An Extended Analysis of the Goddard and Welsby Results

by

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Introduction

The NERC fish target strength project, conducted at Easdale by Birmingham University was a particularly important attempt to obtain realistic values for the target strength of free swimming fish. Much of the previous work had been done with dead or anaesthetised fish (e.g.: Haslett 1969), or had used the maximum target strength rather than the mean (McCartney and Stubbs 1971), with the result that it was difficult to apply the data to real survey situations. Even in this case, the effect of confining the fish might have affected the results, but to date no better technique is available.

The experimental methods and the results obtained have already been presented (Goddard and Welsby, 1975) and there is no need to go into detail here. The main point to note is that each value of target strength for a fish was obtained from the mean amplitude of the echo from about 1000 pings, these means being converted to decibel form in order to calculate regression equations. Since the most useful information for population assessment by echo integration is the mean scattering cross section per fish, or the mean echo intensity, it was decided to reanalyse the original data in terms of mean squared echo amplitude to see if any appreciable corrections were necessary. The extended analysis has so far been limited to the results from the three gadoid species, cod, haddock and saithe, and only the dorsal aspect data have been used.

Work started in late summer 1975 with the aid of a sandwich student Mr.Peter Digby, who wrote the required computer programmes, and is still continuing. This paper should therefore be taken as a preliminary report only, although the results obtained so far are of considerable interest.

Data Processing

Each data point for analysis consists of a set of about 1000 values of echo amplitude for a given fish measured at one of the three frequencies

10, 30 or 100 kHz, these being 377, 114 and 24 data points for cod, haddock and saithe respectively. For the original analysis histograms of the amplitude data were prepared by computer, and after eliminating obviously spurious values the mean and standard deviation were found, and the mean converted to target strength in decibels. For the reanalysis the same technique was used, except that the amplitude values were squared before preparing the histograms and calculating the means. At the same time, for comparison purposes, each amplitude value was converted to decibels individually, and the mean of these was also found.

Results

a) Corrections to the regression equations

The original results from the Easdale data were expressed as equations relating target strength T to fish length L and acoustic wavelength λ (Welsby 1975) and these equations are reproduced for cod, haddock and saithe in dorsal aspect in Table 1, where L and λ are both in metres. The equations are based on a linear regression of 10 log (σ/λ^2) on 10 log (L/λ) where σ is the acoustic scattering cross section of the fish calculated from $T = 10 \log (\sigma/4\pi)$. The first step in the extended analysis was to recalculate T in terms of mean squared amplitude instead of mean amplitude. This will obviously result in an increase in the value of T by an amount depending on the distribution of the amplitudes, and the actual increases found are shown in Table 2 as a function of frequency, the mean increase being 1.31dB. For a Rayleigh distribution of amplitudes, the increase expected is 1.05dB, which is not very different.

The second step in the reanalysis was to check that the correct value of σ would be obtained on converting back from the decibel values of T. At first glance it appeared as though no correction would be required, since the mean target strength for each data point calculated from the decibel values of the individual amplitudes are very close, to within 0.5dB in most cases, to the value obtained from the mean squared amplitude. However, when the mean target strength of all fish was compared with the mean scattering cross section at each frequency, discrepancies were found amounting to 3dB in the case of cod and haddock. These results are shown in Table 3, and indicate that the distribution of scattering cross sections between fish is very different from the distribution of echo intensity for any one fish.

There are thus two major corrections to be made to the original regression equations in order to obtain reasonable estimates of integrated echo intensity. These corrections result in a new set of equations for target strength as a function of fish length and acoustic wavelength, and these are presented in Table 4. It will be seen that the corrections have little effect on the coefficients of log L and log λ, but the constant terms are altered appreciably.

b) Scattering cross sections per kilogram of fish

As a check on the validity of the revised equations, the scattering cross sections were calculated in terms of fish weight, which is a useful parameter for survey work. Since the fish were not weighed at the time of the experiment, the appropriate length/weight relationships had to be applied to give estimates of the weight. In Table 5, figures for the mean scattering cross section of each species per kilogram of fish are shown at (a) as calculated directly from the raw data, while for 30kHz the target strength calculated from the original and revised equations are shown at (b) and (c) respectively. The values at (b) and (c) are based on the mean length for each species and are converted to target strength for one kilogram for direct comparison. In each case, (c) is a much better approximation than (b), although for cod the discrepancy is still over 3dB. The main reason for this residual error appears to be that a linear approximation for the relationship between 10 log (σ/λ^2) and 10 log (L/λ) is not quite good enough, and for maximum accuracy an equation where the coefficients depend on L/λ might be necessary.

