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Hydroacoustic Biomass Estimation Techniques

Paul Kanciruk

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 2019

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ABSTRACT

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The use of hydroacoustic (sonar) biomass estimation techniques as they might apply to power plant aquatic environmental monitoring programs is discussed. Background information on the physics of sound in water and basic hydroacoustic equipment is presented. The hydroacoustic literature is reviewed with examples provided of successful technique application toward a variety of monitoring and assessment goals. The results of a hydroacoustic user survey are presented in an appendix, along with an extensive, computer-indexed hydroacoustic bibliography.

Hydroacoustic biomass estimation techniques are quantitative, cost-effective stock asessment tools, providing information not obtainable with more traditional survey methods. Hydroacoustic techniques are particularly adaptable to monitoring programs at power plant sites and should be strongly considered in designing operational monitoring systems.

Keywords: Acoustics, hydroacoustics, sonar, biological surveys, echo counting, echo integration, sonograms, echograms, acoustic assessment, fishery surveys, downscan sonar, sidescan sonar, echo sounders, biomass estimation, fish abundance, stock assessment, biological monitoring techniques.

SUMMARY

This report introduces the fisheries biologist to the use of hydroacoustic biomass estimation techniques as possible assessment tools for power-plant aquatic monitoring programs. Although it provides information on basic hydroacoustics and hydroacoustic equipment, it is not meant to be a text on either subject. Rather the intent is to introduce sufficient background material so that the field biologist with little experience with such systems can appreciate their operation, application, advantages, and disadvantages as applied to power-plant aquatic monitoring programs. The potential user of hydroacoustic survey methods should delve deeper into the literature, communicate with present users, and attend, if possible, structured training (such as offered by the University of Washington's Applied Physics Laboratory, College of Fisheries) before attempting to apply these techniques in a quantitative assessment program.

This report is divided into the following seven sections:

1. Sound in Water (addressing basic hydroacoustic principles),
2. Hydroacoustic Systems (describing the components of a hydroacoustic survey system, selection of equipment, and operation),
3. Case Studies (use of hydroacoustics for general aquatic surveys in a variety of habitats),
4. Applicability to Power Plant Monitoring (reviewing use of hydroacoustics at power plant sites; general recommendations),
5. Glossary of Technical Terms,
6. User Survey Results, and
7. Indexed Bibliography.

It is designed to introduce hydroacoustic concepts and techniques to the non-user and provide sufficient reference sources for more detailed study.

Sound waves are defined as spreading disturbances in a compressible medium that move in all directions from a source. In water, sound waves travel at approximately 1500 m/s. When sound waves encounter a change in density (fish, bottom, or air bubbles) they are reflected in all directions, and some energy is reflected back toward the source. The time it takes for the original sound pulse to return as an echo allows the distance from sound source to target to be estimated. The intensity of the returning echo is proportional to the target size, target acoustic properties, target orientation, and position within the acoustic beam. It is these properties of sound that allow its use as a biomass estimation technique.

Hydroacoustic systems consist of the following:

1. transmitters that create the electronic pulse;
2. transducers mounted in the water, which converts the electronic pulses to sound and the returning echoes back into electronic signals;
3. receivers that time, amplify, and filter the returning echoes;
4. display devices such as paper chart recorders and oscilloscopes; and
5. echo counters and integrators, which quantify the returning echoes.

Echo counters can be used when the density of fish is relatively low. They yield biomass estimates in number of fish per 10,000 m^3. When fish densities are great, echo integrators must be used because of overlapping echoes. Echo integrators yield biomass estimates in kilograms of fish per 10,000 m^3.

Processing of hydroacoustic data can occur in real time onboard ship, or the signals can be recorded on tape and analyzed on the shore. Hydroacoustic systems can be relatively simple, or complex, depending primarily on the operating environment and survey objectives.

Although the technique of using hydroacoustic methods to scientifically quantify biomass is relatively recent, the literature reflects its successful application in a variety of environments from open-ocean surveys to monitoring power plant intake embayments, with targets of interest varying from 500-kg fish to 2-mm zooplankton. This literature (reviewed in Sects. 3.1, 3.2, and 4.1), as well as the user survey conducted for this report (Appendix B), describe a useful, flexible aquatic survey technique that can be profitably applied to power plant monitoring programs.

The greatest asset of hydroacoustics is its speed and accuracy as a biomass estimation technique; its greatest shortcomings are lack of species identification, and perhaps ignorance of the technique by the general scientific community.

As McKenzie et al. (1979) conclude (and this report and the response to the user survey concur):

> Under conditions favorable for acoustic surveys, no other estimation procedure can provide the quality of information, accuracy of estimation and speed of data acquisition on the demographics of fish.

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The use of hydroacoustics by biologists to estimate the location and biomass of fish requires a fundamental, although not extensive, knowledge of the characteristics of sound in water. The biologist who ventures to use this technique without a minimum understanding invites confusion as to the design, functioning, and interpretation of experimental hydroacoustic surveys. The use of hydroacoustic techniques, although reliable and useful when properly applied, is not at the black box stage where the fishery biologist can afford to be ignorant of basic underlying physical and engineering parameters.

This introduction presents a greatly simplified discussion of the physics of sound in water basic to a preliminary understanding of hydroacoustic techniques. For a more treatment, see any of the standard texts (e.g., Stephens 1970; Urick 1975; Clay and Medurin 1977).

1.1 Sound Waves

Sound waves can be defined as spreading disturbances in a compressible (elastic) medium (Fig. 1). Most common substances are compressible to some degree, and sound waves can travel through air, water, or solid material such as rock. The velocity of sound (c) through a given substance depends largely upon the density of the medium: the denser the medium, the higher the velocity. In air, the value of c is approximately 330 m/s; in seawater, about 1500 m/s. The velocity of sound in water is a function of temperature, salinity, and depth. A reasonable approximation of c (ignoring the influence of depth), is Kuwahare's equation as cited by Burczynski (1979):

$$c = 1445 + 4.66T - 0.055T^2 + 1.3(S-35)$$

where

c = velocity of sound (m/s),
T = temperature of water (°C),
S = salinity of water (ppt).

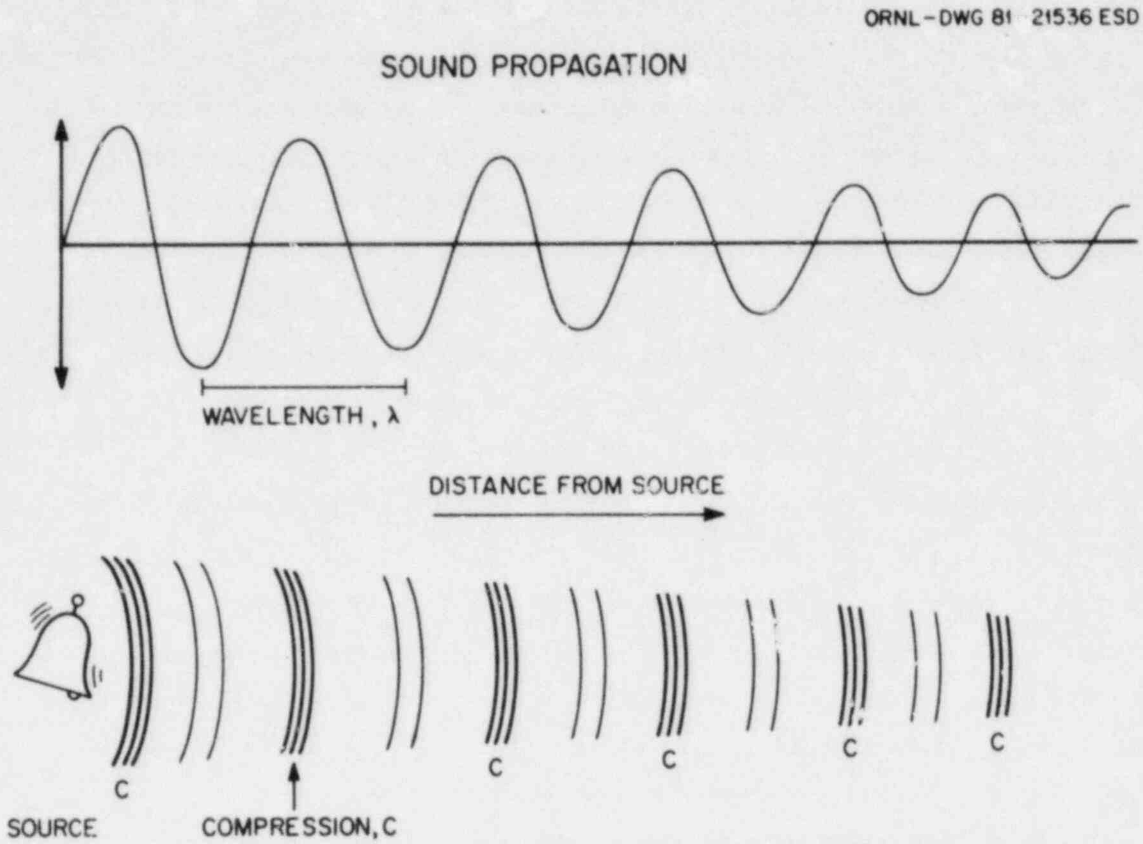

Fig. 1. Sound propagation. Sound can be pictured as a wave of relative energy of fixed wavelength, and decreasing amplitude moving through an elastic medium. Wave peaks represent areas of compression C, and troughs, areas of rarification.

Temperature has the greatest modifying effect on sound velocity within a given medium. The speed of sound in water at 35 ppt salinity, and 10°C is 1486 m/s; at 30°C, 1535 m/s. This influence of environmental factors on the speed of sound results in the bending of sound wave fronts if they travel through a heterogeneous medium. For example, in saltwater if the temperature/salinity structure of the water column is such that velocity of sound decreases with depth, then the lower portion of a horizontally traveling wave front will have its velocity reduced. The wave front will bend downward. If the reverse is true, the wave front will bend upward. This phenomenon confounds the interpretation of hydroacoustic signals projected horizontally (fixed transducer or side-scan sonar systems), particularly in marine environments.

The propagation of sound in fluid is caused by molecules moving back and forth, parallel to the direction of propagation and interacting with adjacent molecules. The distance between successive pressure maxima (or minima) is termed the wavelength, λ (Fig. 1). The relationship between wavelength and velocity is given by:

$$\lambda = c/f \quad ,$$

where

λ = wavelength,

c = velocity of sound in the medium (m/s),

f = the frequency of the sound [Hz (cycles/s)].

The frequency of a sound wave can be thought of as the number of pressure maxima that pass a fixed reference point in one second. The unit of frequency is the Hertz, which has the value of one-cycle-per-second. Given a fixed frequency of sound produced by a stationary source in a homogeneous medium, the wavelength of the sound is fixed. High-frequency sounds have short wavelengths, and low-frequency sounds have long wavelengths.

The intensity of a sound wave is the energy content of the sound, which is the sum of the kinetic energy of the moving water particles and the potential energy of pressure differences. The intensity of sound (I) per unit time per unit area (perpendicular to the sound path) is given by:

$$I = p^2/vc \quad ,$$

where:

- I = intensity of sound (ergs/cm^2/s),
- p = instantaneous acoustic pressure (dynes/cm^2),
- v = density of medium (g/cm^3),
- c = velocity of sound in the medium (m/s).

When pressure is measured in dynes/cm^2, density of water in g/cm^3, and velocity sound in cm/s, then the units of I are ergs/cm^2/s. This can be related to the watt (unit of power) in the following manner:

$$\text{watts/cm}^2 = (\text{ergs/cm}^2\text{/s}) \times 10^{-7} \quad .$$

Many hydroacoustic systems are power-rated in watts (usually as power input to the transducer, typically 500 or 1000 watts input).

The unit of acoustic intensity usually used in hydroacoustic work is the decibel, the intensity of a plane wave in root-mean-square (rms) pressure per unit area. The decibel is a ratio of a given intensity to a reference intensity, or the ratio of two known intensities. The old decibel was defined against a reference pressure of 1 dyne cm^2; the new American National Standards Institute, International System of Units reference pressure is 1 μPa/cm^2 (equivalent to 0.64×10^{-22} W/cm^2; Urick 1975). The decibel is convenient for describing large differences in sound intensities as it is a log scale unit. The differences between two sound intensities, A and B, is equal to 10 $\log_{10}$ A/B (decibels). Note that an increase of 3 decibels, say from 65 to 68 dB, reflects a doubling in sound intensity.

The intensity of sound waves decreases with distance from the source due to (1) spherical spreading (diluting) of the sound waves as they radiate outward and (2) attenuation due to chemical interactions within the medium.

The decreases in the intensity of sound per unit area due to spherical spreading alone is the inverse square of the distance traveled, R (in meters). Expressed in decibels:

$$\text{Spreading loss} = 20 \log R \quad .$$

The decrease due to attenuation alone in decibels is

$$\text{Attenuation loss} = \alpha R \quad ,$$

where

α = a constant dependent on the temperature and salinity of the water and the wavelength of the sound wave (-dB/m).

The attenuation of acoustic signals is much higher for signals of short wavelengths traversing high-salinity mediums. These characteristics influence the selection and operation of hydroacoustic equipment, as they limit the use of high frequencies (e.g., greater than 200 kHz) in the marine environment due to severe attenuation losses that reduce range. In freshwater, higher frequencies (~500 kHz) can be employed without significant reduction in range.

The resultant sound intensity (I) at a distance (R), I_r, is therefore the initial intensity (I_i) reduced by the combined loss due to spreading and attenuation (ignoring scattering losses):

$$I_r = I_i - 20 \log R + \alpha R \quad ,$$

where

$20 \log R$ = loss due to spherical spreading of the sound,

αR = loss due to attenuation (α is negative).

1.2 Reflection of Sound

As long as sound waves propagate in a homogeneous medium, they radiate outward. When they encounter changes in the density of the medium, they are refracted (turned) and reflected (a portion of the energy directed back toward the source). When a sound wave encounters a change in density (i.e., the sea bottom or a fish), part of its energy passes into the target, part is absorbed by the target, and part is reflected, with some energy reflected back toward the source of the sound. In fact, an insonified target (a target within the sound beam) itself acts as a sound source, radiating energy outward depending upon its own physical properties. It is this property of sound that makes possible the detection of underwater targets at distance and forms the basis for hydroacoustic biomass estimation techniques as well as the usual anti-submarine and depth-measuring applications.

Hydroacoustic systems use transducers to produce sound waves and receive their reflections from targets (Fig. 2). The returning sound waves (echoes), reflected by some target (e.g., fish), provide information on the direction and the distance of the target. The direction of the target is given by the direction of the returning echoes (although in simple hydroacoustic systems this information is difficult or impossible to assess). The target distance is proportional to the time it takes for the sound waves to radiate from the transducer to the target and back to the transducer.

The distance from the transducer to the target, range (R), can be determined if the velocity of sound through the water (c), and the time for the sound to travel between the transducer, to the target, and back to the transducer (t), are known. The relationship is as follows:

$$\text{Round trip distance} = ct \quad ,$$

where

c = velocity of sound (m/s),

t = round-trip time (s).

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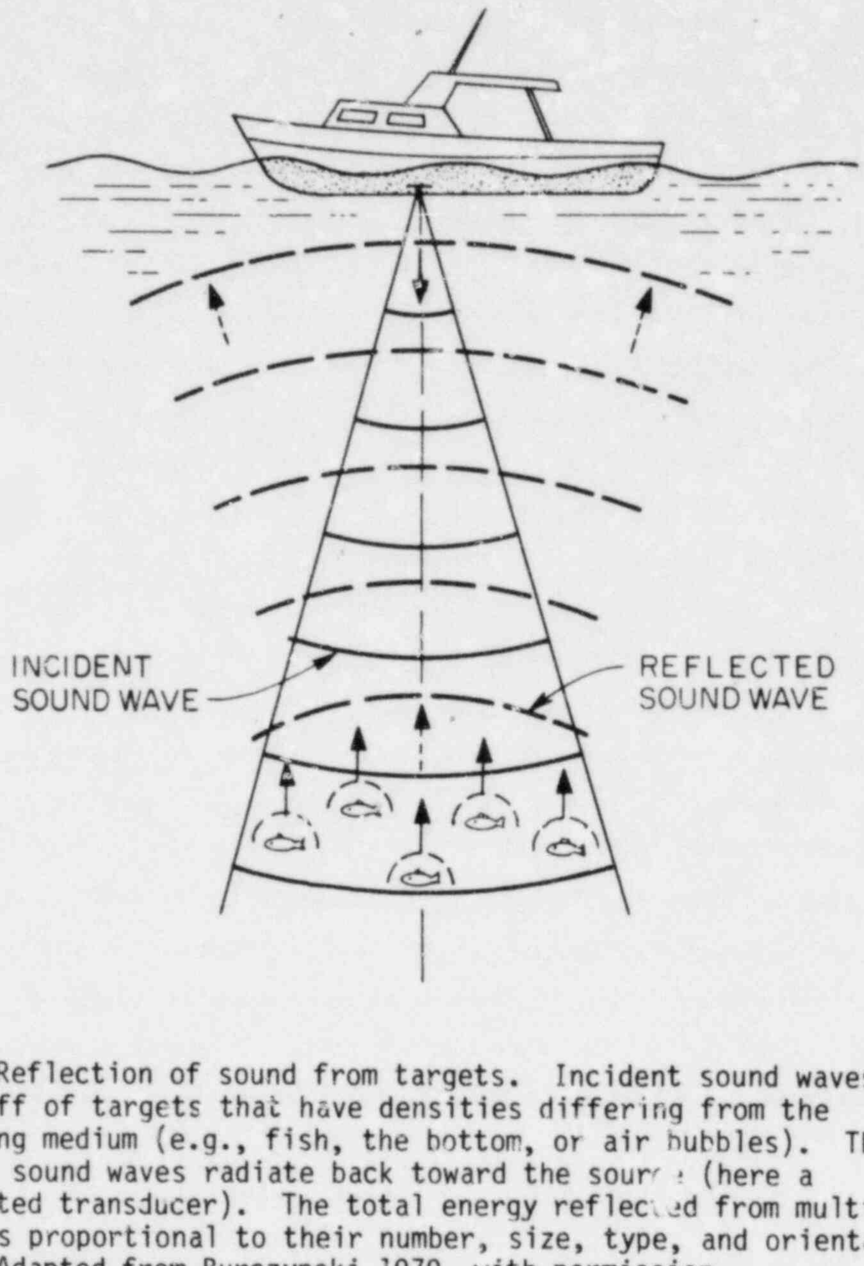

Fig. 2. Reflection of sound from targets. Incident sound waves will reflect off of targets that have densities differing from the surrounding medium (e.g., fish, the bottom, or air bubbles). The reflected sound waves radiate back toward the source (here a hull-mounted transducer). The total energy reflected from multiple targets is proportional to their number, size, type, and orientation. Source: Adapted from Burczynski 1979, with permission.

As the round-trip distance is twice the actual range of the target, this relationship can be reduced to

$$2T = ct \ ,$$
$$R = ct/2 \ .$$

Therefore, by knowing the velocity of sound in water (estimated from the physical characteristics of the water body), and electronically measuring time from transmission of sound pulse to reception of target echo, the range of the target, R, is easily calculated.

For example, if the velocity of sound in seawater is estimated as 1500 m/s, and a sound pulse takes 0.15 s to traverse the distance between the transducer to target and back to the transducer, the range of the target is calculated as

$$\begin{aligned} R &= ct/2 \\ &= (1500 \text{ m/s} \times 0.15 \text{ s})/2 \\ &= 112.5 \text{ m} \end{aligned}$$

The strength of a returning echo is a function of many factors, including

1. intensity of the transmitted sound,
2. distance of the target from the transducer,
3. absolute size, composition, and orientation of the target,
4. size of the target in relation to the sound wavelength,
5. acoustic reflective properties of the target,
6. attenuation characteristics of the water, and
7. position of the target in the transducer beam.

Every target has characteristic reflective properties, called directivity, which can be reduced to the ratio of the intensity of the reflected sound waves to the intensity of the incident sound waves (as a function of aspect):

$$ts = \frac{I_r}{I_i} ,$$

where

ts = target strength,

I_r = intensity of reflected sound waves, and

I_i = intensity of incident sound waves.

Sometimes these target reflective properties are put into perspective by comparing the target strength of the target to that of a perfectly reflecting target (e.g., a sphere of air in water). In these cases an "equivalent cross-section" (σ) can be obtained (i.e., the size of an air-filled sphere in water that would reflect as much energy as the target in question). The size of this ideal target is always smaller than real-world targets, which are less than perfect reflectors. Target strengths are independent of range and are usually reported as negative decibels (e.g., the acoustic reflection from an adult fish might average 40 dB less energy as compared to the initial energy of the acoustic signal. Its target strength would be reported as -40 dB).

The intensity of a returned echo also depends upon the size of the target in relation to the wavelength of the sound waves. The wavelengths used in many sonar systems are about the same size as fish targets (Burczynski 1979), and the heterogeneous body of a fish will generate a mixture of echoes (although some freshwater systems use very high frequencies having wavelengths smaller than average fish lengths). If a group of fish is the target of the transducer, the total energy reflected back will average out to be the approximate sum of the echoes from the individual fish (Fig. 2). The efficiency of a fish in returning echoes depends upon

1. whether the fish contains an air bladder,
2. the size of the fish,
3. the orientation of the fish to the transducer beam,
4. the position of the fish in the transducer beam.

One of the most important factors in the efficiency of a fish in reflecting incident sound energy is whether the fish has an air bladder. Species with air bladders are much better targets, due to the large difference in density between water and the gas in the bladder. The size of the fish is also important; bigger fish of a given species return stronger echoes.

The orientation of the fish in the transducer beam can also influence the strength of returning echoes, as the target properties of a fish vary greatly with aspect in relation to the transducer. Although one usually envisions a transducer pointing downward insonifying a horizontally swimming fish, this is not always the case. Fish can be oriented head- or tail-up, even when schooling, and the difference in the resultant echo strength can be 10-20 dB (up to a sixfold difference, Fig. 3).

The return from multiple targets within a transducer's beam can be treated as the sum of individual targets if their spacing is not too close. However, when fish schools are very dense, artifacts such as acoustic shadowing of fish at the bottom of the school or even the loss of the bottom trace on the chart recorder (due to shadowing by the dense layers of fish in the school) can occur and must be considered when interpreting echograms and estimating biomass (Fig. 4).

1.3 The Sonar Equation

Sound waves produced by a transducer radiate outward, encounter a target, and are reflected back to the transducer where they are received. The time taken for the round trip (given an estimate of the velocity of sound in water) provides the range of the target from the

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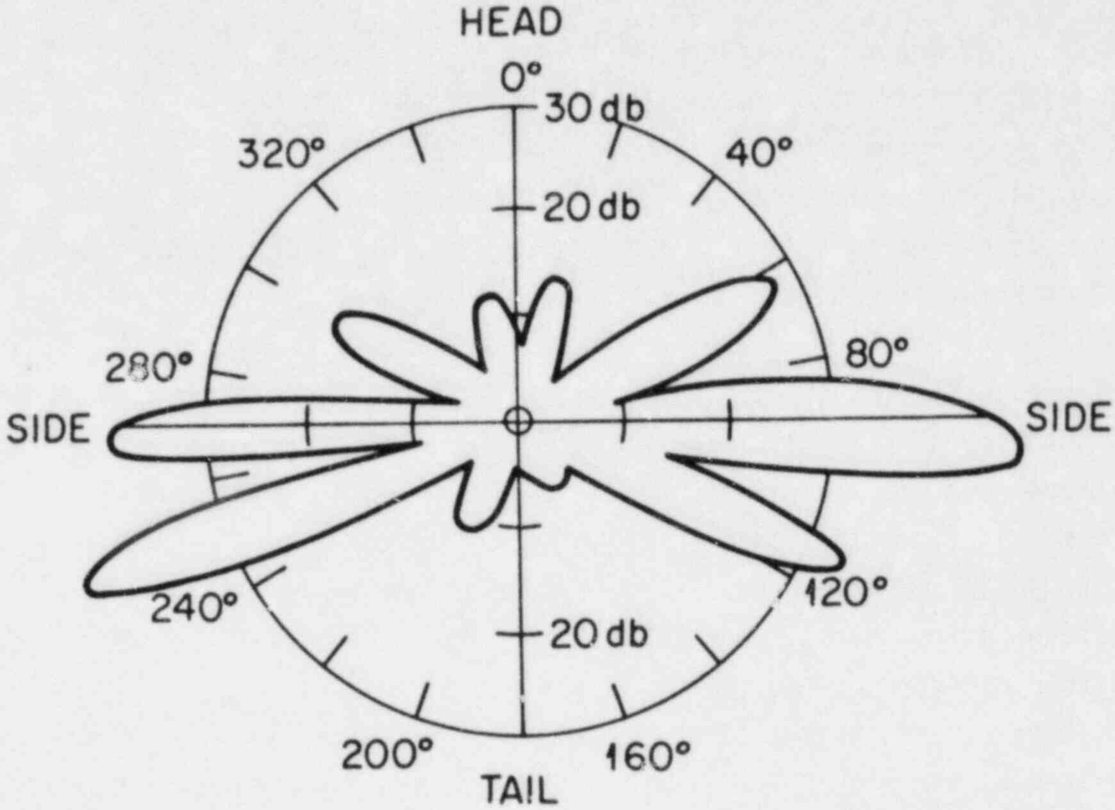

Fig. 3. Reflective properties of fish. The strength of a reflected sound wave from a fish depends on its orientation in the beam. Greatest reflection is in side-aspect, and least head- and tail-on. Source: Adapted from Stephens 1970, with permission of John Wiley & Sons, Ltd., London.

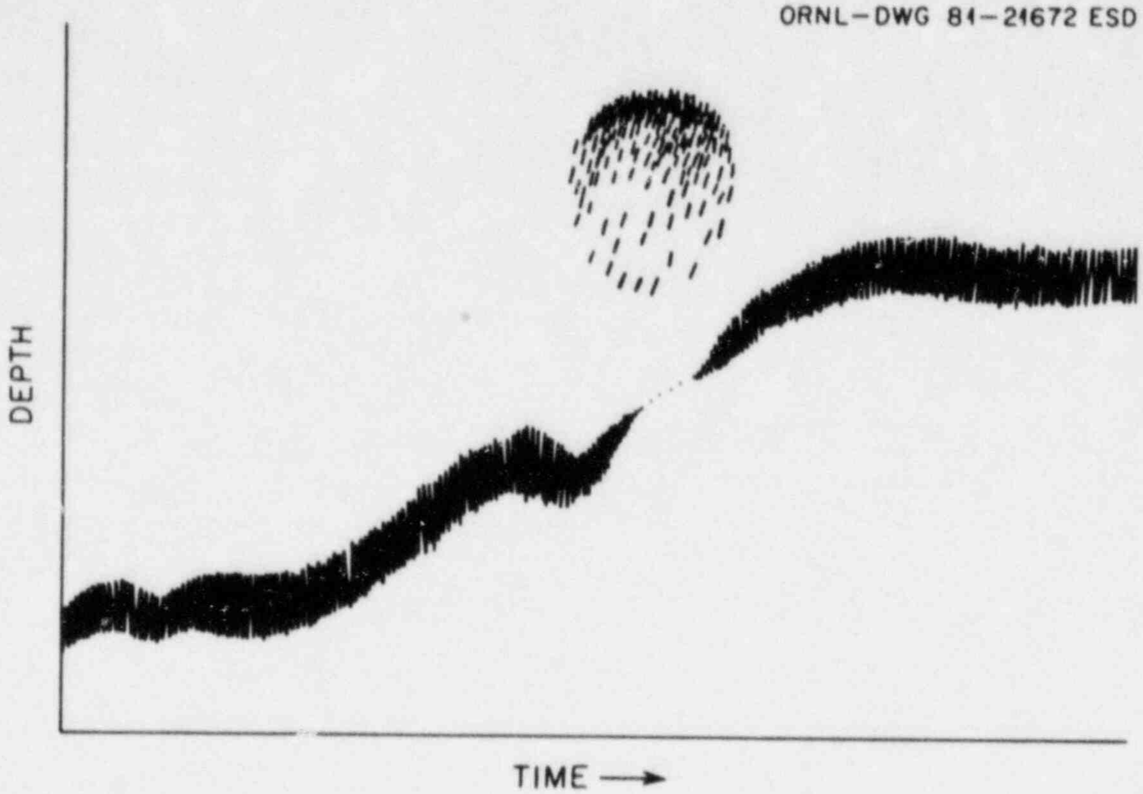

Fig. 4. Acoustic shadowing. Fish schools can be so dense as to prevent the passage of significant acoustic energy through them. This leads to loss of signal return from the lower portion of the school and the bottom trace itself, as shown in the above diagramatic representation of an echogram.

transducer. The strength of the returning echo, relative to the initial strength of the sound pulse (source level), provides information about the size of the target. Electronically timing the return of the echo is simple. Interpreting the true target strength (a measure of target size), using information provided by the returning echo, is complex.

The strength of the returning echo is affected by many factors. The returning echo strength can be expressed in terms of the sonar equation.

The returning echo level = original signal level minus:

- round-trip attenuation loss,
- round-trip spreading loss,
- loss due to nonperfect target reflection,
- loss due to position of target relative to the transducer's axis (the transducer has the most gain on-axis, see Sect. 2.1.2).

Expressed in decibel units:

$$EL = SL + TS - (40 \log R - 2\alpha R) + 20 \log b(\theta, \phi) + GX ,$$

where

EL = returning echo level,
SL = original signal level,
TS = target strength (-dB),
T = range of target (m),
40 log R = round-trip signal loss due to acoustic spreading (one-way loss = 20 log R),
2 αR = round-trip signal loss due to attenuation (α = coefficient of attenuation),

$20 \text{ Log } b(\theta, \phi)$ = two-way signal loss due to transducer directivity pattern with θ and ϕ defining target position in the beam (Sect. 2.1.2),

GX = system gain (includes transducer sensitivity, receiver gain -- both constant and time varied).

The acoustic source level (usually given in decibels 1 m from the transducer face) and system gain of hydroacoustic equipment for a given power input are determined by laboratory measurement. The range of the target is determined by timing the return echo and using the velocity of sound in water for our system. The attenuation coefficient, α, is a measurable parameter of water bodies and is negligible in freshwater systems up to about 1000 kHz transducer frequency. Therefore, the two-way spreading loss (40 log R), and two-way attenuation loss ($2\ \alpha R$) are easily calculated. The difficult parameters to estimate are the target strength of the fish (Fig. 3) and the effect of the transducer directivity pattern (not because the pattern, per se, is difficult to measure, but because it is difficult to estimate the position of the fish within the pattern). There are other parameters that must be quantified such as overall gain (signal amplification) of the system, but these can be measured in the laboratory and calibrated in the field (Sect. 2.3).

2. BASIC HYDROACOUSTIC SYSTEMS

2.1 Equipment

A complete hydroacoustic system for shipboard use in biomass estimation (Figs. 5 and 6) would consist of

1. a transmitter and receiver for creating and receiving the electronic signals, usually located in the same piece of equipment and then called a transceiver;
2. a transducer to create and receive the acoustic signals, either hull-mounted or towed from the vessel in a body;
3. display device(s), such as a paper chart recorder, oscilloscope, or cathode ray tube; and
4. some method of either recording the received signals for future analysis, such as reel-to-reel or cassette tape recorders, or a method for simultaneous analysis of the signal, such as a computerized fish counter, echo integrator, or onboard digital computer. Each of these components is discussed in the following sections.

2.1.1 Transmitters/Receivers

The transmitter/receiver (or transceiver) is the heart of every hydroacoustic system. The function of the transmitter is to create a well-defined, consistent electronic signal (Fig. 7), which is sent to the transducer and there converted to an acoustic signal. The transducer in turn converts the returning acoustic echoes back into electronic signals, to be processed by the receiver. A good, research-grade hydroacoustic transmitter must

1. generate a signal with a specific frequency (usually between 20 kHz and 500 kHz);
2. generate a signal with a specific pulse duration (usually in the millisecond range);
3. generate a signal with a specific pulse repetition rate (usually 1-10 pulses/s);

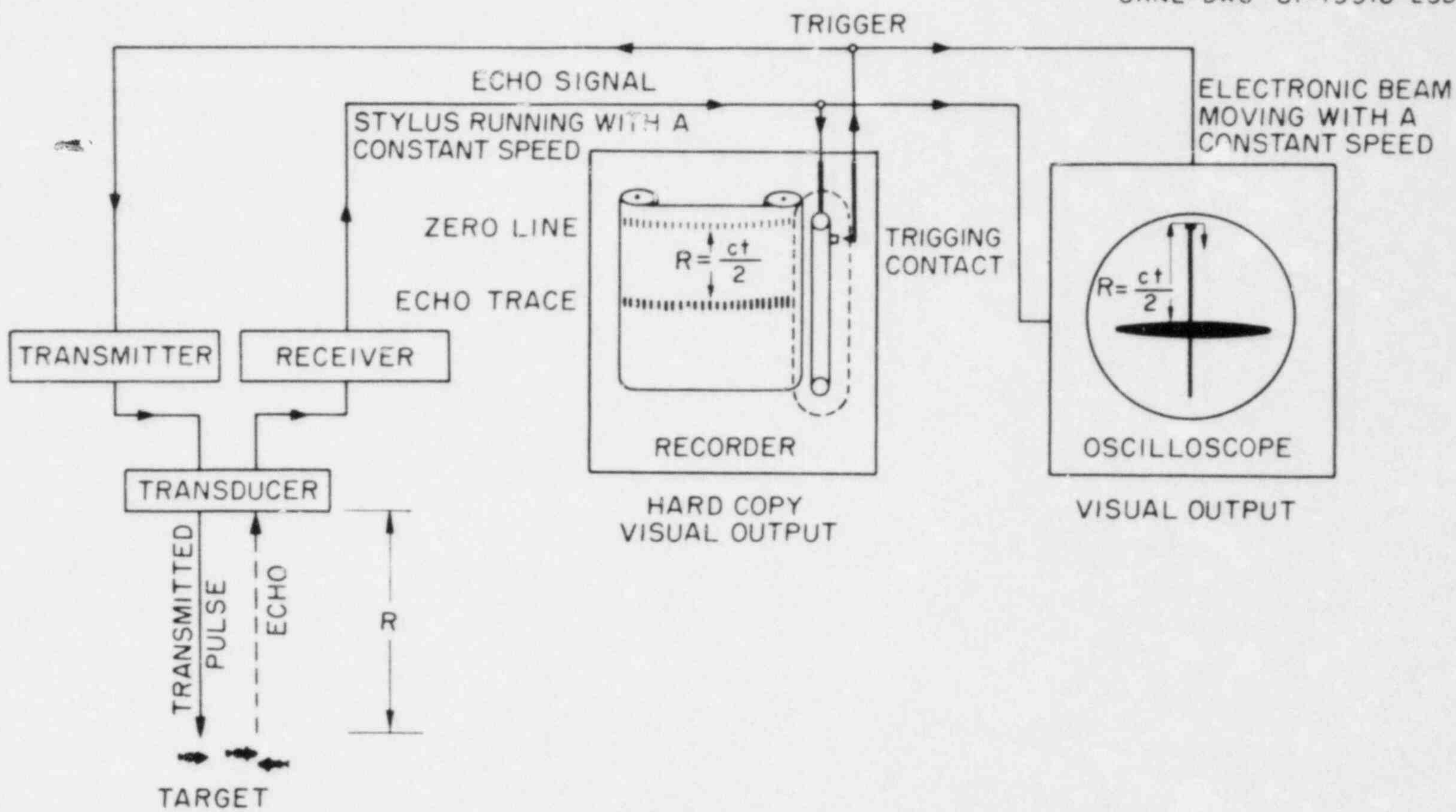

Fig. 5. Schematic of a typical hydroacoustic system. The transmitter generates the electronic signal, which is converted into the acoustic signal by the transducer mounted in the water (hull-mounted or towed). The transmitted acoustic pulse is reflected off a target (fish) and returns to the transducer. The transducer converts this acoustic energy to an electronic signal, which is amplified and filtered by the receiver. The electronic echo signal can be displayed as a trace on a paper chart recorder, where displacement of the trace downward from the baseline is proportional to the depth of the target, and also displayed visually on an oscilloscope. Source: Adapted from Burczynski 1979, with permission.

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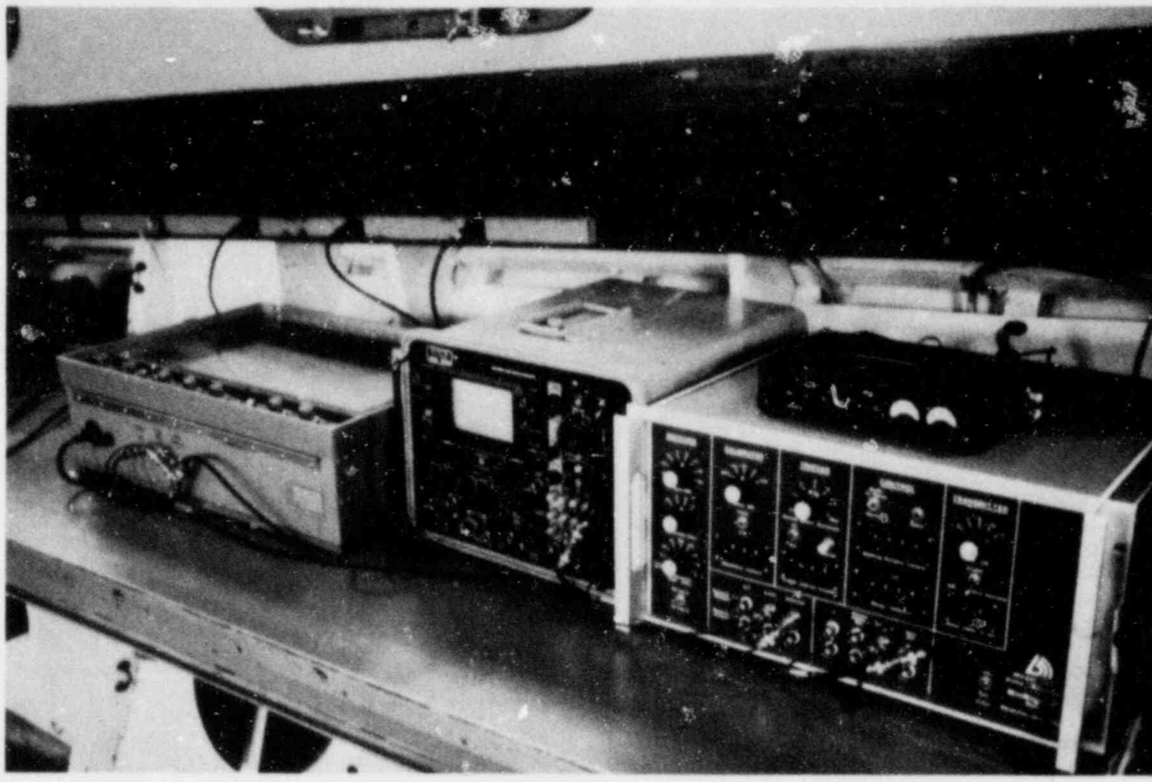

Fig. 6. Typical hydroacoustic installation. This hydroacoustic installation consists of a digital transceiver (far right), oscilloscope (middle), paper chart recorder (left), and portable cassette recorder (on top of transceiver). Photo by P. Kanciruk.

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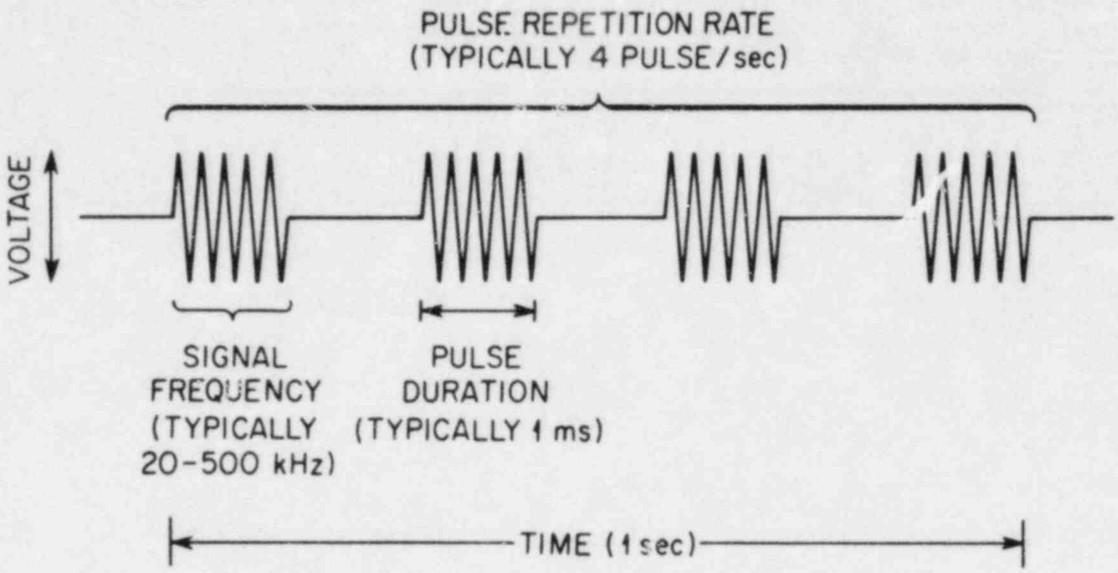

Fig. 7. Transmitter signal. Hydroacoustic transmitters are usually designed to vary the repetition rate, frequency, and duration of the generated signal (not to scale).

4. be stable in both its power output (typically 1 kW), and all signal characteristics (above);
5. be reliable, with easily replaced, modular components;
6. be flexible in operation modes, allowing the researcher to vary the pulse duration, repetition, and frequency; and
7. for certain situations be capable of portable, battery operation.

The receiver amplifies and processes the returning signal from the transducer and supplies the signal to the display, recording, and analyzing equipment. A good, research-grade hydroacoustic receiver should

1. consistently amplify returning echoes;
2. filter out unwanted electrical and/or acoustic noise;
3. have an accurate time-varied gain (TVG);
4. be as flexible as possible in operation;
5. be field-repairable, and modular, in construction; and
6. have multiple outputs to various displays, integrators, counters, tape recorders, etc.

The need to amplify the returning signal is obvious; the round-trip acoustic signal loss due to spreading alone (ignoring attenuation losses) is 40 log R, where R is the one-way range of the target. The returning signals from a target 100-m deep have traveled 200 m round-trip, and the signals have a strength relative to the original sound level of about -80 dB, much weaker than the original source signal level.

In addition to amplification, a good receiver should filter out noise from the signal. There are a number of sources of acoustic noise that affect the operation of sonar equipment, including

1. sound scattering within the water column,
2. on-board mechanical and electrical machinery, and
3. hydrodynamic noise -- along the hull and around the transducer.

Water is not a homogeneous medium. In addition to temperature and salinity variation between water masses, air bubbles, suspended organic and inorganic material, and plankton are often present causing a generalized scattering of sound.

Unprocessed echo signals, in addition to being generally weak (needing amplification) and somewhat noisy (needing filtering), have a serious flaw that severely hampers their use in biomass estimation, and indeed, for almost any use: unprocessed echoes from the equal-sized targets at different ranges from the transducer have different echo strengths.

Consider the situation of two identical fish at ranges R_1 and R_2 ($R_2 > R_1$) from the transducer (Fig. 8). The acoustic echoes returning from the deep target (R_2) have traveled a longer distance and have undergone more signal loss due to signal spreading and attenuation than those from the shallow target (R_1). If the receiver only filtered and amplified the incoming signal using a fixed gain (electronic amplification of the signal), the display device would show a stronger target at shallow depth (interpreted as larger), even though the targets were the same size. The operator would not be able to determine the relative sizes of these two targets.

To overcome this artifact, hydroacoustic receivers are equipped with Time Varied Gain (TVG). A TVG circuit applies gain selectively to incoming signals -- more gain to echoes taking longer to return to the transducer. A TVG applies this selective gain as a function of 20 log R or 40 log R for echo integration or echo counting processing, respectively. For equipment to be used in brackish or saltwater, the signal loss due to round-trip attenuation ($2\ \alpha R$) is taken into account by appropriate gain circuitry.

When using hydroacoustic equipment with an accurate TVG, the displayed echoes from two identical fish at different depths (in the same angle of the beam pattern) are identical (Fig. 9). The use of some type of TVG on even the most inexpensive fish finders is almost universal; however, a TVG that accurately and consistently compensates for signal spreading and attenuation losses is not as common, but is

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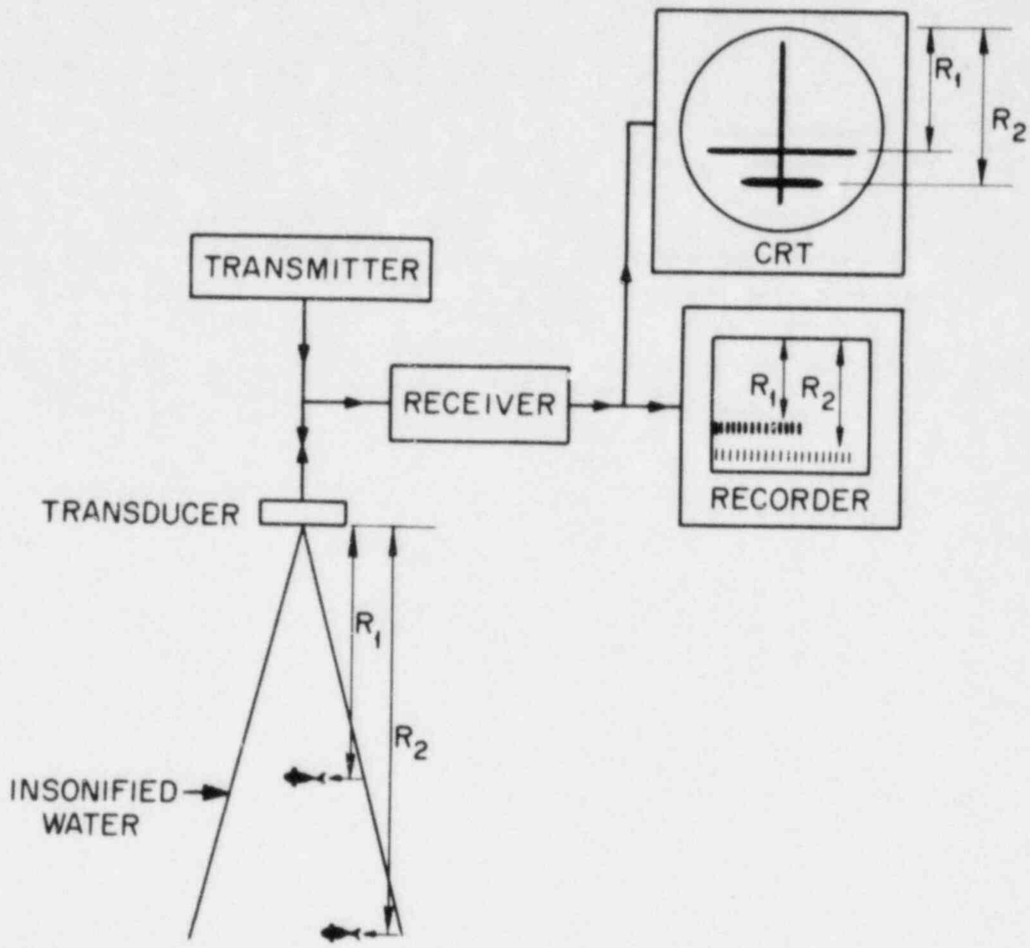

Fig. 8. Echo display without time-varied-gain (TVG). Without TVG the echo returned from the target at R_2 will be displayed as a smaller target even though both targets are actually the same size. This is due to the increased signal loss over the longer distance traveled by the second echo from the deeper target. Source: Adapted from Burczynski 1979, with permission.

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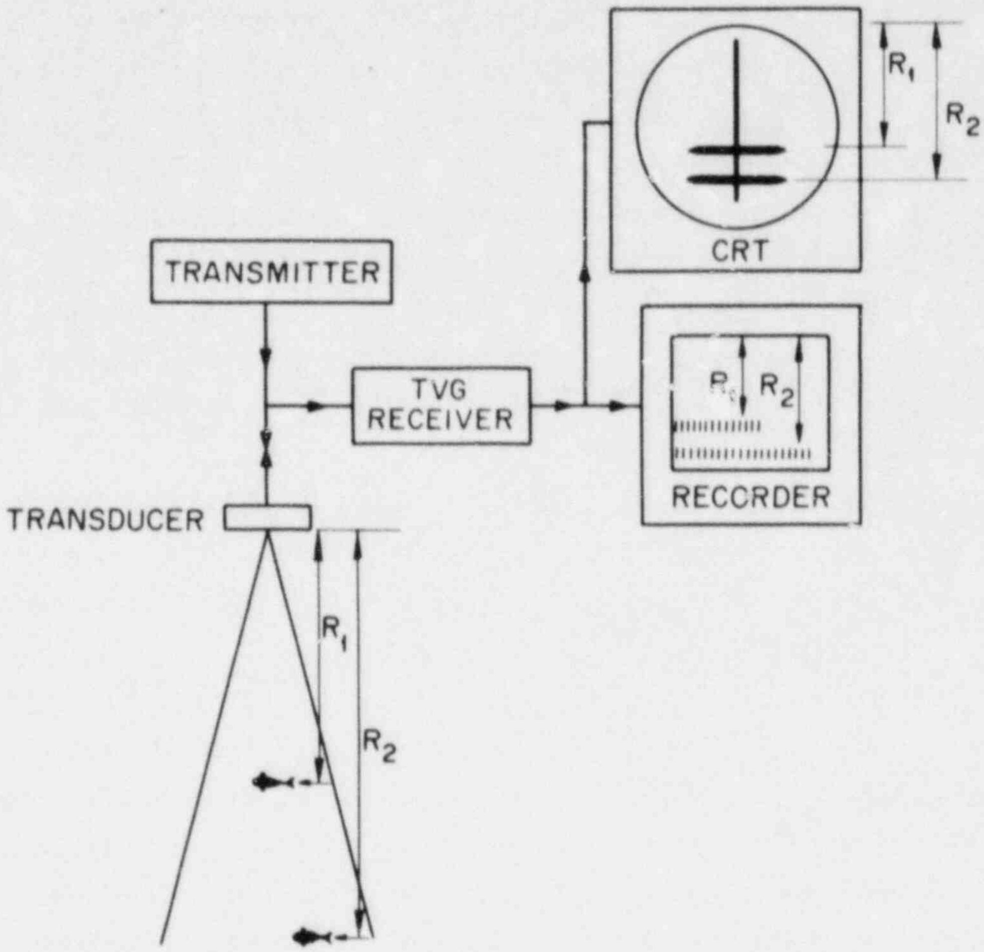

Fig. 9. Echo display with time-varied-gain. The receiver with TVG selectively applies additional amplification to those echoes that take the longest to return. With this modification, targets of equal size at varying ranges from the transducer will be displayed as equal targets on the oscilloscope or chart recorder. Source: Adapted from Bruczynski 1979, with permission.

absolutely essential to the researcher interested in obtaining accurate hydroacoustic biomass estimates. Modern research-grade receivers use digital electronics to assure accurate TVG function.

2.1.2 Transducers

The transducer is an electromechanical device that converts electronic signals from the transmitter into acoustic signals and converts the returning acoustic echoes into electronic signals to be processed by the receiver (Fig. 5).

Transducers can either be mounted to the hull of the survey vessel or towed from it in a hydrodynamic towing body or 'fish' (Figs. 10-12). Placing the transducer in a towing body has the advantage of providing mobility between survey vessels, ease of maintenance, and immunity to interference from air bubbles under the hull due to roll and pitch of the ship.

Transducer size varies greatly from 3-4 cm to 1 m in diameter. As a rule, due to the physics of transducer operation, the lower the frequency and the narrower the desired acoustic beam, the larger (and more expensive) the transducer.

Transducers are not omnidirectional devices. Signal directivity patterns vary greatly between transducers. A directivity pattern measures the on- and off-axis sensitivity of the transducer. Figure 13 is a two-dimensional representation of a typical directivity pattern for a wide-beam hydroacoustic transducer. Figure 14 depicts a narrow-beam transducer pattern. Transducer directivity patterns are measured in laboratory performance measurements and should be provided to the user at the time of purchase.

A transducer is most sensitive on-axis. Sensitivity rapidly decreases off-axis for narrow-beam transducers and more gradually for wide-beam transducers. Due to the inherent difficulty in designing and building transducers, anomalous side-lobes of increased sensitivity are often found off-axis (Figs. 13 and 14). They are undesirable as they confound interpretation of acoustic signals by increasing off-axis signals (noise). Transducers designed with narrow-beam patterns often

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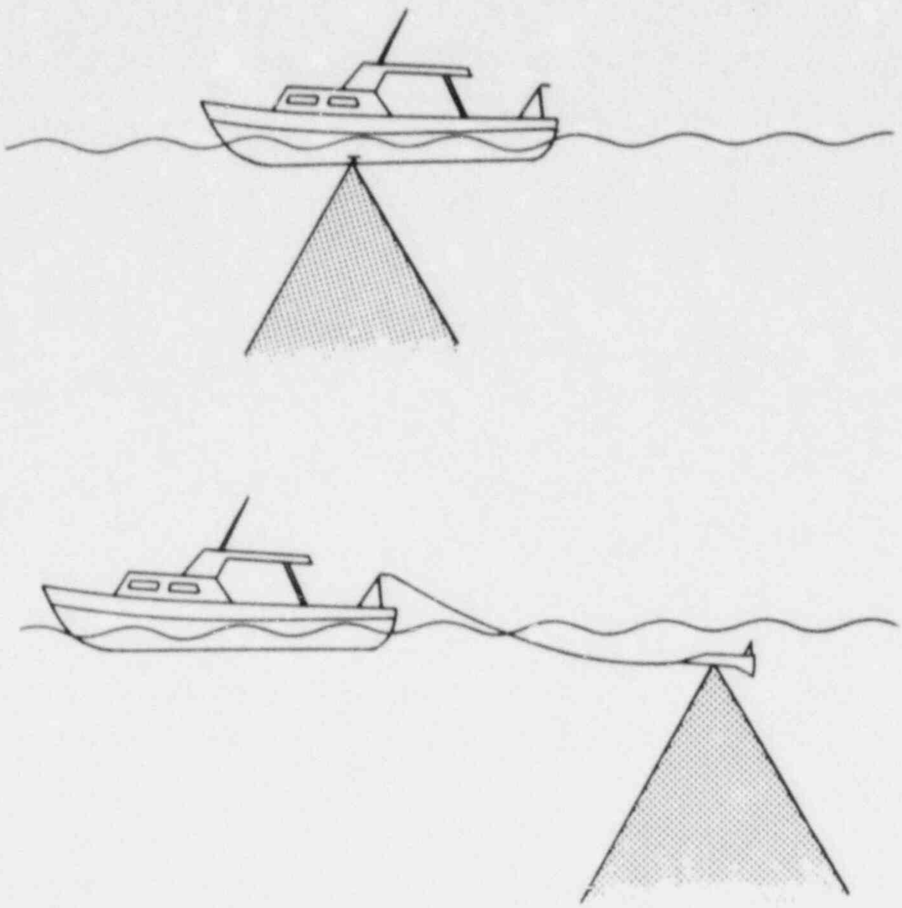

Fig. 10. Hull-mounted and towed transducers. Transducers can either be hull-mounted (upper) or towed behind the vessel (lower). Hull-mounted transducers are not easily transported between survey vessels, are difficult to service, and are subject to interference by bubbles under the vessel's hull as well as pitching and rolling. Large towed bodies are stable and usable even in rough seas and high speeds (over 10 knots).

