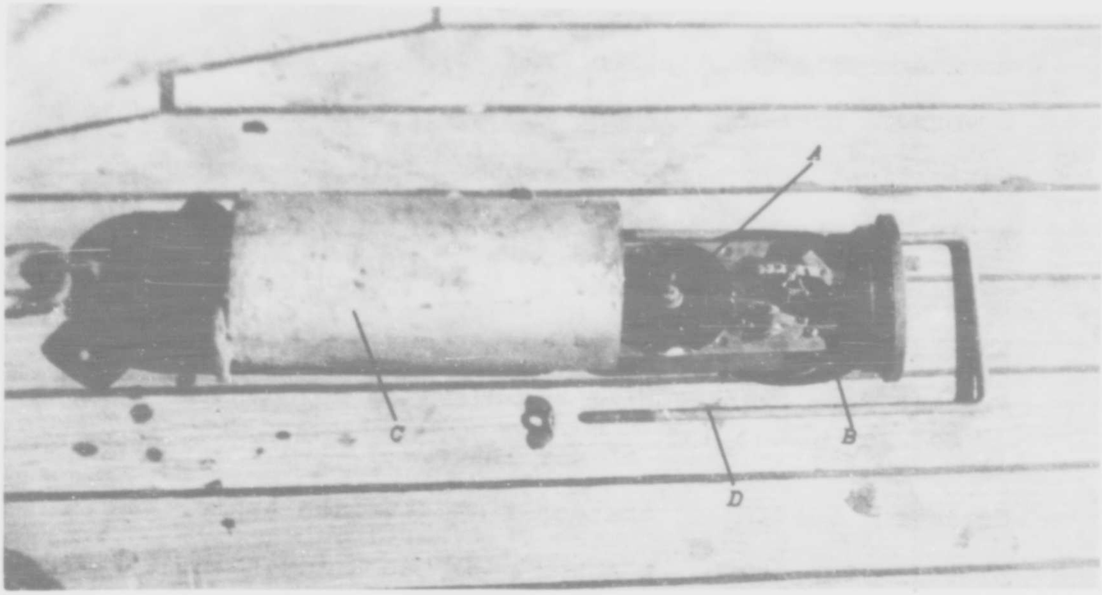

FIGURE 7. AN "EXPLODED" VIEW OF THE DEPTH-TIME RECORDER. THE SMOKED DISK (A), AND THE BOURDON DRIVEN STYLUS (B) CAN BE SEEN. IN USE THE DEVICE IS INSERTED INTO THE PROTECTIVE CASE (C) AND LOCKED DOWN BY THE "U" BOLT (D).

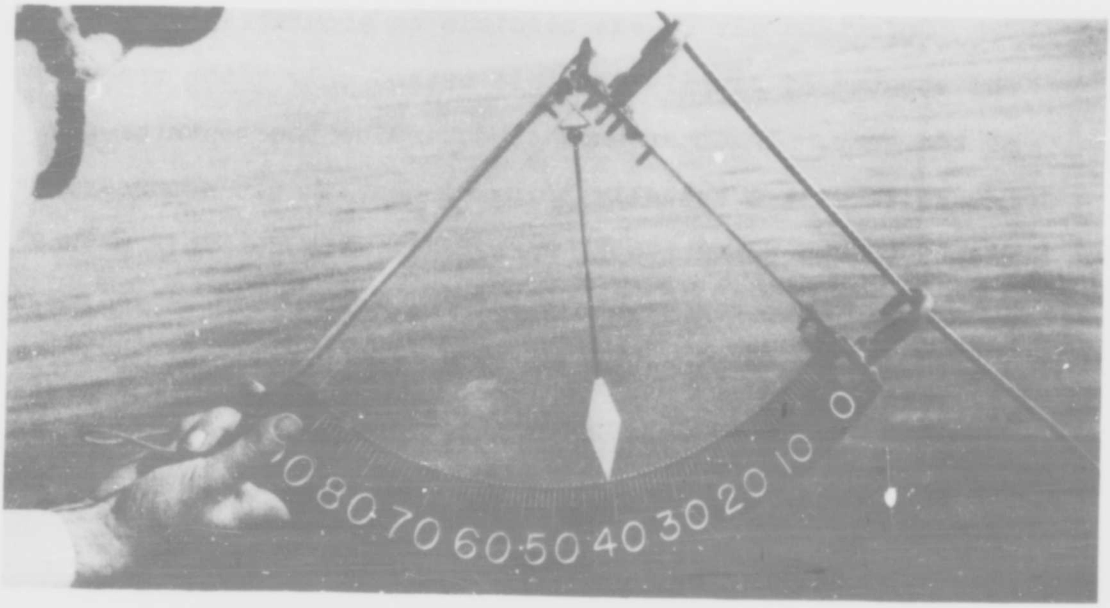

FIGURE 8. THE SCRIPPS INCLINOMETER SHOWN AFFIXED TO THE TOWING WIRE. THE USE OF SAIL SNAPS ALLOWS THE INSTRUMENT TO REMAIN IN POSITION WHEN WIRE IS BEING RECOVERED.

tow cable over a carefully calibrated standard meter block. The angle-of-stray of the towing wire was measured with the aid of a Scripps-type inclinometer (Fig. 8). The instrument consists of a hollow, lucite quadrant with a 90-degree scale marked along its edge. An internal indicator pendulum, swinging in an oil bath, permits a reliable reading of wire-angle even in heavy seas.

The accuracy of depths determined by means of the inclinometer was checked for nearly every haul against the results obtained by the use of the depth-time recorder. A typical depth-time plot of a haul by the two methods is shown in Fig. 9. This diagram and its caption serve to illustrate and explain the method of handling the gear and its behavior. It can be seen that the net follows a course which can be divided into three stages. While the net is being laid the boat is moving ahead at about 5 knots, paying out wire freely. During this period the net sinks rapidly and almost vertically (stage 1). When the desired amount of tow cable has been released, the winch is braked and locked. The path of the net now alters markedly; as it is hauled it moves forward and downward in the water, and begins to fish effectively (stage 2). Speed of hauling was established by use of the primitive but reliable "Dutchman's Log." The average rate of towing in 85 hauls made under all conditions was 1.22 knots, with extreme variations of 1.0 to 1.9 knots

An upward oblique haul can be made by slowly taking

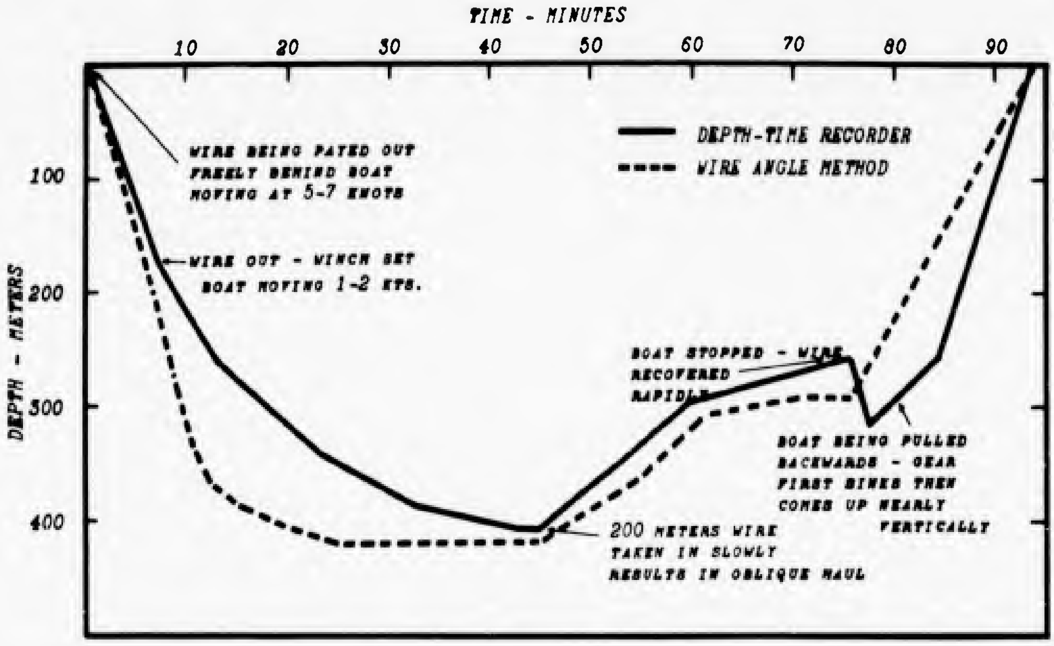

__FIGURE__ 9. A typical "Depth-Time" plot of a haul as determined by Depth-Time Recorder and Wire Angle Measurement. Method of handling the gear and its behavior is also indicated.

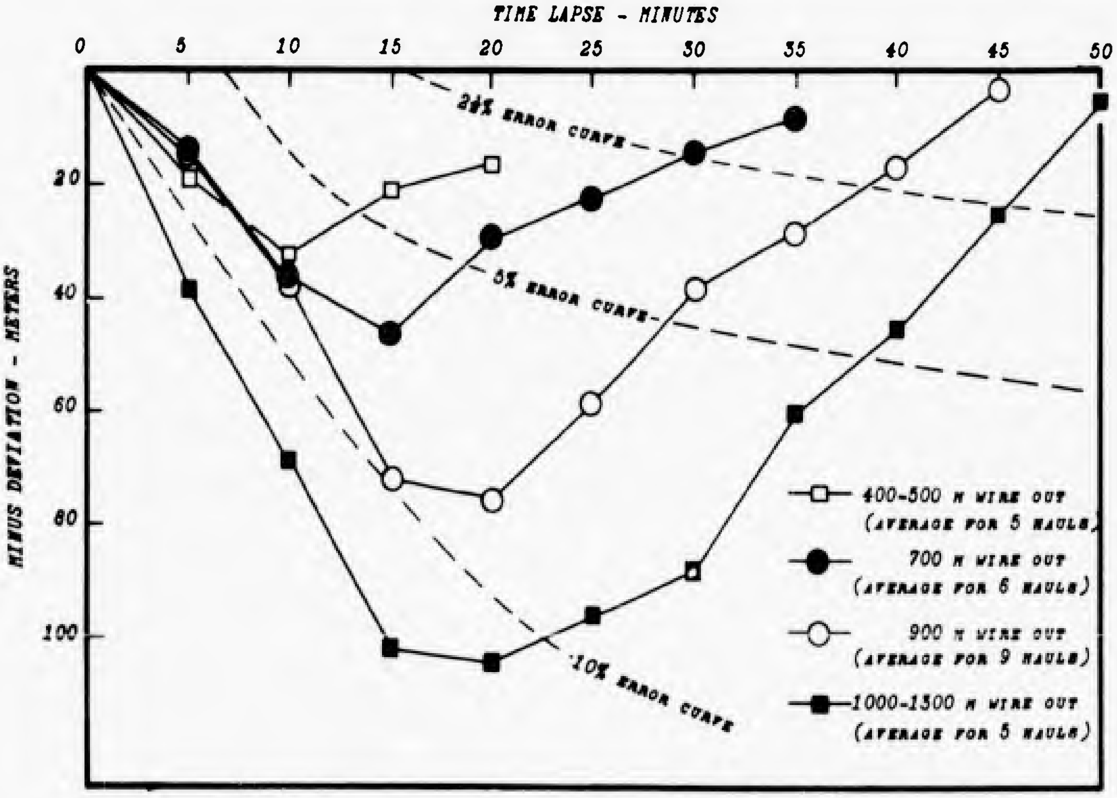

__FIGURE__ 10. The deviation of wire angle measured depth from pressure measured depth as a function of time for various lengths of wire used.

in wire while the vessel is under way. The net may be brought to the surface in this way, but the general practice during the course of this investigation was to take in 100 m. of wire in this manner, in order to take the sag out of the cable, and then to stop the boat and recover the net rapidly by speeding up the motor. At first the net tends to sink as the boat is pulled backwards in the water; then it comes up in a direction that rapidly approaches the vertical (stage 3). As the net surfaces the boat is moved ahead slightly to avoid fouling the gear on the propeller and transducer heads.

In presenting the plots of these hauls in the data to follow, stages 1 and 3 of the haul have been indicated by broken lines, whereas stage 2, referred to as the "effective haul", is shown by a solid line. It will be noted in Fig. 9 that at the beginning of the period of effective haul the discrepancy between actual net depth and that indicated by the wire angle increases rapidly at first, as the wire, which offers less resistance than the net, sinks more rapidly and develops a sag. The catenary of the towing wire decreases steadily as the haul continues. The accuracy with which wire angle indicates depth, therefore, tends to increase with the length of time the gear is towed. Despite the drawbacks of the wire angle method and its dependence on such variables as amount of wire out, speed of boat, set and drift of currents, and direction and velocity of winds and seas, this method can often yield a good estimate (within 5%) of depth of fishing. The most important variables, speed of the boat and amount of wire paid out, could be controlled. Since it was necessary to have some idea of just when such readings could be considered valid, a comparative study of the depth-time plots made by both wire angle and depth-recorder methods was made for 25 hauls taken with various lengths of wire out. This resulted in the establishment of factors for correcting the wire angle readings obtained with various lengths of tow cable and a constant towing velocity of 1.0-1.5 kts. The factors are graphically illustrated in Fig. 10. Here again it is seen that the basic pattern of a sharp increase in wire angle error, followed by gradual decline, holds for all the different lengths of wire used. The 5% error curve superimposed over the data gives the necessary time lapse before one can assume this degree of accuracy. For example, with 900 meters of wire out about 27 minutes must elapse before wire angle readings can be considered to indicate net depth within this limit of error.

Even with the correction factors, however, there are still some disadvantages to the wire angle method of determining net depth. First, the time lapse factors are too long, and by the time the error has dropped to the 5% level the net has already fished for a considerable period. Second, while allowances for greater error can be made in the early stages of a haul, the curves presented represent a statistical average, and wire angle reading of individual hauls show some inconsistency in per cent error at a given time. As a result, it is not always possible to place the net at the desired level by the wire angle method.

In future studies, a possible solution to these problems would be the application of such an electronic telemetering instrument as that described by Dow (1955). The Boden, Kampa, Snodgrass, and Devereux (1955) telerecording device also offers an excellent solution for a ship equipped with an insulated towing wire and operating on an unlimited budget.

Catching Efficiency of Different Type of Nets. In evaluating the results of biological samplings taken at scattering-layer depths, the relationship of the type of gear used to the results obtained has been stressed by many authors (Johnson, 1948; Moore, 1950; Boden, 1950a; Tucker, 1951; Hersey, Johnson and Davis, 1952; Batzler and Westerfield, 1953). In view of the importance of this factor a brief discussion may be of value. It must be admitted that conventional plankton nets constitute extremely poor devices for evaluating the population densities of the micronektonic organisms which probably are the major source of acoustical reverberation in scattering zones. Their effectiveness may be likened to that of a butterfly net in the hands of a blindfolded person who is attempting to sample the winged organisms of a meadow; the net may snare a sampling of insects, but very few birds. The inherent deficiencies of such blind sampling methods are magnified by the fact that the effective volume of water sampled is reduced by the inadequate straining properties of small-mesh netting, and also by the fact that a head of back-pressure is built up in front of the net. Further, vibrations set up by the towing wire, the bridle, and the net itself may provide a warning which results in avoiding reactions on the part of the organisms.

While the importance of the latter factor has not been established by experimentation, several pieces of evidence are at hand to substantiate this view. It has long been argued that in the upper levels where light conditions are good, the organisms can see the net and can therefore successfully avoid it. However, Moore (1950) in his discussion of effectiveness of plankton nets brings out the point that the actual catch of euphausids made at the surface at night compared with visual estimation of the abundance of this brightly luminescent crustacean in the water was in the order of about 1:75. Obviously these organisms are able to avoid nets even at night, and it would appear that some other sense besides sight must come into play. Personal observations of the neritic euphausid <u>Thysanoessa spinifera</u> while it was swarming at the surface during daylight hours indicate that it is extremely sensitive to the vibrations created by the propeller of the boat, the tightly packed shoals sounding rapidly whenever they were approached with the motor running. However, with the engine shut down, we were able to drift into dense schools of these organisms and fill a dipnet to the brim simply by holding the net in the water and allowing them to swim into it. Laboratory observations of Sergestes similis, discussed more fully elsewhere in this paper, suggest that these mid-water prawns are highly sensitive to tactile stimulation, for they respond vigorously to touch and water currents. The lateral-line system of fishes would seem to be ideally suited to aid these organisms in escaping capture.

It would appear then, that the relatively small and partially obstructed mouth-opening of the conventional plankton net, plus its poor straining, pressure and vibration factors, all lead to an unsatisfactory catch of the larger and more active organisms. Up to a certain point, speed of hauling is not necessarily a critical factor. Nets hauled at moderate speeds may give the illusion of being more effective simply because they sample more water per given period of time. On the other hand, large mesh nets, such as the Tucker net, fail to give an accurate picture of the density of the smaller planktonic forms which can pass relatively freely through the webbing of the net.

A quantitative estimation of the dependency of the catch on the type of gear employed is provided by the results of an experiment described below. During the course of this work, five pairs of hauls were made at various depths and on randon dates. One haul of the pair was made with the M-net, the other with the T-net. While it was impossible to make them simultaneously, one haul followed the other as soon as the first net could be recovered and the gear changed. Other factors such as depth, time of hauling, speed, and direction of the vessel were held as constant as possible. The results presented in Table 1 were computed in the following manner. The total counts of the various organisms taken in all the hauls were lumped for each type of net (columns 1, 3). The catch of the M-net was then adjusted to that of the T-net on the basis of the difference in their respective mouth areas (column 2). In making this adjustment the following factor has been considered. While the mouth of the T-net is approximately six by six ft., when it is being hauled the bottom bar drags behind the tow point at an angle of about 40° from the vertical. Therefore the effective opening is reduced to an area approximately 6.0 by 4.5 ft., or 2.43 m.^{2}. The opening of the M-net, being one m. in diameter, presents an aperature of .785 m.^{2}. Thus, to compare the catch of the two nets, that of the M-net must be multiplied by a factor of 3.1. The relative catching effectiveness of the T-net as compared to that of the M-net is expressed as a ratio, and is termed the "catching coefficient" (column 4).

Column	1	2	3	4
ORGANISMS	M-NET		T-NET	
	Total	Adjusted	Total	Catching coefficient
Cyclothone signata	25	72	51	.71
*Diaphus theta**	1	3	58	19.3
Lampanyctus leucopsarus (total)	24	69	215	3.1
Lampanyctus leucopsarus (larger than 40mm.)	9	26	137	5.3
Lampanyctus leucopsarus (smaller than 40mm.)	15	43	78	1.8
Sergestes similis (adults)	11	32	298	9.3
Sergestes similis (immature)	112	325	486	1.5
Euphausia pacifica (adults)	1,785	4,176	619	0.15
Euphausia pacifica (immature)	11,687	33,894	420	0.012
Sagitta lyra (adults)	467	1,344	360	0.27

*Data based on only 1 pair of hauls.

TABLE 1. Catching efficiency of the Tucker net as compared with the meter net.

Even though the method used to compare catching powers of the two nets is crude, it is evident from the results, that while the T-net is considerably more efficient at capturing the micronekton, it fails to retain a large percentage of the planktonic organisms. The importance of considering the factor of the stage of development of a particular organism is also amply demonstrated. The data on the myctophid fish, Lampanyctus leucopsarus, for instance, indicated a catching coefficient of 3.1. However, when the catch is computed for individuals under 40 mm. long this figure drops to a 1.8, whereas when we consider only the individuals over 40 mm. in length the factor is raised to 5.3. A mid-water prawn, Sergestes similis, also shows a catching coefficient for the adults of 9.3, but only 1.5 for the smaller individuals of the next year-class. Concerning the euphausid shrimp, Euphausia pacifica, the results indicate that the M-net retains both large and small specimens much more effectively than the T-net. The catching coefficient values for each species must therefore be considered as indications of the order of magnitude and not as critical figures. In passing, it is interesting to note that the results on the small gonostomatid fish, Cyclothone signata, indicate a catching coefficient of 0.71. It would seem that in terms of catchability, this genus is more planktonic than nektonic. This fact may partially account for the high percentage of fishes of this genus represented in the extensive collections of Beebe which were made with gear similar to the M-net (Beebe and Vanderpyle, 1944).

While it has been shown that the T-net is more effective than the M-net in measuring micronektonic populations, there is still no means at our disposal by which we can judge its absolute effectiveness. We can assume that our net is only sampling a percentage of any given population, but just what this percentage is for individual species and year-classes remains an unknown. Up to this date, underwater television and photography have failed to provide adequate data, and the only direct evidence we have on the _in situ_ population densities of bathypelagic organisms are the qualitative statements of the few observers who have descended into the depths of the oceans.

Barton, in a newspaper account of his bathysphere descent off the Southern California Coast, describes a zone of tumbling, swarming, weird living beings (euphausids? prawns?).* Concerning bathypelagic fishes, we have the much quoted statement of Beebe (1934), who, in summing up his underwater observations from the bathysphere, concluded that the midwater fish population was larger than had been demonstrated by means of six years of trawling with conventional plankton nets. Cousteau (1954), Houot (1954), and Edgerton (1955), in relating their experiences in the French Navy's bathyscaphe, mention no great concentration of midwater fishes. They do, however, talk of a "puree of living creatures," or "crazy snow" which includes entities up to 2 mm. in size.

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*I have not seen this account, but am quoting from Tchernia, (1952).

Medusae, siphonophores, ctenophores, shrimp (euphausids?), shrimp with long bent antennae (sergestids?), large prawns, squid, and a sprinkling of Argyropelicus and other diminutive fishes, are mentioned as the larger organisms in the water soup. Discussion of these observations and the problem of whether large nektonic organisms, which we have completely failed to sample, are present at DSL depths is left for a later section of this paper.

Another important question must be asked. Are micronektonic organisms more or less evenly distributed within given horizontal levels at DSL depths? Careful statistical studies of variation in surface plankton catches are available in the literature (Winsor and Clarke, 1940) and indicate that the distribution is often patchy. No such study has ever been made on the plankton and micronekton of deeper waters. The general results of the present work, and of the five-year plankton research program of which it is a part, suggest that many micronektonic, mid-water organisms are randomly distributed within a given horizontal stratum. Such forms are taken in all hauls throughout the year or during the proper season, and the number of individuals in the catches is roughly proportional to the time that the nets fished at the appropriate depths. While hauls of the duration used appear to sample the organisms reliably, there is as yet no strict proof that true population densities can be established on the basis of such net hauls. It can be said, however, that the larger the net and the longer the tow at the desired depth, the more reliable should be the resulting sample. While the methods used here have sometimes seemed crude, they still represent a degree of overall refinement higher than any heretofore achieved in reported studies of the micronekton at DSL levels.

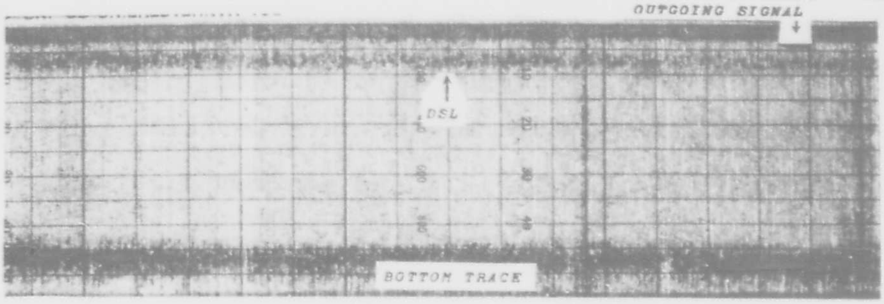
TYPES OF SCATTERING LAYERS

Definitions of Types of Layers.

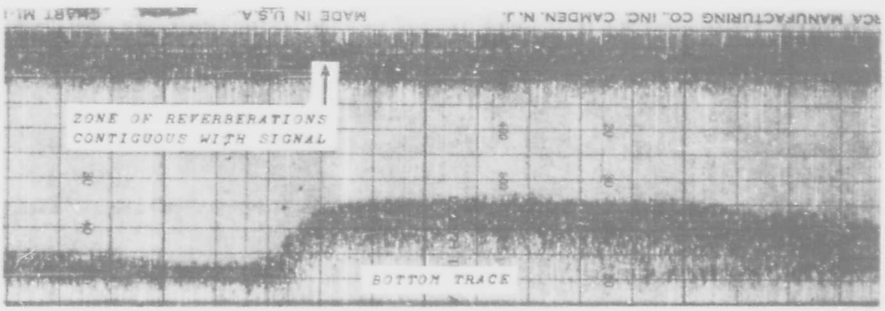
A series of 82 daytime observations over a two-year period with the NMC echo sounder has shown that sonic scattering layers are a constant acoustical property of the deep water masses adjacent to Monterey Bay. In terms of depth, density and general pattern, these layers are so variable in nature that a generalized description is meaningless. However, it has been possible to characterize the scattering patterns recorded, and to classify these into certain types. These are defined below.

Type 1: Single Resolved Layer. The zone of scattering is clearly resolved from the region of the signal and surface scattering into a well defined layer of varying depth, thickness and intensity. This is the classical picture of a scattering layer (Fig. 11-A). Occasional indications of a diffuse zone of scattering below the main layer may be recorded, at times the suggestion of an upper layer, masked by the signal, may be present.

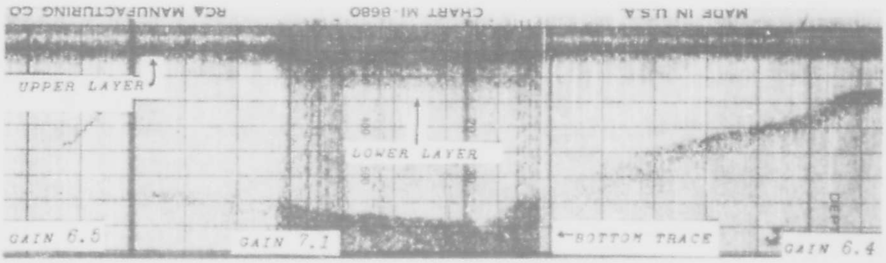
Type 2: Solid Scattering Pattern. The outgoing signal merges with the zone of scattering so that a continuous line is traced by the stylus even at low amplification, and it is difficult or sometimes impossible to differentiate the upper limits of the scattering zone (Fig. 11-B far right portion). On occasions, sporadic scattering



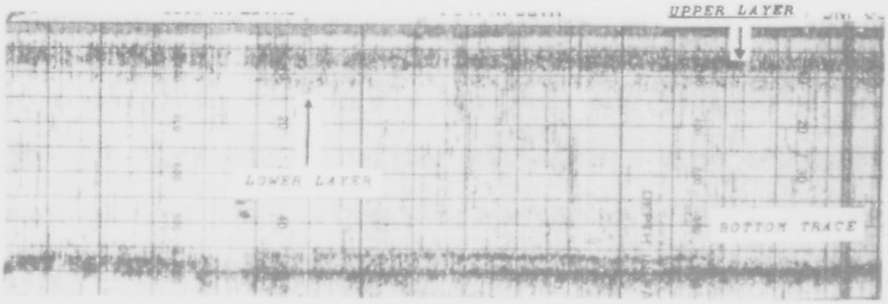
A. Type 1. Single Resolved Layer. Station 497, 23-March-55.



