AD 372 030

CONFIDENTIAL

166344
Ser 083

UNCLASSIFIED

WOODS HOLE OCEANOGRAPHIC INSTITUTION

REFERENCE NO. 66-10

THE GEOGRAPHIC VARIATION OF
MIDWATER SOUND-SCATTERING (u)

by

Richard H. Backus and J. B. Hersey

WOODS HOLE, MASSACHUSETTS

GROUP 13

DOWNGRADED AT 12 YEAR INTERVALS
NOT AUTOMATICALLY DECLASSIFIED

CONFIDENTIAL
UNCLASSIFIED

~~CONFIDENTIAL~~

Logged in 2822-C-74

UNCLASSIFIED

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

REFERENCE NO. 66-10

THE GEOGRAPHIC VARIATION OF
MIDWATER SOUND-SCATTERING(u)

by

Richard H. Backus and J. B. Hersey

March 1966

TECHNICAL REPORT

Submitted to the Office of Naval Research
under Contract Nonr-4029(00)NR 260-101.

Reproduction in whole or in part is permitted
for any purpose of the United States
Government. In citing this manuscript in a
bibliography, the reference should be followed
by the phrase: UNPUBLISHED MANUSCRIPT.

This material contains information affecting the
national defense of the United States within the
meaning of the Espionage Laws, Title 18, U.S.C.;
Section 793 and 794, the transmission or revelation
of which in any manner to an unauthorized person
is prohibited by law.

Approved for Distribution

J. B. Hersey
J. B. Hersey, Chairman
Department of Geophysics

MBL/WHOI

0 0301 0077349 5

AD#

REPORT NO:

DECLASSIFIED DATE: 28 Aug 90

AUTHORITY: ONR Ltr. 14 Aug 90

REFERENCE:

~~CONFIDENTIAL~~

UNCLASSIFIED

TABLE OF CONTENTS

	<u>Page No.</u>
ABSTRACT	i
SUMMARY	ii
TEXT	
Introduction	1
The nature and principal cause of midwater sound- scattering and its effect on active sonar operations	1
Estimating the geographic variation in the intensity of midwater sound-scattering	4
Remarks on the geographic variation in the pattern of midwater sound-scattering	7
Estimating the relative incidence of false targets	9
Recommendations for measurement programs	9
APPENDIX	11
REFERENCES	12
FIGURES	

UNCLASSIFIED

i

ABSTRACT

It is suggested in this report that the intensity of midwater sound-scattering in the ocean varies from point to point as the abundance of marine life varies. Several charts depicting variations in the abundance of marine life are given, from which estimates of the intensity of sound-scattering can be made.

UNCLASSIFIED

SUMMARY

1. The principal causes of midwater sound-scattering in the ocean are small marine animals enclosing bubbles of gas. These animals (certain fishes and jellyfishes) are arrayed principally in layers that move from depths of two or three hundred fathoms by day to near the surface by night. As the layers move up to their nighttime levels they best scatter sound at lower and lower frequencies. The lowest frequency at which many layers best scatter sound is very near 3.5 kcps and so these layers embarrass nighttime operations with the SQS-26.
2. How the intensity of midwater sound scattering varies from place to place in the ocean can be estimated quite well by using various estimates of the variation in abundance of sea life in general from place to place in the ocean. Charts showing this variation are given.
3. Certain of the charts included specifically predict for the oceans of the world where the SQS-26 will be reverberation limited during hours of darkness. This prediction is based on SQS-26 performance in the Slope Water region east of New England. It is possible that in some areas where marine life is very abundant, the SQS-26 will be reverberation limited during daytime as well.
4. In addition to the geographic variation in the intensity of midwater sound-scattering, the geographic variation of the "pattern" of midwater sound-scattering is important. We mean "pattern" to encompass the the number, frequency, and relative intensity of the peaks in the sound-scattering. Probably certain patterns will be found to hold more or less constant over large areas, but this is a moot point. These areas of constant pattern may correspond to areas of similar faunal composition. A chart giving a first approximation of these areas is included.
5. We believe that the incidence of "false" contacts or "false" targets will vary from place to place in the ocean as does the incidence of marine life in general. Figs. 4 - 7 may be used to predict relative "false" target incidence as well as for predicting volume reverberation levels.
6. It is suggested that the primary area of relevant future inquiry is the distribution and behavior of resonant scatterers in the deep ocean.

TEXT

Introduction

Recent tests and limited operational experience with the SQS-26 active sonar system, as reported to the Marine Geophysical Surveys Council early in 1966, have shown that this sonar is volume reverberation limited to a crippling degree under some circumstances. The circumstances in part are during the hours of darkness in some geographic areas where operations appear normal during daylight. In other areas the system operates normally both day and night. The change in effectiveness of the SQS-26 between day and night appears to the authors to be linked with properties of some of the deep scattering layers of the open ocean. In this report the nature of this linkage is described and a basis for predicting the volume reverberation likely to be encountered by the SQS-26 is discussed.

The nature and principal cause of midwater sound-scattering and its effect on active sonar operations.

Information summarized by Hersey and Backus (1960) shows that readily measurable sound is scattered by animals within the upper 400 fathoms or so of the deep oceans of the world. The spectrum of the scattered sound is incompletely understood as a world-wide phenomenon, but limited measurements in the Atlantic Ocean (mostly confined to the band from a few hundred cycles per second to 30 kcps) show that at any given locality there are several quite sharp peaks in the spectrum between about 2.5 kcps and 30 kcps. Below 2.5 kcps intensity diminishes rapidly with frequency. The principal reports dealing with the spectrum of this volume reverberation are Hersey, Johnson, and Davis (1952), Hersey and Backus (1954), Hersey, Backus, and Hellwig (1962), Andreyeva (1964), Andreyeva and Chindonova (1964), Marshall and Chapman (1964), and Bowers (1965).