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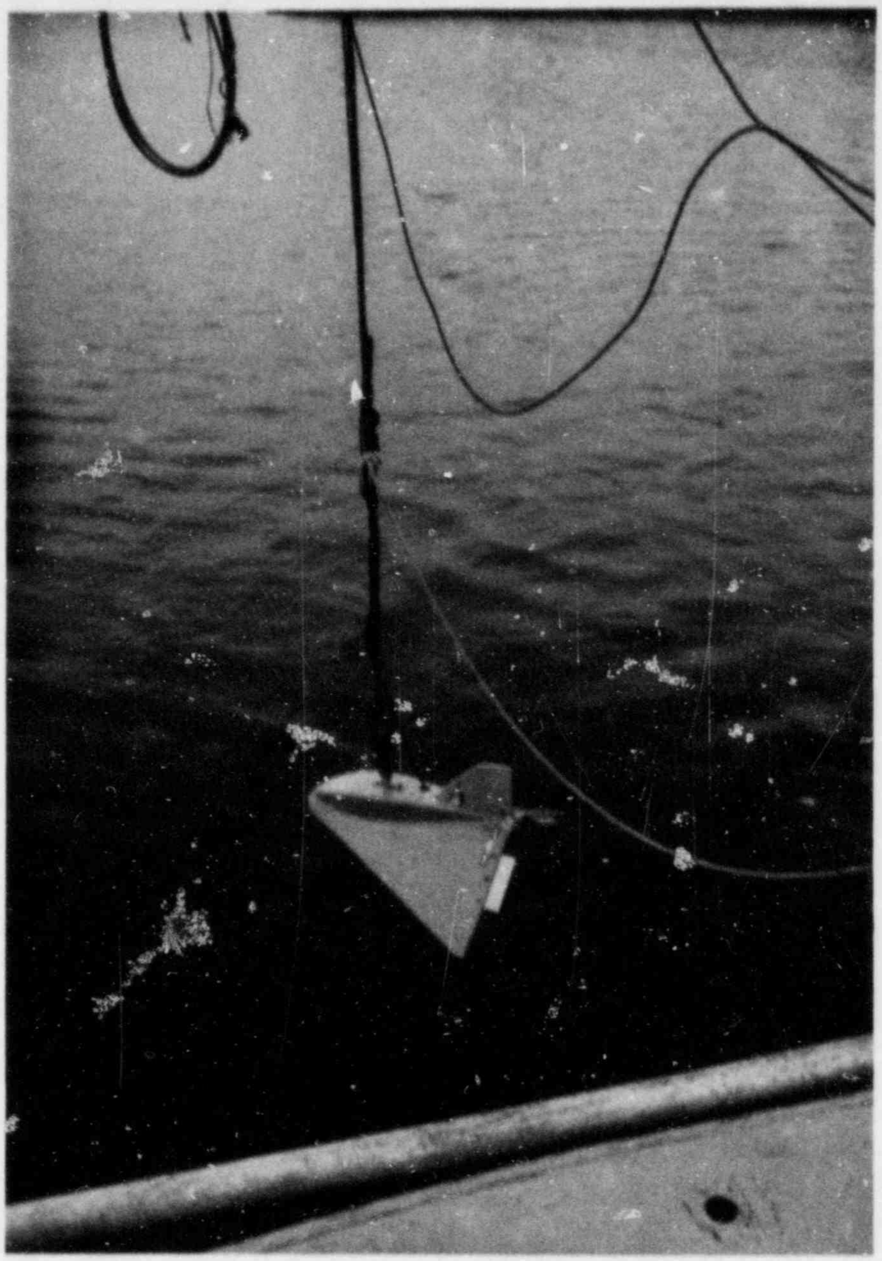

Fig. 11. Towed body. This fiberglass towed body contains a downward-looking hydroacoustic transducer and is being lowered over the stern at the beginning of a survey. The hydrodynamic shape of the body allows it to be stable at high speeds. Photo by P. Kanciruk.

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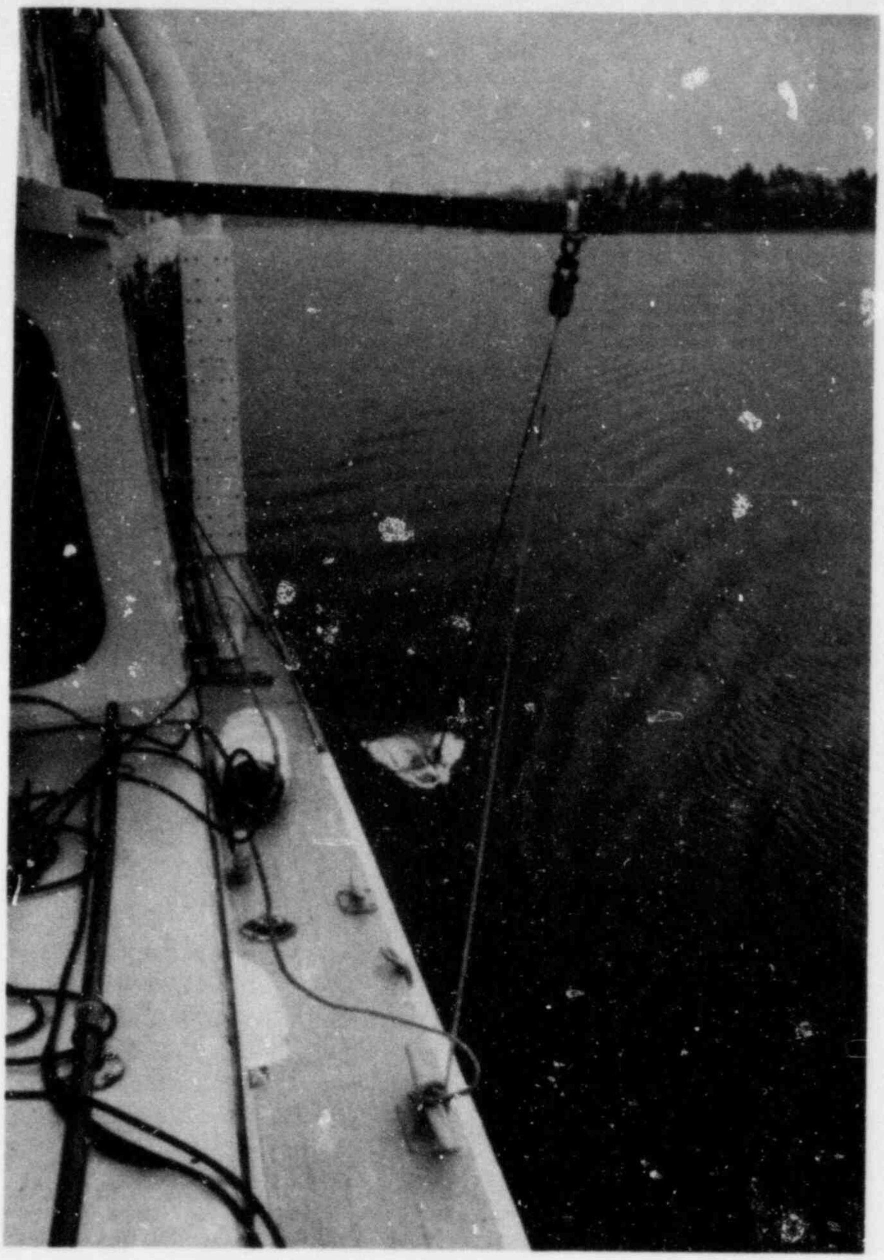

Fig. 12. Deployed towed body. Towed bodies are flexible in their deployment and can be towed behind, alongside (above), or in front of the survey vessel. Photo by P. Kanciruk.

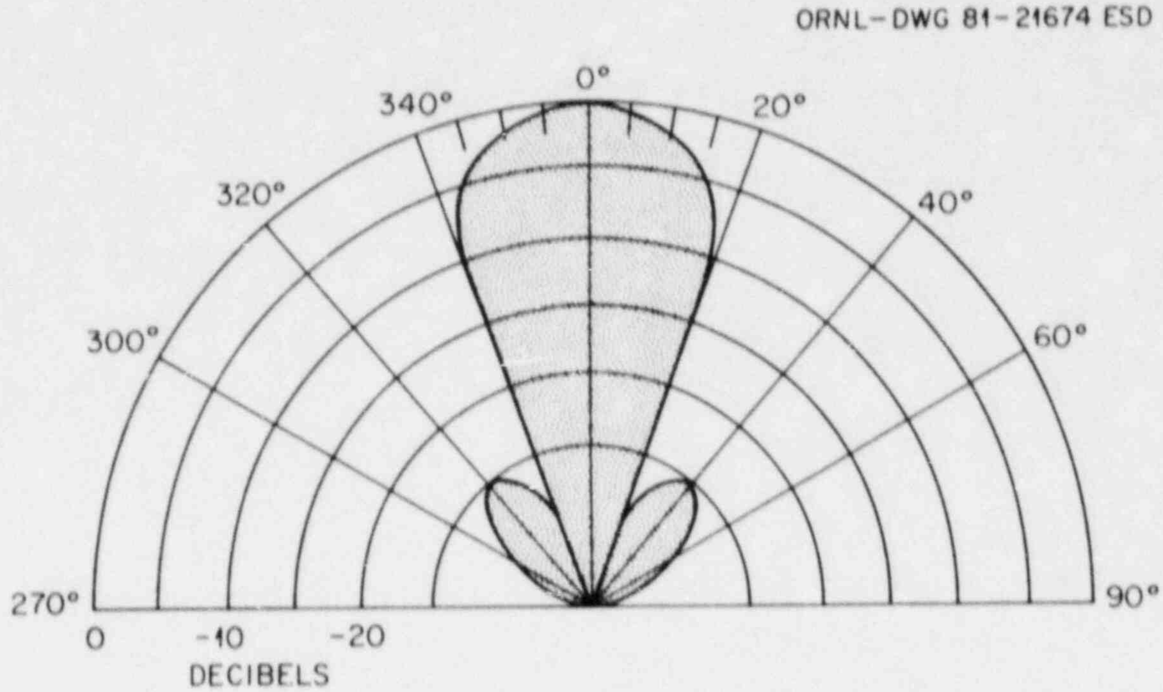

Fig. 13. Wide-beam transducer directivity pattern. A transducer directivity pattern is a measure of its sensitivity in transmitting and receiving hydroacoustic signals. It is most sensitive on-axis (0 dB drop at 0°), while sensitivity decreases quickly off-axis. "Side-lobes" (here at 320° and 40°) are undesirable but often unavoidable. Transducer directivity patterns are measured in laboratory performance measurements and should be provided to the user at the time of purchase.

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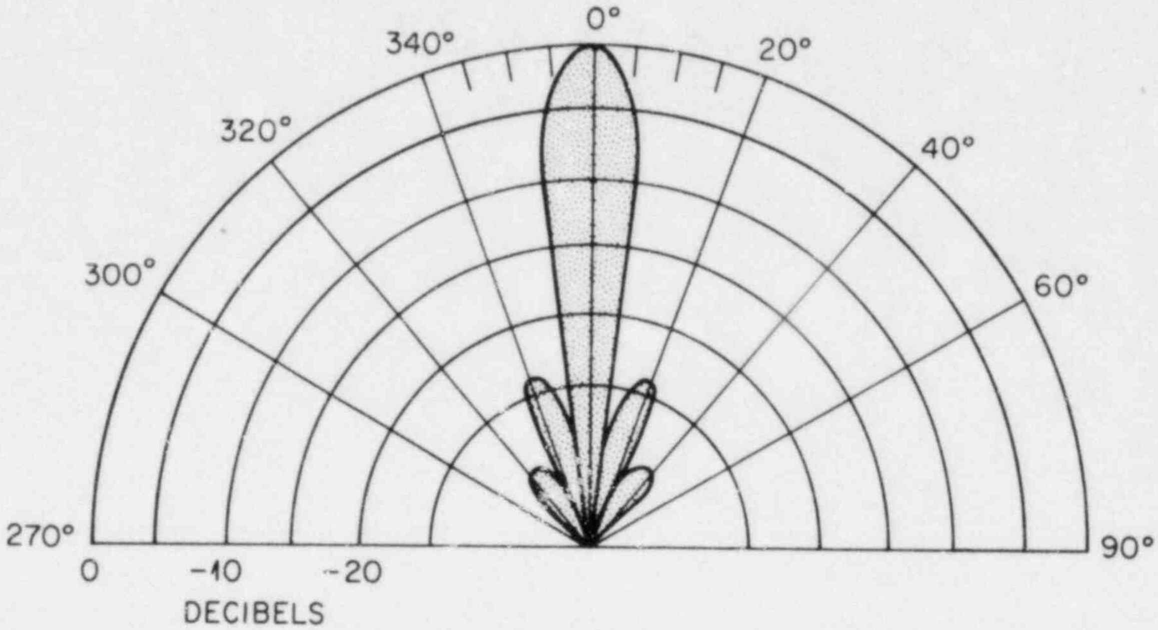

Fig. 14. Narrow-beam transducer directivity pattern. The area insonified by this transducer is much less than that of a wide-beam transducer. Note double side-lobes at the base of the directivity pattern.

suffer from extensive side-lobes. The best (and usually most expensive) transducers have these side-lobes reduced as much as possible.

Three-dimensional transducer directivity can be compared to the light beam from a flashlight (Fig. 15). Sensitivity is high on-axis but drops off rapidly off-axis. It is readily apparent how this characteristic confounds echo analysis, even within the main lobe of the transducer. Two targets of the same size and distance from the transducer will return different strength echoes due to the transducer's directivity pattern (two targets at different distances from the transducer but in the same portion of the beam pattern will return identical echoes due to correction by the TVG circuitry). Unfortunately, using traditional transducers and hydroacoustic equipment, it is not possible to determine the actual location of a target in the transducer's directivity pattern in order to apply a target strength correction factor. Statistical manipulation of the return target data has traditionally been used to interpret such echoes. A relatively new technique, dual beam hydroacoustics, can locate a target within the transducer's directivity pattern by comparing simultaneous echo returns from narrow and wide beams transducers (Ehrenberg 1974, 1976, 1978; Traynor 1979). Two estimates of target strength, one from each beam, allow determination of absolute target strength. This system is available off-the-shelf from at least one manufacturer.

Although transducers are usually used in the downward-looking mode, they can be used from a moving vessel in a side-looking mode (side-scan sonar). A side-looking transducer allows fish detection at a horizontal distance from the transducers (Figs. 16). This technique, usually used at sea by fishermen searching for fish schools, can be applied stationary transducers in rivers by investigators to quantify migrant passage. Doppler hydroacoustic systems are presently under development by at least one manufacturer (personal communication, Tom Carlson, BioSonics, Seattle), which will allow better target resolution in riverine situations. Doppler systems are able to distinguish moving

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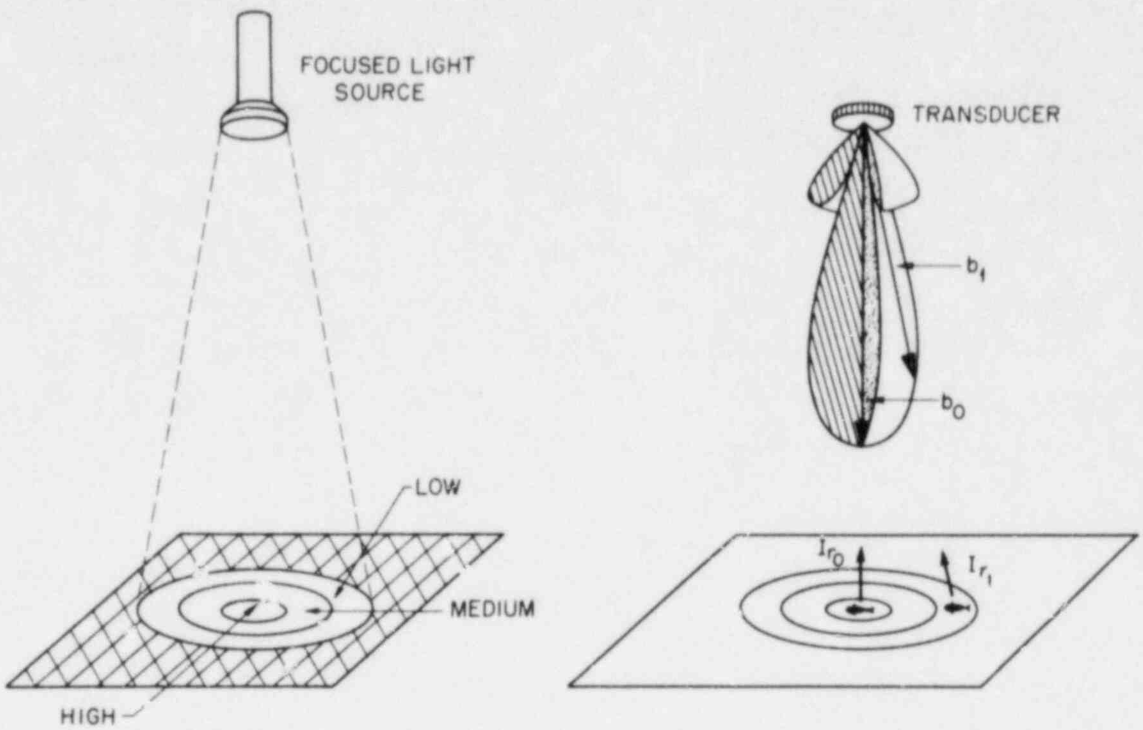

Fig. 15. Transducer directivity pattern. The directivity pattern can be compared to the light from a flashlight falling on a surface, with energy greatest in the center, falling off toward the edges. It is clear that two equal targets (fish), one on-axis (insonified with intensity Ir_0), and one off-axis (insonified with intensity Ir_i), will resolve as two different intensity echoes due to the varying efficiencies within the beam (b_0 and b_i). Source: Adapted from Burczynski 1979, with permission.

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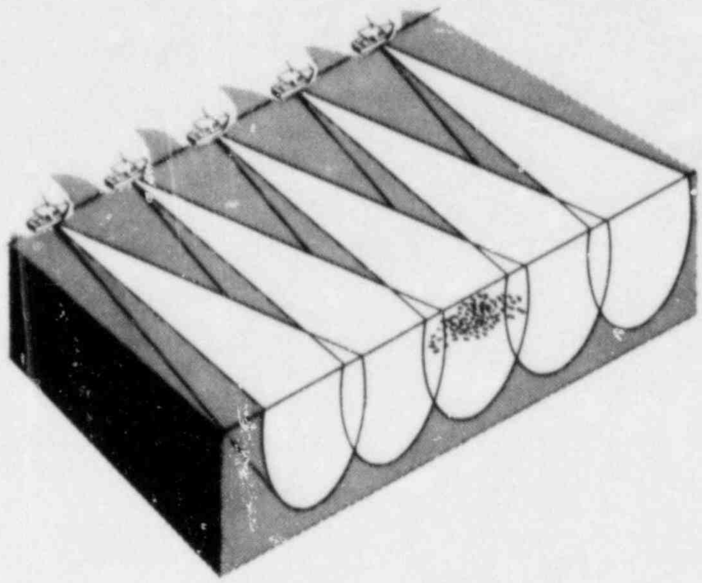

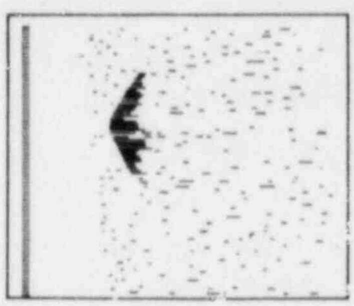

Fig. 16. Side-scan sonar. Top: Hydroacoustic transducers directed horizontally to determine the presence of fish schools at a lateral distance from the vessel (a technique often used by commercial fishermen). Bottom: Side-scan echogram of fish school. Source: Adapted from SIMRAD 1965, with permission.

targets from stationary targets (such as the bottom or bank), and should be of great benefit in working in difficult, shallow riverine systems.

2.1.3 Displays

The transmitter produces the electrical signal. The transducer converts it to an acoustical signal and the returning acoustic echoes back into electronic signals, which are then processed by the receiver. The electronic signal is then visually displayed providing immediate information to the hydroacoustic operator. Two primary types of displays are used for this purpose (either separately or in concert): paper chart recorders and oscilloscopes or CRTs.

The traditional display for depth sounders and fish-finders is the paper chart recorder (Figs. 6 and 17). Electrically sensitive paper continuously rolls horizontally past a vertically moving stylus. An electric current is sent to the stylus by the receiver when the transducer first sends out its acoustic signal (time zero, equivalent to a base line or zero depth on the chart). A second current is sent when the transducer receives an echo. The stylus moving over the chart paper leaves a blackened char mark when it receives each signal. The stylus makes one vertical pass per transducer pulse and leaves two or more marks -- a zero depth line at the top of the chart, target mark(s) below, and a bottom trace. Depth is read on the vertical scale of the chart. Single fish show up as single dots on the paper, whereas dense schools of fish can show up as clouds (Figs. 17 and 18). The bottom shows up as a continuous line or series of parallel lines near the bottom of the chart. Chart speed affects the chart display -- slow paper speeds compress distance (time) in the horizontal scale, making gradual bottom slopes appear as sharp peaks and valleys (Fig. 19).

Chart or echogram interpretation is a nontrivial skill. For example, when fish schools are dense, the bottoms of the schools and even the line representing the substrate beneath the schools can disappear due to the acoustic "shadowing" by the fish at the top of the school (Fig. 4). In anaerobic environments, for example, methane

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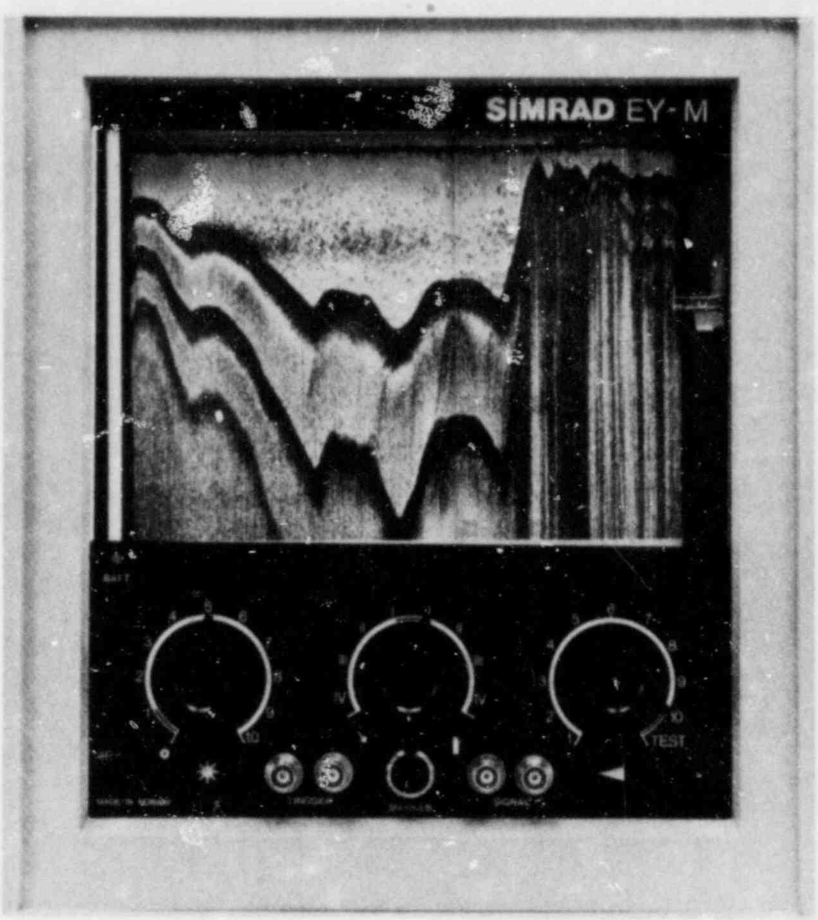

Fig. 17. Paper chart recorder. The standard visual output for a hydroacoustic system is the paper chart recorder. Depth is the vertical axis; time, the horizontal. The solid horizontal lines are multiple bottom echoes. The dots above in center of the chart are fish targets. Source: SIMRAD Marine, Horten, Norway, with permission.

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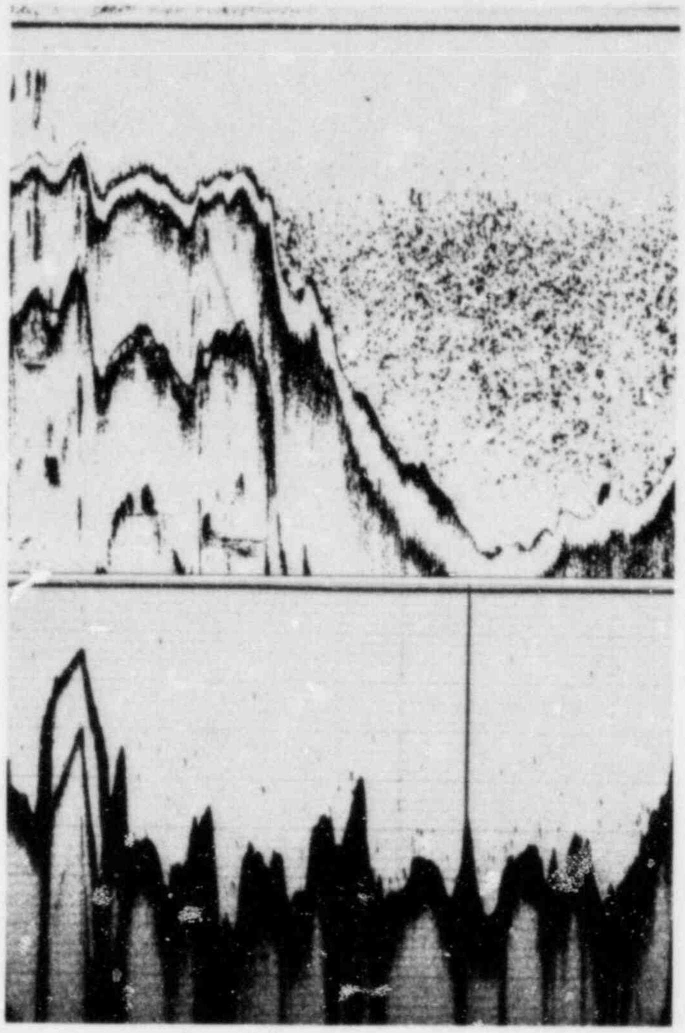

Fig. 18. Paper chart output. Top: Depth is the vertical axis; time, the horizontal. The bottom is the first continuous dark line in this chart (the parallel lines below are multiple echoes of the bottom). Fish appear as dots in the deep basin. Source: SIMRAD Marine, Horten, Norway, with permission. Bottom: Single fish targets in the reservoir behind Wanapam Dam, Columbia River, Wash. The tall thin line right of center is a marker created on the chart to note time and ship position. Depth scale is 0-25 fathoms. Source: BioSonics, Seattle, Wash., with permission.

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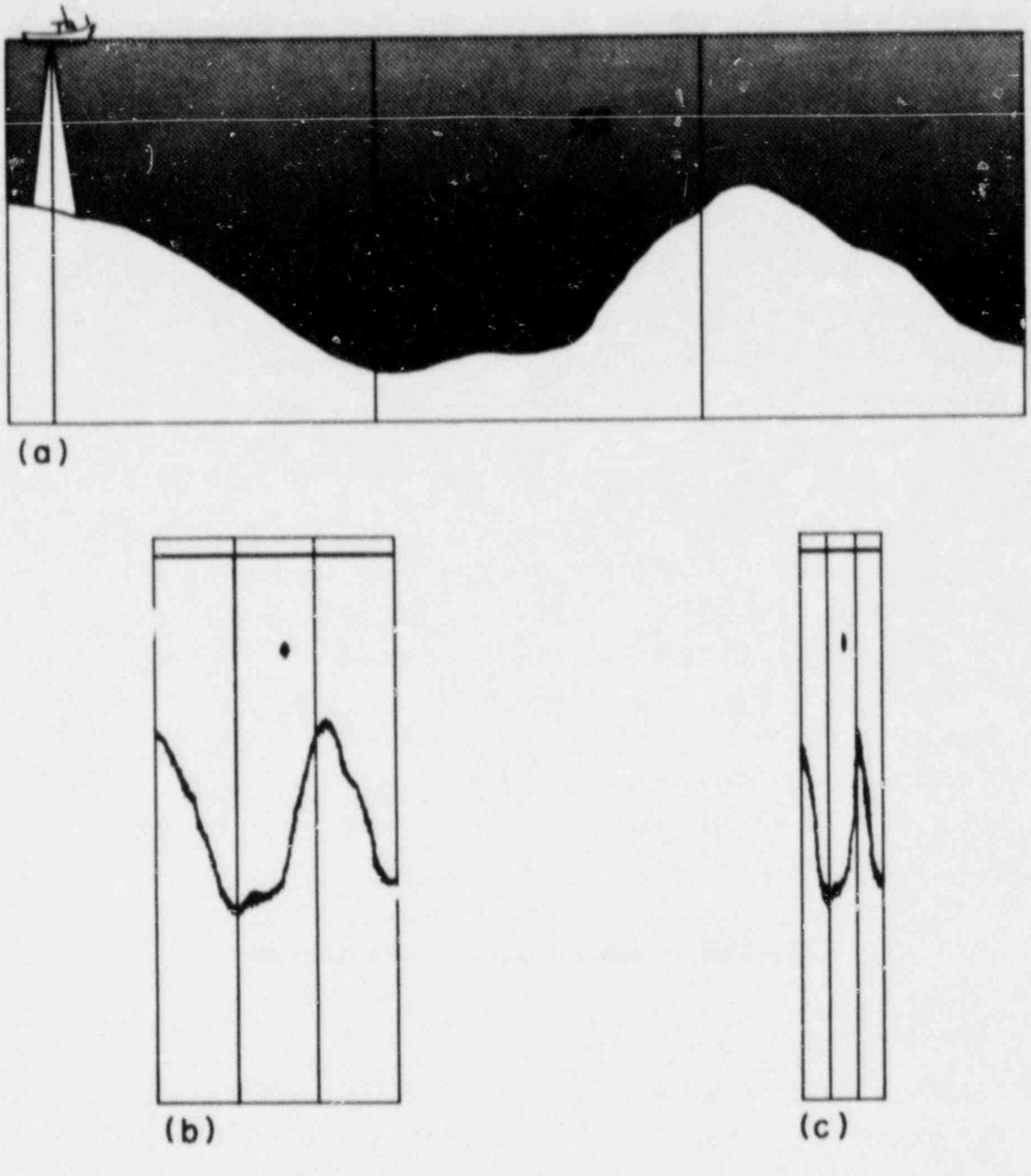

Fig. 19. Paper chart speeds. The actual bottom configuration as it appears in (a) is horizontally compressed using normal paper chart speeds (b) and extremely compressed using slower chart speeds (c). Note that a small school of fish may show up on the slow moving chart as a single clump. Source: Adapted from SIMARD 1965, with permission.

bubbles rising to the surface can show up on echograms as 'fish' (Fig. 20). Knowledge and calibration of hydroacoustic equipment is essential to the interpretation of chart recordings, and indeed, all hydroacoustic data. Figure 21 depicts two transects of the same area within a reservoir, made within minutes of each other. The upper recording shows some fish in the 5-15 m range, whereas the bottom trace shows (what appears to be) many more fish in the same depth range. These differences in apparent fish densities are artifacts due to different gain settings on the recorder. The higher gain used during the second transect creates the illusion of more fish. Knowledge of equipment settings, along with calibration of equipment (Sect. 3.3), avoids such erroneous results. The technique of chart interpretation is a skill acquired only through practice and knowledge of equipment, target species, and the environment.

The CRT or oscilloscope display also renders the returning electronic signal visible (Fig. 22). Oscilloscopes accurately display signal strength and configuration and are useful in hydroacoustic surveys, especially in setting up and calibrating the electronic instruments, measuring target strength, and analyzing the recorded data (either manually or through the use of computer equipment). The ability of certain oscilloscopes to freeze the display is especially useful in analyzing the electronic signals. Recently, CRT "chart recorders" that represent signal amplitude in terms of color, enhancing the displays dynamic range, have become commercially available (Fig. 31).

2.1.4 Counters and Integrators

The simplest method of obtaining quantitative biomass information from hydroacoustic signals is to count the fish echoes obtained on an echogram (Fig. 23), or to tape the signals, play the tape through an oscilloscope, and to count each fish echo. By knowing the area insonified by the transducer, one can calculate the number of fish per unit area (and if the fish are of a uniform and known size, an estimate

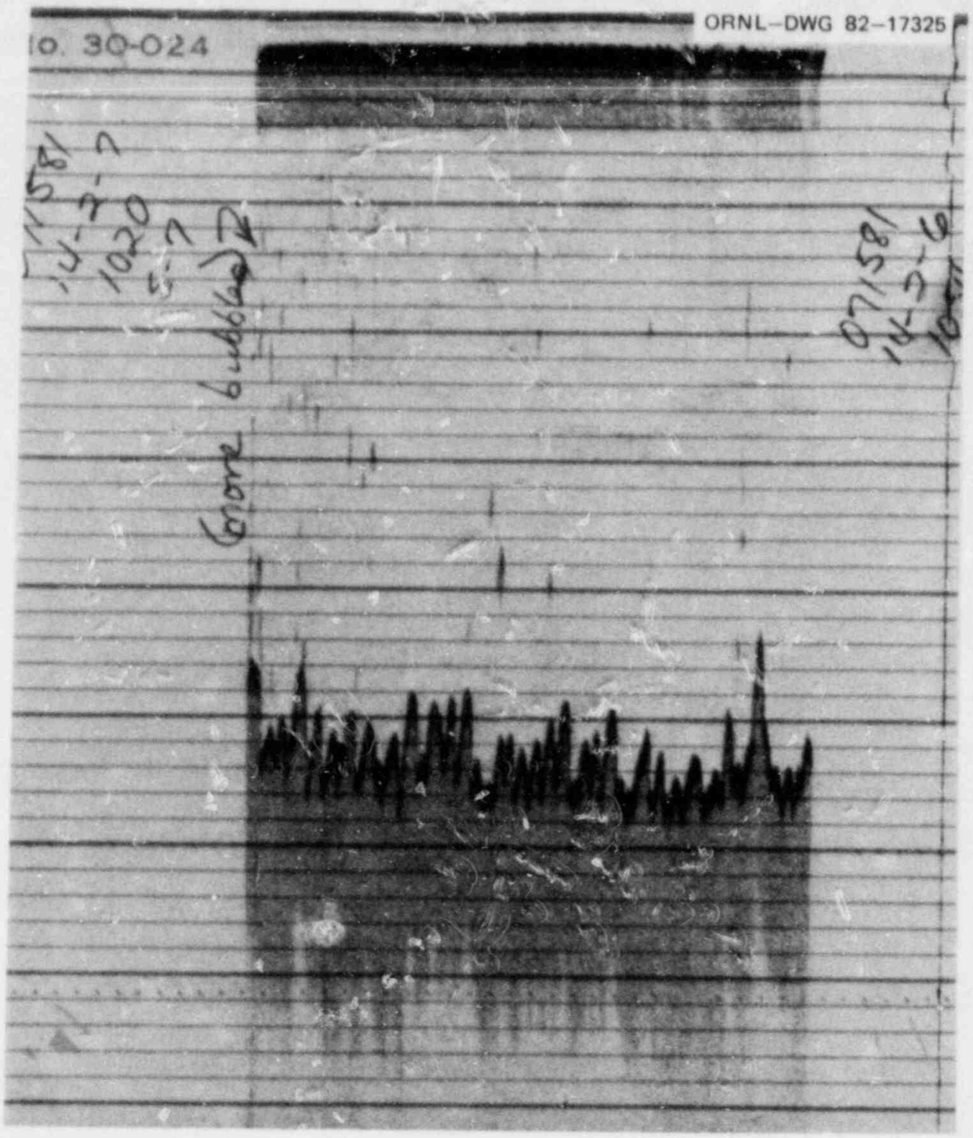

Fig. 20. Methane bubble targets. Artifacts can sometimes appear as targets on chart recorders. This echogram was made on the McNary Reservoir, Wash., where methane bubbles, rising to the surface, provided excellent targets for the hydroacoustic system. Accurate interpretation of echograms is is an acquired skill. Source: Dennis Rondorf, National Fisheries Research Center, Seattle, Wash., with permission.

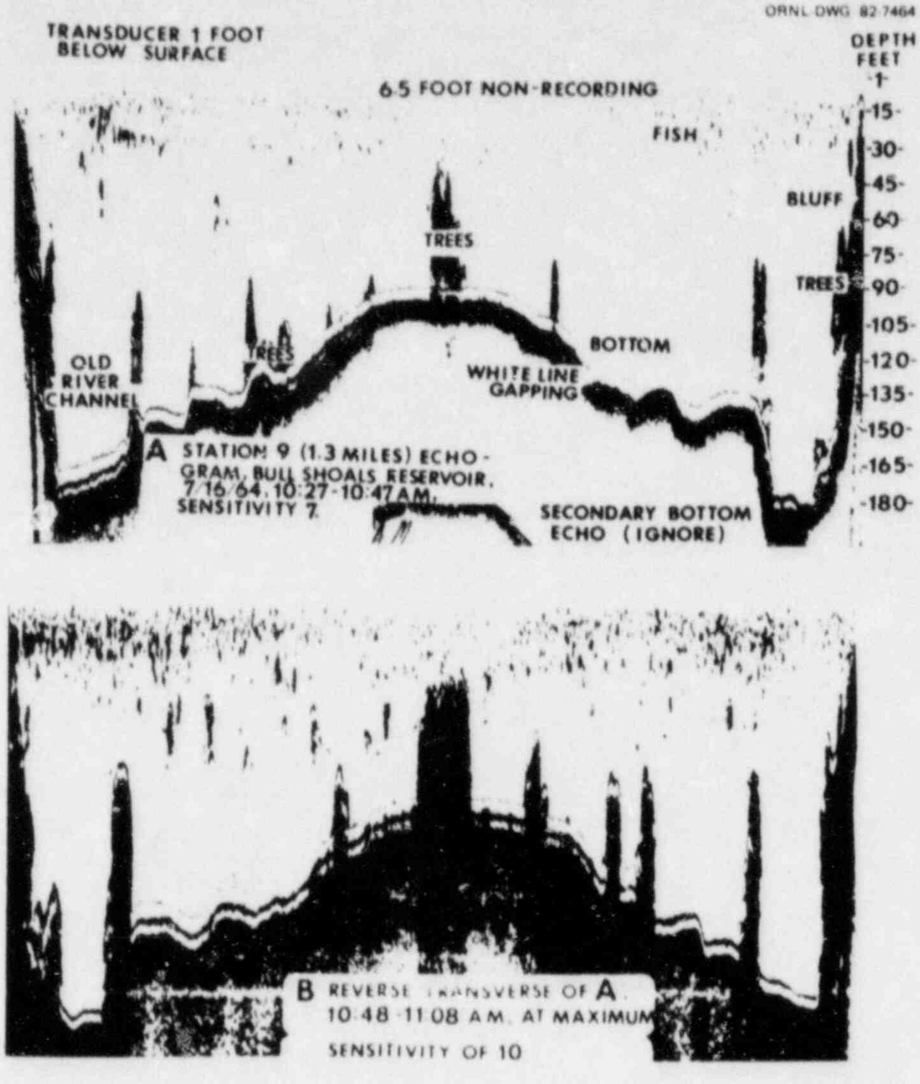

Fig. 21. Effect of gain on echogram recordings. These two echograms were taken at the same transect within minutes of each other. The apparent increase in fish density in the bottom echogram is due to the use of increased gain used during the second transect. Hydroacoustic equipment must be calibrated to avoid such artifacts. (The trees were submerged when the reservoir was flooded). Source: Mullan and Applegate 1969.

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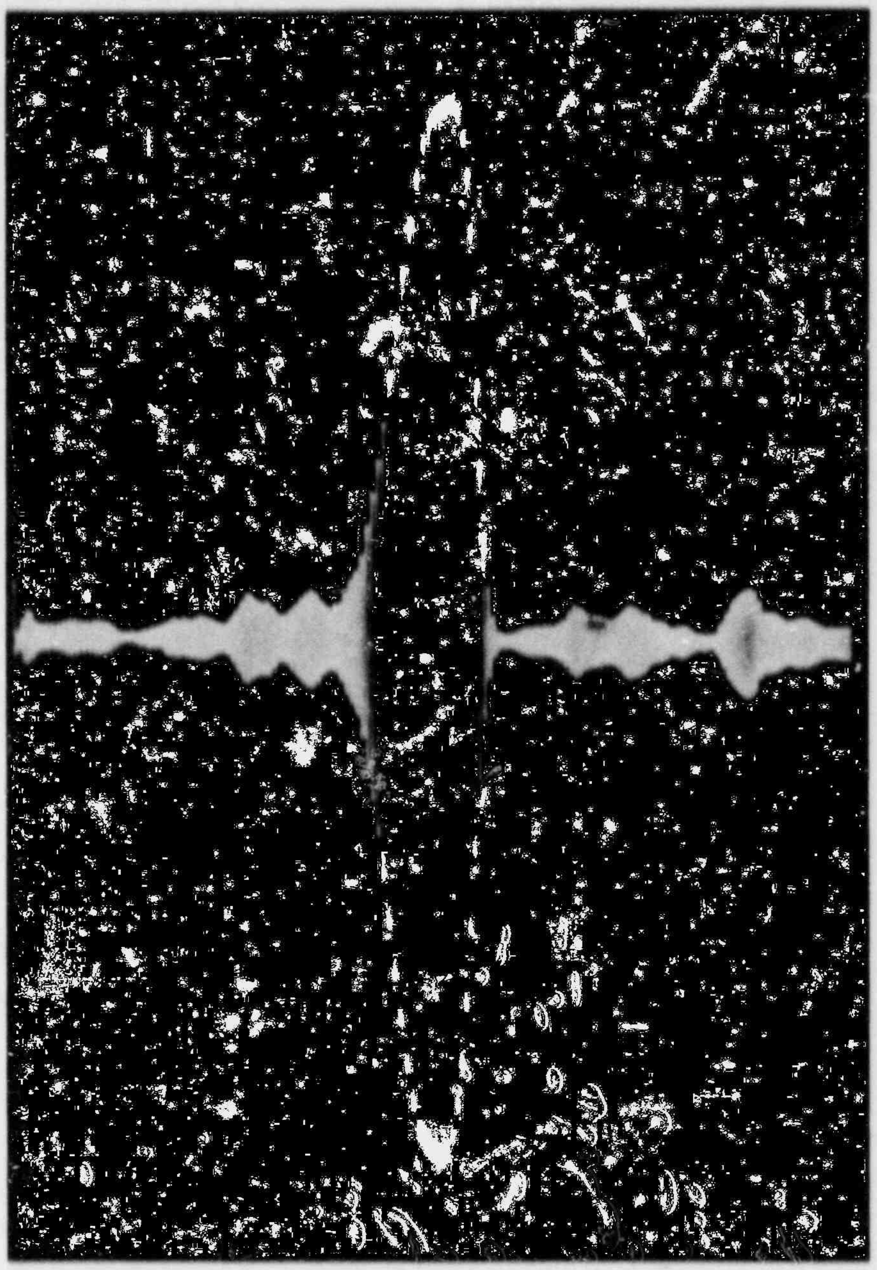

Fig. 22. Oscilloscope display. Single fish target appears on an oscilloscope screen as a vertical, symmetrical blip whose size is a function of target strength. Oscilloscopes are used to calibrate hydroacoustic systems, estimate target strength, and manually count fish. Source: Stephens 1970, with permission of John Wiley & Sons, Ltd., London.

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Fig. 23. Manual fish counting. Fish counts can be manually obtained from well-calibrated echograms if densities are low enough to avoid multiple returns. This method is, however, time-consuming and subject to operator bias. Automated methods of fish counting (or echo integration) should be employed whenever practical. Source: BioSonics, Seattle, Wash., with permission.

of actual fish biomass can be obtained). However, this is possible only when the fish density is low enough to avoid overlapping echo returns which make accurate counting impossible (Fig. 24).

Although possible (and instructive) to quantify fish count data manually, any major hydroacoustic survey where quantitative information is desired should use automated methods of data analysis (about 70% of the hydroacoustic users responding to the survey reported using automated data analysis. This can take two forms: echo conting and echo integration. The researcher can use a general-purpose digital computer and specialized software to analyze the hydroacoustic signals previously recorded on tape or use portable, self-contained fish counters or biomass integrators specifically designed and commercially manufactured to quantify hydroacoustic signals (Figs. 25 and 26). Echo counting and echo integration estimate the number or biomass of fish for each signal transmission (Braithwaite 1971, Dunn 1977, Kelso et al. 1974, Lahore 1969, Maniqa and Furusawa 1978, Yamanaka et al. 1977). Multiple transmissions are then used to generate an average density of fish for the sampled area (Fig. 27). The use of such automated equipment drastically improves data reduction time and reduces operator bias.

The use of computerized analysis also allows the estimation of biomass where densities are great and overlapping echoes are common through echo integration of the signal (Jakobren and Smedstad 1972, Kanemori and Ehrenberg 1978, Lahore and Lytle 1970, Thorne 1980). This method was first available commercially in 1969 (Johannesson and Lose 1977). It essentially integrates the area under the digitized, one-sided representation of the echo signal (sampling rates of 1-10 samples/ms). This integrated area (actually the squared voltage of the echo signal) is proportional to the size and number of fish and is not biased by overlapping echo returns. Given a reasonable estimate of the average target strength (information which is sometimes difficult to obtain -- Stubbs 1971, Ehrenberg 1979, Ehrenberg et al. 1981; and users responding to the survey in Appendix B indicated that the estimation of fish target strength was the area of hydroacoustics

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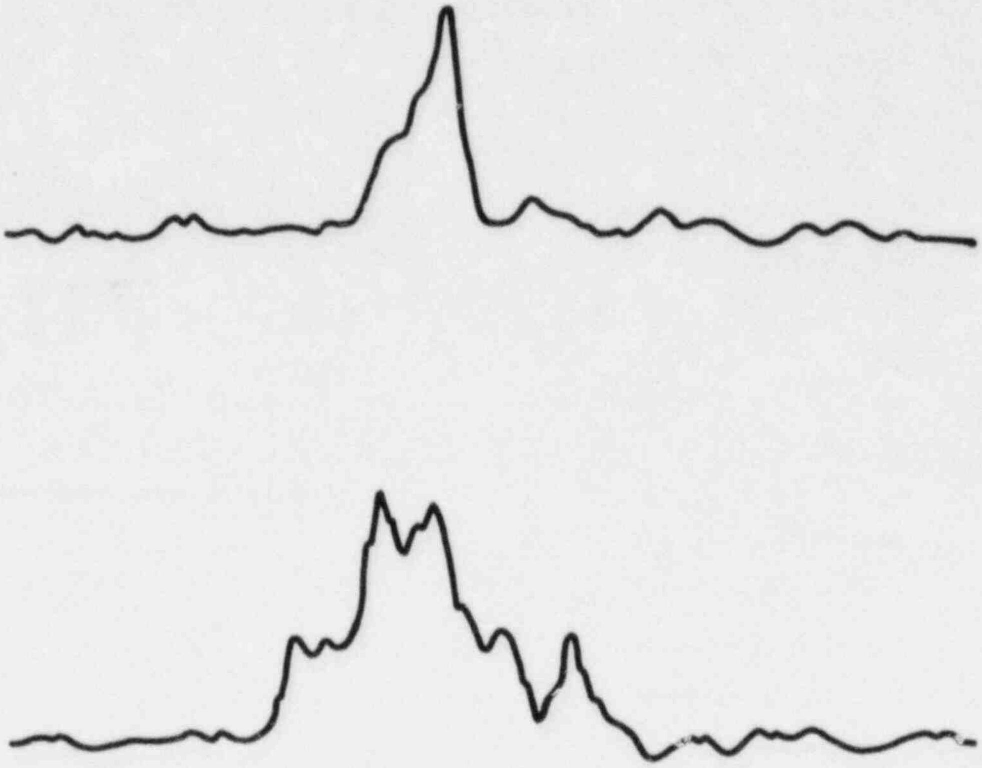

Fig. 24. Single and multiple echoes. These figures represent the one-sided oscilloscope traces for single (upper) and multiple (lower) echoes. When fish densities are low enough to avoid frequent multiple echoes, manual or automatic fish counting methods can be employed. When densities are greater and echoes overlap and interfere with echo counting, then echo integration (determining the area under the trace) should be employed.

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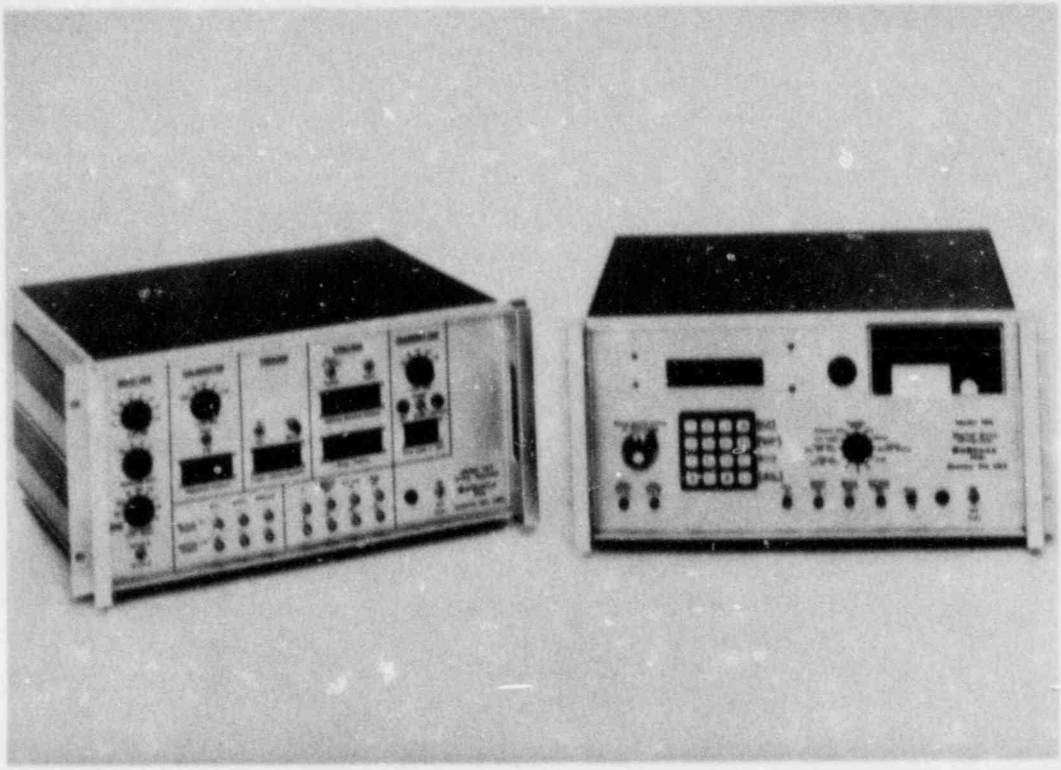

Fig. 25. Hydroacoustic transceiver and echo integrator. The transceiver (left) is both the hydroacoustic transmitter and receiver. It is an example of newer designs using solid-state digital electronics for critical functions such as time-varied gain. The echo integrator (right) provides fish biomass estimates by depth internals in a real-time mode on-board ship or in the laboratory using tape recording of hydroacoustic signals. Source: BioSonics, Seattle, Wash., with permission.

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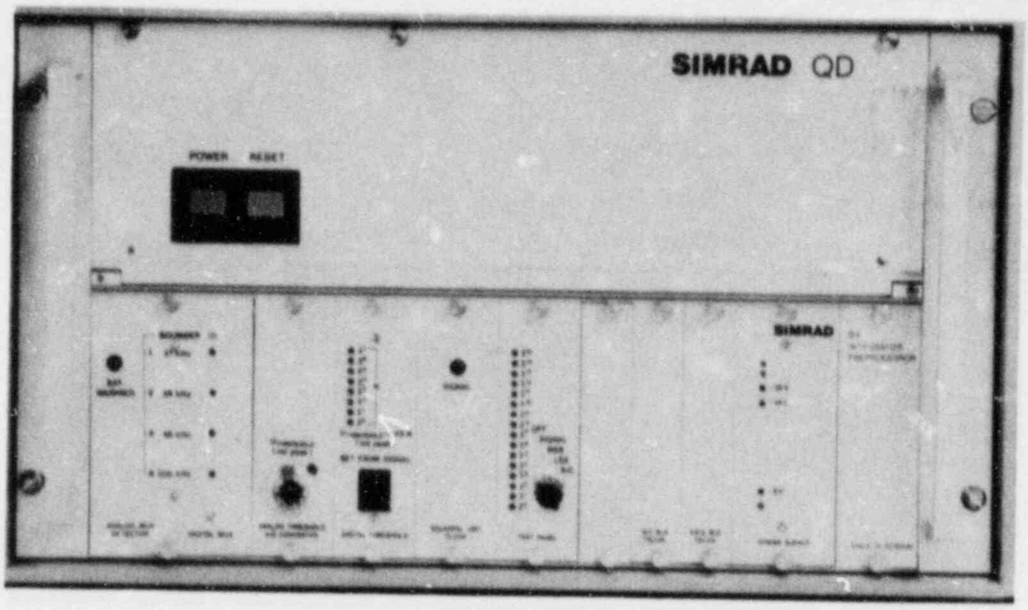

Fig. 26. Echo integrator. Another example of a flexible, research-grade echo integrator using digital technology. Source: SIMRAD Marine, Horten, Norway, with permission.