B. Type 2. Solid Scattering Pattern. Station 426, 10-May-54.



C. Type 3. Modified Double Layer. Station 472, 17-November-54.



D. Type 4. Double Resolved Layer. Station 476, 8-December-54.

FIGURE 11. TYPES OF SCATTERING LAYERS

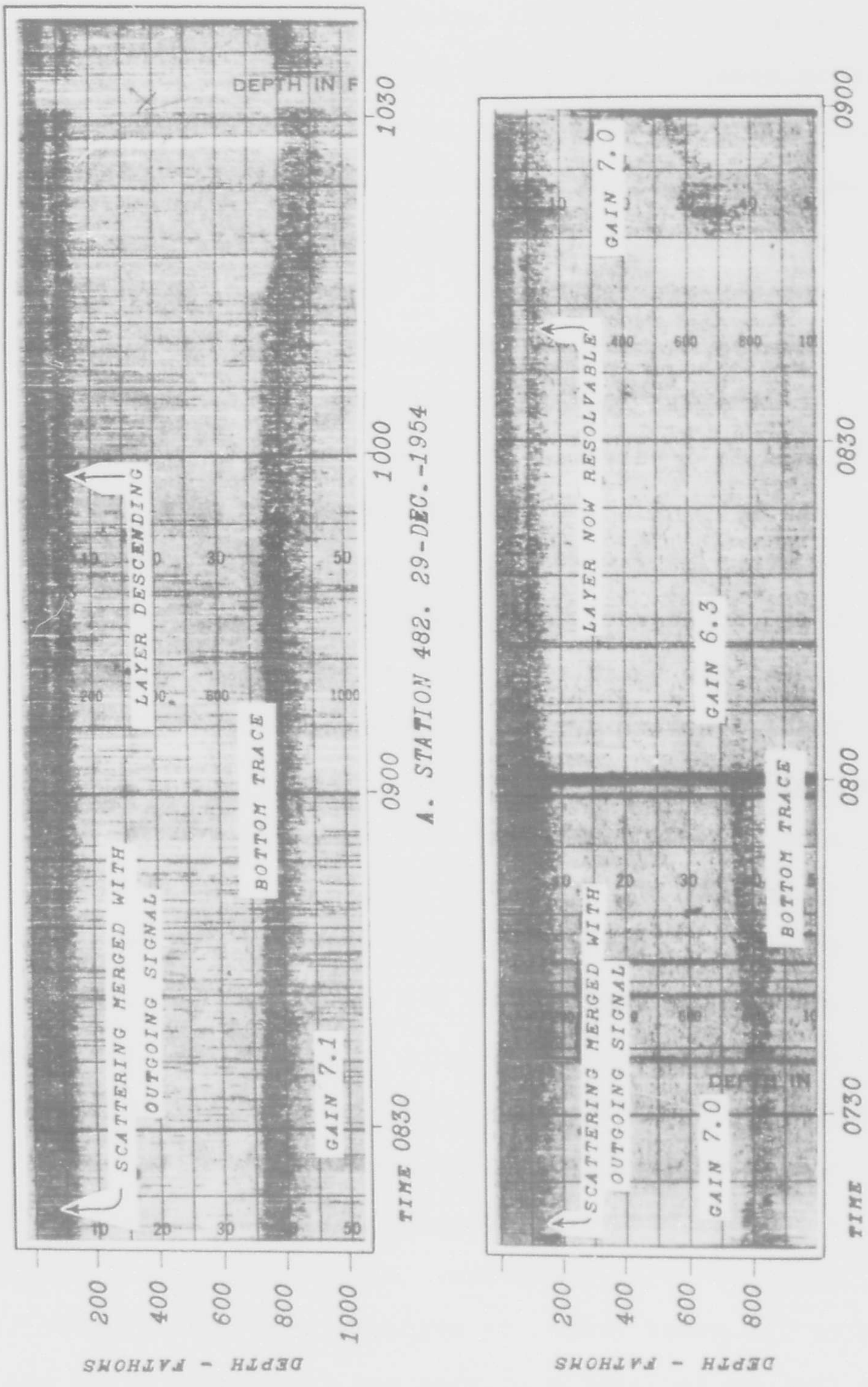
may be registered below the solid scattering zone. In other cases, while no well resolved layer is recordable, a slight differentiation of the reverberation zone is discernable (Fig. 11-B, left and central portions).

It should be emphasized that any scattering pattern can be made to appear solid by increasing the gain to a high level. The Type 2 pattern was considered to prevail only when the lowest sensitivity setting at which clear reverberations could be recorded yielded solid scattering. Fig. 12-B. illustrates a case where an apparently solid type of scattering was resolved into a clear type 1 pattern by reducing the sensitivity setting from 7.0 to 6.3.

Type 3: Modified Double Layer. Two layers are recordable. However, the upper layer is well resolved only at low sensitivity settings, and the lower layer recorded only at high amplification (Fig. 11-C).

Type 4: Double Resolved Layer. Two well defined layers are recorded, both being resolved at the same sensitivity setting (Fig. 11-D).

In reality the scattering patterns outlined above intergrade in a continuous series. Nevertheless, the dominant types are quite distinctive, and can be characterized in objective terms. Because the position of scattering layers varies diurnally, and because of the importance of light on this movement, the type of pattern



A. STATION 482. 29-DEC.-1954

B. STATION 510. 18-JULY-1955

FIGURE 12. RESOLUTION OF SCATTERING LAYERS

for a particular day was established on the basis of midday observations (10:30-13:30 P.S.T.). The time of net hauling was also restricted to these hours. Fig. 12-A shows an example of the daytime movement of a scattering layer. It depicts quite well the transformation from a solid scattering pattern to a single resolved layer as the sun reaches higher positions and its light penetrates to deeper levels. Note that no change in sensitivity settings is involved.

In attempting to explain the causes of these different types of scattering patterns, three major variables must be considered: (1) intrinsic changes in the sounding gear, (2) fluctuations in the nature, size, density, and vertical distribution of the scattering entities, and (3) variations in the physical structure of the water masses present. The influence of intrinsic changes in the sounding gear have been dealt with under methods. As noted earlier, these factors have been taken into consideration in the analysis of the echograms, but it is possible that they may account for occasional variations in scattering patterns recorded (specific examples will be indicated throughout the presentation of the data). They cannot, however, explain the type of pattern in the great majority of echograms. The marked seasonal trend, to be discussed later, is evidence that each pattern is in fact an indication of what can be thought of as the acoustical condition of the water mass on a given day.

Since scattering-pattern types reflect the acoustical properties of the medium through which the sound is transmitted, they should vary with either the physical structure of the water mass, or with certain of its biological contents, or with both. With this in mind, pertinent data obtained on 15 stations when different types of patterns predominated are presented graphically with accompanying comment in the following sections.

The data for each of these "type-layer stations" are organized as illustrated in Fig. 13. At the top of the figure approximately one half of the echogram recorded on the station is reproduced in reduced scale. The instrument was operating on the 2000-fathom range, and to save space only the upper half of the tape is shown. Depth is indicated by horizontal lines at successive 100-fathom intervals. On the horizontal scale, time is marked by vertical lines at six-minute intervals. The chart below the echogram shows a vertical section through the water mass investigated. Position, vertical spread, and nature of the scattering layer was established by measuring its position and width on the original, full-sized echogram with dividers, and reading it against a fathom-to-meter conversion scale. Because of the crudeness of the tracings, the exact limits are rather arbitrary, but the practice has been to select for measurement the clearest section of the echogram recorded during the time the hauls were being made. Hauls are numbered in order of increasing depth and

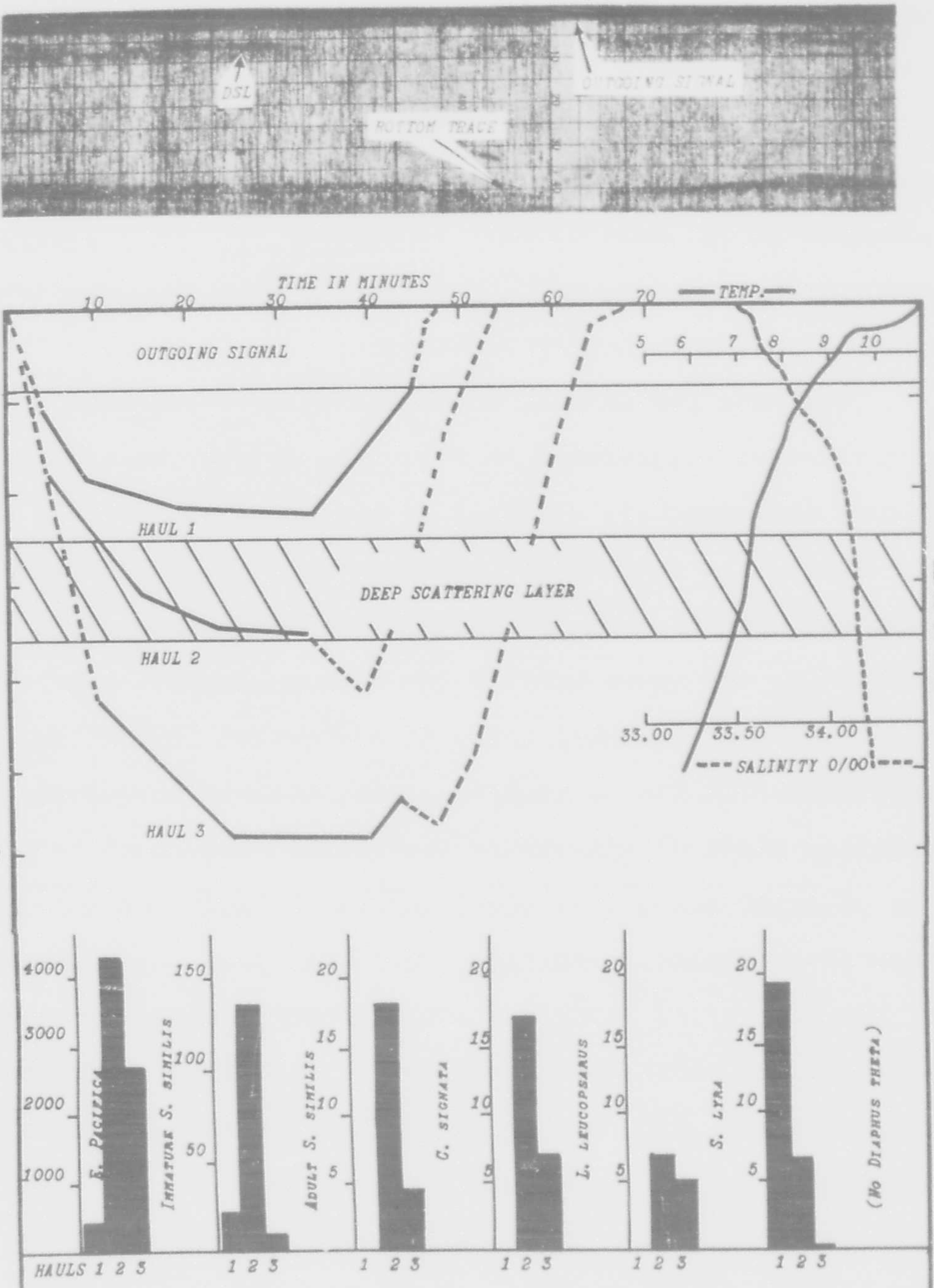


FIGURE 13. STATION 501, MAY 4, 1955.

not necessarily in the order in which they were taken. Duration of net hauls is indicated by the scale in minutes along the top abscissa. Depth for all data is noted on the ordinate at 100 m. intervals. Curves showing variation of temperature (solid line) and salinity (broken line), based on 14 Nansen Bottle samples, are plotted in the upper right, using the same depth scale. The temperature scale, in degrees centigrade, is placed above the curves, and the salinity scale, in parts per thousand, is indicated below the curves. The numbers of individuals of specific organisms taken in the respective hauls are shown graphically at the bottom of the figure. Since populations of different species vary in order of magnitude, it has been necessary to assign different scales to the counts of the various organisms. These are indicated on individual ordinates. Data presented on catches is limited to that of the dominant macro-organisms. These include the myctophid fishes Lampanyctus leucopsarus and Diaphus theta, the small gonostomatid fish Cyclothone signata, the chaetognath Sagitta lyra, the euphausid shrimp Euphausia pacifica, and the mid-water prawn Sergestes similis. The general nature and size of some of these organisms is indicated in Fig. 31. The stations have been grouped according to DSL pattern type and are not arranged chronologically.

Before turning to the data on individual stations, it seems worthwhile to summarize the sources and extent of the error inherent in the complete process of measuring and of plotting on paper the depth and extent of reverberation in the ocean, and the course of the net hauls. As has been indicated, even under ideal conditions there is a built-in error in echo sounders which may be as high as 5 per cent. With the "Tage" equipment a further source of error could be occasional shifts in cyclic output of the generator which served as the power source. A check of echo-sounding accuracy was possible when the water of the upper 200 m. was acoustically clear enough so that a trace of the net was recorded while it was being recovered vertically. The depth of the net trace could then be measured against the amount of wire out. Results of these observations indicate that the possible error in the echo-sounding data is of the order of 5 per cent. Despite careful technique, the possible error involved in interpreting fuzzy scattering layers in terms of a definitive line on paper could be as high as an additional 5 per cent. With regards to measuring the course of the hauls the error inherent in the depth-time recorder is less than that involved in reading the graph traced by the recorder stylus, which may run as high as 10 meters. When depths were based on wire angle measurements, the error may be greater. Some of these errors tend to cancel each other out. Should they by chance all operate in the same direction in a given instance, it is possible that the combined error in plot of the scattering layer and plot of the net haul on the graph may run as high as 15 per cent.

Type 1: Single Resolved Layer Pattern.

Station 501. 4 May 1955, Time: 0815-1420. (Fig. 13).

Echogram. Despite the scratchy tracings due to jamming, a layer could be resolved at a sensitivity setting of 6.5. At the time the net hauls were made, the layer had dropped down to approximately the depth shown on the chart below the echogram.

Hauls. Three hauls were made with the T-net. In each case the path followed by the net, as determined by the depth-time recorder, is plotted on the diagrammatic representation of the echogram. Haul 1 sampled the water just above the layer, haul 2 sampled the layer itself, and haul 3 fished the regions below the layer.

Counts of Organisms. These are not corrected for the slight variation of effective haul time. The results indicate that E. pacifica is concentrated at the DSL level; haul 2 took ten times as many individuals as haul 1. The relatively high numbers taken in haul 3, however, suggests that there was no sharp bottom to the euphausid population. The young Sergestes similis population (about half-grown at this time of year) shows a striking correlation with the zone of scattering. The catch at the DSL level is about seven or eight times that of the hauls taken above and below the layer. Adult S. similis, while not taken in high numbers, show a good relationship with the layer. The same is true of C. signata, but the catch of Lampanyctus leucopsarus is too low and that of the two hauls in which it was taken are too similar to be a reliable indication of trend.

Hydographic data. The temperature curve shows a moderate seasonal thermocline at about 25 m. and a relatively even negative gradient from this point on. The salinity curve indicates water of moderately low salinity at the surface, then fairly rapidly increasing values to approximately 180 meters, and thereafter a very gradual increase with depth. The slopes of both of these gradients are comparatively uniform through the DSL and in the layers immediately above and below it, and they indicate no density anomalies which could account for the layer.

Conclusions. The DSL is associated with a concentration of the organisms *E. pacifica*, *S. similis*, and *C. signata*, with *E. pacifica* dominating numerically, roughly in the order of 30 to 1.

Station 458, 10 September, 1954. Time: 0705-1300. (Fig. 14).

Echogram: The section presented was recorded at an S.S. of 7.0 during the net-hauling phase of operations. Note that as the generator slows down and the power source weakens, the recorded layer shrinks in vertical dimensions. At the left hand portion of the echogram, reverberations from the shallow layers merge with the outgoing signal so that a trace is recorded to 100 fm. This zone shrinks to 70 fm. later in the day. The region between the signal

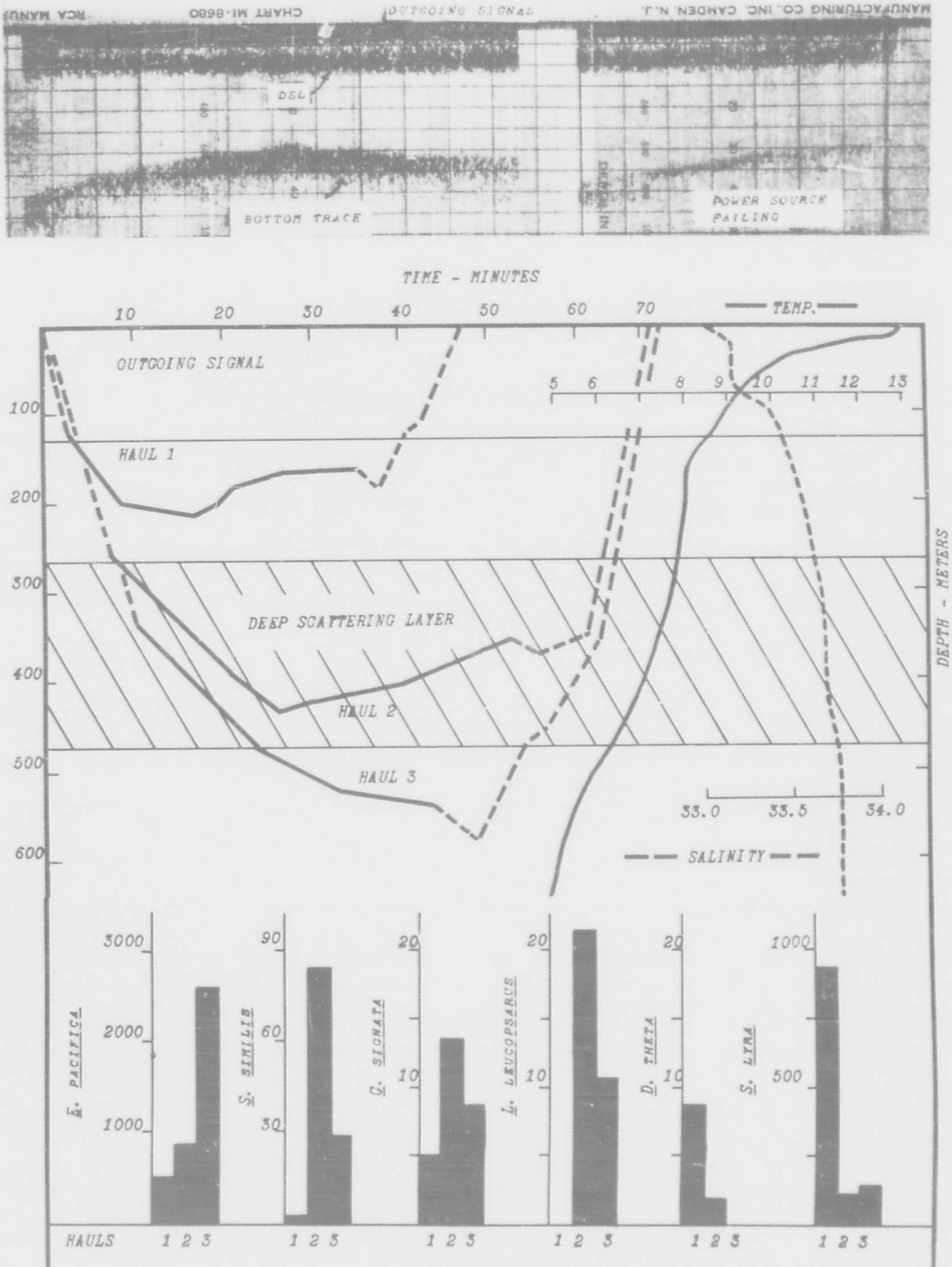


FIGURE 14. STATION 458, SEPTEMBER 10, 1954.

and the DSL is fuzzy with numerous indications of discrete echos being recorded.

Hauls. Three were taken. Haul 1 fished the zone between the shallow scattering and the DSL. Haul 2 fished within the zone of reverberations. Haul 3 was an attempt to sample the area below the layer but in this respect it was only partially successful. However, about half the time of the effective haul was spent below the layer, thus providing a basis of comparison with haul 2.

Counts of Organisms. While taken in fairly high numbers, *E. pacifica* does not reach its peak concentration within the zone of scattering, but instead shows an increase in numbers with depth. The prawn *S. similis* shows an excellent correlation with the scattering zone. The fishes *C. signata* and *L. leucopsarus* also are present in greatest numbers in the DSL. *D. theta* on the contrary, is concentrated above the layer, although taken in low numbers. *S. lyra* is also concentrated at the higher level. The similar numbers of these large chaetognaths taken in hauls 2 and 3 suggest that they may well have been caught while the nets were being set and recovered, since the upper level was fished for an equal amount of time in both cases. This in turn would imply a fairly even horizontal distribution. The vertical distribution of another euphausid taken, *Nematoscelis difficilis*, is of interest and is shown below.

Haul	Total number taken	Gravid Females*	% Gravid Females
1	209	51	24.4
2	159	145	91.2
3	42	8	19.0

In contrast to E. pacifica, this species decreases in numbers with depth. More interesting is the fact that there is a striking concentration of gravid females taken at the middle depth. This is a good indication of how complex the vertical distribution of an organism may be.

Hydrography. A strongly developed thermoclime merges into the region of permanent negative slope at about 150 m. The salinity gradient in the upper 100 m. undergoes step-like flucuations, then grades into a fairly smooth curve from 100 meters down.

Conclusions. S. similis, C. signata, and L. leucopsarus can be related to the recorded zone of reverberations. The data suggest that E. pacifica's greatest density is below the DSL; however this organism is numerically the dominant entity in the layer by a factor of about 7:1. D. theta may be responsible for the echos recorded above the layer. The DSL does not occur at levels characterized by pronounced changes in the hydrographic gradients.

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* The gravid females are easily recognized by the large egg mass carried under the thorax.

Station 429. 17 May 1954. Time: 0645-1203. (Fig. 15)

Echogram. Scattering was higher and more diffuse early in the morning, dropping down and condensing by mid-morning to form an excellent example of the single scattering-layer pattern. The acoustical clarity of the upper water is indicated by the sharpness with which the outgoing signal is cut off. This portion of the echogram was recorded at an S.S. of 6.9; however, even a gain of 7.4 failed to distort the pattern. The hauls were made while slowly approaching the continental shelf and the DSL appears to thin out at about 175 fm. Haul 2 was recovered vertically, and as the net entered the sound cone it was recorded by the instrument. The width of the bottom trace is due to the fact that the splayed-out signal cone is scattering back from the steep escarpment of the Monterey Canyon over a relatively long time period.

Hauls. Haul 1 fished the extent of the layer and was recovered vertically. Haul 2 fished momentarily in the layer while settling and during oblique recovery; however, it traversed the regions below this level for a period nearly 8 times as long and thus provides a basis for comparative purposes. Note that the effective time of hauling for haul 2 is about twice that of haul 1.

Counts of Organisms. The euphausids are present in relatively low numbers, and it is impossible to conclude anything concerning their vertical distribution since the longer period of fishing of the deeper haul may account for

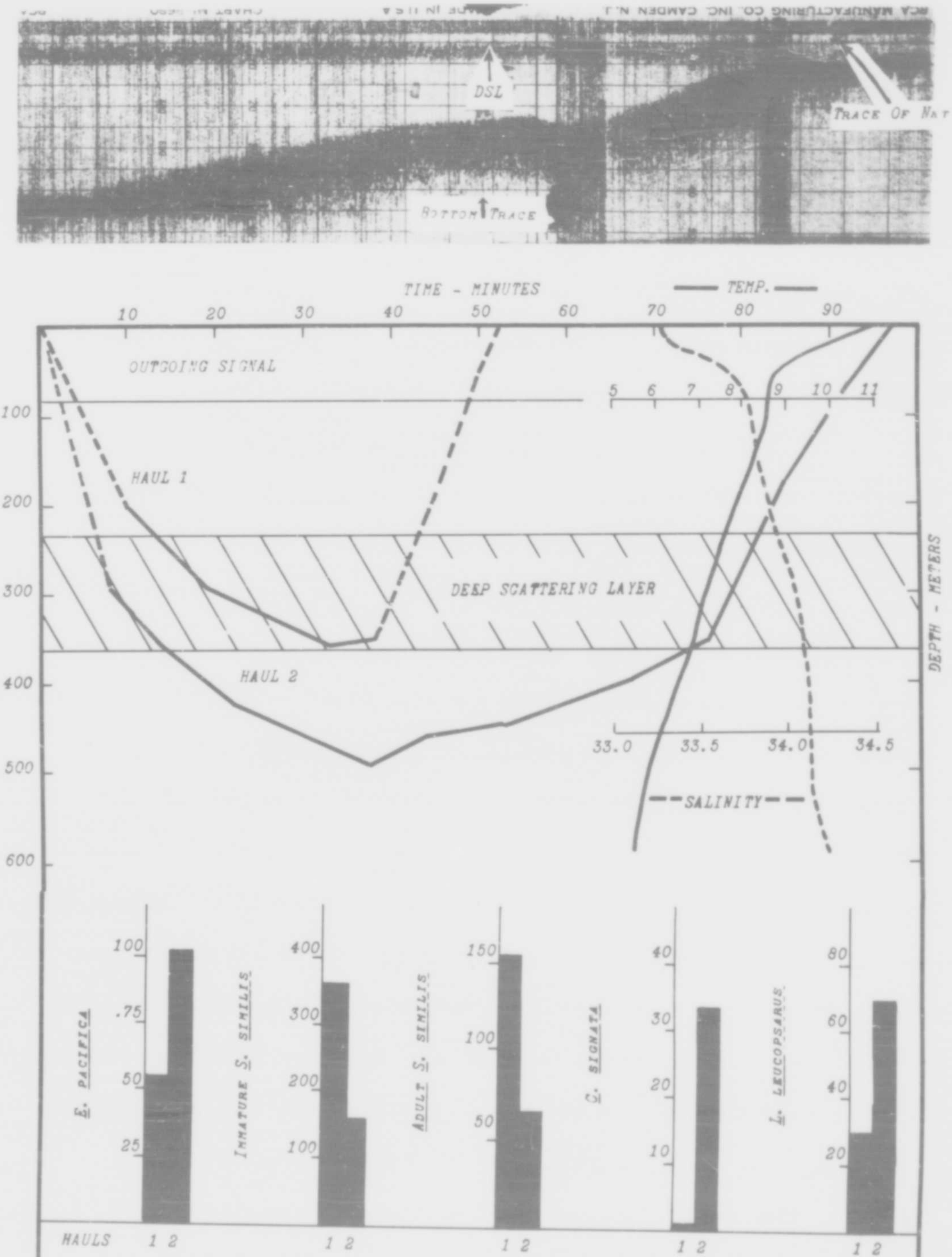


FIGURE 15. STATION 429, MAY 17, 1954.

the increase in numbers. S. similis dominates the catch numerically, and the evidence indicates that both immature individuals and adults are concentrated at the DSL level. L. leucopsarus is common, but correction for the difference in hauling time makes the two counts roughly equal, and no conclusions regarding its relation to the DSL can be drawn from the evidence. C. signata appears to be concentrated at depths below the DSL. No D. theta were taken, and S. lyra was not counted.

Hydrographic Data. Steep gradients in the thermal and salinity curves near the surface give way to low even gradients from 50 m. on down.

Conclusions. A relatively low population of E. pacifica, and high populations of S. similis and L. leucopsarus are demonstrated at DSL depth. In terms of numbers, S. similis predominates by a factor of 8:1. No abrupt changes in temperature or salinity occur in the DSL.

Station 504. 27 May 1955, Time: 0628-1100. (Fig. 16).

