MEASUREMENTS OF FISH TARGET STRENGTH: A REVIEW

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ABSTRACT

The concept of target strength and its application to the quantitative assessment of fishery resources are discussed. Methods of determining the echo characteristics of fish are reviewed and a number of results presented. Among the more important of these results are: (1) practically every case of interest to the fishing industry is in an acoustic region in which the target strength varies widely with fish size and aspect and acoustic frequency, (2) the major contributors to target strength in this region have been determined to be the swim bladder, flesh, and skeleton, and (3) the average maximum side-aspect and dorsal-aspect target strength of an individual fish have been determined for this region.

Quantitative assessment of fishery resources is a difficult task, and many groups have turned to acoustic techniques to conduct assessment surveys. Present acoustic techniques can give an estimate of the number and dimensions of fish schools in a geographic area and, by estimating the density of the fish in a school, the number of individual fish in the area can be approximated. Measurements of fish target strength are being made by various investigators in an effort to enable the direct acoustic estimation of the number and size of individuals in a school and to enable the direct identification of those individuals by acoustic methods. This paper discusses the concept of target strength and its application to the quantification and/or identification of fish schools, reviews target strength measurement techniques, and discusses some results which have been obtained utilizing these techniques.

TARGET STRENGTH

Active sonars project acoustic energy into the water in an effort to detect objects by the echoes they return, the intensity of the echo depending on the proportion of the sound reflected back to the receiver. The target strength of the echo-producing object is a quantitative measure of its reflecting characteristics and is defined as

$$T = 10 \log \left(\frac{I_1}{I_0}\right), \qquad (1)$$

where I_0 is the intensity of the sound striking the target and I_1 is the intensity of the reflected sound measured at 1 m from the acoustic center of the target. If I_r is the intensity of the reflected sound measured at some distance r from the target, then, assuming that the sound spreads spherically, and there are no losses, I_r will be directly proportional to I_0:

$$I_r = \left(\frac{\sigma}{4\pi}\right) \frac{I_0}{r^2}. \qquad (2)$$

σ is defined as the acoustic cross-section of the target, and $4\pi r^2$ is the spherical surface area through which all the incident energy is reflected. σ depends on the size, shape, and orientation of the target, and, in general, will vary with the angle between the incident direction and the direction of the receiver. In all present fisheries work, this angle is zero and therefore in this paper σ will be the acoustic cross-section of a target for the case in which the source and receiver are located at the same point.

By letting r in equation (2) be equal to 1 m and combining equations (1) and (2),

$$T = 10 \log \left(\frac{\sigma}{4\pi}\right). \qquad (3)$$

Now if I_s is the intensity of the projected sound 1 m from the source,

$$I_0 = \frac{I_s}{r^2} \qquad (4)$$

and therefore,

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$$I_r = \left(\frac{\sigma}{4\pi}\right) \frac{I_s}{r^4}, \tag{5}$$

or in logarithmic form,

$$10 \log I_r = 10 \log \left(\frac{\sigma}{4\pi}\right) + 10 \log I_s - 40 \log r. \tag{6}$$

Defining the echo level (E) as 10 log I_r and the source level (S) as 10 log I_s, and rearranging,

$$T = E - S + 40 \log r. \tag{7}$$

Equation (7) can be used to compute target strength in an ideal medium. In a real medium, however, the actual transmission loss will include effects due to absorption, scattering, refraction, and the boundaries. Hence, in a real medium

$$T = E - S + 2H \tag{8}$$

where H is the one way transmission loss. H takes into account spreading loss, absorption, and any anomalies. In actual practice H cannot always be reliably predicted and must be measured unless the ranges involved are small. Equation (8) is known as the active sonar equation and is always used in the computation of target strength since it involves only directly measurable quantities—echo level, source level, and transmission loss.

It is impossible for more sound to be reflected from a target than is incident upon it, and it is therefore seemingly impossible for any object to have a positive target strength, yet many large targets do. This is a consequence of the reference distance being 1 m, and the measurements being made at greater distances, with spherical spreading assumed in order to calculate the target strength. However, the spreading loss very close to a target is less than the spherical spreading loss which is assumed, and hence positive target strengths can be obtained for large targets.

The importance of the target strength of a potential target is obvious from the sonar equation (equation (8)). The maximum range at which a target can be detected in any given environment depends on its target strength and the characteristics of the transmitting and receiving systems. Therefore, an estimate of target strength is essential to the effective design and operation of any active sonar system.

The quantification of a fish school, knowing its target strength, is possible because the target strength of a school depends on the average size, number, distribution, and aspect of the individuals in the school. In order to quantify fish schools using target strength information, it is first necessary to determine the size and number of individuals required to produce a given target strength. The initial step in this process is the determination of the target strength of an individual fish. The application of this knowledge to studies on the acoustic interactions of arrays of scatterers will eventually produce accurate predictions of school target strength. The great majority of work done up to this time has been on individual fish, and quite a bit more must be done before this initial step is completed. Definitive work on the quantification and identification of fish schools utilizing target strength information awaits completion of this step.

