TRAWL AND ACOUSTIC ABUNDANCE COMPARISON

By

William Dickson
Institute of Fishery Technology Research
P.O.Box 1964, N-5024 Bergen, Norway

Bergen, October 1990

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND BACKGROUND

Both trawls and echointegrators have been used for stock surveys of cod and haddock, but there has been difficulty in relating or combining the abundance estimates made by the two methods. Though there are indirect methods of stock assessment, these two represent virtually the only two direct methods which can be used extensively. Since their results present different estimates of the same stock, their status cannot be considered satisfactory until the results can be brought into much closer agreement. In attempting to compare results, one is not the dependant and the other the independant variable; each is a different distorted image of an independant reality. This fact must influence how the comparison is handled.

The deficiencies of the two methods are well known, but briefly stated are:

Trawl: It samples a minute part of the ocean floor at each haul. Its efficiency (defined as, catch/encounters) and its effectiveness (defined as q = catch/(effort* local abundance)) are highly variable.

Even what it encounters may be affected by prior events like propellor noise of the towing vessel.

It gives a biassed fish length selection curve.

It gives a biassed species composition.

The bottom trawl samples only a small portion of the vertical availability profile, within 4 m of bottom for the sampling trawl considered here.

Acoustics: Its inability to measure what is in the deadzone, to which for operational reasons has to be added a zone dependant on the backstep , and these two zones added together are commonly where the fish is most dense.

The fact that in converting from integrator values to fish abundance, the conversion factor is still derived from the lengths of fish caught by trawl, i.e. the method is not wholly independant.

The integrator tells nothing of species composition, and echogram interpretion is only qualitative.

Uncertainties about the equivalent beam angle ψ.

Propellor noise may have already affected fish distribution in the vessel's path.

The value of 25 m for the effective spread of the Norwegian sampling trawl is used in calculations of local fish abundance. Being slightly more than the wing end spread and a little less than half the otterboard spread, this is a plausible value, but it is desired to have more certainty about it. Any such value is an attempt at stating the absolute efficiency of the trawl; it is not a relative value. Also, any such single value could only be true for a particular size range, most likely the middling size of cod and haddock most abundant in the trawl catches. Even if such a value could be correctly established for every trawl haul, its range would be vary considerably. It is desireable from both a research and a commercial point of view to know more about the range of effective spread occuring and what causes the changes. Furthermore, any single value could not be true for all sizes of fish, it being known that the bobbin rig of the sampling gear very considerably undersamples the small fish. The rockhopper rig, though substantially better, is far from completely efficient for small fish. Comparing the length frequency compositions, or even the relative catch rates at each length, remains relative, there is no anchor point to any absolute value which would enable the real length frequency curve of the fish down there to be determined. The point has been put by some investigators that what they want from a sampling trawl is a level response curve, that is they do not much care whether the trawl is 70% efficient or only 20% (for argument 100% being when the effective spread equals the otterboard spread), as long as it stays the same for all size groups. Apart from being an all but impossible demand, proving that it stays constant at some level is hardly different from establishing what the level is.

A more realistic approach would appear to be, to accept that there will remain some bias, to compare catch rates and length frequency curves for old and improved gear, to try to obtain some absolute values as anchor points for the relative curves and then to use both curves to estimate the true length frequency distribution. The prediction from either curve ought then to give the same estimate of true length frequency distribution, the estimates of effective spreads at each length group being incidental to the process. That effective spreads probably change by day and night, from season to season, year to year, place to place, and depth to depth, makes the task no easier, but the same can be said for any other approach.

An new facility providing integration within several narrow channels locked to bottom seemed to provide at least the possibility of establishing a relationship between trawl catches and echo abundance. The questions seemed important enough to justify the effort. The effort had none the less to be restricted to what could be done without disturbing the course of trawl and echosounder surveys and mini surveys that were taking place in any case.

The study was part of a general programme concerning the real effectiveness and efficiency of fishing gears. It later merged into a programme concerned with improving the sampling efficiency of the trawl used in cod and haddock survey. This meant measuring how the sampling efficiency was improved relatively and trying to fit this onto same anchor points.

This is the first of two reports on the subject. The second concerns treating the comparative fishing results.