Echogram. An excellent resolved layer was recorded at low sensitivity settings of 6.3 and 6.5. This portion was taken while making net hauls. Earlier, while on the hydrographic station, the layer was slightly lower; it tended to rise slightly as we approached the continental shelf. The sharp bottom of the signal zone indicates acoustically clear water. A net trace can be made out slightly to the left of the manufacturer's label printed

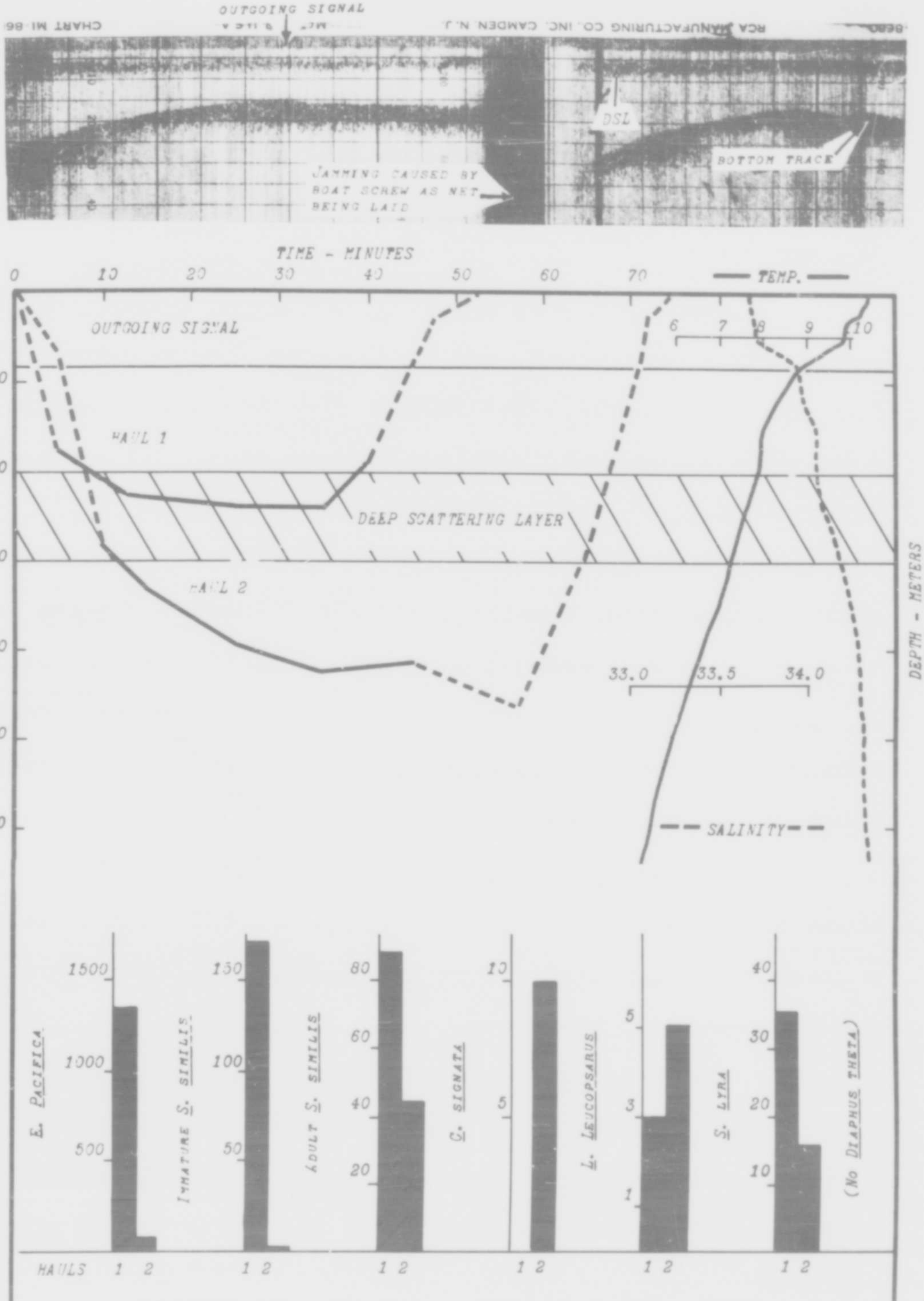


FIGURE 16. STATION 504, MAY 27, 1955.

upside down on the top of the tape.

Hauls. Two hauls were taken. Haul 1 was well-placed and fished to about the middle of the layer, while Haul 2 fished momentarily in the lower region of the layer and then dropped downward, sampling a 120 m. region below the DSL.

Counts of Organisms. E. pacifica is taken in relatively high numbers, and is 30 times more abundant in the haul taken through the layer. The immature sergestid population is even more sharply limited to the upper level, and the counts of the adults also indicate a center of population density at the shallower level. The fishes are poorly represented; however it is clear that C. signata is restricted to greater depths than that sampled by haul 1. S. lyra is also taken in low numbers, and it is a fair surmise that its greatest population density is above the level of the upper haul.

Hydrographic Data. Upper gradients are indicative of turned over water, and while decided clines are present at 50 m., temperature and salinity gradients are low and stable at DSL depth.

Conclusions. E. pacifica and the two year classes of S. similis can be associated with the scattering zone. E. pacifica is the most numerous in the order of 5:1. No hydrographic phenomena appear to be the cause of the reverberations.

Station 505. 6 June 1955. Time: 0654-1110. (Fig. 17).

Echogram. Most of the portion presented was recorded while on the hydrographic station. The zone of light diffuse scattering just below the main zone of reverberations gives the suggestion of a double layer; as the day progressed, however, this pattern disappeared, and the top of the main layer moved downward to the position indicated on the haul diagram.

Hauls. The two hauls provide a basis of comparing the catch from a region near the upper zone of scattering with that of a haul which fished briefly in the layer and then dropped rapidly down to the 600 m. level.

Counts of Organisms. *E. pacifica*, *S. similis* and *S. lyra* are present in relatively high numbers in the DSL. These forms show a sharp decline in population density at the lower level; results are particularly striking for *S. similis* adolescents. The adults of *S. similis* and the fishes were taken in low numbers, which suggests either that few were present or that their greatest density may lie somewhere between the two hauls, perhaps near the zone of diffuse scattering which was recorded early in the morning. Of the 17 individuals of *L. leucopsarus* taken in the upper haul, 15 were young postlarval forms, whereas adults predominated in the lower haul.

Hydrographic Data. The temperature curve shows a pronounced seasonal thermocline to 30 m. The salinity curve

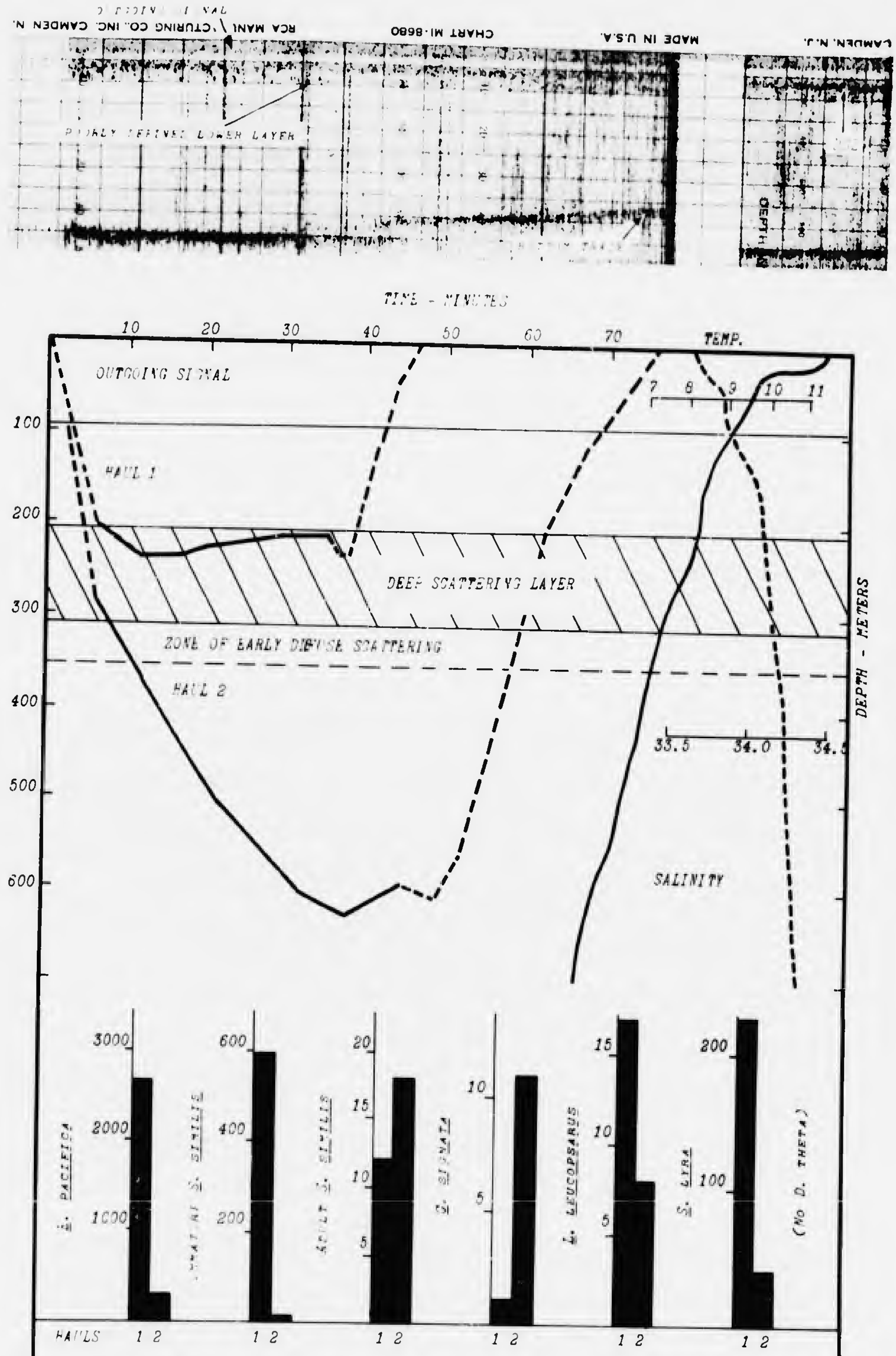


FIGURE 17. STATION 505, JUNE 6, 1955.

shows irregularities to 150 m. and a low, even gradient at greater depths.

Conclusions. E. pacifica and adolescent S. similis, reinforced with low numbers of S. similis adults and post larval L. leucopsarus, appear to be associated with the region near the top of the recorded layer. E. pacifica predominates in the order of 4:1. The DSL is not in the region of hydrographic discontinuity.

Station 478. 15 December 1954, Time: 0800-1220. (Fig. 18)

Echogram. The clear portion of the echogram presented here was recorded while on the hydrographic station. Jamming of the portion on the right was caused by movement of the boat when hauling the net. Note the difference in the recorded intensity of the layer when the gain was increased from 6.8 to 7.2, though even at the latter high setting the layer was relatively light compared to most other recordings. The strength of the bottom echo returning from over 800 fm. indicates that the signal was strong and that faint recording of the layer was not caused by weakened output.

Hauls. Two hauls were taken. Haul 1 dropped into the top of the layer, fishing the upper zone of scattering and the region above the layer. Haul 2 passed through the DSL, fishing both in and below it.

Counts of Organisms. E. pacifica was taken in fairly low numbers, and concentrated in the deeper haul.

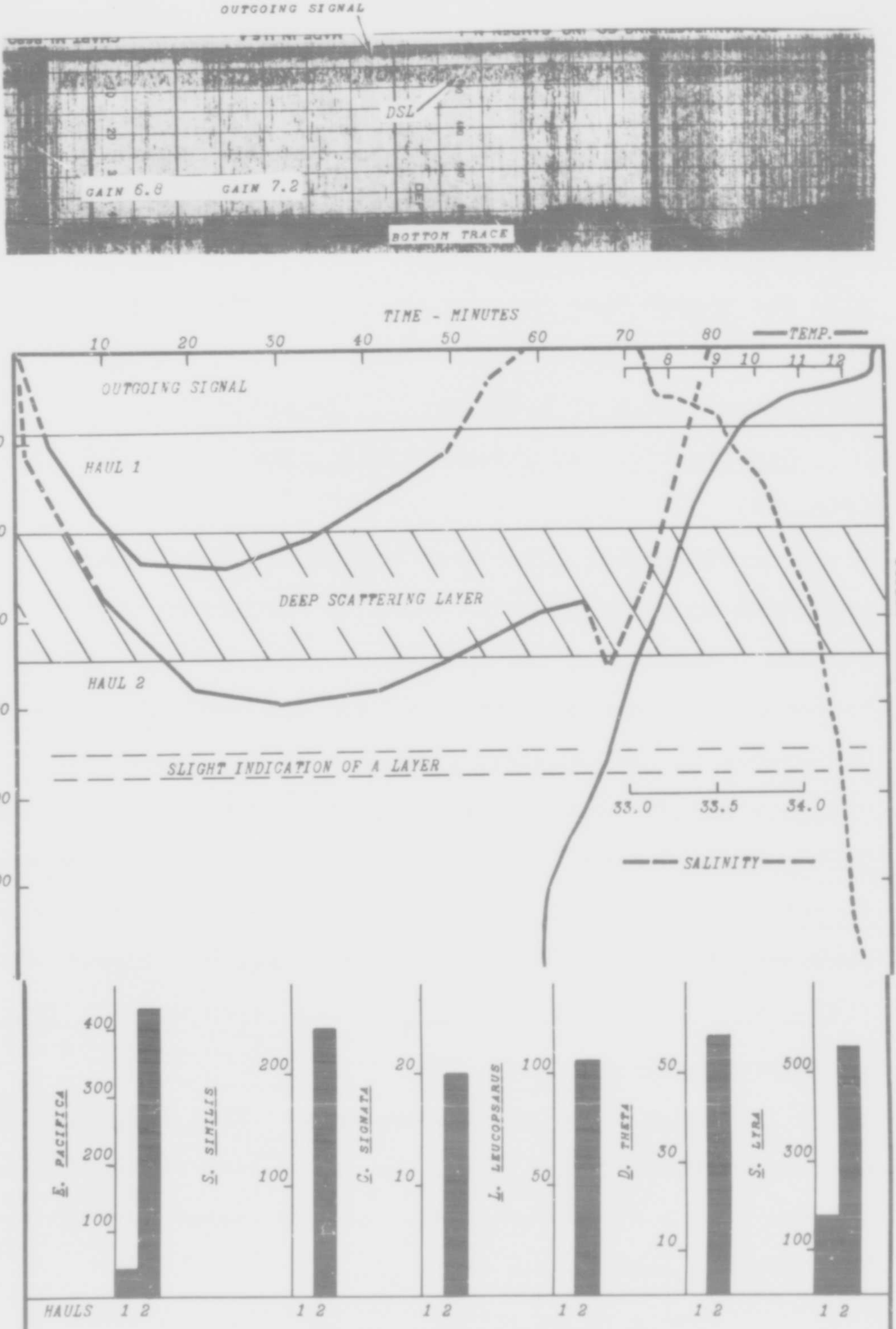


FIGURE 18. STATION 478, DECEMBER 15, 1954.

The haul through the upper part of the layer is negative for S. similis and all of the fishes considered here. These organisms, however, are present in high numbers in the haul taken below and in the lower part of the layer. It would seem that even the S. lyra population, normally concentrated at a higher level, has moved downward.

Hydrographic Data. The thermal curve is characterized by a mixed layer to 30 m.; at this level a well-developed seasonal thermo-cline occurs and grades off at 100 m. into the region of permanent negative gradient. An extremely low gradient, indicative of deep water takes over at 600 m. The salinity curve follows a similar pattern in reverse.

Conclusions. The negative results of the shallow haul which presumably passed through the upper part of the layer, as well as a few other cases of poor catches which have resulted from hauls which apparently passed through the top regions of scattering layers, are most perplexing. Three possible explanations can be considered.

It is entirely possible that on these occasions the previously discussed instrumental and measurement errors may have acted singly or together to make the haul appear a bit deeper than it actually was and the scattering layer appear slightly above its true position. Another possibility is that the organisms responsible for the reverberations were either too active to be captured, or too small to be retained in quantity by the large mesh of the net, and were therefore not adequately sampled. The dominant macroplanktonic forms taken in the haul were amphipods. There were 88 Paraphronema sp., 25 Streetsia challengeri and 8 Phronema sedentaria taken in the upper haul as compared to 37, 11, and 14 respectively in the lower haul. These organisms could pass freely through the meshes of the T-net and may have been present in much greater numbers than indicated by the catch. However, it is very doubtful that they could be responsible for the layer. Not only is their total bulk very small, but these forms are poorly represented in the vast majority of T-net hauls taken through scattering layers.

Finally, very little is actually known concerning the population densities of various types and sizes of organisms which are necessary to create recordable reverberations. The layer recorded this day is light, even at an S.S. of 7.2. A third possible explanation might therefore be, that while the greatest population density is below the level of the top of the recorded layer, enough scatterers to give a recording occurred higher than this. From an acoustical standpoint it can be said that because of rapid loss of sound energy with range, the critical population density needed to cause reverberations would be much less at a higher level than at a lower one.

Station 485. 2 January 1955, Time: 0818-1330. (Fig. 19).

Echogram. A rather light and diffuse layer is recorded at an S.S. of 7.0. There was a tendency for the

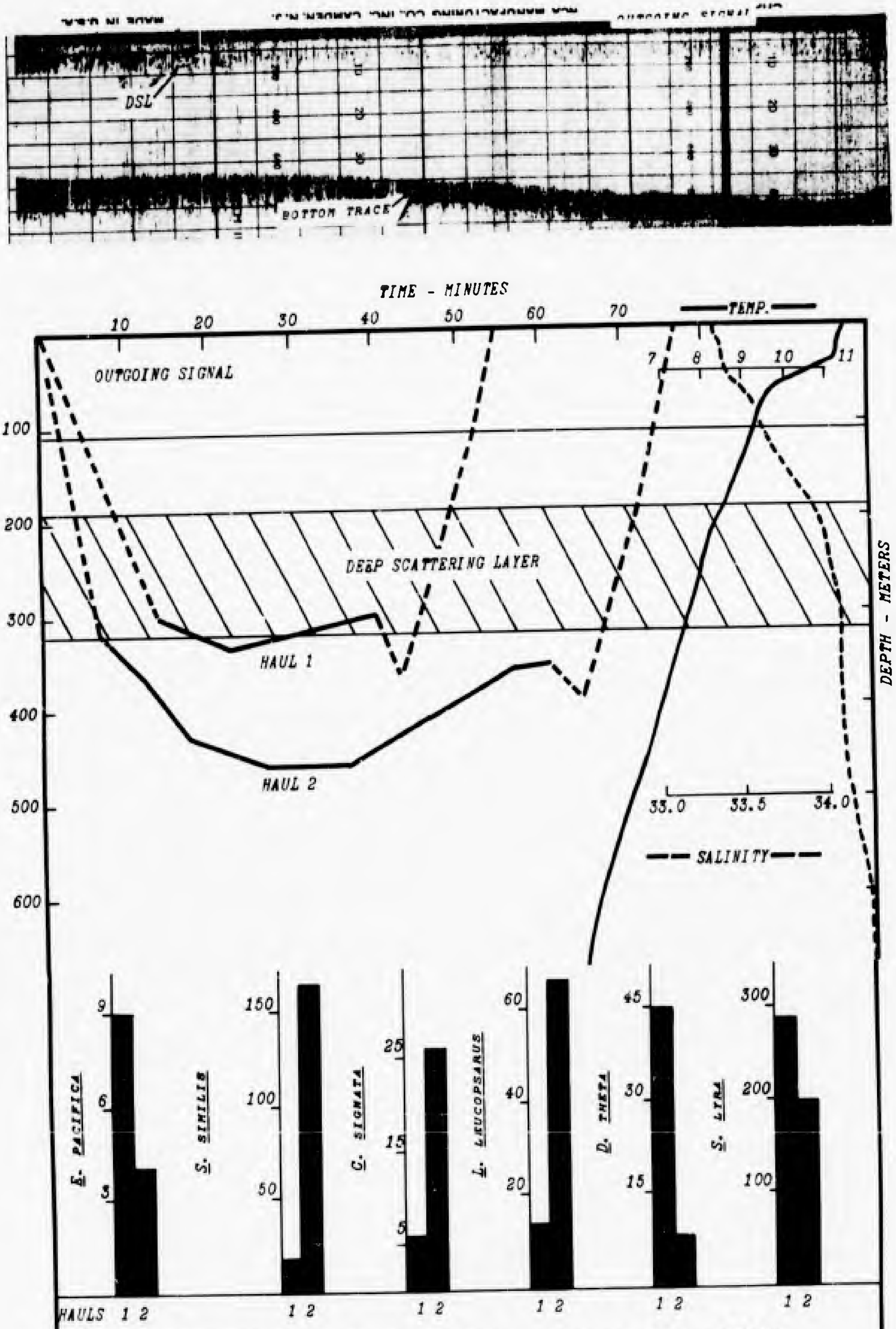


FIGURE 19. STATION 485, JANUARY 2, 1955.

layer to settle slowly throughout the morning. The clear bottom echo indicates a strong signal, while the sharpness with which the signal zone is cut off at its lower margin shows the acoustical clarity of the water at the upper levels.

Hauls. Two hauls were made. Haul 1 passed through the region associated with the bottom of the layer, while haul 2 sampled a region averaging about 100 m. just below the layer. The effective length of haul 2 was about twice that of haul 1.

Counts of Organisms. E. pacifica is represented in both hauls by extremely low numbers, and all individuals captured were immature. The immature S. similis population had grown and merged with the adults at this date, therefore they are not represented separately in the counts. The greatest concentration of S. similis is apparently below the level of scattering. The fishes are present in relatively high numbers; however, D. theta is the only species which appears to be concentrated at the level of the DSL.

Hydrographic Data. The temperature data show a relatively homogeneous mixed layer to 30 m., a mild thermocline between 50 and 74 m. and even gradients thereafter. The salinity curve follows an even gradient to 200 m., where it breaks into a steeper slope.

Conclusions. While a single layer pattern is evident, the diffuseness with which it is recorded indicates a basic difference from other single layers recorded in the spring and fall. Scattering can hardly be attributed to the few euphausids, and it would seem that the dominant scattering organism here is Diaphus theta. At this station recognizable changes in the slope of the salinity curve occur at the approximate upper and lower limits of the DSL.

Station 493. 22 February 1955, Time: 0817-1345. (Fig. 20)

Echogram. This portion of the echogram was made while drifting on the hydrographic station. The surface water was so acoustically clear that even the Nansen bottle casts were recorded (these can be made out as black smudges just below the zone of outgoing signal, e.g. just above the arrow indicating the DSL). The scattering layer is very light and thin, in spite of a relatively high sensitivity setting of 7.0. The strong bottom echo argues against malfunction of the sounding gear as a possible explanation of the low density of the layer. Unfortunately, a leak in the fuel line of the generator providing the power necessitated an early shutting down of the sounding gear. The layer had been settling slowly throughout the morning, and therefore the depth of the DSL as indicated on the graph may be slightly above the true level at the time the net hauls were made.

Hauls. Three hauls provide a basis for comparison. Haul 1 was taken above, and apparently in the layer,

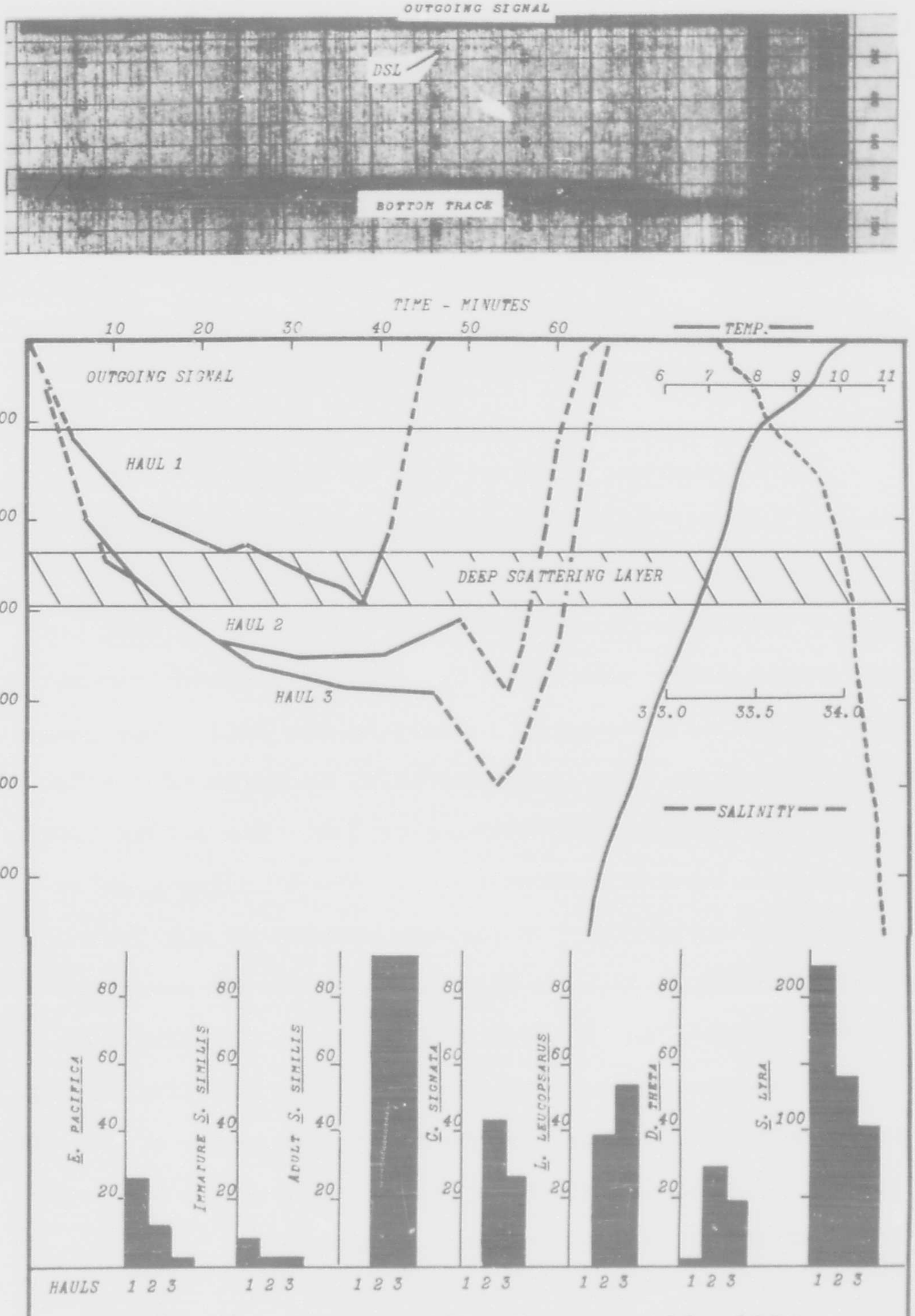


FIGURE 20. STATION 493, FEBRUARY 22, 1955.

whereas hauls 2 and 3 dropped rapidly below the DSL and sampled the layer 50-100 m. below it. Haul 3 was made with 200 m. more wire than was haul 2, yet it only fished about 50 m. deeper. This indicates the potential error in the wire angle method; if these hauls had been plotted on the basis of such measurements, the maximum depth during the effective period of haul 3 would have been placed at about the 450 m. level instead of the 390 m. level.

Counts of Organisms. *E. pacifica* was taken in very low numbers. At this time of year *S. similis* has just spawned and the immature individuals are only represented by a few mastigopus stages which would generally not be retained by the T-net. Adult *S. similis* and the fishes are taken in good numbers in the deeper hauls, but are either lacking in the haul through the DSL or are present in low numbers. *S. lyra* is more common at the scattering level.