Reflection of sound from an object in water occurs when the object has an acoustic impedance which differs from that of the water. Acoustic impedance is defined as the product of the density (ρ) of a substance and the velocity of sound (c) in that substance. The proportion of sound reflected from or transmitted into an object in water depends on the magnitude of the impedance mismatch between the object and the water. The simplest case of reflection occurs when a plane wave is normally incident upon a plane boundary between two semi-infinite media. The pressure amplitude reflection coefficient is defined as the ratio of the reflected pressure amplitude to the incident pressure amplitude, and for this case it is found to be $\frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}$, where $\rho_1 c_1$ is the impedance of the medium in which the incident wave is traveling and $\rho_2 c_2$ is the impedance of the medium upon which the wave is incident. If the second medium is reduced to finite thickness and a third medium is placed behind it (the third medium may or may not be the same as the first), the problem becomes slightly more complicated. When the incident wave arrives at the first boundary, some energy is reflected and some is transmitted. After this transmitted portion reaches the second boundary, some of the energy is transmitted into the third medium and some is reflected back into the second medium, where it is again partially reflected from the first boundary. This process continues until a steady state is reached. The solution of this problem is relatively easy, but it is interesting because the resultant amplitudes of the transmitted and reflected waves depend on the phases of the component waves. The component waves add vectorially and whether the amplitude of the initially reflected wave is increased or decreased depends on the thickness of the second medium and the wavelength of the incident wave.

The reflection of sound from an infinite plate poorly approximates the reflection from a fish, and it is useful to examine the reflection from a finite object such as a sphere. When the sphere is large compared to the acoustic wavelength, the echo originates from specular reflection, in which the part of the sphere near the point where the sound wave is normally incident produces a coherent reflected wave. When the size of the sphere is comparable to a wavelength, interference effects similar to those mentioned for the plate with finite thickness will cause the acoustic cross-section to vary. When the sphere is small compared to a wavelength, scattering takes place and the acoustic cross-section of a sphere of radius a is proportional to a^6/λ^4 where λ is the wavelength. This solution was obtained by Lord Rayleigh and hence this region is called the region of Rayleigh scattering.

For objects other than spheres, analysis becomes difficult, if not impossible. However, as long as the object is not highly compressible, the concept of the regions of Rayleigh scattering, interference effects, and geometric reflection is valid. For a fish, the distinctions between these regions becomes unclear because of the fish's internal structure. When the fish is very small compared to the acoustic wavelength, Rayleigh scattering can be expected. However, if the fish has a gas-filled swim bladder the gas bubble will resonate at some wavelength in this region, greatly increasing the target strength over that predicted by Rayleigh scattering. When the size of the fish is comparable to the wavelength, interferences will occur among the fish flesh and organs, the skeleton, the gas in the swim bladder, and the boundaries of the fish. When the fish is larger than the wavelength, the dimensions of many of these parts will be comparable to the wavelength and the region of interference effects will be greatly extended into what would be the region of geometric reflection for a homogeneous body.

Cushing et al. (1963) have assumed that the region of interference effects extends from $L/\lambda = 8$ to $L/\lambda = 100$, where L is the fish length, and λ is the acoustic wavelength, and they suggest that for quantitative results this region should be avoided. Neglecting the fact that they have ignored the effects of swim bladder resonance, the limits they have placed on the interference region will now be examined. For a rigid sphere of radius a the limits of the interference region are approximately $1 \leqslant 2\pi a/\lambda \leqslant 10$, and for any other object these limits will probably be farther apart. Measurements on individual fish indicate that interference effects occur at values of $L/\lambda = 0.7$ (Love, 1971) and this can be taken as a lower limit. (This is not to say that it is the lower limit, only that this is as low as measurements have been made.) Haslett (1962a) examined a small number of whiting to determine their "standard dimensions." He found that the diameter of the backbone was about 0.01 the length of the fish. Assuming that the backbone of a fish is the smallest part of a fish which contributes to its echo, this means that if interference effects occur in the backbone until its circumference is something near 10 times as large as the wavelength, as in the case for the sphere, then the upper limit of the interference zone for a fish will be at least $L/\lambda = 200$. Again, measurements have been made which indicate that the upper limit will be at least this high (Haslett, 1969). Therefore, it may be assumed that the limits of the interference region are at least $0.7 \leqslant L/\lambda \leqslant 200$.

If it is assumed that fish of interest to commercial fishermen range from 10 cm to 150 cm, and that fish-finding sonars have frequencies ranging from 10 kHz to 200 kHz, then the range of interest for fisheries applications will be $0.7 \leqslant L/\lambda \leqslant 200$, the limits set for the interference region. Therefore, although it would be advantageous to avoid the interference region, it is apparent that this is the region in which the work must be done.

