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SONAR IN FISHERIES

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SONAR TARGET STRENGTH MEASUREMENTS ON LIVE FISH

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Work has been done in the UK by Haslett, McCartney and Stubbs and others, and elsewhere by Love, Midttun and Hoff, Shibata and others on the determination of the acoustic target strength of fish. Most of the measurements have been of fish that are anaesthetised or recently killed, and in some cases the swim bladder has been replaced by an artificial cavity. In 1969 the present project was started, with the object of making statistical measurements of the target strength of live fish (presumably healthy and in good order) swimming naturally within a cage. The site chosen for the work was an old slate quarry at Easdale near Oban, West Scotland, which became flooded with sea water before the turn of the century and which now communicates with the sea at high tide. The tidal range within the quarry is restricted, simplifying some problems that could arise in the open sea, whilst the quarry bank gives a solid base for the portable laboratory that has been erected.

Most of the fish that are being measured with the notable exception of dogfish, are gadoids (i.e. they possess swimbladders). Certainly at low frequencies and most probably at all useful sonar frequencies the state of the swimbladder has considerable effect upon the target strength as it is the principal scatterer of sound. A gadoid controls its buoyancy by secreting or absorbing oxygen through the bladder walls, but this process may take up to 24 hours to complete. Sudden changes of depth are accommodated by muscular control, tensioning the swimbladder wall against excess internal or external pressure, and it has been shown by Hawkins (1) that this is accompanied by an elevation of the swimbladder resonance frequency. Because of this effect it is important to ensure that a fish is equilibrated to a given depth and is then maintained at that depth for the duration of the target strength measurement. At the site the fish is kept in an acclimatisation cage, at the same depth as the target cage (10m) for not less than 48 hours and is then transferred by a diver swimming horizontally to the target cage shortly before the commencement of measurement.

It was originally intended to measure the target strength of each fish at each of five frequencies (10 kHz, 30 kHz, 100 kHz, 330 kHz and 1 MHz) and from each of five elevations (horizontal, $22\frac{1}{2}^{\circ}$, 45°, $67\frac{1}{2}^{\circ}$ and vertical). However, it was soon found that the echoes from the cage used to constrain the fish were greater than those from the target itself at the upper two frequencies. This led to much theoretical and experimental investigation of the target strengths of nets and thin sheets of materials such as polythene, Melinex etc.(2), but it was eventually concluded that it was practically impossible to design a cage which would serve its purpose and yet at the same time would have echo levels low enough to permit worthwhile fish measurements at these frequencies. They were therefore deleted from the programme. The number of elevations was also reduced considerably to enable fish of a greater range of sizes and species to be measured within the available time, and target strength readings are now taken from vertical aspect and $22\frac{1}{2}^{o}$ (to the horizontal) only. These results are considered to be of importance for fish abundance determination and in the design of forward-search sonars respectively.

The fish must be kept at a constant depth, and so it is necessary to move the sonar transducers in order to change aspect. They are mounted on a trolley with a tilting platform, and the whole is driven up and down a 45^{o} inclined railway which forms part of a large steel structure erected for the purpose on the quarry bank. According to the position of the trolley, so the angle of the platform may be adjusted such that the transducers are trained on the target cage. Although routine measurements are made from only two positions, the sonar may in fact view the fish from any angle between horizontal and vertical. The winch that drives the trolley is controlled by a servo-system located within the nearby laboratory, and the sonar-system range-gate is automatically adjusted at the same time so that only echoes from the same range as the target cage are passed to the detector.

A limit is set to the sensitivity of the sonar system by reverberation. Apart from the target cage, echoes are received from weed and rubbish suspended in the water and (at certain times of the year) from jellyfish, and from the water surface and nearby rock faces and even from the support structure itself. Although the surface, rock faces and structure are insonified only via sidelobes of the transducers, they are so large that it proved necessary to take special precautions to prevent radiation in certain directions. Systematic experimental work was conducted to determine the extent to which the sidelobe energy of a transmitting transducer can be reduced by the use of side-baffles of high transmission loss (3). The results of this work were applied to one of the transducers, yielding an improvement in sensitivity of between 10 dB and 20 dB depending upon trolley position.

The dimensions of the cage are 2m by 2m by 1m (in depth). Each transducer has a 3 dB beamwidth of 25^{o}, and so even at the closest range of 6m the variations in sensitivity due to the changing position of the fish within the beam will be within ± 1 dB. Changes in range of the target are compensated for by means of a time-varying-gain system at the receiver. Calibration tests are performed regularly, using a ping-pong ball as a standard target (4).