Hydrographic Data. The thermal curve is characterized throughout by a fairly low and even negative gradient, and there is no region of rapid decrease in the surface layers which could be considered as a real thermocline. The salinity curve is similar in nature with the direction of the gradient reversed.

Discussion and Conclusions. A serious hindrance to the interpretation of data obtained on this station is the uncertainty of the depth of the layer while the hauls were being made. At the time acoustic observations were begun at 0830 the layer was centered approximately at the 130 fm. level. However, two hours later, at the end of the observation period, the layer had settled to a depth of about 160 fm. (This fact can best be appreciated by turning the figure sideways and aiming along the DSL with the paper held close and on a level with the eye. The rate of settling was about 15 fm. (27 m.) per hour. The layer was plotted at the 1030 position, but haul 1 was actually made 2.5 hours later, at 1300. If the layer continued to sink at its mid-morning rate, then the DSL would have been about 70 m. lower and consequently would not have been sampled by this haul. That the mid-morning rate of settling would be maintained is of course an assumption. Moore's (1951) observations in the Atlantic have shown that many times the curve of descent of layers is noticeably flattened at noon. In addition to the uncertainty of positioning the layer, which was made all the more critical by its thin nature, the same possible sources of error outlined in the discussion pertaining to the results of Station 478 (Fig. 18) apply here. One important fact, however, is well demonstrated by the data regardless of possible relationships to zones of reverberation. The adults of S. similis and the bathypelagic fishes are sharply restricted below a critical vertical level.

Type 2: Solid Scattering Pattern.

Station 509. 13 July 1955, Time: 0630-1102. (Fig. 21).

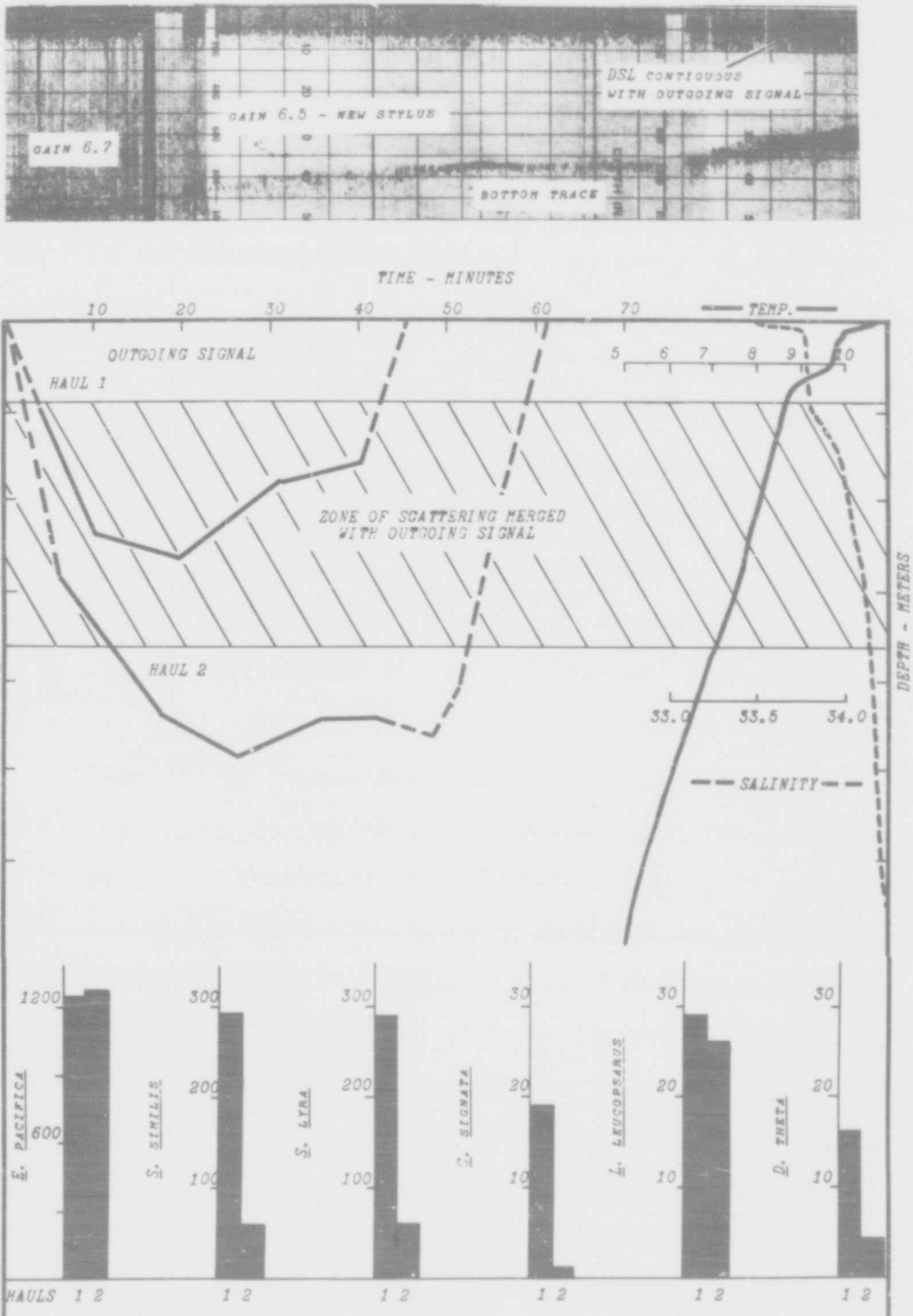


FIGURE 21. STATION 509, JULY 13, 1955.

Echogram. The solid scattering pattern, characterized by an unbroken trace of signal and reverberation, is well demonstrated by this echogram. The darker portion to the left was recorded at an S.S. of 6.7. The lighter portion resulted from reduction of the gain to 6.5, and insertion of a new stylus. Note that this serves to shorten the tracings and lighten their intensity so that a fuzzy, ill-defined zone of scattering is evident below the upper solid pattern. Turning up the gain to an S.S. of 6.9 (the far right-hand portion of the echogram) fills in the fuzzy zone with a solid pattern. The length of the signal without the echo-scattering can be made out in the two short regions where the sensitivity setting has been turned down to avoid jamming when it was necessary to speed up the engine of the boat.

Hauls. Haul 1 was made almost to the bottom limit of the solid scattering recorded at gain 6.5. Haul 2 began at this point, descended rapidly through the zone of diffuse reverberations which were recorded by the increase in gain to 6.9, and sampled mainly in the area below recorded scattering.

Counts of Organisms. E. pacifica counts are moderately high and are almost the same for the two hauls. S. similis, C. signata and D. theta are all definitely concentrated in the shallower haul taken well up in the zone of reverberations, whereas the variation in catch for L. leucopsarus in the two hauls is not significant.

Hydrographic Data. Two mild thermoclines, one at the surface and the other at 50 m., characterize an otherwise monotonous thermal gradient. The salinity curve shows similar breaks, but the region of the second cline is at 100-150 m.

Discussion & Conclusions. The striking fact here is that, considering the data from other stations, the centers of population density of *S. similis*, *C. signata* and *L. leucopsarus* have apparently moved up about 100 m. The fact that the two hauls took *E. pacifica* in equal numbers suggests that these euphausids were distributed in an area which was sampled for an equal time by the two hauls. This would be the area above that sampled by the shallower net during the greater part of its effective phase. At this station noticeable changes occur in the slope of the temperature and salinity gradients at the approximate upper limit of the DSL. No corresponding changes are associated with its lower limit.

Station 512. 1 August 1955, Time: 0635-1040. (Fig. 22.)

Echogram. Variation in the diffuseness of the tracings below the 100 fm. line as a result of the indicated changes in sensitivity settings are evident, although no separate layer could be resolved. Generator trouble necessitated an early shutdown of the sounding gear just prior to commencing the hauls. Two hauls were taken; haul 1 traversed the upper and middle layers of the zone of scattering, while haul 2 fished through and below this zone.

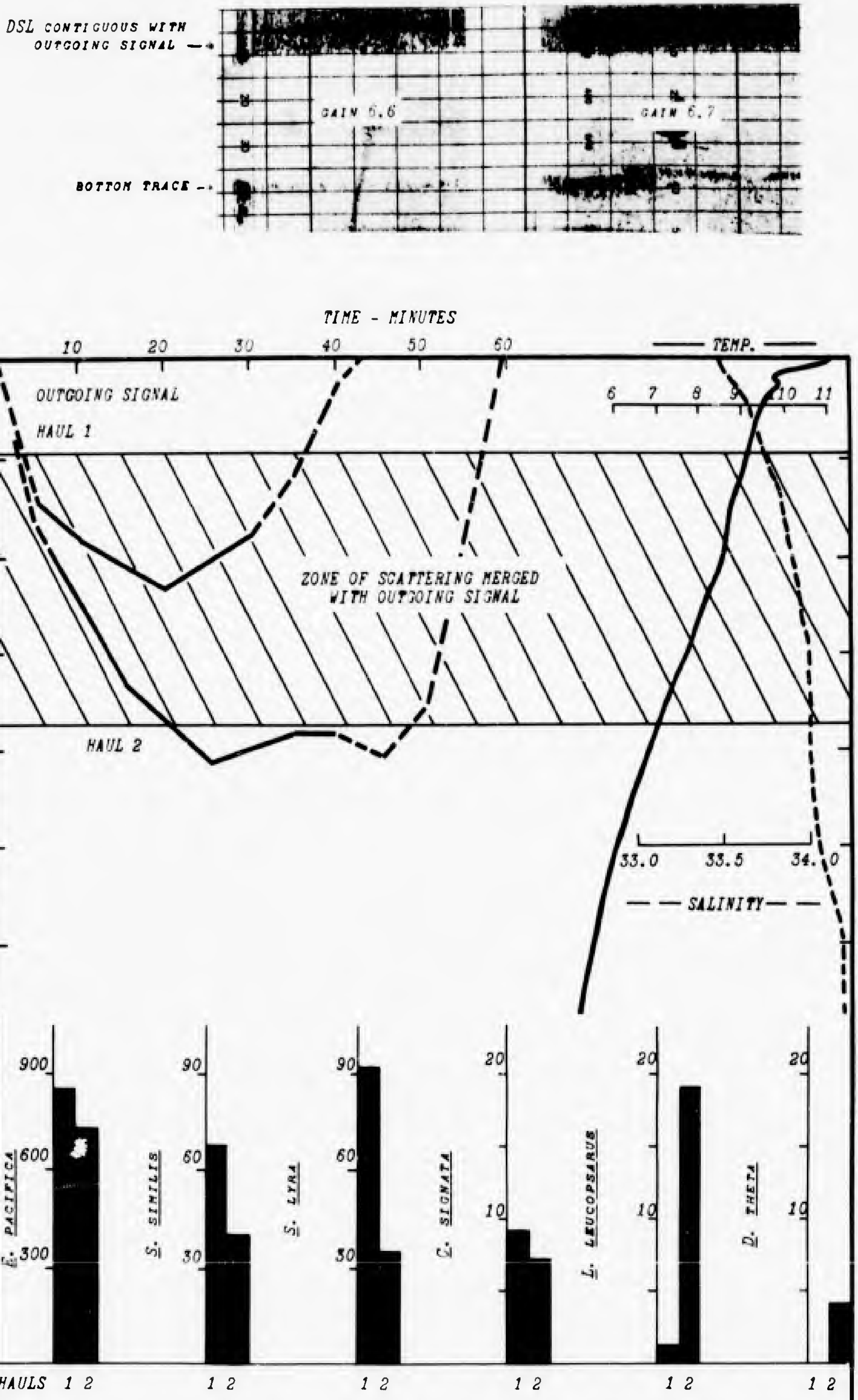


FIGURE 22. STATION 512, AUGUST 1, 1955.

Counts of Organisms. *S. similis* and *S. lyra* are more concentrated in the shallow haul. The situation is strikingly reversed for *L. leucopsarus*. The count for *D. theta* is low, and none were taken in the shallow haul. Numbers of *E. pacifica* and *C. signata* are similar in the two tows.

Hydrographic Data. A temperature inversion is evident between 20 and 30 m., followed by a steady gradient. The salinity curve is fairly even throughout.

Discussion & Conclusions. While the results are not as clear-cut as for the preceding station (509) there is a good indication that *S. similis* and *C. signata* have moved above their more usual depths. Again, the euphausid counts for the two tows are relatively even, indicating that the main concentration of these organisms is very probably above the depths sampled in the main portions of the two hauls. No hydrographic variations characterize the scattering levels.

Type 3: Modified Double Layer.

Station 472. 17 November 1954, Time: 0740-1345. (Fig. 23)

Echogram. The central portion of the echogram, recorded at midday, shows a typical modified double layer pattern. Note the excellent resolution of the shallow layer at a S.S. of 6.5, whereas at the higher gain of 7.1 the upper layer appears to merge with the outgoing signal and the lower diffuse zone of scattering is recorded. It

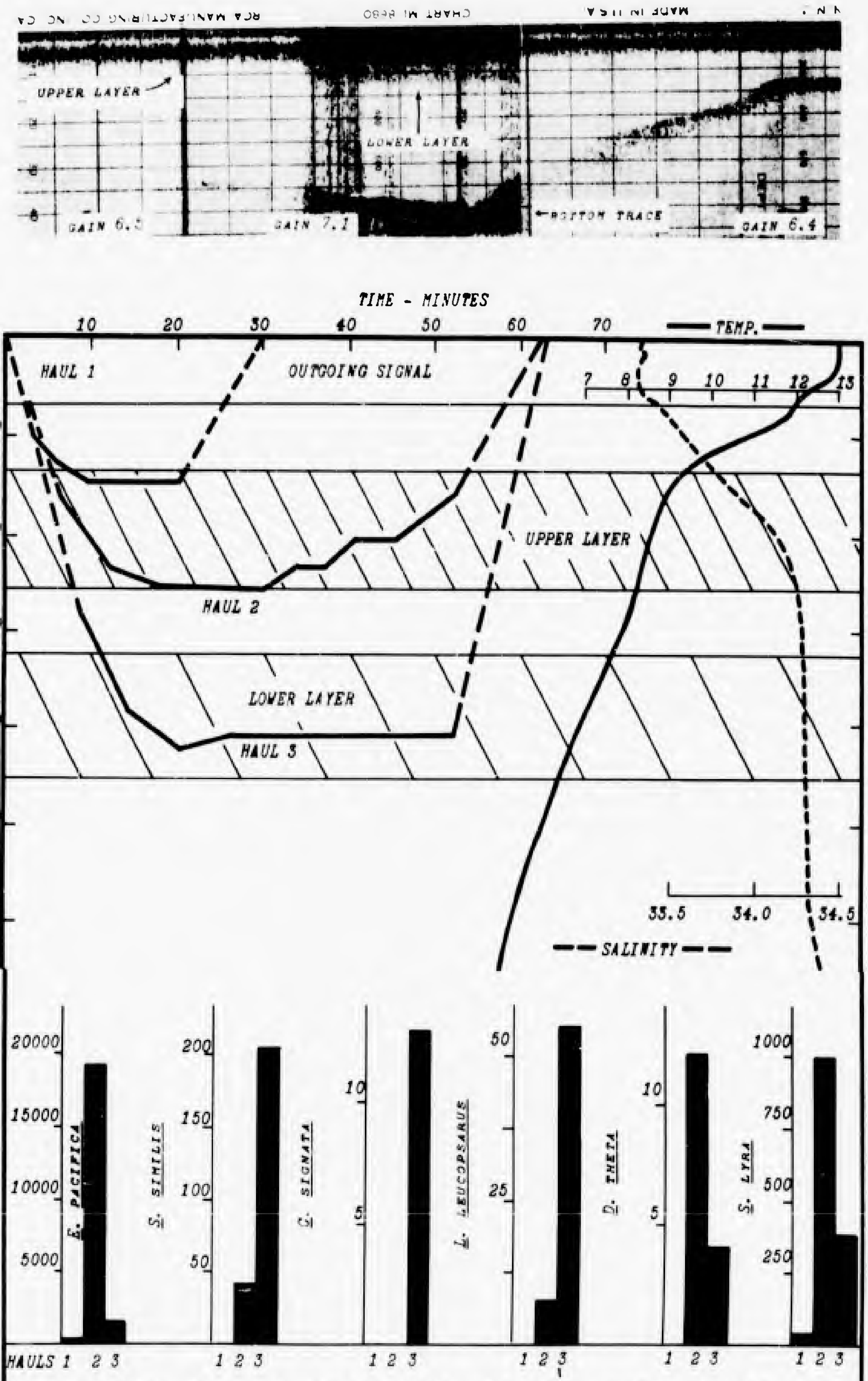


FIGURE 23. STATION 472, NOVEMBER 17, 1954.

is also evident from the far right portion of the recording that the shallow layer tends to rise and nearly fuses with the outgoing signal as the boat moves up the continental slope and approaches shelf water.

Hauls. The three hauls plotted on the diagram, with the exception of the first part of haul 3, were established from wire angle measurements, due to failure of the clock mechanism of the depth-time recorder. Haul 3 fished the lower layer and haul 2 the upper layer. Haul 1 apparently sampled the upper ten meters of the shallow layer.

Counts of Organisms. *E. pacifica* shows a most dramatic and striking concentration at the level of haul 2; there were about 19,000 large, adult euphausids captured at this depth in contrast to only 54 in haul 1. To a lesser degree the same distribution is evident for *S. lyra*. *Sergestes similis* is present in high numbers in the haul through the lower layer. The individuals taken in the middle haul were of the younger year class; those captured in haul 3 were fully grown adults. *C. signata* is limited to the lower layer, and *L. leucopsarus*, while present in haul 2, shows a marked increase at the lower level. On the contrary, *D. theta* appears most abundant in the upper scattering layer.

Hydrographic Data. The thermal curve indicates a very shallow mixed layer overlying a strong, deep thermocline which in turn merges with the permanent negative gradient close to the top of the upper scattering layer. The salinity curve is marked by a shallow inversion, and a change of slope near the middle of the upper layer.

Discussion & Conclusions. Since the depths of hauls 1 and 2 were established by wire angle measurement and computation, there is a good possibility that the actual path of the net in each case may have been shallower than that plotted. This would explain the low catch of haul 1, since the area sampled would have been just above the layer instead of in the upper portion of it. It can be concluded that the middle and lower regions of the upper layer are related to a dominant population of *E. pacifica*, reinforced by small numbers of the lantern fishes *D. theta* and *L. leucopsarus*, the immature year class of *S. similis*, and *S. lyra*. The lower layer can be associated with a numerically dominant population of adult *S. similis*, with high numbers of *L. leucopsarus* and with smaller populations of *C. signata* and *D. theta*. The break in slope of the temperature curve coincides with the top of the upper scattering layer. However, sharper thermoclines than this have been recorded during the present work and they appear to show no spatial relationship with scattering zones. The coincidence in the present case appears due to a combination of two factors: resolution of an extremely high layer, and a seasonal depression of isotherms to a low level. The possible influence of thermal structure on the scatter patterns will, however, be discussed under a more suitable heading.

Station 470. 12 November 1954, Time: 0755-1248. (Fig. 24).

Echogram. While the upper layer is not as well defined as in the previous echogram, a shallow layer is clearly evident at an S.S. of 6.7. A slight indication of a still shallower layer superimposed on the signal zone can be seen at 40-50 fm. An increase in gain to 7.1 brings out a deep layer below the 200 fm. line. While that part of the tape is not presented here, the deep layer was recorded throughout the morning, as well at an S.S. of 7.3.

Hauls. Haul 1 was towed through the upper portion of the shallow layer, whereas haul 2 fished in the upper layer momentarily, then dropped down to sample the area between the layers and in the deeper layer before being recovered.

Counts of Organisms. E. pacifica is about equally represented in the two hauls and, aside from S. lyra, all other organisms are restricted to the deeper haul. At the lower level an extremely heavy catch of S. similis was taken. Some idea of the bulk of the sample can be gained by stating that the approximately 600 individuals taken tightly packed together in a 2000 ml. graduated cylinder, measured over 500 ml. L. leucopsarus and D. theta were also present here in high numbers, while the C. signata count is low.

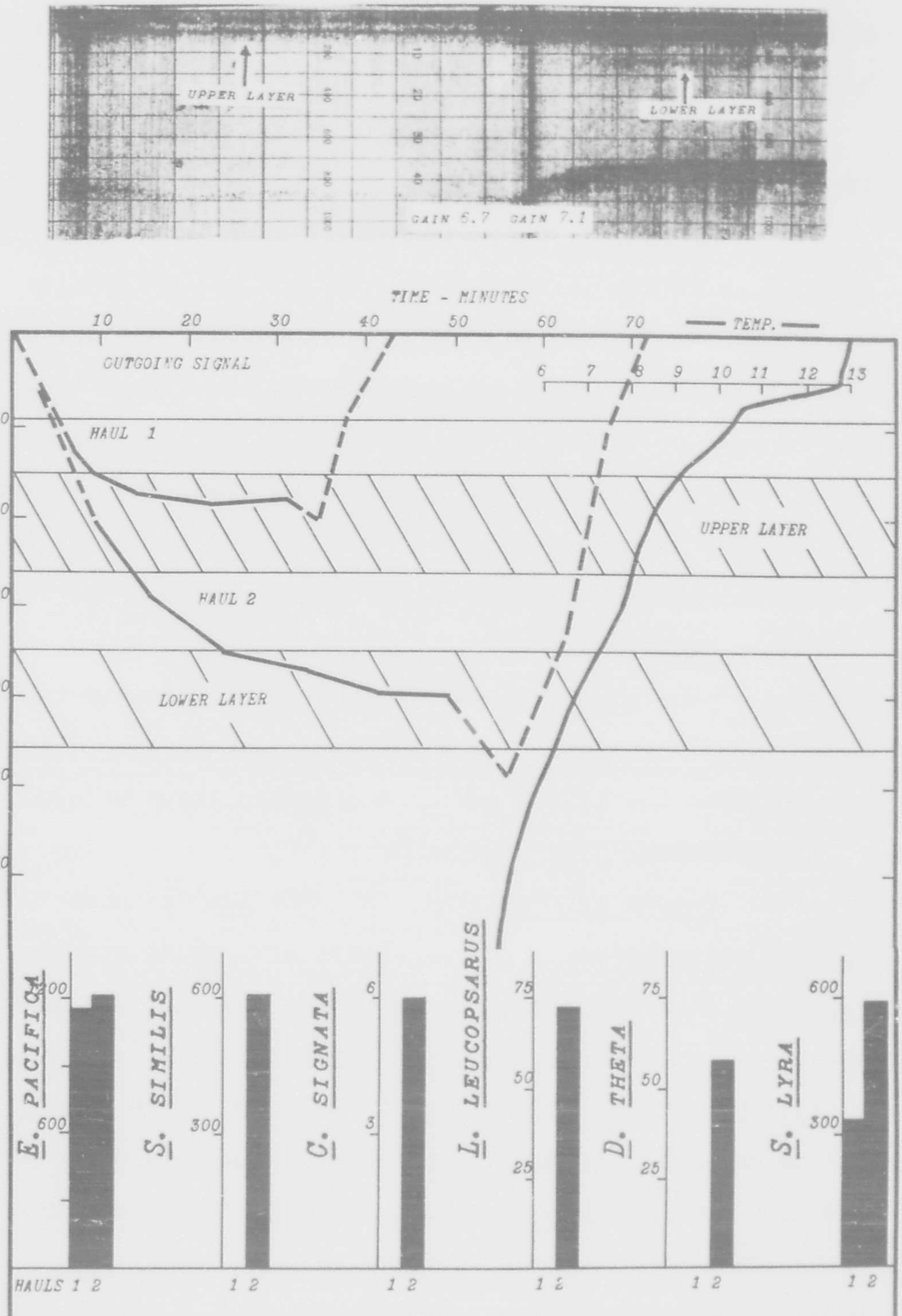


FIGURE 24. STATION 470, NOVEMBER, 12 NOV. 1954.

Hydrographic Data. Thermal measurements indicate that a mixed, low gradient layer overlies a strong thermocline at 50-75 m., below this point the curve undulates along a 30° slope typical of the permanent temperature gradient. Salinity data are not available for this station.

Discussion & Conclusions. The basic acoustic pattern on this day is strikingly similar to that of the preceding station (472). The upper layer, however, is considerably less dense, even though it has been recorded at a high gain (6.7 as compared to 6.4-6.5); a good suggestion of resolution exists even when the gain is turned up to 7.1. The biological sampling clearly shows that *S. similis* and the fishes were restricted to a level below that sampled by haul 1. While good numbers of euphausids were taken, a concentration of *E. pacifica* in the upper layer is not demonstrated as it is in Station 472. Either the net has failed to fish the zone of major concentration or, as indicated by the nature of the echogram, a lesser population is present.

Station 517. 14 September 1955, Time: 0720-1110. (Fig. 25.)

Echogram. A rather fuzzy and ill-defined upper layer is resolved at a gain of 6.9. Note on the extreme right that the portion recorded at an S.S. of 7.0 actually forms a solid-type pattern.

Hauls. The depth-recorder was inoperative on

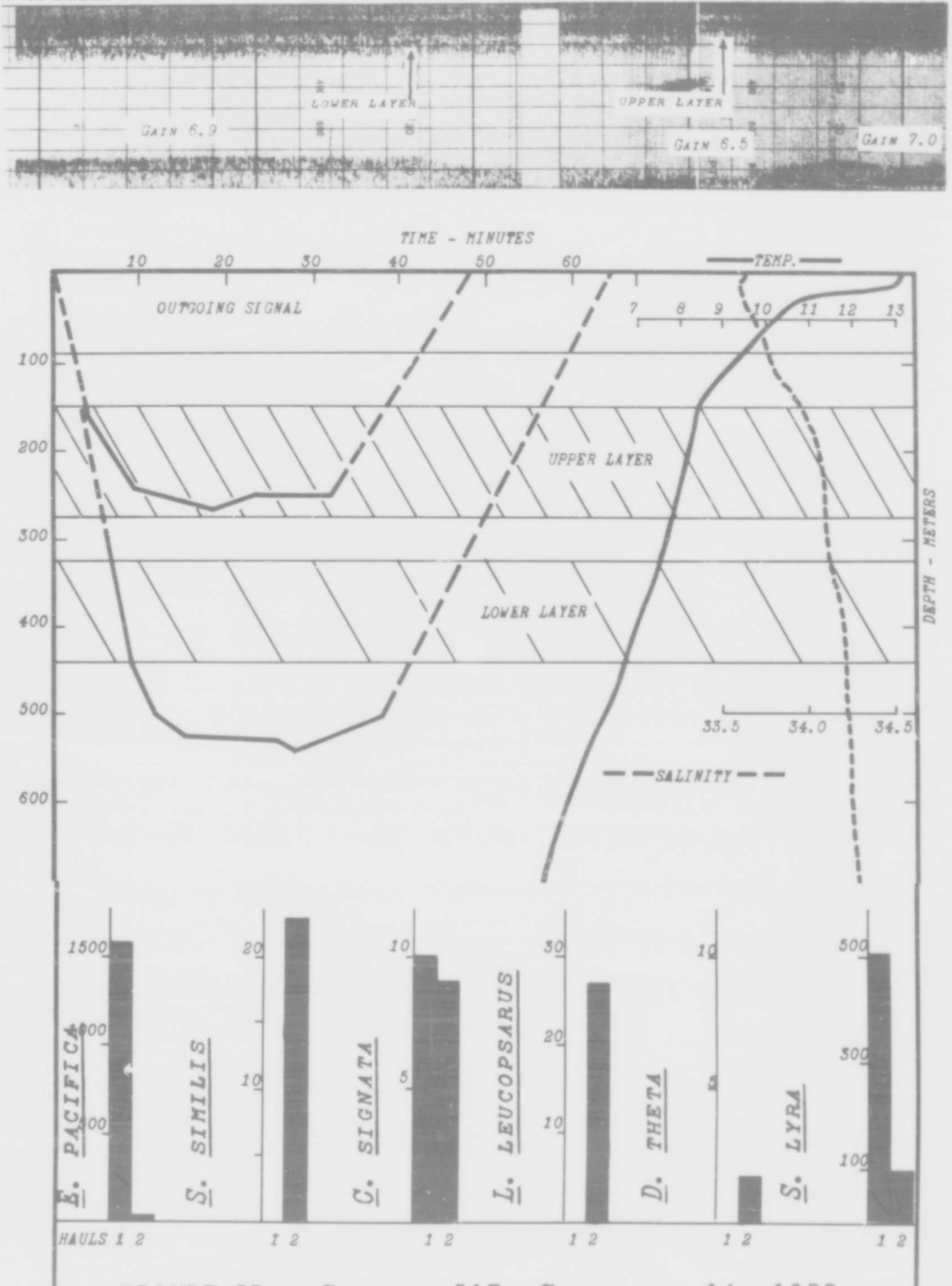


FIGURE 25. STATION 517, SEPTEMBER 14, 1955.

this particular day, and these plots of the hypothetical course of the tow net are based on wire angle measurements. Haul 1 sampled mainly the lower region of the upper layer, while haul 2 apparently fished through and below the deeper scattering layer.