METHODS OF TARGET STRENGTH MEASUREMENT

Analytical methods are of limited value in this interference region and experimental methods must be utilized to obtain any valid answers. It is possible to conduct the needed experiments either at sea or in the laboratory, with each type of measurement having its limitations. Whether the measurements are made at sea or in the laboratory, target strength will be determined from the sonar equation, meaning that the source level of the transmitter, the sensitivity of the receiver, and the propagation loss must be known. The calibration of the transmitting and receiving systems is a standard procedure, but propagation loss is much more difficult to determine if long ranges are involved. One way to avoid the propagation loss problem is to make measurements at short ranges, and this is what is done in the laboratory. This, of course, is impossible with large targets. Another method is to use a reference target for which the target strength is known. In this method neither the transmitting nor receiving systems have to be calibrated and the propagation loss does not have to be measured because all echo levels are compared to the reference level. One of the best reference targets is a thin-walled air-filled rubber sphere, although for large targets buoyancy becomes a problem. Another good reference target, which can be used for large targets, is a tri-plane, three mutually perpendicular planes, for which it can be shown that any incident ray will be reflected in a direction exactly opposite to the incident direction. Hence a tri-plane acts as a single plane perpendicular to the incident rays and reflects a large, calculable percentage of the incident energy. It is possible to measure propagation loss directly and this is fairly simple if a transmitting and a receiving ship are utilized. Propagation loss measurements can also be made by placing a calibrated transponder in the vicinity of the target.

Along with the problem of accurately measuring propagation loss, there are other problems associated with target strength measurements at sea, the most critical of these being relative motion between the sonar beam and the fish target. Roll or pitch of the ship can be overcome by using a stabilized sonar beam, but drift can cause the axis of the beam to move off target. Care must also be taken so that the target support structure does not interfere with the measurements. Other problems that can arise are poor weather, high ambient noise levels, and extraneous targets swimming into the beam.

Of course, there are problems associated with laboratory measurements also, the chief one being the limitation on the size of the target. The fish must be placed at a range great enough to insure that the incident sound energy is approximately equal over the complete fish and to insure that the fish is not in the near-field of the transmitter nor the receiver in the near-field of the fish. However, the range must not be so great that reflections from the boundaries or fish support interfere with the measurements. Nevertheless, by judicious choice of measurement range and by using short pulse lengths, unambiguous work can be done in a laboratory tank. In order to obtain a true value of target strength the pulse lengths of the discrete frequency pulses most often utilized by fisheries sonars must be at least twice the length of the target in the direction of propagation, so that an echo can be obtained from all parts of the target simultaneously.

A typical block diagram of the electronics required for target strength measurements is shown in Figure 1. The transmitting system consists of a signal source of known frequency, a means to generate pulses, amplifiers, a transmitting transducer, a system to match the electrical impedances of the amplifier and transducer, and a means to measure the outgoing signal. The receiving system consists of a receiving transducer, amplifiers, a means to gate out unwanted echoes, possibly a filter, and a means to measure the received signal. The electronic system is basically the same whether it is used in the laboratory or at sea.

If all fish were composed of the same homoge-

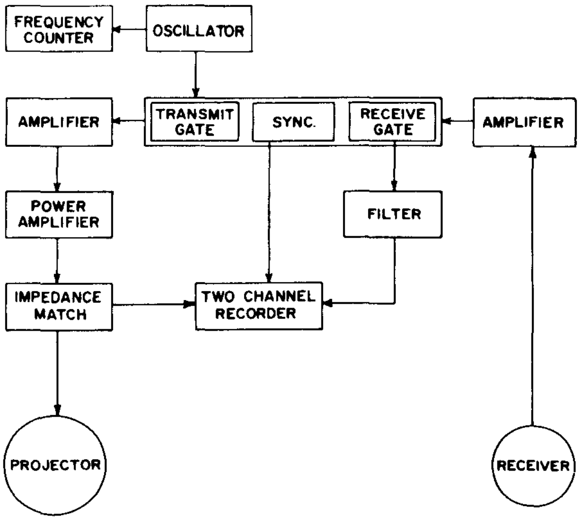

FIGURE 1.—Typical target strength measurement system electronics.

neous material and had the same shape, it would take a comprehensive measurement program to determine the target strength of a fish at all aspects and frequencies because of the complex shape of the body. Since fish are definitely not homogeneous and different species of fish have different shapes and internal structures, the problem of determining the target strengths for all species becomes immense. Considering the differences among individuals of the same species due to age, sex, condition of health, etc., it is obvious that an experimental program to predict completely the target strength of any given fish is impossible. Since the complete determination of the target strength of all fish is impossible, the most that can be hoped for is that experimental techniques will eventually lead to empirical results which can be generalized to apply to any species of importance.

RESULTS OF MEASUREMENTS OF INDIVIDUAL FISH

Most of the early experiments conducted during the 1950's investigated a specific situation. For example, if a researcher had an echo sounder which operated at a given frequency, he would measure the dorsal-aspect target strengths of a number of fish of the commercial species found in his geographic area, in order to obtain an average dorsal-aspect target strength vs. fish size for those species. This information was valuable to anyone designing or using an echo sounder of the same frequency to find these species, but it was of minimal value to anyone else.