c) Target strength/fish length dependence at fixed frequency

The use of a linear regression of 10 log (σ/λ^2) on 10 log (L/λ) makes the implicit assumptions that $(\sigma/\lambda^2) = f\ (L/\lambda)$, and that over the range of L/λ considered this can be simplified to $(\sigma/\lambda^2) = a\ (L/\lambda)^b$ where a and b are constants. It appears from the previous section that this simplification is not strictly valid, and an attempt was made to confirm this by considering the data for each frequency separately. Since the data for cod were most numerous, linear regressions of T on log L were made for cod for each frequency separately, with the results shown in Table 6. Clearly, from the low values of the correlation coefficients r, these equations are not very significant, and fail to show the overall relationship obtained from the full set of data. The main conclusion to be drawn from these observations is that the length range of the fish used was too narrow, and the variability in scattering cross section too large to allow a meaningful relationship to be obtained at any one frequency.

Conclusions

The main conclusions to be drawn from this extended analysis of the NERC fish target strength data may be summarised as follows.

1. The original equations relating target strength to fish length and acoustic wavelength are not suitable for making quantitative fish stock assessments by echo integration. The revised equations give the best possible fit to the observed data if a linear relationship between log (σ/λ^2) and log (L/λ) is assumed, but errors of up to 3dB are still possible. These errors might be further reduced by introducing variable coefficients into the equations, but this has not so far been tried.

2. The fundamental relationship between target strength and fish length at any one acoustic frequency is not confirmed by the data, and relies on the extension of the L/λ range produced by frequency changes for its justification. This is not very satisfactory, and more work using a wider length range of fish would obviously be of great value.

Acknowledgments

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References

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COD	$T = 24.5 \log L - 4.5 \log \lambda - 34.7$ dB
HADDOCK	$T = 22.5 \log L - 2.5 \log \lambda - 34.2$ dB
SAITHE	$T = 25.1 \log L - 5.1 \log \lambda - 37.0$ dB

Table 1 The original regression equations

10 kHz	30 kHz	100 kHz
+0.94dB	+1.47dB	+1.53dB

Table 2 Correction factors for mean intensity

		10 kHz		30 kHz		100 kHz	
	Mean Length	(a)	(b)	(a)	(b)	(a)	(b)
COD	49.1cm	-39.0dB	-35.5dB	-32.1dB	-28.9dB	-33.9dB	-31.9dB
HADDOCK	36.4cm	-41.5dB	-38.8dB	-38.9dB	-35.7dB	-38.3dB	-36.09dB
SAITHE	40.1cm	-41.2dB	-40.3dB	-39.6dB	-38.4dB	-35.6dB	-34.8dB

Table 3 a) Mean of individual target strengths
b) Mean scattering cross section expressed as target strength.

COD	$T = 23.5 \log L - 3.5 \log \lambda - 29.4$ dB
HADDOCK	$T = 22.7 \log L - 2.7 \log \lambda - 30.4$ dB
SAITHE	$T = 25.6 \log L - 5.6 \log \lambda - 35.0$ dB

Table 4 Revised regression equations

	10 kHz	30 kHz			100 kHz
	(a)	(a)	(b)	(c)	(a)
COD	-36.5 dB	-29.9 dB	-37.6 dB	-33.3 dB	-32.8 dB
HADDOCK	-35.7 dB	-32.5 dB	-37.6 dB	-33.7 dB	-32.9 dB
SAITHE	-40.0 dB	-37.2 dB	-38.9 dB	-36.5 dB	-33.5 dB

Table 5
a) Mean scattering cross section per kilogram of fish expressed as target strength
b) Target strength for one kilogram of fish calculated from original equations using mean fish length.
c) Target strength for one kilogram of fish calculated from revised equations using mean fish length.

10 kHz	T = 10.6 log L - 35.7 dB	(r = 0.19)
30 kHz	T = 22.6 log L - 25.3 dB	(r = 0.34)
100 kHz	T = 4.8 log L - 32.4 dB	(r = 0.12)

Table 6 Regression equations for cod at fixed frequencies

DISCUSSION FOLLOWING THE PAPER BY MR.S.T.FORBES:

AN EXTENDED ANALYSIS OF THE GODDARD AND WELSBY RESULTS

DR.McCARTNEY: Did you check that for each one of the distribution points in the lower graph that a good approximation was obtained to a Rayleigh distribution on the 1000 points ? Goddard says that unless you get this you cannot use the set of data because the fish are not behaving.

S.T.FORBES: The data was used regardless of the behaviour of the fish in the experiment, which was unknown. So far, I have used all the data available and these are the results which appear.

