SPECIES RECOGNITION; RESULTS FROM A WIDE-BAND ECHO-SOUNDER 27-54kHz

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INTRODUCTION

Echo-sounders have been used for estimating fish stocks for many years. The data collected from such a system must be attributed to one or more species in order to make accurate stock estimates. The identification of fish species is usually carried out by combining local and historical information about the shoal or layer structures observed by the echo-sounder and the results of fishing operations carried out on these echo traces. Sometimes there is no difficulty in correctly attributing the acoustic backscatter to the correct species. On other occasions the problems are quite severe, particularly when discrete shoals of several species are found in the same area. A wide-band echo-sounder has been constructed to investigate the possibility of using the frequency response information to aid identification. A series of experiments have been conducted in 1986 and 1988 to investigate the frequency response of several species and to use this information to examine the likely success rates for species identification for this system.

MATERIALS

Wide-band Echo-sounder

A 1.2kW transmitter is used to provide an amplitude modulated swept frequency pulse of 1.0ms with a flat frequency response from 27 to 54kHz. This drives a partial sphere transducer constructed from 217 elements arranged in 8 concentric rings around a central element. The rings are driven from an auto-transformer which provides the frequency independent amplitude shading required for constant beam-width on transmission. This technique is due to Rogers and Van Buren 1978 [1]. The same shading function, taking into account the number of elements on each ring, is applied using a summing point amplifier for reception. The receiver is designed with eight separate band pass channels each with a 3dB bandwidth of 3.3kHz equally spaced to cover the octave 27 to 54kHz. The eight channels are envelope detected, multiplexed and sampled at 100kHz, 12.5kHz per channel, by a computer. The data are stored on a tape streaming cartridge for later analysis. Simmonds and Copland 1986 [2] have reported a more detailed description of the echo-sounder and its performance.