A second technique used is just an extension of the earlier technique. With it, different species of fish have been examined at many aspects and/or frequencies in attempts to determine how target strength varies with fish size, species, aspect, and frequency. Figure 2 shows some typical results of this technique. The results are from a live 21-cm black crappie which was rotated about its dorsiventral axis and insonified with frequencies of 30 kHz and 130 kHz. It is seen that the maximum target strength occurs very near the side aspect, where the insonified area is a maximum. At 130 kHz the number of lobes in the pattern is substantially greater, and

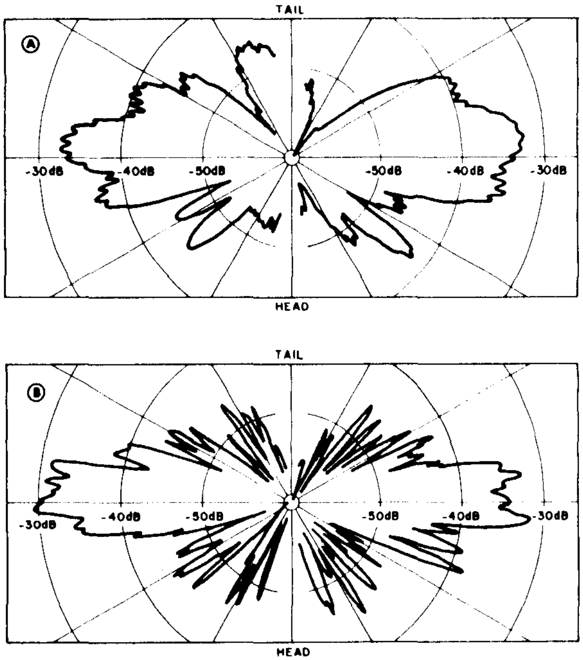

FIGURE 2.—Target strength of a 21-cm black crappie versus aspect. (a) 30 kHz. (b) 130 kHz. (From Love, 1969.)

the maximum target strength slightly greater than at 30 kHz. Although these measurements have produced some useful results on the general changes of target strength with fish size and frequency for aspects of special interest, little has been learned about the fine-scale changes or about the differences among species.

The use of a third technique permits investigation into the nature of the echo-formation process either by dissection or modeling. By dissection, researchers have discovered which parts of a fish are the major acoustic reflectors. By removing the swim bladders from a number of perch, Jones and Pearce (1958) determined that the gas-filled swim bladder accounts for approximately 50% of the dorsal and side-aspect target strengths of perch at $L/\lambda = 4$. Hence, the swim bladder is an important contributor to target strength for L/λ values in the interference region. By systematically removing various parts of a skipjack tuna, Volberg (1963) found that appreciable echoes could be obtained from either the skeleton or a piece of flesh. Diercks and Goldsberry (1970) have indicated the possibility that scales may also be an important contributor to the target strength of a fish at certain frequencies. Unfortunately, they did not remove any scales and their hypothesis is based on considerations of the directivity of the scales as an array of scatterers.

An adjunct to the determination of the parts of the fish which are acoustically important is the determination of the acoustic impedance or reflection coefficient of these parts. The reflection coefficient is defined as it was previously for two semi-infinite media. The impedance of the gas in the swim bladder is readily determined, and the reflection coefficient for the swim bladder is approximately —1. Determination of the acoustic impedance of fish bone or flesh is difficult and care must be taken to insure valid measurements. Shishkova (1958) measured the density of and speed of sound in flesh from a few species of fish and determined the reflection coefficient in fresh water to be about 0.05. Haslett (1962b) used a different technique to indirectly measure the reflection coefficients of flesh and bone from haddock and cod. He found the reflection coefficient of flesh in fresh water to be about 0.05, in seawater to be about 0.02, and the reflection coefficient of bone to be about 0.25.

Using these values for the reflection coefficients and his "standard fish dimensions," Haslett (1962c, 1964) has modeled fish bodies, backbones, and swim bladders. Utilizing rubber ellipsoids to model the fleshy body of the fish, he found that the number of lobes obtained in polar plots for the ellipsoids and for actual fish agreed fairly well, that is, with less than 50% error, but that the target strengths obtained for the models were considerably lower than those obtained for the fish. Using rubber and plastic cylinders to model the backbone and copper cylinders to model the swim bladder, Haslett has examined variations in the target strength of these models as frequency, size, and aspect are varied. A brief summary of Haslett's work for side aspect is shown in Figure 3. Along with his data for the acoustic cross-sections of sticklebacks and guppies, approximations to the acoustic cross-sections of the swim bladder, body, and backbone are given. The various curves for each component were determined by Haslett (1965) using his reflection coefficients and the results of his modeling experiments and depend

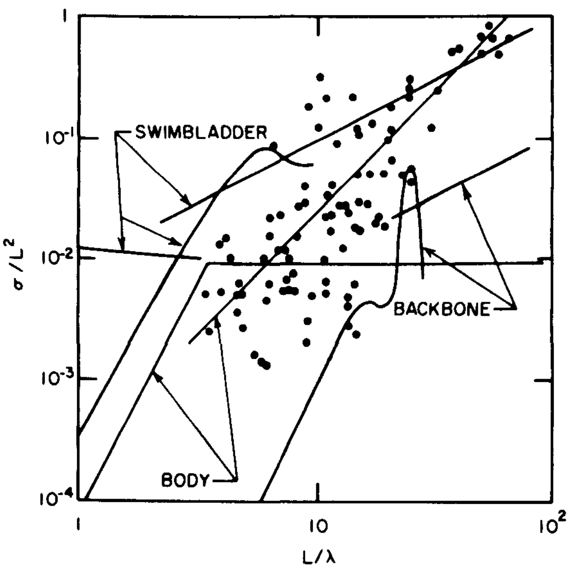

FIGURE 3.—Side-aspect acoustic cross-sections determined by Haslett.