2.0 EQUIPMENT

2.1 Trawl Gear

Details of the survey trawl and its rigging are given in Figures 1 and 2. It is really a shrimp trawl with smallish meshes in the forward parts, as well as in the after, this being considered to preclude or discourage the escape of small fish through the meshes of the trawl. When rigged with bobbins, it has an otterboard spread of some 60 m, wing spread of about 19 m, and a head line height of about 4 m. When rigged with the heavy rockhopper groundrope, which farther precludes the escape of small fish, its spreads are marginally less. A sweep length of 40 m plus 10 m backstrops is an acceptable compromise between, not catching enough fish for survey purposes (shorter sweeps) and biassing the catch toward bigger fish (longer sweeps). Some bias nevertheless does remain.

2.2 Acoustic Equipment

The acoustic equipment on "G.O. Sars" and "Eldjarn" was the 38 KHz Simrad EK400 linked to a Nord 10 computer as described by Blindheim et al. (1982). Instrument settings and calibration was as normal for research cruises and under the control of the acoustic engineers. In the 1987 cruises "G.O. Sars" and "Eldjarn" used 8° full angle ceramic transducers. By the February 1988 cruise "G.O. Sars" had reverted to the narrow beam magnetostriction transducer. On "Michael Sars" an EK-S/38 kHz echosoundera 8° full angle ceramic transducer was in use.

The display of the bottom locked channels was all on the video screen. Somewhat sketchily the output display is shown in Figure 3. The pelagic channels (locked to surface) and only two of the bottom locked channels are on the printout. A description of the latter follows. The spacing of the bottom locked channels can be altered, but that shown in Figure 3 is typical of what was used for comparison with a bottom trawl of 4 m headline height. The bottom 0-2 m is treated in two ways. The BAR channel is a computerised version of the old QM method, to which a chosen backstep is applied. In order to avoid, as much as possible, the ground echo from breaking through into the bottom channel, a backstep of say 1 m is used so that echoes within 1 m of bottom would then not be integrated. Shallower water, better weather, and smoother bottom, may make it possible to use a smaller backstep. Mostly backsteps of 1 m or 0.5 m were used, occasionally 1.5 and 0.375 m. The other 0-2 m bottom locked channel is the BCH channel. Both are illustrated in Figure 4a, b, c, d. Nominal bottom is set to be when the bottom echo voltage rises to a point half way between the Threshold and the Discriminator values. In the BAR method the backstep is set from the nominal bottom. The BCH channel starts integrating from the point at which the echo first sinks below the Threshold. Thus it only integrates echoes which are clearly distinct from the bottom echo. A fuller description was prepared by Ona (1988). Some of the effects will be discussed in the next section.

3. METHODS

The acoustic data are collected during a trawl station as in Table 1. The table mostly comprises area back scattering values for each nautical mile in units m^2/nm^2. The bottom line BAR gives a total M value for the 1.5 nm trawled as (82.6 - 80) + 9 + 5 = 14.6, which is then divided by 1.5 and multiplied by the Dead zone + 1 m backstep correction, 2.28 for 349 m depth, to give 22.2 m^2/nm^2 as the representatives backscattering cross sectional area per $(nm)^2$ for the bottom 0-2 m for that tow. Up to headline height of 4 m 5.9 is added in to give 28.1 m^2/nm^2, and similarly 60.9 m^2/nm^2 up to 14 m above bottom. Clearly in a 0-2 m channel with 1 m backstep plus dead zone the correction factor is going to be greater than 2.

3.1 Dead Zone + Backstep Correction

The correction can be derived from range shell principles, see Mitson (1982) and Figure 5. The correction factor to the nearest to bottom channel is

$$K_F = (\textit{volume integrated} + \textit{dead zone volume} + \textit{backstep volume})/(\textit{volume integrated})$$

On the advice of the acoustic engineers, the dead zone is not calculated on the -3dB half beam angle, but on a slightly wider angle. For the 8° x 8° (full beam) ceramic transducer, this is taken as 5°, and 3.1° for the 5° x 5.5° magnetostriction transducer.