Mechanical Experimental Rig

The experimental rig, shown in Figure 1, is suspended below a 10m

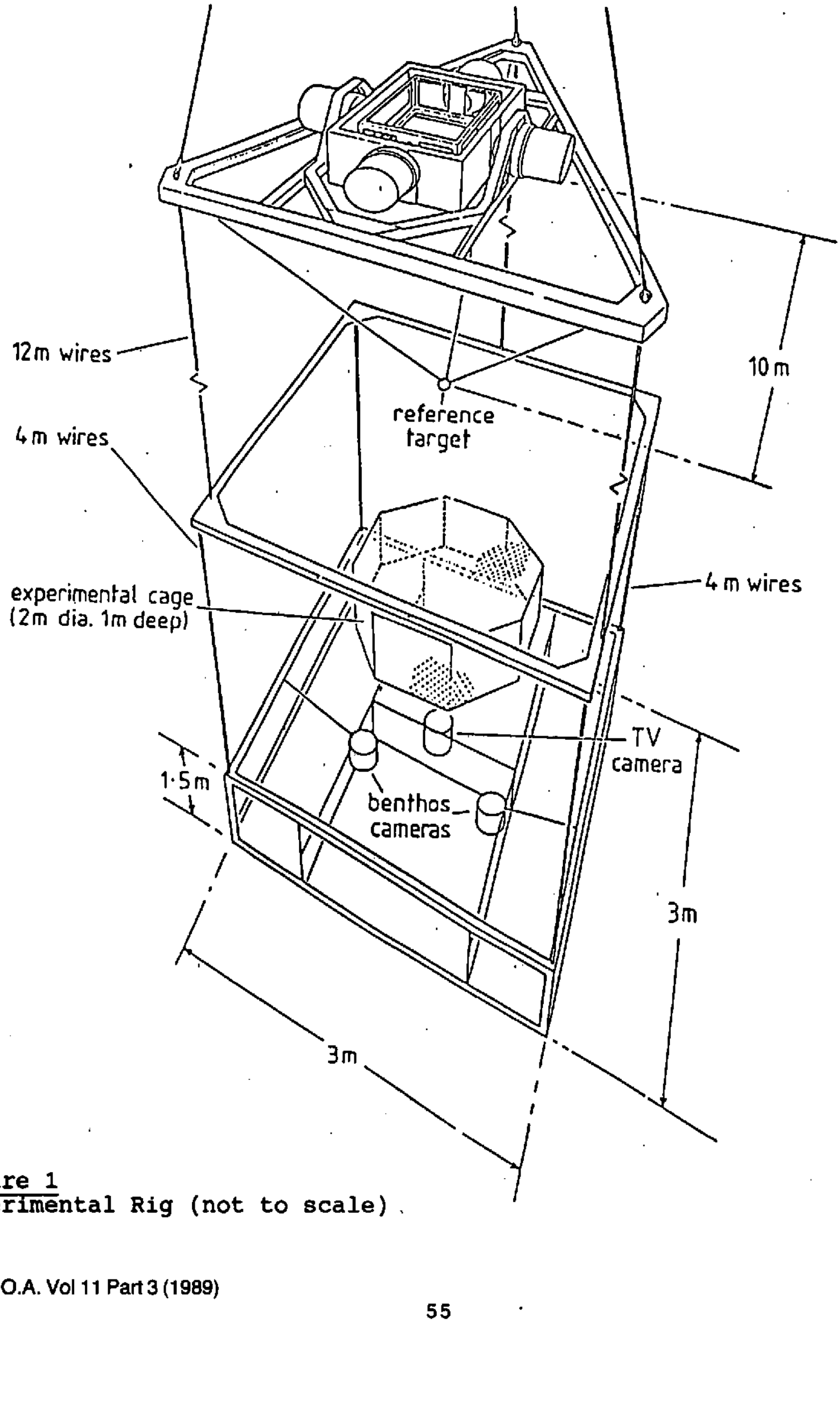

Figure 1
Experimental Rig (not to scale).

by 5m raft moored in 90m of water 600m from the shore in Loch Duich on the west coast of Scotland. The echo-sounder transducer is placed at the centre of the motorised gimbal table at the top of the rig. This is then positioned to ensure that the acoustic axis of the transducer is centred on the cage. A reference sphere, a 38.1mm diameter tungsten carbide ball is suspended 10m under the transducer to monitor the system sensitivity throughout the experiments. The 2m diameter experimental cage is suspended on monofilament nylon from a tube section aluminium frame at a depth of 14m from the transducer. The base of the frame contains two 35mm still cameras and a low light TV camera. The still cameras are used to provide stereo pictures of the fish in the cage to allow three dimensional behavioural analysis. The TV camera is used to monitor the distribution and condition of the fish during the experiments.

EXPERIMENTAL AND ANALYTICAL METHODS

Fish Experiments

The fish were transferred from holding pens to the experimental cage while the rig was at the surface. The whole rig was lowered to a depth of 15m for the experiments, placing the fish at a depth of 29m. In all but one case single species were investigated separately. The number, size and species of fish are shown in Table 1. In the final three experiments, Saithe and Haddock were first measured separately, then a number of each of these species were combined in the third and final experiment to investigate the spectrum from the species mixture.

Table 1
Species, number, length and weight for each experiment

	species		number	mean length cm	mean weight g
1986	cod		26	28.02	212.85
	cod		17	23.74	132.94
	saithe		26	22.63	114.69
	saithe		39	26.56	168.41
	herring		53	28.48	210.48
	herring		96	28.42	205.64
	mackerel		97	32.78	267.94
	mackerel		218	28.02	212.85
1988	mackerel		149	29.61	172.56
	herring		137	24.78	144.33
	saithe		17	31.12	236.41
	haddock		18	28.94	270.78
	Together	saithe	7	29.79	208.43
		haddock	7	30.50	297.29

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Data Collection

The data were collected on a 6 minute cycle, 1000 transmissions were carried out with a repetition rate of 3.3Hz. Each transmission was sampled at 12.5kHz, every 6cm in depth, on each of the 8 frequency channels. Integrals for data from the reference target and from the fish cage were computed for each frequency and each transmission. These integrals and their mean, maximum, minimum and standard deviation for the 8 frequency channels were stored on a tape streamer along with the vertical profiles. A data summary was displayed every 6 minutes to allow the progress of the experiment to be monitored. The mackerel and herring were observed for periods of 4 days, the gadoids, cod, saithe and haddock for up to 6 days to allow for acclimatisation periods of between 1 and 2 days.

Calculation of Spectral Response

The data from each 6 minute period were examined separately, the mean of 1000 transmissions was computed for the integrals from the fish cage and for the reference target. For each frequency the echo integral from the cage was then corrected for system response by dividing by the echo from the reference target and multiplying by the computed area backscattering strength of the target.

$$\sigma_{cijs} = I_{cijs} / I_{tij} * \sigma_{tij}$$

where for the j^{th} data block and frequency channel i
σ_{cijs} is the estimated acoustic cross-section of species s
I_{cijs} is the integral of the fish echo for species s
σ_{tij} is the acoustic cross-section of the reference target
I_{tij} is the integral of the target echo

Then to compute the spectrum each value was normalised by the geometric mean of the 8 area back scattering strengths.

$$S_{ijs} = \sigma_{cijs} / \sqrt[8]{(\sigma_{c1js} * \sigma_{c2js} \ldots * \sigma_{c8js})}$$

where
S_{ijs} is the spectral value for species s frequency i from the j^{th} block