on how the component is approximated and on the limits of that approximation. Hence the curves are a function of whether the swim bladder is approximated by a spherical bubble or a rigid cylinder; what the limits of the geometric and Rayleigh scattering regions are for the body and the backbone; and whether the body is approximated by an ellipsoid or a plane in the geometric region. These curves indicate that the swim bladder predominates over most of the given L/λ range, but that the body and backbone become significant at the higher L/λ's. It is apparent that Haslett's measurements of the acoustic cross-sections of sticklebacks and guppies vary widely and do not follow any of his curves. This variability is not fully explained by any of his experiments on fish or models. Obviously, the nature of the echo-formation process is quite complex if Haslett cannot explain this variability after such comprehensive work.

In attempting to quantify fish resources the objects of interest are usually fish schools rather than individual fish. When the target strength of a school is measured, the question to be answered is "What is the average size and number of fish required to produce this target strength?" The answer will depend on the average target strength of the fish in the school, and any variations among the individuals will be of minor importance. If a forward-looking sonar is used for quantification, the minimum size and number of fish required to produce a given target strength will occur at the aspect for which the target strength of an individual fish is a maximum. This aspect will be near the side aspect of the fish. Thus, average values for the maximum side-aspect target strength of an individual fish are important for quantification of fish schools with a forward-looking sonar. If a downward-looking sonar, or echo sounder, is used for quantification, average values for the dorsal-aspect target strength of an individual fish are important.

For these reasons the author has made maximum side-aspect (Love, 1969) and dorsal-aspect (Love, 1971) target strength measurements as a function of fish size, species, and frequency. The measurements were made in the laboratory, and hollow rubber spheres were used as reference targets for calibration. It was found that the magnitude of the variation in target strength for one species was of the same order as it was for all species. Therefore the data for all species were combined with all other available pertinent data and a regression line was calculated for each aspect using the method of least squares.

Figure 4 shows all the dorsal aspect data. The data were obtained using fish from 16 families in 8 different orders: Clupeiformes, Cypriniformes, Gasterosteiformes, Cyprinodontiformes, Mugiliformes, Gadiformes, Beryciformes, and Perciformes. The fish ranged in length from about 1 cm to 1 m. Some had swim bladders while others did not. Insonifying frequencies ranged from 8 kHz to 1480 kHz. Note that the parameters used here are σ/λ^2 and L/λ, which differ slightly from those used by Haslett. The equation for the regression line calculated from these data is

$$\sigma/\lambda^2 = 0.041 \ (L/\lambda)^{1.94}, \tag{9}$$

and the dorsal-aspect target strength is

$$T_D = 19.4 \log L + 0.6 \log \lambda - 24.9 \tag{10}$$

Equation (10) is for T_D at 1 m and L and λ in meters and is valid in the range $0.7 \leqslant L/\lambda \leqslant 90$.

Figure 5 shows all the maximum side-aspect data. The data were obtained using fish from 13 families in 7 different orders: Cypriniformes, Gasterosteiformes, Cyprinodontiformes, Gadiformes, Beryciformes, Perciformes, and Pleuronectiformes. Fish size and acoustic frequency ranges were approximately the same as those for dorsal aspect. The equation for the regression line calculated from these data is

$$\sigma/\lambda^2 = 0.064 \ (L/\lambda)^{2.28}, \tag{11}$$

and the maximum side-aspect target strength is

$$T_S = 22.8 \log L - 2.8 \log \lambda - 22.9 \tag{12}$$

Equation (12) is valid in the range $1 \leqslant L/\lambda \leqslant 130$, and again T_S is at 1 m and L and λ are in meters.

Figure 6 is a nomogram solving equations (10) and (12), given the acoustic frequency, f, in kHz, and the fish length, L, in cm.