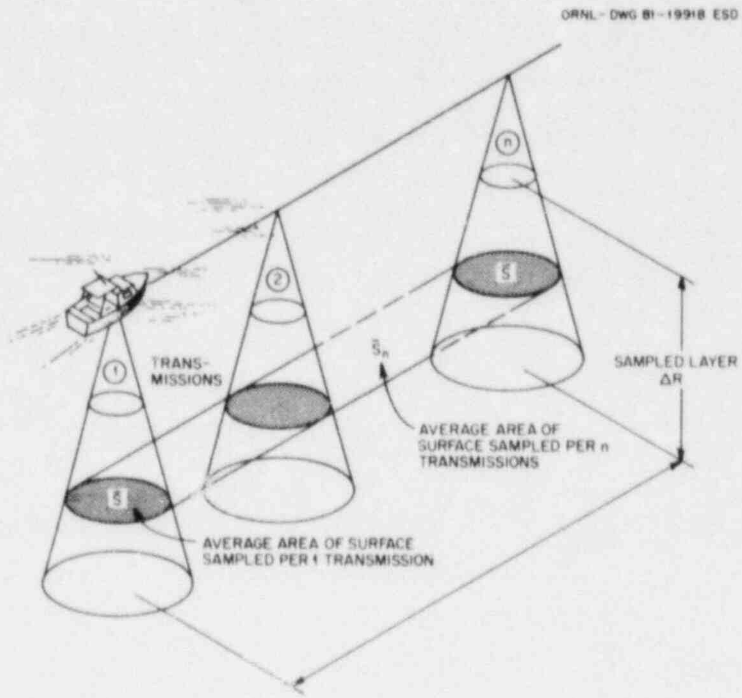

Fig. 27. Echo counting and integration. Echo counting or echo integration estimates the number or biomass of fish for each signal transmission. Multiple transmissions over distance are then used to generate an average density of fish for the sampled area.
Source: Adapted from Burczynski 1979, with permission.

most needing attention), an integrator can scale these averages to provide biomass estimates in terms of kilograms of fish/m^3 of insonified water for any depth intervals of interest.

The question of when to use fish counting and when to use fish biomass integration has been investigated by Ehrenberg and Lytle (1972). They concluded that echo counting was the better technique (exhibited less error) when fish densities were low (less than one fish in 10,000 m^3) and echo integration the better technique at higher fish densities. This relationship is apparently independent of fish size. Echo integration was the most frequent signal analysis method reported in the user survey (Appendix B).

Echo counting and/or echo integration can be accomplished using general-purpose digital computers or specialized equipment. There are advantages and disadvantages to both systems.

1. General-purpose computer
   A. Advantages
      - Use of existing computing facilities; and
      - Hydroacoustic data immediately available for additional analysis using standard statistical, graphical, and report-generation software.
   B. Disadvantages
      - Must have access to a minicomputer although the use of desk-top 8 or 16-bit microcomputers may be feasible in the near future;
      - Must develop or acquire appropriate hardware interface (analog-to-digital converter) to transfer data from tapes to computer;
      - Must develop appropriate software package to analyze data; and
      - System is not very portable.

2. Commercial single-purpose echo counter or integrator
   A. Advantages
      - Portable from lab to lab and ship to ship; and
      - No hardware or software development time/costs.
   B. Disadvantages
      - Specialized equipment expense; and
      - Not as flexible as general purpose computer.

As technology rapidly advances, distinctions between stand-alone single-purpose counters or integrators and general-purpose computers become blurred. For example, manufacturers are now including RS-232 serial data interfaces on some of their counters or integrators allowing direct transfer of data to general-purpose mini- or microcomputers for further analysis or report generation.

2.2 Equipment Selection

There are various types of hydroacoustic equipment manufactured for scientific biomass estimation (Figs. 25, 26, 28, and 29-31). The selection of hydroacoustic equipment for the remote estimation of fish biomass depends upon many factors. Table 1 summarizes various equipment options. In general, the selection of appropriate equipment depends upon

1. survey objectives,
2. biological considerations,
3. environmental considerations, and
4. practical/economic considerations (i.e., vessel size and budget constraints).

As a general rule, the hydroacoustic user should attempt to obtain the best quality equipment within budget. Although seemingly expensive, equipment costs are only a fraction of total personnel, ship, and data-reduction costs. The acquisition of research-grade transmitters, receivers, transducers, counters or integrators, the

Table 1. System parameters and options

Parameter	Options	Comments
Transceiver		
Acoustic frequency	∿20-2000 kHz fixed or switchable	Low frequencies (<50 kHz) provide longer ranges, especially in marine environments, and are less prone to interference from detritus or plankton. They require, however, larger, more expensive, transducers and are not able to resolve small targets. High frequencies (>500 kHz) have very short ranges, especially in saltwater, but can use smaller transducers and resolve very small targets (∿2 mm)[a]. Commonly used frequencies are 28-250 kHz.
Pulse duration	∿0.1-1 ms	Shorter pulse durations return less energy per echo but allow discrimination between targets that are close to each other.
Pulse repetition rate	1-6/s	Repetition rate required depends upon speed of vessel (faster tow speeds require more pulses per second) and speed of digital analyzing equipment.
Time-varied gain	20 log R 40 log R	20 log R used for echo integration; 40 log R is used for echo counting. Time-varied gain should be switchable between these two options and should be accurate and stable (digital implementation is best).
Transducer		
Beam width	Narrow or wide	Narrow beam widths (<5°) allow more selective insonification of the water column, important, for example, for a stationary transducer placed in a water intake embayment.
Number of trandducers	Single transducer Dual beam Multiple beams	Dual-beam systems are a relatively new innovation that allow the calculation of absolute target strength by comparison of echo returns from superimposed narrow and wide beams. Multiple-beam (sector-scanning) allows a large volume of water to be simultaneously insonified (for example, ten 10° transducers covering a 100° sector of water).
Transducer deployment	Fixed or mobile, Hull mounted, towed	Fixed transducer deployment allows continuous monitoring of areas (e.g., passage of fish downstream or in an intake embayment). Mobile deployment allows survey of large areas. Hull-mounted, mobile transducers are less prone to damage, but suffer from hull and water noise and reduced repairability and transportability between ships. Towed transducers are more prone to damage, but are easily repaired or replaced and are transportable.

Table 1. (continued)

Parameter	Options	Comments
Transducer frequency	∿20-3000 Hz	Low frequencies require larger, more expensive transducers. See comments for acoustic frequency.
Visual output		
Chart recorders	Various	Scientific-grade chart recorders interface with acoustic transceivers. Useful options include marker button, variable chart speeds, expanding depth scales, ability to interface with slave recorders, oscilloscopes, and tape recorders.
Oscilloscope	Various	Oscilloscopes are important in target strength measurements, calibration of systems, manual fish counting of recorded signals. Ability to freeze image is important. Digitized output is useful.
Cathode ray tubes	Various	Color chart recorders display different signal amplitudes as colors and improve dynamic range of signal.
Signal recording	Analog cassette Analog reel to reel FM reel to reel Digital reel to reel	Recording options are listed in order of increasing signal quality. Quality cassette recorders are usually adequate.
Signal processing	Visual qualitative chart inspection Quantitative chart inspection Fish counting (manual) Fish counting (automated) Echo integration (automated)	Options are listed in order of increasing desirability. Manual methods should not be used for extensive surveys.
Signal processing equipment	Self-contained echo counters and integrators. Echo counters and integrator programs running on general-purpose digital computers.	Self-contained, dedicated fish counters and echo integrators are easiest to operate, allow convenient on-board data interpretation. Use of general-purpose digital computers requires software and hardware development, but general-purpose digital computers are more flexible and can use existing equipment.

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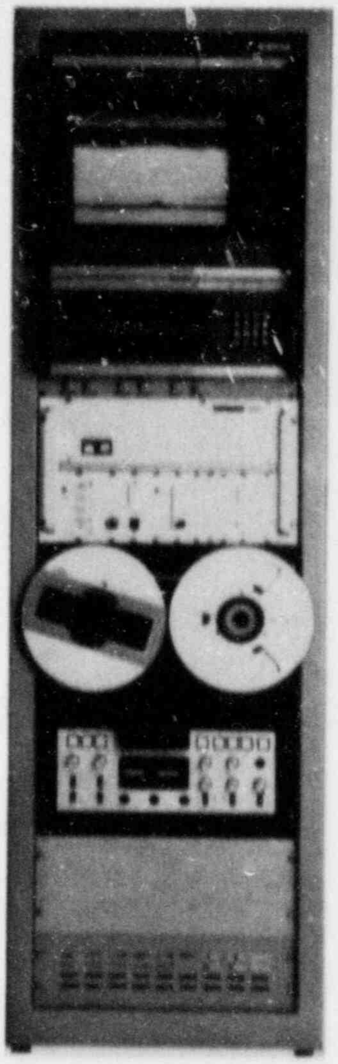

Fig. 28. Complete hydroacoustic system. Top down: chart recorder, microprocessor controller, echo integrator, reel-to-reel tape recorder, and power supply (transducer and oscilloscope not shown). Source: SIMRAD Marine, Horten, Norway, with permission.

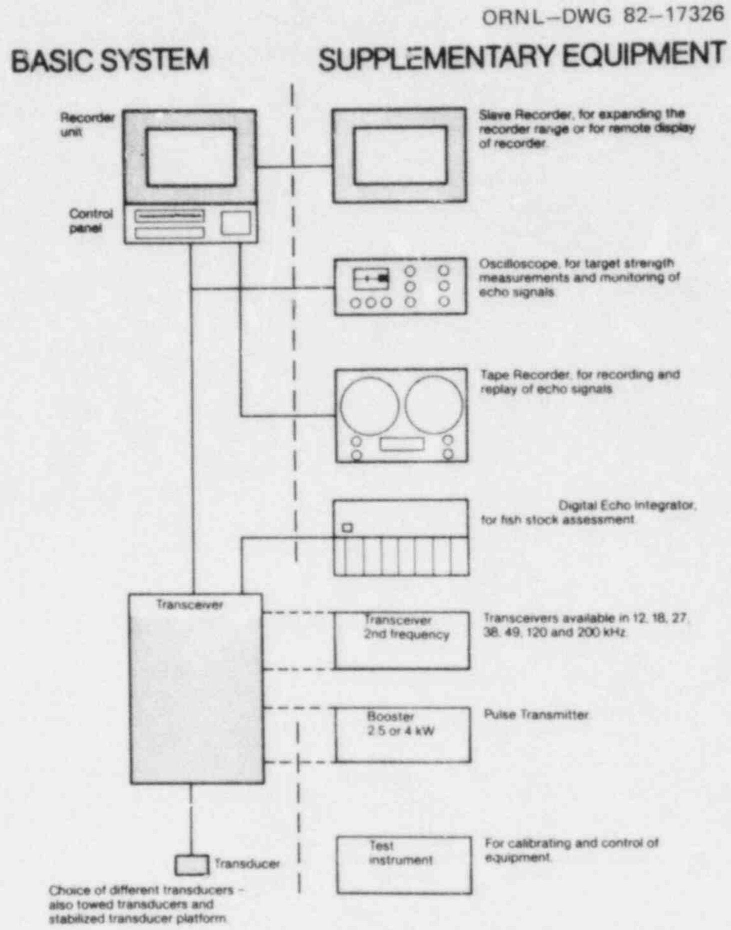

Fig. 29. Basic and optional components. One manufacturer's line of hydroacoustic equipment classified into basic and optional equipment. Usefulness of optimal equipment depends upon survey objective and working environment. Source: SIMRAD Marine, Horten, Norway, with permission.

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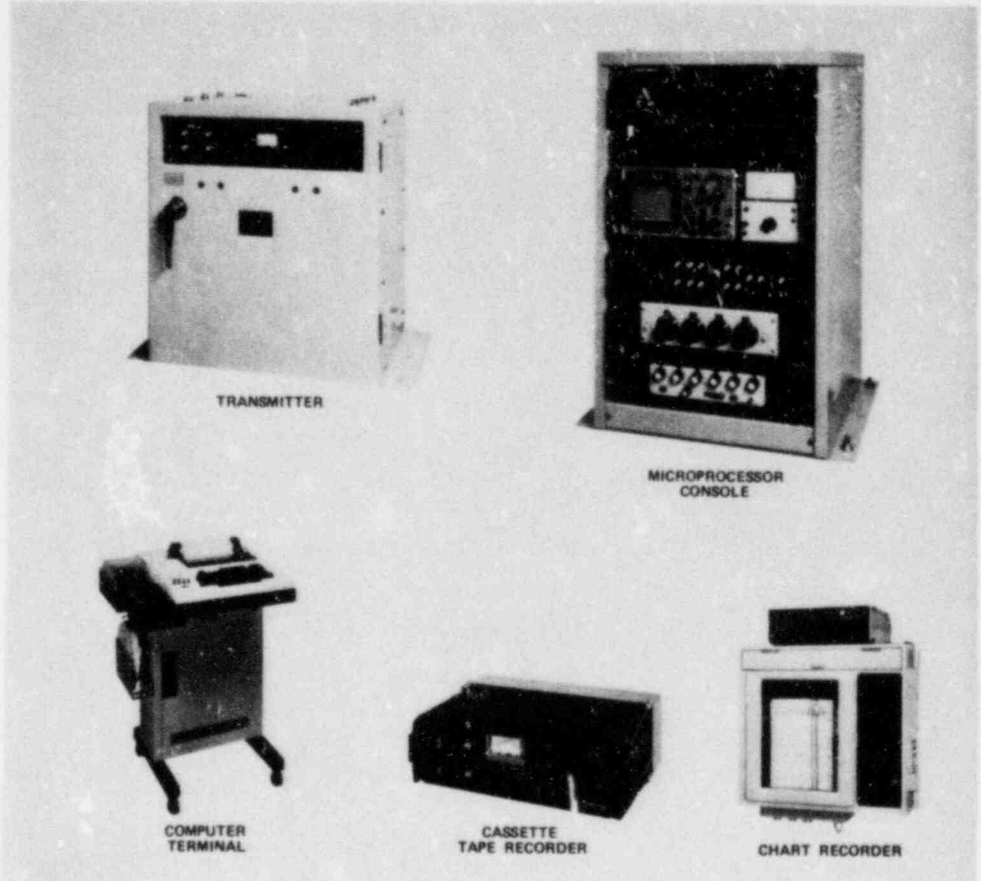

Fig. 30. Complete hydroacoustic system using digital electronics. This system includes an oscilloscope and output printer. Source: FURUNO Electric, Nishinomiya, Japan, with permission.

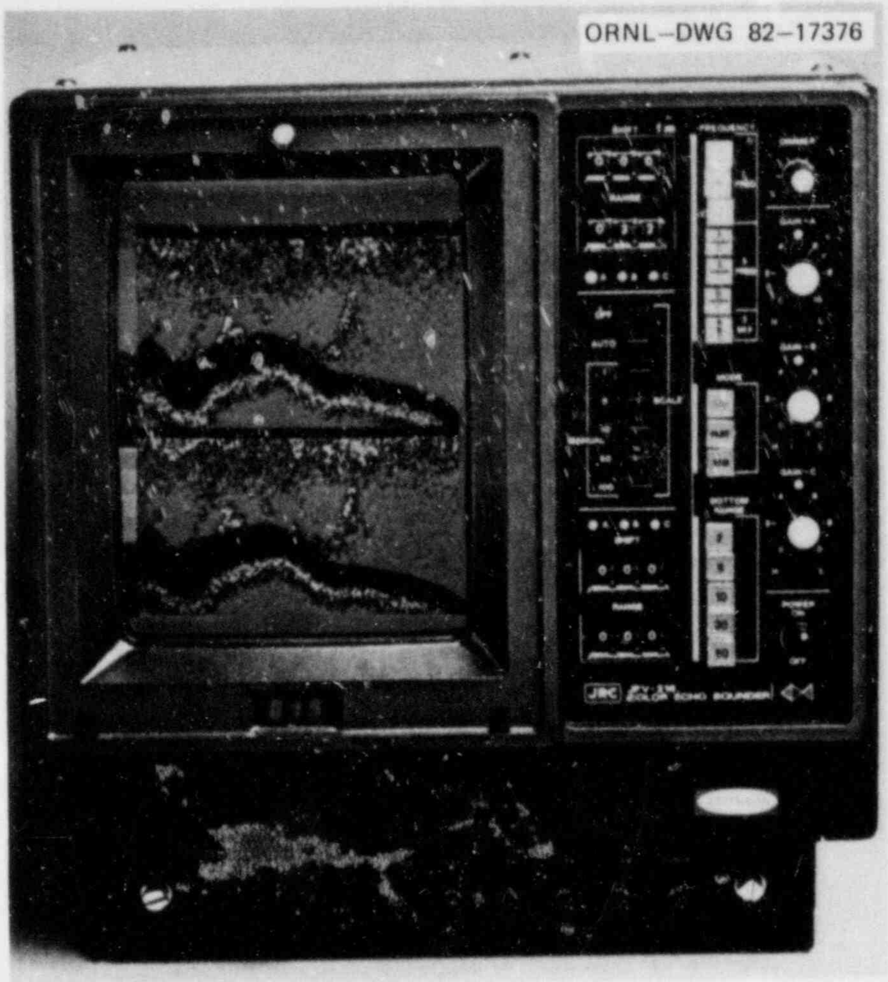

Fig. 31. Color chart recorder. Color chart recorders use cathode ray tubes instead of chart paper to display signal information. They provide information on signal amplitude displayed as a function of color. Advances such as this may be adapted to fisheries research surveys. Source: Raytheon Marine, Manchester, New Hampshire, with permission.

training of personnel, and the accurate and frequent calibration of equipment will repay the hydroacoustic investigator many times over in reliable, quality data.

The most important and overriding factor defining the selection of hydroacoustic equipment is the objective of the proposed hydroacoustic survey. Three categories of surveys amenable to hydroacoustic investigation are

1. qualitative determination of presence or absence of fish in areas of interest,
2. behavioral studies, and
3. quantitative biomass estimates.

Surveys that attempt to only qualitatively determine presence or absence of fish impose the fewest constraints on the selection of hydroacoustic equipment and can be accomplished on a relatively modest budget. Often the researcher can use a simple transciever and chart recorder. For many applications, an oscilloscope display, fish counter, and/or a fish biomass integrator will not be necessary. Such applications include preliminary surveys of proposed discharge or intake sites and construction or dredge and dredge-spoil disposal areas. In these applications, the researcher is interested in defining habitat, bottom morphology, determining gross relative differences in biomass between prospective construction sites, and directing net sampling techniques to define species composition. If more quantitative information becomes necessary, the researcher can purchase additional equipment and incorporate advanced techniques such as fish counting or biomass integration.

Although the objectives of such preliminary surveys are modest, the researcher should not be lured into purchasing anything but scientific-grade transducers, transmitters, and chart recorders. Only quality equipment that does not drift in its parameters and can be accurately calibrated will allow year-to-year, or even week-to-week, comparison of survey results.

Surveys concerned with determining behavioral characteristics of fish populations include such diverse objectives as defining diel vertical or horizontal fish movements, distribution of fish near thermal discharges, raw water intakes, dam turbine intakes or fish passages, and timing of migrations. Simple chart recorder records may suffice for many of these surveys, especially if stationary transducers are used in conjunction with slow-moving chart recorders. However, often more sophisticated equipment will be dictated by unusual circumstances such as the need to monitor absolute density or movement in relation to a water intake (perhaps necessitating an expensive narrow-beam transducer with small side-lobes due to the narrow confines of the intake region), to accurately determine fish biomass, or to simultaneously survey a large portion of the water column (perhaps necessitating multiple-transducers).

Surveys that attempt to use hydroacoustics to quantitatively estimate biomass are often the most demanding of specialized equipment and effort. In addition to the usual transducer, transceiver, and chart recorder, a hydroacoustic setup will include a method to quantify the electronic signals in terms of biomass. The usual methods to accomplish this are fish counting or biomass integration (Sect. 2.1.4). This can be done using a general-purpose computer with specialized software or one of the stand-alone fish counters or echo integrators manufactured specifically for this purpose. This data analysis can be real-time on the vessel, or the signals can be magnetically taped for analysis after the cruise. On-board analysis reduces labor costs and provides immediate information on fish density. It is useful where seasonal fishing quotas or approved fishing regions are defined. Even with shipboard analysis, however, it is good practice to simultaneously record hydroacoustic signals on tape for future re-analysis, if necessary.

2.3 System Operation

2.3.1 Transducer Deployment

The deployment of hydroacoustic equipment in a biomass survey is tailored to species, environment, and overall research objective. In general, deployment can be categorized as using stationary or mobile transducers:

1. Stationary transducers

   - Bottom mounted, upward looking (Fig. 32);
   - Surface mounted, downward looking (Fig. 32);
   - Buoy mounted, sideward, upward, or downward looking (Fig. 32); and
   - Mounted near intakes, discharges, or spillways or mounted within enclosed structures, such as intake penstocks (Figs. 33 and 34).

2. Mobile transducers

   - Ship mounted on hull (Fig. 10);
   - Mounted in towed body (Figs. 10-12;); and
   - Shallow or deep towed.

Operation can be secondarily classified as to whether the data are analyzed on board (or onsite for a stationary transducer) or taped and analyzed at a laboratory. On-board or onsite analysis allows the researcher to modify the research plan or to make rapid fisheries management decisions (i.e., set seasonal or even weekly fishing quota).

Bottom-mounted, upward-looking transducers (Fig. 32) are useful in stream, river, or lake/reservoir situations to determine fish passage, especially if the fish is a mid-water species (Acker 1973) or is migrating under surface ice. Cable can be run from a shore station (housing the transceiver and recording equipment) to the transducer to transmit and receive the signals. In situations where the migrating species swim along the shallow edges of a river or stream, a buoy-mounted, sideward-looking transducer may be necessary. In coastal

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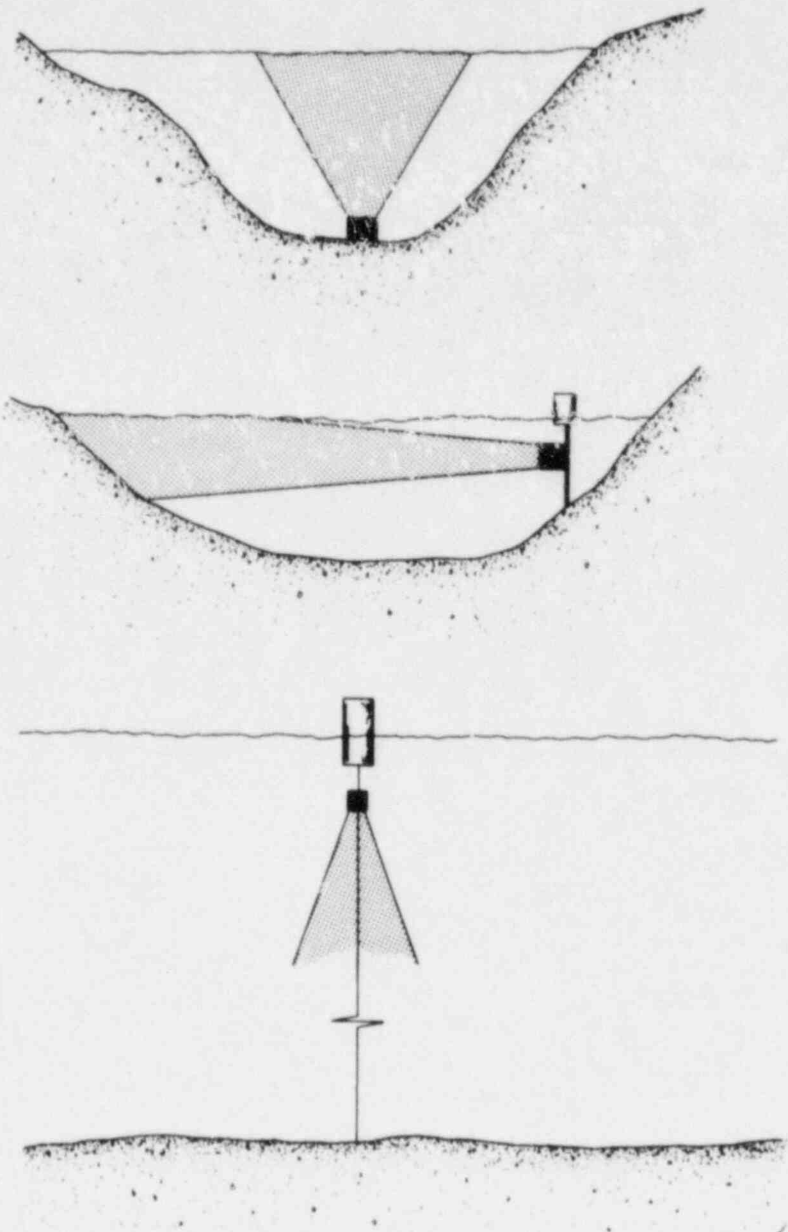

Fig. 32. Fixed transducer deployment. Fixed transducers can be placed on the bottom looking upward (top), on buoys looking sideward (middle), or downward (bottom).

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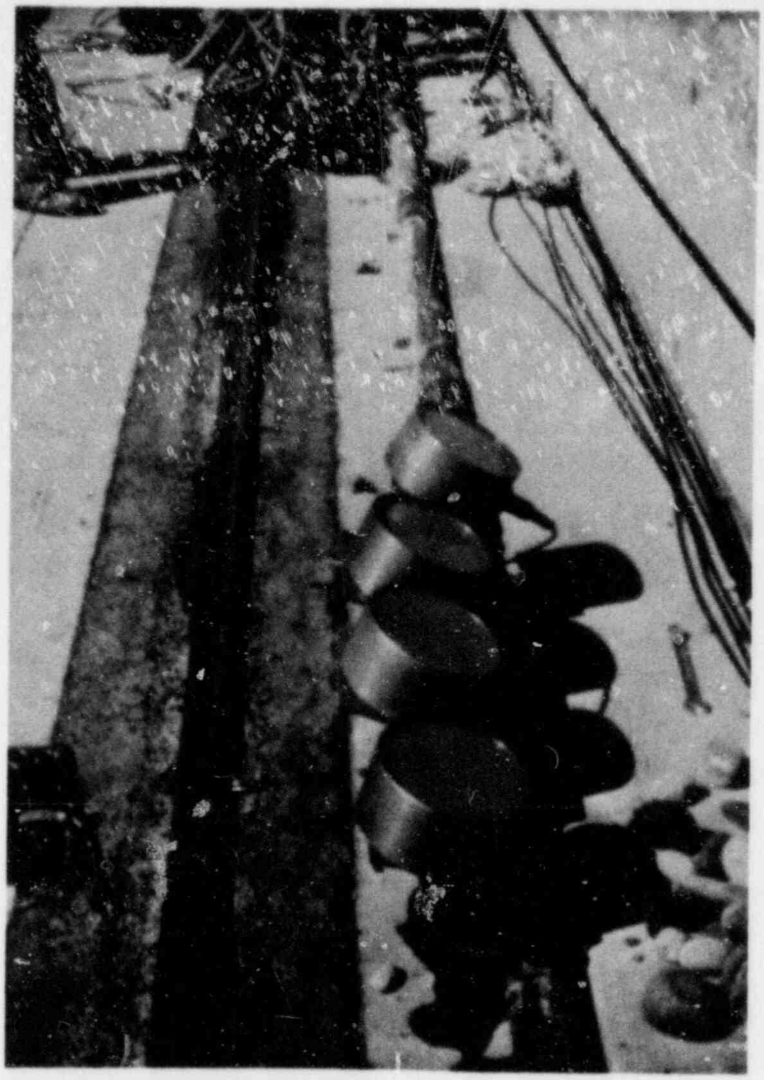

Fig. 33. Transducer array. Set of four fixed transducers to be hung horizontally between piers of an intake structure at Priest Rapids Dam, Wash. Source: BioSonics, Seattle, Wash., with permission.

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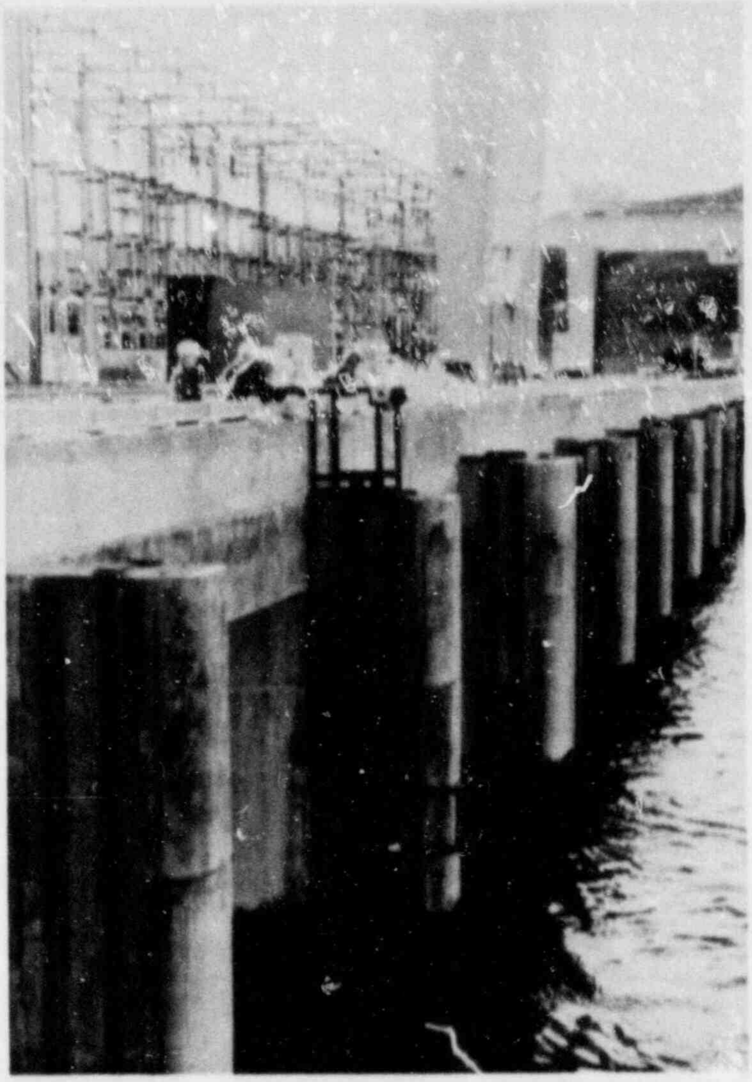

Fig. 34. Hydroacoustic monitoring of an intake structure. A transducer array placed in front of an intake structure on the Wells Dam, Columbia River, Wash. Source: BioSonics, Seattle, Wash., with permission.

situations where records of mid-water moving species are required, a buoy-mounted, downward- or upward-looking transducer may be required. In such cases, the signal may be transmitted and received using cable run to shore or by using telemetry to a shore station or mother ship (Lord et al. 1976).

Mobile systems require the transducer to be hull mounted or towed behind or alongside the vessel (Figs. 10, 12). Hull-mounted transducers are less prone to damage but require installation, are difficult to move from vessel to vessel (or to access for maintenance or calibration), are susceptible to hydroacoustic ship noises, and are affected by excessive ship motion (transducer moving through an arc with pitch and roll instead of pointing straight down).

Towed bodies allow great flexibility of transducer deployment. Usually they are towed near the surface, with the transducer facing downward. In this mode, they are relatively stable, and large tow bodies can be towed at speeds of over 10 knots through rough seas (over 5-m swells; personal communication, Michael C. Macaulay, University of Washington, Seattle). Towed bodies can even house more than one transducer, allowing multiple frequency use (Acker et al. 1975). Under such conditions, air bubbles trapped under the hull because of pounding in the seas would interfere with hull-mounted transducers, and more traditional sampling techniques would be prohibited. In salt water, where increased signal attenuation can limit the depth to which a surface transducer can operate, a downward-looking transducer mounted in a body towed at depth overcomes this interference. If the species of interest is located near the bottom, for example, in 300 m of water, the towed body can be deployed at 200 m, and insonify only the 200-300 m-depth range of interest.

A typical research vessel for hydroacoustic work in semi-sheltered waters might be a semidisplacement, 7-15 m boat with an enclosed cabin, a towing winch and small A frame, and 115-V filtered AC power supply. However, depending upon environmental constraints, hydroacoustic survey vessels can be as small as an outboard skiff (battery-powered hydroacoustic instruments allow their use on vessels lacking AC power) or as large as an ocean-going research ship.

In most cases, the transducer is placed in a towed body and towed alongside or behind the vessel. However, in shallow areas where the boat's passage may affect fish distribution below the boat, a bowsprit arrangement can be used to allow the transducer to be towed slightly ahead of the vessel (Thomas et al. 1980).

2.3.2 Sampling Design

Survey design for any aquatic sampling program is a topic in itself, and only a few comments are appropriate here. By its very nature, hydroacoustic equipment encourages more and larger areas to be surveyed, which leads to the collection of larger amounts of data, a boon to the fishery scientist attempting to make statistically defendable statements on fish abundance and distribution. A traditional trawl might be towed at 2 knots and sample a 2-5-m-wide path at one depth; a hydroacoustic survey can be done at 10 knots, sample all depths (except near-surface and near-bottom) and a much wider area (a 10° beam width sees about a 17-m-wide path at 100 m depth). For example, the time, effort, and manpower necessary to conventionally trawl a stretch of water at a single depth could allow a hydroacoustic team to survey 10 times the area simultaneously sampling all depths. These capabilities can not be overstressed as advantages of hydroacoustic survey techniques over conventional techniques.

Hydroacoustic surveys using mobile transducers essentially use line sampling techniques, as opposed to point sampling. The transects can be quite long. Hydroacoustic sampling is relatively unique in this aspect, even compared to trawl sampling. Hydroacoustic sampling often takes the form of uninterrupted transects orders of magnitude longer than trawl transects would be in the same area. For example, Hewitt et al. (1976) used hydroacoustic equipment to twice survey a 1000 km transect of the Los Angeles Bight in only two weeks.

The most efficient and accurate methods of conducting line surveys have been investigated by a number of researchers (e.g., Nickerson and Dowd 1977. Bazigos (1976) categorizes such surveys into

1. parallel grids,
2. zig-zags, and
3. stratified parallel sample tracks.

These survey techniques are illustrated in Fig. 35. Bazigos suggests that when there is a lack of baseline information about the distribution of the species in question, the method of parallel grids should be employed. The interval between the parallel sample tracks is determined by factors such as the needed precision (necessitating small intervals), local wind and sea conditions, and time and cost constraints. An alternative to the parallel grid method is zig-zag sampling, either a single zig-zag pattern, or multiple shifted patterns. The third recommended method is the sample track or stratified method. The area to be sampled is divided into equal area strata and tracks (either randomly placed or uniform) within each strata are hydroacoustically sampled.

Zig-zag hydroacoustic surveys are probably the most common perhaps because they define a path that is easy to steer. They have been used by Johannesson and Losse (1977) to estimate anchovy and horse mackerel in the Black Sea, by Nickerson and Dowd (1977) on a groundfish inventory off the coast of Nova Scotia, by Thorne (1973) to estimate the hake population in Port Susan, Washington, and by Hewitt et al. (1976) in their 2000+ km survey of the Los Angeles Bight.

In one of the first attempts to use Monte-Carlo simulation methods to quantify various hydroacoustic sampling methods, Kimura and Lemberg (1981) studied the variability of line intercept density estimates using zig-zag, stratified parallel (uniform intervals between

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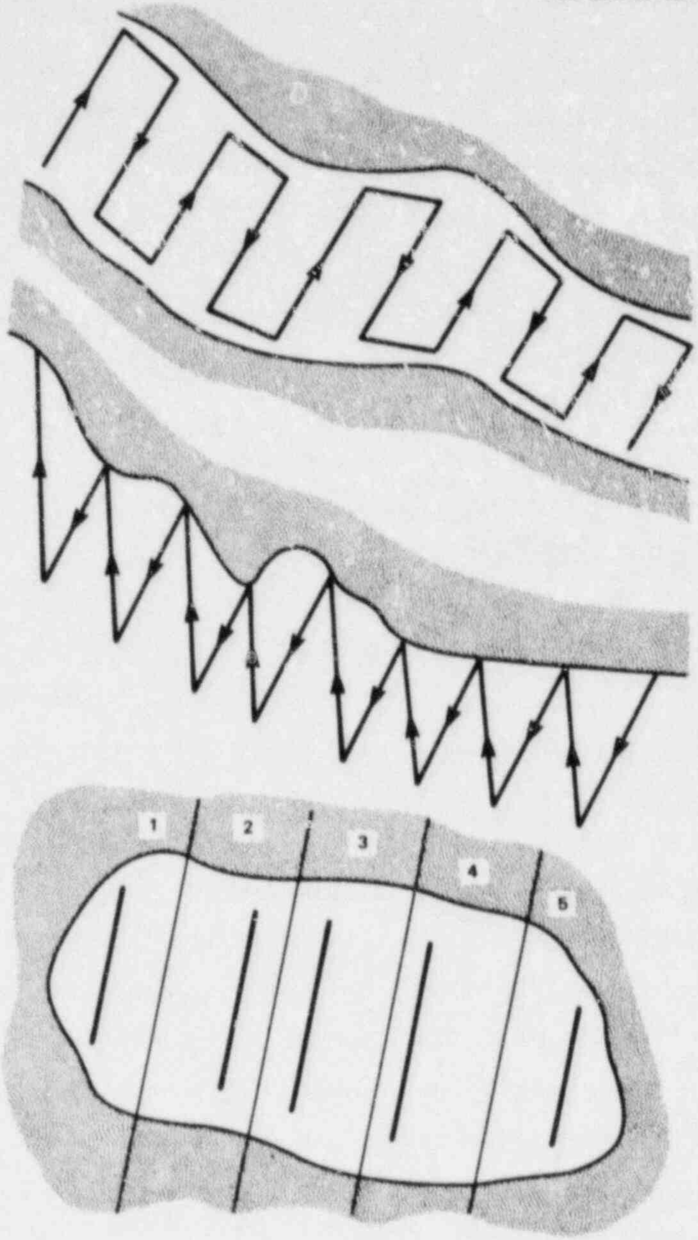

Fig. 35. Sampling schemes. Top to bottom: parallel grids, zig-zag, sample tracks (stratified parallel, where sample transects are randomly placed within equal areas, 1-5). Using Monte-Carlo simulation (Kimura and Lemberg 1981) it has been demonstrated that zig-zag sampling is most efficient for low fish densities, and stratified parallel most efficient for high fish densities.

transects), and random parallel (random intervals between transects) sampling. Their conclusions were:

1. Random parallel sampling was the least efficient.
2. Zig-zag sampling was the most efficient method for sampling low densities.
3. Stratified parallel was the most efficient for sampling high densities.
4. Fish school configuration strongly influenced density estimates.
5. Increasing sampling effort reduced variance due to schooling.

An alternative survey scheme proposed by the FAO (1977) as being an efficient use of ship time uses intensive, parallel grid surveys in areas of high concentrations of commercially important fish and a less concentrated, zig-zag survey for areas of noncommercially important fish concentrations (Fig. 36). This method could be adapted when surveying any areas of higher vs lower interest. The statistical interpretation of any hydroacoustic sampling effort, as with the result of any field sampling program, can be complex, and the use of double sampling, two-stage sampling, stratified sampling, and the problem of serial correlation of data is beyond the scope of this document. However, the statistical interpretation of hydroacoustic data is an important consideration and should be addressed before the start of any survey effort. For reference, see Bazigos (1975, 1976), Bazigos and Henderson (1975), Bodholt (1977), Ehrenberg (1973, 1974), Ehrenberg and Lytle (1977), Lord (1973), Thorne (1978), MacNeil (1971), Bodholt (1977), and Appendix C.

2.3.3 Equipment Calibration

The proper and frequent calibration of hydroacoustic equipment in the laboratory and field cannot be overemphasized as vitally important in the quantitative estimation of fish biomass. Calibration can be as

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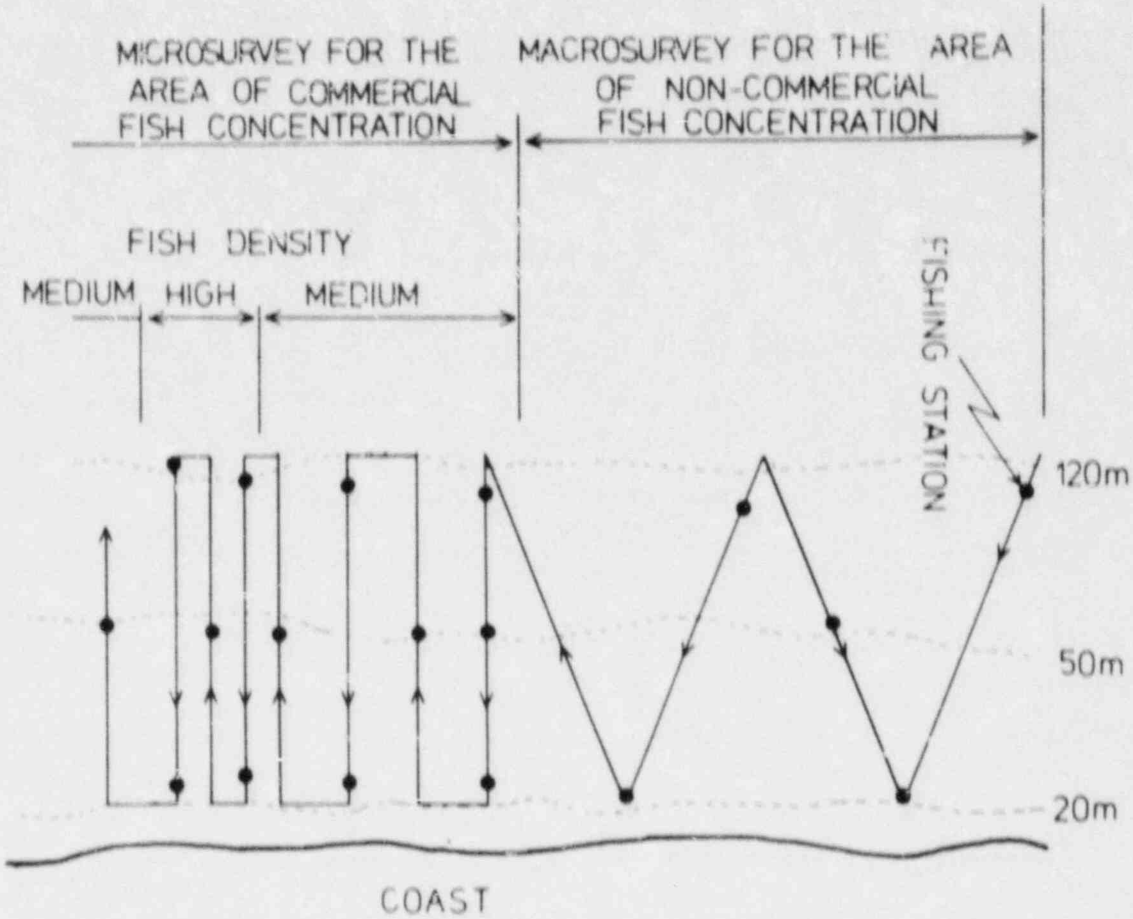

Fig. 36. Hydroacoustic sampling scheme. This scheme partitions areas into high vs low interest and was proposed as being efficient use of time and materials. Source: Adapted from FAO, 1977, with permission.

simple as using the same gain setting on the chart recorder or as complicated as having the transducer calibrated in an acoustics laboratory tank.

Many types of hydroacoustic equipment calibration, such as transducer calibration or overall gain measurements, are beyond the talents and resources of most researchers. For these calibrations, the equipment should be periodically returned (perhaps once per year) to the manufacturer or to a qualified acoustics laboratory (e.g., the Applied Physics Laboratory, University of Washington, Seattle) for such measurements. The equipment actually to be used in the field (including all cables cut to length with connectors) should be included so that the laboratory calibration will simulate field conditions as closely or possible.

There are, however, calibrations that the hydroacoustic researcher can make; these should be detailed in the manufacturer's instructions. For example, the field biologist can use a standard target to adjust system gain and calibrate the echo integration system (if it is employed). A standard target might be a ping-pong ball. Ping-pong balls are remarkably consistent in their acoustic reflective properties, averaging about -42 dB target strength. Such a ball can be attached to a line and sinker and lowered beneath the vessel and transducer (Fig. 37). Target strength measurements can then be measured on the oscilloscope display, or gain adjustments can be made on the chart recorder.

It is necessary to estimate the average target strength of the species in question in order to use echo integration methods to estimate biomass. This estimate can be obtained from the literature (Foote 1980, Goddard and Welsby 1976, Huang and Clay 1980, and Love 1978) or can be made in the field by suspending caged fish under the vessel and actually measuring target strength of these known targets (Fig. 38). This method has many variations and assumptions (e.g., that fish will maintain their natural orientation in the cage, see Fig. 3) but has been useful in providing much of our information on species target strength.

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Fig. 37. The ping-pong ball standard target. A ping-pong ball, attached by monofilament line to a lead weight, makes a convenient standard target of about -42 dB. when suspended below the vessel and transducer. It allows calibration of the hydroacoustic equipment, a function vital to the accurate interpretation of hydroacoustic data. Photo by P. Kanciruk.

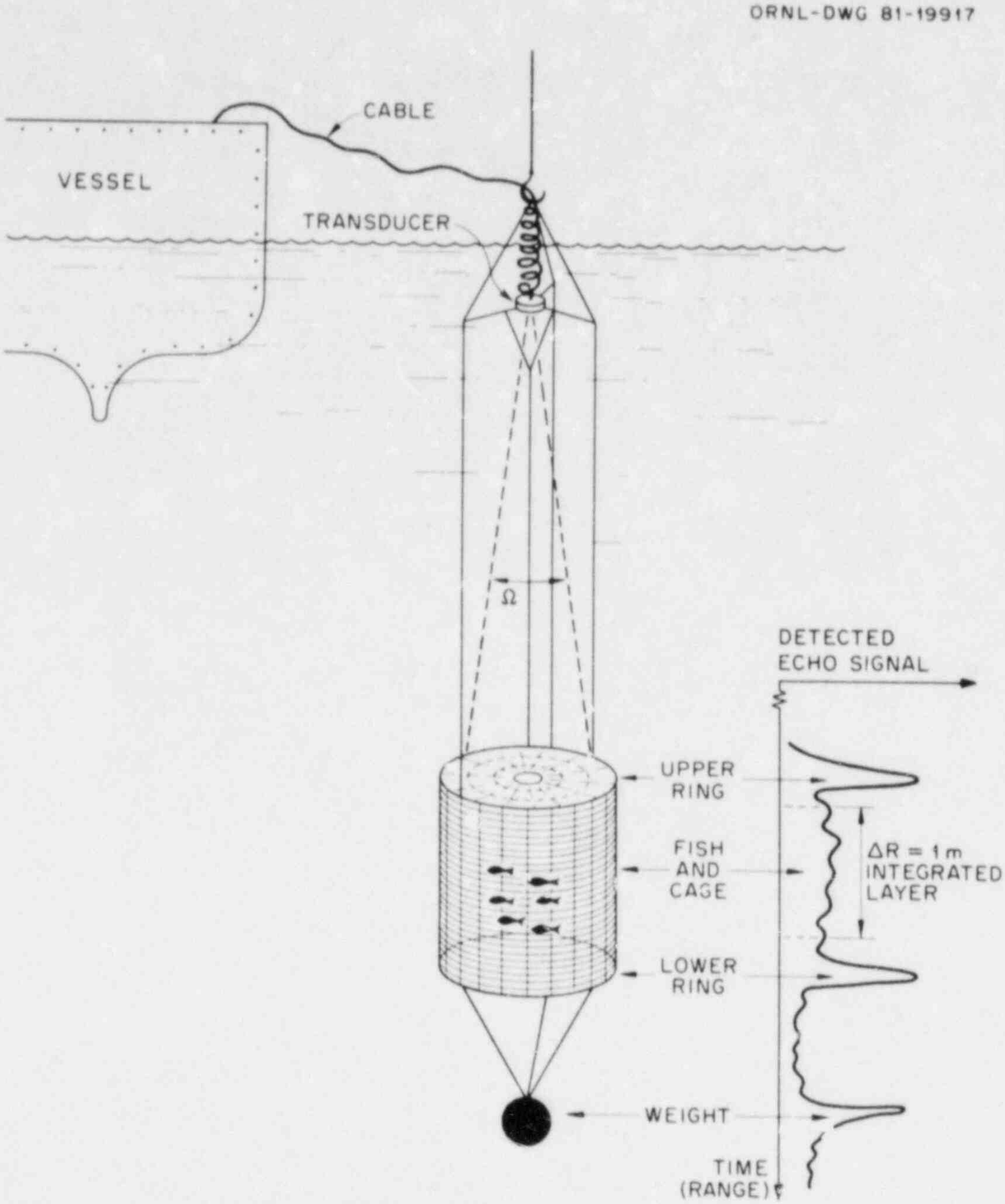

Fig. 38. Estimation of fish target strengths. Captive fish can be placed in a cage (often constructed of acoustically semi-transparent material such as nylon) and suspended below the transducer. The acoustic returns from the cage and weight are ignored, and returns from the fish integrated producing an average target strength. Source: Adapted from Burczynski 1979, with permission.

3. CASE STUDIES

Hydroacoustic methods have been successfully applied in scientific fisheries assessment for over two decades. This section is a review of the use of hydroacoustic techniques in both marine and freshwater environments. It illustrates the application and flexibility of these techniques to a variety of survey objectives. It is divided into section as pelagic/coastal/estuarine and lake/reservoir/riverine studies. Case studies involving power plant monitoring (regardless of environment) are reviewed in Sect. 4.1 Information on the application of hydroacoustics is also available from the User Survey, Appendix B.

3.1 Pelagic/Coastal/Estuarine Studies

The majority of hydroacoustic field research deals with pelagic, coastal, or estuarine environments and species primarily because these environments support the most intense and well-funded fisheries and fishing research efforts. Secondarily, these environments are often better suited to the application of hydroacoustic techniques (in comparison to shallow streams or rivers). The major drawbacks of working in open-water situations is that larger vessels are required, sea conditions can be adverse, and hydroacoustic range is limited when using high frequencies due to increased signal attenuation in salt water (Sect. 1.1).

Useful pelagic surveys can be conducted even with relatively unsophisticated hydroacoustic gear. A hydroacoustic survey in the Barents Sea using only an echo sounder and paper recorder was conducted by the Institute of Marine Research, Bergen, Norway (Hauge and Nakken 1977). The species of interest were the capelin cod, polar cod, and redfish. A combined zig-zag and parallel survey grid pattern was employed, covering a major portion of the Barents Sea north of Norway and east of Novaya Zemlya. Standard echo traces were made on a chart recorder (specifications not given), and the data were combined with information provided by trawl catches. The echograms were visually inspected and graded as having a poor, average, or strong density for each nautical mile steamed. Haug and Nakken were able to translate these data into abundance indices for each species. They concluded that although their results might not be accurate absolute abundance estimates, they were good relative indices. They further stated that the sources of error in their hydroacoustic methods were not due to equipment variability (because they had carefully calibrated their chart recorder between runs) but were due to the variability in the visual interpretation of the echograms by the operators.

Smith (1978) used only a strip chart recorder when he reported a National Marine Fisheries Service survey of the Los Angeles Bight, which set out not to determine fish density directly, but to quantify the number of schools of fish in the area. The 11-kHz transceiver used would not have easily allowed individual fish echoes to be identified in any event due to low target resolution. The R/V David Starr Jordan steamed a two-day, 100-km survey line parallel to the coast. Hydroacoustic signals were directed both downward and to the side, with lateral signal range of about 2600 m. A total of 1729 targets (in this case schools of fish and not individual fish) were recorded. Smith was able to quantify the mean and standard deviation of fish schools (primarily northern anchovy, *Engraulis mordax*, and jack mackerel, *Trachurus symmetricus*) per kilometer steamed.

An experimental hydroacoustic technique also directed toward studying fish schools was reported by Holliday (1977). Fish schools near Santa Catalina Island were tracked using sidescan hydroacoustic gear specially designed to measure the shift in frequency of returning echoes due to fish movement relative to transducer position. This is the Doppler effect, the same principle employed in police radar. Holliday was able to determine school movement, fish school swimming speed profiles (cruising, burst endurance, and endurance speeds), and movement internal to the school. This type of information would be difficult if not impossible to obtain using other monitoring techniques, and illustrates an innovative, if experimental, application of hydroacoustic techniques.

An extensive and more traditional use of hydroacoustic techniques to directly estimate fish abundance was reported for a survey conducted off the coast of Cochin, India (FAO 1977). Fish density was determined between the 20 and 120 m isobaths along about 1000 km of coastline. A commercially available 38-kHz transducer and echo integrator was used. As discussed in the section on echo counters and integrators (Sect. 2.1.4), the use of an echo integrator requires knowledge of the average target signal strength (Sec. 2.1.4). The hydroacoustic equipment was calibrated in this study using a known concentration of live fish suspended below the transducer (Fig. 38). A zig-zag grid (Fig. 39) using about 50-km intervals between transects, with ship speed of 10 knots was used. The survey lasted 16 days. Trawls to determine species identification and hydrographic stations to define physical and chemical characteristics over the transect were also employed. The use of hydroacoustic equipment, and in particular echo integration, allowed charts of the offshore region to be generated indicating high, medium, or low fish density for both demersal and pelagic species and identification of schooling fish (Figs. 40-42).

Johannesson and Robles (1977) reported on a hydroacoustic survey off the coast of Peru to determine the abundance of the Peruvian anchovetta. A 39-kHz transducer was coupled to an echo integrator. The system was calibrated by insonifying a known number of anchovetta contained in a large net suspended under the survey vessel (Fig. 38). A parallel grid pattern was steamed along about a 220-km stretch of Peruvian coast. Trawl stations were taken along the transect to permit species identification. The results of the one-week survey allowed absolute abundance charts for the anchovetta to be drawn and an estimate of total abundance to be made (4 $\pm$ 0.44 million tons).

A novel approach to assessment of fish abundance was reported by Lord et al. (1976; also see Baldwin and Gelyman 1973). They used a number of free-floating buoys, beneath which were suspended upward-looking, 120-kHz transducers. The buoys were fitted with radio transmitters that sent the hydroacoustic information to a centrally located mother ship where it was recorded for subsequent analysis (Fig. 43). The system was designed to assess the abundance of high-seas migrating salmon but could be modified to operate in any environment where the counting or integrating equipment must be located remotely from the transceiver or transducer package.