The principal sound-scattering animals of the sea are arranged in layers (the so-called "deep scattering layers"), most of which show a diurnal vertical migration. They move from a daytime depth of two or three hundred fathoms (for instance) up to depths of tens of fathoms or even to the very sea-surface itself. Some layers scarcely migrate vertically or do so not at all. A very few go contrary to the general rule and at night move to greater depths.

The peaks in the spectrum of the scattered sound already referred to are associated with these layers. During the vertical migration of the layers, the principal frequency at which a layer scatters sound shifts as layer depth changes. The peak frequency of an upwardly migrating layer has been observed to change from well above 20 kcps to below 5 kcps. This frequency shift follows rather closely one of two relationships: (1) peak frequency varies as the $5/6$ power of the pressure (hydrostatic plus atmospheric), or (2) peak frequency varies as the $1/2$ power of the pressure. These relationships can be written:

$$f_{\text{peak}} \sim (D + 10)^{5/6}$$

and

$$f_{\text{peak}} \sim (D + 10)^{1/2},$$

where D is the depth of a layer in meters (10 meters being added to account for the pressure of the atmosphere).

The frequency-pressure relationships observed correspond to the expected resonant responses of (1) a bubble of gas of constant mass whose radius changes with changing ambient pressure, the $5/6$ -power relationship, or (2) a bubble of gas of constant volume whose radius is held constant by internal pressure changes accompanying ambient pressure changes, the $1/2$ -power relationship. Such bubbles exist as the swimbladders of numerous species of midwater fishes, many of which are known to make diurnal vertical migrations. The most abundant of these swim-bladdered fishes are from about one inch to six inches long when adult. Gas-filled organs also are used as flotation devices by certain jellyfishes of the siphonophore class. In many of the fishes, at least, it is known that there are elaborate structures for secreting gas into and absorbing gas from the swimbladder. Such an arrangement explains the existence of the $1/2$ -power frequency-pressure relationship, in which the radius of the gas bubble is held constant in spite of changing ambient pressure.

Both fishes and siphonophores are tentatively identified as the sound-scatterers causing these peaks in the spectrum of the sound scattered by deep scattering layers. Indeed, Barham (1963, 1966) has made, from deep submersibles, visual associations of these animals with deep scattering layers in the Pacific Ocean off California and Baja California. In addition to the

- 3 -

peaked or resonant scattering caused by gas bubbles (and taken to be coming from fishes and siphonophores), there is also weaker sound-scattering in the sea that has no pronounced frequency peak. This weak scattering may be attributable to animals and possibly to plants and other particulate matter. These weak scatterers may occur in layers at some considerable depth, but are especially noticed in the upper few tens of fathoms of the sea.

The above sketch summarizes what is known of the frequency-dependent sound-scattering by deep scattering layers. Of the relatively few published observations of the spectrum of this sound, most have been made in the western North Atlantic, a few in the Mediterranean Sea, and a single observation by Russian workers off the coast of Argentina.

By far the greater part of the volume reverberation experienced in an active sonar operation comes from these layers of animals having strongly peaked sound-scattering spectra. Because little evidence has been seen so far for high-level scattering at frequencies below about 2.5 kcps, it may be that sonars operating at frequencies well below this would not experience high volume-reverberation levels. Reverberation levels experienced at frequencies above 2.5 kcps will depend upon the operating frequency of the sonar in use and its directional properties. At mid-day, layers that migrate vertically are at their highest peak frequency. At this time, sonar systems having high vertical directionality and operating over near-surface paths will tend to be free of reverberation from deep scattering layers and will operate with lowest background whatever the operating frequency. At night, the layers that migrate vertically (most layers) are at their shallowest depths and many of them are squarely in the beam of a sonar operating over near-surface paths. Thus, volume reverberation will be highest during hours of darkness whatever the operating frequency.

For high-frequency sonars (about 15 kcps or higher), the increase in nighttime reverberation will not be so severe, because the peak scattering frequency of the upwardly migrating layers will shift to frequencies lower than 15 kcps. For low-frequency sonars such as the SQS-26, however, nighttime volume-reverberation levels are made all the higher because of the shift downward in the peak scattering frequencies of migrating layers into the band between 2.5 and 5 kcps. Ratios between nighttime and daytime reverberation levels of 10 to 15 decibels have been observed for this band. It is not now possible to say whether such a change is representative or too low.

The operation of the SQS-26 in the bottom-bounce mode is subject to a day-to-night contrast in volume reverberation similar to that experienced when operating in the near-surface-path mode. The daytime reverberation levels are due to a class of deep-scattering layers at a depth of 200 or 300 fathoms, whose peak scattering frequency at midday is quite near 3.5 kcps. The sonar beam must penetrate these layers when operating in the bottom-bounce mode. In general, it would seem that the SQS-26 will suffer masking due to reverberation from this layer during the day; at night, however, the masking level will be increased because other layers, having migrated closer to the surface, will also resonate near 3.5 kcps.