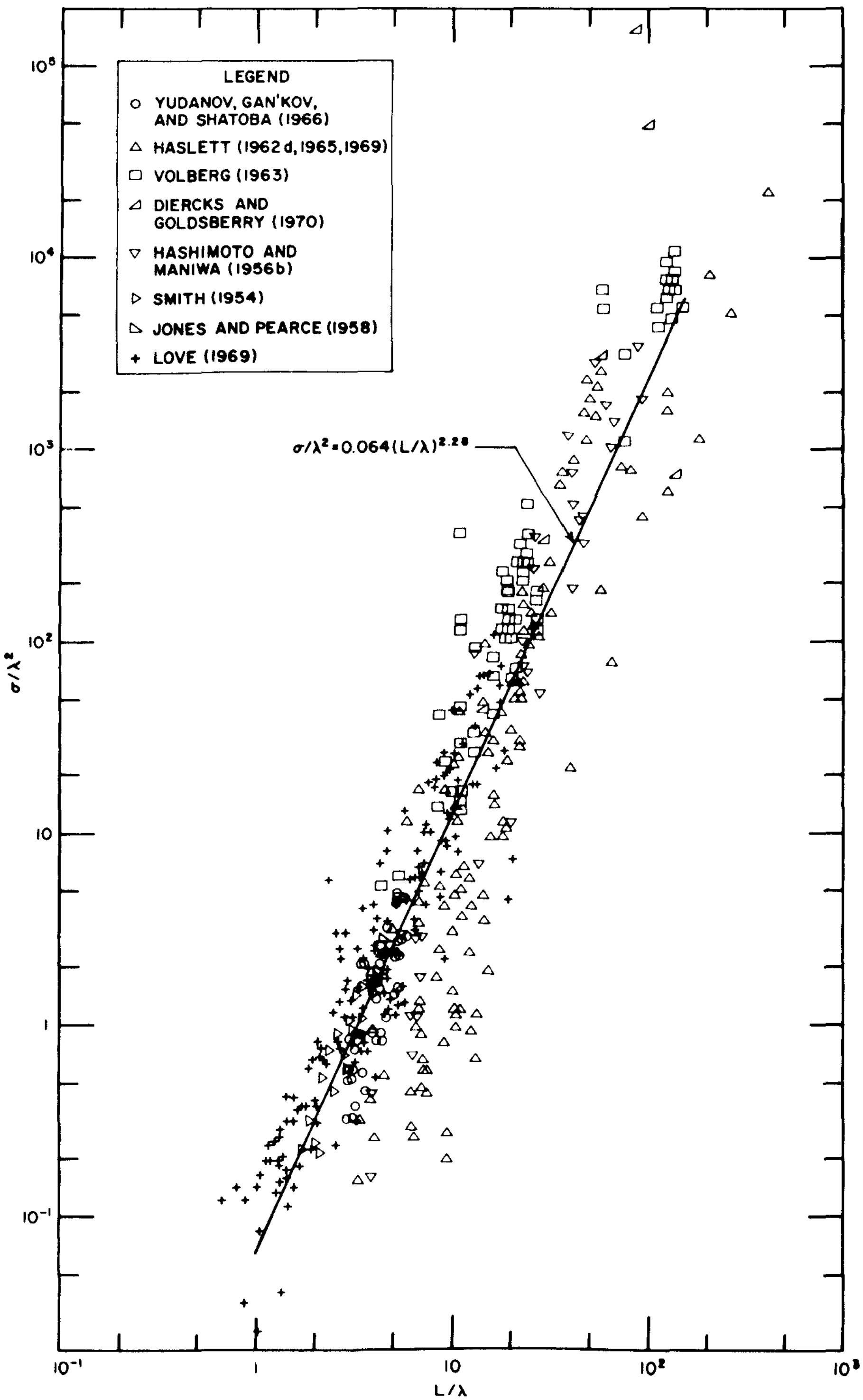

FIGURE 4.—Dorsal-aspect acoustic cross-section of an individual fish.