Counts of Organisms. *E. pacifica* was over 70 times more abundant in the shallower haul, and the population was made up of medium to small individuals. A similar population distribution in relation to depth is evident for *S. lyra*. *S. similis* and the myctophid fishes are restricted to the deeper haul, and are poorly represented. *C. signata*, however, was captured in approximately equal numbers at both levels.

Hydrographic Data. A strong seasonal thermocline was present, and the top of the upper layer is associated with a change in slope of the thermal curve, which assumes an even gradient from this point on. The salinity curve shows a shallow inverstion just below the surface and a slight change in gradient in the vicinity of the upper scattering layer.

Discussion & Conclusions. The upper layer can be related to a dominant population of *E. pacifica*, which due to their small size, and therefore their ability to pass through the net, may actually be six to 80 times more plentiful than is demonstrated by this haul (See capture coefficients, previously discussed). *S. lyra* and *C. signata* are also present at the upper level. It seems probable on the basis of other stations, that the low numbers of S. similis and myctophids can be related to the fact that haul 2 fished primarily below the deeper scattering layer.

Type 4: Double Resolved Layer.

Station 495. 8 March 1955, Time: 0828-1410. (Fig. 26).

Echogram. Two layers are clearly evident at an S.S. of 7.1. They were poorly recorded while the vessel was under way and making the net tows, but were again well marked during the latter part of the day (not shown on this portion of the echogram). Note that while the lower layer is similar in nature to the deep layers of Type-3 patterns, the upper layer, in terms of depth relationships, density, and degree of diffuseness, is conspicuously different from the shallow layers of the Type-3 pattern.

Hauls. Haul 1 was taken in the upper layer; haul 2 passed through both upper and lower layers and haul 3 fished mainly below the lower layer, providing a fine example of perversity in the behavior of large nets towed by small boats.

Counts of Organisms. E. pacifica was completely lacking from the upper level, and taken only in extremely low numbers in hauls 2 and 3. The immature S. similis year class, represented by small, post-larval forms, was taken in low numbers mainly in the two upper hauls, whereas the adults were captured in high numbers in the region

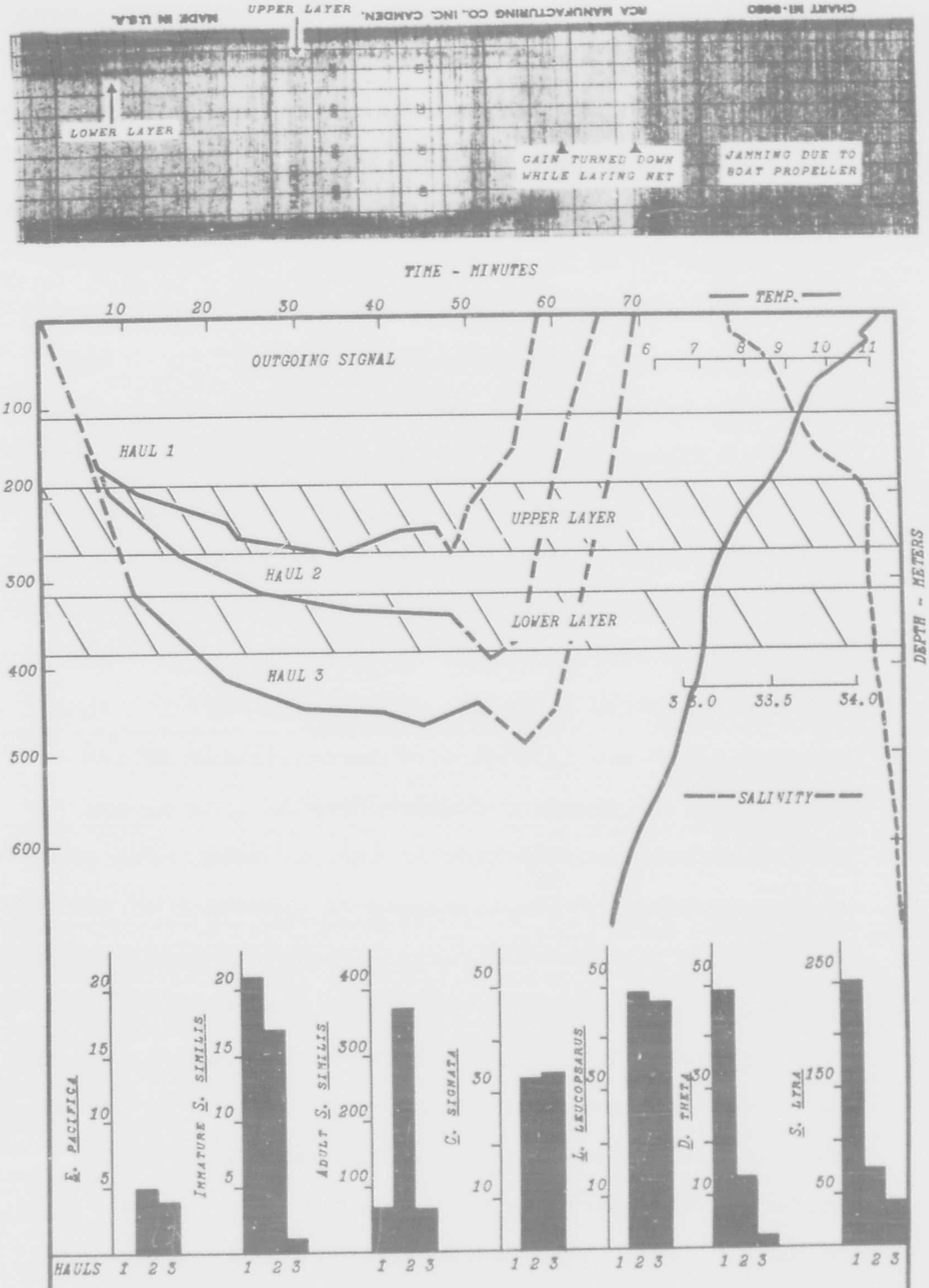


FIGURE 26. STATION 495, MARCH 8, 1955.

of the bottom layer. *C. signata* and *L. leucopsarus* were sampled in equally good numbers in hauls 2 and 3. The *D. theta* population, however, is concentrated in the upper haul. *S. lyra* follows the same type of distribution.

Hydrographic Data. The thermal curve is marked by an inversion at 25 m. and an undulating slope thereafter. The salinity curve also indicates a break at 25 m., followed by a relatively steep slope which changes sharply to a low gradient near the top of the upper layer.

Discussion & Conclusions. It would seem that adult euphausids can be eliminated as the dominant scattering organisms here. Immature *S. similis* may have been present in high numbers, but due to their small size they are not adequately sampled. It is to *D. theta*, however, that our attention is drawn. The counts indicate that this myctophid was concentrated in the region of the upper layer. A slight refinement can be made by the following crude manipulation of the raw data. One can reasonably assume full efficiency of operation of the net during the effective haul (solid line), and half efficiency while it is being set and recovered (broken line). On this basis the total time in minutes that each haul has fished the upper layer can be computed. Dividing these figures into the catches of *D. theta* in the respective hauls yields the following figures: Haul 1 1.3, haul 2 1.4, and haul 3 1.0. The figures are sufficiently close to justify the conclusion that *D. theta* is concentrated in the region of the upper layer. Applying this same manipulation to the S. lyra data gives equally good results and leads to a similar conclusion. Adult S. similis shows an excellent correlation with the lower layer, where it dominates the catch numerically and by bulk. Good numbers of C. signata and L. leucopsarus are also present.

Station 476. 8 December 1954, Time: 0800-1300 (Fig. 27)

Echogram. A double-layer pattern is resolved at an S.S. of 6.7 to 7.0. The upper layer was extremely thick early in the morning and then exhibited a tendency to shrink and to settle at a rate of approximately 10 fm. per hour as the day progressed. The lower layer was thin and sketchy, and was poorly recorded during much of the day.

Hauls. Unfortunately, the two hauls plotted were very poorly placed for comparative purposes.

Counts of Organisms. All of the forms under consideration were represented in both hauls, but only E. pacifica and S. lyra predominate at the shallower level. D. theta is present in unusually large numbers.

Hydrographic Data. A positive gradient indicative of surface cooling characterizes the thermal curve to 30 m. From this point a strong negative gradient is assumed which gives way to a more gentle slope at the 100 m. level. The salinity curve is marked by a strong, shallow inversion near the surface. The remainder of the curve is relatively even.

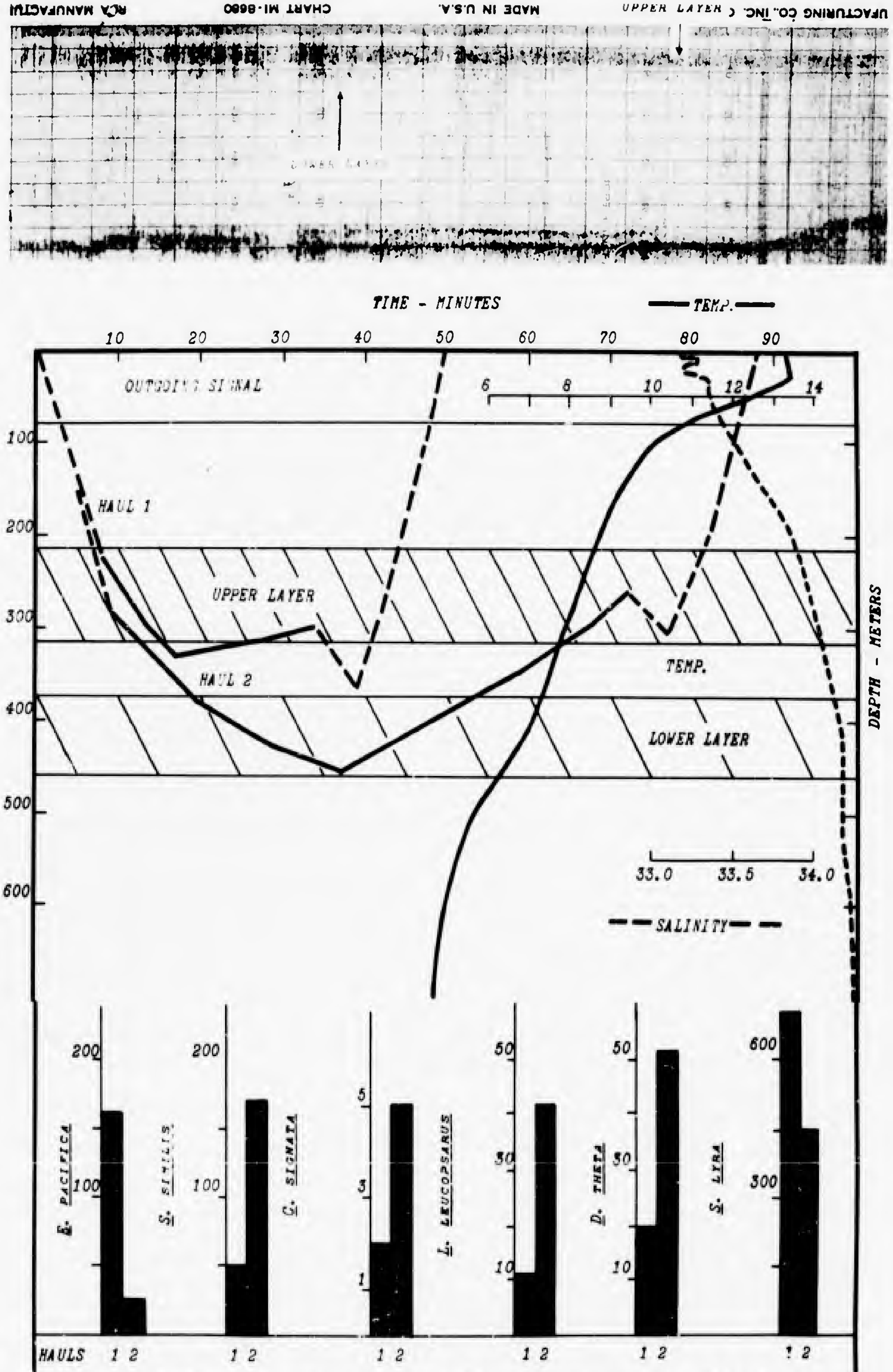


FIGURE 27. STATION 476, DECEMBER 8, 1954.

Discussion & Conclusions. Because of the placement of the nets and the variation in time of effective hauling (haul 1, 27 minutes: haul 2, 62 minutes) it is extremely difficult to draw conclusions from the data. To this writer, however, the fact that *D. theta* was a prominent feature of the bathypelagic population is of value as will be pointed out later.

Discussion.

The use of a classification recognizing four basic patterns in the recorded echograms provides a useful framework for the organization of data. It is apparent, however, that there is variation within each of the defined scattering pattern types, particularly within Type 1, the single scattering layer. The single layers, as recorded, exhibit diversity in vertical position, in thickness, and in the intensity or darkness of the tracing made by the needle. Some of these variations are due directly to differences in the nature, abundance, and distribution of the scattering organisms. Others may be due, directly or indirectly, to hydrographic variables. Still others relate primarily to the recording instrument itself. A detailed interpretation of the roles of individual species in creating scattering patterns is deferred to a later section. The following discussion is therefore confined to a consideration of variations within scattering pattern types, and to the relation of physical conditions and instrumental adjustments to these variations.

It seems very likely that hydrographic variables are not directly responsible for the scattering patterns recorded. The major discontinuities noted in temperature and salinity curves in Figs. 13 to 27 are generally located within the upper 100 m., where any scattering effects produced would be masked effectively by the recording of the outgoing signal. This is not always the case, however. In five of the 15 stations (Figs. 19, 21, 23, 25 and 26) a break in temperature or salinity cline appears to be associated with a scattering layer. That these discontinuities themselves are not causing reverberations is strongly suggested by the fact that in five other stations (Figs. 13, 14, 17, 20, and 27) there occur breaks in temperature and salinity clines that are not associated with scattering layers.

Some of the correspondence shown between hydrographic discontinuities and the scattering layers is very likely an artifact due to the positioning of the Nansen bottles. Below the range of the outgoing signal these sampling bottles with attached reversing thermometers were located at 100, 150, 200 m., and every 100 meters thereafter. The salinity and temperature curves represent lines drawn between points at these fixed levels. Breaks in curves for these variables are therefore located only approximately. The relation between locations of scattering layers and hydrographic breaks is not consistent enough to lend confirmation to a direct physical explanation of scattering.

However, the importance of hydrographic factors cannot be dispensed with so lightly. In the first place, these chemical and physical variables may well influence the distribution of the scattering organisms and thus be related indirectly to the formation of scattering layers. Secondly, a relationship much more subtle than density variation at the recorded level of scattering may well play a role in the creation of the various scatter patterns. It is necessary to consider this hypothetical physical factor in some detail.

Focusing and defocusing of sound waves due to the action of local thermal inhomogeneities as lenses has been considered as a possible cause of fluctuation in the form of transmitted sound signals (transmission anomaly) by the UCDWR workers (*Physics of Sound in the Sea*, Anon 1951a). Horizontally directed sound signals were considered in this report, whereas in the present work we are dealing with vertically directed sound pulses. The two situations are not parallel, but it is still possible that the physical structure of the water masses in the layers between the DSL and the thermocline may have an effect on the reception of reverberations.

Consider the following hypothetical example. A relatively non-directional, magneto-striction transducer, such as that used in conjunction with the NMC gear, creates a sound pattern of which the main lobe is of such form that the diverging sound rays spread out in the shape of a cone, the outer rays forming about a 20° angle from the point of origin (Herdman, 1955). The velocity of sound transmission in the upper levels of the ocean is primarily related to the temperature of the medium. For this reason, if a region of rapid decrease in temperature (thermocline) is present a sound field consisting of two sharply delimited zones of velocity will be created. As the individual sound rays making up the cone pass through the transitional layer they will be refracted downward in a manner similar to light, as predicted by Snell's Law (Principles of Underwater Sound, Anon. 1951b). The magnitude of the bending that could take place would depend on such factors as the degree and rate of change in the negative temperaature gradient, depth of the thermocline below the sound source, and the directionality of the transducer which would effect the angle of the individual sound rays incident on the thermocline. A detailed analysis of the importance of such a phenomenon is beyond the scope of this paper (and the mathematical ability of the writer). It can be said, however, that theoretically it is quite possible that a discontinuity layer could act as a lens which would concentrate and focus the sound rays.

The potential importance of sound lensing lies in the following effect. Because the sound rays spread out in a cone, the acoustic energy in any one impulse of the outgoing signal is dissipated over an area which increases by the square of distance it travels. Sound returning in the form of reverberations and echos also suffers energy loss by the square of the range, so that in effect the returning sound has decayed by the fourth power (Principles of Underwater Sound, Anon. 1951b). The above rule states a proven theory, but in actual practice, energy loss from signals is even greater than that predicted. Additional attenuation is due to absorption and other little understood causes. The greatest loss - perhaps by refraction - takes place on the periphery of the sound field so that the cone takes on the shape of a cylinder, and at even greater ranges, an inverted cone (Cushing, et al., 1952).

When watching the light indicator (a flashing neon light which has a higher energizing threshold, and is therefore a better indication of an echo then the stylus trace) for signs of the vertically hauled net in the sound field, it has been noted that reeling in 10 meters of wire may make the difference between no light indication and a "hot flash". On the basis of this observation it appears that regardless of the target strength of a single large object, or the total acoustic size of a scattering population, there is a critical threshold depth range for a given instrumental setting within which the amplitude of the returning energy will drop rapidly from readable to zero.

Therefore, even a slight reduction in the loss of peripheral energy by bending of the individual sound rays tending to concentrate the sonic energy in a narrower beam, may be of critical importance in the reception of reverberations from deep ranges. For these reasons it is suggested that it is the physical structure of the <u>upper</u> water layers which may play a direct influencing role on the recording of the various scatter patterns, and <u>not</u> possible temperature inhomgenities at the scattering-layer depth.

Assuming that such a mechanism is operative then it would be during the periods of strong thermocline development that one would anticipate the most sensitive reception. Conversely, isothermal conditions or gentle gradients in the upper 100 m. should result in poor reception of deep reverberations. In a general way the results of the present study fit this pattern. The period of surface warming characterized by strong thermoclines is the season when deeper layers which result in a double layer designation are most consistently recorded, and the relatively low temperature gradients of January and February correspond with the period of weak, thin, Type 1 layers. Evidence suggesting the validity of this concept will be brought out in the discussion of seasonal changes in the scattering layer which follows the present sections. Meanwhile the hydrographic data presented for the individual stations in the present section also offers evidence indicative of such a relationship. Figs. 23, and 25 show the recording of deep reverberations when strong thermoclines were present, and Fig. 20 a thin, faint layer recorded when a low thermal gradient was evident.

The modifying effects of instrumental variables on scattering patterns has already been stressed (see Echo Sounder). Other things being constant, an increase in gain yields a darker, more intense recording of the scattering layer. It may or may not result in an apparent increase in the vertical dimensions of the layer. In this latter regard the experimental sound studies reviewed in Cushing and Richardson (1956), which laid a foundation for the empirical application of echo sounding devices to commercial fisheries work, have important implications.

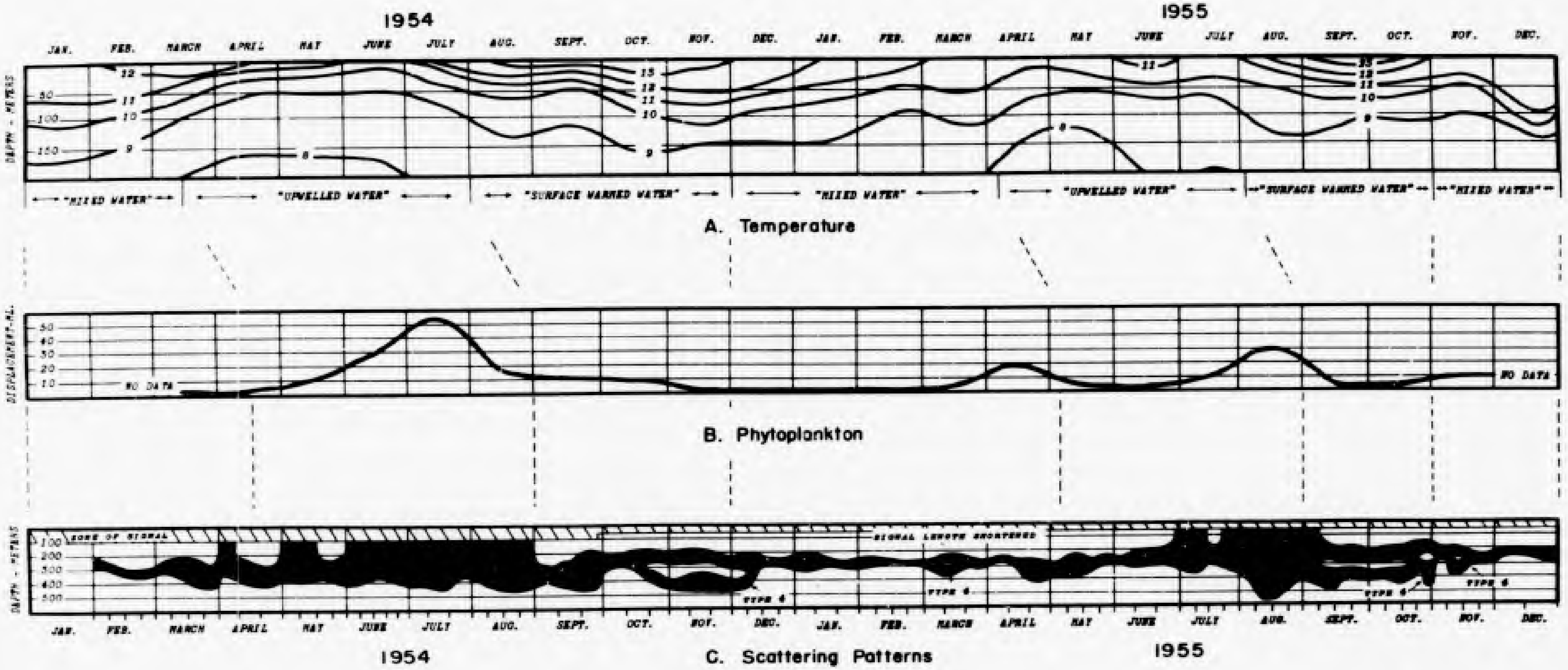
Briefly, these workers established that the band of reverberations recorded from a shallow zooplankton population is increased in both intensity and vertical dimensions with an increase in sensitivity setting, whereas the discrete traces representing echos and reverberations from fishes will be intensified with increasing gain, but the recorded depth range remains unchanged. The authors do not imply that this finding pertains to recordings made at DSL depths with an NMC echo sounder, but its applicability and importance for the present work seem clear. For example, a plot of population density vs. depth for a euphausid layer in the sea follows a normal or somewhat skewed curve. Such a distribution of zooplankters will yield a single resolved layer if critical reduction of the gain limits recorded reverberations to those returning from the peak population depth. If the sensitivity setting is increased, then reverberations will also be recorded from the marginal depths of the euphausid layer where the population is less dense, and the DSL will undergo an apparent increase in vertical dimensions. It is obvious that if the layer is present close to the zone of the recorded outgoing signals, or if a shallower scattering population is present, the increase in gain may merge the tracings so that a solid layer is recorded on the echogram. If the major scattering entities are fishes with a relatively narrow vertical range, Cushing and Richardson's principle suggests that an increase in gain may not result in an apparent change in the thickness of the scattering layer, but only an intensification of the recorded traces. This concept is referred to in specific instances in the sections to follow. It should be reiterated that in all field observations the sensitivity setting used was the lowest setting at which clear layers could be recorded by the instrument under the prevailing complex of conditions.

SEASONAL VARIATIONS

Scattering Layer Patterns.

The 83 echograms resulting from two years of observations have been studied and characterized in terms of type of pattern, vertical position, and thickness. Usually the recording could be classified as to type of pattern with assurance. However, the nature of scattering layers is dynamic; a solid pattern in the early morning may give way to a well resolved single layer by mid-day, or a thick single layer may split into two definite strata which remain separate or reunite after a brief period. Because of the importance of light on the position and movements of the DSL (Hersey and Moore, 1948; Kampa and Boden, 1954), scattering-layer type and depth on any particular day was determined on the basis of its predominant nature during the mid-day hours (1030-1300 pst). This time span also covered the hours of biological samplings.

While it is impractical to reproduce all of the echograms obtained in the course of the study, data from these have been tabulated in the Station List appended to this paper. In this list the type of scattering pattern, vertical spread, and brief comments are given for the individual stations. These data are summarized graphically in Fig. 28-C. The seasonal silhouette of the DSL was constructed by plotting the mid-day patterns in the appropriate order and position, connecting adjacent observational periods



A. Temperature

B. Phytoplankton

C. Scattering Patterns

FIGURE 28. SEASONAL CORRELATIONS

(indicated by the short vertical lines along the bottom of the graph), and smoothing by eye. The graph is intended to show long-term, seasonal changes in the predominant mid-day scattering pattern, and, therefore, diurnal movements have not been taken into consideration. It contains much interpolation, but the monthly picture is probably as reliable as the monthly plots of isotherms (standard oceanographic procedure), each based on about four Nansen bottle observations. The double layers shown are all Type-3 patterns unless otherwise indicated. The approximate length of the signal used is indicated along the top of the figure.

It can be seen that in 1954 the winter and spring months were generally characterized by single-layer patterns. These were very attenuated and weakly recorded in February, and became more strongly developed in late spring. Solid-layer patterns dominated throughout the summer months, followed by double-layer types during the fall period. Because of the difference in signal length used, the two years' data are not completely comparable, but it is quite apparent that the basic pattern was repeated during 1955. Very thin, attenuated layers were recorded in February. The single-layer pattern developed to a solid-pattern climax in summer, to be displaced in the fall by a period of double-layer types. These in turn gave way to the single-layer pattern in early winter. Isolated observations in the fall and winter of 1953, and monthly recordings continued through the early part of 1956, fit perfectly into the seasonal picture established by this study of the 1954-55 data. All the available evidence indicates that the acoustic properties of the water masses in Monterey Bay undergo a rhymthmic, three-phase, annual cycle.

Hydrographic Data.