Whatever the mode, if scatterers resonating at 3.5 kcps are dense enough, as they apparently are in some areas, nighttime reverberation levels may limit detection severely. If only a sparse population is present, its effect may be of little consequence, day or night. There is a third possibility, of course; populations of scatterers may exist that are so dense as to limit severely both daytime and nighttime performance.

One thing that we badly need to know, therefore, is how the intensity of volume reverberation varies from one place to another in the sea. There are insufficient measurements for allowing us to plot charts of this variation. However, the authors believe that marine biology can provide a reasonable estimate of this variation. We believe that such an estimate not only can be used to great advantage in planning a program of measurements, but also that it can be used as an interim guide for answering many questions in which the geographic variation of midwater sound-scattering is concerned.

Estimating the geographic variation in the intensity of midwater sound-scattering

Now, the dependence of all animals upon plants is as complete in the ocean as it is upon the land. Plants make food, and animals eat plants or eat other animals that eat plants. The principal plants of the ocean are microscopic and so they mostly go unappreciated. These tiny plants are eaten by very small animals, which are eaten in turn by larger animals and so on.

The rate of growth and abundance of microscopic plants in the ocean is limited generally by the availability of nutrient materials, most often nitrates and phosphates. The abundance of these materials is controlled in turn by physical processes that cause them to be transported from deeper waters, where they accumulate, up into well-lit waters where they can be utilized by plants.

Thus, it is possible to relate a purely physical process like upwelling to the profusion of some large fish, even though several distinct stages of happenings will separate the two phenomena. As an illustration of the general principle we offer Figure 1, in which the distributions of phosphate and total plankton in the South Atlantic are shown. The similarity of the two distributions is marked.

As a first approximation, it can be said, then, that if there are several times as many microscopic plants at locality A as there are at locality B, there will be several times as many of the animals that depend upon these plants at A as at B. This is only generally true, of course, and there is plenty of evidence that very exact correspondence cannot be expected when bridging the several stages of a food chain from tiny plant to large predator. It is apparent, however, that better results can be expected when comparisons are made of the abundances of organisms close together in the food chain than when comparisons are made of abundances of organisms far apart. (The theory of food-chain relations in the sea has been discussed recently by Riley (1963).)

Because there are many species of bubble-bearing (sound-scattering) animals in the ocean, it is probable that such animals comprise a rather constant percentage of the total fauna from point to point in the ocean. It seems reasonably sure, then, that as the abundance of life in general varies from point to point in the ocean, so will the abundance of sound-scatterers vary. (A dozen years of sea-going with the echo-sounder tells us that this is so.) Sound-scattering intensity itself varies directly as the number of sound-scatterers. In short, and finally, we argue that if there be an ocean-wide measure of the variation in abundance of some link in the food chain connecting tiny plant to large predator, there exists, in effect, an ocean-wide estimate of the variation in intensity of midwater sound-scattering.

The displacement volumes of plankton tows made by the "Dana" and other Danish research vessels between 1903 and 1934 is a body of data that can be used to such an end (Jespersen 1923, 1935). These Danish expeditions explored at first in the North Atlantic Ocean and Mediterranean Sea and finally around the world. A part of the regular program of observations were tows with stramin nets with mouths of two-meter diameter. (Stramin resembles a closely woven burlap.) These nets are not effective in catching grown specimens of even small species of fish and furthermore, are so coarse as to let escape the tiny plants and other very small organisms. What these nets do catch are organisms of an intermediate size that serve as food for the ocean's small fishes; that is, this body of data pertains to organisms that comprise the link in the food chain immediately adjoining the ocean's principal sound-scatterers.

We have used these data, which are given for 10-degree squares, to prepare a chart showing midwater reverberation levels over most of the North Atlantic Ocean and Mediterranean Sea. The details of our manipulation of the data and construction of the charts are given in an appendix. In brief, we have pooled Jespersen's 1923 data from several depths of capture within the upper 200 fathoms of the ocean or so and struck an average. The resulting values are shown in Figure 2.

Next, we have referred all such values to a base value (1300) assigned by us to a location in the Slope Water east of New England and just outside the area covered by Jespersen's data. We chose to do this for two reasons. The location chosen is one of the sites in which the SQS-26 has had operational experience and was limited by nighttime reverberation levels (though not by daytime ones). Also, this Slope-Water locality is one in which we and others have made broad-band sound-scattering observations. This spot, then, is the one with which all others on the chart are compared.

The normalized data are plotted and contoured in Figure 3. Localities having values of two, for instance, have midwater reverberation levels that are twice as high as those found in the Slope Water east of New England, and so on. Localities having values in excess of one are localities in which the SQS-26 is very apt to be volume-reverberation limited during nighttime hours. It is possible that where the reverberation values are very high, the SQS-26 may be limited during daytime. In contouring the data we have drawn freely on our knowledge of the North Atlantic and so have introduced here and there, perhaps, some of our own prejudices. The charts for the Mediterranean Sea (Figures 4 and 5) have been done in a way similar to the North Atlantic

ones, although the distinction is made between summer and winter. The summer chart includes some information for the Black Sea and for the Sea of Marmora.

We need make little remark about the charts, which speak for themselves, beyond calling attention to the very high reverberation levels over the West European Basin and on into the Norwegian Sea. These levels are 50 to 100 times greater than the lowest, found in the southwestern Sargasso Sea. Reverberation levels off Dakar on the west coast of Africa are also high.