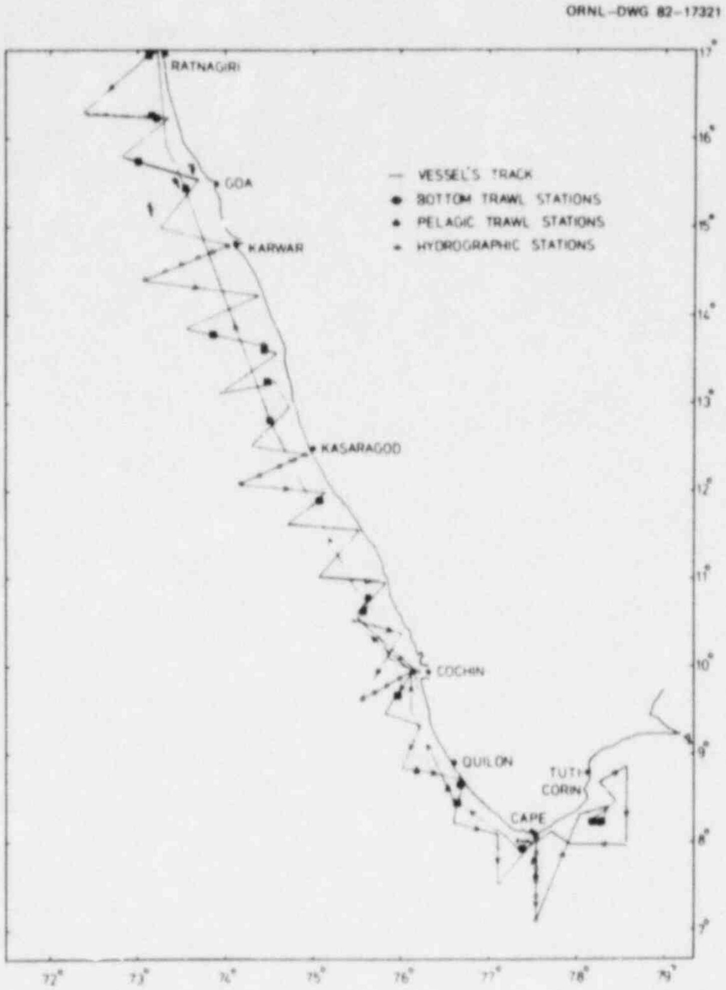

Fig. 39. Hydroacoustic transect. Transect of the survey course used by the FAO (1977). The survey incorporated hydroacoustic monitoring, bottom and pelagic trawls, and hydrographic stations (indicated). Source: FAO 1977, with permission.

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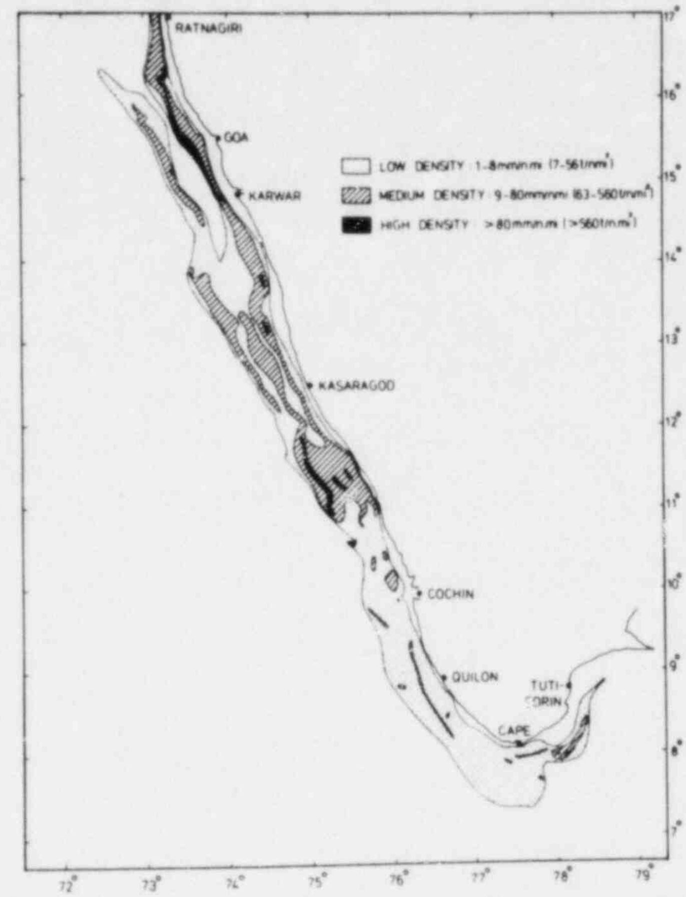

Fig. 40. Demersal fish distribution. Chart of demersal fish distribution generated with the combination of hydroacoustic data (analysized using echo integration) and spot trawls. Source: FAO 1977, with permission.

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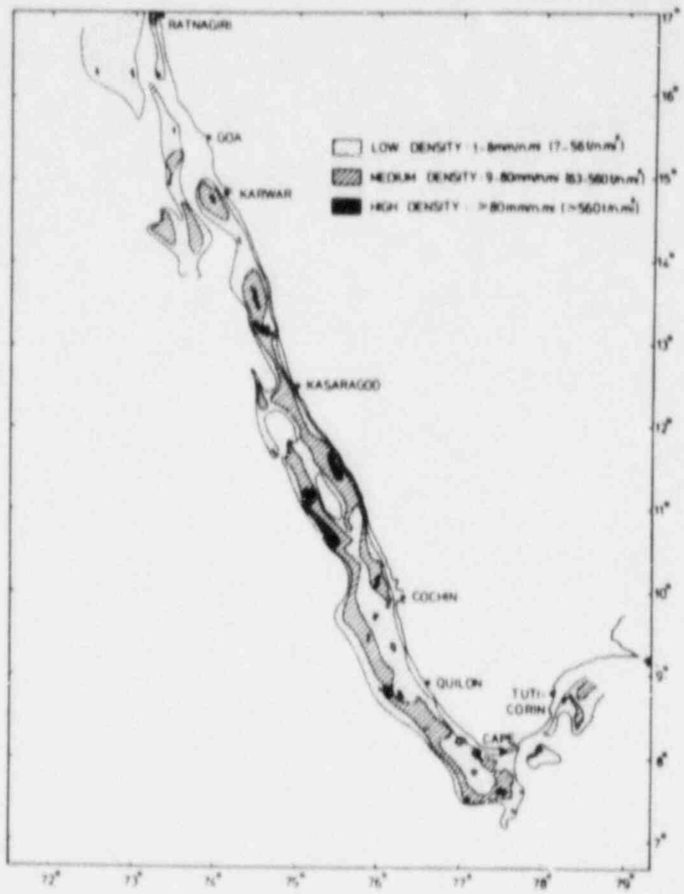

Fig. 41. Pelagic fish distribution. Pelagic fish distribution based on hydroacoustic and trawl data. Source: FAO 1977, with permission.

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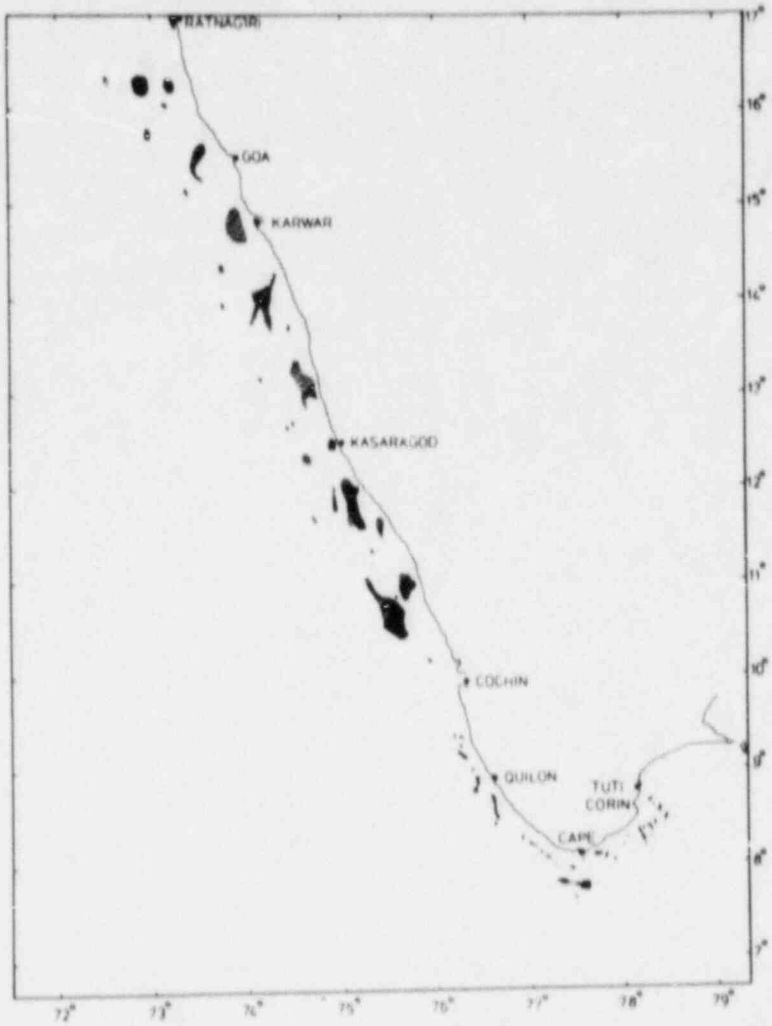

Fig. 42. Fish school distribution. Distribution of fish schools based on the hydroacoustic survey depicted in Fig. 39. Source: FAO 1977, with permission.

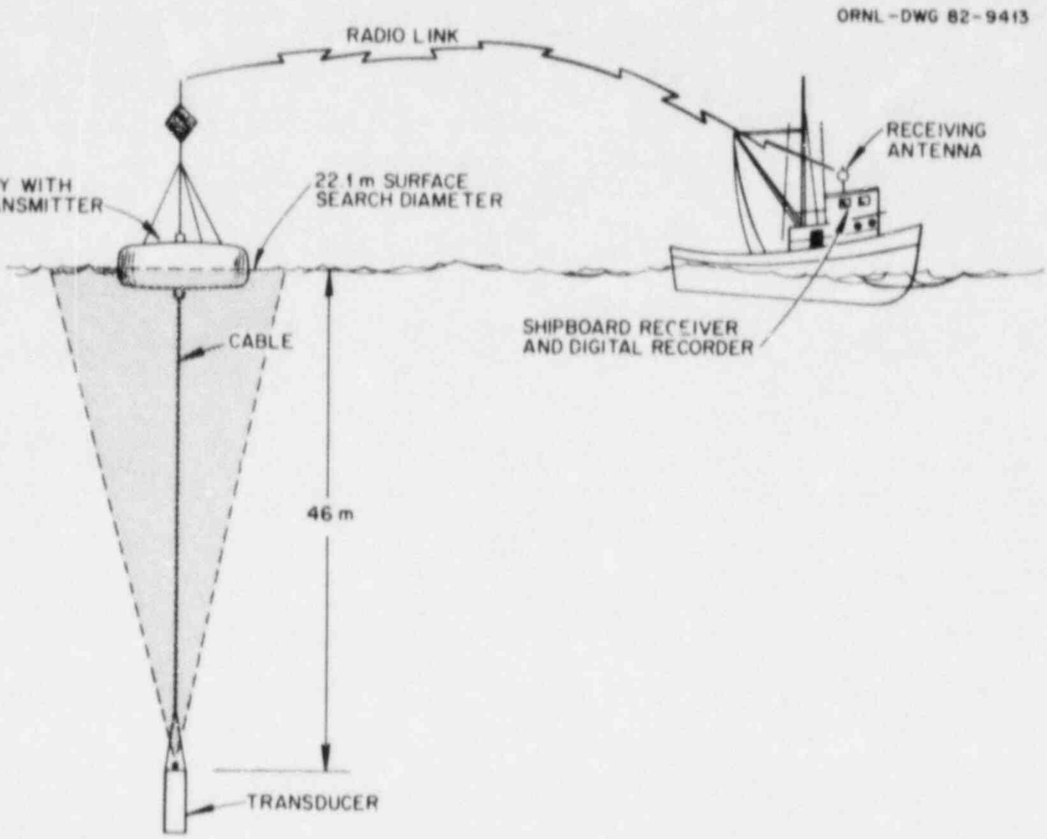

Fig. 43. Remotely monitored, buoy-mounted transducer. The upward-looking transducer suspended 46 m below the surface was designed to quantify high-seas migrating salmon populations. The use of a radio link to the mother ship allowed numerous buoy/transducers to be used at a distance from the survey vessel without the need for cables. Source: Adapted from Lord et al. 1976, with permission.

Adult and juvenile fish are not the only organisms amenable to quantification using hydroacoustic techniques. Even zooplankton densities are measurable with the proper hydroacoustic equipment (Beamish 1971, Greenblatt and Pinkel 1978, and Greenlaw 1979). Holliday and Pieper (1980) described an apparatus consisting of a side-looking transducer, a current meter, a depth sensor, and sampling hose, all of which were mounted on a rectangular frame (Fig. 44). As the apparatus was slowly lowered 100 m beneath the survey vessel the hydroacoustic signals provided a vertical profile of zooplankton density. Samples for species identification were obtained by pumping water up through the sampling hose mounted near the transducer. Using high frequencies (500-3000 kHz), Holliday and Pieper were able to quantify echoes from targets (mainly copepods and primarily Calanus pacificus) in the 1-mm-size range. The complex vertical density structure of zooplankton they documented would have been difficult (if not impossible) to obtain using nonhydroacoustic methods.

3.2 Lake/Reservoir/Riverine Studies

Reservoirs differ from lake environments in that they are man-made, have small to very large level fluctuations, usually are more turbid, and have less diverse environments. Rivers are high-current and shallow and can be very turbid environments with significant amounts of debris. Hydroacoustic surveys on lakes are often used to define overall species abundance and/or distribution (Engel and Magnuson 1971, Thorne 1979, and Thorne and Thomas 1981). Hydroacoustic surveys at reservoirs are often used to define dam passage and turbine mortality (Carlson et al. 1981). Riverine hydroacoustic surveys can be designed to quantify migratory species, especially commercially valuable salmonids (Engel and Magnuson 1971 and Thorne and Thomas 1981). This section reviews some of the literature dealing with the use of hydroacoustic techniques in these environs. Surveys defining power plant effects are discussed in Sect. 4.1.

Engel and Magnuson (1971) used very simple hydroacoustic equipment to determine pelagic vertical distribution of coho salmon (Coregonus

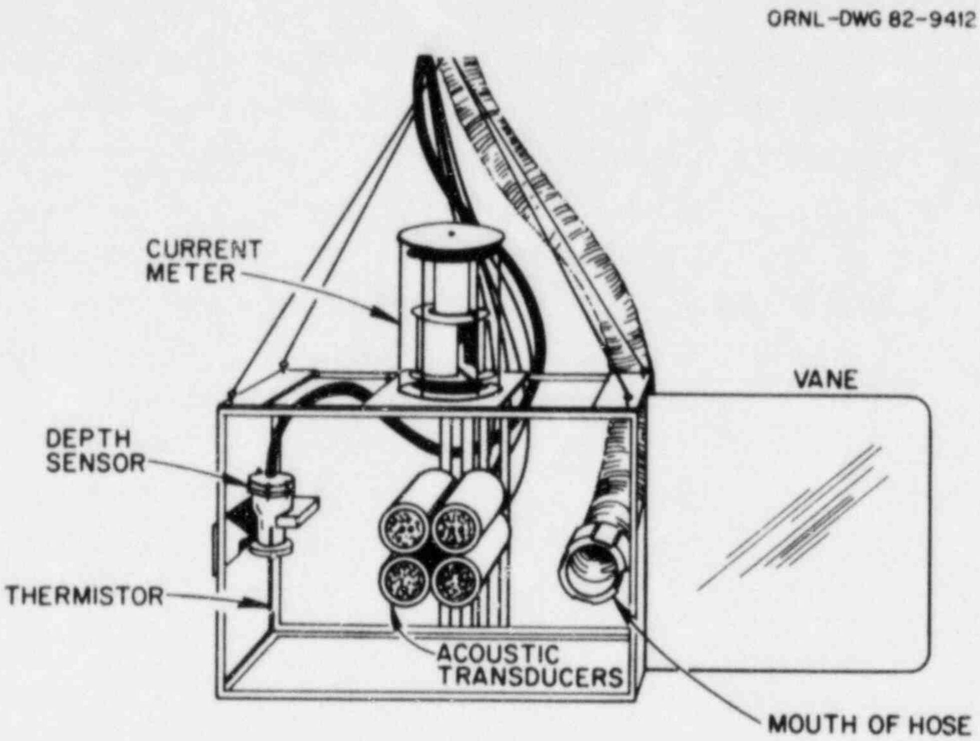

Fig. 44. Hydroacoustic zooplankton sampler. Side-looking, high frequency transducers (500-3,000 kHz) were mounted on a cage and slowly lowered beneath the survey vessel. The use of high frequencies allowed resolution of zooplankton in the 1-mm-size-range. The hose mounted on the cage permitted simultaneous water samples to be obtained for species identification. Source: Holliday and Pieper 1980, with permission.

artedii) and yellow perch (Perca flavescens) in Pallette Lake, Wisconsin. They were interested in determining the seasonal variability in vertical and horizontal distribution as a way to define the interaction between native perch and introduced salmon populations. A hydroacoustic chart recorder (50 kHz) was simultaneously operated with deployment of vertical gill nets. These echograms clearly recorded a heavy concentration of fish along the metalimnion from shoreline to shoreline--information which the gill nets alone could only have provided at distinct sampling stations. The echograms also defined a nocturnal concentration of small food organisms (probably pupae of the aquatic insect Chaoborus punctipennis) at and near the surface.

Tanaka and Ou (1977) hydroacoustically assessed populations of himemasu (Oncorhynchus nerka), biwamasu (Oncorhynchus rhodurus,), and rainbow trout (Salmo fontinalis) that were stocked in a small, shallow mountain lake in Japan (Lake Yunoko). They used minimal hydroacoustic equipment, a 200-kHz sounder and chart recorder, calibrated using a ping-pong ball. They employed a zig-zag survey pattern of the small lake (0.35 km^2 surface area) and compared fish counts taken off the echograms with a simultaneous creel census. Good correlation was obtained between the hydroacoustic biomass estimates and the creel census, although the first 4 m below the surface were hydroacoustically unmeasurable due to poor side-lobe characteristics of their transducer, which injected considerable surface noise into the system.

Kelso, Pickett, and Dowd (1974) quantitatively determined abundance of smelt in Lake Erie and alewife in Lake Ontario as a function of depth. They used a 200-kHz transducer, oscilloscope display, and a digital echo counter of hybrid design. Hydroacoustic equipment was used in conjunction with midwater trawls for species identification and for density estimates as a check against the hydroacoustic data. They determined that the hydroacoustic fish count estimates were in good agreement with the trawl estimates (overall correlation of 0.94), an agreement which other researchers have also reported (Dowd 1967). The question as to whether the small discrepancy observed was due to errors in hydroacoustic or trawl techniques is a mute point. They concluded that their hydroacoustic techniques

1. responded linearly to fish abundance (as long as density was low enough to prevent multiple-echoes that otherwise would necessitate echo integration techniques),
2. did not separate species, and
3. provided a rapid method for assessing the abundance of pelagic fishes.

Hydroacoustic estimates of sockeye salmon (Oncorhynchus nerka) in Lake Washington have been numerous (Thorne et al. 1975, 1979; Thorne and Dawson 1974) because of the importance of this fishery in the Pacific Northwest and because Lake Washington is near the University of Washington's Applied Physics Laboratory, College of Fisheries and Fisheries Research Institute.

Thorne (1979) reports on three years of hydroacoustic surveying of sockeye in Lake Washington to help establish local salmon management policies. Adult sockeye migrate into Lake Washington and remain for several weeks before continuing the upstream spawning migration. While in the lake they are subject to sport and commercial fisheries (gill netting). The fishery manager's role is to allow cropping of these adults without harmfully reducing escapement levels into upstream spawning areas. Therefore, managers need information on total run size. However, the use of hydroacoustic techniques to estimate the salmon run is complicated since migrating adults mix in Lake Washington with smaller resident salmon. To overcome this, Thorne used a 105-kHz sounder with a 8° transducer. He set the sensitivity threshold on the receiver so that only larger, migrating salmon would be detected.

The hydroacoustic biomass estimates of adult sockeye reported by Thorne agreed well with visual estimates (made by the Washington State Department of Fisheries) of fish passing through locks feeding Lake Washington. Thorne concluded that, in addition to accuracy, hydroacoustic techniques required considerably less manpower and provided rapid population estimates allowing for adjustment of management estimates and additional recreational and commercial fishing to occur.

Mathisen et al. (1977) also studied salmon but estimated juvenile salmon densities in Lake Quinault, Washington. They used a 105-kHz system, towed transducer, echo integrator and adjusted their equipment to the maximum gain possible (short of tape saturation). Their study concluded "acoustic methods have proved superior to any other method in assessing the pelagic population of juvenile salmon."

A study was recently undertaken to quantify the population of introduced lake trout in Twin Lakes, Colorado, prior to the startup of a 200-MW pump-storage operation linking the two lakes (Thorne and Thomas 1981). A 120-kHz sounder powering a 10° transducer was connected to a chart recorder for visual output. The echoes were also recorded on tape for offsite echo counting analysis (echo counting applicable due to low fish densities). The transducer was deployed from a 5-m skiff, illustrating the portability and modest vessel requirements of some hydroacoustic equipment used in sheltered environments. For survey purposes, the lakes were divided into seven transect regions, three depths (3-7.5 m, 7.5-16 m, and 16-25 m), and targets (fish) into five size categories (1-5, with 5 largest). The resulting fish counts, partitioned into 105 area/depth/size classes (7 areas x 3 depths x 5 fish-size classes), exemplify the detail of information even a modest, two-day survey can produce using hydroacoustic equipment.

The concluding example of the use of hydroacoustic techniques in freshwater systems illustrates the versatility of these methods. Shireman and Maceina (1979) of the Aquatic Weeds Research Center, University of Florida, Gainsville, reported favorably on the ability of a simple recording echo-sounder to quantify the biomass of Hydrilla in two central Florida lakes. Using a transducer mounted to the transom of a 5-m aluminum Jon boat, they obtained records of thick Hydrilla plants growing from the bottom of the lake. They were able to obtain valid and accurate quantitative data on

1. percent transect cover,
2. total percent cover,
3. percent vertical area infestation,
4. biomass and total standing crop,
5. mean *Hydrilla* height off the bottom, and
6. mean water surface-to-*Hydrilla* distance.

The wide-variety of hydroacoustic studies documented in this section indicates that the application of hydroacoustic techniques is perhaps most limited by the imagination of the researcher.

4. APPLICABILITY TO POWER PLANT MONITORING

The successful application of hydroacoustic techniques in a variety of biological surveys documented in the previous section clearly demonstrates that these techniques can augment power plant impact studies where an overall quantitative aquatic census is desired. In addition to general surveys, however, these techniques can be applied to answer specific concerns uniquely associated with power plant construction and operation.

4.1 Case Studies

Kelso and Minns (1975) studied the relationship between thermal discharge and fish distribution at the Pickering Nuclear Generating Station at Lake Ontario. Transects were made from 0.2 to 2.9 km out from and parallel to the shoreline. They used a five-thermister towed array to measure the vertical temperature profile (manually extracting temperatures over a 10-m depth from a strip chart recorder). The acoustic equipment consisted of a 200-kHz transducer and a custom fish counter that stored fish counts for five 5-m-depth shells (2.5 through 22.5 m). Species composition information was obtained using hoop net sampling.

Kelso and Minns determined that the nearshore populations were dominated by brown bullhead and the offshore community by alewives and smelt. Densities ranged from about 21 to 1040 fish/10,000 m^3. Hydroacoustic and thermal data indicated that when the vertical temperature profile was relatively homogeneous, fish distribution was more uniform. Observing plume and nonplume conditions, they concluded that species abundance and distribution were not appreciably affected by the presence of the nuclear generating station's thermal plume. This study would have been difficult to duplicate without using hydroacoustic methods.

Minns et al. (1978) studied fish spatial distribution and abundance near the thermal outfalls of two generating stations, Nanticoke (Lake Erie, a coal-fired plant) and Douglas Point (Lake Huron, a nuclear plant). These studies employed hydroacoustic techniques, simultaneous towed vertical thermister arrays, and gill or trap nets for species identification. By comparing abundance on thermal vs nonthermal load days they concluded that water turbulence, rather than thermal plumes, was responsible for fish aggregation near discharge areas. They observed that the use of hydroacoustic biomass estimation techniques uniquely allowed examination of the effect of environmental factors acting in concert (temperature, light, current, etc.) to influence spatial distribution of fish.

Richkus et al. (1977) documented the abundance of fish in semienclosed power plant intake embayments as a function of environmental factors, abundance outside the embayments, and how abundance in the embayments correlated with fish impingement on the intake screens. They collected data at the Morgantown Power Plant, located on the Potomac River, using a combination of hydroacoustic and trawl sampling techniques. Only hydroacoustic equipment could be used within the embayment due to its small size. A 105-kHz transmitter was used to drive a wide-beam transducer (22° beam used to sample a large volume of water) that was either towed behind a small skiff in a downscan mode or placed on the bottom in an upward-loading mode. Outside the embayments, the transducer was towed in a downscan mode, with trawls used for species identification. The echoes were recorded and contracted for offsite analysis using echo integration.

Their results indicated that few fish congregated near the intake screens or bottom, probably due to increased water velocities. This distribution explained that, in spite of high densities of fish in the intake embayment, relatively low fish impingement on the intake screens was observed. They also noted consistency between acoustic biomass estimates within sampling dates and concluded that their study demonstrated the overall feasibility of using hydroacoustic techniques to estimate fish density in confined power plant intake embayments.

Thomas et al. (1980) conducted hydroacoustic surveys at four Southern California Edison electric-generating stations located on the

Southern California coastline (Ormond Beach, EL Segundo, Huntington Beach, and San Onofre). They were interested in defining fish entrainment in these once-thru cooling systems as a function of

1. fish density near the offshore, tower intakes;
2. water transparency;
3. presence of a velocity cap on the intake structure; and
4. intake water volume flow.

The hydroacoustic equipment used consisted of a 120-kHz transducer with a transducer mounted in a 0.6 m tow body towed at 4 knots 2 m in front of the 7-m outboard boat (from an elongated bowsprit). Transducer placement reduced the influence of the boat's passage on the distribution of the fish at the shallow intake sites. Two 600-m perpendicular transects were run (intersecting over the intake sites) twice per hour. The data were analyzed by echo integration with offsite PDP-11 minicomputers and software developed at the University of Washington, Seattle.

Lampara-net sampling at the intake sites was used to identify species composition and to complement the hydroacoustic biomass estimates. The latter was accomplished by fishing acoustically observed fish assemblages with the lampara net and comparing the lampara catch/unit effort with the hydroacoustic density estimates. A very good correlation was observed. An entrapment vulnerability statistic was developed. This statistic is the ratio of the weight of fish entrained by the plant to the weight of fish in the vicinity of the intake (estimated hydroacoustically). Thomas et al. determined that entrapment vulnerability increased with water turbidity, absence of a velocity cap on the intake, and increased intake flows during turbid conditions. They conclude: "Hydroacoustic techniques have been demonstrated as the only technique to date that can effectively measure nearshore fish densities in the vicinity of intakes with the speed and accuracy required to diagnose the entrapment problem."

4.2 Conclusions and Recommendations

It is clear from field cases reviewed in Sects. 3.1, 3.2, and 4.1 and the results of the user survey (Appendix B) that hydroacoustic biomass estimation techniques can be successfully applied in most aquatic environments toward achieving a variety of research goals. This is not to indicate that implementing hydroacoustic techniques is without problems, or that they can be even applied in all situations. For example, at power plant monitoring sites it is often necessary to quantify small juvenile or fry life stages, but the use of hydroacoustics on such small targets in turbid reservoir or riverine environments may be difficult (McLean et al. 1980) and require specialized equipment and techniques.

This section is a summary of the general advantages and disadvantages of hydroacoustic techniques and specifically address its applicability to the power plant ecological monitoring program.

4.2.1 Advantages and Disadvantages of Hydroacoustic Techniques

In addition to this section, also see the results of the user survey (Appendix B).

Advantages of Hydroacoustic Techniques

1. The techniques provide quantitative biomass estimation and absolute population estimations.
2. Surveys can be conducted at high speed and over long transects, providing better spatial and temporal coverage.
3. Surveys can be simultaneously conducted over multiple depth intervals.
4. Ease of acquisition of large quantitative data bases improves statistical interpretation and comparison of data.
5. Good sampling power (summation of points 1-4 above) reduces overall costs.
6. The techniques provide independence from net-avoidance problems.

7. Real-time data acquisition and interpretation are possible.
8. The techniques are not labor intensive, thus reducing overall costs.
9. Hydroacoustic techniques are nondestructive and noninvasive (neither destroying the sampled fish or disturbing the environment).
10. The techniques allow behavioral observations, in addition to density estimates, to be obtained (e.g., diurnal vertical migrations, response to power plant operating conditions).

Disadvantages of Hydroacoustic Techniques

1. Species identification is not yet possible.
2. Specialized equipment (capital expense) are needed initially.
3. Specialized personnel training and frequent calibration of equipment are required.
4. The techniques are not easily applied for near-surface, near-bottom species.
5. The techniques are not easily applied to very shallow, riverine situations (although Doppler hydroacoustic systems are being developed, which will help in these situations).
6. Quantification of fish target strength for echo integration is difficult (although introduction of dual-beam systems may address this weakness).
7. Understanding and acceptance by field biologists, educational materials (texts), and formal hydroacoustic instruction at most universities are lacking at this time.
8. There is a potential difficultly in quantifying small life stages of interest at power plant sites.

4.2.2 Applicablility to Power Plant Aquatic Monitoring Programs

Hydroacoustic biomass estimation techniques should be strongly considered for any power plant monitoring program for the following reasons:

1. Hydroacoustic techniques can provide the quantified population estimates necessary to predict and monitor operational impacts. These estimates are often statistically defendable due to large sample sizes involved--a data characteristic of no small merit in adjudicatory proceedings.

2. Power plant studies have unique sampling problems suitable for hydroacoustic techniques. For example, density estimation in confined intake embayments and in front of intake screens.

3. Power plant monitoring programs are of sufficient importance, duration, and funding levels to justify the expense of equipment acquisition and operator training (these additional costs may also be offset by increased sampling efficiency and reduced vessel and/or personnel requirements).

Hydroacoustic techniques are not the answer to all sampling problems. For example:

1. Species identification can be only inferentially determined in single-species situations or where there are clear spatial and/or temporal separations between species. Species identification is problematic where mixed assemblages occur.

2. Biomass estimation of juvenile and/or larval populations, often of importance in estimating entrainment impacts, may be difficult and require specialized equipment (e.g., high-frequency transducer short-pulse width systems).

3. Biomass estimation in confined areas (intake structures, embayments, etc.) may require specialized equipment (e.g., very narrow-beam transducers with small side-lobe characteristics to reduce extraneous noise).

Such applications may require special considerations, but hydroacoustic techniques have been used successfully to augment power plant monitoring programs, and can provide information not available using other methods. They should be applied to general aquatic surveys and in specific power plant monitoring applications, whenever feasible.

McKenzie et al. (1979) reviewing the application of fisheries management techniques to the assessment of impact, conclude that hydroacoustic techniques do have limitations, but (and I concur):

> Under conditions favorable for acoustic surveys no other estimation procedure can provide the quantity of information, accuracy of estimation and speed of data acquisition on the demographics of fish.

APPENDIX A

GLOSSARY OF TECHNICAL TERMS

Acoustic -- having to do with sound.

Acoustic signature -- particular reverberation of sound and reflections from a target (usually with swim bladder), which typyfies that target and may someday be used for species identification.

Acoustic taging -- ultrasonic transmitters (∿70 khz) attached to fish used to track their movements - not a hydroacoustic biomass estimation technique.

Attenuation -- loss of acoustic signal strength due to internal friction within a water body. Attenuation is greater for salt water systems.

Beam width -- angle of transducer acoustic beam. Transducers are usually classified as wide-(perhaps 15°) or narrow (perhaps 4°)-beam units.

Biological background noise -- noise due to biological sources, usually much lower in frequency than hydroacoustic signals and not a problem in signal interpretation.

Biomass density -- measured as g/m^3, or $kg/10,000\ m^3$, or # fish/10,000 m^3, for example.

Calibration -- method of defining and setting characteristics of the electronic/mechanical equipment which allows repeatability of results. Very important in quantitative hydroacoustic work.

Decibel -- logarithmic measure of sound levels (intensity, power) relative to a standard.

Deep scattering layer -- layer of small fish and invertebrates in the deep ocean which undergoes diel vertical migrations and shows up as a 'fake bottom' echo on echograms.

Depth finder -- simple hydroacoustic device for determining water depth; often not suitable for fisheries research.

Depth sounder -- see depth finder.

Directed net fishing -- use of hull, towed, and especially net-mounted transducers to direct trawls to proper location and depth to maximize catch.

APPENDIX A (continued)

Directivity pattern -- pattern of sensitivity or efficiency of a transducer in transmitting and receiving hydroacoustic signals. Best efficiency is on-axis, usually falling off rapidly off-axis.

Doppler effect -- the alteration of apparent frequency when the sound source is moving relative to the observer, or when the target is moving relative to the transducer.

Down-scan sonar -- a downward-looking transducer

Dual-beam sonar -- simultaneous use of wide and narrow beam transducers, allowing in-situ estimation of target strength.

Echo -- returning sound reflected off a target of density differing from the medium in which the sound is traveling.

Echosounder -- see depth finder; echosounders usually have a paper chart output.

Frequency -- the number of pressure maxima (or minima) passing a fixed point is one second. Units are Hertz (Hz). Hydroacoustic systems usually have frequencies in the range of 20-500 kHz.

Ground truth -- use of trawls, gill-nets, etc., to independently estimate biomass and provide species identification hydroacoustic data.

Hertz -- frequency, defined as one-per-second, abbreviated as Hz.

Hydroacoustics -- the study or use of sound in water to remotely obtain information about the physical characteristics of the water body, its bathymetry, or biotic populations.

Incident sound -- sound which impinges on a target.

Insonified volume -- volume of water into which acoustic signals are directed to obtain biomass information.

Integrated layer -- layer of water, defined by upper and lower depths, which integrated biomass estimates or fish counts are based.

Integrator -- the computerized integration of fish echoes to estimate biomass.

Kilohertz (kHz) -- 1,000 Hz.

Medium -- substance in which sound is traveling.

Multiple targets -- more than one target within the beam of the transducer.

APPENDIX A (continued)

Noise -- unwanted electrical signals originating within the equipment or from hull or water sounds picked-up by the transducer.

Power -- usually measured as watts input to the transducer, typically 500 to 5,000 watts in typical hydroacoustic systems.

Propagation -- ability of acoustic signals to progress outward in a medium.

Pulse duration -- length of time a pulse of a given frequency is emitted by the transducer.

Pulse repetition rate -- the rate of repetition acoustic pulses, of a given pulse duration and frequency, emitted by a transducer.

Receiver -- instrument to amplify, filter and otherwise process electronic signals (echoes) produced by the transducer.

Reflection -- the "bouncing" of sound off a target, due to the differences in density between medium and target and target orientation.

Refraction -- deflection of sound from a straight path, e.g., when passing through a thermocline at an angle.

Sector scanning -- the use of a multiple transducer array, with each transducer insonifying only a portion of the total area of interest, to increase overall transducer coverage.

Side-scan sonar -- side-looking transducer, usually used by commerical fisherman to spot distant fish schools.

Sound intensity -- power of sound waves, measured in $ergs/cm^3/s$.

Sound radiation -- spreading of sound equally in all directions.

Sound velocity -- velocity of sound through a medium; in water, about 1500 m/sec, and dependent upon temperature, salinity and depth.

Sound wave -- pressure maxima and minima moving within a compressable medium.

Stationary transducer -- transducer fixed to buoy or to the bottom looking upward, sideward or downward.

Stylus -- electrical 'pen' on chart recorder which marks paper to indicate echo returns as it passes over the chart.

Swimbladder resonance -- characteristic 'ringing' of air-filled swim bladders when insonified by a hydroacoustic system.

APPENDIX A (continued)

Target strength -- the ability of a given target to reflect acoustic signals; usually given in terms of negative db's.

Time-Varied Gain (TVG) -- selective application of more gain (amplification) to echoes which take longer to return in order to compensate for their lower intensify.

Transducer -- electro-mechanical device which translates electrical energy to sound energy to produce the hydroacoustic signal, and connects returning echoes back into electrical signals.

Wavelength -- distance between soundwave successive pressure maximal. High sound frequencies have shorter wavelengths, and short wavelengths have shorter ranges underwater.

Zero line -- base line on a chart recorder (echosounder, depth sounder) representing zero time (zero depth or depth of the transducer).

APPENDIX B

HYDROACOUSTIC USER SURVEY

A user survey was sent to over 130 research institutions in this country and overseas to define user application and satisfaction with these techniques. Appendix B.1 presents the survey form; B.2 summarizes the results; B.3 lists the respondents.

B.1 User Survey

YOUR
ORGANIZATION: ____

____

____

____

NAMES OF PRINCIPAL INVESTIGATORS IN YOUR ORGANIZATION INVOLVED WITH HYDROACOUSTIC TECHNIQUES:

____

____

____

____

____

____

PERSONNEL: Number of staff actively engaged in hydroacoustic research/utilization ______; as a percent of your total staff ______%.

BUDGET: (Optional) Approximate annual funding devoted to purchasing/utilizing hydroacoustic equipment/techniques, __________ ($US).

APPENDIX B (continued)

APPLICATION: Please rank the following hydroacoustic applications as to relative importance to your organization/group:

(A)

Application	Rank	% of Total Effort
Commercial fishery assessment	_____	_____
Non-commercial fishery assessment	_____	_____
Environmental impact monitoring	_____	_____
Non-fish biotic assessment	_____	_____
Pure/applied engineering/research	_____	_____

(B)

Application	Rank	% of Total Effort
Open-ocean surveys	_____	_____
Coastal surveys	_____	_____
Inshore/littoral surveys	_____	_____
Estuarine surveys	_____	_____
River surveys	_____	_____
Lake/reservoir surveys	_____	_____
Surveys/monitoring at dam sites	_____	_____
Surveys/monitoring at power plant sites	_____	_____

Average survey speeds _____ knots.

Average survey depths _____ meters.

Use of towed body _____% of time.

Species of interest	Reason for study

APPENDIX B (continued)

EQUIPMENT: (Please include major items such as transducers, echo-sounders, tape recorders, echo-integrators, computers, etc.)

(A) Purchased:

Type	Manufacturer	Model	Frequency

(B) Developed at your organization:

Type	Frequency	Comments

Approximate total capital investment in hydroacoustic equipment (excluding vessel costs) __________ ($US).

VESSELS:

Type	Length	Exclusively used for hydroacoustic work?

APPENDIX B (continued)

MISCELLANEOUS:

Have any of your personnel received formal training in hydroacoustic techniques? _____. If yes, where? ______________________________

Do you use trawls, gillnets, etc., to "ground-truth" your hydroacoustic surveys? (Circle one) Always Often Sometimes Hardly ever

Do you use echograms, echo-counting, or echo-integration to quantify your surveys?

Echograms ____% Echo-counting ____% Echo-integration ____%

Does your application of hydroacoustic techniques include computer analysis of the signals? _____. If yes, is the analysis real-time (on board), or done at a shore station? ____________________. Do you run your own analyses or contract them out? ____________________.

What is the direct result of your hydroacoustic surveys? (example-used to set commercial fishing quotas)______________________________

____

____

Do you feel that your investment in hydroacoustic equipment/personnel is justified by the benefits gained? _____. If not, please explain:

____

____

What are the aquatic habitat/conditions you find most suitable for hydroacoustics? ____

____

What are the aquatic habitat/conditions least suited for hydroacoustics? ____

____

Has the use of hydroacoustics enabled you to reduce the cost of biomass surveying? _____

APPENDIX B (continued)

Has the use of hydroacoustics enabled you to enhance the quality of your surveys? ______

In your opinion, the greatest strengths of hydroacoustic techniques are:

1. ______________________________
2. ______________________________
3. ______________________________

In your opinion, its greatest weaknesses are:

1. ______________________________
2. ______________________________
3. ______________________________

In your opinion, the areas in hydroacoustic biomass research which need the greatest attention are:

____

____

____

APPENDIX B (continued)

B.2 Results of Hydroacoustic User Survey

The results of the user survey are presented below. This survey was distributed to over 130 organizations, with 40 responding. Over 80 researchers in 13 countries actively using hydroacoustic techniques are represented in this survey. Although it was not intended to be a statistically valid sample of the overall user population, the results indicate overwhelming satisfaction with hydroacoustic techniques applied towards a variety of scientific goals.

Summary of Results

Respondents were satisfied with the use of hydroacoustics to estimate biomass and felt the data gained justified the costs. Areas indicated as needing the greatest attention were the accurate determination of in-situ target strength and the need for methods of species identification. All felt that the use of hydroacoustics reduced their overall sampling costs, and 27 out of 28 stated that it improved the quality of their surveys. (Note that many respondents did not answer all questions and that therefore response totals vary).

Results

Number of staff actively engaged in hydroacoustic research/utilization?

Mean 6
Range 1-20

As a percent of your total staff?

Mean 22%
Range 1-100%

APPENDIX B (continued)

Approximate annual funding devoted to purchasing/utilizing hydroacoustic equipment/techniques ($US)?

Mean 260 K

Range 20-1500 K

Please rank the following hydroacoustic applications and conditions as to relative importance to your organization/group.

	Number of respondents*
Applications	
Commercial fishery assessment	21
Noncommercial fishery assessment	13
Environmental impact monitoring	6
Nonfish biotic assessment	2
Pure/applied engineering/research	16
Conditions	
Open-ocean surveys	19
Coastal surveys	21
Inshore/littoral surveys	4
Estuarine surveys	1
River surveys	3
Lake/reservoir surveys	8
Surveys/monitoring at dam sites	1
Surveys/monitoring at power plant sites	2

*Number of respondents indicating this application as their primary application (first or second in rank).

Average survey speed 7.4 knots, range 1-12 knots

Average survey depth 180 m

APPENDIX B (continued)

Use of towed body?

Percent of time	Number of respondents
100	11
>50 but <100	4
<50 but >0	6
0	9

Species of interest	Reason for study
Alewife	Fisheries assessment
Anchovy	Fisheries assessment
Pelagic fish	Research
Blue whiting	Fisheries assessment
Broad whitefish	Fisheries assessment
Capelin	Fisheries assessment
Char	Fisheries assessment
Clupeids	Fisheries assessment
Cod	Fisheries assessment
Copepods	Research
Euphausids	Research
Freshwater	Environmental impacts
Haddock	Fisheries assessment
Hake	Fisheries assessment
Herring	Fisheries assessment
Horse mackerel	Fisheries assessment
Inshore pelagic species	Fisheries assessment
Krill	Environmental impacts
Lake whitefish	Fisheries assessment

APPENDIX B (continued)

Species of interest	Reason for study
Mackerel	Fisheries assessment
Midwater fish	Research
Myctophids	Scattering layers
Nearshore marine	Environmental impacts
Northern anchory	Fisheries assessment
Norway pout	Fisheries assessment
Pacific whiting	Fisheries assessment
Pejerrey	Fisheries assessment
Pollock	Fisheries assessment
Redfish	Fisheries assessment
Rockfish	Fisheries assessment
Saithe	Fisheries assessment
Salmonids	Fisheries assessment
Sardine	Fisheries assessment
Seals/whales	Environmental impacts
Siphonophores	Scattering layers
Smelt	Environmental impacts
Snapper/grouper	Fisheries assessment/management
Sprat	Fisheries assessment
Tropical and subtropical species	Fisheries assessment
Trout	Fisheries assessment
Various	Fisheries assessment
Vendace	Environmental impacts
Walleye pollock	Fisheries assessment
Whitefish	Fisheries assessment
Whitefish	Environmental impacts
Zooplankton	Food chain research

APPENDIX B (continued)

Major equipment?

Users responded with the names of a variety of commercially purchased hydroacoustic equipment (SIMRAD, BENDIX, ROSS, BioSonics, Instruments, Inc., AMETECK, FURUNO, etc.) as well as the names of equipment developed by their own organizations. Transducer frequencies reported were as follows.

Frequency (kHz)	Number of respondents
10-40	26
41-75	17
76-120	5
121-200	6
201-500	1
501 and above	2

The predominance of low-frequency equipment reflects the fact that many of the researchers responding work primarily in deep marine environments, where low frequencies ensure adequate range.

Approximate total capital investment in hydroacoustic equipment excluding vessel costs ($US)?

Mean 340 K

Range 6-1700 K

Types of vessels?

Three groups of vessels were reported:
R/V's and large fishing vessels (trawlers) averaging about 50 m, small workboats in the 10-m class, and outboards (and even one rubber boat) in the 5- to 8-m class.

APPENDIX B (continued)

Have any of your personnel received formal training in hydroacoustic techniques?

Yes 24
No 7

If so, where?

Place	Number of respondents
University of Washington, Seattle (U.S.A.)	13
SIMRAD, Norway	2
Marine Research Institute of Bergan, Norway	2
C.N.R.S., France	1
University of Wisconsin, Madison (U.S.A.)	1
Birmingham University, England	1
Loughborough University, England	1
Fisheries Laboratory, England	1
Fisheries Laboratory, Scotland	1
Institute Oceanographic, Canada	1
Technical University of Trondheim, Norway	1

Do you use trawls, gillnets, etc., to "ground truth" your hydroacoustic surveys?

Always 23
Often 7

A number of respondents pointed out that "ground truth" is probably a poor choice of words because of the implication that trawl data could quantitatively corroborate the hydroacoustic data (they believe it could not). Trawls were used, they indicated, to provide species identification.

APPENDIX B (continued)

Do you use echograms, echo counting, or echo integration to quantify your surveys?

Echograms	36%
Echo counting	30%
Echo integration	82%

Does your application of hydroacoustic techniques include computer analysis of the signals?

Yes	20
No	8

If yes, is the analysis done on board (real time), or at a shore station?

Real time	4
Shore	6
Both	8

Do you run your own analyses or contract them out?

Do own	18
Contract out	1

What is the direct application of your hydroacoustic surveys?

Research	5
Fisheries management	21
Environmental impact studies	6

Do you feel that your investment in hydroacoustic equipment/personnel is justified by the benefits gained?

Yes	26
No	0

APPENDIX B (continued)

What are the aquatic habitats/conditions you find most suitable for hydroacoustics?

Midwater, pelagic species	16
Deep waters	6
Calm seas, overcast skies	6
Single species, finite and definable range, uniform distribution	6
Night sampling	1
Fast-flowing, low-debris rivers	1
Smooth bottom, deeper than 20 m	1

What are the aquatic habitats/conditions least suited for hydroacoustics?

Very shallow/very deep water	11
Demersal species	7
Species at surface	5
Multispecies situations, patchy distribution, migratory species	5
Rough seas, bright nights	2
Swift, turbulent rivers	2
Rough bottom/shallow water	2
Open ocean, low productivity	1
Shallow streams	1

Has the use of hydroacoustics enabled you to reduce the cost of biomass surveying?

Yes	18
No	5
Not sure	2 (i.e., little experience with equipment)

APPENDIX B (continued)

Has the use of hydroacoustics enabled you to enhance the quality of your surveys?

Yes	27
Probably	1
No	0

What are the greatest strengths of hydroacoustic techniques?

Speed of sampling	20
Sampling power (large area covered, large number of samples)	17
Low cost	11
Accuracy, precision, reliability of results	10
Real-time data analysis	7
Synoptic view of environment	6
Independence from fishing catch data	4
Absolute population estimates	3
Flexibility	2
Comparability of results from year to year	2
Track vertical migrations	1
Nondestructive	1
Comparative technique for trawling estimates	1
Continuous nature of sample	1

What are the greatest weaknesses of hydroacoustic techniques?

Lack of species identification	19
Maintenance, service, calibration difficulty	6
Lack of in-situ target strength data	5
Initial costs	4
Ignorance of technique by fisheries scientists	3
Difficulty in data interpretation	3
Need for specialized training	3
Difficulty in quantifying dense fish schools	2

APPENDIX B (continued)

Boundry problems (surface, bottom)	2
Vessel avoidance problem	2
Statistical limitations with some types of fish distributions	2
Rough weather limitations	2
Target strength variability due to fish behavior	1
Overconfidence in data	1
Not appropriate to all surveys	1
Low R&D funding	1
Side-scan sonar will not detect nonschooled fish effectively	1
Lack of educational programs	1

Which areas in hydroacoustic biomass research need the greatest attention?

Determination of in-situ target strength	18
Species identification	7
Statistical tools for sample design, variance estimation, analyzing data	7
Ability to provide length-frequency information	5
Development of inexpensive, flexible, reliable, compact hydroacoustic systems	5
Education of fisheries management/fisheries biologists on application/benefits	5
Simple, accurate calibration techniques	3
Multiple transducer arrays, Doppler effect systems	2
Dual-beam, multifrequency systems	2
Application to high-density situations	2
Ship avoidance	2
Application to impact studies	1
Theoretical sound scattering by organism	1
R&D funding	1

APPENDIX B (continued)

B.3 Survey Respondents

Alaska Department of Fish and Game
Division of Commercial Fisheries
Box 3-2000
Juneau, AK 99802

Alaska Department of Fish and Game
FRED Division
Box 3150
Soldotna, AK 99669

BioSonics, Inc.
4520 Union Bay Place N.E.
Seattle, WA 98105

California Department of Fish and Game
1416 Nonth Street
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APPENDIX B (continued)

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APPENDIX B (continued)

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APPENDIX C

BIOLIOGRAPHY

C.1 Reference Listing

1
Acker, W.C., 1973. An acoustical bottom-mounted fish enumeration system. In: Ocean '73: IEEE Int. Conf. Eng. Ocean Environ., New York:243-245.

The annual run of sockeye salmon into Bristol Bay, Alaska, is the largest run of this species in the world, and is of vital economic importance to the state of Alaska. To optimize catch and escapement, fishery management personnel need accurate and timely fish population data, but the test fishing techniques currently employed have had limited success. To improve management data, a system of bottom-mounted, upward-looking acoustic sensors specifically designed to assess Bristol Bay salmon is currently under joint development by the Fisheries Research Institute and the Applied Physics Laboratory, both of the University of Washington. This paper describes that system. (Author)

2
Acker, W.C., 1977. Acoustic assessment of North Pacific salmon stocks. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:189-195.

Acoustic sampling of various fish stocks and the acoustic characteristics of fish targets are being investigated as part of the Marine Acoustics Program at the University of Washington. An important outgrowth of this research is the development of a free-floating acoustic system which is being used south of Adak Island to help monitor the North Pacific salmon population. This is an upward-looking system which operates at 265 kHz. Average target size of the migrating salmon is about -30 dB within the aspect angles encountered in the sample volume. Acoustic source level and time-varied gain receiver sensitivity were adjusted for that average size, but a fairly wide range of target sizes can be accommodated. Studies of relative abundance indicate that the population density in that particular area is related to the spawning migration to Bristol Bay, Alaska, the following year. A second acoustic system is now being developed for use in Bristol Bay. This system's goal is to generate population data on which to base the day to day management of the fishery so that catch and escapement are optimized. The system will use bottom-mounted hydrophones, with data provided to fishery management personnel by a satellite communications link. A prototype system will be operating in the autumn of 1973. (Author)

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3
Acker, W.C.; Lewis, H.W.; Brune, F.A.; Thorne, R.E., 1975. A towed dual-frequency hydroacoustic fish assessment system. In: Ocean '75: IEEE Int. Conf. Eng. Ocean Environ., San Diego, Calif. 5pp.

A towed hydroacoustic system that provides rapid and precise estimates of pelagic (mid-water) fish stock abundance has been developed at the University of Washington. The system is self-contained, and therefore suitable for use on 'ships of opportunity.' It has been used to assess pelagic fish as part of the Coastal Upwelling Ecosystems Analysis program sponsored by the National Science Foundation. (Author)

4
Acker, W.C.; Wirtz, A.R., 1981. Versatile sonar system for ocean research and fisheries applications. IEEE Trans. Oceanic Eng. 6(3):107-109.

5
Aglen, A.; Iversen, S.A., 1980. Distribution and abundance of sprat in the North Sea in winter 1979/80 determined by acoustic methods. Int. Counc. Explor. Sea, 68th Meet., Copenhagen, ICES Rep. CM 1980/H:41.

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Altes, R.A. Detection and identification of fish schools from sonar echoes. Orincon Corp., La Jolla, Calif., Final Rep. to NSF, OC-R-81-9588-1 106pp.

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Alverson, D.L., 1971. Manual of methods for fisheries resource survey and appraisal. Part 1. Survey and charting of fisheries resources. FAO Fish. Tech. Pap. 102 83pp.

8
Anma, G.; Sano, N., 1975. Study for estimating the existent amount of salmon resources by means of echo sounding techniques. I. On a preparative experiment for the use of the vertical echo sounder in the Bering Sea. Bull. Fac. Fish. Hokkaido Univ. 26(2):137-153.

The method of research of salmon resources has been used up to now for statistics. This paper describes a method of estimating the amount of salmon resources by roughly calculating the echo traces on a recording paper. The echo sounder used was the 50 kHz ultrasound, a transducer having 22 degrees of effective beam angle. It was attached to the

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bottom of the ship. The recording range of the echo sounder was 100 m, the number of transmissions of ultrasound waves per minute was 450, and the pulse width was 2 milliseconds. These preparative experiments were undertaken in a gillnet fishing of salmon by the training ship 'Oshoro Maru' of the Faculty of Fisheries, Hokkaido University, in the Bering Sea in June, 1974. We set salmon gillnets 135 tans and hauled the nets the next morning. The authors compared the echo traces of salmon on echo patterns obtained by vertical echo sounder with the actual catch of salmon. The results obtained are summarized as follows: 1) In the echo patterns obtained by a vertical echo sounder, the authors tried to discriminate exactly between the echo traces of salmon and those of other fish. 2) Calculating the echo traces of salmon to record the echo patterns, one would be able to estimate the existent amount of salmon resources. (Author)

9
Anonymous, 1965. An introduction to echosounding. Kiel, Electroacustik Gmbh., 146pp.

10
Anonymous, 1965. Fish-finding with sonar. SIMRAD, Simonsen Radio AS, Oslo, 96pp.

11
Anonymous, 1969. Fish schools counted by sonar for first time. Commer. Fish. Rev. 31(12):18.

Fish schools were counted and measured in a 200,000-square-mile area off California and Baja, California, from BCF's 'David Starr Jordan.' This assessment of fish abundance is the first of its kind using sonar. The technique will yield a more exact assessment of the ocean's fishery resources. (Author)

12
Anonymous, 1971. 'Pop' technique. The echo sounder. SIMRAD, Simonsen Radio AS, Oslo, Pub. P446E, 96pp.

13
Anonymous, 1971. Proc. of the Symp. on Remote Sensing in Marine Biology and Fishery Resources, held January 25-26, 1971, College Station, Texas. Texas A. & M. Univ., Remote Sensing Center, College Station, Rep. TAMU-SG-71-106:1-306.