The hydrographic data have likewise been examined for evidence of an annual cycle. As might be expected, it was found that seasonal trends were displayed by the salinity, oxygen, phosphate and silicate data. In general, these trends were not only correlated with, but better demonstrated by, the changes in thermal conditions of the upper 200 m.. For this reason no detailed accounts of the chemical variables are presented; instead, a graph of isotherms based on monthly averages is shown, which depicts cyclic changes in hydrographic conditions during the two years of scattering-layer observations (Fig. 28-A). The dates and frequency of observations, which coincide with those made on the DSL, are listed in the appendex.

Skogsberg's pioneering hydrographic study of Monterey Bay (1936) provides an excellent background on which to project a discussion of the thermal conditions of 1954-55. By a study of five years' data (1929-33), Skogsberg was able to define three definite phases which dominated the annual thermal rhythm in this region: (1) The Upwelling Period, a cold-water phase caused by upwelling subsurface water. On the average, this period was considered to extend from the middle of February to the middle of August. (2) The Oceanic Period, a warm-water phase characterized by depression of the isotherms and attributed to the influx of the California Current. This period was of short duration and developed during the months of September and October. (3) The Davidson Current Period, a season marked by low thermal gradients and relatively warm water, extending from mid-autumn to February, and attributed to the inshore northward-flowing Davidson Current.

The monthly averages of the temperature data covering the period of this project closely follow Skogsberg's annual cycle which was established solely on the basis of thermal relationships. The 1954-55 data have been surveyed from the point of view of temperature-salinity relationships by means of T-S diagrams (temperature plotted against salinity). Sample diagrams, drawn from data taken at three stations which typify the three periods, are shown in Fig. 29.

The waters of the Monterey Bay region form a part of the Transitional Water that lies along the Pacific Coast of the United States and Baja California. This water mass is formed by the mixing of Subarctic Pacific Water and Pacific Equatorial Water. In the latitude of Monterey Bay, Equatorial Water has been shown to form 40-50% of the Transitional Water (Tibby, 1941). The temperature-salinity curves

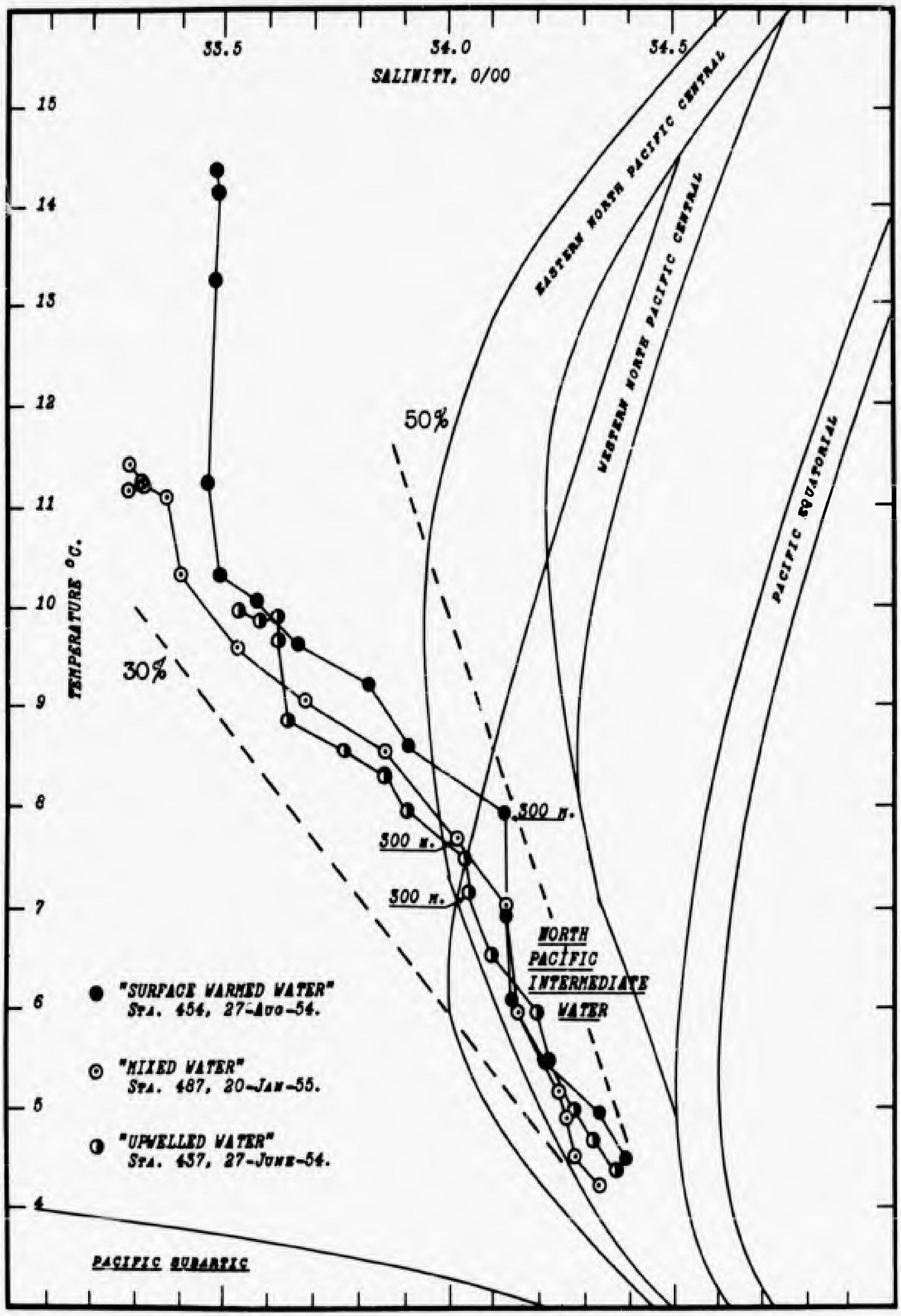


FIGURE 29. TEMPERATURE-SALINITY CURVES

representing 30% and 50% Pacific Equatorial Water in the Transitional mixture are plotted in broken lines on Fig. 29, and the T-S curves drawn from the present study are shown to fall close to the 40% curve. Transitional Waters below 300 meters cannot be distinguished from either Eastern or Western North Pacific Central Water on the basis of T-S properties.

It is clear from Fig. 29 that water in the upper 50 m. is variable; this is to be expected, and this surface water is not usually considered in any interpretation of T-S relationships. Below 50 m., however, the water mass is relatively homogeneous and constant in its T-S properties throughout the entire year. This fact is at odds with Skogsberg's concept that the shift in thermal properties of Monterey Bay is due to the seasonal influx of characteristic types of water into the bay. If such an ebb and flow of water of distinctly different origins is a hydrographic fact in Monterey Bay, then this water must either be present as a very shallow surface layer, or it has become so adulterated by mixing processes that its detection presents a problem too subtle for the classical T-S method of Helland-Hansen. Work now in progress at this institution by Mr. Thomas Fast and Mrs. Stephen McCann may yield sufficiently sensitive criteria so that foreign-water flushes can be objectively labled. For the present, it can be accepted as a working hypothesis that the shallow water in this area is local shelf water, which may sometimes be influenced by influxes of water of foreign origin, but whose basic seasonal changes are primarily due to local meteorological conditions. It is suggested that the Oceanic Period may be due to surface warming in the summer months, and the Davidson Current Period to turning over or mixing of the surface layers by strong southwesterly winds to form a homogeneous stratum at the surface in late fall and winter.

For this reason I hesitate to use Skogsberg's terminology, and instead redefine his three periods as follows: (1) Upwelled-water Period, the onset of which can be objectively marked by the ascent of the 9° isotherm above the 100 m. level, and the termination fixed by its subsidence below this depth. (2) Surface-warmed Water Period, characterized by what can be considered as a well developed thermocline in the superficial layers. (3) Mixed-Water Period, indentified by a low thermal gradient on the order of less than 1° C. change in the upper 50 m. The periods established by these criteria are marked off under the temperature diagram in Fig. 28-A. In some cases the exact line of demarcation is rather arbitrary, since of course short transitional periods are to be expected.

It will be noted that the hydrographic year of 1954 is a classical example of the Skogsbergian Cycle. Briefly, the Mixed-water Period prevails until March, at which time the Upwelling phase becomes dominant. This latter period reaches its peak in June and gives way to the Surface-warmed state in August. The cycle is completed when the latter period is replaced in mid-November by the Mixed-water Period. This phase carries over into 1955 when Upwelling again predominates.

The Upwelling Period of 1955 differs basically from that of the preceding year in that two peaks are evident, well-marked by the humps in the 8° isotherm. The period begins in April, reaches the major peak in May, then tends to subside in June, and increases slightly again in July. The Surface-warmed phase takes over in August but while covering approximately the same season as in the preceding year it is not as strongly developed. In fact, there is no evidence of a depression of isotherms indicative of Oceanic Water, but instead the 9° isotherm rises to a point just below the 100 m. level in September and remains at this depth until December. On the basis of the development of a low thermal gradient layer at the surface, the Mixed-water Period can be considered to begin in mid-November.

Phytoplankton Population.

Weekly phytoplankton samples have been taken at a location approximately 4.5 miles due north of the scattering-layer station (Fig. 1). These samples were collected in conjunction with the California Co-operative Sardine Research Program at Hopkins Marine Station. They were obtained by means of a phytoplankton net with a mouth opening of 17 cm. and hung with No. 20 bolting silk. The weighted net was dropped to a depth of 15 m. and recovered in as vertical a manner as drift of the boat would allow. The contents of the net were flushed, drained, preserved, returned to the laboratory, and allowed to settle to a constant volume in a graduated cylinder. Usually these samples were taken on the day preceding or following the scattering-layer observations. Dates and the raw data are included in the appendix; monthly averages of phytoplankton volume are plotted in Fig. 28-B. Beginning in March of 1954 the phytoplankton volume increased steadily to a peak in July, declined rapidly to a moderate figure in August, and dropped nearly to a zero level from November to February of the following year. In contrast, 1955 was marked by two phytoplankton peaks, one in April and a second in August, the latter being higher.

Correlation of Seasonal Variations.

The three graphs in Fig. 28, representing thermal conditions, phytoplankton population and scattering patterns, have been considered individually; they can now be discussed from a comparative standpoint.

An excellent correlation between upwelling and phytoplankton bloom is evident; however, the two factors are out of phase. The phytoplankton blooms lag behind the upwelling cycle by a 30-60 day period. This correlation can best be appreciated by mentally allowing for the lag period and then following simultaneously the course of the 9° isotherm and the phytoplankton curve with the eye. Aside from the straightforward relationship between the 1954 peak and the major peak in 1955, it can be seen that the early phytoplankton bloom in April of 1955 is preceded by a slight, incipient upwelling in February. Even the unseasonally late increase in phytoplankton volume in the fall of 1955 is foreshadowed by a rise of the 9° water in late September.

The obvious point of correspondence between the phytoplankton picture and the seasonal scattering profile is the correlation between peak phytoplankton blooms and the periods where the solid type of scattering pattern dominates. The basic relationship between thermal conditions, phytoplankton, and scattering pattern can be briefly summarized.

THERMAL PERIOD	PHYTOPLANKTON	DOMINANT SCATTERING PATTERN
Mixed Water	Low to Moderate	Type 1, Single Resolved Layer
Upwelled Water	Peak Bloom	Type 2, Solid Pattern
Surface-warmed Water	Moderate to Low	Type 3, Modified Double Layer

In addition, all four of the Type-4, Double-Resolved-Layer patterns occurred during times of Mixed Water, or at the rather arbitrary boundaries between this period and that of Surface-warmed Water.

Interpretation and Discussion.

It has been shown in the foregoing account that the seasonal fluctuations in thermal conditions, phytoplankton, and type of scattering layer recorded are correlated.

There remain to be considered the causes for these fluctuations, and the functional interrelationships which underlie the correlations. First to be treated here are the causes of the seasonal shifts in thermal conditions in the Bay. Detailed, quantitative information on the meteorological conditions of the general area, while available, has not been included here, nor is such necessary to a presentation of the annual weather cycle and its effects on the hydrographic climate.

Upwelling can be attributed to the northwesterly winds which prevail off this region of the California Coast from early spring to mid-summer. The stress exerted by these winds pushes the surface layers of the ocean away from the coast, and cold water from moderate depths wells up in its place (Sverdrup et al. 1942). The combination of this cold surface water and a warm overlying air mass results in the formation of a dense layer of low fog. This thick bank of fog overlies the coastal regions during the summer months, reduces illumination, and serves to buffer heat exchange between the air and the surface waters. With the abatement of the winds from the northerly quarters, upwelling quickly subsides. By early autumn the fog bank usually is burned away and a short period of clear skys, warm sun, and quiet air combine to create conditions conducive to warming of the surface layers. The onset of cold weather cools the surface layers which have become slightly more saline due to evaporation during the warm period. These factors combine to create a relatively heavy, unstable surface layer which is easily turned over by the stress exerted by the strong westerly and southwesterly gales of winter. The characteristic, homogeneous layers of the Mixed-water Period are a result. Clear weather in early spring, in conjunction with stability gained by reduced salinity at the surface due to winter precipitation and run-off from flooding rivers, can result in incipient surface warming before the influence of the northwesterly winds again induces upwelling.

The relation between upwelling and periods of phytoplankton growth is one of the best documented in marine biology (Sverdrup et al., 1942). Upwelling is instrumental in returning plant nutrients (phosphates, nitrates, silicates, and other trace elements) to the depleted waters of the euphotic zone, where, if light conditions are favorable, dynamic plant growth (blooms) may take place. While a short time-lag is normally to be expected in this process, the unduly long 30 day lapse evident from the data presented in Fig. 28 is very likely explained in the following manner. Work on the interpretation of detailed, weekly temperature surveys of Monterey Bay, implemented by 14 bathythermograph stations, has shown that the Monterey Canyon plays a dominating role in the upwelling phenomenon in the Bay (California Cooperative Research Program, Progress Report, Anon. 1952). The canyon acts as a fountainhead from which the cold waters rise and then spread out to other regions of the Bay. The DSL observation station appears to be in a region of divergence caused by this upwelling of water, and it seems likely that plant cells which represent the potential inoculum for a bloom are carried along with this water to the shoreward shelf regions of the Bay before they have time for multiplication. In support of this hypothesis, studies show that the burst of diatom growth occurs much earlier and is stronger in the shelf waters circling the canyon than in waters overlying the canyon itself. For example, on April 1, 1954, the phytoplankton volume of the standard vertical tows (expressed in terms of ml. displacement) over the canyon was 2.0, whereas on the southerly side of the Bay off Pacific Grove it was 18 and on the northern shelf off Santa Cruz, 20. By May 17 the shallow water blooms had reached their peak volumes of 135 and 94 respectively, while the deep-water station was still only 9. By the end of July, however, when upwelling had slackened, the shelf counts had leveled off and the DSL station had risen to its peak bloom, so that counts of the same high order of magnitude were the rule all over the Bay. The same general situation is evident in the spring and summer of 1955.

The most obvious direct relationship between phytoplankton concentration and scattering-layer pattern lies in the manner in which the plant-like entities and the by-products of their metabolism reduce the penetration of light into the water. Photometric measurements of transparency of the surface water layers were carried out on some of the DSL stations. Essentially the method involved lowering a selenium photocell into the sea and measuring the electron flow caused by the incident light energy with the aid of a galvanometer at regularly increasing depth intervals. Unfortunately, the conditions necessary for obtaining good data (flat seas, low drift, and constant surface light) are rare in the open ocean outside of Monterey Bay. A review of the results of two observations taken at opportune times, however, will give a general idea of the importance of phytoplankton in reducing light penetration. On Station 458, 9 September 1954, 95% of the light measured just at the surface was extinguished at a depth of 12 m. The galvanometer used was not sensitive enough to record light below a depth of 20 m. on this day. In contrast, on Station 485, occupied on 11 January 1955, the 95% extinction point was at 40 m. Approximately the same amount of light was still recordable when the photocell had been lowered to the limit of available wire at 50 m. On the first occasion, medium phytoplankton fouling was reported in a surface haul made with the M-net on that station, and the phytoplankton count measured on the preceding day in the middle of the Bay was 18. In contrast, no plant fouling was noted in the surface haul with the

M-net on the January station, and plant concentration measured two days later on January 13 was less than 1. In times of peak bloom, when turbidity is extremely high, it is safe to assume that light penetration would be even further reduced. These are the times when the solid-layer pattern predominates.

What causes this pattern? All of the available evidence points to the role of light as a dominating influence on the vertical distribution of bathypelagic organisms (Cushing, 1950). It is not surprising that the results of hauls taken during this period in the present study indicate an upward spread in the populations of potential scattering organisms, and undoubtedly the factors of reduced illumination (due to summer overcast conditions) and reduced light penetration (due to phytoplankton) are partially responsible. Another possible influence of phytoplankton concentration on scattering pattern is the importance of diatom blooms in providing forage for planktonic herbivores. However, before a further attempt can be made to piece together the evidence for these relationships it is necessary to consider the general biology of key potential scattering organisms in more detail.

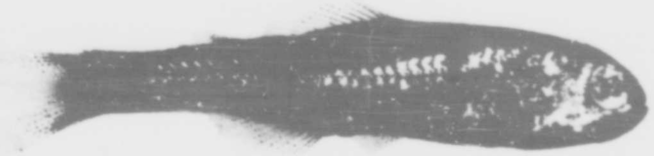
PRINCIPAL SCATTERING ORGANISMS

Euphausia pacifica (Fig. 30-D).

The primitive, shrimp-like members of the Order Euphausiacea are among the commonest of macroplanktonic organisms, and are known to be of prime importance in the economy of the sea. Euphausia pacifica, the dominant midwater euphausid in Monterey Bay, is very probably the most common and widespread of the euphausid species in the North Pacific. It's range extends from North America to Asia, and it occurs in great numbers in both coastal and oceanic waters, from 25°N to 59°N (Banner, 1949). In the DSL studies of Boden (1950a) and Tucker (1950) this species was considered to represent the dominant, potential scattering organism of the sonic layers which were recorded on NMC-2 echo-sounders in the San Diego region. Individuals reach a length of about 2.5 cm., are light red in color, and bear complex light producing organs (photophores). The larval stages have been described by Boden (1950b), but little is known of the basic biology of the species. It is considered to be a setous filter feeder, particulate matter being carried in a current, induced by the beat of abdominal appendages to a basket formed by the bristly, thoracic appendages. It's essential role in the ecology of the midwater regions is that of a key-industry organism, it represents the major link between the products of photosynthesis and economically exploitable animal protein.

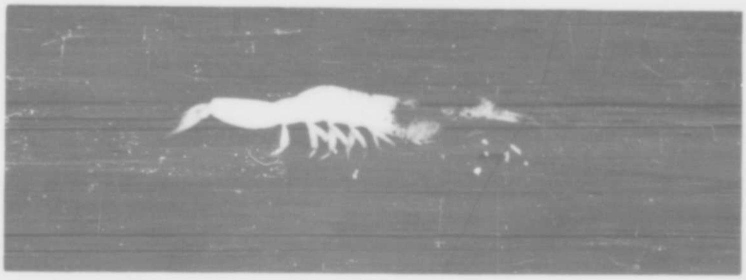
1.5X

A. *Diaphus theta*



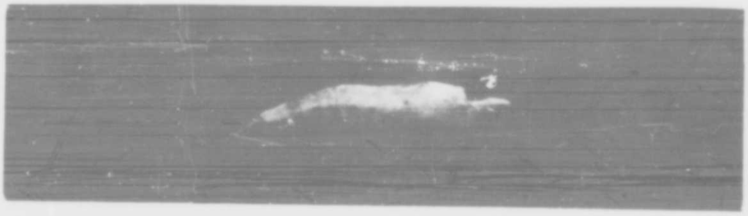
1.0X

B. *Lampanyctus leucopsarus*



0.8X

C. *Sergestes similis*



1.8X

D. *Euphausia pacifica*

FIGURE 30. PRINCIPAL SCATTERING ORGANISMS

A general idea of the population dynamics, bathymetric range, and relationship to scattering patterns, of Euphausia pacifica can be gained from the data obtained during the course of this investigation. In addition to the net hauls made at critical levels for the DSL investigations, standardized hauls were taken once a week as part of the regular oceanographic program. While the results of these hauls cannot adequately serve to associate organisms with zones of reverberation, they do provide considerable additional information on the species. In conjunction with data already presented (see Types of Scattering Layers) this information has been drawn upon as an aid in forming a picture of the changes in abundance and distribution of E. pacifica.

From the first of the year until about the beginning of April, the Euphausia pacifica population of the DSL station consists of adolescents which are present in very low numbers (less than 50 specimens to a haul). In mid-spring, full grown adults enter the area, and a dramatic change in population density at scattering layer depths is noted. During this season the catches may fluctuate to such a degree that the variation in numbers between successive weekly hauls may be as great as from 8 to more than 12,000. These statements are briefly documented by the list of dates and catches for stations extending over this period in Table 2. (The catch data on the myctophid, Diaphus theta, are included here for convenience, and are discussed

Station	Date	Type of Layer	Gain	Figure	E. pacifica	D.theta
476	8 Dec.54	4	6.7-7.0	27	159	51
478	15 Dec.	1-M	6.7-7.2	18	436	47
480	20 Dec.	1-M	6.7-7.1		629	21
482	29 Dec.	2 & 1-H	7.1	12	634	13
485	2 Jan.55	1-L	7.0	19	19	45
487	20 Jan.	1-L	7.1		4	148
489	25 Jan.	1-L	6.7-7.4		7	58
490	3 Feb.	1-L	7.2		4	38
491	9 Feb.	1-VL	6.8-7.3		47	10
492	15 Feb.	1-VL	7.1-7.3		8	32
493	22 Feb.	1-VL	7.0	20	27	28
494	2 March	1-VL	6.9-7.7		2	12
495	8 March	4	7.1	26	5	49
496	17 March	1-M	7.0		47	14
497	23 March	1-M	7.0	11	3	0
498	5 April	1-H	6.3-7.0		625	0
499	13 April	1-H	6.7-7.0		8	0
500	23 April	1-H	6.8-7.0		12,941	0
501	4 May	1-H	6.5	13	4,290	0

Table 2. Winter and spring fluctuations in the type of scattering layer and in catches of *Euphausia pacifica* and *Diaphus theta*.

in a later section). When more than one haul was made, the numbers of individuals taken in the heaviest catch is listed. Figure numbers are given for those stations for which echograms and detailed data have already been presented. The sensitivity setting of the echo sounder during the period of sonic observations is noted. Finally, the type of scattering layer predominating during observations is listed. Differences in the intensity of recordings of the type-1 patterns are indicated by the following code (H-heavy, M-medium, L-light, VL-very light). Echograms representative of these designations can be checked by reference to the figures cited.

With regard to the significance of the data presented in Table 2, two points may be briefly mentioned here. The period of light and very light type-1 layers, coincides with the low phase in E. pacifica density. Low amplification of returning reverberations cannot account for the faintness of the recorded layers; in fact, it is during this period that, in order to register a trace of the layer, the gain must be advanced to the point where background noise jams the recordings.

The dynamic flux in the numbers of E. pacifica in early spring may be due to large-scale horizontal shifts of the population. However, an abrupt change in vertical distribution may also occur. For three consecutive years during the month of April, tremendous swarms of E. pacifica have been observed at the surface in broad daylight. These shoals occur in the regions above and adjacent to the Monterey Canyon. This rather surprising behavior on the part of an organism which is normally found at depths of from 100 to 400 m. is very probably associated with spawning activities, but the phenomenon calls for proper investigation.

During late spring and early summer, _E. pacifica_ occurs in good numbers at scattering-layer depths. At times it outnumbers all other species considered as potential scatterers (e.g. Figs. 13, 16, 17). On other occasions it is taken in lesser quantities than are the sergestid prawns, which during this phase of the year generally show a higher biomass at DSL depths. _E. pacifica_ populations are characteristically dense during the summer months while the period of solid patterns holds sway. It is proposed that these organisms are largely responsible for this type of trace. It is evident that the solid pattern is caused by a filling in of the space between the zone of outgoing signals and the top of the scattering layer. There are two possible explanations for this phenomenon. Scattering organisms forming the later could shift their center of bathymetric distribution upward (evidence for this has already been brought out) and scatterers present in the surface layers could cause extensions of the signal trace downwards as surface reverberations. The evidence to substantiate the view that _E. pacifica_ is primarily responsible for the solid pattern follows.

Hauls taken during the solid-scattering season are typically characterized by relatively high and equal numbers of E. pacifica. In general this holds for hauls taken below the 150 m. level, regardless of depth and time of fishing. One way of explaining this situation is to assume that the E. pacifica population is concentrated in the upper levels and evenly distributed horizontally. Therefore the nets, which fish the upper levels for relatively equal times while being recovered, would sample this population in even numbers. This relationship has previously been pointed out for hauls made with the T-net (Figs. 21, 22). Additional evidence is available from a series of hauls made with the M-net during the summer of 1954. This net was used in the interim between the loss of T-net No. 1 and the procurement and hanging of T-net No. 2. Hauls were made following the standard practice of shooting 900 m. of wire rapidly, towing for an hour and then recovering obliquely. The results are presented in Table 3, page 126.

It is evident that with the possible exception of the first haul in the series, the numbers of adults captured are certainly of the same order of magnitude. The increase in the catches of the immature forms suggests that the summer months of this year were a period of recruitment for the E. pacifica population.

Station	Date	Numbers of E. pacifica		Time
		Adults	Juvenile	Net Fished 0-200 m.
441	31-June-1954	107	864	16
443	7-July	642	3,289	14
445	19-July	444	3,829	16
447	26-July	294	2,789	8*
449	2-Aug.	676	6,788	14

* Recovered vertically to avoid loading of the net with salps.

Table 3. Number of E. pacifica taken in M-net tows during period of dominant Solid-scattering Pattern, 1954.

The results of an investigation by Cushing and Richardson (1956), published as this paper was nearing completion, provide an excellent piece of evidence for a casual relationship between a high euphausid population and solid scattering. As part of a standard survey, the acoustic characters of the shallow water masses in the North Sea were measured with the aid of a recording echo sounder. The transducer was mounted so as to project a horizontal sound beam of high energy output and brief signal pulse. The length of recorded reverberations extending out from the signal zone at various standardized sensitivity settings was used as a measure of the noisiness of the water in the upper layers. At times this feature was extensive, while on other stations it was poorly developed or lacking. Possible entities which could be responsible for what these workers refer to as the "noisy trace," but which is analogous with our solid-scattering pattern, were sampled with a metal, high speed net, hauled just below the surface at 6-8 knots. An excellent correlation was shown between a large euphausid catch and the presence of a noisy trace.

Information pertaining to the fall and early winter euphausid distribution also has a bearing on the cause of solid scattering. During the dominance of the double-layer pattern in the fall, the available data (esp. Figs. 23,25) strongly suggest a cause and effect relation between the *E. pacifica* population and the shallow upper layer. The difference between the solid pattern and the Type 3 modified double-layer pattern lies in the clearing up of a critical level at about 100-200 m. depth, plus resolution of a second layer. A downward movement of the scattering population in the upper layers will bring about the first of these changes and this is very probably what happens. It is suggested that the *E. pacifica* population which was diffusely distributed in the upper levels during the period of solid scattering, at this time has contracted its vertical limits and sought a slightly deeper daytime level, with the result that the zone of reverberations from it can now be resolved as the upper layer of the Type 3 pattern by careful adjustment of the sensitivity settings.