A dead or anaesthetised fish will have a fixed directional pattern, and most previous investigators have determined the target strength as the maximum for a given elevation. When the fish is swimming about a cage, however, (and presumably the same would apply in the ocean) the instantaneous target strength fluctuates over a wide range. This is partly because the directional pattern is being sampled from varying directions, and partly because the pattern is itself changing as the fish bends and twists. One difficulty that arises, therefore, is that of deriving a single figure to describe the target strength from a given elevation - clearly statistical methods must be employed to describe the mean value. Allied to this is the question of the choice of the sonar pulse length; if this is long such that the whole of the fish is insonified at the same time then effective CW conditions prevail and the measured target strength will be that of the whole fish, if it is short then it is possible that many discrete echoes may be received and again there is the problem of how to produce a single figure. For the purposes of the measurements in the Easdale quarry the sonar system is adjusted to measure the CW target strength of the fish, although this is done by means of a narrow-band filter in the receiver rather than by using a long transmission pulse. In fact the transmission pulse is made as short as possible, thus permitting the receiver range-gate (which precedes the filter) to operate very tightly on either side of the target cage. This has been done to minimise the occurrence of spurious echoes from rubbish in the water etc.

The sonar receiver comprises a wideband amplifier, range-gate, frequency changer and IF amplifier (10 kHz). Band limiting is effected within the IF amplifier, which is followed by a peak-reading detector. This has a dynamic range of 70 dB, and will read the peak amplitude from the IF stage and hold this value until it is recorded by the data logger. The results, which are collected at the rate of approximately 100 per minute, are punched onto 8-hole paper tape. All functions are automatic, the only controls other than those of the servo-system driving the trolley are the on/off switches on the various units.

Each complete experiment involves the recording of 1000 measurements of a given fish at a given aspect and frequency. The paper tape is then assigned a seven-digit code number which identifies the particular experiment, frequency, aspect and target, and each week a batch of tapes is sent for processing on the MAFF computer according to a program written by the authors. The first stage of data reduction is the generation of a histogram showing the distribution of the received amplitudes recorded on each tape. The mean of each distribution is converted into a mean target strength using a table of calibration factors which is stored on disc file and which is updated occasionally. The results are then sent to Birmingham University for further processing.

At the time of writing a total of 1093 tapes (representing over 10^6 individual measurements) have been run on 126 fish. These have been 89 cod, 22 haddock, 8 saithe and 7 dogfish, and the results have been analysed for all fish and also for individual species. The analysis has taken the form of a least mean-square regression of $10 \log (\sigma/\lambda^2)$ on $10 \log (L/\lambda)$ where σ is the fish target area in square metres and λ is the wavelength in metres. In the results quoted below, T is the target strength expressed in dB relative to $4\pi\ m^2$. The correlation coefficients ranged from 0.89 to 0.93.

All species tested:

Dorsal $T = 25.8 \log L - 5.8 \log \lambda - 35.1$ dB

$22\frac{1}{2}°$ $T = 21.3 \log L - 1.3 \log \lambda - 34.5$ dB

Cod:

Dorsal $T = 26.6 \log L - 6.6 \log \lambda - 35.5$ dB

$22\frac{1}{2}°$ $T = 21.9 \log L - 1.9 \log \lambda - 35.0$ dB

Haddock:

Dorsal $T = 25.0 \log L - 5.0 \log \lambda - 34.4$ dB

$22\frac{1}{2}°$ $T = 21.0 \log L - 1.0 \log \lambda - 35.9$ dB

Saithe (based on only eight results):

$$\text{Dorsal} \quad T = 25.1 \log L - 5.1 \log \lambda - 37.0 \quad \text{dB}$$

$$22\tfrac{1}{2}^{\circ} \quad T = 17.7 \log L + 2.3 \log \lambda - 31.6 \quad \text{dB}$$

References:

(1) A.D.Hawkins and O. Sand, "Acoustic properties of the cod swimbladder", J. Exp Biol. In course of publication.

(2) V.G.Welsby and G.C.Goddard, "Underwater acoustic target strength of nets and thin plastic sheets", J.Sound Vib. (in course of publication)

(3) B.G.Watters, G.C.Goddard and V.G.Welsby, "The suppression of transducer sidelobes by the use of acoustic baffles", (paper presented at A.S.A. meeting, Miami, November '72)

(4) V.G.Welsby and J.E.Hudson, "Standard small targets for calibrating underwater sonars", J.Sound Vib., 1972 (20) pp 399 - 406.