We should point out that the areas in which high reverberation levels are shown are ones that will show more marked seasonal variations than will low-level ones. These high-level areas will also show more variation between nearby localities than will the low-level areas. We also should say that this chart is meant to apply to deep ocean areas. As a rule, reverberation levels will be higher than shown over adjacent continental shelves and also higher than shown wherever deep water approaches the land.

There are a number of published charts that can be readily adapted for showing the geographic variation in the intensity of sound scattering. We chose to construct our own charts, because we wished to begin with actual reduced data and, so, know exactly how the final product was come by. We include a sampling of these published charts. Each has its advantages and disadvantages, but, significantly, they are in essential agreement.

Figure 6 is from Friedrich (1950). This chart is based on plankton data from a number of extensive Atlantic Ocean expeditions. (This is an appropriate place to point out that some of the similarity from chart to chart is due to the use of common data.)

Figure 7 is taken from Ebeling (1962) and is based on a chart originally published by Fleming and Laevastu (1956) with alterations based on data from Reid (1962).

Remarks on the geographic variation in the pattern of midwater sound-scattering.

The charts presented so far pertain to the geographic variation in the intensity of the scattered sound. We are suggesting that if sound-scattering intensity were measured over a broad band (from a few hundred cycles to

30 kcps, for instance), it would vary from place to place in the ocean according to these charts.

We have said that there are one or a few peaks in the spectrum of the scattered sound and that these peaks migrate in frequency as layers migrate in depth. Do these peaks always occur at the same frequencies? Are there wide stretches of ocean, at least, within which the pattern of frequency peaks is fairly constant? Does the pattern of frequency peaks vary in such a random way that no useful generalization at all can be made? These are questions important to sonar operation that cannot now be answered. A reasonable speculation can be made, however.

In the ocean, as on the land, there are wide regions within which the animal inhabitants are more or less the same. Since the principal sound-scatterers of the ocean are animals, a plot of ocean faunal regions (regions within which the animal inhabitants are more or less the same) might be a plot of regions within which the patterns of sound scattering are more or less the same.

Although it is obviously too simple a scheme, there appears to be some correlation between marine animal distribution and the water masses of the oceans as defined by their temperature-salinity characteristics. A good discussion of the matter is found in Ebeling (1962) and we take our Fig. 8 from his paper. It shows the water masses of the world ocean (adapted from Sverdrup, Johnson, and Fleming, 1942) and can be thought of as an expression of the faunal regions of the world ocean. It is possible that certain general features of the sound-scattering pattern may hold constant within each region. Our own experience in the North Atlantic indicates that subdivisions of this chart are necessary to describe adequately the geographic variation in sound-scattering pattern. We should also say that, whatever the nature of sound-scattering patterns within these regions, large changes from season to season should be expected. Nevertheless, we believe this chart may be used to advantage in planning programs of actual measurements.

Estimating the relative incidence of false targets.

The argument presented so far and the charts accompanying it are also relevant to another problem in sonar operation that is of biological origin. This is the problem of so-called "false targets". It is the belief of the authors that in most cases the false contacts that defy rapid classification are fish schools. Generally speaking, these false contacts will occur with an incidence that is proportional to the abundance of sea life in general. Therefore, Figures 3 - 7 may be used also as charts of the expected incidence of false targets. It is probable that these figures represent somewhat less well the incidence of false targets than they represent the abundance of midwater sound-scatterers. We think this is so, because fewer kinds of sea animals cause false contacts than contribute to midwater sound-scattering. The more special the group of animal species causing the problem the less the general picture of the abundance of animal life will be applicable. Until more is known about the specific identity of animals responsible for false contacts difficult to classify, however, the charts given here will be useful in anticipating false contact incidence.

The false target problem, though it may be caused almost entirely by life in the sea, is not to be solved solely by gaining information about the distribution of such natural targets. There needs to be a distinct capability for distinguishing between submarine (SS) targets and all others. Information such as that shown in Figs. 3 - 7 will assist scientists or engineers to find false targets for study in developing this capability.

Recommendations for measurement programs

1. In order to assess the extent and nature of the volume reverberation problem, the primary area of relevant future inquiry is the distribution and behavior of resonant scatterers in the deep ocean. The secondary area is a similar investigation of non-resonant scatterers there.
2. The appropriate programs, including objectives, methods, and schedules, can be designed based on previous research both in oceanographic acoustics and marine biology. Such programs will probably be partly experimental and partly deliberate exploration. These two parts should interact with the shortest possible reaction times, and hence a large scale survey should be planned, if at all, only after thorough consideration of both the survey and its supporting research.

UNCLASSIFIED

- 10 -

3. Sufficient information is available from marine biologists about the distribution of life in the open ocean (as is demonstrated elsewhere in this report) to direct initial research and survey activity for considerably more efficient distribution of observations than would be possible without this guidance.

UNCLASSIFIED

APPENDIX

Figures 2 and 3 were made as follows: plankton catches in cc/hr for 10-degree squares were taken from Jespersen (1923). These samples had been collected with two-meter stramin nets at depths down to 300 or 400 meters. Jespersen's data is presented by him on four charts, each chart showing average values for tows made with a certain towing-warp length. The data from these four charts have been pooled and averaged again by us. This second averaging introduces slight biases, because for each ten-degree square the number of tows at the several wire lengths varies somewhat and, at the same time, plankton volume diminishes with increasing depth.

In the case of tows made with 600 meters of wire (Jespersen's Fig. 4, p. 8), stramin nets of two diameters were used, one and one-half and two meters. We have brought the volumes recorded for the tows made with the 1 1/2-m net up to the remainder (the great majority, made with the 2 m net) by multiplying them by 1.8.