Leaving changes in population of *E. pacifica* in abeyance for the moment, and dealing strictly with acoustical patterns, it is evident that there was a difference between the shallow layers of the Type 3 patterns of 1954 and those recorded in 1955. During 1954 the shallow layers were extremely well developed and were clearly resolved with the proper sensitivity adjustment (Figs. 23, 24). In contrast the upper layers of the Type 3 patterns in 1955 were more diffuse and even careful sensitivity tuning could not resolve them into as definite an acoustic feature as those of the preceding year (Fig. 25). A difference in scattering pattern between the two years was also evident in the nature of the echograms of early winter. In 1954 (with one exception) early winter echograms indicated well-developed single layers which were centered vertically at about the 300 m. level. On the other hand, during the corresponding period in 1955 the acoustic observations revealed the prevalence of a different sort of single resolved layer. These 1955 Type 1 layers were generally contiguous with the signal zone in early morning to form solid scattering patterns, during the morning they moved slowly downward, coming to rest at noon at about the 180-200 m. depth. A single example of this type of layer appeared in 1954 (Fig. 12-A). Thus even though the basic fall and winter scattering patterns were similar in 1954 and 1955, there were still important differences between the acoustical recordings of the two years.

These acoustical differences were paralleled by differences in the 1954 and 1955 euphausid populations.

In 1954 the population taken by the T-net in the vicinity of the upper layer of the Type 3 pattern was dominated by large adults, and this size group made up the bulk of the euphausid catches in the early winter as well. On the other hand, during the same period in 1955 fewer adults were taken with the large net, and immature forms were of equal importance numerically. However, the true density of the immature euphausid population was not realized until November, 1955. At this time two hauls were taken through the relatively shallow, migrating single scattering layer which dominated during the early winter of 1955. The first haul was made with the T-net followed by a duplicate haul with the M-net. The courses of the two hauls through the scattering layer and the time of fishing in this region as judged from a depth-time records were almost identical. The T-net took 407 adults and 380 adolescents of Euphausia pacifica. The catch for the M-net, on the other hand, was 1,115 adults and 10,821 adolescents. No other organisms were taken in either haul which could account for scattering.

In addition to the foregoing data, the differences in dominant age groups of E. pacifica in catchs from various years were evident to the author while sorting hauls over a four year period, and qualitative statements of this were noted on sorting records. From this information it seems very likely E. pacifica has a life cycle of two years. For the period of 1952-1955, at least, during the even-numbered years the population was dominated by large adults, whereas the odd-numbered years were characterized by the numberical predominance of adolescent forms.

This relationship may, in turn, account for the differences in acoustic patterns recorded during the two years of observations. The presence of the dominant adolescent population in 1955 appears to have caused the heavy reverberation in the upper water masses which made resolution of the upper layer of the Type 3 pattern more difficult. The nature of this population would also explain why the layer was not well-defined. The adolescent population contained a number of different instars, each of which might be expected to have somewhat different and distinct reactions to light and perhaps other conditions. With each stage seeking a slightly different light optimum, and hence a different vertical level (Cushing, 1950). The diffuse type of layer characteristic of the 1955 patterns would result.

Evidence that the high Type 1 layers present during the early winter of 1955 were caused by young euphausids is provided by the catch records already discussed. In addition, when the echograms covering this period are placed side by side and examined, it is evident that there was a marked tendency for this high Type 1 layer to become less diffuse and more strongly developed as the weeks progressed. It is doubtful that changes in illumination can account for this, since light intensity was decreasing at this time of year. It is more reasonable to assume that the physical growth of the euphausid population had, in fact, increased the target strength of the scattering layer. As the weeks went by the layer gradually transformed into the well defined and heavily recorded pattern characteristic of the upper layers of the Type 3 patterns in 1954, which were shown to be associated with heavy catchs of large adult euphausids. An adult population, made up of individuals of similar size would be expected to cluster more closely about a single optimum in physical conditions than a population of mixed sizes, even though the adult tolerance range for physical variables may be greater. This factor could account for the more definite layering associated with the adult populations. One more bit of evidence can be introduced. There is a close similarity in the nature of the scattering layers recorded in Monterey Bay shown to be associated with a heavy population of adult euphausids, and the nature of layers recorded with the same type of sounder in the San Diego Trough in 1948 by the "E. W. Scripps". Carefully placed vertical closing hauls made with Clark-Bumpus samplers also indicated a definite relation between the scattering layer and euphausids in that area (Boden, 1950a).

The annual cycle in 1954 was terminated by the sudden disappearance of adult euphausids and the extreme drop in numbers at the end of the year which was discussed and documented in the first part of this section. Monthly hauls, continued after the termination of the program of weekly stations, provide definite proof that this pattern was repeated again in 1955.

It seems clear, at this point, that an understanding of the cyclic changes in the Euphausia pacifica population is crucial in any interpretation of the seasonal scattering picture in Monterey Bay. These cyclic changes have been sketched in broad outline here, but much more detailed information on the biology of this species is a prime desideratum.

Sergestes similis. (Fig. 30-C).

In the course of the present work considerable information has been gained concerning the general biology of the midwater prawn, Sergestes similis. This species reaches a maximum length of about five cm. (measuring from eye orbit to tip of telson). The body is covered with a transparent, membranous exoskelton; the cardiac and gastric regions of the thorax are bright red, and red chromatophores are scattered over the remainder of the body. S. similis is known to range throughout the north Pacific from Japan to Washington and as far south as the Gulf of California (Schmitt, 1921). The use of the T-net has demonstrated that high numbers of the species are often present at scattering-layer depths in Monterey Bay.

Living sergestids taken for observation were carefully removed from the codend bucket as soon as the net was recovered, and placed in jars in a portable ice box to insure safe return to the laboratory. Here the prawns were maintained and studied in small aquaria at temperatures of 12-13° C.

Concerning movement and orientation, normally the animals remain in the bottom corners of the aquaria, with heads directed downward at an angle of 20-30° from the vertical and pleopods in constant motion. Occasional sorties are made by a swimming action that involves only the pleopods and last two pairs of thoracic appendages. Swimming individuals continue on a set course until they come up against the walls of the tank or the surface film. The course followed is so straight that the rate of movement can be measured easily with the aid of a stopwatch. Average speed of swimming, based on 20 measurements of three individuals, was eight cm. per second (4.8 m. per minute, or 288 m. per hour). This speed of swimming coincides very closely with the rate of vertical movement of scattering layers. Another type of movement observed in _S. similis_ consisted of backward flips, executed by rapid flexure of the abdomen in typical caridoid style. The shrimp sometimes leap clear out of aquaria in a series of such flips occurring in rapid succession, and a fair number of casualties resulted from this behavior.

The exceptionally long flagella of the second antennae (a prawn four cm. in length may bear antennae 16 cm. long) are normally carried like a pair of buggy whips, canted forward at a 45° angle and directed anterolaterally. Characteristically the antennae bend, and the terminal two-thirds of the flagellum trails backward along either side of the body. Flagellar segments in this region are each armed with two long hairs. Apparently the antennal flagella serve as sensitive tactile organs, for stimulation of the trailing terminal portion by touch or directed water currents initiates a rapid series of backward flips. The other regions of the body are relatively insensitive to such stimuli.

With regard to food and method of feeding, examination under a dissecting microscope indicates that <u>Sergestes similis</u> is a selective particle feeder. The steady beating of the abdominal appendages creates a current which brings particulate matter toward the head region, where it is trapped in a complex of long hairs born on the thoracic appendages. Particles are then selected by the third maxillipeds and passed inward toward the mouth. If offered larger food material, such as diced sand dollar gonad (about one sq. mm. in size), this is readily accepted and held to the mouth by the third maxillipeds where it is minced by the other mouth parts. Individuals showed no interest in living copepods and chaetognaths which were introduced into the aquarium.

Gross examination of the digestive glands reveals large quantities of bright orange oil. As in so many mid-water forms, this material probably provides both bouyancy and stored food. Ethyl-ether extraction of 10 specimens in a Soxhlet apparatus indicates a body lipoid content equal to 19.2% of the dry weight. The figure is high but in keeping with other bathypelagic marine forms (Baalsrud, 1955).

In a general way, it was possible to note cyclic changes in the composition of the population of Sergestes similis while sorting the material taken in hauls over a four year period. Two overlapping age classes or breeding populations are present. Individuals of the two populations are similar in form, but for most of the year can easily be distinguished on the basis of size. During the period from mid-November through January and again during July and August the two groups overlap so that only the extremes can be easily determined. Careful measurements and statistical treatment would undoubtedly make it possible to follow the life history through its entire course. Briefly, a winter class is spawned in December and January, passes through typical sergestid larval stages, and grows rapidly to maturity. By fall, this population has reached full size, and after spawning in December and January it disappears. The second or overlapping population is spawned in June and July, and undergoes the same developmental history, six months out of phase with the winter population. Because of the existence of these two coexisting populations, a relatively constant number of immature and adult specimens is found in the water mass throughout the year. This is evident from the results of numerous hauls made with the M-net early in the Hopkins Marine Station's oceanographic research program. These hauls fished mainly below 600 m., but the nets were recovered obliquely at a moderate rate so that good biological samples of the upper water masses were obtained. In 1952 all of the 40 such hauls, taken roughly at weekly intervals, were successful in catching Sergestes similis. The numbers caught per haul ranged from two to 30, with an average of 10.3 per haul. If the species spawned only once a year, one would expect the number of immature forms in the population to change greatly with season. On the contrary, most of the individuals taken with the M-net were immature regardless of season.

It was not until after the T-net was developed and used to sample specific bathymetric layers that an understanding of the life cycle and an appreciation of the size and importance of the S. similis population at scattering layer depths were gained. The following account summarizes present knowledge of the seasonal population changes of S. similis as these are related to the DSL in Monterey Bay. In winter during the period of lightly developed Type 1 scattering patterns, large numbers of mature adults which entered the population the previous winter are present along with the six month old individuals of the summer spawning. A few of these sergestids are taken at scattering layer depths, but their greatest population density seems to be below this region (Figs. 18-20). Indications of a scattering layer at the depth of greatest sergestid concentration are faint or absent on the echograms; however, on the few occasions when a definite Type 4 double layer pattern was recorded, the lower layer showed an excellent correlation with the S. similis population (Fig. 26). In spring and early summer a medium to heavy Type 1 scattering layer is present, and the sergestid population occurs within the layers. The population at this time is composed of adults from the previous summer's spawning, reinforced by large numbers of adolescents from the incoming winter group. The younger sergestids tend to be distributed at a slightly higher level, but both classes are within the vertical limits of the DSL (Figs. 13, 15, 17). An indication of the close correlation of the vertical distribution of the adult sergestids with the scattering layer can be gained from Fig. 31. This graph has been constructed by plotting the catch of S. similis adults as a function of the number of minutes the net fished within the general vertical extent of the scattering layer (225-375 m.) during spring and early summer. The 1954 series (symbolized by open circles) began when the T-net was first used as a standard part of the field program and ended when the net was lost early in June. The 1955 series (indicated by solid circles) covers approximately the same

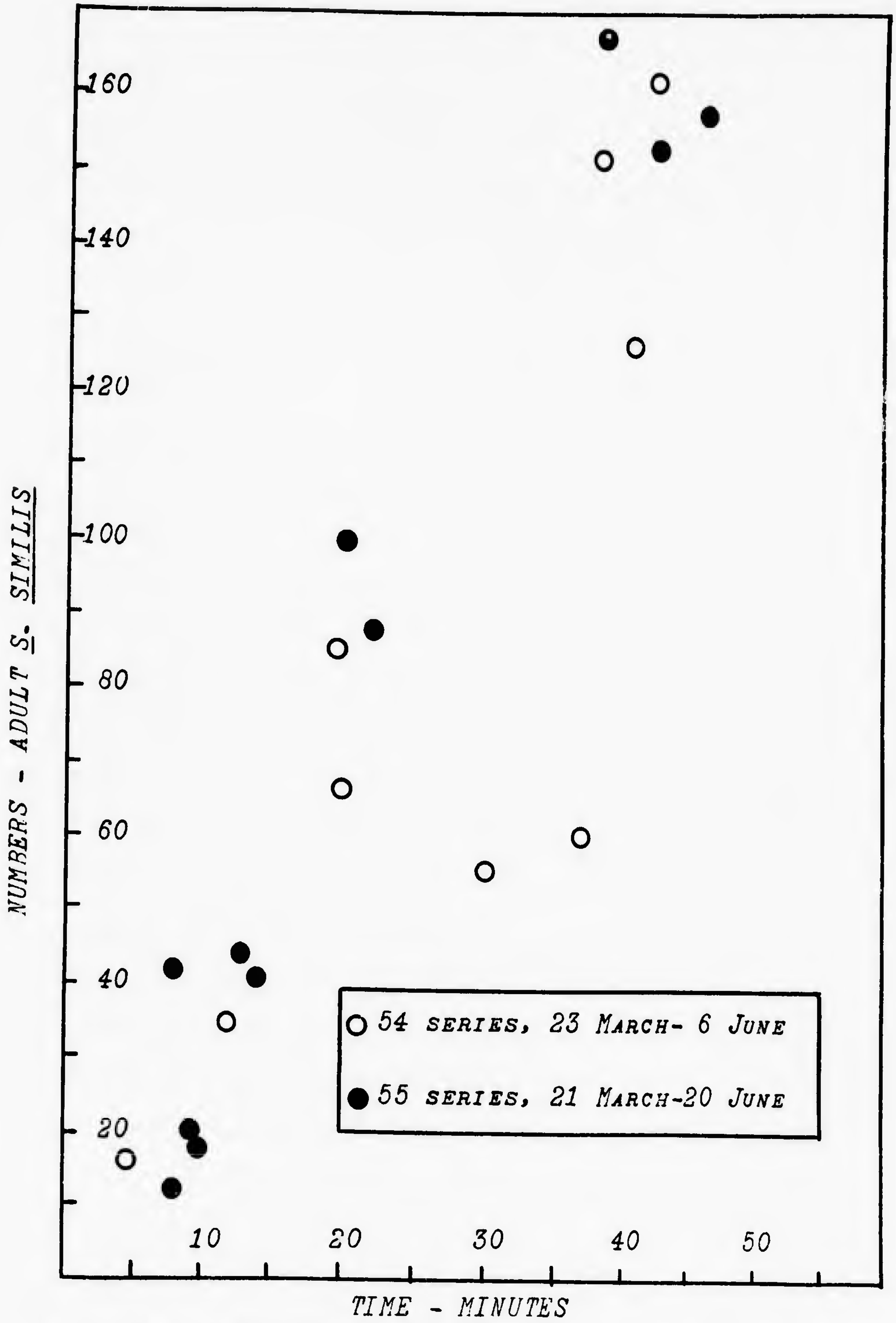


FIG. 31. NUMBERS OF SERGESTES SIMILIS IN NET HAULS PLOTTED AGAINST THE TIME GEAR HAS FISHED AT DSL DEPTHS.

part of the year. The two points of the 1954 series which lie to the right of the general curve represent stations at which diffuse and light scattering layers were recorded.

In summer when the solid (Type 2) scattering pattern dominates, the vertical center of the prawn population moves upward 50-100 m., well into the mid-region of the zone of reverberations. The winter year class has now reached young adult status and dominates the catches (Figs. 21, 22). In the fall these adults are fully grown, and they move down into the region of the lower layer in the Type 3 and Type 4 double layer patterns. The data indicate that their vertical distribution may be sharply limited, and that they are present in this stratum of water in high numbers (Figs. 23, 25).

Previous mention of the mid-water prawns as scattering organisms is limited to a brief suggestion by Moore (1950), and an admission of the possibility of their importance by Boden (1950) and Tucker (1951), both of whom took mid-water prawns in tow nets. The evidence presented here clearly relating Sergestes similis to zones of reverberation is thus of particular interest. On the basis of the reported laboratory observations, this species appears to play the role of a mid-water scavenger, foraging on the particulate detritus and dead organisms sifting down to it from higher levels. Because of its wide geographical distribution it may well play an important part in the economy of the entire North Pacific. That this possibility has been overlooked by most workers in the past may be attributed to the sensitivity and agility shown by sergestids which enables them to escape capture by conventional plankton nets, and to their relatively small size which allows them to pass freely through the larger meshes of fish trawls. The Japanese, however, have not failed to recognize their biological and economic importance. Since 1915, a species (probably Sergestes lucens) has been the major object of a mid-water fishery in the bay of Suruga which yields up to 10 million pounds annually. The shrimp are taken by means of hugh lampara type nets, 200 m. in length, handled by two boats.* Mr. Masao Sekin of the Fisheries Experimental Station, Shimizu, Japan, (in litt, 1955) indicates that the Sergestes fishery is of considerable economic importance at the present time in Japan. Varying numbers of squid (Loligo japonica), a mackeral-like form, the cutlass fish (Trichiurus japonicus) and a myctophid (Diaphus coeruleus) are also taken in the nets with sergestid prawns. The Japanese sergestids (apparently more than one species is involved in the fishery) are thought to be associated with the bottom as detritus feeders in the daytime and migrate upward at night. According to my correspondent, one luminescent species of Sergestes has not been detected

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*This information was kindly provided by Dr. Fenner A. Chace Jr. of the U. S. National Museum. It is taken from a handwritten English summary distributed with a paper by Nakazawa, 1915 (or 1916).

by echo sounder during the day but is easily recorded at night when it rises to a level of 600-900 ft. (In a night collection made in Monterey Bay at the DSL station in the summer of 1954 S. similis was taken in high numbers in the upper 100 m. Unfortunately, the solid scattering pattern in evidence at that time prevented clear correlation of the catch with movement of the layer.)

The information from Japan appears to indicate that economic exploitation of the animal complex which is very probably responsible for scattering layers is not only a possibility but has been an accomplished fact for many years.

The Myctophids.

Two representatives of the large subfamily Myctophinae, whose members occur in vast numbers in the oceans, dominate the bathypelagic fish catches in Monterey Bay. These fishes are relatively small in size, with compact bodies provided with ventrolateral rows of light-producing organs. Detailed studies of the distribution, and biology of these fishes are now in progress by Dr. Rolf L. Bolin and Mr. Thomas Fast of this institution. Both species feed primarily on crustaceans. Stomach analysis indicates that D. theta eats euphausids and calanoid copepods, while young S. similis and deep water copepods have been found in the stomach of L. leucopsarus. Both fishes have swim bladders largely or wholly occluded by fatty material. A summary of the possible contribution of these fishes to acoustic scattering patterns recorded in Monterey Bay is presented below.

Diaphus theta. Fig. 30-A. This species appears to be one of a number of closely allied forms which are widely distributed throughout the oceans, the present form being the eastern north Pacific representative. Few specimens were taken in early hauls with M-net in the general oceanographic program. Evidently because the fish are fast swimmers which are hard to catch, and their daytime vertical position is above the depths which were extensively fished by the M-net.

Hauls with the T-net have shown that the Diaphus theta population is highly dynamic in nature. The period of highest population density occurs in mid-winter, at which time this species forms the dominant micronektonic population at scattering layer depths. It can be seen from Table 2 (p.122) that this period coincides with one of low E. pacifica density, and that it also spans the dates of the faintly recorded layers. As indicated previously, during days of very light scattering layers it is necessary to increase the sensitivity setting of the echo sounder, amplifying returning reverberations to the point of background interference before the layer can be recorded clearly. It is of importance to note that during this period of light and very light layers the gain can be increased from 6.8 to 7.2 (Fig. 18) without affecting the vertical dimensions of the layer. Only an intensification or darkening of the traces is noticeable, and this is exactly what is to be expected of a fish layer as established in the shallow water experiments by Cushing and Richardson (1956). Such an increase in gain during the summer not only increases the vertical dimensions of the recorded layer, but a sensitivity setting of 7.2 in the summer results in a solid trace that will actually burn holes through the iodized recording tape. Obviously then, there are important differences in the nature of the reverberations recorded during these two periods of the year. While T-net haul data are available only for one winter period, echo sounding observations for three years have revealed these thin layers to be a regular acoustic feature of the mid-winter months. There is also a good indication that *D. theta* zonation is closely related to the upper layer of the Type 4 pattern (Figs. 26, 27).

Following this period of *Diaphus theta* dominance, the population disappears during the spring months when *Sergestes similis* abounds at the DSL level. In the early summer *D. theta* returns to the upper waters of Monterey Bay and is taken in low numbers throughout the season of solid scattering in company with *L. leucopsarus* and *S. similis* at the center of the solid pattern. In the autumn *D. theta* is captured in increasing numbers, and the evidence indicates that the species is associated with the bottom region of the upper scattering layer in Type 3 patterns. Following this period a build-up to the mid-winter dominance is evident.

Lampanyctus leucopsarus. Fig. 30-B. This species is the fish most frequently taken in mid-water hauls in Monterey Bay. Its range is considered to extend along the coast from Northwestern Alaska to Southern California (Bolin, 1939). In the latter region it was taken in large numbers in the T-net hauls of Tucker (1951). He reported that it was associated with the lower region of the scattering layer and at depths below any layer recordable on an NMC-2 echo sounder (but in a zone of reverberations detected by oscillographic recordings). It's relationship with scattering layers in Monterey Bay is very much the same. While representatives of this species are taken in the deeper portions of scattering layers, their maximum density occurs at depths below the usual effective limits of the NMC echo sounder used in this study. On the few occasions when Type 4 double layer patterns were recorded, this lantern fish and Sergestes similis were apparently responsible for reverberations forming the lower layer. L. leucopsarus, like Diaphus theta, rises in the summer into the layer of solid scattering.

A feature probably related to the scattering capacity of this fish is the modification of the swim bladder into an oil-filled storage organ, described in detail by Jollie (1954). In the adult stage the bladder is largely filled by fatty connective tissue. A well-developed gas gland is present and almost fills the reduced lumen, but in some specimens a gas bubble may be present. In immature forms the potential gas space is considerably larger; if it actually contains gas it should act as a resonator, and thus the young of this species may be more effective in producing reverberations than the fully grown adults. As with most bathypelagic forms, the younger members of the population tend to occupy a higher position in the water column than the adults.

Cyclothone, Sagitta, and Gonatus.

Since they represented relatively conspicuous and abundant members of the sampled bathypelagic populations, the gonostomatid fish, Cyclothone signata, and the large chaetognath, Sagitta lyra were sorted and counted along with organisms previously discussed. Data on these species is presented in Figs. 13-27. Neither form appears to be closely correlated with recorded zones of reverberation. C. signata may reinforce scattering layers on occasion, but the present findings as well as Aughtry's extensive study (1953a) indicate the populations of this fish to be restricted mainly to depths below the recorded scattering layers. The arrowworm, Sagitta lyra, is clearly concentrated in the waters above the DSL, and because of its watery consistency it is of doubtful acoustic importance.

Mid-water squid have been considered as possible scattering organisms, and hauls with both types of nets have captured small numbers of cephalopods. The species most commonly taken was Gonatus fabricii, a cosmopolitan form which Berry (1912) has reported as present along the coast of California. It is doubtful that the fast-moving adults have been adequately sampled, but the younger individuals taken in equal numbers with either type of net, give no indication of a large population. This form may well play a secondary role as a scatterer in high layers where it appears to be associated with euphausids.

Other Large Crustacea.

Aside from *Sergestes similis*, other decapod crustaceans have been taken occasionally in the T-net hauls. These include the prawns *Pasiphea pacifica*, *Gennadas borealis*, *Acanthephyra curtirostris*, and *Sergestes sp*. With the exception of *P. pacifica*, which is occasionally taken at the 450 m. level, these forms are members of the deep water community located considerably below the level of recordable daytime scattering layers. The same is also true of the giant red mysid, *Gnathophausia ingens*, and the smaller but commoner (or easily caught) mysids, *Boreomysis californica* and *Eucopia australis*.

While *Euphausia pacifica* is the dominant euphausid in the area studied, other species are also taken in the hauls. The commonest of these, *Nematoscelis difficilis* is rarely present in high numbers (the results of its heaviest catch were presented in the discussion of Station 458, p. 56). Apparently it is commoner in waters off southern California, where it was taken in numbers by Boden (1950a) and Tucker (1951). On the basis of the scanty information available it appears to be most abundant in the summer and fall in Monterey Bay, although it is taken throughout the year in low numbers. At no time does it rival E. pacifica in numbers; during the winter when E. pacifica catches are small, N. difficilis is also uncommon with an average catch of only five specimens per haul. The possession of extremely long, bristle-tipped, second thoracic appendages would suggest that this species is a particulate scavenger or predator rather than a filter feeder (Marshall, 1954). It probably does not compete with E. pacifica for food, though its bathymetric distribution is much the same.

The euphausid, Thysaneossa spinifera, is sometimes taken in good numbers, but this species is essentially a neritic form and is restricted mainly to the shelf waters. It has been observed swarming at the surface near the 100 fm. line off Pt. Pinos, Pacific Grove, California, and its presence very probably accounts for some of the shallow scattering which sometimes extends downward below the signal zone. Other euphausid stragglers occasionally taken in the T-net hauls are Stylocheiron maximum, Bentheuphausia amblyops and Nematobrachion boopis. The mysids and euphausids were determined by Dr. Albert Banner (in litt., and 1954), except for the last named species which was identified by the writer, and which probably represents a new record for Californian waters.

Finally, several species of hyperid amphipods are commonly taken in the hauls, particularly those made with the M-net. Their vertical distribution shows no relationship with the zones of reverberation, and they are never taken in numbers large enough to suggest a significant contribution to recorded layers.

Organisms Responsible for Shallow Scattering.

It is evident from the inspection of many echograms that the tracing attributed to the outgoing signals is variable in width. This variation is due to "surface reverberations" which are returned, amplified, and recorded while the stylus of the instrument is still moving downward across the upper segment of the echo tape. As noted earlier the extent to which surface scattering will be recorded is controlled partly by the sensitivity setting of the receiver; the higher the gain, the more extensive will be the recording of the surface reverberations. However, even at a constant sensitivity setting, considerable variation in surface scattering was recorded during the course of the work. Specific examples were noted in presenting the detailed results of particular stations (see types of scattering layers), and such expressions as "acoustic clarity" were used to describe conditions where surface scattering was virtually absent.

As in the case of deeper scattering layers, changes in surface scattering appear to be associated primarily with changes in the nature and concentration of living organisms. Little evidence is at hand to indicate what species are responsible, but the fact that an increase in gain results in an increase in the vertical dimensions of the surface scattering layer is highly suggestive of zooplankton and not fishes (Cushing and Richardson, 1956). Among the probable causes of surface scattering are the euphausids, particularly juvenile individuals and the frequent swarms of calyptopis and furcilia larval stages which are taken in surface hauls. On occasion, large swarms of calanoid copepods may also be responsible. These are highly seasonal forms, occurring in such great numbers in late winter and early spring that a five minute haul with the M-net (sampling about 100 cu.m. of water) may yield a half gallon of copepods. The basking shark, Cetorhinus maximus is associated with these swarms. Great numbers of fish larvae, particularly those of Sebastodes, may also be present and probably contribute to shallow scattering.

A myctophid, Tarletonbeania crenularis, may be responsible for shallow "flash" reverberations of echos. This lantern fish is occasionally taken in our net hauls in low numbers, and on the basis of evidence provided by depths of capture and by its physical appearance (streamlined, slim-peduncle, firm-bodied, non-deciduous scales, silver coloration) it inhabits the surface waters of 50-150 m. Due to its proclivity for periodic large scale amphibious landings on the beaches adjacent to Monterey Bay, some idea of its potential population size is at hand. Aughtry (1953b) reported these fish on the sands of Still Water Cove, Monterey Co., Calif., on October 17, 1952.

"Along approximately 200 yards of beach there were thousands of fish, all of the same species, all of the same general size range, and all dead." Another mass mortality was observed at San Jose Creek Beach, Monterey Co., Calif., on December 29, 1954 by Mr. Danial Miller of the California Division of Fish and Game. Concentrations of dead fish as high as 80-100 per linear yard were estimated. The stomachs of these fish were filled with freshly eaten *Euphausia pacifica* and they undoubtedly had been feeding on these organisms, which migrate into the surface layers at night, before they became beached.