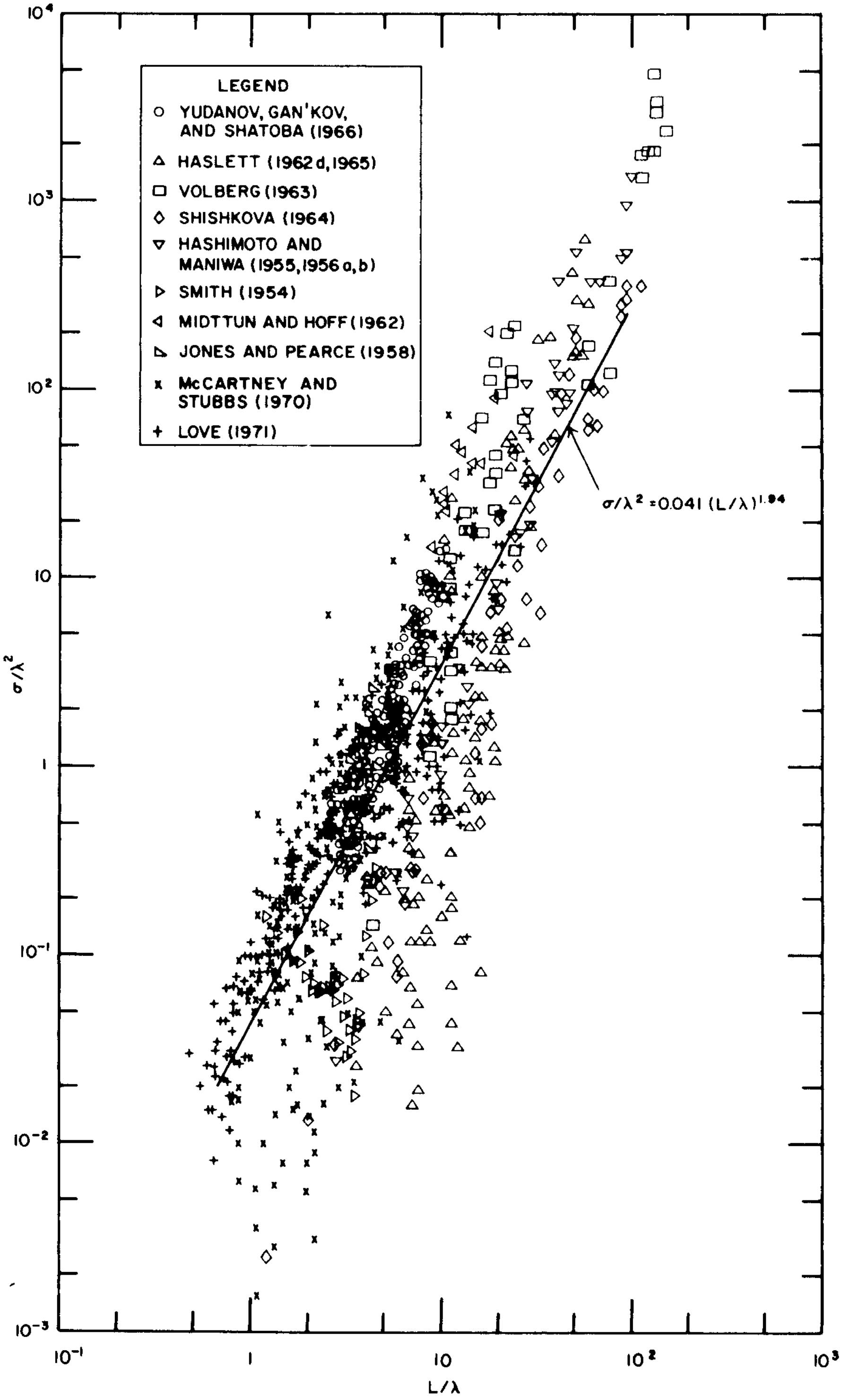

FIGURE 5.—Maximum side-aspect acoustic cross-section of an individual fish.

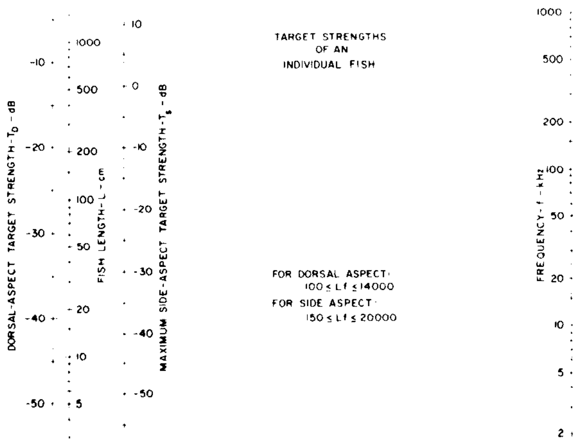

FIGURE 6.—Nomogram for calculating the dorsal-aspect and maximum side-aspect target strengths of an individual fish.

QUANTIFICATION AND IDENTIFICATION OF SCHOOLS

Since estimates for the maximum side-aspect and dorsal-aspect target strengths of individual fish are available, the determination of the target strengths of fish schools at these aspects will depend on the determination of the effects of the number of fish in the school and their distribution. If the fish are widely spaced, or in a plane perpendicular to the sonar beam, so that there is no acoustic interaction among the individuals, the target strength of the school is equal to the average target strength of an individual plus 10 times the logarithm of the number of fish. The probability of finding a school that meets these qualifications is quite small and therefore the effects of interactions among the fish must be taken into account.

Little experimental work on the acoustic interactions of fish in a school has been done, although some measurements of the target strengths of groups of fish have been made, usually with little concern for the distribution of the individuals (e.g., Thorpe and Ogata, 1967; Shishkova, 1960). Some theoretical work on distributions of scatterers has been done, the scatterers usually being point scatterers or small bubbles (e.g., Foldy, 1945; Weston, 1966). Weston (1967) has applied the results for bubbles to fish schools and has estimated reflection coefficients for regions well-below and well-above resonance. Since there is no interference region for a bubble, he does not concern himself with interference effects, and his results are of limited value in the interference region. Boyles (1969) has discussed the mathematical theory of multiple scattering from fish schools, but to obtain results in the interference region the complete spatial scattering and absorption pattern of an individual fish must be known.

The identification of a school of fish utilizing target strength information is obviously much more difficult than its quantification, and since it is not yet possible to quantify fish schools with this information, it is surely not yet possible to identify them.