Jespersen, in his 1923 paper, gives no data for the two ten-degree squares on the African coast between the equator and 20°N bounded on the west by the meridian 20°W. We have taken comparable data for these squares from a later paper by him (Jespersen, 1935).

We have omitted data for the 10-degree squares embracing the North Sea and the seas immediately around Great Britain. These are shallow-water areas and for various reasons not strictly comparable to deep-ocean areas.

Next, the data were reduced to fractions of a base volume. This base volume, to which all others have been related, was not chosen from Jespersen's data, but is one that was assigned by ourselves to a location just outside the area that Jespersen covers. This point, 41°N, 65°W, is in the Slope Water east of New England and was given a plankton value of 1300 cc/hr. This volume was chosen because Slope Water plankton tows are three to four times as rich as Sargasso Sea tows just to the south (Grice and Hart, 1962). We multiplied 439, the plankton volume in the 10-degree square just to the south, by three and rounded off to 1300. We used 3 rather than, say, 3.5 because a few of the samples in the 10-degree square just to the south may themselves have come from Slope Water.

In the charts for the Mediterranean Sea (Figs. 4 and 5) the primary data come from a single towing depth and have been taken directly from Jespersen's Figs. 6 and 7 (p. 12). They are plotted by 5-degree squares.

REFERENCES

- Andreyeva, I. B., 1964. Scattering of sound by air bladders of fish in deep sound-scattering ocean layers. *Akust. Zhur.*, 10:20-24. (English translation by the American Institute of Physics, New York.)
- Andreyeva, I. B. and Yu. G. Chindonova, 1964. O prirode zvukorasseivayushchikh sloev. (On the nature of sound-scattering layers.) *Okeanologiya*, 4:112-124.
- Barham, E. G., 1963. Siphonophores and the deep scattering layer. *Science*, 140:826-828.
- Barham, E. G., 1966. Deep scattering layer migration and composition: observations from a diving saucer. *Science*, 151:1399-1403.
- Bowers, G. H., Jr. (editor), 1965. Volume reverberation from deep scattering layers. AVCO Marine Electronics Office, New London, Conn., 39 pp.
- Ebeling, A. W., 1962. Melamphaidae I: systematics and zoogeography of the species in the bathypelagic fish genus Melamphaes Günther. Dana Report No. 58, 164 pp.
- Fleming, R. H. and T. Laevastu, 1956. The influence of hydrographic conditions on the behavior of fish. *FAO Fish Bull.*, 9:181-196.
- Friedrich, H., 1950. Versuch einer Darstellung der relativen Besiedlungsdichte in den Oberflächenschichten des Atlantischen Ozeans. (An attempt at describing the relative population density in the surface layers of the Atlantic Oceans.) *Kieler Meeresforsch.*, 7:108-121.
- Grice, G. D. and A. D. Hart, 1962. The abundance, seasonal occurrence and distribution of the epizooplankton between New York and Bermuda. *Ecol. Mon.*, 32:287-309.
- Hentschel, E. and H. Wattenberg, 1930. Plankton und Phosphat in der Oberflächenschicht der Sudatlantischen Ozeans. (Plankton and phosphate in the surface layer of the South Atlantic Ocean.) *Ann. Hydrog. (Berlin)*, 58:273-277.

- Hersey, J. B. and R. H. Backus, 1954. New evidence that migrating gas bubbles, probably the swimbladders of fish, are largely responsible for scattering layers on the continental rise south of New England. *Deep-Sea Res.*, 1:190-191.
- Hersey, J. B. and R. H. Backus, 1962. Sound scattering by marine organisms. In M. N. Hill (edit.), *The Sea*, 1:498-539. Interscience Publishers, New York and London.
- Hersey, J. B., R. H. Backus, and J. Hellwig, 1962. Sound-scattering spectra of deep scattering layers in the western North Atlantic Ocean. *Deep-Sea Res.*, 8:196-210.
- Hersey, J. B., H. R. Johnson, and L. C. Davis, 1952. Recent findings about the deep scattering layer. *J. Mar. Res.*, 11:1-9.
- Holmes, R. W., M. B. Schaefer, and B. M. Shimada, 1957. Primary production, chlorophyll, and zooplankton volumes in the tropical eastern Pacific Ocean. *Bull. Inter-Amer. Trop. Tuna Comm.*, 2:129-169.
- Jespersen, P., 1923. On the quantity of macroplankton in the Mediterranean and the Atlantic. *Rept. Dan. Oceang. Exped. 1908-1910*, 3(3):17 pp.
- Jespersen, P., 1935. Quantitative investigations on the distribution of macroplankton in different oceanic regions. *Dana Report No. 7*, 44 pp.
- Marshall, J. R. and R. P. Chapman, 1964. Reverberation from a deep scattering layer measured with explosive sound sources. *Jour. Acoust. Soc. Amer.*, 36:164-167.
- Reid, Joseph L., Jr., 1962. On circulation, phosphate-phosphorus content, and zooplankton volumes in the upper part of the Pacific Ocean. *Limn. and Oceanog.*, 7:287-306.
- Riley, G. A., 1963. Theory of food-chain relations in the ocean. In M. N. Hill (edit.), *The Sea*, 2:438-463, Interscience Publishers, New York and London.
- Sverdrup, H. U., M. W. Johnson, and R. H. Fleming, 1942. *The oceans*. 1087 pp. Prentice-Hall, New York.