This process was repeated for each 6 minute block of data for each experiment providing between 900 and 1500 estimates of spectral response for each experiment.
These values were then used to compute the mean spectrum $\overline{S}_{is}$ for species s by taking the arithmetic mean of all the values for that frequency.

$$\overline{S}_{is} = \sum_{j=1}^{n} S_{jis} / n$$

In addition the standard deviation SD_{is} was calculated for each of the 8 frequency values as:

$$SD_{is} = \sqrt{\left(\sum_{j=1}^{n} (S_{jis} - \overline{S}_{is})^2 / (n-1) \right)}$$

The standard deviation SD_{is} was used to provide a weighting function, for the recognition procedure, W_{is} for frequency channel 'i', species 's'.

$$W_{is} = 1/SD_{is} \; / \sum_{i=1}^{8} (1/SD_{is})$$

Calculation of Identification rates

The data collected in 1986 were used to define mean spectra for the four fish species cod, saithe, herring and mackerel. In addition the same data was used to estimate recognition rates for the four species, these results were presented in [3] . In order to improve confidence in the recognition rates it was decided to use the same spectra as reference spectra and to use the data collected in 1988 as the test sample. The same recognition criteria presented in [3] were used again to estimate possible success rates. The estimated species, 1 of 4, for the j^{th} data block for species experiment S was:

$$\text{minimum}(s=1 \text{ to } 4) \sum_{i=1}^{8} ((S_{jis} - \overline{S}_{is}) * W_{is})$$

The data from 3 experiments on saithe, herring and mackerel carried out in 1988 were compared with the templates calculated from the four experiments in 1986 on cod, saithe, herring and mackerel

Species Mixtures

The final 3 experiments were carried out to examine the possibility of determining the species proportion from mixed aggregations of fish. In the first two experiments the species saithe and haddock were measured separately and in the final experiment some fish retained from the two earlier experiments were placed together in the cage. For data analysis, the spectrum resulting from the mixture was compared with the two spectra found during the two single species experiments.

RESULTS

Absolute Back-Scattering Strengths

The level of the absolute backscatter from the caged aggregations of fish followed the pattern observed for these species over the previous years, which are reported in [4] and [5]. The echo from the herring showed a strong diurnal cycle with a slow decline over the 4 day period thought to be due to gas absorption from the swimbladder. The echo level from the mackerel was highly variable with some reduction at night. All the gadoids exhibited a rise in backscattering strength over the first 1 to 2 days and a more settled echo later.

Recognition Rates

The recognition rates for the 3 species measured in 1988 compared with the spectra obtained in 1986 are shown in Table 2. These can be compared with Table 3 reprinted from [3] showing the recognition rates using the same data for both test and template.
Table 4 shows the proportions of haddock and saithe by weight, number, absolute backscattering strength and recognition procedure.

Table 2
Recognition rates using 1986 mean spectra and data from 1988

Species Recognised	Actual Species		
	herring	saithe	mackerel
herring	95.3	1.1	0.5
saithe	4.8	90.1	4.5
cod	0.0	8.7	1.3
mackerel	0.0	0.0	93.2

Table 3
Recognition rates reprinted from [3] showing rates using mean spectra and data from 1986

Species Recognised	Actual Species			
	herring	saithe	cod	mackerel
herring	96.2	4.1	0.1	0.5
saithe	3.8	91.8	10.5	2.1
cod	0.1	4.1	89.4	1.5
mackerel	0.0	0.0	0.0	95.9

Table 4
Species Mixture

Species	Fish No	Length	Total Wt. Kg	% by Wt.	% Back-Scatter	% Recognised
Saithe	7	29.8	1.46	42.8	54.6	61.8
Haddock	7	30.5	1.95	57.2	45.4	38.2

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DISCUSSION

The recognition rates shown in Table 2 support the conclusions of earlier work [3] that gadoids can be distinguished from herring and mackerel, in the case of large shoals with 95% confidence. The separation of gadoid species is more difficult. The results for herring and saithe are derived from data of good quality. The results for mackerel must be treated with care, although there is apparently a high degree of recognition, since the fish echoes are relatively weak, reverberation from the cage may affect the results to some extent.

The results shown in table 4 indicate some ability to determine species proportion from a known species mixture although their validity may be questioned because, unusually, some of the haddock died during the experiment. Data recorded after the fish had died were excluded, but it is likely that these fish were in a worse condition than usual while still alive. The results never the less, are encouraging.
It should however be noted that had the haddock/saithe species mixture been compared with the 5 available single species spectra, a significant proportion of its mean spectra would have been identified as herring. Thus some prior knowledge of the species likely to be present in a mixture would probably be required before attempting to assess the species composition.

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