The objectives of this Symposium were two-fold: (1) to bring together the investigators active in the utilization of remote sensing in marine biology and fisheries; and (2) to provide for discussions leading to improved harvest and management of these resources. The agenda for this symposium was arranged to satisfy or complement the objectives and provide an overall review of the expertise in this particular application of remote sensing. This symposium is one of a continuing series by one or both of the sponsoring organizations and is devoted to the many diverse disciplines. (Author)

14
Anonymous, 1975. 'Kapala' tests netsonde in midwater trials. Aust. Fish. 34(4):35-36.

Objectives of cruises 74-02 to 05 by the New South Wales State Fisheries research vessel 'Kapala' in June and July 1974 were to continue surveying midwater trawl resources, test a SIMRAD FL Trawlink netsonde, and positively identify plankton schools with an Isaacs-Kidd midwater trawl. Results are detailed in Cruise Report 21. (Author)

15
Anonymous, 1977. Estimation of stock biomass by use of echo integration techniques. EAO/NORAD/IMARPE. Lima, Inst. Mar, Peru, 35pp.

16
Anonymous, 1980. A program for the acoustic assessment of nekton in the Southeastern Atlantic bight. Draft Planning Document by TRACOR Sciences and Systems (San Diego) prepared for South Carolina Wildl. and Mar. Resour. Dept., Charleston:1-103.

17
Aron, W.I., 1970. Bio-acoustic and biological sampling gear studies. Smithsonian Institution, Washington D.C. Final Rep., 85pp.

This book describes hydroacoustic instruments used on scouting and fishing vessels. An account is given of the experience gained in applying hydroacoustics to fishing. The book consists of three sections. The first section explains the physical principles of fish finding, taking into account recent research in acoustics. Sonar computation, required by the operator to evaluate the tactical data of the fish finder under various hydrological conditions are given. The second section describes Soviet-made hydroacoustic equipment and some

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foreign types. The Soviet-made NEL-5r instrument is described in much detail, since it incoprorates all the elements typical of other types of echo sounder. The third section deals with the practical aspects of using hydroacoustic equipment and the procedure of fish finding with their aid. This textbook is intended for captains in the fishing fleet, hydroacoustic operators, and fish-prospecting personnel. (Author)

18
Aron, W.I.; Jossi, J.W.; Pieper, R.E., 1970. Bio-acoustics and biological sampling gear studies. U.S. Gov. Res. Dev. Rep. 70(15):64.

19
Azhazha, V.G.; Shishkova, E.V., 1960. Fish location by hydroacoustic devices. Israel Program for Scientific Translations, tr. J. Flancreich, 1967. IPST Cat. 1856 114pp.

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Bakken, E.; Chakraborty, D.; George, K.; Ostvedt, O., 1972. Estimation of fish abundance by acoustics during the North Sea young herring survey 1972. Int. Counc. Explor. Sea, Copenhagen, CM 1972/H:10.

21
Baldwin, H.A.; Freyman, R.W., 1973. Telemetry link for an automatic salmon migration monitor. Sensory Systems Lab., Final Tech. Rep. NASA-CR-138152.

22
Batzler, W.E.; Friedl, W.A.; Reese, J.W., 1973. Can acoustic volume scattering be predicted from net haul data?. J. Acoust. Soc. Am. 54(1):290.

Explosive volume-scattering measurements made in widely separated areas in the Pacific and Indian Oceans exhibit a similarity in frequency pattern over the range 1-20 kHz. Typically, column scattering strength (for columns extending from the water surface to a depth of 1000 m) increases sharply in the range from 1 kHz to about 6 kHz and is fairly constant or decreases slowly thereafter. The similarity, from area to area, in the shape of this pattern suggests a mechanism common to all these areas even though the individual scatterers vary, from area to area, in size and depth distribution. We believe that this characteristic pattern is produced by resonant scattering from an assemblage of several species of mid-water fishes, principally myctophids, which vary in size within the rather narrow limits characteristic of these midwater fishes. (Myctophids, for example,

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have swim-bladder radii falling within the limits 0.5 to 5 mm). Tests of this hypothesis using a fictitious but plausible assemblage of fishes have produced patterns similar to those measured acoustically. Further comparisons in which column strength measurements in a given area are compared with column strengths which were calculated from net-haul data giving the sizes and depth distribution of the mid-water fishes in that area also give considerable support to our hypothesis. Refinement of the calculations, provided by a better knowledge of net-haul efficiency and more exact information on target characteristics (resonance frequency, Q, and target strength), is expected to provide further support for this hypothesis. (Author)

23
Batzler, W.E.; Pickwell, G.V., 1970. Resonant acoustic scattering from gas-bladder fishes. In: Farquhar, G.B. (ed.) Proc. Int. Symp. Biol. Sound Scattering, U.S. Dept. Navy, Maury Center for Ocean Science, MC Rep. 005:68-179.

Live fish, their swimbladders, and rubber balloons the size and shapes of fish bladders have been used as targets in acoustic scattering measurements made in the frequency range 400 to 4,000 Hz. Our chief interest is the frequency of resonant response, the Q of that response, and the strength of the target. All fish were small compared with the acoustic wavelength. The balloon targets exhibited a fairly sharp resonant response with Q's as high as 20, corresponding to a target strength enhancement of about 32 dB. The resonance curves for the scattering from fish were broader; Q's in the range 3 to 5 were observed. Results obtained using a 10.6-cm anchovy as a target are typical: resonance frequency, 1,275 Hz; Q, 4.5; and target strength, -35 dB at 1 m. Results using the gas bladder as a target are: resonance frequency 1,250 Hz, Q, 21; target strength, -22 dB. With the bladders completely deflated the fish produced no measurable response. The values of resonance frequency determined acoustically were used to predict the volume of gas in the fish bladders by applying the theoretical expression relating the resonant frequency to the bladder size. These predictions show good agreement with the measured gas volumes. Comparison of the Q of the whole fish with that of its bladder gives an estimate of the damping effect of the fish tissue surrounding the bladder. Tests made in a sound-transparent pressure chamber clearly demonstrate the upward shift in resonance frequency expected with an increase in water depth. (Author)

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24
Batzler, W.E.; Reese, J.W.; Friedl, W.A., 1975. Acoustic volume scattering: Its dependence on frequency and biological scatterers. Naval Undersea Center, San Diego, Rep. NUC-TP-442:1-26.

The report discusses the dependence of acoustic volume scattering on frequency and biological scatterers in the Westfall Seamount Area, 200 miles off the coast of San Diego, California. Theoretical calculations and experimental data both showed a correlation between the frequency dependence of scattering (from 1 to 20 kHz) and midwater gas-bladder fishes. It is the hypothesis of the report that the size limitation of the swimbladders (0.5 to 5.0 mm) of these dominant scatters determines the frequency pattern (a sharp increase in scattering from 1 to 5 to 6 kHz followed by a relatively constant value to 20 kHz) which is observed off San Diego and many other deep ocean areas.

25
Batzler, W.E.; Regan, M.C.; Pickwell, G.V., 1968. Resonant acoustic scattering from air-bladder fishes. J. Acoust. Soc. Am. 44(1):356. (Abstract).

Mesopelagic fishes inhabiting horizontally stratified layers are believed to be the principal source of strong backscattering from these layers. The target strength of an individual fish is low and difficult to measure, even at its resonant frequency. A novel procedure that gives the scattering response, or target strength and resonance "Q", as a function of frequency also yeilds a theoretical volume of air, which is then compared with the volume of the bladder. Measurements were made at NUWC's Transdec calibration pool. Small rubber balloons, live goldfish, anchovies, and FUNDULUS were used as acoustic targets. Acoustic frequencies used were in the range 0.4 to 4.0 kHz. All fish were small as compared with the acoustic wavelength. The balloon targets exhibited a fairly sharp resonant response with Q's as high as 15, corresponding to target strength enhancements of about 30 dB. The resonance curves for the scattering from fish targets were broader, and Q's in the range 3-5 were observed. With the bladders completely deflated, the fish produced no measurable response. Tests in a sound-transparent pressure chamber clearly demonstrate the upward shift in resonant frequency expected with increase in water depth. (Author)

APPENDIX C (continued)

26
Bazigos, G.P., 1975. The statistical efficiency of echo surveys with special reference to Lake Tanganyika. FAO Fish. Tech. Pap. 139:1-52.

An acoustic survey assessed the total biomass and distribution of pelagic fish in Lake Tanganyika (lat. 5 degrees S, long. 29 degrees E) in November 1973. The lake was post-stratified and by using graphic methods, total biomass of the surveyed population was estimated at about 2.8 million metric tons. Night sample observations were significantly higher than day-light observations with an estimated average ratio 4:1. Night estimates were strongly over-dispersed and fitted the negative binomial distribution. Day estimates were also over-dispersed and after a proper smoothing of the empirical data fitted the negative binomial distribution. The arithmetic data were log-normalized for use in any further statistical analysis. The acoustic surveys have been compared with the traffic surveys and suggestions have been made for the development of Quality Check Surveys of Echo Surveys. The Mean Difference of GINI has proved to be useful for providing indications of the level of dispersion of pelagic fish in the lake by stratum and by day and night periods. Also, the dispersion pattern of pelagic fish in the lake can effectively be portrayed by use of oblique projection charts. The sources and causes of potential errors inherent in echo surveys are discussed, and their spectrum has been classified into domains by taking into account the nature of the errors. It is indicated that the joint effect of the various sources of errors (sampling and nonsampling errors) are responsible for the observed differences between night and day sample observations. An estimator based on the method of collapsed strata has proved effective for estimating both the size of the total biomass of pelagic fish and its precision. It has been proved that the level of efficiency of the line sample of the survey is a function of the density of fish, and that for increasing the precision of sample estimates the distance between tracks should be reduced in proportion to the density of the surveyed fish population. (Author)

27
Bazigos, G.P., 1976. The design of fisheries statistical surveys - Inland waters: Populations in non-random order, sampling methods for echo surveys, double sampling. FAO Fish. Tech. Pap. 133 (Suppl. 1):1-46.

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28
Bazigos, G.P.; Henderson, H.P., 1975. Indicators of movement useful to problems of biomass estimation of pelagic stocks. FAO Fish. Tech. Pap. 140 FIPS/FIRS/T140.

Various indices are proposed for the study of movement in fish populations where the changes in spatial distribution of the population over time rather than the movements of individuals are of primary interest. The need for such indices arose in studying the precision and efficiency of acoustic surveys of the biomass of pelagic fish in Lake Tanganyika. Data from these surveys are used to illustrate the calculations and uses of the indices. Further, the need to measure and account for pattern and movement of fish in the design of catch assessment surveys and other fishery investigations is discussed. Finally, a general linear model of fish movement, tailored to the needs of statistical studies of the spatial distribution of pelagic fish, is suggested. (Author)

29
Beamish, P., 1971. Quantitative measurements of acoustic scattering from zooplankton organisms. Deep-Sea Res. 18(8):811-822.

In situ measurements at 102 kHz have been made of the scattering of sound from a small volume of the ocean containing a distribution of a zooplanktonic organism, the euphausiid, EUPHAUSIA PACIFICA. Quantitative information was recorded on analog magnetic tape and subsequently converted to digital form for analysis. Based on simultaneous measurements of side and backscattering from euphausiids and on a mathematical model, four-fifths of the scattered sound is considered to be caused by the compressibility contrast between the animals and the seawater. The remaining one-fifth is attributed to density contrast. The backscattering cross-section of a typical euphausiid at 102 kHz has been found to be 1.4 X 10(E-4) sq cm. Based on this value it is possible to predict the optimum frequency and intensity of incident sound for future acoustic studies involving these animals. (Author)

30
Berdichevsky, Z.M.; Tesler, V.D., 1969. Echo integration in echo-survey. Tr. PINRO, 24:50-78.

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31
Berkson, J.M.; Clay, C.S., 1973. Transformation of side-scan sonar records to a linear display. Int. Hydrogr. Rev. 50(2):55-59.

A procedure for removing the linear and nonlinear distortion in side scanning sonar records is described. The sonographs are placed on one rotating drum and optically scanned. The optical signal is converted to an electrical voltage and marks an electrosensitive paper on the second drum. The two drums have a common shaft and rotate together. The position and rate of scan of the marking stylus is controlled to remove the distortion. An example of distorted and corrected sonograph is shown. (Author)

32
Blackburn, M., 1977. Studies on pelagic animal biomasses. In: Oceanic sound scattering prediction, Plenum Press, New York:283-300, Anderson, N.R. and Zahuranec, B.J. (eds.).

Selected data on biomasses of pelagic micronekton and large nekton, together with zooplankton, are given for different latitudes in the open North Pacific, and for a coastal upwelling area in the Atlantic. The Pacific data, taken from the literature, show that several kinds of micronekton occur down to about 1000 m in the subtropics, 2000 m in the tropics, and 4000 m in the subarctic. These animals are principally mesopelagic fish, euphausiids, and decapods. Areal distribution of their total biomass is very broadly like that of zooplankton, although the relation between the two biomasses is not linear. Comparable biomass data for large nekton are not available. In the upwelling study, on the other hand, good estimates of biomass of large nekton (epipelagic fish) were made acoustically. (Author)

33
Bodholt, H., 1977. Variance error in echo integrator output. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:196-204.

The variance error involved in the abundance estimate from a hydroacoustic system comprising an echo-sounder with a 20 log R TVG and an echo integrator is investigated. The model used in the analysis is a random distribution of fish in a horizontal layer. A mathematical expression for the variance error is derived, and the contributions from the three variance sources, random phases, Poisson distribution of the number of fish in the sampling volume, and variation in target strength are discussed. The variance error increases when the number of fish in the insonified volume decreases, and it increases with the pulse length. Having regard to the variance error, one should therefore use a short pulse and a wide beam and avoid being in close range to the layer. A typical example, with integration over one nautical mile, is analyzed. It shows a relative variance error of 10(E-4), corresponding to a standard deviation of 1%. (Author)

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34
Bodholt, H.; Olsen, K., 1977. Computer-generated display of an underwater situation: Applications in fish behavior studies. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:31-35.

A new sonar system with a computer-generated display of the underwater situation has been built by SIMRAD in cooperation with Norwegian research institutes. The system comprises four main units - a navigation unit, consisting of a Doppler log and a gyro compass, a stabilized multibeam sonar, a digital computer and a data display. It has been installed aboard the purse-seiner 'Havdron' and evaluated for fishing and marine research applications by the Institute of Marine Research, Bergen. The underwater situation is shown as a true motion picture, and this, combined with a computer estimation of the velocity vector of the sonar target, has proved to be of great advantage in fish school behavior studies. (Author)

35
Bongers, L.H.; Polgar, T.T.; Lippson, A.J.; Krainak, G.M.; Moran, L.R.; Holland, A.F.; Richkus, W.A., 1975. The impact of the Morgantown

Power Plant on the Potomac estuary: An interpretive summary of the 1972-1973 investigations. Maryland Power Plant Siting Program, Maryland Dept. Nat. Res., PPSP-MP-15.

36
Boyles, C.A., 1969. The mathematical theory of the multiple scattering of an acoustic pulse from a random collection of volume scatterers with application to scattering from fish Schools. TRACOR Inc., Rockville, Prelim. Rep. TRACOR-RL/69-074-U 86pp.

This study evaluates the character and extent of the long-range classification problem. It was decided to investigate first the BB mode of propagation, reserving the CZ mode for future work. An investigation has shown that schools of fish are probable sources of false contacts for sonars operating with a CW pulse in the BB mode.

37
Braithwaite, H., 1971. A sonar fish counter. J. Fish. Biol. 3(1):73-82.

The basic principles of a new technique for counting fish moving up or down stream are given. The counter is based on the ability to detect the presence of fish in an acoustic beam directed across the river. The counter is capable of counting several fish moving up or down stream simultaneously and is designed for use in wide open channels.

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The results of field trials with the equipment at two different sites are discussed together with the problems encountered. The results obtained are in good agreement with other methods of counting fish but the totals obtained were insufficient to put confidence limits on the counter. (Author)

38
Braithwaite, H., 1973. Discrimination between sonar echoes from fish and rocks on the basis of hard and soft characteristics. J. Sound Vib. 27(4):549-557.

The discrimination between the sonar echoes from fish and rocks on the basis of 'hard' and 'soft' characteristics is investigated. A theoretical analysis of the echo structure from a complex 'hard' echo is given to assess the possibility of distinguishing between complex 'hard' and 'soft' echoes, and the conditions for discrimination are discussed. Experimental results are obtained from a stone, and from a live fish in broadside aspect, with varying amounts of the fish being insonified. The results show that the principle is not effective unless individual echoes are resolvable in range and bearing or the object has a single highlight. (Author)

39
Brodie, P.F.; Sameoto, D.D.; Sheldon, R.W., 1978. Population densities of euphausiids off Nova Scotia as indicated by net samples, whale stomach contents, and sonar. Limnol. Oceanogr. 23(6):1264-1267.

40
Brooks, A.L.; Brown, C.L., 1977. Ocean acre final report: A comparison of volume scattering prediction models. Naval Underwater Systems Center (New London) Rep. NUSC-TR-5619:1-44.

Vertical profiles of scattering strength were successfully predicted for an ocean area off Bermuda from net trawl data on the vertical population density of 55 species of air-bladdered, midwater fish collected during different years and seasons. The final predicted profiles compare favorably in shape and magnitude with measured profiles of scattering strength at 3.85, 5.0, 7.0, 9.0, and 15.5 kHz. At 3.85 kHz, only one of the predicted scattering strength values exceeds the measured scattering strength by more than 5 dB. For the predictions at 15.5 kHz, most values lie within 2 dB of the measured data. The surprisingly simple prediction model, using fish abundance as a function of depth correlated with measured profile data, achieves a notably superior attainment in its predictive capabilities over an earlier, more complicated model that required inputs on

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difficult-to-obtain swimbladder volume information. The success of the final prediction model is attributed largely to the fact that the vertical distribution density of the 55 species used serves as a reliable index to the total population scatters within the insonified volume measured.

41
Burczynski, J., 1977. The hydroacoustic system on R/V 'Professor Siedlecki' and its use in fish stock assessment by integration of thin depth layers. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:142-151.

A major task for the Polish fisheries research vessel R/V 'Professor Siedlecki', built at Gdansk Shipyard in 1972, is speedy and direct evaluation of fishery resources using advanced acoustic instruments and techniques. The hydroacoustic system for this is described. Also described is a method of fish abundance estimation based on digital processing of the hydroacoustic echo signals, referred to as the 'thin layers method.' A SIMRAD EK 38 echo-sounder, SIMRAD QM analog echo-integrator and ELLIOTT 905 computer are linked so that the computer controls on-line sampling of the integrator output for every echo-sounder transmission and performs the real time processing of the integrated echo signals. Thus profiles of fish distribution by depth are obtained and these are output to a digital plotter every 0.2 nautical miles of the ship's travel. Some results of the use of this system obtained on the first survey cruise to SE Atlantic grounds during November 1972 are presented. (Author)

42
Burczynski, J.; Azzali, M., 1977. Report to the Government of Italy on the quantitative acoustic estimation of sardine stock and distribution in the Northern Adriatic Sea. Italian Funds-in-Trust, FAO, Rome, TF-ITA 3 (ITA) 53pp.

43
Burczynski, J.; Martin, W.; Stepnowski, A., 1971. A project of hydroacoustic data processing for the B-424 research vessel. Pr. Morsk. Inst. Ryb., Ser. B, 16:7-25.

44
Burczynski, J.; Stepnowski, A.; Salamon, R.; Martin, W., 1979. Introduction to the use of sonar systems for estimating fish biomass. FAO Fish. Tech. Pap. 191:1-89.

How sonar systems function and are used for estimating fish biomass and spatial distribution are discussed. (PK) Various types of sonar and their applications in fisheries biology are described.

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45
Burridge, A.J.; Griffiths, P.G.; Griffiths, J.W.R.; Hoare, D. W., 1977. Time-varied gain echo-sounder receiver systems for use with fish echo signal processing equipment. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:83-87.

A 30 kHz receiver has been developed with automatic time-varied gain facility for alternative 20 log R + 2 alpha R dB or alpha 40 log R + 2 alpha R dB correction laws for ranges from 3 to 600 m. A digital time division system controls the gain of differential operational amplifiers providing sufficient dynamic range for echo signals from fish of -60 to 20 dB target strength, with reference to a 2-m radius sphere. A TVG amplifier for 100 kHz signals is being developed for ranges from 3 to 600 m. Parallel high- and low-level automatically selected channels handle the extra 30 dB dynamic range requirement. The technique adopted is to cascade three operational amplifiers with 20 log R, 20 log R and 2 alpha R dB gain control. (Author)

46
Buzeta, R.; Nakken, O., 1975. Abundance estimates of the spawning stock of blue whiting, MICROMESISTIUS POUTASSOU, in the area west of the British Isles in 1972-1974. Fiskeridir. Skr. Ser. Havunders. 16(7):245-257.

An analysis is made on the blue whiting data from the echo surveys conducted during 1972-1974 for assessment of the spawning stock west of the British Isles. Acoustic data are evaluated using a length-dependent density coefficient. Area and time coverage are discussed for each survey. Mean density and total abundance are calculated for the three years in the investigated area, and a stock size of approximately 6 million tons is suggested for the spawning stock. (Author)

47
Capen, R.L., 1967. Swimbladder morphology of some mesopelagic fishes in relation to sound scattering. Navy Electronics Lab, San Diego, Rep. NEL-1447:1-35.

An examination was made of fresh and preserved specimens of Pacific lantern fishes, hatchet fishes, and hake. Most of the lantern fishes under 50-mm standard length contain gas in their swimbladders and, hence, are probably major sound scatterers. The hatchet fishes possibly contribute to scattering of nonmigratory layers. The resonance depths of the swimbladders differ widely for sound of different frequencies. Because of its larger size, the swimbladder of the hake should resonate at low frequencies.

APPENDIX C (continued)

48
Carlson, T.J., 1978. Near dorsal aspect hydroacoustic target properties of rainbow trout and an echo-classifier based abundance estimation method. Ph.D dissertation, Univ. Washington, Seattle.

49
Carlson, T.J.; Acker, W.C.; Gaudet, D.M., 1981. Hydroacoustic assessment of downstream migrant salmon and steelhead at Priest Rapids am in 1980. Univ. Washington, Seattle, Appl. Phys. Lab., APL-UW 8016:1-68.

50
Carpenter, B.R., 1967. A digital echo counting system for use in fisheries research. Radio Electron. Eng. 33:289-294.

The echo-counting system to be described was designed for use in conjunction with a high frequency (100 kHz) echo-sounder and was primarily intended for use in surveying pelagic fish stocks. The counter incorporates a variable gating system, synchronized to the transmission pulse repetition frequency, enabling signals occurring between any two selected depth limits to be processed. Time-swept gain amplifiers are utilized to compensate for fall-off of signal strength with depth, although the counter differs from previously published systems inasmuch as echo duration rather than echo amplitude is the parameter under consideration. The processed signal information is displayed as an in-line digital readout from a conventional scaler. A permenent record is obtained from a printer coupled to the scaler. (Author)

51
Caruthers, J.W., 1973. Lectures of marine acoustics. Volume II. Part I: Selected advanced topics in marine acoustics. Texas A. & M. Univ. (College Station) Rep. TAMU-SG-73-403:1-221.

52
Castle, M.J., 1980. Proc. of the Australian Workshop on the Use of Underwater Acoustics in Biological Oceanography. Commwlth. Sci. Industr. Res. Org. Div. Fish. Oceanogr., Australia.

APPENDIX C (continued)

53
Chapman, D.W., 1975. Acoustic estimates of biomass of pelagic fish in Lake Tanganyika. FAO EIFAC, Tech. Pap. 23 (Suppl. 1) (1):307-324.

A FURUNO echosounder was tested side-by-side with a more sophisticated echo-integration system to determine whether a cheaper echosounder could provide reasonable estimates of biomass. The fish stocks sampled were entirely pelagic, schooling during the day and diffusing into layer at night. Integrator readings were regressed as dependent variables against a variety of independent variables. The resulting regressions were used for estimates for biomass based on subjective interpretation of the density of echo traces.

54
Clay, C.S.; Medwin, H., 1977. Acoustical oceanography: Principles and applications. Wiley Interscience, New York, 544pp.

55
Cole, F.W., 1968. A familiarization with lateral or side-scanning sonars. Columbia Univ., Hudson Laboratories, Dobbs Ferry, N.Y. Tech. Rep. 159 37pp.

56
Coombs, R.F., 1977. Digital system for recording fish echoes. N.Z. J. Mar. Freshwater Res. 11(3):479-488.

A system to record digitized echo information from echo sounders was developed as part of a project to improve methods of estimating the abundance of fish stocks around New Zealand. The depth of echoes appearing at the echo-sounder receiver is determined, followed by a sequence of samples of the echo envelope defining its shape. All data are digitized and recorded on a 7-track digital magnetic tape recorder. The system is designed to preserve as much information about the echoes as possible. In contrast to other published systems designed to either 'count' or 'integrate' fish echoes, this system allows free choice of methods of analysis. (Author)

57
Coombs, R.F.; Francis, R.I.C.C.; Do, M.A.; Surti, A.M., 1980. An echo sounder data aquisition system. Fish. Res. Div., Min. Agri. Fish., Wellington, New Zealand Pub., 4pp.

A flexible, digital system for recording echo information from echo sounders for fish stock assessment work is described. The system uses an LSI 11/02 microcomputer to organise and edit data, track the sea bottom and exercise overall control. Echo data from the echo-sounder

APPENDIX C (continued)

are envelope dectected, and echoes over a software selectable threshold are digitized and input to the computer using direct memory access. Edited data are digitally recorded on industry compatable half-inch magnetic tapes. (Author)

58
Cosgrove, M.A., 1970. Target detection using echo-to-echo cross covariance. Acoust. Soc. Am. J. 47(1):123.

59
Craig, R.E., 1973. The quantitative use of echo sounders - introductory notes. FAO Fish. Circ. 319 18pp.

60
Craig, R.E.; Forbes, S.T., 1969. Design of a sonar for fish counting. Fiskeridir. Skr. Ser. Havunders. 15(3):210-219.

The paper describes (a) A very high resolution echo-sounder, (b) A method of sorting echoes by amplitude and range, (c) A study of the analysis required to transform from distribution of echoes to distribution of targets. Under (a) the main parameters were - frequency 400 kHz - range resolution 15 centimetres - beam angle to half-power point 0.011 radians. The equipment for recording echoes (b) is a pulse height analyser. Echo information is stored in twenty range intervals, each subdivided into 20 categories of amplitude. It was shown (c) that the process of determining target distribution from echo distribution can be dealth with by computer, and resolves itself into a correction for angular spread of the beam, followed by a transformation to allow for the directivity pattern. This latter transformation is equivalent to solving twenty simultaneous linear equations for each range element. The coefficients of the equations are constants for the equipment, thus the set can be solved once, and the result applied to each successive range element by a simple programme. (Author)

61
Cram, D.L.; Hampton, I., 1976. A proposed aerial/acoustic strategy for pelagic fish stock assessment. J. Cons. Int. Explor. Mer 37(1):91-97.

Aerial and acoustic observations on SARDINOPS OCELLATA shoals in the Southeast Atlantic show that the extreme patchiness of the shoals, the mobility of the fish, and their tendency to avoid vessels may invalidate the results of quantitative acoustic surveys on the stock. It is suggested that these survey errors can be reduced considerably by employing an aerial/acoustic strategy where the aircraft locates and measures the shoal area, and the vessel makes synchronous measurements of shoal thickness and packing density from as many shoals as possible. The combined data provide a direct estimate of stock size. (Author)

APPENDIX C (continued)

62
Currie, W.E., 1969. Small sonar systems problems and developments. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-27, 1968:14-20.

63
Cushing, D.H., 1952. Some modern methods of fish detection. FAO Fish. Bull. 5(3/4):95.

64
Cushing, D.H., 1966. The diurnal variations in depth and quantity of echo traces and their distribution in area in the southern bight of the North Sea. J. Cons. Int. Explor. Mer 30(2):237-254.

65
Cushing, D.H., 1968. Direct estimation of a fish population acoustically. J. Fish. Res. Board Can. 25(11):2349-2364.

A method is described of estimating fish stocks by length-groups acoustically. Hake off southern Africa were recorded as individuals on the paper record of a Kelvin Hughes 'Humber' echo sounder down to 350 fathoms. Signal strengths of single fishes were observed on the cathode ray tube and the target strengths of fishes are known; estimates of fish sizes were made. The signals were considered as being received from a mean angle (to the axis of transmission) in the volume insonified. Hence, average target strengths, average numbers/unit volume, and average heights above the sea bed were calculated. The echo survey made between Cape Town and Walvis Bay was expressed as numbers of fish/unit volume in a range gate of 1 or 4 fathoms above the sea bed. A length distribution of the hake stock was derived. (Author)

66
Cushing, D.H., 1973. Computations with a sonar equation. J. Cons. Int. Explor. Mer 35(1):22-26.

The sonar equation for echo level has been used to estimate the average signals at different ranges expected from fishes between 20 and 90 cm in length, at intervals in length of 2-5 cm. The volume sampled (in one transmission, or in each nautical mile) has been determined in range and size of fish. The signal expected at different ranges using a time-varied gain (TVG) for different size of fish has been calculated. The height above the bottom and the number of tranmissions/target for different sizes of fish at different ranges has been calculated. (Author)

APPENDIX C (continued)

67
Cushing, D.H., 1973. The detection of fish. International Series Monographs in Pure and Applied Biology, Vol. 52, Pergamon Press, Oxford, England 200pp.

68
Cushing, D.H., 1977. Observations on fish shoals with the ARL scanner. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:15-20.

An examination of fish shoals with the ARL scanner revealed that packing density interfish distance appeared to increase with size of shoal. This phenomenon can be explained if it is assumed that the interfish distance is a function of the variance of swimming speed; if fish swim more slowly the interfish distance is less. Examination of large shoals suggested that they were composed of many groups, each of which was rather small. (Author)

69
Cushing, D.H., 1978. The present state of acoustic survey. J. Cons. Int. Explor. Mer 38(1):28-32.

A distinction is drawn between methods for counting single fish and estimating biomass. Biases in both systems are indicated and the most important of these is the capacity of the biomass method to record signals from animals smaller than desired. The best system counts individual fishes and records integrated signals from shoals and in this way the biases in either system are minimized. (Author)

70
Cushing, D.H.; Jones, F.R.H.; Mitson, R.B.; Ellis, G.H.; Pearce, G., 1963. Measurements of the target strength of fish. J. Br. Inst. Radio Eng. 25:299-303.

71
Cushing, D.H.; Richardson, I.D., 1955. Echo sounding experiments on fish. Fish. Invest. Lond., Ser. 2, 18(4):1-34.

72
Dalen, L.; Lovik, A., 1981. Influence of wind-induced bubbles on echo integration surveys. J. Acoust. Soc. Am. 69(6):1653-1659.

APPENDIX C (continued)

73
Dang, B.S.; Andrews, F.A., 1971. A literature survey on the subject of the use of acoustics in fish catching and fish study. Cathol. Univ. Am., Washington, Rep. 71-7:1-165.

The paper traces the history of the use of acoustics in fish catching and fish study and briefly describes the present state of the art, gives a comprehensive bibliography of the relevant papers and books, and presents summaries of some of the significant papers. It also lists the problems to be solved. (Author)

74
Davies, I.E.; Vent, R.J.; Brown, J.O., 1977. Fish school acoustic target strength. J. Cons. Int. Explor. Mer 37(3):288-292.

Acoustic target strengths of 10,534 fish schools were measured in the California current system during 6 cruises from Nov. 1974 - Oct. 1975. Measurements were made with a side-looking, 30 kHz sonar with a pulse duration of 10 ms; a separate set of 260 schools were measured with a pulse duration of 170 ms. Peak target strength for the 10 ms data set ranged from -20 to +20 dB with a mean of -7.3 dB (s.d. of 5.9 dB); mean intensity target strength was -2.4 dB. For the 170 ms data set, peak target strength ranged from -10 to +23 with a mean of +1.6 dB (s.d. of 5.6 dB); mean intensity target strength was +4.8 dB. Target strength was found to be dependent on pulse length and range (volume sampled). (Author)

75
Deuser, L.M., 1975. An environmentally adaptive, nonparametric approach to some classification problems in underwater acoustics. Texas Univ., Applied Research Labs, Austin, Rep. ARL-TR-75-56:1-206.

The subject of this report is the classification of received signals which result from the scattering of underwater waves. The specific problem area of investigation is a part of the more general domain of remote sensing of an environment. The fundamental influence of environmental conditions and intrinsic properties of the object under study on the correct classification of received waveforms is explicitly incorporated by use of suitably defined environmental state variables. Conventional approaches to this problem employ composite hypothesis tests involving ensemble averages over the various environmental states. It is shown here that alteration of the classification algorithm by introducing available, pertinent environmental state information leads to a reduction (i.e., an improvement) in the expected loss to this user. This procedure for alteration is called environmental adaptation, and the procedure itself is referred to as an environmentally adaptive approach to classification.

APPENDIX C (continued)

76
Deuser, L.M.; Middleton, D.; Plemons, T.D.; Vaughan, J.K., 1979. On the classification of underwater acoustic signals. II. Experimental applications involving fish. J. Acoust. Soc. Am. 65(2):444-455.

In a previous paper (Part I) a general approach to adaptive classification has been presented. That approach is applied here (Part II) to classification of waveforms obtained in a number of illustrative experiments. Experiments at 116 kHz (in the ARL Test Tank Facility) have provided backscattered waveforms (echoes) from known types of scatterers, randomly located and with random acoustic cross sections. Scatterers of primary interest here are a variety of small fish. Signals which form competing categories are scattering from seaweed (aquarium grass), surface reverberation, and artifacts (glass bottles). The data obtained are representative of three classification problems that have some practical significance in underwater acoustics. These three problems require distinguishing between the received signals which result from scattering by: (1) fish versus air-water surface, seaweed, and/or artifacts; (2) fish and air-water surface versus air-water surface only; and (3) 'low density' versus 'medium density' versus 'high density' of fish. In each case the waveforms are analyzed and features appropriate to the classification task are extracted from a portion of the data. These features are then used to design a classification algorithm for the environmentally adaptive approach and for its conventional counterpart. These algorithms are then used on the remaining data to make classification. The superiority and usefulness of the proposed environmentally adaptive approach is demonstrated here by the noticeable improvement in quantitative classification which results from the exploitation of environmental state data. (Author)

77
Dickson, W., 1967. The use of INST sonar and the INST Bathy-kymograph purse seining in Peru. FAO Dev. Prog. TA 2277-11:215-221.

78
Diercks, K.J.; Goldsberry, T.G., 1970. Target strength of a single fish. J. Acoust. Soc. Am. 48(1,2):415-416.

79
Doubleday, W.G., 1976. A pilot study of a survey design for a combined acoustic and otter-trawl groundfish survey. Int. Counc. Exlpor. Sea, Copenhagen, CM B.30.

APPENDIX C (continued)

80
Dowd, R.G., 1967. An echo counting system for demersal fishes. UN/FAO Conf. on fish behavior in relation to fishing techniques and tactics. FAO Fish. Rep. 62(2):315-321.

81
Dowd, R.G.; Bakken, E.; Nakken, O., 1970. A comparison between two sonic measuring systems for demersal fish. J. Fish. Res. Board Can. 27(4):737-742.

Two sonic methods for estimation of abundance of fish stocks, the echo integrator and the digital counter methods, were compared on single and schooling fish in the Lofoten area of Norway during March 1969. Good correlation was obtained between the two systems for both situations, but the slopes of the regressions of integrated values on the digital counter differed significantly between low and high density fish concentrations. This suggests that the two systems treated the echo information differently, but nevertheless maintained a linear relation between themselves over a wide range of counts. (Author)

82
Dragesund, O.; Olsen, S., 1965. On the possibility of estimating year-class strength by measuring echo-abundance of 0-group fish. Fiskeridir. Skr. Ser. Havunders. 13(8):48-75.

The possibility of estimating the distribution and abundance of 0-group fish by a combination of echo surveying and fishing experiments with pelagic trawl and purse seine is discussed. (Author)

83
Dunn, W.I., 1977. A controlled beamwidth echo-sounder for fish counting. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:162-166.

A signal processing technique is described in which the acoustic beam width of an echo-sounder is defined by determining the direction of each target and eliminating from the output those echoes corresponding to targets outside the desired beam angle. (Author)

APPENDIX C (continued)

84
Dunn, W.I.; Forbes, S.T., 1977. The use of the Aberdeen fish counter as a 400 channel echo integrator. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:159-161.

A method has been developed for converting the 400 channel pulse height analyser used for fish echo counting at the Marine Laboratory, Aberdeen, into an echo integrator, to permit abundance estimation where fish densities are too high to allow resolution of the echo-sounder output into individual echoes. The resulting equipment integrates echo intensities in 400 separate depth channels over any desired time interval or distance run. Output takes the form of punched tape for computer analysis, together with an X-Y plot of total echo intensity against depth for immediate use. The integrator has been used to date on one research vessel cruise, and some preliminary results are described. (Author)

85
Edwards, J.I., 1980. A preliminary investigation of the target strength of herring. Int. Counc. Explor. Sea, 68th Meet., Copenhagen, ICES Rep. CM 1980/B:19.

86
Edwards, J.I.; Wilson, J.P.F. Echo-integrator surveys for sprats in U.K. Coastal waters from the Firth of Forth to the Moray Firth, January and March 1980. Int. Counc. Explor. Sea, 68th Meet., Copenhagen, ICES Rep. CM 1980/H:44.

87
Ehrenberg, J.E. Estimation of the intensity of a filtered poison process and its applications to acoustic assessment of marine organisms. Ph.D dissertation, Univ. Washington, Seattle.

88
Ehrenberg, J.E., 1971. Derivation and numerical evaluation of a general variance expression for fish population estimates using an echo integrator. Univ. Washington, Seattle, Div. Mar. Resour. Sea Grant Pub. 71-4, 24pp.

89
Ehrenberg, J.E., 1971. The variance of fish population estimates using an echo integrator. Univ. Washington, Seattle, Div. Mar. Resour. Sea Grant Pub. 71-3, 17pp.

APPENDIX C (continued)

90
Ehrenberg, J.E., 1972. A method for extracting the fish target strength distribution from acoustic echoes. In: Ocean '72: IEEE Conf. Eng. Ocean Environ. 1:61-64.

91
Ehrenberg, J.E., 1973. Estimation of the intensity of a filtered Poisson process and its application to acoustic assessment of marine organisms. Univ. Washington, Seattle, Div. Mar. Resour. Rep. WSG-73-2 146pp.

One goal of this research was to analyze the role of signal processing in acoustic systems for estimating the abundance of marine organisms. The model used assumes that the organisms are distributed according to a spatial Poisson distribution. It is shown that the scattered signal received is a filtered Poisson process with intensity (Lambda sub o) Beta (t), where Beta (t) is a known deterministic function of time and (Lambda sub o) is the unknown spatial density of the scatterers. The problem of estimating the intensity factor of a fitered Poisson process may arise from a variety of physical models. For this reason, the general problem is considered first. Estimates obtained using independent samples from the filtered Poisson process are treated in detail. (Author)

92
Ehrenberg, J.E., 1974. Recursive algorithm for estimating the spatial density of acoustic point scatterers. J. Acoust. Soc. Am. 56(2):542-547.

A recursive algorithm for estimating the spatial density of acoustic point scatterers is derived. This algorithm, which is based on the stochastic approximation estimation technique, is shown to be equivalent to an echo counter for low densities and to an energy detector or echo integrator for high densities. The problem of estimating fish density from a scattered acoustic signal is considered in detail. The recursive algorithm is shown to have a mean-squared error that is a factor of 6 lower than either an echo integrator or an echo counter in the medium density region. (Author)

APPENDIX C (continued)

93
Ehrenberg, J.E., 1974. Two applications for a dual-beam transducer in hydroacoustic fish assessment systems. In: Ocean '74: IEEE Int. Conf. Eng. Ocean Environ., Halifax, Nova Scotia, IEEE 74CHO 8730-OCC:152-155.

The paper describes the advantages of using a narrow- and a wide-beam acoustic transducer in systems for estimating fish abundance. In the technique considered, the acoustic pulse is transmitted with a narrow beam and the echo is received on both the narrow and wide beams. The signals received at the two transducers can be used to determine the acoustic scattering cross section of the fish. The mean value of the acoustic scattering cross section can be used to evaluate the scale factor needed by echo integrators to obtain an absolute abundance estimate. The outputs of the two transducers can also be used to control the sampling volume in an echo counting system. (Author)

94
Ehrenberg, J.E., 1976. Dual beam system for measuring individual fish target strengths. In: Ocean '76: Second Annu. Comb. Conf., Washington, D.C., 13-15 Sept. 1976.

95
Ehrenberg, J.E., 1978. The dual-beam system - a technique for making in situ measurements of the target strength of fish. In: Proc. of 1978 Inst. of Acoustics Spec. Meeting on Acoust. in Fish., Hull, England.

96
Ehrenberg, J.E., 1979. A comparative analysis of in situ methods for directly measuring the acoustic target strength of individual fish. J. Oceanic Eng. 4(4):141-52.

In recent years, acoustic techniques have been used extensively to monitor and quantify fish stocks remotely. One of the parameters that is often measured is the target strength of the individual fish in the population. To obtain the target strength of a fish from its acoustic echo, the effect of the transducer beam-pattern factor must be removed from the echo amplitude. This paper discusses a number of different approaches for directly estimating the beam-pattern factor for an individual fish target. The effects of noise and interfering signals on the various estimation techniques are investigated. Expressions are derived for the bias and variance in the estimates of the beam-pattern factor as a function of signal-to-noise ratio and angular location of the target. Results of a Monte Carlo simulation of the effect of interference on the various processing techniques are presented. Some of the problems encountered in implementing the various techniques are discussed. (Author)

APPENDIX C (continued)

97
Ehrenberg, J.E.; Carlson, T.J.; Traynor, J.J.; Williamson, N.J., 1981. Indirect measurement of the mean acoustic backscattering cross-section of fish. J. Acoust. Soc. Am. 69(4):955-962.

A technique is described for indirectly determining the average backscattering cross section of individual fish from the measured probability distribution function for the amplitudes of the envelopes of single fish echoes. The technique is based on the assumption that the on-axis echo envelope is Rayleigh distributed. The validity of the Rayleigh assumption was tested by making controlled measurements of the envelope amplitude statistics of single fish echoes for two acoustic frequencies and four different fish lengths. These tests showed that the echo envelope data most closely fit the Rayleigh model when the ratio of fish length to wavelength was large. The indirect measurement technique described has been used to analyze some single fish-echo amplitude data for Bering Sea walleye pollock. These results are compared with some measurements made using a dual beam, direct target strength measurement system. Expression for the bias and variance of the indirect estimation technique are derived in an Appendix. (Author)

98
Ehrenberg, J.E.; Green, J.H.; Wirtz, A.R., 1976. A dual-beam acoustic system for measuring the target strength of individual fish. Univ. Washington, Seattle, Div. Mar. Resour., Rep. WSG-TA-76-7:1-8.

A dual-beam error sonar system has been developed for making in situ measurements of the target strength of individual fish. Estimates of fish target strength distribution obtained with this system are superior to estimates obtained using other techniques. The estimates of the mean value and distribution of fish target strengths obtained with the system are used in conjunction with other acoustic techniques for assessment of fish populations. This paper gives an overall description of the system and a more detailed discussion of some of the innovative hardware and software aspects of the system's development.

99
Ehrenberg, J.E.; Lytle, D.W., 1972. Acoustic techniques for estimating fish abundance. IEEE Trans. Geosci. Electron. GE-10(3):138-145.

Echo counting and echo integration are two acoustic techniques for estimating the abundance of fish stocks. Mathematical models for the echo counting and echo integrating systems are presented and analyzed. Expressions for the mean squared errors of the abundance estimate obtained with each system are obtained. Both theoretical performance and the practical problems of implementation are considered in the discussion of the relative advantages and disadvantages of each system. (Author)

APPENDIX C (continued)

100
Ehrenberg, J.E.; Lytle, D.W., 1973. A bound on the variance of fish abundance estimates obtained from acoustic echoes. In: Ocean '73: IEEE Int. Conf. Eng. Ocean Environ., Seattle:239-242.

In recent years, there has been increasing interest in acoustic techniques for estimating fish abundance. A lower bound on the variance of the abundance estimates is derived in this paper. The analysis assumes that the fish are Poisson-distributed in volume and that the estimate is obtained using independent samples from the received acoustic signal. It is shown that the variance of the estimate obtained from an echo counter satisfies the bound in low fish densities and that the variance of the estimate obtained from an echo integrator satisfies the bound in high fish densities. (Author)

101
Ehrenberg, J.E.; Lytle, D.W., 1977. Some signal processing techniques for reducing the variance in acoustic stock abundance estimates. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:205-213.

The most important criterion on which to judge any resource assessment technique is its performance in the field. Numerous applications of acoustic methods have shown that they can provide a fast, accurate and relatively inexpensive estimate of fish abundance. However, it is difficult to determine the sources and magnitudes of the error in the abundance estimate from field studies. In this paper, the various sources of error are discussed. A theoretical model for acoustic assessment systems is presented and error expressions for counting and integrating systems are given. A lower bound on the mean squared error of abundance estimates shows that integrators are optimum processors in high densities and that counters are optimum in low densities. An adaptive processor that satisfies the lower bound on the mean squared error of the estimate is described. The important feature of this processor is that it changes its structure with changing density to produce an optimum estimate for all populations. Although the investigation of the adaptive processor is still in progress, it appears that this technique has the potential of being an extremely useful tool for acoustic assessment. Two indirect methods for estimating the target strength distribution from acoustic echo levels are simulated. Both the techniques are shown to provide reasonable estimates in unimodel populations but poor estimates for biomodal populations. It is concluded that a method for directly obtaining the target strength from the echo level is needed. One possible technique using a dual transducer system is suggested. (Author)

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102
Ehrenberg, J.E.; Traynor, J.J.; Williamson, N.J., 1980. An evaluation of methods for indirectly measuring the mean acoustic scattering cross section of fish. Univ. Washington, Seattle, Appl. Phys. Lab., Rep. WSG-TA-80-6:1-7.

Acoustic techniques are being used throughout the world for assessment of fish stocks. The most common acoustic assessment technique is to process the output of an echo sounder using a procedure called echo integration. This paper discusses two methods for indirectly extracting the mean scattering cross section from the empirical distribution of single fish echo amplitudes. The first method discussed obtains the estimate of mean scattering cross section by first estimating the single fish target strength probability density function. The second method assumes that the square root of the scattering cross section is Rayleigh distributed. The performance of the two estimation techniques is evaluated using a Monte Carlo simulation. (Author)

103
Ehrenberg, J.E.; Weimer, R.T., 1974. Effects of thresholds on the estimated fish scattering cross section obtained with a dual beam transducer system. Appl. Phys. Lab., Univ. Washington, Seattle, Rep. 7421.

104
Ehrenberg, J.E. Calculation of the constants needed to scale the output of an echo integrator. SACR/SCOR/IABO/ACMRR Group of Specialists on Living Resources of the Southern Oceans, Biomass Handbook 7 11p.

105
Engel, S.; Magnuson, J.J., 1971. Ecological interactions between coho salmon and native fishes in a small lake. In: Proc., Conf. Great Lakes Res. 14:14-20.

Seasonal changes in vertical and horizontal distribution of cisco (COREGONUS ARTEDII), yellow perch (PERCA FLAVESCENS) and introduced coho salmon (ONCORHYNCHUS KISUTCH) were studied in Pallette Lake, Wisconsin using gill nets, fyke nets, electrofishing gear, and echo sounders. Coho salmon were inshore in spring and fall, while cisco and yellow perch were more widely dispersed. In late summer, coho salmon and cisco occupied the metalimnion, whereas yellow perch were in warmer water. Insects, zooplankton, and some fishes were eaten by coho salmon. Between April and October, coho salmon grew from 130 to 175 mm total length. These results suggest that young cisco and yellow perch were not available as food for these small coho salmon. (Author)

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106
Ermolchev, V.A., 1973. Calculation of sampling volume by numbers of echoes. Rybn. Khoz. 49(1):50-52.

107
Everett, J.T., 1973. Underwater acoustic activities of National Marine Fisheries Service. In: Ocean '73: IEEE Int. Conf. Eng. Ocean Environ., Seattle, 25-28 Sept. 1973:230-234.

Report identifies areas for underwater acoustics to assist fisheries research, assessment, and management. Present NMFS operational capability in fisheries acoustics and development work since 1967 is reviewed. Future research and development direction is discussed. (Author)

108
Farquhar, G.B., 1970. Proc. Int. Symp. on Biol. Scattering in the Ocean. U.S. Dept. Navy, Maury Center for Ocean Science, Washington, D.C., MC Rep. 005 629pp.

109
Farquhar, G.B.; Holliday, D.V., 1977. Recommendations of the working group on bioacoustics. In: Oceanic sound scattering prediction, Anderson, N.R. and Zahuranec, B.J. (eds.), Plenum Press, New York.

110
Flores, F.E.C., 1972. Echo-traces typical of squids in waters surrounding Japan. FAO Fish. Circ., Rome, 142:7-13.

111
Food and Agriculture Organization of the United Nations (FAO), 1977. Report of acoustic survey along the southwest coast of India, November 1976. FAO Pelagic Fisheries Investigation Project on the Southwest Coast of India, Rep. FIRS-IND/75/038:1-44.

112
Food and Agriculture Organization of the United Nations (FAO), 1967. Report of ACMRR working party on direct and speedier estimation of fish abundance. FAO Fish. Rep. (41):31.

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113
Food and Agriculture Organization of the United Nations (FAO), 1969. Technical report of the ICES/FAO acoustic training course, Svolvaer, Norway, 2-15 March, 1969. FAO Fish. Rep. 78.

114
Food and Agriculture Organization of the United Nations (FAO), 1978. Report of the meeting of the working party on fish target strength. UN/FAO/ACMRR Meeting, Aberdeen, Scotland, December 1977. ACMRR 9/78 Inf. 14.

115
Food and Agriculture Organization of the United Nations (FAO), 1980. Echo sounding and sonar for fishing. FAO Man. Fish. Sci.:1-104.

116
Food and Agriculture Organization of the United Nations (FAO), 1980. Guidelines for sampling fish in inland waters. FAO EIFAC, Tech. Pap. 33:1-176.

117
Food and Agriculture Organization of the United Nations (FAO), 1980. Report of the first session of the working party on acoustic methods for fish detection and abundance estimation. FAO Fish. Rep. 231 FIPL/R231:1-27.

118
Foote, K.G., 1978. Analysis of empirical observations on the scattering of sound by encaged aggregations of fish. Fiskeridir. Skr. Ser. Havunders. 16(11):422-455.

The experimental findings of Rottingen (1975 and 1976) for the scattering of ultrasonic sound by encaged aggregations of saithe and sprat are analyzed. The insensitivity of the relationship of the mean time-integrated echo intensitive and fish number density v to both the center frequency and pulse duration of the ensonifying signal is considered qualitatively. A general theory for the scattering of sound by a collection of randomly distributed and oriented, but otherwise identical scatters, whose individually complicated scattering behavior is described by two parameters, the backscattering and extinction cross sections, is applied to Rottingen's experiment with saithe. The empirical e-v relationship is reproduced successfully with respect to a unique set of parameters of a model whose main ingredients are the

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following assumption of a truncated Gaussian distribution in tilt angle for the orientation distribution; expression of the scattering cross sections in terms of the mean and variance of this distribution; assumption that the mean tilt angle is independent of v and that the variance in tilt is the sum of two variances; the intrinic variance, which is postulated to be an exponentially decreasing function of v, and the perspectival variance, assumed constant, which is the mean square apparent tilt of the scatterer due solely to its azimuthal orientation relative to the generaly obliquely located source/receiver. By comparing predictions of the ebar-v relationship with those observed for saithe, the mean extinction cross sections at the two frequencies of Rottingen's experiment are deduced. (Author)

119
Foote, K.G., 1979. Biasing of fish abundance estimates derived from use of the sector scanning sonar in the vertical plane. In: Proc. of the Conf. Prog. in Sector Scanning Sonar,' Inst. Acous., Edinburgh:44-52.

120
Foote, K.G., 1979. Fish target strength-to-length regressions for application in fisheries research. In: Proc. of Ultrason. Int. 79, IPC, Guildford, England.

121
Foote, K.G., 1979. On representing the length dependence of acoustic target strengths of fish. J. Fish. Res. Board Can. 36(12):1490-1496.

The problem of representing the length dependence of acoustic target strengths of fish is addressed by studying the legitimacy of merging target strengths that are inhomogeneous in species or frequency. The target strengths are of two kinds: maximum and averaged dorsal aspect target strengths, which are derived from measurements of gadoid target strength functions of three species at two ultrasonic frequencies. The target strengths are expressed variously according to unnormalized, wavelength-normalized and length-normalized schemes. Overall coincidences and coincidences of slopes among simple linear regressions of target strength on fish length, when segregated by target strength type and manner of representation, are investigated through analysis of covariance. Examination of computed significace levels demonstrates that merging of target strengths in species or frequency is generally unjustified and that no one representation method is superior to another in facilitating the merging of such data. The unnormalized representation is to be preferred when merging is justified because of its simplicity and avoidance of the frequency bias inherent in the normalized representations. The hypothesis of scaling of target strengths is refuted. (Author)

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122
Foote, K.G., 1980. Angular measures of dorsal aspect target strength functions of fish. Fiskeridir. Skr. Ser. Havunders. 17(2):49-70.

123
Foote, K.G., 1980. Averaging of fish target strength functions. J. Acous. Soc. Am. 67(2):504-515.

124
Foote, K.G., 1980. Effect of fish behavior on echo energy: The need for measurements of orientation distributions. J. Conseil. 39(2):193-201.

125
Foote, K.G., 1980. Importance of the swimbladder in acoustic scattering by fish: A comparison of gadoid and mackerel target strengths. J. Acoust. Soc. Am. 67(6):2084-2089.

Previous determinations of the swimbladder contribution to the fish backscattering cross section have been hindered by ignorance of the acoustic boundary conditions at the swimbladder wall. The present study circumvents this problem by direct comparison of target strengths of three gadoid species and mackerel - anatomically comparable fusiform fish which respectively possess and lack a swimbladder. The relative swimbladder contribution to both maximum and averaged dorsal aspect backscattering cross sections is shown to be approximately 90% to 95%, which is higher than most other estimates. The new results were established for fish of 29- to 42-cm length and acoustic frequencies of 38 and 120 kHz. (Author)

126
Foote, K.G., 1981. Absorption term in time varied gain functions. Fiskeridir. Skr. Ser. Havunders. 17(5):191-213.

A potential source of error in acoustic measurements of fish density is the absorption part of time-varied-gain functions and should be determined from the 1977 Fisher and Simmons equation. Use of its predecessor, the 1962 Schulkin and Marsh equation, is shown by comparison to introduce large errors in fish density estimates. Adjustments of the absorption term with changing hydrography is also necessary. This is supported by an analysis of errors due to deviations from an assumed reference temperature. The various computations are performed for 6 echo sounder frequencies used in fisheries surveying, i.e., 30, 38, 49.5, 70, 105 and 120 kHz. A broad hydrographical range is considered. (Author)

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127
Foote, K.G., 1981. Evidence for the influence of fish behaviour on echo energy. In: Proc. of the Meeting on Hydroacoustical Methods for the Estimation of Marine Fish Populations, Suomala J.B. (ed.), Draper Laboratory, Mass. Inst. Tech., Cambridge.