UNCLASSIFIED

Figure 1

Distribution of phosphate (left) and total plankton (right) in the upper layers of the South Atlantic Ocean (from Hentschel and Wattenberg, 1930). The figure is included to show the general resemblance in distribution of a nutrient mineral and small plants and animals.

UNCLASSIFIED

Figure 2

Average plankton catch in cubic centimeters per hour of tow for certain 10-degree squares in the North Atlantic. The numbers in parentheses are the number of samples used in arriving at the average value. A value of 1300 has been assigned to a locality in the Slope Water east of New England. See text and Appendix I.

UNCLASSIFIED

UNCLASSIFIED

Figure 3

Reverberation levels in the North Atlantic Ocean relative to a station in the Slope Water east of New England. Normalized and contoured data follow Figure 2. The normalization is based on the value of 1300 assigned to the locality in the Slope Water. Contours (broken) are drawn at one-tenth unit intervals where values are less than 1 or 1.5, and at unit intervals (solid contours) where values exceed 1.

The areas where values exceed 1 are shaded and here volume reverberation may limit SQS-26 operation during night hours.

In using this and other charts it is reasonable to suppose that a two-times increase in marine life will represent a 3-db increase in volume reverberation.

This chart can be used with Figs. 4 and 5 in making North Atlantic-Mediterranean comparisons.

A second use for this chart is in the estimation of the relative incidence of false targets.

OUTLINE CHART OF THE
NORTH ATLANTIC OCEAN
ON AN
AZIMUTHAL EQUAL AREA PROJECTION
CENTERED AT 40°N, 35°W

REPRODUCED FROM
WOODS HOLE OCEANOGRAPHIC INSTITUTION
BY U.S. GOVERNMENT PRINTING OFFICE

This is a detailed outline chart of the North Atlantic Ocean, centered at 40°N, 35°W. The chart uses an azimuthal equal area projection. It displays isobars (depth contours) and bathymetric features. Key features include the Mid-Atlantic Ridge, the Azores, the Azores High, and the Azores Low. The chart is bounded by 0° to 60°N latitude and 10°W to 50°W longitude. The title and projection information are at the top. The publisher information is at the bottom right.

FOODS HAVE CHEMICALS, NOT
POISON

Figure 4

Mediterranean Sea, summer. Volume reverberation levels with respect to a station in the Slope Water east of New England. See text, and Appendix I. Areas where night-time operations of the SQS-26 may be reverberation limited are cross-hatched.

A second use for this chart is in the estimation of the relative incidence of false targets.

Figure 5

Mediterranean Sea, winter. Volume reverberation levels with respect to a station in the slope water east of New England. See text, Appendix I, and the caption to Figure 4.

A second use for this chart is in the estimation of the relative incidence of false targets.

CONFIDENTIAL

CONFIDENTIAL

Figure 6

Relative density of plankton in the Atlantic Oceans (from Friedrich 1950). Volume-reverberation levels can be taken to be proportional to plankton density (see text). This chart will be useful when comparisons involving both Atlantic Oceans are to be made. Estimates of SQS-26 performance can be made by comparing the plankton abundance shown for a given area with the abundance shown for the base station in the Slope Water east of New England (see text).

The relative densities are expressed in percentages. White - 1 to 15, thin dots - 15 to 30, horizontal lines - 30 to 60, vertical lines - 60 to 200, thick dots - over 200.

A second use for this chart is in the estimation of the relative incidence of false targets.

Figure 7

Organic production (in grams of carbon under a square meter of sea surface per year) for the world ocean (from Ebeling 1962). Volume reverberation levels can be taken to be proportional to organic production (see text). This chart will be useful when comparisons involving the world ocean are to be made. Estimates of SQS-26 performance can be made as before (see caption to Fig. 6 and text).

A second use for this chart is in the estimation of the relative incidence of false targets.

Figure 8

The water masses of the world ocean (from Ebeling 1962 after Sverdrup, Johnson, and Fleming 1942). There is some conformance of ocean faunal regions to these water masses. Therefore there may be some general features of the pattern of sound-scattering that are constant within each area. See text.

UNCLASSIFIED

UNCLASSIFIED

DISTRIBUTION LIST

No. of Copies	Addressee	No. of Copies	Addressee
	Office of Naval Research		Chief, Bureau of Ships
	Department of the Navy		Department of the Navy
	Washington, D. C. 20360		Washington, D. C. 20360
1	Attn: Code 416	1	Attn: Code 300
1	418	1	343
1	437	1	345
4	466	1	631
1	468	1	1620
		1	1630
	Chief of Naval Operations		
	Navy Department	1	Chief of Naval Material
	Washington, D. C. 20350		Navy Department
1	Attn: OP 95		Washington, D. C. 20360
1	OP 03EG		DONM (Development)
1	OP 31		
1	OP 32	1	Chief, Bureau of Naval
1	OP 07T		Weapons
1	OP 71		Navy Department
			Washington, D. C. 20360
1	Commanding Officer		Attn: RU222
	Office of Naval Research		
	Branch Office	1	Project Manager
	495 Summer Street		Antisubmarine Warfare Systems
	Boston, Mass. 02210		Navy Department
			Washington, D. C. 20360
1	Assistant Secretary of the Navy		
	(Research and Development)	1	Director, Special Projects
	Navy Department		Navy Department
	Washington, D. C. 20350		Washington, D. C. 20360
			SP-240
1	Commanding Officer		
	Office of Naval Research	1	Director, U. S. Navy
	Branch Office		Underwater Sound
	Box 39, F. P. O.		Reference Laboratory
	New York 09510		P. O. Box 8337
			Orlando, Florida 32806