3.2 Using Next to Bottom Channel as Back Up

As indicated in Figure 4c, the bottom BAR (QD) channel can quite frequently give misleading values due to breakthrough of the bottom echo. The 2-4 m channel may then be considered as a bottom channel of 0-4 m with a backstep of 2 m + dead zone, and used as a back up. this is how in Table 1 the K_F of 2.15 is used on the 5.9 to derive the back up value of 12.7 m^2/nm. This back up value can be used after a relationship has been established from the values which appear good in both channels. The following relationships were established on the Nysleppen ground in February 1988, when both "G.O. Sars" and "Michael Sars" were working together:

For the 5° x 5.5° transducer:

$$QD \cdot KF_1 + M_{(2\text{-}4)} = 2.56 \cdot M_{(2\text{-}4)} \cdot KF_2 - 1.38\ m^2/(nm)^2$$

$$R = 0.96$$

and for the 8° x 8° transducer:

$$QD \cdot KF_1 + M_{(2\text{-}4)} = 2.76 \cdot M_{(2\text{-}4)} \cdot KF_2 + 9.85\ m^2/(nm)^2$$

$$R = 0.89$$

Such relationships may be expected to change from place to place and time to time with changes in near bottom vertical distribution. It was never found that the back up abundance value derived from the 2-4 m channel was higher than the QD (0-2 m) derived value. This clearly shows the method must be to use a small interval QD channel when comparing trawl and acoustic abundance, and shows how close to the ground many of the fish often are. One can, however, think of vertical distributions where the back up value would be higher than the QD derived value.

3.3 Choice of Bottom Channel BAR (QD) or BCH

Only occassionally did the BCH channel give a greater value than the QD value, and usually it gave very considerably less. So much less acoustic abundance than trawl abundance that it is all but impossible to consider how the trawl could have been all that efficient, meaning that if the BCH derived abundance were correct, then the effective trawl spread would have been considerably more than the otterboard spread. Also no meaningful relationship emerged between the BAR (QD) channel values and the BCH values, presumably because of the quite variable (ping to ping) height above nominal bottom at which the BCH channel begins to integrate. The BCH channel is presumably designed to start integrating in the way that it does (Fig. 4) in order to avoid corruption of the wanted fish echo by the unwanted bottom echo. As currently operating it seems very largely to throw out the baby together with the bath water, but that does not necessarily mean it cannot be re-programmed to give a more effective output. For the above reasons the method was to use the BCH channel only as a qualitative check on the credibility of the values in the BAR (QD) channel.

3.4 Derivation of trawl and acoustic abundance

Trawling and acoustic abundance estimates are not wholly independant viz:

Integration value ⟶ ↓

Catch->Length RMS->Target strength->Conversion factor->Acoustic abundance, fish/(0.1 nm)²

↳ *trawl abundance, fish/(0,1 nm)²*

Formally, it is more correct to convert trawl catch to acoustic values as pointed out by Engås, Jacobsen and Soldal (1988), thus:

Integrator values m²/(nm)²

Catch -> Length RMS -> Target strength -> Conversion factor -> m²/(nm)²

↳ *Trawl abundance* ⟶ ↑

In practical terms the results of the comparison are just the same and the meaning of abundance is more easily grasped.

The target strength used to establish conversion factor has been

$TS = 21.8 \log L_{RMS} - 74.96$ and $CF = (10^{-TS/10})/4\pi$.

The trawl/acoustic abundance comparisons are made for cod, haddock and sometimes saithe lumped together. The other fish often present in significant numbers were one and sometimes two species of *sebastes*. As in Table 1 for instance the integrator value within the trawl gape came to 28.1 $m^2/(nm)^2$ and from the catch the conversion factor for cod, haddock and *sebastes* came respectively to 550, 779 and 2754, while the numbers caught were respectively 136, 938 and 1441, then the cod and haddock abundance is estimated to be:

$$Cod = 28.1 \{(136/550)/(136/550 + 938/779 + 1441/2754)\} 550 = 1900/nm^2$$

and similarly for haddock 13400/nm^2, giving total gadoid abundance $P_{A(0-4)} = 153/(0.1\ nm)^2$. This is as entered in Table 1.

That is to say the integrator value is divided according to species and dependant on the number of that species present and its backscattering cross section derived from the root mean square length L_{RMS}.

The bottom trawl abundance estimate within the headline gape is made on an initial assumption of 25 m effective spread, the distance towed, and the catch numbers. So for 1074 cod and haddock and a 1.5 nm tow, the trawl abundance is entered in Table 1 as $P_T = 530/(0.1\ nm)^2$.