128
Foote, K.G., 1981. Systematic species and frequenc_ dependent differences among gadoid target strength functions. In: Proc. of the Meeting on Hydroacoustical Methods for the Estimation of Marine Fish Populations, Vol. 2, J.B. Suomala (ed.), Draper Laboratory, Mass. Inst. Tech., Cambridge.

129
Foote, K.G.; Nakken, O., 1978. Dorsal aspect target strength functions of six fishes at two ultrasonic frequencies. Fiskeridir. Skr. Ser. Havunders., Ser. B, 3:1-95.

130
Forbes, S.T., 1970. A quantitative fish-counting echo sounder. In: Proc. Conf., Electric Eng. in Ocean Tech., Inst. Electric Radio Eng., London:95-108.

131
Forbes, S.T.; Nakken, O., 1972. Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO Man. Fish. Sci. 5 138pp.

132
Forbes, S.T.; Simmonds, E.J.; Edwards, J.I., 1980. Progress in target strength measurements on live gadoids. Int. Counc. Explor. Sea, 68th Meet., Copenhagen, ICES Rep. CM 1980/B:20.

133
Goddard, G.C.; Welsby, V.G., 1977. Statistical measurements of the acoustic target strength of live fish. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:70-73.

An experiment is described in which the target strength of caged but swimming live marine fish is being measured. Measurements are made at each of three frequencies, and at elevations vertical and 22 1/2 degrees

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to horizontal. Fish tested include four gadoid species and dogfish. A large number of measurements are made on each fish at the rate of 100 per minute, these being recorded on paper tape and analyzed by computer. The first results of this continuing experiment are given. (Author)

134
Greenblatt, P.; Pinkel, R., 1978. Measurement of zooplankton Patchiness with a 87.5 kHz sonar system. J. Acoust. Soc. Am. 64 (Suppl. 1):S97.

A narrow beam 87.5 kHz sonar is being used to quantitatively estimate scattering strength as a function of range and time in the upper ocean. The sonar is aimed horizontally from the bottom of FLIP. Backscattered intensity will be used to estimate horizontal zooplankton patchiness on a scale of 10's-100's of meters. During a fall 1978 cruise, the sonar system and a multiple opening-closing plankton net, towed from a second ship, will simultaneously measure zooplankton patchiness. The objectives of this effort are to determine whether the sonar provides a consistent picture of plankton patchiness, whether there is a significant change in the scales of patchiness from night to day, and whether a specific category of organisms can be identified as being primarily responsible for the scattering. (Author)

135
Greenlaw, C.F., 1979. Acoustical estimation of zooplankton populations. Limnol. Oceanogr. 24(2):226-242.

Acoustical estimates of zooplankton abundance can be made rigorously if the scattering behavior as a function of size and frequency for the zooplankters is known. Measurements of scattering at a single frequency can be used to estimate abundance if the mean zooplankter size is known. Measurements at 2 frequencies can be used to estimate the dominant size and abundance if a single size zooplankter dominates the acoustical scattering. Measurements at several frequencies can be used to estimate size distributions and abundances. In a field experiment, acoustical scattering was measured at 3 frequencies for zooplankton layers composed largely of euphausiids (for which an approximate scattering model is known). These data are analyzed by each method and estimates of numerical abundance given. (Author)

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136
Gresik, J.H., 1977. Experimental deep water bottom trawling off Portland, Western Victoria. Fish. Wildl. Pap. Victoria (14):1-39.

Results of acoustic surveys and exploratory fishing by the Fisheries and Wildlife Division's, Victoria, Australia, research vessel Sarda show that fishing grounds suitable for trawling and supporting large quantities of marketable fish exist off western Victoria. In 1976 about 1200 sq mi of ocean along and beyond the edge of the continental shelf was surveyed. From Jan. - June 1977, the 'Sarda' made 61 hauls during 28 days fishing in waters 200-450 m deep and caught a total of 29 tonnes of marketable fish; an average catch rate of 259 kg/h of trawling. Gemfish (REXEA SOLANDRI) formed 38% of the catch, and mirror dory (ZENOPSIS NEBULOSIS) 11%, Morwong NEMADACTYLUS MACROPTERUS (5%), blue grenadier MACRURONUS NOVAEZELANDIAE (5%), frostfish LEPIDOPUS LEX (4%), deepsea trevalla HYPEROGLYPHE POROSA (3%) and trawl flathead NEOPLATYCEPHALUS spp, (2%) made up most of the remainder. A close relationship was found between species caught and depth fished, time of day, and mesh size. Gemfish and morwong were taken mainly at depths of 220-330 m; frost fish, cucumber fish CHLOROPHTHALMUS NIGRIPINNIS, blue grenadier and deepsea trevalla were caught in deeper waters. The catch rates show that trawling would be profitable only for relatively, large vessels; sea and weather conditions are unsuitable for smaller vessels. (Author)

137
Groot, C., 1972. Migration of yearling sockeye salmon (ONCORHYNCHUS NERKA) as determined by time-lapse photography of sonar observations. J. Fish. Res. Board Can. 29(10):1431-1444.

The seaward migration of sockeye salmon smolts through the Babine Lake system to its outlet was examined by taking film records of the Plan-Position-Indicator display of a high-frequency sonar whereby each frame of film was exposed during one scan of the sonar unit. Frame-by-frame analysis of the films revealed information on speed, direction, and diurnal timing of migration of sockeye smolts during a 24-hr period. Migratory activity in the lake centered around dusk and dawn, a similar pattern to that near the outlet for smolts entering the river on their way to sea. Speeds of movements were 19-51 cm/sec (mean 30 cm/sec). Greatest velocities occurred at dusk and dawn. They were close to the maximum sustained swimming speeds determined under laboratory conditions for sockeye smolts of the same size and within similar temperature ranges as in the field. The most direct movements of targets were found at twilight, when migration activity was highest. In general, directional tendencies were consistent with the shortest route to the outlet. In some observations near the junction of Main Lake and Morrison and North arms, movements were observed which would lead the smolts away from the outlet. Consequences of such movements are discussed and compared with data from tagging operations. (Author)

APPENDIX C (continued)

138
Gunderson, D.R.; Sample, T.M., 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev. 42(3):2-16.

The methods employed during the demersal (bottom trawling) phase of the 1977 Rockfish Survey and in obtaining catch and biological data during the demersal and pelagic (hydroacoustic-midwater) phases are outlined. Geographic and bathymetric trends in the abundance and species composition of the demersal rockfish community are discussed, and the results of the demersal and pelagic surveys are compared. Biomass estimates (50- to 250-fathom or 91-to 457-m depth zone) are given for the dominant rockfish species in each statistical area of the International North Pacific Fisheries Commission (INPFC). Canary rockfish, SEBASTES PINNIGER (26,000 t), yellowtail rockfish, S. FLAVIDUS (23,000 t), and Pacific ocean perch, S. ALUTUS (15,000 t), dominated the rockfish biomass in the Vancouver and Columbia INPFC areas. Rockfish biomass was low in the Eureka area (about 4,000 in the 50- to 250-fathom zone) but increased again to the south. The rockfish biomass in the Monterey and Conception INPFC areas was dominated by shortbelly rockfish, S. JORDANI (320,000 t), splitnose rockfish, S. DIPLOPROA (10,000 t), chilipepper, S. GOODEI (9,000 t), stripetail rockfish, S. SAXICOLA (7,000 t), and bocaccio, S. PAUCISPINIS (6,000 t). Shortbelly rockfish were found to be principally pelagic in their distribution; less than 10 percent of the stock was encountered during the demersal survey. The precision of most biomass estimates for rockfish was relatively low because of the highly contagious spatial distribution characterizing most of these species. (Author)

139
Gunderson, D.R.; Thomas, G.L.; Cullenberg, P.; Eggers, D.M.; Thorne, R.E., 1980. Rockfish investigations off the coast of Washington. Univ. Washington, Seattle, Fish. Res. Inst., Rep. FRI-UW-8021 62pp.

140
Hamilton, D.; Lozow, J.B.; Suomala, J.B.; Werner, R., 1977. A hydroacoustic measurement program to examine target quantification methods. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:105-121.

The procedures and results of a basic hydroacoustic measurement experiment to quantify aggregations of targets are presented. Relevant theoretical and practical details of the experiment are discussed. Standard series production instrumentation was used wherever possible. The experiment employed a variable-density static random target array of 10 cm diameter spherical targets within a cylindrical volume 9-5 m in diameter and 2 m thick deployed in a water-filled tank. Target densities of from 1.7 to 7 per cubic meters were insonified by a

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pressure pulse at a carrier frequency of 122 kHz. The hydroacoustic transducer was positioned offset from the axis of symmetry of the tank and rotated in angular increments about this axis. The received echo signals from each hydroacoustic transmission at a specified transducer azimuth angle were recorded in analog form on magnetic tape, digitized, and then processed in a digital computer algorithm to obtain an estimate of target density. The results of the experiment are not entirely consistent with the results predicted by prior theoretical investigations and those expected from standard hydroacoustic measurement techniques. (Author)

141
Hampton, I., 1973. Fish counting with an echo sounder. Abstracts of the Papers of the South African National Oceanographic Symp., Cape Town, South Africa. August 6-10, 53pp. Sea Fisheries Branch, Department of Industries, Private Bag, Sea Point, Cape Town, South Africa.

A calibrated high-frequency echo-sounder is being used to measure the density of pelagic fish shoals. The information can be combined with aerial measurements of shoal cover to give rapid estimates of fish abundance over a wide area. Problems of calibrating the instrument are discussed and the validity and accuracy of the method examined. (Author)

142
Hampton, I., 1975. Digital data logging system for acoustic studies of fish Stocks. Proc. Joint Conf. on Instrum. in Oceanogr., Bangor, U.K., 23-25 Sept. 1975.

143
Hampton, I.; Agenbag, J.J.; Cram, D.L., 1979. Feasibility of assessing the size of the south-west African pilchard SARDINOPS OCELLATA stock by combined aerial and acoustic measurements. Fish. Bull. S. Afr. 11:10-22.

A method is being developed for determining the stock size of the South West African pilchard from night-time aerial measurements of shoal area combined with synchronous acoustic determinations of fish density within the shoals. An analysis of the possible errors in an aerial and an acoustic survey, conducted independently, suggests that by combining the two methods it should be possible to estimate the relative stock size with a precision of at least 50 per cent with 95 per cent confidence. It is estimated that the random errors and biases would contribute up to 20 per cent and 30 per cent respectively to the total error. Meaningful assessements of absolute abundance would probably be precluded by large uncertainties in any value assumed for the mean acoustic target strength of the fish. (Author)

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144
Hashimoto, T.; Maniwa, Y. Ultrasonic reflection loss of fish shoal and characteristics of the reflected wave. Fish. Boat (Japan) Tech. Rep. 6:113-139.

145
Hashimoto, T.; Maniwa, Y., 1956. Study on reflected loss of ultrasound of millimeter wave on fish-body. Fish. Boat (Japan) Tech. Rep. 9:165-173.

146
Hashimoto, T.; Maniwa, Y., 1956. Study on reflection loss of ultrasonic wave on fish body by millimeter wave. Fish. Boat (Japan) Tech. Rep. 8:113-118.

The writers reported the study on the reflection loss of ultrasonic wave on the fish body by the range of frequencies between 10 and 50 kc.

147
Haslett, R.W.G., 1962. Determination of the acoustic scatter patterns and cross-sections of fish models and ellipsoids. Br. J. Appl. Phys. 13:611-620.

148
Haslett, R.W.G., 1962. Determination of the acoustic back-scattering patterns and cross sections of fish. Br. J. Appl. Phys. 13:349-357.

Using a scale-model technique, the back-scattering polar diagrams of small fish in water were determined at 1.48 Mc/s, 625 kc/s and 360 kc/s over a wide range of fish length. As the fish length increased, the acoustic back-scattering cross sections in the reference directions undulated in a regular fashion, indicating interference between the signals from various parts of the fish. From the results, using suitable scaling factors, the acoustic cross sections of an isolated fish can be calculated over wide ranges of size and frequency. The ratios of the signals in different directions and of side-lobe amplitudes are also determined for fish of various lengths. The acoustic cross sections of a few simple bodies are amenable to calculation and, on comparison with the observed experimental trends, the part of the fish giving the largest signal at a given fish length can be inferred, as well as the effect of variation of frequency. The latter is checked by comparing the results at 625 kc/s with those at 1.48 Mc/s. The results are correlated with those of other workers who used large fish. Prior observations (Cushing and Richardson 1956) of the ratios of signals received from a fish at different frequencies can now be explained. (Author)

APPENDIX C (continued)

149
Haslett, R.W.G., 1962. Measurements of the dimensions of fish to facilitate calculations of echo-strength in acoustic fish detection. J. Cons. Int. Explor. Mer 27:261-69.

150
Haslett, R.W.G., 1965. Acoustic backscattering cross sections of fish at three frequencies and their representation on a universal graph. Br. J. Appl. Phys. 16:1143-1150.

151
Haslett, R.W.G., 1969. The target strengths of fish. J. Sound Vib. 9(2):181-91.

152
Haslett, R.W.G., 1970. Acoustic echoes from targets under water. In: Stephens, R.W.B. (ed.), Underwater Acoustics, Wiley Interscience, London:129-199.

153
Haslett, R.W.G., 1977. Automatic plotting of polar diagrams of target strength of fish in roll, pitch and yaw. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:74-81.

A few years ago, under the auspices of the U.K. White Fish Authority, a versatile equipment was built for measuring the polar diagrams of fish at five frequencies between 30 and 547 kHz, using various pulse-lengths. Some of the more important parts of the equipment are described briefly, including the arrangement of ten transducers, the pulse transmitter (coherent from ping to ping), the special fish suspension for high echo-to-background ratio, the gating of peak echo, and the absolute calibration of target strength. Defrosted frozen codfish were used. In the earlier part of the work, about a hundred polar diagrams were plotted at angular intervals of 30 degrees, thereby giving averaged values. For the more recent observations, the apparatus has been mechanised to record the amplitudes of the echo continuously over 360 degrees rotation in roll, pitch, or yaw, at intervals of 0.1 degrees. A selection from the numerous results is given for cod fish of lengths between 60 and 104 cm, including the fifteen aligned diagrams for one fish of length 69 cm, taken in the three planes at the five frequencies. Considerable fine structure is observed, due to interference between the various contributions to the overall echo from different parts of the fish. Thus, the effects of aspect angle, frequency, and pulse length can be studied. (Author)

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154
Haslett, R.W.G., 1979. The fine structure of sonar echoes from underwater targets, such as fish. In: Proc. of Ultrason. Int. 79, IPC, Guildford, England:307-320.

155
Haslett, R.W.G.; Burgess, W.H.; Frost, K., 1973. Equipment for plotting the polar diagrams of target strength of fish at five frequencies. Ultrason. Inte. 1973 Conf., London, 28 March.

156
Haug, A.; Nakken, O., 1977. Echo abundance indices of O-group fish in the Barents Sea, 1965-1972. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:259-264.

In order to obtain estimates of year class strength of O-group fish, joint international surveys have been conducted each year since 1965 in the Barents Sea. The density of fish has been estimated by visual grading of the echo-sounder paper recordings and the scattering layers have been identified by small-meshed pelagic trawls. The year class strengths of the species under consideration have been stated to be poor, average or strong, and this grading has so far been based on the experience of the participating scientists. In this present paper, abundance indices for each year are calculated for the most important species. The indices are based on the visual density grading of the echograms and on the size of the trawl catches. Echo integrator readings are used to calculate the true ratio between the 'visual' density groups. The usefulness of such indices will increase with increasing knowledge of the sound reflecting properties of the scatterers. (Author)

157
Hawkins, A.D., 1977. Fish sizing by means of swimbladder resonance. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:122-129.

It has been suggested that the phenomenon of swimbladder resonance can be used to determine the size of commercially valuable species of fish. In predicting the resonance frequency of the swimbladder for a fish of given size, it is usual to assume that the organ behaves acoustically rather like a free gas bubble. However, recent experimental evidence suggests that, for the cod, both the resonance frequency and damping of the swimbladder are much higher than simple bubble theory would predict. This observed elevation in the resonance frequency can be explained in terms of a high dynamic stiffness of the tissues surrounding the swimbladder, which may be associated with a

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muscle tonus controlled actively by the fish. Further data on the resonance frequencies of single fish of known hydrostatic history are required before free-living fish can reliably be sized by low frequency spectral response methods. (Author)

158
Hergenrader, G.L.; Hasler, A.D., 1965. Diel periodicity of activity and vertical distribution of perch (PERCA FLAVESCENS Mitchill) under the ice. Univ. Wisconsin, Madison, Fin. NSF Rep.

An echo sounder was utilized from early January to mid-March to collect information on the daily activity patterns and depth distributions of yellow perch in Lake Mendota, Wisconsin, a highly productive eutrophic lake with winter characteristics very similar to other eutrophic lakes of temperate regions. The ice reaches a thickness of at least 20 inch (50 cm) and the lake usually remains ice covered for an average of 114 days. Recordings of 24 hours duration were made throughout the winter at selected sites. It was learned from these observations that the yellow perch are active primarily during daylight hours with peak periods occurring in mid-morning and early afternoon. Usually the afternoon peak is of smaller magnitude than the morning peak. The peaks are in large part owing to perch schools which are active at those times. There was a marked difference in the number of perch recorded at shallow stations as compared to deep stations. The number of fish recorded was always much larger at the deep (over 50 feet) stations. Perch appear to remain concentrated in the deeper portions of the lake throughout the duration of ice cover. (Author)

159
Hester, F.J., 1970. Sonar target classification experiments with a continuous transmission Doppler sonar. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 607:1-20.

A continuous-transmission sonar with very fine echo frequency discrimination was designed and constructed to study Doppler effects caused by the motion of fish as they relate to fish size and swimming characteristics. Although the equipment performed as theory predicted, difficulties with sea noise and trouble in maintaining contact with fish schools showed that commercial application of this approach is unsuitable without considerable additional development work. These problems and some results are discussed, and notes on target-strength measurements of several species of fishes are included in this report. (Author)

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160
Hewitt, R.P.; Smith, P.E.; Brown, J.C., 1976. Development and use of sonar mapping for pelagic stock assessment in the California Current area. NOAA Fish. Bull. 74(2):281-300.

A method for pelagic fish stock assessment is presented which utilizes a fixed sonar beam for mapping fish schools. Samples of the two major acoustic properties of fish schools are presented, i.e., acoustically derived horizontal dimensions (representative of school volume) and target strengths (which may be representative of school compaction). Sampling biases and sources of sampling variability in the measurement of these properties are discussed. The results of two experiments, conducted to determine the weight of a fish school as a function of its acoustic characteristics, are presented. In the first experiment, an acoustically transparent trap was used to recreate an aggregation of fish and in the second, commercial fishing boats were chartered to capture whole schools. An automated sonar data acquisition and processing system is described and test results presented. The results of paired automated surveys of the Los Angeles (southern California) Bight are presented and discussed. The paper reports development of the sonar-fish school mapping method first documented by P.E. Smith in 1970. Field investigations, conducted in cooperation with the Navy and the California Department of Fish and Game, indicate a median school size of 30 m diameter, a mean fish density of 15 kg of fish biomass per square m of horizontal school area, and a biomass estimate of 1.23 to 2.30 10(E6) metric tons for pelagic schooled targets in the Los Angeles Bight. (Author)

161
Hocking, P.D., 1974. A twenty-three day twenty-mile echo record of fish behaviour. Int. Cons. Explor. Sea Coop. Res. Rep., Ser. B, 36(1):1-7.

162
Holden, M.J.; Raitt, D.F.S., 1974. Manual of fisheries science. Part 2. Methods of resource investigation and their application. FAO Fish. Tech. Pap. (115) Rev. 1:214.

163
Holliday, D.V. Resonance and doppler structure in echoes from pelagic fish schools. Ph.D dissertation, Univ. California, San Diego.

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164
Holliday, D.V., 1972. An acoustic data acquisition system for research on pelagic fish schools. Scripps Institution of Oceanography, San Diego, Mar. Phys. Lab. Tech. Memo:1-111.

The document describes a small, flexible acoustic data acquisition system which was developed for studying the acoustic signatures of pelagic fish schools. The hardware was centered about a PDP-8/L mini-computer. Hardware interfaces to peripheral data gathering and display devices are described in detail. A unique software system was developed for use with the data acquisition system at sea. The software is an interpretive, algebraic-like language with special high-level functions and commands designed to service the system hardware. A detailed description of the major elements of this flexible software system and its operation are provided. (Author)

165
Holliday, D.V., 1972. Resonance structure in echoes from schooled pelagic fish. J. Acoust. Soc. Am. 51(4):1322-1332.

Explosive acoustic sources were used to obtain echoes from aggregations and schools of commercially important marine fish. Narrow-band spectral analysis of the echoes from these targets revealed significant structure in the frequency range from 200 to 5 kHz. The targets were partially captured after the acoustic tests; three yielded northern anchovy (ENGRAULIS MORDAX), one consisted of a mix of anchovy and jack mackerel (TRACHURUS SYMMETRICUS), and the last sample contained an aggregation of seven species of rockfish (SEBASTES), a whitefish (CAULOLATILUS PRINCEPS), and a striped seaperch (EMBIOTOCA LATERALIS). The results of the direct biological sampling were combined with theoretical predictions for the resonant swimbladder response and compared with the experimentally observed resonances. (Author)

166
Holliday, D.V., 1974. Doppler structure in echoes from schools of pelagic fish. J. Acoust. Soc. Am. 55(6):1313-1322.

The frequency distribution of energy in direct path echoes from three schools of pelagic fish is presented. One-half-second 30 kHz CW pulses were used to study motions internal to the fish schools from distances up to 1200 m. The measured Doppler spread of echo energy ranged from 30 to 70 Hz. The Doppler spread-at-side aspect is related to swimming motions by a simple algebraic model based on Bainbridge's equation relating fish swimming speed, length, tail-beat amplitude, and tail-beat frequency. The mathematical model was used to estimate the length of the fish in two of the schools. These length estimates agree with average fish lengths derived from school cruising speeds. Near head or tail aspect, the observed Doppler structure appears to be related to behavioral swimming characteristics. (Author)

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167
Holliday, D.V., 1977. Extracting bio-physical information from the acoustic signatures of marine organisms. In: Oceanic sound scattering prediction, Anderson, N.R. and Zahuranec, B.J. (eds.), Plenum Press, N.Y.:619-624.

A formal mathematical procedure is introduced for extracting bio-physical information from the acoustic signatures of layers, aggregations or schools of marine organisms. Several possible generalizations and limitations of the technique are briefly discussed. (Author)

168
Holliday, D.V., 1977. First quarterly report on a program of joint biological and acoustic resonance surveys of pelagic fish populations in the southern California Bight. TRACOR Document T-77-SD-1108-U.

169
Holliday, D.V., 1977. Minimum acoustic resonance system specifications for Routine surveying of pelagic fish populations. TRACOR Document T-78-SD-001-U.

170
Holliday, D.V., 1977. Second quarterly report on a program of joint biological and acoustic resonance surveys of pelagic fish populations in the southern California Bight. TRACOR Document T-77-SD-009-U.

171
Holliday, D.V., 1977. The use of swimbladder resonance in the sizing of schooled pelagic fish. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:130-135.

An acoustic method for remotely determining the presence and size of gas-filled swimbladders in schools of pelagic fish from a drifting ship has been extended to underway operation. Resonance structure was observed at ship speeds of up to five knots. In the absence of direct sampling of the schools studied, the underway results are compared with data for which samples of the school were available. (Author)

APPENDIX C (continued)

172
Holliday, D.V., 1977. Two applications of the Doppler effect in the study of fish schools. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:21-30.

The Doppler effect was applied to the study of the dynamic motions of several fish schools. One application of the Doppler effect involved the accurate measurement of the motions of the sonar platform relative to the motion of the water column. This allows accurate, long-term tracking of a school of fish relative to a water reference. From the school track, a school swimming speed, relative to the water, was plotted as a function of time. The resulting swimming speed curves are interpreted in terms of cruising, burst swimming, and endurance. A second application of the Doppler effect is the study of internal motions of a fish school. Side aspect data are interpreted in terms of swimming and body motions and tail aspect data in terms of swimming behavior. Estimates of average fish length derived from cruising speed are compared with length estimates derived from the Doppler spread of echo energy. (Author)

173
Holliday, D.V., 1980. Use of acoustic frequency diversity for marine biological measurements. In: Advanced concepts in ocean measurements for marine biology, F.P. Diemer, F.J. Vernberg, and D.Z. Mirkes (eds.), The Belle W. Baruch Library in Marine Science 10:423-460.

The conclusions one may draw upon looking into the ocean with sound of a particular frequency are severely colored by the frequency chosen. The dependence of acoustic scattering from marine biological targets on frequency has been known since early observations of the deep scattering layer. It is only in recent years, however, that the electronics associated with complex signal and data processing of acoustic information have become sufficiently small, reliable, and inexpensive to be incorporated in broadband or multi-frequency sensors for use at sea. This technological advance, which appears to be in its infancy, has already made possible the design of acoustic instruments that make the use of frequency as valuable in some bioacoustic applications as time or space. A simplified review of frequency dependence of sound scattering from marine organisms is followed by two examples of the use of frequency diversity taken from the author's recent work. (Author)

APPENDIX C (continued)

174
Holliday, D.V.; Edwards, R.L.; Yayanos, A.A.; Weinert, H.L.; Hickman, G.D. Problems in marine biological measurements. In: Advanced concepts in ocean measuroments for marine biology, F.P. Diemer, F.J. Vernberg, and D.Z. Mirkes (eds.), The Belle W. W. Baruch Library in Marine Science 10:523-530.

Analysis of the problems associated with sampling and analysis of marine biological parameters are presented. Discussion is of hydroacoustic sampling as a unique sampling technique. (PK).

175
Holliday, D.V.; Larsen, H.L., 1979. Thickness and depth distributions of some epipelagic fish schools off southern California. Fish. Bull. 77(2):489-94.

The thickness and vertical distributions of shallow schools of many fish cannot be accurately measured by conventional echo sounding techniques. Consequently, a new approach which makes use of the bottom bounce acoustic propagation path has been developed and used for measurements on northern anchovy schools off southern California. These measurements, at three locations in three different seasons, revealed that the schools occupied a depth zone only a few meters thick. Good agreement was found between occurrences of the mean depths of the schools and the seasonal thermocline, where it is hypothesized that thermal stratification and associated water density microstructure may lead to an aggregation of some part of the fishes' food supply in thin layers. (Author)

176
Holliday, D.V.; Pieper, R.E., 1980. Volume scattering strengths and zooplankton distributions at acoustic frequencies between 0.5 and 3 MHz. J. Acoust. Soc. Am. 67(1):135-146.

Measurements of ultra-high-frequency acoustic volume scattering strengths in California Current waters revealed a complex structure of thin scattering layers in the upper 100 m. These scattering strength profiles are illustrated along with size distributions of zooplankton collected at the same time and depth as the acoustic measurements. Within the uncertainties in the biological measurements and the assumed physical properties of the animals collected, the principal features of the acoustic profiles can be explained by the zooplankton distributions. (Author)

APPENDIX C (continued)

177
Holliday, D.V.; Smith, P.E., 1978. Seasonal changes in fish size distributions as detected by acoustic-resonance survey and by conventional sampling. J. Acoust. Soc. Am. 64 (Suppl. 1):S95.

The larvae, juveniles, and adults of the northern anchovy inhabiting the southern California Bight were monitored by conventional direct sampling, by the commercial fishery, by trawl sampling, and by plankton net sampling during 1977. Broadband acoustic techniques were used to further characterize sonar targets in terms of the presence or absence of gas-filled swimbladders. For targets whose spectra exhibited resonance structure, distributions of swimbladder sizes were calculated for individual schools, school groups, and for ensembles of school groups. Observed seasonal changes in swimbladder size distributions implicate fish growth, mortality, and behavior as parameters impacting the frequency dependence of the acoustic backscattering from schools. A comprehensive list of species known to frequent this ocean area will be discussed in this context. An overview of the distribution and biophysical characteristics of the common pelagic nekton which inhabit the southern California Bight will provide the background for a description of the distribution of schools and aggregations as determined acoustically in March, May, and September of 1977. [Work supported by NOAA/NMFS. (Author)

178
Hopkins, C.C.E.; Falk-Petersen, S.; Tande, K.; Eilertsen, H.C., 1978. A preliminary study of zooplankton sound scattering layers in Balsfjorden, Norway: Structure, energetics, and migrations. Sarsia 63(4):255-264.

An investigation of zooplankton-generated Sound Scattering Layers (SSL), using both echosounders and net sampling methods, was started in Balsfjorden, a Norwegian fjord situated within the Arctic circle, in April 1977. Results of preliminary work over a 24-h period from April 5-6 were presented. Samples were taken in and out of the SSL with a Beyer's Low Speed Midwater Trawl. The SSL was mainly due to concentrations of euphausiids, chaetognaths, and calanoid copepods. Analyses of dry weight, lipid, protein, C, N, ash, and caloric value showed that these factors were up to 30 times more concentrated in the SSL than outside it. The species composition and abundance of zooplankters in the SSL changed diurnally indicating the dynamic nature of the assemblage. Acoustic profiles taken with a 120 kHz precision echosounder showed that the SSL had a text-book pattern of diurnal migration, apparently related to changes in incident and sub-surface radiation. Migration speeds of the SSL were 8.1-24.2 m/h. Hydrography and phytoplankton were examined as possible factors influencing migration. The implications of zooplankton SSL in fjords were considered in terms of ecological energetics and resource biology. (Author)

APPENDIX C (continued)

179
Hopkins, J.C. A note on methods of producing corrected side scan sonar displays. Int. Hydrogr. Rev. 49(2):99-106.

Existing methods of display of side scan sonar information are reviewed. A proposal is made for a new type of display which will enable substantial areas to be surveyed and the results displayed in a form corrected for the major errors introduced by ship motion. (Author)

180
Hopkins, J.C., 1972. Tape recording of side-scanning sonar signals. Int. Hydrogr. Rev. 49(1):59-69.

A system for the tape recording of side scan sonar signals permitting automatic reply into a graphic recorder. The economical use of tape, and the facility to effect "on line" monitoring of the tape recorded signals, are further advantages. (Author)

181
Huang, K.; Clay, C.S., 1980. Backscattering cross sections of live fish: PDF (probability density function) and aspect. J. Acoust. Soc. Am. 67(3):795-802.

The probability density function (PDF) of the peaks of the envelopes of sonar echo from live fish were measured at beam aspect. The measurements were made at 220 kHz and in a waveguide. The fish was the common shiner (NOTROPIS CORNUTUS) and was about 120 mm (about 18 acoustic wavelengths) long. The PDF of the echoes was approximately Rayleigh when the fish was moving gently. The backscattering cross section equaled 4.2x10(-3) square meters. Transformation of the PDF's to a target strength display in decibels displaced the maximum of the PDF to the target strength equaling 10log10 (ob/Ao)+3 dB where c is the mean backscattering cross section and Ao=1 square meters. The target strengths of the common shiner (120 mm) and the mummechog (FUNDULUS HETEROCLITUS, 100 m) were measured as a function of aspect angle. Comparison of the experimental measurements and Love's empirical target strength for any aspect showed that the measured target strengths at broadside aspect were about the same and the target strengths at other aspect angles were several decibels less than Love's values. Linear arrays of point scatters were chosen to match the gross aspect dependence of the target strengths of the fish. The lengths of the arrays were 6.5 mm for the common shiner and 16.5 mm for the mummechog. These lengths were less than the lengths of the corresponding fish's swim bladders. (Author)

APPENDIX C (continued)

182
Hylen, A.; Smedstad, O.M., 1972. Norwegian investigations on young cod, haddock and redfish in the Barents Sea and adjacent waters 1970-1972. Int. Counc. Explor. Sea, Copenhagen CM 1972/F:38.

183
Iida, K.; Suzuki, T., 1980. Study about quantification of echo-sounder signals I. A signal acquisition of an echo-sounder. Bull. Fac. Fish. Hokkaido Univ. 31(4):339-353.

184
Ishii, T., 1976. Studies on counting the echo pattern of individual fish by pattern analysis method - II. Identification of the echo pattern. Bull. Jpn. Soc. Sci. Fish. 42(10):1065-1076.

In order to judge and count the echo pattern of the individual fish from echo data, a software (Module AUPACS) is proposed, and some functions and supplemental techniques of this method are explained. (Author)

185
Ishii, T., 1976. Studies on counting the echo pattern of individual fish by pattern analysis method - I. Total system and hardware. Bull. Jpn. Soc. Sci. Fish. 42(3):251-264.

In order to furnish quantitative information to the study of the dynamics of exploited fish populations, a new method is proposed where by it is possible to count directly from the echo patterns of large-sized fish individuals such as tunas by the pattern analysis. Contents are summarized as follows: 1) Total system was designed for the purpose mentioned above. 2) Firstly, some attachment devices (AD-0, AD-I, AD-II, AD-III) were developed and manufactured to connecting fish detector with computer. 3) The devices were tested in several field experiments. The performances of these devices were generally found to be at a good level. 4) Process data and interrupt process program were completed for the test of hard wears. 5) The system, for collecting the field data, was completed, and from these data it is possible to analyze and count the echo patterns with a digital computer. 6) The digital data, obtained by this system, were very useful to analyze the echo patterns to develop soft wears for the project. (Author)

APPENDIX C (continued)

186
Ishii, T., 1976. Studies on counting the echo pattern of individual fish by pattern analysis method - III. Analysis of elements of echo data. Bull. Jpn. Soc. Sci. Fish. 42(11):1251-1261.

In order to design the mask and to count echo patterns by field data, the structure and characteristics of the group of element 'SET' and the relationship between these characteristics and several factors were analyzed from field data obtained during the cruise of the 'Hakuho Maru' in 1969. From these analyses, it was determined that 0.4 or 0.5 for slice level and ship speed of 6 knots are optimum levels for the designing of the mask and echo pattern counting. (Author)

187
Ishii, T., 1977. Studies on counting the echo pattern of individual fish by pattern analysis method - IV. Design of the echo pattern mask. Bull. Jpn. Soc. Sci. Fish. 43(1):19-30.

Among several modules for counting echo patterns of individual fish in the ocean the AMDESS module is described. Some functions of this module are explained with several graphic examples. (Author)

188
Ishii, T., 1977. Studies on counting the echo pattern of individual fish by pattern analysis method - V. Analysis of the relationship between echo pattern counts and fish density by the simulation method. Bull. Jpn. Soc. Sci. Fish. 43(2):151-161.

189
Ishii, T.; Kuroki, T.; Nishimura, M.; Shibata, K.; Yamanaka, H.; Morita, J., 1975. Basic experiments on echo survey for estimating fish population by R/V 'Tansei Marui'. Bull. Jpn. Soc. Sci. Fish. 41(11):1087-1094.

190
Jakobsen, T.; Smedstad, O.M., 1972. Counting of Arctic cod with echo integrator in Lofoten in 1972. Fisken Havet 3:49-51.

APPENDIX C (continued)

191
Johannesson, K.A.; Losse, G.F., 1977. Methodology of acoustic estimations of fish abundance in some UNDP/FAO resource survey projects. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:296-318.

Echo integrators have been used in FAO field projects to measure absolute abundance of standing stocks. The methodology employed and developed is presented and discussed. A 'direct calibration method' to obtain the relationship between integrator readings (in mm) and the fish density (in number of fish per sq m or tons per sq nautical mi) is described in detail. The method is based on experimental measurements of a known concentration of live fish, kept in a special net-cage, and arranged in the echo-sounder beam about 4-5 m below the transducer. The method is particularly suitable for smaller pelagic species. Estimation of school parameters, including the volume, mean internal school density, and weight of schools, from echo-sounder and integrator records is given and certain error possibilities in these estimates are considered. Results from observation of target strength, both experimental and field measurements, are given. (Author)

192
Johannesson, K.A.; Robles. A.N., 1977. Echo surveys of Peruvian anchoveta. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:237-244.

A method of direct calibration of an echo integration system, using many live fish captive in a cage suspended beneath the echo-sounder, is described. A section of the Peruvian coastal waters was surveyed using an echo integrator and the results combining the integrator values with the calibration values are presented; the stock of pelagic fish was estimated as 4 $\pm$ 0.44 million tons. Evidence from trawl sampling and from the subsequent commercial fishery in March suggests that these fish were predominantly anchoveta. (Author)

193
Jones, F.R.H., 1973. Tail beat frequency, amplitude, and swimming speed of a shark tracked by sector scanning sonar. J. Cons. Int. Explor. Mer 35(1):95-97.

APPENDIX C (continued)

194
Jones, F.R.H., 1980. Acoustics and the fisheries: Recent work with sector scanning sonar at the Lowestoft Laboratory. In: Diemer, F.P.; Vernberg, F.J.; Mirkes, D.Z. (eds.), Advanced concepts in ocean measurements for marine biology, Belle W. Baruch Library in Marine Science 10:409-421.

A high-resolution 300 kHz modulation scanning sonar has been installed in the Ministry of Agriculture, Fisheries and Food's research vessel 'Clione'. The equipment is stabilized against roll, pitch, and yaw and can be used in horizontal (plan) or vertical (elevation) mode to scan a 30 degree sector. The equipment has been used to determine the efficiency of the Granton otter trawl for catching plaice. In these experiments plaice fitted with acoustic transponding tags were released individually and kept under surveillance by sonar. A second research vessel, towing an otter trawl, was directed to catch the fish, the whole catching process being followed by sonar and recorded on 16-mm film and video tape. For 166 valid attacks made on individual fish lying between the otter boards, the overall efficiency of the gear was 44% + or - 8%. For fish lying between the otter boards and wing ends of the net, the efficiency was 22% + or - 10%, and for those in the path of the net 61% + or - 10%. The addition of the board-to-board tickler chain increased the overall efficiency of the net to 67%, and to 48 and 79% for fish in the positions 'boards to wing ends' and 'path of the net' respectively. The high resolution and exceptional picture-forming qualities of the sector-scanning sonar have being applied to: wreck and bottom surveys, measurements of the parameters of fishing gear, fish tracking, the structure and behaviour of fish shoals, and the study of fish target strengths. Modulation sector-scanning sonar has proved to be a remarkable and versatile invention and very reliable in operation. (Author)

195
Jones, F.R.H.; Brown, C.L.; Myrberg, A.A.; Warner, H.L.; Watkins, W.A., 1980. The future of hydroacoustics as an aquatic biological tool. In: Advanced concepts in ocean measurements for marine biology, F.P. Diemer, F.J. Vernberg, and D.Z. Mirkes (eds.), The Belle W. Baruch Library in Marine Science 10:549-550.

196
Jones, F.R.H.; Pearce, G., 1958. Acoustic reflection experiments with perch (PERCA FLUVIATICIS Linn.) to determine the proportion of the echo returned by the swimbladder. J. Exp. Biol. 35:437-450.

APPENDIX C (continued)

197
Kanemori, R.Y.; Ehrenberg, J.E., 1978. A microcomputer-based echo-integration system for fish population assessment. In: Ocean '78: IEEE Int. Conf. Eng. Ocean Environ.:204-207.

Abundance estimates obtained with acoustic echo-sounding equipment play an important role in the management of fish stocks. The common technique presently used is to process the signal from the echo sounder with a digital computer or to record the analog signal for later processing. A microcomputer-based echo-integration system has been developed for fish population assessment. It is a relatively inexpensive, field-oriented, portable instrument that can process data in real time from any existing echo sounder. The signal from the echo sounder is detected, digitized, squared, and averaged for various depth ranges. The averaged squared echo level is then scaled to provide a measure of the density of the fish school at the selected depth ranges. The system automatically tracks the bottom depth and prevents integration of the return from the bottom. (Author)

198
Kato, M., 1975. An echo survey on the distribution of fish schools that pass into the trawl net mouth. Bull. Jpn. Soc. Sci. Fish. 41(5):515-528.

199
Keir, R.S.; Melcer, J., 1975. Application of modern technology and management methods to the assessment of fisheries resources in Mexico. In: Ocean '75: IEEE Int. Conf. Eng. Ocean Environ., San Diego, Calif.:480-483.

Mexico is now in process of developing scientific management of its fisheries and promoting full harvesting of its large latent resources. To do this quickly, economically, and efficiently, the investigators are attempting to apply methods of systems analysis, computer data processing, modern acoustic survey, and methods of simplified data recording to develop a systematic methodology. The approach has emphasized concentration on the study of one developed fishery, the Pacific shrimp, and one developing fishery, the Pacific anchovy. As experience is gained the approach is being transferred to the study of other fisheries. (Author)

APPENDIX C (continued)

200
Kelso, J.R.M.; Minns, C.K., 1975. Summer distribution of the nearshore fish community near a thermal generating station as determined by acoustic census. J. Fish. Res. Board Can. 32(8):1409-1418.

The relation between thermal plumes and fish abundance and distribution was studied at the Pickering Nuclear Generating Station, Lake Ontario, using simultaneous digital echo counting and temperature monitoring systems during summer thermal stratification of the lake. Fish relative abundance varied from 20.8/10,000 cubic meters to 1,037/10,000 cubic meters and both these extreem density estimates occurred in the 7.5-12.5 m depth shell. Also, changes in distribution of the nearshore community were apparent during the study period, July-October. The fish community in July was pelagic and selected 10-11 deg. C and 14-16 deg. C. That same community later appeared to become segregated into benthic and pelagic communities. Thermal plumes, either well defined or diffuse, appeared to have little effect on the pelagic community either because fish were not available to elevated temperatures by habitat selection or because fish failed to respond to increased surface temperatures. (Author)

201
Kelso, J.R.M.; Pickett, E.E.; Dowd, R.G., 1974. A digital echo-counting system used in determining abundance of freshwater pelagic fish in relation to depth. J. Fish. Res. Board Can. 31(6):1101-1104.

The digital echo-counting system consisted of a 200 kHz echo-sounder, cathode-ray tube, preamplifier rectifier, and digital logic. Incoming signals were gated by delayed pulses of 6.6 msec duration to represent 5-m-depth shells from 5 to 25 m depth. Response to density was linear. Acoustic estimates of density ranged from 19.3/10,000 cubic meters to 524.0/10,000 m3 and trawl estimates of density ranged from 17.4/10,000 cubic meters to 420.0/10,000m3. A high degree of correlation (0.94) existed between densities estimated acoustically and by midwater trawl. Species differences, smelt in Lake Erie and alewife in Lake Ontario, did not seem to affect density estimates. (Author)

202
Kemmerer, A.; Russell, M.; Minkler, R., 1972. Target strength measurements for the basic hydroacoustical measurement program. Nat. Mar. Fish. Ser., Fish. Center Lab., Pascagoula, Miss.

APPENDIX C (continued)

203
Kimura, D.K.; Lemberg, N.A., 1981. Variability of line intercept density estimates (A simulation study of the variance of hydroacoustic biomass estimates). Can. J. Fish. Aquat. Sci. 38:141-1152.

'Line intercept density estimates' are defined as estimates of mean density arrived at by sampling density along randomly selected transects. For these estimates, the school (or patch) configuration being sampled strongly influences the variance of the mean density estimate. By simulating schools as circles (or ellipsoids) the variance component due to schooling was calculated by numerical integration, where the variance generating probability measure was a uniform distribution determined by the type of transect sampling employed. Results indicate that the component of variability due to schooling is large; that it can be effectively reduced (at practical sampling levels) by increasing sampling density; and that relative variance (as measured by a coefficient of variation) is extremely sensitive to the percentage of the sampling region covered by schools. Stratified methods of sampling (zig-zag and stratified parallel) were uniformly more efficient than random parallel sampling. Furthermore, zig-zag sampling was more efficient than stratified parallel sampling at low sampling intensities, while the opposite was true at high sampling intensities. No difference in efficiency was detected between sampling a rectangular as opposed to a square region. Although analyses were aimed principally at evaluating the variability of hydroacoustic biomass estimates, results are also applicable to line intercept estimates common in field ecology. (Author)

204
Kung, H., 1977. Probability density function of backscattered Sound from live fish. MS thesis, Univ. Wisconsin.

205
Lahore, H.W., 1969. University of Washington echo integrator and counter. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-57, 1968:25.

206
Lahore, H.W.; Lytle, D.W., 1970. An echo integrator for use in the estimation of fish populations. Univ. Washington, Seattle, Fish. Res. Inst., Rep. WSG-70-1:1-46.

The echo integrator is a sonic device that enables the fishery researcher to quantify fish stocks more accurately than he has been able to do by the use of test fishing and/or an unmodified echo sounder. In this report the fundamentals of underwater acoustics are discussed, the echo integrator is described, and its operation and performance in field experiments are treated. (Author)

APPENDIX C (continued)

207
Larsen, H.L., 1974. Distributions of target strengths and horizontal dimensions for aggregations and schools of marine organisms. TRACOR Sciences and Systems, Austin, TRACOR-T74-SD-1054-U 75pp.

Recordings of absolute echo levels from marine acoustic targets (schools of pelagic organisms) were analyzed to measure distributions of peak target strengths at two frequencies, 11 and 30 kHz. Since the recordings were not simultaneous, different sets of targets were analyzed at each frequency. At 30 kHz, peak target strengths ranged between - 10 dB and 28 dB with a mean target strength of 18.8 dB. At 11 kHz, the measurements ranged from -25 dB to 11 dB with a mean of 4.2 dB. Distributions of two target horizontal dimensions were also obtained. These dimensions ranged between 5 m and approximately 400 m with a mean approximately 40 meters. Most probable target diameter (highest frequency of occurrence) was approximately 20 m. A trend toward higher target strength for larger targets was observed at both frequencies. (Author)

208
Latyshev, V.N.; Sitnikov, L.S.; Utyakov, L.L., 1978. A digitizer for use with a depth sounder. Akad. Nauk SSSR. Bull. Atmos. Ocean. Phys. Ser. 17(4):484-486.

209
Lee, K.C.; Brannian, L.K.; Mathisen, O.A.; Thorne, R.E., 1979. Coastal upwelling ecosystems analysis. Data report 60. Acoustic observations on the distribution of nekton off the coast of Peru, 1977, R/V 'Melville' 6 April-24 April, 1977, R/V 'Cayuse' 6 May-17 May, 1977. Univ. Washington, Seattle, Coll. Fish., Rep. 37pp.

210
Lee, K.C.; Mathisen, O.A.; Thorne, R.E., 1979. Coastal upwelling ecosystems analysis. Data report 59. Acoustic observations on the distribution of nekton off the coast of Peru, R/V 'T.G. Thompson', 20 May-8 June, 1976. Univ. Washington, Seattle, Coll. Fish., Rep. 91pp.

211
Lemberg, N.A., 1975. Hydroacoustic assessment of the 1973 sockeye salmon escapement into Lake Quinault, Washington. MS thesis, Univ. Washington (Seatle) 78pp.

APPENDIX C (continued)

212
Lenarz, W.H.; Green, J.H., 1971. Electronic processing of acoustical data for fishery research. J. Fish. Res. Board Can. 28(3):446-447.

A system for processing acoustical data is described. Acoustical data are recorded on magnetic tape in analog form in the field. The data are converted to digital form and analyzed with the aid of a digital computer. The system provides investigators with considerably more information than is available from paper records now in common use. (Author)

213
Lipscombe, L.N., 1975. High-rate acoustic telemeter for fish studies. Proc. Joint Conf. on Instrum. in Oceanogr., Bangor, U.K., 23-25 Sept. 1975.

214
Lord, G., 1973. Acoustical sensing and assessment of Bristol Bay sockeye salmon. In: Ocean '73: IEEE Int. Conf. Eng. Ocean Environ. New York:246-248.

A system of bottom-anchored upward-looking acoustic sensors is currently under joint development by the Fisheries Research Institute and the Applied Physics Laboratory, both of the University of Washington. The sensors are to be deployed in the Port Moller area of Bristol Bay to provide population data on the annual sockeye salmon run some 4 to 8 days prior to the entry of the fish into the various commercial fishery districts. This system is designed to augment the gill-net test fishing currently carried out and to overcome many of the shortcomings of gill-netting such as size selectivity, variable efficiency, and the inability to fish in rough weather. Sampling statistics indicate that ten such sensors in a randomized design will provide sufficient coverage. A mathematical formulation utilizing statistical decision theory and dynamic programming has been developed to characterize the optimum experimental design as well as the optimum fishery management policies. The need for near real-time data over large distances suggested the use of a satellite as a data transmission link. This would permit the use of remote large-scale computing facilities in the processing of the population data.

APPENDIX C (continued)

215
Lord, G.; Acker, W.C.; Hartt, A.C.; Rothschild, B.J., 1976. An acoustic method for the high-seas assessment of migrating salmon. Fish. Bull. 74(1):104-111.

A system of free-floating acoustic buoys with upward-looking transducers has been developed for use in assessing high-seas salmon stocks. The transducers, operating at 120 kHz, are suspended 46 m below the surface. The fish counts and the range to each fish are obtained in digital form, and the data are radioed from each buoy to the tending vessel where the data are decoded and recorded on magnetic tape. The present system consists of four bouys although the receiver-decoder system can accommodate up to 10 buoys operating synchronously. (Author)

216
Lord, G.E., 1973. Population and parameter estimation in the acoustic enumeration of a migrating fish population. Biometrics 29(4):713-725.

A method of salmon population estimation using acoustic echo counting is presented. A parametric fish depth distribution is assumed and large sample methods are used. Asymptotic results are obtained for sampling continuously in depth and also for sampling in discrete depth increments. First order corrections for unresolved targets are presented. The effect of variable acoustic scattering strengths of the fish is discussed briefly, but there are as yet insufficient data on which to base quantitative inferences of this effect. (Author)

217
Love, R.H., 1969. An empirical equation for the determination of the maximum side-aspect target strength of an individual fish. Naval Oceanogr. Off., Washington D.C., Rep. NOO-IR-69-11:1-23.

Experiments are described in which the target strengths of a number of individual fish were measured at various frequencies. The results of these experiments are combined with results from six other sources and an empirical equation approximating the maximum side-aspect target strength of an individual fish is found to be: T = 24.1 log L - 4.1 log lambda - 33.2, for ' (less than sign) or = L/lambda (less than sign) or = 100, where T is the target strength at one yard in dB, L is the fish length in feet, and lambda is the acoustic wavelength in feet. This result combined with a theoretical estimate of the resonance of a fish containing a swimbladder to produce a curve approximately the maximum side-aspect target strength of an individual bladder-fish for L/lambda (less than sign) or = 100. (Author)

APPENDIX C (continued)

218
Love, R.H., 1969. Maximum side-aspect target strength of an individual fish. J. Acoust. Soc. Am. 46(3):746-752.

Experiments are described in which the target strengths of a number of individual fish were measured at various frequencies. The results of these experiments are combined with results from six other sources and an empirical equation approximating the maximum side-aspect target strength of an individual fish determined for 1 less than or equal to L/lambda less than or equal to 100, where L is the fish length and lambda is the acoustic wavelength. This result is combined with a theoretical estimate of the resonance of a fish containing a swimbladder, to produce a curve approximating the maximum side-aspect target strength of an individual bladder fish for L/lambda less than or equal to 100. (Author)

219
Love, R.H., 1971. Dorsal aspect target strength of an individual fish. J. Acoust. Soc. Am. 49(3):816-823.

Experiments are described in which the dorsal-aspect target strengths of a number of individual teleostean fishes of eight species were measured at various frequencies. The results of these experiments indicate that the variations of target strength with frequency are different for fishes in two major teleostean groups, the malacopterygians and the acanthopterygians. These results are combined with results from eight other sources and an empirical equation approximating the dorsal-aspect target strength of an individual fish determined for 0.7 less than or equal to L/lambda less than or equal to 90, where L is the fish length and lambda is the incident acoustic wavelength. The combined results are compared to similar results for the maximum side-aspect target strength of an individual fish, and curves showing the trend of dorsal-aspect and maximum side-aspect acoustic cross sections of an individual swimbladder-bearing fish are presented for all L/lambda less than or equal to 90. (Author)

220
Love, R.H., 1971. Measurements of fish target strength: A review. Fish. Bull. 69(4):703-715.

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

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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. (Author)

221
Love, R.H., 1976. New model of resonant acoustic scattering by swimbladder-bearing fish. J. Acoust. Soc. Am. 60 (Suppl. 1):S55.

A new model of a swimbladder-bearing fish has been developed in order to provide improved predictions of the resonant frequency and acoustic cross section of such a fish. The model consists of a small spherical shell in water, enclosing an air cavity which supports a surface tension. The shell is a viscous, heat-conducting Newtonian fluid, with the physical properties of fish flesh. A comparison of the results obtained with the new model to experimental data indicates that the new model constitutes a definite improvement over previous models. The new model can predict the high values of damping and elevated resonant frequencies that previous models could not. The model appears to be most accurate for fish in which tension in the swim-bladder wall has a minor effect on resonant scattering. This includes the fish which are of interest in studies of volume reverberation and therefore, the new model should be of considerable value in such studies. (Author)

222
Love, R.H., 1977. Target strength of an individual fish at any aspect. J. Acoust. Soc. Am. 62(6):1397-1403.

A set of empirical equations has been developed for use in determining the target strength or acoustic cross section of an individual fish at any insonified aspect as a function of fish size and insonifying frequency in the range 1 = L/lambda = 100, where L is fish length and lambda is acoustic wavelength. The equations were developed by interpolating experimental data obtained by insonifying individual fish as they were rotated about one of their principal axes. It was found that acoustic cross section sigma is proportional to slightly less than L squared for each aspect, indicating that, sigma is approximately proportional to insonified area. Since sigma is almost proportional to L squared, a modified set of empirical equations was developed with sigma exactly proportional to L squared, thus eliminating the dependence of sigma on frequency. The resulting errors are relatively minor and in some situations the modified equations lead to considerable simplifications which make their use quite convenient. (Author)

APPENDIX C (continued)

223
Love, R.H., 1978. A model for estimating distributions of fish school target strengths. J. Acoust. Soc. Am. 64(1):596.