Interestingly enough, "watery plankton" may be partially responsible for surface reverberations. *Doliolum tritonis*, a small gelatinous tunicate, may be found with the gut tightly packed with diatoms. The wad of silicious diatoms shells thus formed should act as an efficient reflector of sound. *D. tritonis* may be present in such numbers in the surface waters as to fill a full five feet of the cod end of the M-net during a five minute haul. High populations appear irregularly in the surface waters from early spring to midfall. Another gelatinous organism which may play a role in shallow scattering is a siphonophore of the stephonomia type. This animal is equipped with an ovate, gas-filled pneumatophore about five mm. in length, a structure which should certainly resonate and which may contribute to surface scattering when the species appears in numbers in the surface waters.

Surface scatterers may, at times, form layers in Monterey Bay similar to those described by Burd and Lee (1951) in the shallow waters of the English Channel. Two such layers have been recorded on the shallow range transducer of the NMC echo sounder in occasional random observations of waters over the continental shelf. A detailed study leading to a better understanding of the phenomenon in this area would demand special techniques and instruments not at present available.

The Possible Importance of Large Scattering Organisms.

The relationships of the dominant micronecktonic populations to the scattering layer phenomenon in Monterey Bay has been discussed in detail. Other less important but possible contributors to the various patterns have been treated. Probable sources of surface reverberations have also been indicated. We must still consider the possibility that macronecktonic organisms--which we have completely failed to sample--may play a role in creation of the scattering zones.

At brief, random periods in the program, attempts were made to catch large, predaceous fishes which might have been present at DSL depths. One method used consisted of trailing a pair of 30 m. cod lines from the two ends of the top mouth-bar of the T-net when regular hauls were being made. Each cod line was terminated with a 5 m. leader bearing either hooks baited with anchovie or squid, or luminescent bone jigs. While the gear performed satisfactorily, the results were negative (not surprising when one considers the scare effect of the T-net preceding the trailing lures through the water).

The second attempt to catch any macronektonic organisms that might be present at DSL depths was made possible through the cooperation of California State Fish and Game biologists John A. Apling and James Squire, Jr. In the fall of 1954 the State research vessel, N. B. Scofield, was engaged in exploratory work with a large, mid-water trawl net (Anon. Pacific Fisherman, 1953). This net had a mouth opening 30 ft. by 30 ft. and was hung with an 80 ft. bag made of 4.5 in. mesh netting terminating in a 10 ft. cod end of 1.5 in. mesh. It had proved successful in capturing such large and powerful swimming fishes as rockcod, blackcod, and hake. A station was occupied in Monterey Bay in the immediate area of the DSL observation station. While the "Scofield" was not equipped with sounding gear capable of recording the DSL, the large net was hauled at about 3-4 knots for two hours at depths below, in, and above the vertical range of scattering layers in this region. Depth of hauling was checked by means of our depth-time recorder. No large, necktonic organisms were captured, and because of the extremely large netting very little planktonic and micronecktonic material was even retained in the bag. A few jellyfish, picked up at the surface as the gear was lowered, served to plug the cod end of the net sufficiently to trap a small, badly mangled sample. A count of the captured organisms, based on a hasty field examination by the author, follows in Table 4.

Vertebrate Organisms	No.	Invertebrate Organisms	No.
Lampanyctus leucopsarus	28	*Sergestes similis*	17
**Chauliodus macouni*	6	Cephalopods (Unident.)	8
**Tactostoma macropus*	4	*Aurelia sp.*	6
**Idiacanthus antrostomus*	3	*Boreomyis californica*	5
Cyclothone sp.	2	*Gnathophausia ingens*	4
Bathylagus pacificus	1	*Periphyllia hyacinthina*	3
Flat fish (post larvae)	1	*Atolla sp.*	1
		Eucopia australis	1
		Cystosoma sp.	1

*"Dragon fishes".

Table 4. Count of organisms taken in haul made with California mid-water trawl.

It can be seen that with the exception of a rather high proportion of cephalopods in relation to the rest of the catch and the relatively large numbers of "dragon fishes", the haul might well have been made with the T-net. Most of the dragon fishes were snagged by their long, needle-like teeth in the meshes of the main bag of the net, and a swarm of scavenging gulls which descended on the gear after it surfaced very probably made off with many others during the 15 minute period it took to effect recovery of the net after it surfaced.

In contrast to these negative indications, a few large fishes have been captured by the many hauls made during the five years of the Hopkins Marine Station's oceanographic program. Two of these were mature specimens of the grenadier, *Macrurus acrolepis*. These are codlike, bottom dwelling fishes, which are common along the slopes of the continental shelves, and they were taken in the M-net when it was inadvertently used as a bottom trawl. In June of 1955, the only large mid-water fish which has been captured was taken in the T-net. This was a 38.5 cm., 1.25 lb. specimen of the hake, *Merluccius productus*. The exact depth of capture is problematical. A stomach analysis revealed the following recognizable material: *E. pacifica* (44); *S. similis* (7; all mature specimens and three in an advanced stage of digestion); *Gonatus fabricii* (2); large calanoid copepods (2); *Sagitta lyra* (1); and one post larval myctophid, badly torn. Some interesting deductions can be drawn from a comparison of these stomach contents with the remainder of the catch of the T-net. For instance, the cod-end bucket contained no post-larval myctophids and only 5 *Gonadus fabricii*, the immature year class of *S. similis* predominated, and a total of 16 amphipods and pasiphaeid prawns were taken in contrast to none of either species in the stomach contents. The organisms in the stomach could have been swallowed after the fish was captured by the net, but the foregoing comparisons are hardly indicative of random gulping of the swirling contents of a plankton bucket. Instead the findings are strongly suggestive of highly selective feeding on what very probably were the dominant components of the top of a heavy Type 1 scattering layer, which was located at about 185 m. and through which the net was drawn obliquely.

Aside from the hake, a large fish probably present occasionally at scattering levels is the handsaw fish, *Alepidosarus aesculapius*. The anatomy of this large, fang-toothed, flabby-bodied, big-eyed fish has lead to the suggestion (Clemens and Wilby) that it is an inhabitant of deep water. What are apparently pathological individuals have occasionally been found in a stricken condition in the intertidal region of Monterey Bay.

There is no evidence that such commercially important fishes as the salmon, anchovy, sardine, or the squid *Loligo opalescens* are present at scattering layer depths. All of these organisms tend to concentrate into more or less well defined schools, and all are associated with the surface waters. On many occasions, discrete blips and sparks are emitted by the stylus of the echo-sounder as it traverses the upper 100 fm. section of the recording tape. These markings may be repeated at the same depth for three or four signals before suddenly disappearing. Such traces very probably are created by fishes.

In summary it can be said that the largest fishes generally taken by the T-net are the "dragon fishes" (*Chauliodus macouni*, *Tactostoma macropus* and *Idiacanthus antrostomus*). These are of sporadic occurrence and are associated with the lower limits of the DSL and with the depths below it. The largest specimens taken are about 30 cm. in length. In addition, on the slim basis of one catch and its stomach contents, the hake (which is known to occur seasonally in large numbers in Monterey Bay) may be a seasonal inhabitant of, and predator in, the upper regions of the DSL. It is clearly not responsible for the scattering layer itself. Large fishes, and smaller forms like the myctophid, *Tarletonbenia crenularis*, may cause sporadic "flash" echos, but they are not the cause of deep scattering layers.

GENERAL REVIEW AND DISCUSSION

The factual information gained from this study has been presented under various headings in the previous sections. The scattering layer phenomenon in Monterey Bay (as burned into some 30 meters of recording tape) has been considered as a dynamic, structural feature showing changes which are correlated with seasonal fluctuations in the physical and biological environment. Specimens and data have been collected and drawn upon to yield information on the role played by pelagic organisms in creation of the scattering patterns. The possibility of thermal lensing of the sound cone has been postulated as a modifying factor. Many gaps in our information still exist, but it is logical to preface a concluding discussion by integrating the essential observations and conclusions into a whole but simplified picture of the dynamic flux of bathypelagic populations thought to be responsible for the shifting acoustical patterns. The gross features seem clear, but much of the finer structure is as yet unknown.

In January and February the waters at scattering layer depth are dominated by the myctophid fish, Diaphus theta. These fish are concentrated at the mid-day depth of 250-300 m., and a well resolved but faintly recorded scattering layer is present. The low thermal gradients in evidence at this time may fail to concentrate the sound cone, and the large population of adult Sergestes similis which is centered at a lower level is seldom recorded as a layer. Only a few straggling Euphausia pacifica are present and the upper waters are acoustically clear.

In March a dramatic change in the scattering populations takes place. Diaphus theta moves out beyond reach or detection, perhaps in response to a shift in hydrographic factors or water masses too subtle to be noted by our gross approach, perhaps in answer to some biological drive. The dominant organism concentrated at DSL depth is now Sergestes similis which is represented by two generations, large adults which have moved up from deeper water with the rise of colder isotherms at the onset of upwelling, and juveniles which descend from upper layers as they grow. Fishes, primarily Lampanyctus leucopsarus, play a secondary role in the formation of the well-developed, single scattering layer which records at medium to heavy intensity. During this period, Euphausia pacifica appears again in Monterey Bay in large numbers. The population is dominated by large, second year adults which indulge in sexual activities appropriate to spring and demonstrate a highly erratic vertical distribution. The animals may swarm in large shoals at the surface, or descend to reinforce the main scattering population at mid-depths.

As spring turns to summer upwelling reaches a climax, and the fertilized phytoplankton crop blooms. Diatom concentrations cloud the water and at the same time the incident light is further reduced by the development of the summer fog bank. Very probably in response to these factors the populations of *Sergestes similis* and *Lampanyctus leucopsarus* move upward. Simultaneously, the *Euphausia pacifica* population, now dominated by half-grown first year adults, moves upward as well. The waters in the upper levels are now populated by clouds of immature *E. pacifica* which have developed from eggs spawned by the surface-swarming adults in the spring, and which are browsing on the phytoplankton. The upper 100 m. teems with gelatinous organisms, some of which possess structures of possible acoustic significance. A complex of forms therefore contributes to the intense surface scattering present at this time. The net effect of these organisms and their activities is to produce a solid region of acoustical reverberations from the surface to at least 400 m. and sometimes beyond.

Toward the later part of the summer abatement of the northwest winds signals an end to upwelling, the diatom bloom fades and the fog bank is burned away. Light penetrates to deeper levels and surface warming causes a depression of colder isotherms. Oceanic water may invade the bay and contribute to these changes. The euphausid population which formerly occupied a vertical range overlapping both the signal zone and the strata of deeper reverberations, moves downward and condenses vertically until it is recorded as a shallow scattering layer. This layer is reinforced by such predators as *Diaphus theta* which has moved back in the bay during the summer months. The prawns and *Lampanyctus leucopsarus* likewise move downward to lower levels presumably in response to the changing physical conditions. Here they are recorded as a deep secondary scattering layer, the resolution of which may be due in part to the lensing effect of the strong thermocline which has developed at this time.

During the autumn this thermocline is broken by cooler weather and the over-turn created by the onset of the southerly winds. Soon the lower secondary scattering layer is no longer recordable, and the pattern shifts to the single layer again. In late fall and early winter *Euphausia pacifica* continues to play the role of dominant scattering organism until, for reasons still obscure, their numbers decline sharply. At this point *Diaphus theta* once more becomes the major scattering organism and the cycle begins again.

It is of interest to examine such a general synthesis and interpretation of the data in terms of earlier published work on deep scattering layers. One thing immediately apparent is that the earlier studies of scattering layers have not been based on a sufficient number of echograms and biological samplings. They have not been extensive enough in time, and have been far too extensive in space to yield a coherent picture of the phenomenon. For that matter, the present study also suffers from inadequacies all too glaringly apparent to the writer. Nevertheless, drawing upon data collected over a two year period at one locality, the present work makes it possible to resolve with at least some confidence, the conflicting conclusions and opinions of earlier workers as to the relative importance of fishes and euphausids as primary scattering organisms. It is evident that at the same and different seasons and levels both are important. In addition the midwater prawns must also be considered as major scattering entities. These results tie in very well with pioneer work done by Boden (1950a) and Tucker (1951) in the San Diego Trough some 360 miles to the southeast. Apparently the major organisms responsible for scattering over the Monterey Canyon also dominate scattering layers over a large area of the Pacific. On the other hand, some of the complexity in reverberation patterns in Monterey Bay is caused by shallow scattering, and a good share of this is very probably due to the proximity of our DSL station to the neritic regions. The picture in true oceanic waters should be somewhat simpler.

Another controversial point on which some light is shed indirectly is the concept that fishes possessing gas-filled swimbladders, which can function as resonating structures, are necessary to create reverberations of DSL intensity. In view of the fact that both of the species of myctophids which figure prominently in an interpretation of the results in this study have swimbladders largely or wholly filled with fatty connective tissue, it would seem that this is not necessarily so. Instead the results suggest that fat or oil-filled structures such as are present in the two fishes and in the stored lipoids of Sergestes similis may be of some importance in this capacity, or that no such specialized resonating structure is really necessary to produce recordable echos.

Concerning the possibility that sharp thermal gradients act as an acoustic lens, if such a mechanism is indeed operative an explanation is provided for the apparent disappearance of the scattering layers recorded by Dietz (1948) after his ship moved southward across the Antarctic convergence. Judging from data presented in Sverdrup, Johnson and Fleming (1942), a sudden change in thermal conditions was experienced. In the South Atlantic a relatively steep thermal gradient is possible, whereas across the Antarctic Convergence an isothermal structure is more likely. Since Dietz reported that the NMC echo sounder was primarily in use for other purposes it is doubtful that a high increase in sensitivity setting was attempted in an effort to regain reception of the layer. The change in thermal conditions in Dietz's voyage appears comparable to the change from the thermal conditions existing in Monterey Bay in the late summer with well-developed thermoclines, to the mid-winter conditions of low temperature gradients. According to local experience, the winter layer might not be resolved at a sensitivity setting used to record the summer scattering.

A further implication of the present work relates to the ideas of Moore (1950) that light and temperature act together as factors modifying the daily behavior and movement of scattering layers. Diurnal changes were not considered in the present study, but results obtained indicate these variables to be of major importance in influencing seasonal shifts in the distribution of scattering organisms and layers.

The limited information obtained in the present study on shallow scattering layers indicates that the term "deep" as applied to scattering layers has lead to unnecessary confusion. There appear to be basic similarities in all biological scattering phenomena, whether the layers be caused by copepods at three meters depth in a freshwater lake or by bathypelagic fishes at 300 meters in the sea. This suggests the following definition of scattering layer phenomena in general. Scattering layers can be considered to be echos and reverberations of acoustic energy reflected from biological entities with sufficient intensity to cross the lower threshold of receptive sensitivity of a sonic recorder. The biological entities themselves being sufficiently stable in time and space that a consecutive series of measurements are recorded by an appropriate instrument as a subsurface layer in aqueous media.

Aside from providing answers or partial answers to problems directly related to the scattering layer, this work is intended as a contribution toward a better understanding of the ecology of mid-water micronektonic organisms. The echo sounder is a crude tool, and the recorded scattering layer is but a dull shadow of the complex biological communities below the sea which are so poorly sampled by plankton hauls. The problem of the nature and behavior of the DSL is a problem in bathypelagic ecology and will only be understood when development of observational and measuring devices permit a really effective attack on the ecological problems involved.

SUMMARY

A series of weekly observations taken over a two year period indicate that scattering layers are a constant acoustic property of the waters adjacent to Montery Bay. The relatively crude recordings made with an NMC echo sounder show that these layers, observed during daylight hours, are of a variable nature. They can, however, be reduced to four basic types: (1) A single resolved layer; (2) A solid zone of scattering contiguous with the trace of the outgoing signal; (3) A double layer pattern which can be resolved only by a critical adjustment of the amplifier or sensitivity setting; and (4) A double layer pattern which can be resolved at a single sensitivity setting. These designations have been of value in organizing and interpreting the data, though they are in part a reflection of the characteristics and limitations of the recording instrument.

A seasonal study of these scattering layer patterns indicates that they undergo a three-phase annual cycle. The solid pattern dominates in summer, double layer types are most evident in the early fall, and a single (but variable) layer is found from mid-autumn until late spring. This annual cycle is shown to be correlated with parallel seasonal changes in hydrographic conditions and phytoplankton. The most important factors appear to be those which influence light penetration into the sea and the vertical shifting of

isotherms. It is doubtful that hydrographic inhomogeneities, per se, are responsible for reverberations. However, sharp thermal gradients may cause apparent changes in recorded scattering patterns by functioning as acoustic lenses which reduce attenuation of sonic signal energy. Hydrographic conditions may also affect the distribution of scattering organisms.

No one organism can be assigned sole responsibility for the reverberations which form the different types of recorded layers. Instead different organisms may play the dominating scattering role at different seasons, or a layer may represent reverberations from more than one species. The major scattering organisms in Monterey Bay appear to be the euphausid, *Euphausia pacifica*, the midwater prawn, *Sergestes similis*, and the myctophid fishes *Diaphus theta* and *Lampanyctus leucopsarus*. Adult populations of *D. theta* and *E. pacifica* are associated with 100-300 m. strata, whereas *L. leucopsarus* and *S. similis* are related to the 300-500 layers.

Populations of the shallower forms are highly dynamic in nature, and much of the variation in scattering patterns is attributable to these organisms. The fish *Diaphus theta* predominates at DSL level in winter months when thin, poorly developed scattering layers are in evidence. The euphausid, *Euphausia pacifica* plays a major role in the intense shallow scattering which is primarily responsible for the solid summer pattern. *E. pacifica* is also an important element in shallow scattering layers at other times of the year except in the winter.

In contrast, populations of the deeper bathypelagic scattering organisms are more constant in numbers. These forms can sometimes be detected as a deep layer underlying a shallower zone of scattering. The prawn *Sergestes similis* very probably is the major species responsible for the single scattering layer during the spring months when a population shift upward is correlated with a rise in colder isotherms accompanying upwelling. *L. leucopsarus* may also be present in considerable numbers at DSL depths where it may reinforce the scattering population; its daytime distribution, however, is usually centered below recorded scattering layers.

Other nektonic organisms may play subsidiary roles in the production of deep scattering, but too little evidence is at hand to warrant their consideration in the present study. Shallow scattering, which may be caused by organisms ranging in structural complexity from siphonophores to large predaceous fishes, may, on occasion affect or modify the recordings.

The available evidence indicates that the criteria used to discriminate between fish and zooplankton scattering patterns in shallow water are applicable as well to the organisms responsible for the DSL.

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APPENDIA

A. List of Stations and Type of Echogram Recorded.

Number	Date 1954	Type of Layer (mid-day pattern)	Comments
403	9-Feb.	1-M	Type 2 early, dropping down to good type 1.
405	19-Feb.	1-VL	Light, but definite layer.
407	23-Feb.	1-VL	Very light, SS* of 7.4 to bring out. Experimental station, no hydrographic data taken.
408	24-Feb.	1-M	Well developed at SS 7.3-7.7, indications of lower layer.
410	3-Mar.	1-H	Solid early at high gain of 7.6.
412	11-Mar.	1-M	Indication of deep lower layer early at SS 7.5.
414	22-Mar.	1-M	Layer fuzzy, ill-defined.
416	1-Apr.	2	Indications of a resolved layer.
418	7-Apr.	1-M	Layer diffuse, ill-defined.
420	15-Apr.	1-M	Layer well developed.
422	20-Apr.	1-M	Layer diffuse early, dropping down into well-formed layer at end of morning.
424	3-May	2	Some indication of a layer.

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* Sensitivity setting of receiver.

Number	Date 1954	Type of Layer (mid-day pattern)	Comments
426	10-May	2	Very heavy, indication of resolved layer late in day.
429	17-May	1-H	Excellent, heavy layer.
431	28-May	1-H	Solid early due to worn stylus.
433	3-June	1-H	Excellent layer at SS 6.7.
435	10-June	2	No indication of a resolvable layer.
437	17-June	2	No indication of a resolvable layer.
439	22-June	2	No indication of a type 1 pattern even at SS 6.5.
441	30-June	2	At SS 6.2 light, but solid scattering.
443	7-July		No echograms, generator inoperative.
Class Trip	14-July	2	Heavy solid pattern.
445	19-July	2	Very heavy solid pattern.
447	26-July	2	No indication of type 1 at SS 6.5 - 6.8.
449	2-Aug.	2	Solid layer throughout, much of tape badly jammed.
450	11-Aug.	2	Deep reverberation below solid pattern.
452	18-Aug.	2	Observations begun at 0215. Solid pattern throughout with indication of deeper reverberations during daylight hours.

Number	Date 1954	Type of Layer (mid-day pattern)	Comments
454	27-Aug.	2	No indication of a type 1 pattern at 6.3 - 6.8.
456	2-Sep.	1-M	Very probably this would have been recorded as a type 3 with shorter signal or more critical tuning. The resolved layer represents the lower layer. The upper is merged with the signal area.
458	10-Sep.	1-H	Layer was lighter in the morning.
460	15-Sep.		No echogram. Gear inoperative.
462	27-Sep.	1-H	Deep solid scattering early, layer only resolvable at 6.3. Signal length reduced between stations.
464	5-Oct.	1-M	Indications of both a higher and lower layer.
466	11-Oct.	1-M	Resolution poor early, well-defined at mid-day.
468	19-Oct.	3	Poor example of type 3, more critical tuning would have brought out upper layer to better advantage. Bottom layer very sketchy, ill-defined.
470	12-Nov.	3	Typical type 3 pattern, well-developed lower layer.
472	17-Nov.	3	Typical pattern, excellent shallow layer.
474	23-Nov.	3	Typical type 3 pattern.
476	8-Dec.	4	Two layers, clearly resolvable, water acoustically clear, compared to Summer and Fall stations.

Number	Date	Type of Layer (mid-day pattern)	Comments
	1954		
478	15-Dec.	1-M	Change of gain 6.8-7.2 intensifies layer but does not tend to extend surface scattering.
480	20-Dec.	1-M	Well-developed but thin layer, upper water acoustically clear.
482	29-Dec.	1-H	High layer solid early, then dropping down.
	1955		
485	11-Jan.	1-L	Layer sketchy, but well defined.
487	20-Jan.	1-L	Layer thin, but well defined. Indications of shallower scattering merged with signal.
489	25-Jan.	1-L	Layer sketchy, only recordable at high sensitivity settings.
490	3-Feb.	1-L	Layer diffuse early, consolidating towards mid-day.
491	9-Feb.	1-VL	Layer very light, gain of 7.3 necessary to bring it out.
492	15-Feb.	1-VL	Very light layer similar to that of 491.
493	22-Feb.	1-VL	Very thin, light.
494	2-Mar.	1-VL	Takes gain of 7.7 to bring out extremely thin, weak layer.
495	8-Mar.	4	Upper layer not as heavy as 476 type.
496	17-Mar.	1-M	Layer well recorded at a gain of 7.0.

Number	Date 1955	Type of Layer (mid-day pattern)	Comments
497	23-Mar.	1-M	Excellent layer, heavier early.
498	5-Apr.	1-H	Surface scattering heavy, layer thick and very hard to resolve, Undoubtedly would have been recorded as a solid pattern with a long signal.
499	13-Apr.	1-H	Solid early with indications of deeper scattering.
500	23-Apr.	1-H	Layer splitting into double pattern then reconsolidating on several occasions, but essentially a thick, single layer pattern.
501	4-May	1-H	Well developed layer with indications of lower scattering.
502	10-May	1-M	Well defined, low single layer, definite indication of an upper layer for short intervals.
503	18-May	1-M	Solid scattering early, dropping down and consolidating into excellent single layer at mid-day.
504	27-May	1-M	Well developed layer throughout the day.
505	6-June	1-M	Good layer with indications of a poorly defined lower layer.
506	13-June	1-M	Solid early, then a high layer resolvable, with indication of a lower layer.

Number	Date 1955	Type of Layer (mid-day pattern)	Comments
507	28-June	1-M	Solid early, then dropping down into a thick resolvable layer.
508	6-July	2	Solid throughout the day. No indication of a resolvable~~-~~layer at 6.5.
509	13-July	2	Definite solid pattern.
510	25-July	1-M	Solid early, but layer resolvable at very low gain of 6.3.
511	25-July	1-M	Solid early with a high layer resolvable at a low SS of 6.3.
512	1-Aug.	2	Solid throughout day.
513	10-Aug.	2	High gain brings out very deep reverberations.
514	17-Aug.	2	High gain records deep reverberations, low gain results in sketchy solid pattern.
515	22-Aug.	2	While a definite solid pattern, indications of a type 3 pattern are evident.
516	2-Sep.	3	Definitely a type 3 pattern, although more critical tuning would have resulted in a better recording.
517	14-Sep.	3	Good type 3 pattern, lower layer strongly recorded.
518	21-Sep.	3	Indication of lighter upper layer than preceding stations.

Number	Date 1955	Type of Layer (mid-day pattern)	Comments
519	27-Sep.	3	Upper layer weakly developed.
520	4-Oct.	3	Poor example of pattern.
521	9-Oct.	3	Generator operating poorly, but good indication of a type 3 pattern.
522	19-Oct.	1-M	Solid early, dropping down to form shallow layer.
523	25-Oct.	4	Heavy and extremely deep layer with a definite lighter upper layer recordable late in the morning.
524	2-Nov.	1-M	Solid early, dropping down into excellent layer at mid-morning.
525	8-Nov.	4	Well developed upper layer, ill-defined lower.
526	16-Nov.	1-M	Solid early, dropping down into high layer.
527	30-Nov.	1-M	Layer diffuse early, then concentrated, upper water acoustically clearer than preceding stations.
528	14-Dec.	1-M	Well developed high layer, dropping down slightly throughout morning.
529	31-Dec.	1-H	Excellent, heavy layer recorded throughout day, upper water acoustically clear.

B. Phytoplankton Station Data

All samples taken at 36° 46.2' N, 122° 01' W, between 0600-0900 PST. Volume of sample in ml..

Date 1954	Sample	Date	Sample	Date	Sample
23-Mar.	1	20-Oct.	8	17-May	15
1-Apr.	2	11-Nov.	5	2-June	1
8-Apr.	5	22-Nov.	1	7-June	7
13-Apr.	1	30-Nov.	1	14-June	1
21-Apr.	1	14-Dec.	1	24-June	5
4-May	9	21-Dec.	2	2-July	10
11-May	5	30-Dec.	1	7-July	4
18-May	10	1955		12-July	5
27-May	9	8-Jan.	2	19-July	14
2-June	7	13-Jan.	1	28-July	7
8-June	37	4-Feb.	.25	9-Aug.	32
23-June	56	10-Feb.	.2	16-Aug.	20
2-Jul.	62	17-Feb.	3.75	25-Aug.	13
13-Jul.	52	23-Feb.	.3	1-Sep.	1
21-Jul.	61	1-Mar.	7.5	16-Sep.	6
27-Jul.	48	10-Mar.	.25	22-Sep.	1
13-Aug.	1	18-Mar.	.5	28-Sep.	.5
20-Aug.	17	24-Mar.	5	5-Oct.	1
26-Aug.	28	31-Mar.	.2	13-Oct.	4
1-Sep.	1	6-Apr.	35	20-Oct.	2.5
8-Sep.	18	19-Apr.	22	26-Oct.	6
14-Sep.	10	27-Apr.	2	3-Nov.	19
28-Sep.	8	6-May	15	7-Nov.	5.5
12-Oct.	10			10-Nov.	4.5