Figure 3, which summarized Haslett's work, seems to indicate that no reasonable pattern of target strength vs. frequency can be found for any species due to the rapid fluctuations of target strength. Haslett's measurements were made at three widely spaced frequencies. Measurements made by the author at a larger number of more closely spaced frequencies indicate that for individual fish these fluctuations are not so rapid and that possibly individual fish may be identified through the use of target strength vs. frequency (σ/L^2 vs. L/λ) curves. Dorsal aspect target strength measurements made on six bay anchovies, *Anchoa mitchilli*, one Atlantic menhaden, *Brevoortia tyrannus*, five goldfish, *Carassius auratus*, and six Atlantic silversides, *Menidia menidia*, revealed that all of these fish had similar σ/L^2 vs. L/λ curves (Love, 1971). The most notable feature of these curves is a deep minimum in the neighborhood of $L/\lambda = 10$. This minimum is easily seen in the average curves for each species shown in Figure 7. Similar measurements on three mummichogs, *Fundulus heteroclitus*, five striped killifish, *Fundulus majalis*, six black crappies, *Pomoxis nigromaculatus*, and four spotted seatrout, *Cynscion nebulosus*, revealed that the σ/L^2 vs. L/λ curve for any individual of these species bears no easily discernible relation to that of most, or all, of the other individuals of that species, or to the average curve for that species.

The anchovies, goldfish, and menhaden are malacopterygians, the more primitive teleosts; the crappies and seatrout are acanthopterygians, the more advanced teleosts; and the mummichogs, killifish, and silversides belong to intermediate orders which have characteristics of both groups (Berg, 1947; Bertin and Arambourg, 1958). In general, the malacopterygians have physostomous swim bladders, osseous bone tissue, intermuscular bones, comparatively many vertebrae, fins without spines, and cycloid scales. In general, the acanthopterygians have physoclistous swim bladders, osteoid bone tissue, no intermuscular bones, comparatively few vertebrae, fins with spines, and ctenoid scales. Considering that the swim bladder, bones, and possibly scales of a fish contribute to its acoustic cross-section, it is obvious that the malacopterygians and the acanthopterygians have significant structural differences in components which have been shown to be acoustically important. Why the malacopterygians and one intermediate species display the characteristic minimum in

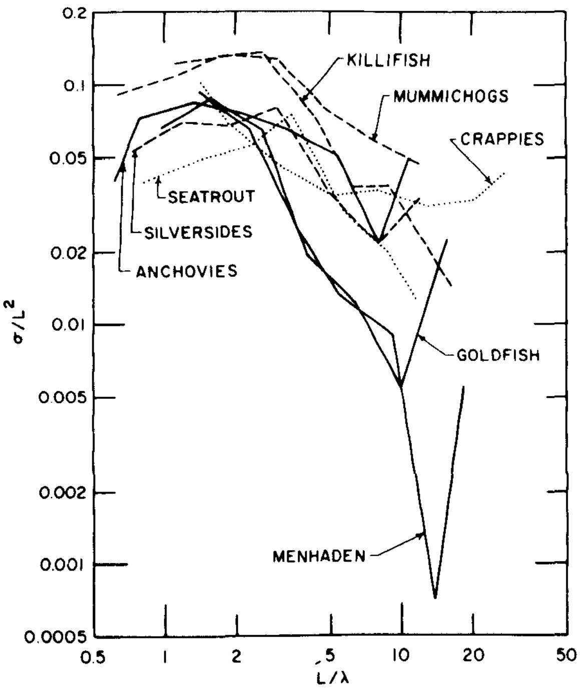

FIGURE 7.—Average measured dorsal-aspect acoustic cross-sections for different species of fish. (From Love, 1971.)

σ/L^2 near $L/\lambda = 10$, or why the acanthopterygians and the other two intermediate species have no distinctive σ/L^2 vs. L/λ curve cannot be answered, given the present limited knowledge of echo-formation by fish.

Although these differences cannot be presently explained it seems probable that if there were a geographic area in which two species with about the same size and habits predominated, and if one species were a Clupeiform and the other a Perciform, a ship with a wide-band sonar could differentiate between individuals of each species by examining their target strength vs. frequency curves. This hypothetical example indicates how very limited the present capability to identify fish by determining target strength is. Hopefully, more measurements at many frequencies, with dissection and removal of various components of the fish, and more sophisticated modeling techniques will explain the features of the target strength vs. frequency curves for individuals of a few species. This could then lead to the prediction of curves for other species, which in turn could greatly increase the ability to differentiate between individuals of different species. This information could then be applied to the differentiation of schools of different species, although it is to be expected that the manner of distribution of the fish in the school will cause significant differences between the target strength vs. frequency curve obtained for the school and the average curve for the individuals in the school.

SUMMARY

Some of the more important results of measurements of fish target strength to date are: (1) it has been determined that practically every case of interest to the fishing industry is in the region of interference effects, (2) the major contributors to the target strength of a fish in this region have been determined and their acoustic impedances measured, (3) the variations of target strength with aspect for an individual fish have been examined, (4) estimates of the dorsal-aspect and maximum side-aspect target strength of an individual fish have been made, (5) there

are indications that the identification of individual fish based on target strength vs. frequency curves is possible for limited cases.

The two goals of fish target strength measurements, namely quantification and identification of fish schools, have not yet been attained. The quantification of fish schools and the identification of many individual fish should be hopefully accomplished in the next few years. The identification of schools will require the information on quantification of schools and identification of individuals, and therefore will probably not be accomplished for some time.

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