A model has been developed to estimate the distribution of fish school target strengths for any schooling species. The model has both biological and acoustic components. The biological component estimates distributions of school size and density for a given species. A discrete spectrum of nondimensionalized school densities, developed by combining and synthesizing the results of experimental studies on intraschool spacing, is utilized to estimate school density distributions. Discrete spectra of school sizes based on empirical knowledge and assumptions of school growth and reduction are utilized to estimate school size distributions. The acoustic component combines estimates of target strengths of individual fish with numbers of fish insonified to calculates school target strengths at any aspect for a school of given size and density. Multiple scattering is neglected, but attenuation through the school is accounted for by the use shadowing factors. Provision is made for schools which are not totally insonified due to limitations of sonar beam width or pulse length. Comparison to available experimental data indicates that the model produces a reasonable estimate of target strength distributions. (Author)

224
Love, R.H., 1978. Resonant acoustic scattering by swimbladder-bearing fish. J. Acoust. Soc. Am. 64(2):571-580.

A new model of swimbladder-bearing fish has been developed in order to provide improved predictions of the resonance frequency and acoustic cross section of such a fish. The model consists of a small spherical shell in water, enclosing an air cavity which supports a surface tension. The shell is a viscous, heat-conducting Newtonian fluid, with the physical properties of fish flesh. A comparison of the results obtained with the new model to experimental data indicates that the new model constitutes a definite improvement over previous models. The new model can predict the high values of damping and elevated resonance frequencies that previous models could not. The model appears to be most accurate for fish in which tension in the swimbladder wall has a minor effect on resonant scattering. This includes the fish which are of interest in studies of volume reverberation, and the new model should therefore be of value in such studies. (Author)

225
Love, R.H., 1981. Model for estimating distributions of fish school target strengths. Deep-Sea Res. 28(7A):705-725.

APPENDIX C (continued)

226
Lovik, A., 1977. Acoustic holography: A future method for underwater viewing?. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:319-327.

The general principles of holography are briefly reviewed and practical underwater viewing systems based on acoustic holography and their limitations are discussed. It seems possible to achieve a range and image-quality useful for many underwater applications, including fish behaviour studies, stock estimation, underwater navigation, etc.

227
Lovik, A.; Hovem, J.M., 1979. An experimental investigation of swimbladder resonance in fishes. J. Acoust. Soc. Am. 66(3):850-854.

An investigation of the resonant behavior of the swimbladder for different species and sizes has been performed. Most measurements have been done using the ring-hydrophone method, but also a few normal echo measurements have been done. The results show the resonance frequency to increase with depth, but also to depend on to what degree the fish is adapted to the depth. After a sudden transfer to new depth, the resonance frequency will first oscillate and then gradually adjust to a new resonance frequency given by the necessary swimbladder volume to retain neutral buoyancy. The time required to adapt to a deeper depth is longer than for a transfer in the opposite direction, suggesting that gas production takes longer time than letting out gas. The observed Q values are also dependent on adaption, but appear to increase almost linearly with the resonance frequency at least for low Q values. The measured values are compared with a model for scattering from swimbladder fish and values for the swimbladder tension, and viscosity of the fish tissue are calculated. (Author)

228
Lozow, J.B., 1977. The role of confidence intervals in the application of hydroacoustic techniques for biomass estimates. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:214-218.

If a hydroacoustic system is employed to estimate population density, uncertainty due to randomness of the environment and uncertainty due to ignorance of the true state of the system parameters must be contended with. An estimate of population density is not meaningful without a measure of confidence in that estimate. The theory of calculation of confidence intervals for acoustic estimates of biomass is explored and a working method developed. Practical examples of the method are given. (Author)

APPENDIX C (continued)

229
Lozow, J.B.; Suomala, J.B., 1972. The application of hydroacoustic methods for aquatic biomass measurements. A note on echo envelope sampling and integration. Mass. Inst. Tech., Charles Stark Draper Lab., Rep. CSDL-R-712 100pp.

A detailed analysis of basic fish abundance estimation techniques and their respective errors is presented. Echo sampling and integration schemes approach unbiased population estimates if the following details are known: (a) the average target strength of the aggregation, (b) the approximate 'shape' or geometry of the fish aggregation, and (c) the transducer directivity function, source level, voltage response, etc. It is shown that unbiased estimates of dense populations demand a priori knowledge of the geometry and distribution of the randomly assembled targets with respect to the transducer's effective volume coverage. Two typical geometries are examined; they may be loosely described as (1) thick layer of infinite expanse, and (2) thin layer of infinite expanse. The effect of the random phase components on the variance of the population estimate is demonstrated and the autocorrelation of the echo intensity is given. (Author)

230
Lozow, J.B.; Suomala, J.B., 1972. The application of hydroacoustic methods for aquatic biomass measurements. Mass. Inst. Tech., Rep. MITSG 72-8.

231
Lozow, J.B.; Suomala, J.B., 1976. A short note on hydro-acoustical echo signal components and their effect on fish target density estimations. Int. Comm. Northwest Atl. Fish., Res. Doc. 76/VI/10, Ser. 3779, 5pp.

232
MacNeill, I.B., 1971. Quick statistical methods for analysing the sequences of fish counts provided by digital echo counters. J. Fish. Res. Board Can. 28:1035-1042.

The data records of digital echo counters consist mainly of sequences of overlapping counts. To estimate target density and the total number of distinct targets present, one should make appropriate allowances for the redundancy induced by overlapping. With this in mind, point and interval estimation methods are suggested for use in the hand analysis of such sequences. The techniques were developed in response to the need for ship-board analysis of data when there is an immediate requirement to gauge variations in target density as fish surveys are being conducted. (Author)

APPENDIX C (continued)

233
Mais, K.F., 1969. Use of acoustical detection gear in surveying pelagic fishes of California. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-57, 1968:25.

234
Mais, K.F., 1974. Pelagic fish surveys in the California current. Calif. Dept. Fish Game, Sacramento, Rep. Fish. Bull. 162:1-82.

The California Department of Fish and Game started routinely acoustically surveying the smaller schooling pelagic fish resources in the California Current System in 1966. This report covers the first 6.5 years of these surveys (1966-1973). The purpose of these surveys was to determine the abundance, distribution, availability, and other pertinent biological information of the commercially important northern anchovy, jack mackerel, Pacific sardine, and Pacific mackerel. Latent resource species including Pacific saury, Pacific hake, squid, and pelagic red crab also were surveyed. The principal technique consisted of running acoustic transects with a horizontal ranging sonar and vertical echo sounder during daylight hours and fishing a midwater trawl at night. Results show the northern anchovy grossly dominates all other species in terms of biomass and abundance with the southern Baja California region containing most of the total population. Although it was not possible to determine absolute population size, results indicate the estimates of 2 to 6 million tons made from egg and larvae surveys are reasonable. Behavior and availability studies indicate that although the anchovy population is large, its vulnerability to harves by the present commercial fishery varies considerably from year to year as well as seasonally. Most of the common schooling behaviors are unfavorable for effective harvest by roundhaul net. Only a small portion of the population is harvestable during any particular time period. Acoustic surveys were much less effective for estimating abundance of Pacific sardines, Pacific mackerel, and jack mackerel. The distribution of jack mackerel was patchy with nearly all significant concentrations located at a limited number of rocky banks and island coasts. Pacific sardine and Pacific mackerel population levels in California were apparently too low to assess. There were indications of larger population of both species in Baja California. (Author)

APPENDIX C (continued)

235
Mais, K.F., 1977. Acoustic surveys of northern anchovies in the California current system, 1966-1972. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:287-295.

The California Department of Fish and Game has been routinely utilizing a vertical echo-sounder and horizontal sonar to survey the northern anchovy (ENGRAULIS MORDAX) population in the California Current System. Since 1966, 38 survey cruises covering nearly 40,000 miles of acoustic transects have been completed. Acoustically detected anchovy schools were enumerated per unit of surface area insonified, and estimates of the total population of schools were made for the entire survey region. These surveys have produced valuable information on relative abundance, distribution, migration, availability, and behaviour. Surveys consistently found the bulk of the population residing in southern California and northern Baja California, with relatively minor quantities over the remainder of its range. A southward and offshore movement coinciding with the spawning season was also detected. Availability or vulnerability to harvest by purse-seining varied greatly both within and between years. The most prevalent schooling behaviours are unfavourable for capture by purse-seine. Occurrence of favourable behaviours was erratic and unpredictable. Estimates of anchovy school numbers based on acoustic surveys have varied greatly within regions, and cannot be used to measure changes in the absolute population. These large variations are undoubtedly due to fluctuations of school biomass which unfortunately cannot yet be accurately measured. Solution of this problem would provide reasonably accurate and timely estimates of absolute biomass. (Author)

236
Maniwa, Y.; Furusawa, M., 1978. Hydroacoustic system for fish counting. J. Acoust. Soc. Am. 64 (Suppl. 1):S95.

The hydroacoustic systems to count the numbers of sea fish with precision have been studied. Experiments have been performed on fish cultivated in culturing nets, numbers of which have been counted manually. In this system, the volume of fish school and their distribution density are separately measured by applying the principles of the fish finder, and then the number of fish are determined by multiplying one by another. The approximate volume is determined by the shape of section of fish school which is displayed by using the principle of PPI sonar. The ultrasonic waves reflected from fish in the effective volume are compounded. Accordingly, the number of fish in the effective volume is obtained from the intensities of the reflected waves. The distribution density is calculated by dividing the number by the effective volume. In the case of good distribution of fish, the error is within + or - 5%. It is expected that such a system will be extended to the measurement of fish stocks. (Author)

APPENDIX C (continued)

237
Marchal, E.; Boely, T., 1977. Acoustical evaluation of fish resources on continental-shelf off West Africa from Bissagos Archipelago (11-degrees-N) to Point-Stafford (28-degrees-N). Cah. ORSTOM Oceanogr. 15(2):139-161.

238
Margalef, R., 1973. Acoustic estimate of the distribution of the relative density of pelagic animals over the area of upwelling in Northwest Africa Crusie Sahara II. Res. Exp. Cient B/O Cornide 2:125-132.

239
Margetts, A.R., 1977. Symposium on the hydroacoustics in fisheries research, Bergen, Norway, June 19-22, 1973. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:5-327.

240
Marshall, W.C., 1977. A prototype precision time-varied-gain amplifier for an echo sounder receiver. In: Proc. Rocky Mtn. Bioeng. Symp., April 1977.

241
Mathisen, O.A., 1975. Three decades of hydroacoustic fish stock assessment. Mar. Technol. Soc. J. Tech. Notes 9(6):31-34.

Reviews advances in acoustic measuring between 1945 to 1975 with an overlook of the future. (K).

242
Mathisen, O.A., 1980. Acoustic stock assessment. In: Backiel, T.; Welsome, R.L. (eds.), Guidelines for sampling fish in inland waters. FAO EIFAC, Tech. Rep. 33:115-141.

243
Mathisen, O.A., 1980. Methods for the estimation of krill abundance in the Antarctic. Univ. Washington, Seattle, Fish. Res. Inst., Rep.:1-35.

In the energy budget of the Antarctic aquatic ecosystem, southern krill (EUPHASIA SUPERBA) occupy a central position. Because of their vast areal expansion and vertical distribution pattern, there can be no doubt that an assessment of krill must be based largely on hydroacoustic techniques. The present study should be seen as a

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contribution to the adaptation of hydroacoustic techniques to krill assessment. Field work was conducted from the South Georgia base of the British Antarctic Survey aboard its research vessel R/V 'John Biscoe'. Three specific objectives were identified: (a) to conduct acoustic experiments to assess the target strength of krill at different densities; (b) to determine diel changes in vertical distributions and the relationship between surface and deeper schools of krill; (c) if possible, to determine the size, configuration and density of krill swarms in and near Cumberland Bay.

244
Mathisen, O.A.; Croker, T.R.; Nunnallee, E.P., 1977. Acoustic estimation of juvenile sockeye salmon. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:279-286.

The optimum escapement level to a sockeye salmon producing lake is commonly established empirically by relating escapement to subsequent production of juveniles of the 0-group the next year. Acoustic methods have proved superior to any other method in assessing the pelagic population of juvenile salmon. The equipment and signal processing used in the studies reported here were developed by a multi-disciplinary team at the University of Washington in Seattle. Computer analysis of the tape-recorded analog signals, after transformation to digital values, gives relative density estimates. These are converted to absolute numbers by finding empirically the effective sample volume and a regression line for converting relative biomass estimates into real numbers. The reproducibility of the results was tested by repeated assessment over four consecutive days in a small lake. A set of confidence limits was derived mathematically and computed for monthly observations throughout one year in the same lake. The width of the confidence interval is a function of fish behavior, and the smallest interval was obtained during the winter with minimal feeding, growth and migration. (Author)

245
Mathisen, O.A.; Nunnallee, E.P., 1975. Acoustic stock estimation as a tool in management of sockeye salmon (ONCORHYNCHUS NERKA, Walbaum) runs. EIFAC (Eur. Inland Fish. Adv. Comm.) Tech. Pap. 23 (Suppl. 1) (1):346-363.

Acoustic assessment techniques are being used in management of sockeye salmon runs to an ever-increasing extent because this species of salmon can be enumerated at many life stages and new or improved instruments are constantly becoming available. A system based on computerized analysis of echo signals in the field in analogue form has been used in sockeye salmon management. The unit consists of a hydroacoustic data

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acquisition unit and a data processing unit. Methods for making numerical estimates, mapping of distribution in space or determination of length-frequency histograms are illustrated by reference to results obtained in a number of studies of various sockeye salmon producing lakes.

246
Mathisen, O.A.; Ostvedt, O.J.; Vestnes, G., 1974. Some variance components in acoustic estimation of nekton. Tethys 6(1-2):303-11.

In Nov-Dec. 1972 the Norwegian research vessel 'G. O. Sars' made a comprehensive survey of the coastal shelf area from Cape Vert to Cape Blanc. Advanced acoustical equipment and computer processing facilities aboard allowed experiments to assess the magnitude of some components of variance in acoustical estimation of nekton and larger forms of zooplankton. These were: (1) within station, (2) between days and (3) diel variability. The last component is by far the largest one. The ratio of day to night signals of the same population ranged usually between 1:2 or 1:3, but varied according to the frequency of the sounder. Estimates of the two other sources of variability were obtained from balanced experimental designs involving replicated 10 mile course lines with integrated acoustical values computed for each mile. In all cases where the bottom sloped abruptly such as along the continental shelf or along the edges of the many canyons found in the area, bottom signals from the steep slopes were superimposed on target signals. These could only be deleted by visual inspection of the echograms. The consistency of individual observers and the differences between observers were likewise studied. Population estimates are commonly based on the estimation of mean density, absolute or relative, in homogeneous strata. Usually the variance is proportional to the mean and this Poisson distribution can be normalized through a square root transformation. This was studied further by computing mean densities within areas delineated by density isopleths drawn from echo integrator values. (Author)

247
Matsui, T.; Teramoto, Y.; Kaneko, Y., 1972. Target strengths of squid. In: Japanese echo sounding research on squid, FAO Rep. FIRM/C142:27-29.

APPENDIX C (continued)

248
McCartney, B.S.; Stubbs, A.R., 1971. Measurements of the acoustic target strengths of fish in dorsal aspect, including swimbladder resonance. J. Sound Vib. 15(3):397-420.

The need for measurements of the acoustic target strength of fish is discussed. The phenomenon of swimbladder resonance of small deep ocean fish is well known and is a useful means of estimating their sizes. For larger commercial fish in shallower seas the resonant frequency is much lower and resonance is very difficult to observe in the field. A method of observing and measuring the swimbladder resonance of a captive live fish in controlled conditions is described, and results on several gadoids are given. Reasons for the observed resonant frequencies being higher than predicted are given; the damping of resonance is high, which is expected. Application of these results to acoustic sizing at sea appears remote. They are relevant, however, to studies of low-frequency sound propagation, and the experimental technique is offered as a useful tool in physiological studies involving swimbladder function. Measurements at higher frequencies in the diffraction and geometrical regions are also presented, resulting in an empirical equation for target strength as a function of length of the fish and wavelength. It is believed that this equation is useful for acoustic fish sizing using echo sounders at sea. The swimbladder is the major scatterer over the whole frequency range. (Author)

249
McKenzie, D.H.; Baker, K.S.; Metzger, R.M.; Fickeisen, D.H.; Skalski, J.R., 1979. The application of fisheries management techniques to assessing impacts: Task I report. U.S. Nucl. Regul. Comm., NUREG/CR-0572:1-82.

Task I efforts examined the available fisheries management techniques and assessed their potential application in a confirmatory monitoring program. The objective of such monitoring programs is to confirm that the prediction of an insignificant impact (usually made in the FES) was correct. Fisheries resource managers have developed several tools for assessing the fish population response to stress (exploitation) and were thought potentially useful for detecting nuclear power plant impacts. Techniques in three categories were examined: catch removal, population dynamics and nondestructive censuses, and the report contains their description, examples of application, advantages and disadvantages. The techniques applied at nuclear power plant sites were examined in detail to provide information on implementation and variability of specific approaches. The most suitable techniques to incorporate into a monitoring program confirming no impact appear to be those based on Catch Per Unit Effort (CPUE) and hydroacoustic data. In some specific cases, age and growth studies and indirect census

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techniques may be beneficial. Recommendations for task II efforts to incorporate them into monitoring program designs are presented. These include development of guidelines for: 1) designing and implementing a data collection program, 2) interpreting these data and assessing the occurrence of impact, and 3) establishment of the monitoring program's ability to detect changes in the affected populations. (Author)

250
McLean, R.B.; Singley, P.T.; Lodge, D., 1981. Threadfin shad impingement: Population response. Oak Ridge National Laboratory, TN, ORNL/NUREG/TM-339.

Threadfin shad populations in Watts Bar Reservoir, Tennesse during the period 1976-1979 underwent dramatic fluctuation in abundance and size frequency distribution. These fluctuations were due to cold-induced mortality, predation, and impingement, listed in probable decreasing order of importance. Water temperatures in the winters of these three years went below the lower lethal limits of the fish, but a remnant of the population survived each winter by inhabiting small areas warmed by springs. The population recovered to some extent each year, but the size frequency distribution changed and the numbers probably progressively declined each year. Recovery of the population may be aided by high egg hatching success at low egg densities. This hypothesis is amenable to laboratory testing and validation in the field. A sonar system composed of a Simrad EY-M sounder, Phillips PM 3212 oscilliscope, and a Nakamichi 550 tape recorder was evaluated as a tool for quantification of larval and adult shad stocks. This system, coupled with daytime trawling was not effective in assessing larval stock abundance but, coupled with nighttime trawling, was effective in quantifying juvenile and adult stock abundance. Limitations of the sonar-trawling system included (1) possible inability of the sonar to detect larvae smaller than 1.45 cm, (2) difficulty in obtaining an accurate size frequency distribution of larvae needed for the target strength estimation, (3) difficulty in doing night trawls because phantom midge larvae clog the nets, and (4) unknown effects of zooplankton and detritus on the sonar signal. The biomass of juvenile and adult fish estimated using sonar two different years, however, agreed with estimates based on trawl data (R squared = 0.64 and 0.81). (Author)

251
McLendon, R.I., 1968. Detection of fish schools by sonar. Eastern Tropical Pacific, July-November 1967. Commer. Fish. Rev. 30(4):26-29.

In 1967 an investigation of the physical and biological oceanography of the eastern tropical Pacific was begun. This program, known as EASTROPAC, is intended to provide the necessary data for more effective use of marine resources of the area, especially tropical tunas. (Author)

APPENDIX C (continued)

252
McNaught, D.C., 1969. Developments in acoustic plankton sampling. Proc., Conf. Great Lakes Res. 12:61-68.

Evidence from net hauls has verified the hypothesis that acoustic back-scattering strength is proportional to the biomass of zooplanktonic targets when the proper frequency is used. Consistent and increasing underestimations occur with depth, requiring a correction of 5x biomass at 20 m distance from the transducer. Future investigations with a multi-frequency sounder will provide estimates of biomass within five size classes. Moreover, recently evolved methods employing reflectance spectrophotometry in analysis of echographs will eventually be replaced with digital recordings, providing automated recording both in time and space. (Author)

253
Menin, A.; Paulus, R.D., 1974. Fish counting by acoustic means. In: Ocean '74: IEEE Int. Conf. Eng. Ocean Environ. IEEE 74 CHO 873-D OCC 1:166-168.

During the past ten years Bendix, in conjunction with the Alaska Department of Fish and Game, has been developing acoustic fish counters. Early development included Doppler systems which evolved into the present day, bottom-mounted, upward-facing counters for enumeration of migrating river fish which range in size from 50 to 1,000 mm. The present systems which are undergoing continuing development, have demonstrated accuracies as high as 95 percent compared to visual counts on migrating sockeye salmon (ONCHORHYNCHUS NERKA). In 1970, a biomass counter was developed to enumerate downstream migrating schools of fingerling salmon smolt that average 100 mm in length and 50 fish to the pound. Three such systems are currently in use in Alaska and calibrations performed by Alaska's netting have shown long term accuracies better than 96 percent. A recent development is an acoustic smolt counter used in conjunction with a fyke net tunnel. Initial results show great promise for this system. Development of a biomass herring counter for the east coast of the United States is eminent. This system will count upstream migrating herring and automatically convert the biomass input to actual numbers of fish which will be displayed on a digital readout. (Author)

254
Midttun, L., 1966. Measurements of the reflection of sound by fish. Fiskeridir. Skr. Ser. Havunders. 13(3):1-18.

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255
Midttun, L., 1966. Note on measurement of target strength of fish at sea. Int. Counc. Explor. Sea, Copenhagen CM 1966/F:9, 3pp.

256
Midttun, L., 1971. Acoustic methods for estimation of fish abundance. In: Proc. Symp. Remote Sensing in Mar. Biol. Fish. Resour., Texas A. & M. Univ., College Station, Sea Grant TAMU-SG-71-106:218-226.

A history of echo sounders and their role in fisheries research is presented, along with a description of typical European hydroacoustic equipment. (PK)

257
Midttun, L., 1973. Plan for a pelagic fish assessment survey, North Arabian Sea. FAO, Rome, IOFC/DEV/25:23.

A method using the fish angle (i.e., the change in target strength with fish aspect) for identification purposes is described. Significant differences in fish angle between cod and coalfish have been observed at sea. The effect of fish angle on the sampling volume of an echosounder is discussed and it is shown that the sampling volume decreases with decreasing fish angle. A method for abundance estimation applying an echo integrator is described and discussed. (Author)

258
Midttun, L.; Nakken, O., 1971. On acoustic identification, sizing and abundance estimation of fish. Fiskeridir. Skr. Ser. Havunders. 16(1):36-48.

A method using the fish angle (i.e. the change in target strength with fish aspect) for identification purposes is described. Significant differences in fish angle between cod and coalfish have been observed at sea. The effect of fish angle on the sampling volume of an echosounder is discussed, and it is shown that the sampling volume decreases with decreasing fish angle. A method for abundance estimation applying an echo integrator is described and discussed. (Author)

259
Midttun, L.; Nakken, O., 1972. The application of acoustic stock abundance estimation of capelin and blue whiting. Int. Counc. Explor. Sea, Copenhagen CM 1972/B:16.

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260
Midttun, L.; Nakken, O., 1977. Some results of abundance estimation studies with echo integrators. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:253-258.

Two examples of acoustic fish stock abundance estimation are given. The first is the estimation of the exploited Barents Sea capelin stock; the second is measurement of the size of the unexploited blue whiting stock. Surveys of both species were undertaken at the time of the year when conditions were favourable, i.e., the fish were located as pelagic scattering layers and unmixed with other species. When the echo-sounder is operated with a TVG equal to 20 log R + 2 'alpha' R, the integrated echo intensity is proportional to the number of fish per unit area. To obtain absolute values, the system is calibrated on scattered recordings when single fish can be counted. (Author)

261
Miers, U. Fish detection systems for midwater trawling. S. Afr. Ship. News Fish. Ind. Rev., Cape Town, 25(5):69, 71, 73, 75.

262
Miller, D.S., 1980. Hydroacoustic assessment of pelagic fish stocks in the Newfoundland and Labrador areas. Int. Counc. Explor. Sea, 68th Meet., Copenhagen, ICES Rep. CM 1980/H:51.

263
Minns, C.K.; Kelso, J.R.M.; Hyatt, W., 1978. Spatial distribution of nearshore fish in the vicinity of two thermal generating stations, Nanticoke and Douglas Point, on the Great Lakes. J. Fish. Res. Board Can. 35(6):885-892.

At Nanticoke, Lake Erie, 1974, mean fish density varied considerably, range 162(-14), 204/10,000 cu m, as estimated by digital acoustic fish enumeration. At Douglas Point, Lake Huron, 1975, mean density varied less, range 108-671/10,000 cu m. At both sites fish densities were generally greatest in the shallowest, 3-5 m, depths. At Nanticoke, where the nearshore has low relief, there were no distinguishable communities. At Douglas Point, where depth increases rapidly offshore, there was evidence of benthic and pelagic communities. There was no evidence of altered fish distribution in relation to temperature. At Nanticoke there was no vertical variation in temperature and no vertical response was to be expected. At Douglas Point there was thermal stratification present in the summer and there was no apparent response. The influence of incident radiation was uncertain because of the effects of diurnal migrations. At both locations fish were

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clustered horizontally to varying degrees in the spring and fall, while in the summer fish were distributed more evenly. Densest clusters were usually in the vicinity of the turbulent discharge at both locations. The lack of temperature response and the similarity of Nanticoke with situations at nearby streams on Lake Erie suggest that the fish are responding to currents and perhaps topography. (Author)

264
Mitson, R.B., 1968. Development and application of the trition acoustical counter. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-27, 1968:27-28.

265
Miyajima, J., 1971. Sound beam stabilization for echo sounding and sonar. Modern fishing gear of the world: 3. Fish find purse seining and aimed trawling, UNIPUB Inc., New York:84-87.

A beam regulator to stabilize a ship's sonar beam using automatic horizontal and vertical controls is described. (PK).

266
Moose, P.H., 1971. A simplified analysis of the statistical characteristics of the fish echo integrator. Univ. Washington, Seattle, Div. Mar. Resour. Sea Grant Pub. 71-2, 28pp.

267
Moose, P.H.; Ehrenberg, J.E., 1971. An expression for the variance of abundance estimates using a fish echo integrator. J. Fish. Res. Board Can. 28(9):1293-1301.

A mathematical model of the fish echo integrator, an acoustic device for measuring the abundance of pelagic fish, is presented. This model is analyzed and general expressions for the mean and variance of the integrator output are obtained. The integrator output can be scaled to provide an estimate of the total number of fish in the volume of water surveyed. The effect of each system parameter on the variance of the estimate is investigated and optimum operational procedures are suggested. (Author)

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268
Moose, P.H.; Ehrenberg, J.E., 1971. Three publications related to echo integration from the Washington Sea Grant Marine Acoustics Program. Univ. Washington, Seattle, Div. Mar. Resour., Rep. WSG-71-2:1-73.

The publication contains three articles about fish echo integrators: 'A Simplified Analysis of the Statistical Characteristics of the Fish Echo Integrator'; 'The Variance of Fish Population Estimates Using an Echo Integrator'; 'Derivation and Numerical Evaluation of a General Variance Expression for Fish Population Using an Echo Integrator.' (Author)

269
Moose, P.H.; Thorne, R.E.; Nelson, M.O., 1971. Hydroacoustic techniques for fishery resource assessment. J. Mar. Tech. Soc. 5(6):35-37.

Principles of hydroacoustic equipment operation, applications, and recent developments of research conducted at the University of Washington are reviewed. (PK)

270
Mullan, J.W.; Applegate, R.L., 1969. Use of an echosounder in measuring distribution of reservoir fishes. U.S. Bur. Sport Fish. Wildl., Tech. Pap. 19:1-16.

A recording white-line depth sounder was used to study annual fish distribution in two deep reservoirs on the White River, Arkansas and Missouri. Varying seasonal activity levels of fish, attenuation of the sound beam at depths over 100 feet, and lack of precision in the identification of echo traces precluded rigorous interpretation of echograms. The inherent picture sense of echograms provided seasonal perspectives of fish distribution with respect to (1) diel movement, (2) depth and basin location, (3) limnetic concentrations, and (4) oxygen-temperature conditions. Scattering layers associated with planktonic chaoborid populations and suspected chemical constituents were disclosed in one of the reservoirs undergoing initial filling. (Author)

271
Nakken, O.; Dommasnes, A., 1975. The application of an echo integration system in investigations of the stock strength of the Barents Sea Capelin (MALLOTUS VILLOSUS Miller) 1971-1974. Int. Counc. Explor. Sea, Copenhagen, CM (B.25):20.

APPENDIX C (continued)

272
Nakken, O.; Olsen, K., 1977. Target strength measurements of fish. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:52-69.

During the summer of 1971, target strength measurements of fish were made at two frequencies, 38 and 120 kHz. The relationships between dorsal aspect target strength and fish length were worked out for four species. The results for the gadoid fishes were in accordance with the results reported from previous studies and also in accordance with observations from field measurements. For fish of lengths 6-12 cm, the dorsal aspect target strengths of gadoids and clupeoids are approximately equal. For bigger fish the dorsal aspect target strength of clupeoids was found to be lower than that of the gadoids. No significant differences in side aspect target strengths were found between the two groups. As the dorsal aspect target strength of fishes depends heavily on the inclination of the fish, more information on fish behaviour will improve both abundance estimation and length determination by acoustic equipment. (Author)

273
Nazumi, T., 1972. Echo-traces of squid, OMMASTREPHES SLOANEI PACIFICUS, in the central waters of Japan Sea. FAO Fish. Circ., Rome, 142:15-25.

274
Nelson, M.O., 1969. Use of vertical echo sounders in assessing the abundance of offshore Pacific hake populations. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-27, 1968:29.

275
Nickerson, T.B.; Dowd, R.G., 1977. Design and operation of survey patterns for demersal fishes using the computerized echo counting system. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:232-236.

Up to now a major effort has been concentrated on the development of electronic and acoustic parameters of the computerized echo counting system with little consideration being given to its adaptation to surveys. This paper considers the design and operation of survey patterns using a continuous sampling device such as this to estimate the groundfish population over a large area. Development of survey patterns that are operationally suitable and yield statistically significant results are discussed. The use of the echo counter survey methods for a groundfish inventory of the Scotian Shelf are discussed. (Author)

APPENDIX C (continued)

276
Nielson, R.L.; Hampton, I.; Everson, I., undated. Calibration of hydro-acoustic instruments. SCAR/SCOR/IABO/ACMRR Group of Sepcialists on Living Resources of the Southern Oceans, Biomass Handbook 1 52pp.

277
Nikolaev, A.S., 1968. Use of hydroacoustic instruments for Studying distribution of Pacific Ocean salmon in the sea. Rybn. Khoz. 44(5):5-7.

278
Nunnallee, E.P., 1974. A hydroacoustic data acquisition and digital data analysis system for the assessment of fish stock abundance. Univ. Washington, Seattle, Div Mar. Resour. Sea Grant Pub. WSG-74-2 48pp.

A hydroacoustic data acquisition and digital data analysis system has been designed and constructed at the University of Washington, Seattle, to measure the abundance of pelagic fish. The portable data acquisition unit consists of an echo sounder interfaced to a magnetic tape recorder. The digital data analysis unit incorporates a small computer, a line printer, and various hardware to interface the computer to an echo sounder or a tape player. This paper was written to provide a basic operators manual for the hydroacoustic data acquisition and analysis system and to compile various publications relative to its use. General descriptions, instructions for use, and theory of operation are given for each major component of the system. Several methods for the analysis of recorded hydroacoustic data are also included. (Author)

279
Nunnallee, E.P., 1975. An operators' manual for the hydroacoustic data collection system. Univ. Washington, Seattle, Div. Mar. Resour., Rep. WSG-TA-75-1:1-33.

The paper is written for use as an operator's manual for the hydroacoustic data collection system. There are no descriptions of data analysis methods other than occasional comments as to various control settings, noise levels, etc., that can influence the quality of data analysis results. The manual is written in three chapters. Chapter 1 is a description of the parts of the various pieces of equipment in the system and will include photographs indicating the locations of connectors and controls. Chapter 2 outlines the interconnections of the various system components. Chapter 3 includes descriptions of system setup, calibration, and operation during a hydroacoustic survey. The major components of the hydroacoustic data collection system include a ROSS model 200 A echo-sounder chart recorder, an interface amplifier, a Sony model 560D magnetic tape recorder, a Teredo AC to D.C. power inverter, a variac (variable transformer) and an oscilloscope. (Author)

APPENDIX C (continued)

280
Nunnallee, E.P.; Green, J.H., 1970. A universal interface amplifier for coupling an echo sounder to a magnetic tape recorder. Univ. Washington, Seattle, Fish. Res. Inst., Rep. WSG-70-3.

A universal interface amplifier was designed and constructed recently as part of the University of Washington's Marine Acoustics Program. The device converts the frequency and amplitude of the video output of an echo sounder, the signal that represents target information, to a frequency and amplitude that is acceptable to a standard stereophonic tape recorder. The unit was designed for ease of operation and utility. Only two external switch settings are required for its operation. The first switch selects the echo sounder output frequency that is to be converted and recorded on magnetic tape. The second switch selects input attenuation so that an acceptable output voltage level for the tape recording system is obtained. (Author)

281
Ol'shevskii, V.V., 1973. Characteristics of the correlative and square-law detection of echo signals in sonar systems for the location of biological targets. Sov. Phys.-Acoust. 19(1):41-44.

The probabilistic characteristics of the correlative and square-law detection of echo signals having an incompletely predictable shape are determined for the case of pulsed sonar systems using noise-like signals. It is shown that with a decrease in the cross-correlation coefficient of the transmitted and echo signals the detection probability in the correlative mode decreases and does not tend to unity with an unlimited increase of the signal-noise ratio. The conditions are ascertained under which square-law detection is more efficient than correlative detection. (Author)

282
Olsen, K., 1971. Orientation measurements of cod in Lofoten obtained from underwater photography and their relation to target strength. Int. Counc. Explor. Sea, Copenhagen CM 1971/B 17:1-8.

283
Olsen, K., 1979. Observed avoidance behaviour in herring in relation to passage of an echo survey vessel. Int. Counc. Explor. Sea, Copenhagen CM B:18 10pp.

APPENDIX C (continued)

284
Olsen, S.; Chruickshank, O.; Hansen, K., 1977. Target strength of porcupine fish - an outstanding deviation from the established target strength/length regression. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:82.

The target strength of porcupine fish (DIODON HYSTRIX) was found to be much higher than that of regular shaped fish of the same size. Thus, caution should be exercised when generalizing about fish echo characteristics. (Author)

285
Olsen, S.; Tveite, S.; Chakraborty, D., 1977. Acoustic surveying in tropical waters. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:248-252.

In an area containing many species of pelagic fish, it was found that concentrations were usually dominated by one and occasionally by two or three species. Under particular conditions, echoes characteristic of different species groups of fish were recognized. Together, these two features facilitated distribution and abundance estimates by echo and fishing surveys, examples of which are given. (Author)

286
Orr, M.H.; Hays, E.E.; Hess, F.R., 1978. Acoustic detection of demersal fish closer than 15 centimetres to the bottom in 80 metres of water. J. Fish. Res. Board Can. 35(8):1155-1156.

Records from an acoustic backscattering system operating at 200 kHz are presented which show that demersal fish can be individually detected closer than 15 cm to the ocean bottom in 88 m of water. (Author)

287
Parker, K.; Paulus, R., 1973. Sockeye salmon smolt enumeration study. Alaska Dept. Fish Game, Juneau, Rep.:1-77.

The Kvichak River smolt study was initiated to establish a basis for accurate prediction of returning adult run size and to arrive at an estimate of the optimum annual escapement needed to reach maximum sustained yield for the Kvichak fishery. The program has attempted to accomplish this by providing an estimate of the total annual smolt outmigration and by continuing the collection of data on age and size of smolt. During development of total outmigration hardware and techniques, the index program was continued to facilitate its eventual relation to total outmigration estimates. Various methods of smolt population enumeration were evaluated. In 1970 experiments were

APPENDIX C (continued)

conducted testing the feasibility of using underwater sonar counting equipment in the Kvichak River. Three sonar models were designed and field tested. As a result, total sockeye salmon smolt outmigration estimates were computed for 1971 and 1972. (Author)

288
Parrish, B.B., 1975. Progress report of Advisory Committee on Marine Resources ad-hoc group of experts on the facilitation of acoustic research: A survey of extent and status of current research. FAO Fish. Circ. 324:1-21.

289
Pearson, N.D., 1973. Acoustic systems for surveying fish Stocks. Br. Acoust. Soc., Meeting on Sonar in Fisheries, Lowestoft, U.K., 27 March 1973.

290
Pearson, N.D.; Mitson, R.B., 1977. Electro-acoustic systems to aid the analysis of pelagic and demersal fish stocks. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:167-173.

Equipments are described having different resolution and sampling volume but which are precisely calibrated on the acoustic beam axis. Signals are standardized by the use of digitally-controlled time-varied gain amplifiers before being processed by a number of methods. These methods include the use of integrators for separately totalling voltages from single fish and schools of fish. An electronic discrimator selects the signals from single fish and allows a pulse height analyser to sample the peak amplitude of each signal over a range of 40 dB and hence display distributions proportional to fish size. Possible electronic beam-processing techniques are considered. (Author)

291
Penrose, J.D.; Kaye, G.T., 1979. Acoustic target strengths of marine organisms. J. Acoust. Soc. Am. 65(2):374-380.

The empirical relationshps linking fish length and target strength for geometric region scattering, which have been developed by Love are shown to apply in the case of peak dorsal values, to some other marine organisms. Peak dorsal target strengths for squid, crab and penaeid prawns lie within 6 dB of the appropriate predictions due to Love. Some zooplankton values are within similar limits provided insonifying frequencies are sufficiently high to ensure that geometric region interactions occur. The target strength data reviewed show little overall frequency dependence in the geometric region, as would be expected if the scatterers were modeled as finite cylinders. (Author)

APPENDIX C (continued)

292
Penrose, J.D.; Sofoulis, N.G.; Kaye, G.T., 1978. The acoustic target strength of marine organisms. In: Proc. 1978 Inst. of Acoust. Spec. Meeting on Acoust. in Fish., Hull, England.

293
Pereyra, W.T., 1969. Problems of echo interpretation related to sampling gear. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-27, 1968:29-30.

294
Peterson, M.L.; Clay, C.S.; Brandt, S.B., 1976. Acoustic estimates of fish density and scattering function. J. Acoust. Soc. Am. 60(3):618-22.

The amplitude of a sonar echo from a fish depends upon the species and size of the fish, acoustic wavelength, aspect, position of the fish in the sonar beam, range and backscattering cross section. We simplify the problem to a single species and size of fish, vertically downward echo sounding, single aspect, and non-overlapping echoes. After removal of attenuation due to range and absorption two random functions remain. The position of the fish in the sonar beam is random and the scattering cross section for each trial is random. We assume that the fish have a uniform density (number/cu m) and calculate the probability density function (PDF) for insonification and reception. We assume that the PDF of the envelope of the echo (excluding the variability of insonification and reception) has a Rayleigh PDF. Assuming two PDF's are independent, we calculate the PDF of the echo envelopes WE(e). WE(e) depends upon the beamwidth of the sonar and the mean backscattering cross section. The theoretical PDF has the same shape as the measured PDF of echoes from alewife in Lake Michigan. We use the fit of the PDF's to estimate the backscattering cross section and fish density. This calibrates the echo-integration processing system. A profile of the density of alewife in Lake Michigan is shown. (Author)

295
Pickwell, G.V., 1969. Resonant acoustic scattering from air-bladder fishes. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-27, 1968:12.

296
Pieper, R.E. The relationship between sound-scattering and the collection of planktonic organisms, and a comparison of a narrow-beam echo-sounder with a standard, wide beam-angle echo-sounder. Smithsonian Institution, Washington D.C., Final Rep.:66-83.

APPENDIX C (continued)

297
Pieper, R.E., 1979. Euphausiid distribution and biomass determined acoustically at 102 kHz. Deep-Sea Res. 26(6A):687-702.

102 kHz scattering was recorded at depths varying from 130 to 280 m in the San Pedro and Santa Catalina basins off southern California. The scattering from these layers was quantified and volume scattering strengths were determined. These acoustic measurements are correlated with the biomass and distribution of euphausiids (primarily EUPHAUSIA PACIFICA), which were collected concurrently. Qualitative and quantitative variations in scattering are related to the patchiness of the euphausiids. (Author)

298
Pieper, R.E.; Bargo, B.G., 1980. Acoustic measurements of a migrating layer of the Mexican lampfish, TRIPHOTURUS MEXICANUS, at 102 kilohertz. Fish. Bull. 77(4):935-942.

Biological sampling in a migrating scattering layer recorded at 102 kHz resulted in collections which consisted primarily of juvenile TRIPHOTURUS MEXICANUS. The scattering from this layer was quantified. Volume scattering strengths and corresponding target strengths were determined. The rate of migration and the target strength of T. MEXICANUS changed as the layer approached the surface. Target strengths at 102 kHz ranged from -60.6 decibels at 284 m to -71.3 decibels at 206 m. (Author)

299
Pincock, D.G.; Easton, N.W., 1978. The feasibility of Doppler sonar fish counting. IEEE J. Ocean. Eng. 3(2):37-40.

In the course of monitoring and evaluating fish population in the seas, sonar systems have proved a practical and efficient measurement approach. The results obtained, however, from the use of sonar for monitoring fish migration in rivers have been somewhat disappointing - the most troublesome problems being the inability to recognize invalid targets. It has been proposed that a high-resolution Doppler sonar which recognizes a valid target on the basis of its Doppler signature would be a solution to this problem. This paper examines the feasibility of such a target identification scheme. In particular, an examination is made of the nature of returns to be expected from a fish, and of interference sources - principally surface reverberation. From this it is concluded that the Doppler approach is indeed feasible, but that the use of a high-resolution pulsed system capable of separating multiple targets is only possible in a channel width of a few meters (2).

APPENDIX C (continued)

300
Proctor, L.W., 1975. Sonar system for fish detection in deep water. Proc. Joint Conf. on Instrum. in Oceanogr., Bangor, U.K., 23-25 Sept. 1975.

301
Rand, G., 1969. Sonar problems in the deep ocean environment. Inst. Environ. Sci. 1969 Annu. Meet., Tech. Meet. Proc.:439-445.

302
Rao, K.K.; Natarajan, S.; Daniel, G.P.E., 1980. Estimation of fishery resources by sonar surveys. Fish. Technol. 17(1):7-11.3.

303
Revie, J., 1973. An experimental survey of a herring fishery by long-range sonar. Mar. Biol. 22(3):271-292.

304
Richkus, W.A.; Mulryan, D.; Zankel, K.; Kobler, B., 1979. Calvert Cliffs acoustic finfish surveys, 1977. Martin Marietta Corp., Environmental Center, Baltimore, Rep.:1-100.

305
Richkus, W.A.; Zankel, K.L.; Kobler, B.; Haire, M.S., 1977. Acoustic surveys of Fish distributions in the Morgantown SES intake embayment. Martin Marietta Corp., Environmental Technology Center, Baltimore, PPMP Tech. Note 77-1.

306
Rijavec, L.; Burczynski, J. Calibration of hydroacoustic equipment on board R/V 'Rastrelliger' (March-April 1977). Technical Rep. 2, Phase II. UNDP/FAO Pelagic Fishery Investigation Project on the Southwest Coast of India, Cochin. FAO, IND/75/038:52.

307
Rijavec, L.; Johannesson, K.; Gueblaoui, M., 1977. Estimation de l'abondance absolue des stocks de poisson pelagique dans les eaux tunisiennes. Bull. Inst. Natl. Sci. Tech. Oceanogr. Peche Salammbo 4(2-4):221-261.

In this paper are presented the results of the quantitative acoustique survey of pelagic resouces in Tunisian waters carried out in June/July 1973. The description of direct calibration of the echo-integrator,

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using live fish, is given in detail. The absolute abundance of the total pelagic fish stocks present in Tunisian waters was measured as 580,000 metric tons. The average fish density over the whole area surveyed was estimated at 54 tons per square nautical mile or 15.7 grammes/sq m. By comparing the relative and absolute data obtained during the present survey, a conversion factor was obtained for each category of the relative abundance scale (very dense, dense, rare and very rare). This enabled to quantify in absolute terms the relative abundance indices obtained during the preceeding echo survey cruises carried out in 1972 and 1973. The absolute abundance of the main pelagic stocks was estimated by using the species composition of commercial catches in the Tunisian light fishery. A preliminary estimate of the potential yield of pelagic stocks in the coastal waters of Tunisia has been derived. (Author)

308
Robertson, A.A., 1979. Adaptions permitting aimed trawling with rectangular midwater trawls from non-fishery research vessels. Fish. Bull. S. Afr. 12:85-92.

Minor modifications to a research-sized rectangular midwater trawl and to the afterdeck layout of a vessel not designed for fisheries research enabled qualitative, aimed sampling for krill in the Southern Ocean to be successfully conducted as part of a general acoustic survey. A hull transducer and a netsonde were used for directing the net to the target. Nets with different mesh sizes were used but their performance was not compared. Blind sampling was not attempted, but 80% of the 32 hauls made proved positive. (Author)

309
Robinson, B.J., 1978. In situ measurement of fish target strength. In: Proc. 1978 Inst. of Acoust. Spec. Meeting on Acoust. in Fish., Hull, England.

310
Roettingen, I., 1976. On the relation between echo intensity and fish density. Fiskeridir. Skr. Ser. Havunders. 16(19):301-314.

Integrated echo intensities for a wide range of fish densities were measured. The experiments were carried out on live saithe POLLACHIUS VIRENS and sprat (SPRATTUS SPRATTUS) which were kept in a net cage. Echo intensities were measured at 38 kHz and 120 kHz and pulse lengths ranging from 0.1 ms to 0.6 ms. The echo intensity was proportional to fish density below certain density limits. At high fish density a shadowing effect was observed. Factors encountered during survey work

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on schooling fish which indicate shadowing are also discussed. The exact density values at which shadowing occurs, appear to depend on parameters such as fish species, size, orientation, and probably also the vertical extention of the school. (Author)

311
Rottingen, I., 1980. Indication of high natural mortality for juvenile herring from acoustic and tagging data. Int. Counc. Explor. Sea, 68th Meet., Copenhagen, ICES Rep. CM 1980/H:62.

312
Rusby, J.S.M., 1970. A long range side-scan sonar for use in the deep sea. Int. Hydrogr. Rev. 47(2):25-98.

313
Rusby, J.S.M., 1973. An experimental survey of a herring fishery by long range sonar. Br. Acoust. Soc., Meeting on Sonar in Fisheries, Lowestoft, U.K., 27 March, 1973.

This brief description of a long range side-scan sonar, developed by the National Institute of Oceanography, has been written at the request of the International Hydrographic Bureau. A more detailed paper is being written at the moment by the team responsible for its development, which will describe the system more adequately. (Author)

314
Rusby, J.S.M., 1977. Long range survey of a herring fishery by side-scan sonar. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:7-14.

Since 1969 the Institute of Oceanographic Sciences has been operating a long-range side-scan sonar designed to view the topography of the ocean floor. In 1970 it was recommended that the sonar should be used on the continental shelf in an experiment to determine whether it could usefully detect pelagic fish at long ranges. This paper briefly describes the result of such an experiment arranged in September 1971, to detect herring in an area south of the Minch on the west coast of Scotland. Under the best propagation conditions it was found possible to detect herring out to a maximum range of 15 km, using 9 kW of acoustic power in a 4 second FM pulse centred at 6.4 kHz. For a period of three days a fishery of 170 sq km was kept under surveillance by steaming up and down a 13 km-long base line, the movement of large fish aggregations was plotted and a purse-seine vessel was used to identify targets by catching them. The paper also very briefly discusses possible research applications based on the performance of low-frequency sonar systems. (Author)

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315
Rusby, J.S.M.; Somers, M.L.; Revie, J.; McCartney, B.S.; Stubbs, A.R., 1973. An experimental survey of a herring fishery by long-range sonar. Mar. Biol. 22(3):271-292.

For 3 years, the Institute of Oceanographic Sciences has operated a long-range side-scan sonar for viewing the texture and topography of the ocean floor (project G.L.O.R.I.A., Geological Long Range Inclined Asdic). It was recommended that an experiment should be arranged to discover if such a device could detect commercial pelagic fish on the Continental Shelf at long ranges, and if so, to determine any research on commercial applications. This paper describes such a trial, carried out on a Scottish inshore herring fishery in the Sea of the Hebrides, during late September, 1971. A survey was first made in the area by echo-sounder and short-range side-scan sonar to confirm the bathymetry, to locate false targets, and to observe the distribution and diurnal vertical movement of the herring. During the subsequent G.L.O.R.I.A. runs, up to 9 kW of acoustic power was transmitted at 6.4 kHz, with the signal returns processed by a linear correlation with a time-bandwidth product of 400, so that signal/noise ratios obtained were equivalent to a short-pulse sonar with peak powers in excess of 1 mW. Due to the summer water-conditions, it was found that the propagation depended critically on the position of the source in the water column. Under the best conditions, with the source towed at 33 m in an isothermal surface layer, herring were detected to a range of 15 km in a water depth of 120 to 170 m. For a period of 3 days, a fishery area of 170 sq km was kept under surveillance by steaming up and down 13 sq km-long base lines at a speed of 13 km/h facing SE towards Hawes Bank and the islands of Tiree and Coll. As a result, a plan view of the area, including both fish and the geological features of the bank, was generated every 1.25 h. It was found possible to track certain aggregations of herring using these records for periods up to 5 h. On the final night, remotely directed catches were made on 3 aggregations by guiding a purse-seine vessel to within 1 km of each target. The internal composition of the aggregations detected by G.L.O.R.I.A. is discussed in terms of both the echo-sounding data and expanded A-scan excerpts from the recorded G.L.O.R.I.A. target signals. Possible research and commercial applications for the long-range detection of pelagic fish by low-frequency towed or fixed sonar systems are briefly discussed. (Author)

316
Saila, S.B., 1971. An application of the theory of games toward improving the efficiency of certain pelagic fishing operations. In: Proc. Symp. Remote Sensing in Mar. Biol. Fish. Resour., Texas A. & M. Univ., College Station, Sea Grant TAMU-SG-71-106:249-65.

APPENDIX C (continued)

317
Salamon, R.; Martin, W.; Stepnowski, A.; Burczynski, J., 1972. A hydroacoustic system of fish stock assessment on the layers. Archwm. Akust. 7(3-4):337-54.

318
Sameoto, D.D., 1980. Quantitative measurements of euphausiids using a 120 kHz sounder and their in-situ orientation. Can. J. Fish. Aquat. Sci. 37(4):693-702.

Biomass and density of euphausiids were estimated using a 120 kHz sounder during 2 yr in the Gulf of St. Lawrence. Simultaneously, biological samples were taken with 2 types of multiple opening and closing nets: MOCNESS-type and BIONESS. Correlations for biomass and density estimates between the acoustic and biological data range from 0.391 to 0.791. Acoustic data showed that a high percentage of euphausiids avoided the MOCNESS-type net during the day. A comparison of the relationship between biological and acoustic data for both years showed that the BIONESS sampler captured euphausiids more efficiently during both day and night. Target strength of the euphausiids estimated from acoustic and biological data showed that it was lower than would be expected if the animals were oriented horizontally. Photographs taken from the BIONESS sampler at depths having acoustic scattering layers showed that the average orientation of euphausiids changed with time, the average orientation being closet to horizontal during daytime. Orientation changed from 27 degrees from the horizontal at 1400 h to 51 degrees during 0200 h. The effect of orientation on target strength is discussed. (Author)

319
Samovol'kin, V.G., 1974. Apparatus and experimental technique for the study of ultrasonic backscattering by biological objects in water. Okeanologiya 14(1):187-191.

A description is presented of the apparatus and technique for experimental investigations of ultrasonic backscattering (20-200 kHz) by small underwater objects. The employed method made it possible to dispense with the calibration targets and did not require a knowledge of the parameters of acoustical transducers. The performance of the apparatus was controlled by a comparison of theoretical and experimental frequency dependence of backscatter from a steel sphere. The method of data processing is described for investigations of scattering properties of objects whose polar backscatter patterns are substantially nonuniform. (Author)

APPENDIX C (continued)

320
Samovol'kin, V.G., 1975. Acoustic backscattering cross sections of small fish, crustaceans, and medusae as functions of their foreshortening. Oceanology 14(5):655-660.

Studies of the nature of acoustic scattering in sound-scattering layers are reported on in part. The angular dependences of acoustic backscattering by small fish, shrimp, crabs, and medusae in the frequency range 20-200 kHz are reported. The acoustic backscattering patterns of medusae are strongly fluctuating curves whose mean level shows little dependence on irradiation angle. The effective backscattering cross sections of fish and crustaceans depend strongly on the orientation of the animals. To estimate the total intensity of acoustic scattering by a school of animals, it is necessary to average the values obtained for sigma in a certain range of angles. (Author)

321
Sand, O.; Hawkins, A.D., 1973. Acoustic properties of cod swimbladder. J. Exp. Biol. 58:797-820.

Intact cod suspended at various depths were insonified and their swimbladder resonance frequency and damping were measured. It was determined that at adaptation depth, the resonance frequency was greater than predicted. (PK)

322
Sano, N., 1968. On some techniques of detecting salmon by the echo sounding method. II. On the trial of horizontal fish finder for salmon. Jpn. Soc. Sci. Fish. Bull. 34(8):670-680.

At present fishing boats do not use their echo sounders for estimating numbers of fish in a certain area because their echo sounder are not designed for such a use. One of the most difficult problems for the fisherman is to decide what kind of fish he is seeking. Our present idea is that it is good to use the horizontal fish finder with wide ultrasonic beams and lower frequencies (28 KC and 50 KC); thus, we tried horizontal fish finders for the purpose of looking for salmon over a wider area. A fish finder using a transducer mounted on the sheer strake of a ship was kept at a depth of 1 m most of the time, and was always put into the sea even in moderately rough seas. These are records made by the 'Hokusei Maru' in July, 1966 and 1967. The horizontal echo pattern mentioned is shown in Figs. 3-1 to 3-10. In this paper, the author compares an echo pattern obtained by horizontal with that of a vertical fish finder, and the degree to which it was possible to distinguish salmon from marine scatters with each device. The results obtained are summarized as follows: 1) In the echo patterns recorded by a horizontal fish finder, we had comparatively

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little noise near the surface and were able to distinguish each single echo from others. When using it with a vertical fish finder, we would be able to estimate fishing grounds more effectively. 2) When the horizontal echo and oblique echo are recorded on seperate papers, it is more convenient for us to distinguish the echo pattern and obtain the necessary information. (Author)

323
Sano, N., 1968. On some techniques of detecting salmon by the echo sounding method. I. Estimation of the fishing grounds of salmon according to swimming speed and swimming depth calculated from echo traces on recording papers. Jpn. Soc. Sci. Fish. Bull. 34(8):660-669.

324
Sano, N., 1971. On some techniques for detecting salmon by echo sounding methods. III. On tests for the practical use of the horizontal fish finder for salmon. Jpn. Soc. Sci. Fish. Bull. 37(1):1-7.