No. of Copies	Addressee	No. of Copies	Addressee
	U. S. Naval Oceanographic Office Washington, D. C. 20390	1	U. S. Naval Ordnance Test Station
2	Attn: Commander		Pasadena Annex
1	Radm. Waters		3202 East Foothill Boulevard
1	Capt. T. K. Treadwell		Pasadena, California 91107
1	Mr. W. E. Maloney (Code 7000)		Attn: Pasadena Annex Library
5	Mr. C. H. Cline (Code 9000)	2	Commanding Officer
1	Mr. W. B. Randlett (Code 9000)		U. S. Naval Ordnance
2	Mr. Bates (Code 9000)		Laboratory
	Director		White Oak, Silver Spring
	U. S. Naval Research Laboratory		Maryland 20910
	Washington, D. C. 20390		
1	Attn: Code 2021	1	Commanding Officer
6	2027		U. S. Naval Underwater
1	5500		Ordnance Station
1	5510		Newport, Rhode Island 02844
10	Mr. John Heacock	1	Commanding Officer
	Office of Naval Research		U. S. Naval Air Development
	Department of the Navy		Center
	Washington, D. C. 20360		Johnsville, Pennsylvania 18974
	Code 408/416	1	Commanding Officer and
2	Commanding Officer and Director		Director
	U. S. Navy Electronics Laboratory		U. S. Navy Mine Defense
	San Diego, California 92152		Laboratory
1	Commander (Code 753)		Panama City, Florida 32402
	U. S. Naval Ordnance Test Station	1	Librarian
	China Lake, California		U. S. Naval Postgraduate
	Attn: Technical Library 93557		School
			Monterey, California 93940

No. of Copies	Addressee	No. of Copies	Addressee
1	Systems Analysis Group Undersea Warfare Research and Development Council Room 5-224 U. S. Naval Ordnance Laboratory White Oak, Silver Spring Maryland 20910	1	Office of Naval Research Project Officer U. S. Navy Sofar Station APO 856 New York, N. Y. 09856
2	Commanding Officer and Director U. S. Navy Underwater Sound Laboratory Fort Trumbull New London, Connecticut 06321	1	Air Force Missile Test Center Technical Library MU-135 Patrick Air Force Base Florida
OTHER U. S. GOVERNMENT AGENCIES		1	Air Force Missile Test Center (MTASI) Patrick Air Force Base Florida
20	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	1	Commander Antisubmarine Force U. S. Atlantic Fleet Norfolk, Virginia 23511
1	Director Bureau of Commercial Fisheries Biological Laboratory U. S. Fish and Wildlife Service Woods Hole, Massachusetts 02543	1	Commander Antisubmarine Force U. S. Pacific Fleet FPO San Francisco California 96610
2	Commanding Officer and Director (Code 560) David Taylor Model Basin Washington, D. C. 20007	1	Commander Submarine Force U. S. Atlantic Fleet Norfolk, Virginia 23511
1	Water Quality Section Basic Data Branch Division of Water Supply and Pollution Control Department of Health, Education and Welfare 1014 Broadway Cincinnati 2, Ohio	1	Commanding Officer and Director ASW Tactical School U. S. Atlantic Fleet Norfolk, Virginia 23511

No. of Copies	Addressee	No. of Copies	Addressee
1	Commander Submarine Force U. S. Pacific Fleet FPO San Francisco, California 96610	1	Fluid and Solid Mechanics Laboratory Institute of Science and Technology Post Office Box 618 Ann Arbor, Michigan
1	Commander Submarine Development Group TWO FPO New York, New York	1	Institute of Defense Analyses Communications Research Division Von Neumann Hall Princeton, New Jersey
1	U. S. Naval Applied Science Laboratory Code 9360 U. S. Naval Base Brooklyn, New York 11251	1	Library Lamont Geological Observatory Columbia University Palisades, New York 10964
1	Commander Destroyer Development Group TWO FPO New York, New York 09501	1	Director Marine Physical Laboratory of the Scripps Institute of Oceanography San Diego, California 92152
U. S. LABORATORIES AND UNIVERSITIES (except those of U. S. Government)		1	National Academy of Sciences National Research Council 2101 Constitution Avenue Washington, D. C. 20318 Attn: Dr. William Rainey
1	Advanced Research Projects Agencies Pentagon Washington, D. C. 20360 Attn: Nuclear Test Detection Office	1	ONR Liaison Officer Woods Hole Oceanographic Institution Woods Hole, Massachusetts
1	Dr. G. P. Woollard, Director Hawaii Institute of Geophysics University of Hawaii Honolulu, Hawaii 96822		
	Director Hudson Laboratories 145 Palisade Street Dobbs Ferry, New York 10522		

No. of
Copies Addressee

- 1 Ordnance Research Laboratory
 Pennsylvania State University
 University Park, Pennsylvania
- 1 Director
 Marine Laboratory
 University of Miami
 1 Rickenbacker Causeway
 Virginia Key
 Miami, Florida 33149
- 1 Director
 Narragansett Marine Laboratory
 University of Rhode Island
 Kingston, Rhode Island
- 1 Director
 Defense Research Laboratory
 University of Texas
 Austin, Texas
- 1 Director
 Department of Oceanography
 Texas A and M University
 College Station, Texas
- 1 Applied Physics Laboratory
 University of Washington
 1013 East 40th Street
 Seattle, Washington 98105