DR.McCARTNEY: I do not think that one can talk about a Rayleigh distribution and then use data which does not have this characteristic.

DR.WELSBY: With target strength amplitude measurements insufficient constancy of statistical parameters was found to enable any empirical law to be formulated regarding the nature of amplitude distributions to the ratio L/λ. All that could be said was that for L/λ greater than 20 there was quite a good fit to Rayleigh for all species of fish and for all frequencies used. For L/λ less than 5 the Rayleigh model was quite inadequate. For values intermediate between 5 and 20 the fit to a Rayleigh curve was sometimes good and sometimes very bad.

S.T.FORBES: I am not trying to base any conclusions on Rayleigh distributions. The only point I wished to make about distributions was that, although for any one fish there was no significant difference between mean log intensity and log mean intensity, for several fish it is no use taking the mean target strength and working on that basis. It is necessary to use the mean scattering cross sections to get meaningful results.

MR.NAKKEN: I am interested in these results and wish to congratulate the people doing the work. A lot of data is presented on free swimming fish which has been needed for many years by the biologists. My questions are, firstly, at what level are the slopes in Table 1 significantly different 24.5, 22.5, 25.1. Secondly, is this Table what we would expect when we are out at sea using an echo sounder, that is, having the fish in dorsal aspect, and knowing something about fish behaviour and orientation. Thirdly, in Table 5 are all the values calculated for 50cm fish because if this is not so, there is no functional relationship between scattering cross sections/kg and length of fish.

S.T.FORBES: I do not think that the differences in slope are significant. If you look at Table 3 in detail you will see that target strength varies non-uniformly with frequency. For cod, for example, the 4.5 log λ relationship results from an increase of about 7dB from 10 to 30 kHz followed by a small decrease from 30 to 100 kHz, and as the coefficients of log L and log λ are interdependent, the slope of 24.5 log L is the mean of a similarly variable factor. Thus I think it can be said that the difference in slopes is not very significant.

DR.CUSHING: The question is, are the actual slopes significant at all ?

S.T.FORBES: They certainly are significant if you assume that there is a functional relationship between scattering cross section normalised by λ^2 and length normalised by λ. However, Table 6 shows that we cannot prove the relationship from results at any one frequency. To answer Mr.Nakken's second question, it is very difficult to say if these fish are behaving in the same way as they would do at sea. If they are, then it is the sort of thing you would expect to see from a ship.

DR.WELSBY: It is what you would expect to see from a ship if you were able to take 1000 pings from the ship on each fish. If you take one ping you can take any value you like.

DR.CUSHING: Would it be true to say that the mean is interesting but the variance is not ?

DR.McCARTNEY: No, the variance has a potential value.

MR.NAKKEN: Taking 1000 pings with an echo sounder from one fish should be approximately the same as taking one ping from each of 1000 fish.

S.T.FORBES: I am not sure that this is true. From the results of the present investigation, I think that although the means might be the same, the statistical distributions will be very different.

Finally, I must comment on Mr.Nakken's third query. The true value of target strength per kg was obtained by dividing the mean scattering cross section of all fish by the mean weight, and the use of a 50cm fish in the calculation from the equations is clearly not correct. However, the conclusion that the equations are not suitable as they stand is not affected, as the use of the mean length actucally increases the discrepancy. (For the final version of the paper the mean length was in fact used. Even this is not strictly correct as the length corresponding to the mean weight should have been used, but the difference is negligible.)

MR.SMAILES: One point which arises out of what you have just said. This is taking 1000 pings of one fish or one ping of 1000 fish. It was said earlier that more than one fish had been used in the experimental cage at one time. The question is whether or not the relationship between the number of fish and the target strength was linear, so that when the number of fish is doubled the target strength increases by 3dB.

DR.WELSBY: Yes it does. This was an encouraging sign. A phase of the Easdale work concerned multiple fish measurements. There was a small but statistically significant increase in the target strength of fish as the number of fish in a group is increased. This means that you would expect the target strength to go up by 3dB every time the number of fish was doubled but in fact it went up by 3 point something, where something is quite small but there is a statistical significance above the 3dB. Theorising, one could say that as you get more and more fish they will shadow each other, the ones behind will produce less signal and you would expect to get less than 3dB every time that you double the numbers - it might be due to multiple scattering inside the aggregation. As an arguing point of view considering the acoustics, there is another possibility. Has anyone thought that if a lot of fish are milling about close together they will produce air bubbles. A rough calculation shows that 1 ml of gas has a TS of -40dB so a 1 ml bubble could make a significant difference.

DR.HARDEN-JONES: These fish have closed swimbladders so they are not going to produce bubbles.