This paper presents results of experiments on the practical use of the horizontal fish finder in the salmon fishing grounds in the North Pacific Ocean. The tests were made in July, 1968. On the ship we mounted two fish finders, each of which had a transducer with a 50 kHz supersonic. We kept these transducers 1 m deep. The dip angles of the transducers were changed with the state of the sea. These echo patterns were made on the occasion of the voyage of the research ship 'Wakshio Maru' (153 tons) for fishery investigations. Recordings by the fish finder were made as long as possible while the ship was floating by the set-nets. One of the characteristics of the echo patterns of the horizontal fish finder was that the echo of sawtooth recorded on the paper was cleared away almost completely. Because of the use of T.V.G. circuit a relation was found between wind direction and the transducers. The echo pattern of the horizontal fish finder showed salmon echoes quite clearly. We set salmon gillnets of 55 tans and hauled the nets the next morning. Considering the catches of salmon, we found that the catch of salmon was in proportion to the numbers of echo traces of salmon in the patterns. (Author)

APPENDIX C (continued)

325
Sano, N.; Anma, G., 1976. Study for estimating the existent amount of salmon resources by means of echo sounding techniques. II. On model of system for the estimation of standing crop. Hokkaido Daigaku Suisan Gakubu Kenkyu Iho Jpn. 27(2):78-90.

This paper describes a method of estimating the fishing grounds of salmon according to characteristic types of echo image. We computed the swimming depths and speeds of reflecting bodies. The echo sounder used was the 28 KC ultrasound, a transducer having 28 degrees of effective beam angle. It was attached to the bottom of the ship. The recording range of the echo sounder was 150m, the number of transmissions of ultrasound waves per minute was 450, and the pulse width was 1.5 millisecond. Time marks were recorded on paper. These experiment were undertaken in gill-net fishing of salmon by the training ship 'Hokusei Maru' of the Faculty of Fisheries, Hokkaido University, in the Okhotsk Sea in 1964 and 1966. In this paper, the author compares the information about salmon obtained from the echo pattern with the actual catch of salmon. The results obtained are summarized as follows: 1) The swimming speeds of reflecting bodies were computed according to the echo patterns on the basis of some assumptions. 2) The distribution of salmon estimated from the swimming depths and speeds of the reflecting bodies corresponded comparatively well with the salmon catch in the Okhotsk Sea. 3) Further improvement in the use of the echo sounder will enable us to detect the salmon distribution more accurately. (Author)

326
Sawyer, G.N.; Butler, J.A., 1971. Computerized acoustic fish assessment system. In: IEEE Int. Conf. Eng. Ocean Environ.:41-43.

327
Schulkin, M., 1975. Basic acoustic oceanography. Naval Oceanogr. Off., Washington D.C., Rep. NOO-RP-1:1-83.

328
Scrimger, J.A.; Turner, R.G., 1969. Volume scattering-strength profiles in the northeast Pacific Ocean. J. Acoust. Soc. Am. 46(3):771-779.

A technique is described that permits the determination of the acoustic scattering strength of the ocean volume in terms of depth, frequency, and time. A pod of charges is lowered together with a hydrophone to various depths in the ocean and, by observing the amount of scattered energy produced by detoning units of the explosive charge pod, a profile of good resolution of the scattering strength versus depths

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obtained. The broad-band acoustic characteristics of the charges permit the spectral characteristics of the scattered returns to be determined. Observations made over an extended time period yield the time dependence of scattering. Measurements made in the northeast Pacific Ocean are given. (Author)

329
Scrimger, J.A.; Turner, R.G.; Heyd, G.J.H., 1972. Backscattering of underwater sound in Saanich Inlet, British Columbia, including observations of scattering from a fish school. J. Acoust. Soc. Am. 51(3):1098-1105.

The frequency dependence of acoustic volume backscattering strength has been measured at depths of 100, 200, 300 and 400 ft in Saanich Inlet, British Columbia, Canada, over a 24-h period. The measurements were made for comparison with open-ocean (Pacific) results, since the biology of the inlet has been extensively studied, and it serves to some extent as a reference water volume. In the course of carrying out the above measurements, the backscattering spectral characteristics and strength of a school of young hake of apparent mean size of 11 in., was obtained. The time series measurements revealed unchanging scattering characteristics at the 300 and 400 ft depths, with broad peaks near 1.2 and 4.8 kHz superimposed on otherwise flat spectra. Greater variability was observed at the 200 ft depth, while the greatest variability was observed near the surface, i.e., at the 100 ft observation depth. The fish school, which was observed to be closely packed (less than a fish length spacing near the surface) and randomly oriented, was shown to have a flat backscattering spectrum between 1 and 9 kHz and an estimated backscattering strength of -47 plus or minus 3 dB. (Author)

330
Seidel, W., 1969. Midwater school fish survey off the southeast coast of the U.S., using standard high-frequency vertical sounder. In: Proc., U.S. Bur. of Commer. Fish. Acoust. Workshop, Pereyra, W.T. (ed.), Seattle, Wash., November 25-27, 1968:31.

331
Semple, J.R., 1977. Video television and sonar sampling techniques in the study of adult alewives at a hydroelectric dam bypass. Can. Fish. Mar. Serv. Resour. Dev. Branch Marit. Reg. Tech. Rep. Ser. Mar-t 77(1):1-13.

332
Shibata, K., 1966. Echo-survey of tuna fishing ground. La Mer Bull. Soc. Fr.-Jpn. d'Oceanogr. 4(3).

APPENDIX C (continued)

333
Shibata, K., 1970. Analysis of echo-sounder records. Aoustic information of fish size. Jpn. Soc. Sci. Fish. Bull. 36(5):462-468.

When attempt is made on the direct estimation of the number of commercial fishes, using wide-beam echo-sounder, coupled with a pulse counter, it is necessary to consider statistically the echo strengths from individual fishes. The echo strengths from a given target passing through the sound beams, varies with its directional angle from the acoustic axis; fishes of identical size will give all possible echo levels below the maximum on the axis. The apparent loss through fish reflection, which is determined by the maximum of a series of echoes from a fish, included two components, the actual reflection loss which varied with the third power of fish size, and the directivity loss on the angular distribution of fish. Actual reflection loss were only observed when a fish existed on the acoustic axis. In this paper, a method is described on the correction for angular distribution of fish and also for the distribution frequency of observed reflection loss of fishes which are the acoustic information of fish size. It describes also the determination of echo sampling volume and average number of pulses received from a fish.

334
Shibata, K., 1970. Study on details of ultrasonic reflection from individual fish. Bull. Fac. Fish. Nagasaki Univ. 29:1-82.

335
Shibata, K., 1971. Experimental measurement of target strength of fish. In: H. Kristjonsson (ed.) Modern Fishing Gear of the World. Fishing News (Books), London.

336
Shibata, K., 1971. Studies on echo counting for estimation of fish stocks. I: Overlap counting and reading of S-type echo counter. Jpn. Soc. Sci. Fish. Bull. 37(8):711-719.

337
Shibata, K.; Aoyama, T.; Mimoto, K.; Nishinokubi. H., 1971. Studies on echo counting for estimation of fish stocks - II: An example of field survey. Jpn. Soc. Sci. Fish. Bull. 37(9):825-830.

The total amount of fish stocks could be estimated from data obtained by the S-type echo counter. The results of the trial calculations are: 1. The densities of densely concentrated fish schools are 1.84 to 76 fish per 1 cubic m around the waters off Koyama-Misaki. 2. The total amount of fish stocks is given as 590 x 10(E+6) anchovies of 9 cm

APPENDIX C (continued)

in length, and 5,300 tons when the body weight is 9 g per fish. 3. From the power spectrum of fish density index, Ni, it is estimated that the geographic distribution of fish schools is of a clustered nature and the relative distance of densely concentrated fish schools may be more than 1,000 m. 4. Errors of the echo counting system could not be clarified. Deep and careful attention should be paid to the calibrations of the acoustic, electronic and mechanic circuits, because errors in estimated value is directly due to that of the counting system. (Author)

338
Shireman, J.V.; Maceina, M.J., 1979. Techniques utilizing a recording fathometer in determining distribution and biomass of HYDRILLA VERTICILLATA Royale. Aquatic Weeds Res. Cent., Univ. Fla., Final Rep. to Corps of Eng., Vicksburg, Miss. 94pp.

339
Shishkova, E.V., 1958. An investigation of the acoustic properties of fish. Tr. Vses. Nauchn.-Issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 36:259-269.

340
Shishkova, E.V., 1960. Sound reflecting capacity of pelagic and benthic fish. Rybn. Khoz. 36(10):56-63.

341
Shishkova, E.V., 1964. Study of accoustical characteristics of fish. In: Modern Fishing Gear of the World 2 Fishing News (Books), London.

342
Shivarov, A.P., 1970. Determination of the density of fish concentrations from the optimum pulse length of sonar. Div. Foreign Fisheries, D.C. Translation TT 70-54000/9 3pp.

343
Smith, P.E., 1970. The horizontal dimensions and abundance of fish schools in the upper mixed layer as measured by sonar. In: G.B. Farquhar (ed.), Proc. Int. Symp. on Biol. Sound Scattering in the Ocean, Maury Center for Ocean Science, Washington D.C.

This paper reports progress in a study to develop an acoustic method to count, measure the horizontal dimensions, estimate the biomass, estimate the size composition, and identify the species of fish schools in the upper mixed layer from a moving ship. Several thousand fish

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schools were counted and measured in the California Current region in 1969 using a sonar at a frequency of 30 kHz, with a 10 degree conic beam (at -3dB), at ranges from 200 to 450 during day-light hours. Counts and measurements were made at ship's speed of 8 to 13 knots. In the 200,000-square-mile study area there exists a great variety of sonar propagation conditions due to upwelling, stratification, internal waves, and volume reverberation. The counts of fish schools, after correction for known biases and area, indicate the presence of about 1 million schooled sonar targets in the 200,000-square-mile area adjacent to the coast-line between San Francisco and Cape San Lazaro, Baja California, Mexico. Most fish schools are between 10 and 30 m diameter, normal to the ship. Less than 5% of the schools exceed 60 m diameter. Most schools occur in groups of schools near the axis of the California Current, in the gyral waters of the Los Angeles Bight, Sebastian Vizcaino Bay, and the Abreojos Bight, and nearshore along the entire coast. Occasionally groups of schools were located over 160 miles from the coast. Analyses of the concentrations of schools during the spawning period indicates that their location coincides with known spawning grounds. (Author)

344
Smith, P.E., 1975. Acoustics in fisheries research - A perspective. In: Ocean '75: IEEE Int. Conf. Eng. Ocean Environ., San Diego, Calif.:477-479.

Simple extension of existing fishery acoustics procedures will result in unnecessary delays in adding acoustical fishery survey data to the existing fishery management techniques. Progress in the coupled collection of amplitude - and frequency - domain acoustical data from fish aggregation promise useful advances in the utility of fishery acoustic studies. Fishery management problems are listed and transitions in the management of acoustics development, in the technology, and the biological studies are recommended. (Author)

345
Smith, P.E., 1976. Acoustic characteristics of populations of epipelagic schooling fish. J. Acoust. Soc. Am. 59 (Suppl. 1):S74.

Pelagic schooled fish populations have acoustic characteristics derived from their individual reflection or backscattering properties, their tendency to school, the tendency of schools to be aggregated in groups, and the tendency for populations of different species to be aggregated in regions of high productivity. In addition to those static properties, the different species populations can be expected to have characteristic swimming and feeding behavior at the individual level and foraging behavior at the school level. Schooling-level foraging behavior is affected by the fact that a school of fish eats far more

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than is produced per unit of school area. The foraging behavior of schools is expressed as the number of unit areas to be grazed per unit of school area. For example, a moderately compact school of anchovy (0 dB target strength) might contain 15 kg of fish per sq m of sea surface. Food requirements of such an aggregation probably exceed 40 g C/sq m/day but primary productivity of the nothern anchovy is only of the order of 0.5 g C/sq m/day. Therefore, an individual anchovy school must cover a minimum of 80 times its own area each day. Other fish species appear to school in less compact schools and probably have other food requirements. Schooling and foraging behavior also differs by day and night. Work in California waters has demonstrated acoustical techniques for the estimation of fish size and school motion. These acoustic parameters remain to be combined with static and dynamic, biological and geographic knowledge of fish populations to provide practical acoustic means of fish target identification. Similarly, the acoustic characterization of water masses and particularly the distribution and abundance of epipelagic schooled fish targets which we are investigating appear to be lacking for most of the world ocean in the upper 100 m. (Author)

346
Smith, P.E., 1977. The effects of interval waves on fish school mapping with sonar in the California current area. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:223-231.

Sonar mapping of schools of fish in surface waters where echo-sounders are effective is influenced by changes in the effective range of detection caused by changes in the sound velocity profile as well as by vertical migrations and changes in packing density within the schools. Analysis has been made of 38 sound velocity profiles over a short period in one region and their variation compared with that in a mass of data for the California area: the short-term variation was of comparable magnitude to that over a 20 year period, with effective detection range varying five-fold. As analysis of the sound velocity profiles at each school mapping station is impractical, a statistical approach is made to determine an 'average' effective detection range. This utilizes historical data, partitions areas and seasons according to intensity of variation in the sound velocity data, allocates sound velocity profiling so as to reduce the standard error of the mean sound velocity gradients in upper waters to a uniform value for all areas and seasons and then, for these profiles, creates a probability diagram for corrections to the number of targets detected at various ranges and depths. An example of the application of the method is given. (Author)

APPENDIX C (continued)

347
Smith, P.E., 1978. Precision of sonar mapping for pelagic fish assessment in the California Current. J. Cons. Int. Explor. Mer 38(1):33-40.

A large scale sonar map of fish schools in the Los Angeles Bight is described and used to determine the amount of sampling required to estimate the number of schools at various levels of precision. About 8 nautical sq mi (2,744 ha) must be directly surveyed to get an estimate of fish schools with a 25% level of precision: 47 nautical sq mi (16,121 ha) must be sampled for a 10% level of precision using the observations and assumptions of this paper. Although spatial autocorrelation indicates independent observations can be taken at 5 nautical miles (9 km) spacing or greater, there is a possibility of exclusion or reduction of the number of schools at 7 to 15 nautical miles (13 to 28 km) range which should be further investigated. (Author)

348
Sofoulis, N.G., 1978. A study of the acoustic strengths of small targets relevant to the prawning industry. M. App. Sc. thesis, W. Aust. Inst. Tech.

349
Sofoulis, N.G.; Penrose, J.D.; Cartledge, D.R.; Fallon, G.R., 1979. Acoustic target strengths of some penaeid prawns. Aust. J. Mar. Freshwater Res. 30(1):93-101.

Equipment was developed to facilitate measurement of the acoustic target strengths of single penaeid prawns arranged at various orientations to the insonifying beam direction. The dorsal plane target strengths of several species of penaeid prawns. PENAEUS ESCULENTUS, P. MERGUIENSIS and P. LATISULCATUS. in the length range 16 plus or minus 2 cm and for frequencies in the range 50-1200 kHz are described by: TS = -44.4 -2.52(E-3) for the maximum target strength values observed and TS = 51.2 -1.68(E-3) f for values of target strength averaged over the dorsal plane. TS values are in dB ref. 1 m and f, the insonifying frequency, is in kHz. Target strength values averaged over the central plus or minus 40 degrees of the dorsal plane were essentially constant with frequency, at a value of approximately -47 dB ref. 1 m. For the target lengths and sound frequencies used the amplitude of the backscattered pressure signal varies rapidly with changes in target orientation and an ensemble of such amplitudes, measured at 200 kHz in the dorsal plane, is distributed approximately according to the Rayleigh distribution function. (Author)

APPENDIX C (continued)

350
Somers, M.L., 1970. Signal processing in Project Gloria, A long range side-scan sonar. Nat. Inst. Oceanogr., Wormley, England, Collected Reprints 18 12pp.

It is very interesting to study the ecological problem of schooling of salmon in fishing grounds, but it is very difficult to catch its real structure. An analysis of fishing data has been reported that several individuals of salmon have been netted in patch in commercial gillnet hauling. The authors have already carried out various experiments on the developments of the salmon fish finder since 1964, and attained to its object as reported in 1972. In an echogram of such salmon fish finders, the fish images are recorded as single fish image (so-called single comet), double fish image (double comet), triple one (triple comet) and so on. Data give fish images per hour at the time of net setting. The fishing grounds were estimated in the following three grades (less than 1.0, 1.1-3.0, 3.1-6.4) as the fish abundance index was calculated from the catch per unit (tan) the next morning. The results obtained are as follows: The ratio of total recorded fish images to numbers of schooling fish images showed 62.6% without consideration of fish abundance in the fishing grounds, but when considering three grades of fish abundance, the ratio showed 16.4, 44.4 and 76.7%, and still more; the most recorded image is the single comet in fishing grounds of lower fish abundance, and the higher the fish abundance the more frequent the fish school, and the fish number of school tends to increase. The most numerous individuals of fish schools were composed of 7 in this observation. From the facts described above, salmon schooling is observed to be defined by fish abundance in its fishing grounds, and schooling tends to increase proportionally to its fis abundance. (Author)

351
Sonoda, H., 1972. On the schooling of salmon in the North Pacific Ocean observed by salmon fish finder. Hokkaido Daigaku Suisan Gakuba Kenkyu Iho Jpn. 23(2):77-81.

352
Squire, J.L., 1978. Northern anchovy school shapes as related to problems in school size estimation. Fish. Bull. 76(2):443-448.

Horizontal fish school profiles of the northern anchovy, ENGRAULIS MORDAX, taken from day aerial photographs and video tapes of school bioluminescence at night were examined to determine the percentage of school area within a circular field of view and the school length and width ratios. Schools observed during the day had an average length to width ratio of 2.09:1; at night the ratio was 2.53:1. The percent

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coverage of the school's area in relation to a circle drawn tangent about the school averaged 42.1% during the day and 29.2% during the night. The effect of school shape on estimation of individual school area as observed with a side-looking sonar was determined. School width measurements, similar to that obtained by the sonar, were used to determine school area and indicated a possible average overestimate of the actual school area of 1.72:1 The relation of school length and width to the error was determined, indicating the greater the length to width ratio the greater the error. (Author)

353
Stephens, R.W.B., 1970. Underwater acoustics. Wiley Interscience, London 269pp.

354
Stepnowski, A., 1974. Computerized system of hydroacoustic data processing for fish abundance estimation. 8th Int. Congr. on Acoust. - Satell. Symp. on Underwater Acoustics, Birmingham, U.K., 1-2 Aug 1974.

355
Stepnowski, A.; Martin, W.; Salamon, R., 1972. Hydroacoustic data processing in the fish stock assessment system on board the R/V 'Professor Siedlecki'. In: Acous. Comm. Polish Acad. Sci., Polish Acoust. Soc., Proc. 19th Open Semin. on Acoust.

356
Strand, R.F.; Scidmore, W.J., 1969. Sonar - An aid to under-ice rough fish seining. Minnesota Dept. Conserv., St. Paul, Div. Game Fish Rep. SP-68 36pp.

Field tests of commercially available sonar (horizontal echo-ranging gear) during three operating seasons with commercial and state seining crews have demonstrated that concentrations of rough fish, such as carp and buffalo, can be detected under the ice with a high degree of reliability under most conditions encountered in shallow inland lakes. (Author)

357
Stubbs, A.R., 1971. Measurements of the acoustic target strengths of fish in dorsal aspect, including swimbladder resonance. Nat. Inst. Oceanogr., Wormley, England, Collected Reprints, 19:25pp.

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358
Suomala, J.B., 1972. The application of hydroacoustic methods for aquatic biomass measurements. Mass. Inst. Tech. Sea Grant Project Office, Cambridge, Rep. 72-8 95pp.

359
Suomala, J.B., 1975. A short note on the applicability of hydroacoustic methods for demersal fish counting and abundance estimations. Int. Comm. Northwest Atl. Fish., Res. Doc. 75/95. Ser. 3575 4pp.

The fundamental requirement for counting is the capability of the sensor (in this context the combination of the hydroacoustical apparatus and the received echo signal processor) to resolve or distinguish between the objects to be counted and then to perform the counting function. This note will address the general situation concerning target resolution as it affects the counting of demersal fish targets. (Author)

360
Suomala, J.B.; Lozow, J.B., 1980. Hydroacoustics and fisheries biomass estimations. In: Diemer, F.P.; Vernberg, F.J.; Mirkes, D.Z. (eds.), Advanced concepts in ocean measurements for marine biology, University of South Carolina Press.

361
Tanaka, M., 1979. A basic study on the estimation of Fish stocks by an echo sounder. Bull. Freshwater Fish. Res. Lab., Tokyo 28(2):77-139.

362
Tanaka, M.; Ou, H.C., 1977. Estimation of fish population and length composition through pulse enumeration: An experimental echo survey in Lake Yunoko, Nikko. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:136-141.

A series of echo surveys with a 200 kHz sounder was carried out to estimate the size of fish stocks in Lake Yunoko, Nikko. During the echo survey, a creel census was taken at intervals, in particular before and after the opening day of fishing and on the day on which 100,000 trout were released. The number of pulses in the trace of individual fish was visually read on the echogram for depths greater than 4 m. The speed of the echogram paper was increased so that individual echoes could be resolved, and then the fish target strength and subsequently the fish size could be obtained from the number of received echoes per fish. The results from the echo reading coincided with those from the catch data. The total stock of fish over 3.3 cm long was estimated at between 220,000 and 470,000. Because of equipment limitations, the data above 4 m were erratic and thus the size of the stocks in the surface layer is still questionable. (Author)

APPENDIX C (continued)

363
Tesler, V.D., 1971. The distribution of amplitudes and stability of echo-signals from fishes. Mater. Rybokhozyaistv. Issled. Severnogo Basseina 17:270-279.

364
Tesler, V.D., 1977. Measuring of average amplitude of echoes for fish density estimation. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:152-158.

This paper describes a USSR-designed commerical echo-integrator, IS-1, that averages the measured amplitude of echoes. Besides integration, the device also measures the lengths of echo signals. Thus, the average amplitude and square amplitude of the envelope can be determined. The paper also discusses a method for obtaining the target strength of single fish with this device. The results of calibrating the IS-1 are described. The calibration was done by simultaneously measuring the density of blue whiting concentrations on the IS-1 and on a five-channel single-fish counter attached to a SIMRAD EK-120 echo-sounder. As a result of the calibration, a statistical relation between the square of an average amplitude and the fish density was determined for use in assessing blue whiting stocks. (Author)

365
Tesler, V.D.; Berdichevsky, Z.M., 1970. On development of a method and a device to measure average amplitude of echoes from fish concentrations. Mater. Rybokhozyaistv. Issled. Severnogo Basseina 16(2):220-227.

366
Thomas, G.L., 1979. The application of hydroacoustic techniques to determine the spatial and distribution and abundance of fishes in the nearshore area in the vicinity of thermal generating stations. In: Proc. Oceans, IEEE Rep. CH1478-7/79/0000-006:61-63.

Hydroacoustic surveys of the nearshore population of fishes along the southern California coastline have been conducted in the vicinity of thermal generating stations since 1976. A digital echo integration system was used in conjunction with SIMRAD EK 120 and ROSS 105 kHz echo sounders. The nature of the hydroacoustic data made it far superior to net measuremnets of fish density because of the quantity, the speed, and the accuracy of the information collected. The hydroacoustic data revealed that significant changes in the nearshore fish density occurred between days and diel peiods. This finding indicates that conventional net sampling techniques are inadequate to describe nearshore fish densities because of the length of time required for deployment of the nets. The acoustic surveys were supported by data from lampara sein catches. (Author)

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367
Thomas, G.L.; Johnson, L.; Thorne, R.E.; Acker, W.C., 1979. Techniques assessing the response of fish assemblages to offshore cooling water intake structures. Univ. Washington, Seattle, Fish. Res. Inst., Rep. FRI-UW-7927.

A ROSS 105 kHz transducer was mounted in a V-fin and towed ahead of a small survey vessel to hydroacoustically estimate fish biomass near offshore power plant intakes. Lampara and gill nets provided species identification. (PK)

368
Thomas, G.L.; Johnson, R.L., 1980. Density dependence and vulnerability of fish to entrapment by offshore-sited cooling-water intakes. In: Oceans '80: IEEE Int. Conf. Eng. Ocean Environment.

Simultaneous measurements of the offshore fish density and in-plant fish entrapment were made during eight surveys at four electric-generating stations along the southern California coastline in 1979. Hourly estimates of the fish biomass in the vicinity of the cooling-water intake sites with state-of-the-art precision were made possible with hydroacoustic techniques. Synchronous hourly measurements of fish entrapment were made in order to describe the density dependence of fish entrapment. An entrapment vulnerability statistic, the ratio of the weight (kg) of fish entrapped in the plant (E) to the weight (kg) of fish offshore in the vicinity of the intake (B), i.e., E/B, was employed to describe the effect of water transparency, the velocity-cap and volume of flow on the entrapment of fish. (Author)

369
Thomas, G.L.; Rose, C.; Gunderson, D.R., 1981. Rockfish investigations off the Oregon Coast. Univ. Washington, Seattle, Fish. Res. Center Rep. FRI-UW-8119 20pp.

Echo integration was used to investigate rockfish schooling behavior off the coast of Oregon in April 1981. It was determined that schooling in this species is highly dynamic, and that widow rockfish schools were recorded only in specific areas along the continental shelf break. An experimental 'search-light' sonar aboard the R/V 'Chapman' was also tested. (PK)

370
Thorne, R.E., 1970. Investigations into the use of an echo integrator for measuring pelagic fish abundance. Ph.D dissertation, Univ. Washington, Seattle.

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371
Thorne, R.E., 1971. Investigations into the relation between integrated echo voltage and fish density. J. Fish. Res. Board Can. 28(9):1269-1273.

An echo integrator, working in combination with an echo sounder, measures the total voltage of the fish echoes received from a given depth interval and sums these voltages over time. Investigations were made on the relation between integrated echo voltage and fish density for juvenile sockeye salmon (ONCORHYNCHUS NERKA) in Lake Washington and Pacific hake (MERLUCCIUS PRODUCTUS) and Pacific herring (CLUPEA HARENGUS PALLASI) in Puget Sound. When fish were distributed at densities at which they could be acoustically resolved as individual targets, the relation between net catch and integrated voltage was linear. At higher densities when the fish echoes were multiple targets, the net catch was related to the square of the integrated voltage. (Author)

372
Thorne, R.E., 1972. Hydroacoustic assessment of limnetic-feeding fishes. In: Franklin, J.F.; Dempster, L.J.; Waring, R.H., (eds.). Proc. Symp. Res. Coniferous Forest Ecosys., U.S. Int. Biome Prog. Pac. N. West Forest Range Exp. Stn., Portland:317-322.

373
Thorne, R.E., 1973. Application of acoustics to the assessment of the Pacific hake population in Port Susan, Washington, 1969-1973. In: Ocean '73: IEEE Int. Conf. Eng. Ocean Environ.:249-52.

Acoustic surveys of the spawning population of Pacific hake (MERLUCCIUS PRODUCTUS) in Port Susan, Washington have been conducted annually since 1969. Analog echo voltage and voltage-squared integrators were used in conjunction with 38 kHz echo sounders for the 1969 and 1970 surveys. In 1971 a digital echo integration system was developed and applied to the surveys in conjunction with a 105 kHz echo sounder. Surveys were expanded in 1972 to the areas adjacent to Port Susan to evaluate the importance of the spawning behavior and timing in the assessment of the stock size. Surveys in 1972 and 1973 used the digital system in conjunction with both 38 kHz and 105 kHz echo sounders. The acoustic surveys, supported by data from net catches, indicate considerable variation in the hake population during the five years. (Author)

APPENDIX C (continued)

374
Thorne, R.E., 1973. Digital hydroacoustic data-processing system and its application to Pacific hake stock assessment in Port Susan, Washington. Fish. Bull. 71(3):837-43.

A digital hydroacoustic data-processing system was developed at the University of Washington utilizing the general-purpose computer PDP/8L. The system, which functions as a 20-channel squared voltage integrator, was applied to the annual assessment of the spawning stock of Pacific hake, MERLUCCIUS PRODUCTUS, in Port Susan, Washington. Four surveys were conducted between 14 and 16 March 1971. The population estimates were based on calibration by NE+, hauls ranged from 15.9 to 18.8 million lb. An estimate of 18.2 million lb was obtained with an analog voltage integrator for one of the surveys. The digital system provided more detailed information on the horizontal and vertical distribution of the fish and resulted in a much smaller variance of the estimated mean fish density than the analog system. (Author)

375
Thorne, R.E., 1976. Echo sounding and fish population estimation. In: Proc. 56 Annu. Conf. Western Assoc. of State Game Fish Comm., Sun Valley, Idaho, 1976:257-263.

Hydroacoustic methods have many advantages over conventional techniques for determining the distribution and abundance of midwater fishes. The advantages include much greater sampling power, low manpower requirements, and capability for absolute population estimates. Despite the relatively high initial cost for equipment and the requirement for specially trained personnel, these techniques are becoming widely used in marine investigations and are rapidly gaining acceptance in freshwater studies (Mathisen, 1975). (Author)

376
Thorne, R.E., 1977. A new digital hydroacoustic data processor and some observations on herring in Alaska. J. Fish. Res. Board Can. 34(12):2288-2294.

A new hydroacoustic data processor using a PDP 11/45 computer was developed and applied to some herring studies in southeastern Alaska. The new processor allows for analysis of up to 50 different depth intervals, has a threshold to eliminate noise, and has greater dynamic range than any previous hydroacoustic data processor. The new system was used to analyze some data previously recorded on analog magnetic tape, including a series of 20 replicate hydroacoustic surveys over a 4-day period in Carroll Inlet. Comparisons were made with an earlier model digital integrator and with results of oscilloscope (CRT)

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measurements. Results of replicate surveys and comparisons between different areas demonstrated that the distributional characteristics of the herring can greatly affect the results of hydroacoustic surveys. (Author)

377
Thorne, R.E., 1977. Acoustic assessment of Pacific hake and herring stocks in Puget Sound, Washington, and southeastern Alaska. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:265-278.

Acoustic surveys were conducted on the Pacific hake stock in Puget Sound, Washington, from 1969-1972, on the Pacific herring populations in Puget Sound from 1972-1973, and on the herring populations in southeastern Alaska from 1971-1973. Surveys in 1969 and 1970 used analog echo integrators in conjunction with 38 kHz echo-sounders. Surveys in 1971-1973 used 105 kHz sounders and sometimes both 38 kHz and 105 kHz systems, with data processing by digital echo integrator. The variability associated with population assessment for the three stocks was clearly influenced greatly by the patchiness of fish distribution. Surveys of the broadly dispersed hake produced the highest precision. Relative errors of population estimates on hake ranged from 2% to 16%, whereas those for the more patchy herring in Puget Sound ranged from 10% to 30%. Greatest variability was associated with the herring stock in southeastern Alaska which was distributed in large schools. (Author)

378
Thorne, R.E., 1978. Investigations into the accuracy and precision of hydroacoustic techniques for fishery resource assessment. J. Acoust. Soc. Am. 64 (Suppl. 1):S96.

Hydroacoustic techniques are becoming widely used in fishery resource assessment. There are many sources of variability and uncertainty in these techniques, and their accuracy and precision has been questioned. Studies at the University of Washington have evaluated the performance of hydroacoustic techniques in a variety of applications where substantial ground truth data were available. These studies have documented the magnitude of several variance components and shown that many of the large sources of variability are biological rather than physical. (Author)

APPENDIX C (continued)

379
Thorne, R.E., 1979. Hydroacoustic estimates of adult sockeye salmon (ONCORHYNCHUS NERKA) in Lake Washington, 1972-1975. J. Fish. Res. Board Can. 36(9):1145-1149.

Hydroacoustic techniques were used on Lake Washington from 1972-1975 to estimate the potential escapement of sockeye salmon (ONCORHYNCHUS NERKA). Target strength measurements were used to establish a threshold which would seperate the larger adult sockeye salmon from smaller resident fish. The acoustic estimates of escapement were very similar to those obtained from visual observations at the Hiram M. Chittenden ship canal locks, observations on the Cedar River, and spawning ground surveys. (Author)

380
Thorne, R.E., 1980. Application of stationary hydroacoustic systems for Studies of Fish abundance and behavior. Univ. Washington, Seattle, Fish. Res. Inst., Rep. WSG-TA-80-9:1-7.

In most applications of hydroacoustic techniques for fish detection and abundance estimation, the data collection procedure involves echo sounding in a down-looking mode from a moving vessel. This study reports on two applications of stationary hydroacoustic systems: one at a coastal power plant intake in southern California, and the second under the ice near Prudhoe Bay, Alaska. Several advantages of stationary systems were apparent, including more detailed information on fish behavior, capability for detection closer to boundaries, and better signal to noise characteristics.

381
Thorne, R.E.; Dawson, J.J., 1974. An acoustic estimate of the escapement of sockeye salmon (ONCORHYNCHUS NERKA) into Lake Washington in 1971. J. Fish. Res. Board Can. 31(2):222-225.

The feasibility of estimating the escapement of sockeye salmon (ONCORHYNCHUS NERKA) into Lake Washington by hydroacoustics was explored during 1971. Surveys were made of large fish targets within the lake just before and after the spawning migration of sockeye salmon up the Cedar River. A decrease was observed after the spawning migration comparable to the estimated escapement as determined by weir counts and spawning ground surveys. (Author)

APPENDIX C (continued)

382
Thorne, R.E.; Dawson, J.J.; Traynor, J.J.; Burgner, R.L. Population studies of juvenile sockeye salmon in Lake Washington with the use of acoustic assessment techniques. FAO EIFAC, Tech. Pap. 23 (Suppl. 1):328-345.

Acoustic assessment techniques in conjunction with biological sampling have been used to monitor the seasonal abundance of juvenile sockeye salmon (ONCORHYNCHUS NERKA) in Lake Washington since 1969. The periodic population estimates have provided valuable information on the timing and rates of recruitment and outmigration and on the magnitude and possible causes of mortality. Population estimates of juvenile sockeye salmon immediately prior to outmigration have proven to be especially valuable for forecasting the magnitude of adult returns. (Author)

383
Thorne, R.E.; Lahore, H.W., 1969. Acoustic techniques of fish population estimation with special reference to echo integration. Univ. Washington, Seattle, Fish. Res. Inst., Rep. Circ-69-10:1-12.

384
Thorne, R.E.; Mathisen, O.A.; Trumble, R.J.; Blackburn, M., 1977. Distribution and abundance of pelagic fish off Spanish Sahara during CUEA expedition JOINT-I. Deep-Sea Res. 24:75-82.

The distribution and abundance of pelagic fish was investigated during Expedition JOINT-I of the Coastal Upwelling Ecosystem Analysis Program. The studies were conducted off Spanish Sahara, primarily along 21 degrees 40 minutes N between 17 degrees 05 minutes and 17 degrees 40 minutes W from 31 March to 10 May 1974. Data on fish abundance were collected with a hydroacoustic system consisting of 120 and 38 kHz echo sounders and a computerized signal processing system. Two congregations of fish were observed, one associated with the upper continental slope and the second at midshelf. The upper slope congregation was primarily horse mackerel (TRACHURUS sp.) and was associated with high abundance of large (over 500 micro-m) zooplankton. The second congregation was primarily sardine (SARDINA PILCHARDUS) and was distributed coincident with maximum abundance of small zooplankton and phytoplankton. The mean abundance of fish was estimated at 60 g/sq m wet weight over an area of about 4,000 sq km. (Author)

APPENDIX C (continued)

385
Thorne, R.E.; Nunnallee, E.P.; Green, J.H., 1972. A portable hydroacoustic data acquisition system for fish stock assessment. Univ. Washington, Seattle, Div. Mar. Resour., Rep. WSG-72-4:1-18.

Since March 1968, research in acoustic techniques for resource assessment has been conducted by the Washington Sea Grant marine acoustics program. These studies have included development of data acquisition and processing systems, theoretical studies of sources of variance in hydroacoustic techniques, and applications of hydroacoustic techniques to fish stock assessments, especially to juvenile sockeye salmon in Lake Washington (Thorne and Woodey, 1970) and to Pacific Lake in Port Susan (Thorne, Reeves and Millikan, 1971). (Author)

386
Thorne, R.E.; Reeves, J.; Millikan, A., 1971. Estimation of the Pacific hake (MERLUCCIUS PRODUCTUS) population in Port Susan, Washington, using an echo integrator. J. Fish. Res. Board Can. 28(9):1275-1284.

Echo integrators developed at the University of Washington were utilized for estimation of the size of a commercially exploited spawning stock of Pacific hake (MERLUCCIUS PRODUCTUS) in Port Susan, Washington, in 1969 and 1970. A simple voltage integrator was used in 1969, and a voltage-squared integrator was used in 1970. This change increased the objectivity of the technique, and enabled estimation of confidence intervals. Both population estimates were based on the results of echo integration over a number of transects distributed over the survey area. The integrators were calibrated against net hauls on the assumption of 100% net efficiency. An apparent decrease in the spawning stock size between 1969 and 1970 was indicated by the acoustical census and was supported by a decline in the commercial fishing catch rates between years. Annual catch and age data indicate that this difference apparently is not due to overfishing. The difference probably resulted from variation in the proportion of the total stock that was present in Port Susan at the time of maximum concentration. The major source of variability in the estimates for both years was associated with the net haul calibration. Alternate methods of calibration and improvements in the technique are discussed. (Author)

387
Thorne, R.E.; Thomas, G.L., 1981. Hydroacoustic surveys of fish abundance and distribution in Twin Lakes, Colorado. US Dept. Inter. Water Power Res. Serv., REC-ERC:84-1:1-14.

APPENDIX C (continued)

388
Thorne, R.E.; Thomas, G.L.; Acker, W.C.; Johnson, L., 1979. Two applications of hydroacoustic techniques to the study of fish behavior around coastal power generating stations. Univ. Washington, Seattle, Div. Mar. Resour., Rep. WSG-79-2:1-26.

Acoustic techniques were used to study the behavior of fish around the cooling water intake structure of the southern California Edison Generating Station at Redondo Beach, California. The transducer was positioned on the bottom near the intake and alongside a television camera atop the intake structure. Considerable information was obtained on the diel behavior of fish and their response to the television camera lights. (Author)

389
Thorne, R.E.; Woodey, J.C., 1970. Stock assessment by echo integration and its application to juvenile sockeye salmon in Lake Washington. Univ. Washington, Seattle, Fish. Res. Inst., Rep. WSG-70-2:1-37.

An echo integrator for use in the estimation of fish populations was designed and built. The first part of this paper describes an investigation into the relationship between the integrated echo strength of the echo integrator and number of juvenile sockeye salmon. The second part details an estimation of the pelagic population of presmolt sockeye salmon in Lake Washington by means of the echo integrator. (Author)

390
Thorpe, H.A.; Ogata, C.T., 1967. Hydroacoustic reflections from captive anchovies. Lockheed Corp., San Diego, Rep. 20989, 45 pp.

391
Traynor, J.J.; Ehrenberg, J.E., 1978. In situ target strength measurement for acoustic fish stock assessment. J. Acoust. Soc. Am. 64 (Suppl. 1):S95.

In an acoustic fisheries assessment survey, the target strength distribution of the fish being surveyed is an important parameter, primarily as a factor to scale the output of an echo integration system to fish density; however, good techniques to evaluate target strength of the surveyed fish are not readily available. Results of target strength measurements using tethered or caged fish are available but, because little is known about the orientation and aspect of the surveyed fish population, the scaling of echo integration to fish density using these results is questionable. In situ estimation

APPENDIX C (continued)

techniques are the most promising alternative. Indirect in situ methods which statistically convert echo strength distributions to target strength distributions are available but often provide poor results. A duel beam method (J.E. Ehrenberg, Proc. 1974 IEEE Conf. Eng. Ocean Environ. 1, 152-155) utilizes a duel beam transducer system and corrects echo strength to target strength for each detected single fish target. Unlike the indirect techniques, the dual beam method allows the effect of an inherent bias caused by a system noise induced threshold to be reduced. Field results using a standard target (ping-pong ball) and fish targets are reported and comparisons with theoretical predictions are made. (Author)

392
Traynor, J.J.; Ehrenberg, J.E., 1979. Evaluation of the dual beam acoustic fish target strength measurement method. J. Fish. Res. Board Can. 36:1065-1071.

During surveys to assess fish stocks, the acoustic scattering properties of the fish population are required to obtain stock size measurements. The recently developed dual beam technique of target strength measurement has shown great promise as a method for fish target strength measurement. An improved dual beam target strength measurement system is described, and we report the application to a marine population of walleye pollock (THERAGRA CHALCOGRAMMA). In addition, we dicuss field calibration using a ping-pong ball as a standard target. Results of target strength measurements of the fish and ping-pong ball are compared with predicted values based on simulation analyses of the technique operating under the noise conditions observed in the field. The agreement between field results and theoretical predictions were quite good. (Author)

393
Truskanov, M.; Shcherbino, M., 1964. Methods of direct calculation of fish concentrations by means of hydroacoustic apparatus. VNIRO, Seminar on Fishery, Biology and Oceanography, Moscow, U.S.S.R.

394
Truskanov, M.D.; Scherbino, M.N., 1966. Methods of direct calculation of fish concentrations by means of hydroacoustic apparatus. Res. Bull. Int. Comm. N.W. Atlant. Fish. 3:70-80.

395
Truskanov, M.D.; Sherbino, M.N., 1967. Hydroacoustic methods for determining the abundace of schooled fish. Tr. Vses. Nauchno-Issled Inst. Morsk. Rybn. Khoz. Okeanogr. 62:243-251.

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396
Truskanov, M.D.; Zapherman, M.L., 1977. Some characteristics of hydroacoustic methods of determination of fish abundance in sound scattering layers. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:245-247.

A method of echometric survey for estimation of fish stocks is described. In this the fish component in a sound scattering layer (SSL) is isolated from that of the plankton. The method is applicable to the situation where fish are at any one time both dispersed and schooled within the SSL. The thickness of the SSL varies inversely with fish density and changes with diurnal vertical migrations. Identification of fish species and measurement of their densities are made by a photographic method. An example of the use of the method is given as the measurement of the herring and poutassou stocks in the Norwegian Sea, the result of which was that the total number of specimens of both species together was 2.7 x 10(E+9). (Author)

397
Tucker, D.G., 1966. Underwater observation using sonar. Fishing News (Books), London 144pp.

398
Tucker, D.G., 1967. Sonar in fisheries - A forward look. Fishing News (Books), London 136pp.

399
Tucker, D.G., 1970. Sonar for fisheries: Possibilities and trends for future development. Underwater Sci. Tech. J. 2(3):145-154.

Modern trends in micro-electronics are having a profound effect on the design of sonar equipment for fisheries. Micro-electronics are finding application in the "digital sonar", in the within-pulse electronic sector-scanning sonar, and in the use of metal oxide silicon transistors. Other current developments are the trend to higher angular resolution, and the possibility of three-dimensional sonar systems, as well as low-frequency, ultra-long-range, wideband sonar, and field anomaly sonar. (Author)

400
Tucker, D.G.; Gazey, B.K., 1966. Applied underwater acoustics. Pergamon Press, Oxford 244pp.

APPENDIX C (continued)

401
Ulltang, O., 1977. Methods of measuring stock abundance other than by the use of commercial catch and effort data. FAO Tech. Pap. 176:1-23.

The paper reviews methods of monitoring the abundance of fish stocks other than by the analysis of catch and effort data. The main methods considered are: fishing surveys; acoustics, sightings and aerial surveys; egg and larval surveys; and tagging experiments. For each method consideration is given to the precision obtained, the possible causes of bias, and the costs involved. A tabulation is given of the advantages and disadvantages of different methods in respect of different types of stock. The ultimate choice of method depends on the biological and environmental characteristics of the situation, as well as the specific purpose of the work, and the resources of personnel, expertise and equipment that are available. (Author)

402
Urick, R.J., 1971. The sonar equation. In: Caruthers, J.W. (ed.), Lectures in mariine acoustics, Vol. 2, Part 1. Selected advanced topics in marine acoustics. Texas A. & M. Univ. (College Station), Sea Grant Rep. TAMU-SG-73-403:60-72.

403
Urick, R.J., 1975. Principles of underwater sound. McGraw-Hill, New York 384pp.

404
Vent, R.J., 1978. Fish school target strength measurements off southern California. J. Acoust. Soc. Am. 64 (Suppl. 1):S96.

Measurements of target strength were made of pelagic fish schools in the Los Angeles Bight where the dominant schooling species is the northern anchovy, ENGRAULIS MORDAX. Data were collected using a hull-mounted, side-looking 30 kHz sonar system. Among the parameters studied were peak target strength, integrated target strength, target extent, and variation of peak target strength with aspect. Three schools were interrogated, while the vessel was hove to, with varying pulse durations: 2, 10, 50, and 170 ms. Results indicate that peak target strength varies directly with the pulse duration when the pulse length is less than the target extent, whereas integrated target strength appears to be independent of pulse duration. School peak target strength and target extent, for 10-ms pulse duration, were measured while the vessel circled a school through 360 degrees. Variations in target strength of 20 dB and in target extent of 30 m were observed. The minimum target strength corresponded with the maximum target extent, which may possibly be explained by the school's geometry and variations of individual fish target strength with yaw aspect. (Author)

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405
Vent, R.J.; Davies, I.E.; Townsen, R.W.; Brown, J.C., 1976. Fish school target strength and Doppler measurements. Naval Undersea Center, San Diego, Rep. NUC-TP-521:1-36.

406
Vestnes, G.; Saetersdal, G., 1966. El ecosonda y su aprovechamiento por los pescadores. Santiago De Chile. Instituto de Fomento Pesquero Pub. 20 16pp.

407
Volberg, H.W., 1963. Target strength measurements of fish. Straza Industries (El Cajon, Calif.) Rep. R-101, 146 pp.

408
Volberg, H.W., 1970. Acoustic target strength of several species of fish. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 607:21-26.

To design fish-finding sonar equipment it is necessary to have information about target strengths of fish. This study was made principally to determine the target strenght of tunas at several acoustic frequencies. In addition, measurements were made on other living, dead, fresh, and frozen freshwater and saltwater fishes, some without swim bladders. (Author)

409
Vucetic, T., 1973. Fluctuations of zooplankton and echo-trace abundance in the central Adriatic. Gen. Fish. Counc. Med. Stud. Rev. 53:19-38.

410
Walker, M.G.; Mitson, R.B.; Storeton-West, T., 1971. Trials with a transponding acoustic fish tag tracked with an electronic sector scanning sonar. Nature 229(5281):196-198.

APPENDIX C (continued)

411
Weimer, R.T.; Ehrenberg, J.E., 1975. Analysis of threshold-induced bias inherent in acoustic scattering cross-section estimates of individual fish. J. Fish. Res. Board Can. 32(12):2547-2551.

During acoustic fish stock assessment surveys, it is often desirable to measure the distribution of the acoustic scattering cross-section of single fish. One of the problems in such measurements is that a threshold in the electronic circuitry discriminates against small fish. This effect is analyzed in detail, and an expression is derived for the threshold-induced bias in the mean scattering cross-section estimate. Results are plotted for a typical set of operating conditions. (Author)

412
Welsby, V.G., 1973. Sonar target strength measurements on live fish. Br. Acoust. Soc., Meeting on Sonar in Fisheries, Lowestoft, U.K., 27 March 1973.

413
Welsby, V.G.; Creasey, D.J.; Barnickle, N., 1973. Narrow beam focused array for electronically scanned sonar. Some experimental results. J. Sound Vib. 30(2):237-248.

Successful trials are described of a focused array, used in conjunction with a within-pulse sector-scanning sonar. The array operates at 500 kHz and is 690 wavelengths long so its 3 dB beamwidth is about 0.084 deg for "additive" processing. In the experiments, however, "multiplicative" processing was used which, under suitable conditions, reduces the effective beamwidth to less than 0.05 deg. The system, with its focal distance set to 80 m, has been used to detect simulated fish targets close to the bottom in a sea-flooded quarry. The full angular resolution of the scanning sonar has also been achieved in a tank, with the focal distance set to 8 m, a range which is less than four times the length of the array itself. Further theoretical consideration is also given to the design of variable-focus electronically scanned sonars in general. (Author)

414
Welsby, V.G.; Goddard, G.C., 1973. Underwater acoustic target strength of nets and thin plastic sheets. J. Sound Vib. 28(1):139-149.

The purpose was to find the most suitable material to form a cage, itself having a very small acoustic echo strength, for use in experiments on the acoustic target strength of fish. A series of measurements have been carried out in the Acoustic Tank Laboratory at the University of Birmingham on samples of various materials and a

APPENDIX C (continued)

theoretical analysis has been made which gives a useful insight into the way the echo strength depends on the dimensions and mechanical properties of nets and sheets. Sufficient agreement was obtained between theory and practice to show that the results will be valuable for future design work. Plastic sheets were shown to have no advantage over nets. The study has shown that significant effects are caused by surprisingly small amounts of gas adhering to the solid materials. It is this which is likely to set a practical lower limit to the target strengths which can be attained. (Author)

415
Welsby, V.G.; Hudson, J.E., 1972. Standard small targets for calibrating underwater sonars. J. Sound Vib. 20:399-406.

416
Werner, R., 1977. A reasonableness algorithm for hydroacoustic estimation of biomass density. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:219-222.

Reasonableness testing of hydroacoustic estimates of biomass density involves a comparison of the estimate with some known or expected density value. The difference between the estimate and the known is then compared with some limiting values. If the difference falls within the limiting values the estimate is deemed reasonable. Unreasonable values cause an action to be initiated to determine the error source and adjust the values of appropriate parameters. This process when viewed macroscopically approximates a feedback control system regardless of the degree of automation. The pseudo-algorithms presented are an attempt to delineate present thought processes and activities required to determine reasonableness criteria and apply them to hydroacoustic biomass density estimation techniques. (Author)

417
Weston, D.E., 1967. Sound propagation in the presence of bladder fish. In: Albers, V.M. (ed.), Underwater Acoustics, Plenum Press, New York.

418
Weston, D.E., 1973. Fish traces on a long range sonar display. Br. Acoust Soc., Meeting on Sonar in Fisheries, Lowestoft, U.K., 27 March 1973.

419
Weston, D.E., 1974. Long-range sonar studies - A five-day record of an extensive concentration of fish. In: 8th Int. Congr. on Acoustics, London 23-31 July 1974.

APPENDIX C (continued)

420
White, B.F., 1976. Transportable acoustic fish census system. In: Ocean '76: Sec. Annu. Combined Conf. Washington D.C., 13-15 Sept. 1976.

The CCIW high resolution Acoustic Fish Census System is a transportable fish counting and assessment tool designed to support biological studies of fish population in Canada's inland waters. The system features an 80 kHz transducer, a transceiver with a unique precision TVG receiver, a hard-wired signal processor and data logger, a fibre optics-CRT graphic intensity display, digital data printout and digital magtape storage. The system is configured to operate from survey launches in freshwater of depths ranging from 3 to 100 m. It processes target returns in 4 echo amplitude intervals and 6 adjustable depth ranges. A bottom-tracking digital servo is incorporated to improve the security of bottom echo rejection. A brief summary of the system mathematical modelling problem is presented together with some inferred limitations on system application. Two of these systems have been constructed, and are being used by two environmental study groups. (Author)

421
Wilhjalmsson, H.; Reynisson, P.; Hampe, J.; Rottingen, I., 1980. Acoustic abundance estimates of the Icelandic Stock of Capelin. October 1978 - January 1980. Int. Counc. Explor. Sea, 68th Meet., Copenhagen, ICES Rep. CM 1980/H:63.

422
Wolfe, D.C., 1976. Pelagic fish survey 2. Fish schools in offshore waters. Tasmanian Fish. Res. 10(1):15-27.

423
Yamanaka, H.; Yukinawa, M.; Morita, J.; Nishimura, M., 1977. Acoustic fish counting system for tuna and related species. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:174-184.

This paper describes an acoustic fish counting system and the results of experiments carried out in coastal waters and on the tuna fishing grounds of the western Pacific Ocean during the period 1970 to 1972. The prototype device, which was designed to calculate fish density (number of fish per cu meter), was manufactured late in 1969. Several experiments with this device were conducted with model targets and an actual fish school in order to determine the correction factor N (N = average number of counted echoes for a single fish). We found it difficult to measure the correction factor in the field directly. In late 1970, a fundamental reconstruction was made so that the present device measures the relative abundance for vertical 50 m layers. In

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field experiments with this counter, the number of targets and the echo count correlated well. The echo count does indicate the relative abundance of fish stocks, although it is difficult to calculate the number of fish directly from the echo count. (Author)

424
Yudanov, K.I., 1967. Interpretation of echo-soundings in hydroacoustic fish-finding devices. Izd. Pischevaya Promyshlennost, Moscow.

425
Yudanov, K.I., 1967. Possibilities of hydroacoustic methods of fish abundance determination. Tr. Vses. Nauchno-Issled Inst. Morsk. Rybn. Khoz. Okeanogr. 62:252-255.

426
Yudanov, K.I., 1970. On the prospects of quantitative evaluation of the density of fish accumulation according to data obtained by hydroacoustic instruments. Tr. Vses. Nauchno-Issled Inst. Morsk. Rybn. Khoz. Okeanogr., Moscow 709:312.

427
Yudanov, K.I., 1971. Interpretation of echograms of hydroacoustic fish-finding instruments. Israel Program of Scientific Translations, Jerusalem, 101pp.

428
Yudanov, K.I., 1977. Reflective power of commercially important fishes and fish concentrations. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 170:185-188.

The reflective power of an individual fish is a function of its type, size, shape and orientation as well as of the wavelength and other factors. The space and plane patterns of fish backscattering derived for different species support this conclusion. Averaged values of individual fish acoustic sections in a sound beam have acquired practical importance because it is usual for fish to be randomly orientated. The acoustic section values of fish on various axes can be averaged over given conditions. The average acoustic section value allows the size of detected fish to be assessed. The reflective power of fish concentrations is characterized by the volume coefficient of scattering, the latter being determined from an echo signal intensity. In this case a fish detection device is calibrated against a standard target. The density of recorded fish concentrations can easily be

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calculated from an individual fish acoustic section using the volume coefficient of fish concentration scattering. Methods of calculation of density of fish concentrations worked out on artificial schools were applied to commercial fish concentration. The results of experiments made on scattered concentrations were in good agreement with theory. Conclusive solution of the problem in question presupposes experiments on dense concentrations. (Author)

429
Yudanov, K.I.; Jankov, A.A.; Shatoba, O.S. Reflection properties of industrial fish species of the North Basin. Rybn. Khoz. Kiev (12):57-60.

430
Yudanov, K.I.; Kalikhman, I.L., 1981. Acoustic characteristics of marine animals. In: Proc. of the Meeting on Hydroacoustical Methods for the Estimation of Marine Fish Populations, Vol. 2, J.B. Suomala (ed.), Draper Laboratory, Mass. Inst. Tech., Cambridge.

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ORNL/TM-8304
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3. L. W. Barnthouse
4. J. E. Breck
5. G. F. Cada
6. S. W. Christensen
7. C. C. Coutant
8. J. W. Elwood
9. M. P. Farrell
10. S. G. Hildebrand
11-15. P. Kanciruk
16. B. L. Kimmel
17. J. M. Loar
18. A. L. Lotts
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