INDUSTRY

- 1 Bell Telephone Laboratories Inc.
 Whippany, New Jersey 07981
 Attn: Mr. C. F. Wiebusch
 Division 54

No. of
Copies Addressee

- 1 Daystrom Electric
 Division of Daystrom Inc.
 753 Main Street
 Poughkeepsie, New York

FOREIGN ACTIVITIES

- 1 SACLANT
 Anti-Submarine Warfare
 Research Centre
 Viale San Bartolomeo, 92
 La Spezia, Italy
- 1 Bermuda Biological Station
 St. George's West, Bermuda
 Attn: Mrs. Leida Piip,
 Librarian
 Via: ONR (Code 466)
 Washington, D. C. 20360
- 1 National Institution of
 Oceanography
 Wormley, Godalming
 Surrey, ENGLAND
 Attn: Library
- 1 Pacific Oceanographic Group
 Nanaimo, British Columbia
- 1 Seyir ve Hidrografi Dairesi
 Cubuklu-Istanbul, Turkey
 Via: (1) ONR (Code 466)
 Washington, D. C. 20360
 (2) Officer in Charge
 Schools Advisory
 Detachment
 JUSMMAT APO 380
 New York, New York

Woods Hole Oceanographic Institution
Reference No. 66-10

THE GEOGRAPHIC VARIATION OF MIDWATER
SOUND-SCATTERING by Richard H. Backus and
J. B. Hersey. 24 pp. March 1966. Contract
N00R 4029(00)NR 260-101.

It is suggested in this report that the
intensity of midwater sound-scattering in
the ocean varies from point to point as the
abundance of marine life varies. Several
charts depicting variations in the abundance
of marine life are given, from which estimates
of the intensity of sound-scattering can be
made.

1. Midwater sound-scattering

2. Reverberation

3. Active sonar operation

I. Backus, Richard H.

II. Hersey, J. B.

III. Nonr-4029(00)NR260-101

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
Reference No. 66-10

THE GEOGRAPHIC VARIATION OF MIDWATER
SOUND-SCATTERING by Richard H. Backus and
J. B. Hersey. 24 pp. March 1966. Contract
N00R 4029(00)NR 260-101.

It is suggested in this report that the
intensity of midwater sound-scattering in
the ocean varies from point to point as the
abundance of marine life varies. Several
charts depicting variations in the abundance
of marine life are given, from which estimates
of the intensity of sound-scattering can be
made.

1. Midwater sound-scattering

2. Reverberation

3. Active sonar operation

I. Backus, Richard H.

II. Hersey, J. B.

III. Nonr-4029(00)NR260-101

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
Reference No. 66-10

THE GEOGRAPHIC VARIATION OF MIDWATER
SOUND-SCATTERING by Richard H. Backus and
J. B. Hersey. 24 pp. March 1966. Contract
N00R 4029(00)NR 260-101.

It is suggested in this report that the
intensity of midwater sound-scattering in
the ocean varies from point to point as the
abundance of marine life varies. Several
charts depicting variations in the abundance
of marine life are given, from which estimates
of the intensity of sound-scattering can be
made.

1. Midwater sound-scattering

2. Reverberation

3. Active sonar operation

I. Backus, Richard H.

II. Hersey, J. B.

III. Nonr-4029(00)NR260-101

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
Reference No. 66-10

THE GEOGRAPHIC VARIATION OF MIDWATER
SOUND-SCATTERING by Richard H. Backus and
J. B. Hersey. 24 pp. March 1966. Contract
N00R 4029(00)NR 260-101.

It is suggested in this report that the
intensity of midwater sound-scattering in
the ocean varies from point to point as the
abundance of marine life varies. Several
charts depicting variations in the abundance
of marine life are given, from which estimates
of the intensity of sound-scattering can be
made.

1. Midwater sound-scattering

2. Reverberation

3. Active sonar operation

I. Backus, Richard H.

II. Hersey, J. B.

III. Nonr-4029(00)NR260-101

This card is UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Woods Hole Oceanographic Institution Woods Hole, Massachusetts		2a. REPORT SECURITY CLASSIFICATION Confidential	
		2b. GROUP 3	
3. REPORT TITLE THE GEOGRAPHIC VARIATION OF MIDWATER SOUND-SCATTERING			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical			
5. AUTHOR(S) (Last name, first name, initial) Backus, Richard H. and Hersey, J. R.			
6. REPORT DATE March 1966		7a. TOTAL NO. OF PAGES 24	7b. NO. OF REFS 21
8a. CONTRACT OR GRANT NO. Nonr-4029(00) NR 260-101		8a. ORIGINATOR'S REPORT NUMBER(S) Reference No. 66-10	
A. PROJECT NO. c. d.		8b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10. AVAILABILITY/LIMITATION NOTICES Qualified requesters may obtain copies of this report from DDC.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office of Naval Research (Code 466) Washington, D.C. 20360	
13. ABSTRACT It is suggested in this report that the intensity of midwater sound-scattering in the ocean varies from point to point as the abundance of marine life varies. Several charts depicting variations in the abundance of marine life are given, from which estimates of the intensity of sound-scattering can be made.			

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Midwater sound-scattering						
Reverberation						
Active sonar operation						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

CONFIDENTIAL

UNCLASSIFIED

UNCLASSIFIED

CONFIDENTIAL