3.5 Correction for solid angle ψ, the equivalent beam angle

When no correction was made for change in equivalent beam angle in deep water, the average trawl effective spread so derived came out greater than otterboard spread, which seemed improbable. Ona (1987) pointed out that to better estimate abundance in any layer, account has to be taken of the change of solid angle ψ in the acoustic beam pattern with depth. This present report uses his to correct the near bottom acoustic abundance estimates for beam pattern. For the 8° x 8° (full angle) ceramic transducers which were used on R/V "G.O. Sars" and R/V "Eldjarn" with $\psi = (8° \times 8°)/5800$, a nominal value of $10\log\psi = -19.6$ dB, the correction used in depths greater than 225 m was $(\psi nominal/\psi actual) = 1.8$ depth/225 -0.8. No correction was used in depths less than 225 m.

If this excercise were to be repeated, a smooth correction curve rather than 2 straight lines could be fitted through Ona's plus any new data. This can be done by fitting the reciprocal of suitable (Foote 1988) ψ_r/ψ_o curves, which are also fairly flat at low range.

Lacking any experimental data on which to base corrections for "G.O. Sars" narrow beam magneto striction transducer, and for "Michael Sars" with a different transmitter system, no corrections were made for these cases.

3.6 Comparing trawl and acoustic abundance

Since neither is the dependant variable, it is not proper to use regressions. Instead a method proposed by Gullard (1987) is used. This was originally devised for comparative fishing trials, but may just as well be used here when P_T/P_A can be 0.5 for one haul and 2.0 the next. Each is given the same weight by taking logarithms of the ratios each haul. The variance and confidence limits are calculated from the logarithms. The final results is, however, $\Sigma P_T/\Sigma P_A$ with 95% confidence limits back calculated from the logarithmic confidence limits. A short example of the process is given in Table 2. The method is also useful in that the course of a comparison can be monitored during the experiments to show how the average value is settling down, and whether or how the confidence limits are narrowing.

3.7 A Possible Test for Diving

When some of these results were first presented to an ICES Working Group Meeting in Oostende in April 1988, there was some criticism that the possible effects of fish diving had not been fully considered. The possibility of ploughing effect was also raised, and although this is even harder to deal with it will at least be discussed later. What may be deduced from indirect methods related to trawl/acoustic abundance comparisons can hardly be as convincing as direct demonstration, but seemed none the less worth a try.

Consider Figure 6. In principle hauls may be divided into cases where there are no echoes appearing above headline height as it appears on the echosounder, and cases where there is a substantial amount recorded above headline height. The practical difficulties will be considered under treatment and discussion of results. In ideal conditions case (2) = case (4), so that comparing case (1) v. (2) and (3) v. (4) is just the same as comparing (1) v. (4) and (2) v. (3). Comparing (1) with (3) is not comparing two cases, but only integrating up to two different levels on the same group of hauls, and it does not lead to any useful comparison.

The tests (1) v. (2) and (3) v. (4) may be tried by day and night, in shallow water (taken as < 250 m) and deep water, then tested for significant difference by a one tailed Student t test, one tailed since it is taken that movement can only be downward.

3.8 Gear Influence on Conversion Factor

The method of calculating the conversion factor from the RMS length of the fish has already been described. When on a wide ranging survey there is little choice but to deal with RMS lengths and calculate the conversion factor haul by haul. It was early noticed that when using the rockhopper gear in the same place as the bobbin gear, the conversion factor could be as much as 15% higher for the RMS lengths derived from the rockhopper gear with its greater percentage of smaller cod and haddock. The conversion factor derived from the rockhopper gear will be the truer, though the real one would be higher still. If work continued in an area for several hauls, the conversion factor could be derived from all hauls rather than haul by haul, or it could be derived separately for day hauls and night hauls. The effects of not differentiating between day and night conversion factors will be demonstrated in sections 5.5 and 5.6.1.

4. RESULTS

Results are taken from 5 cruises by 3 ships: "Eldjarn" October 1986 and September/October 1987, "G.O. Sars" February 1987 and February 1988 (in same area as "Michael Sars"), and "Michael Sars" February 1988.

Much of the time was spent on general wide ranging survey, but 3 mini surveys where the vessels stayed in one place did take place; firstly "Eldjarn" October 1988, using rockhopper gear and fishing together with the commercial vessel "Anny Kræmer", secondly later in the same cruise "Eldjarn" herself fishing on good quantities of mainly haddock and interestingly, because less common, when the night fishing was heavier, thirdly "G.O. Sars", "Michael Sars" and the commercial vessel "T.O. Senior" together in February 1988. Mini surveys are most useful because there is long enough in an area to get a feel of what is happening there, and usually the area is picked for reasonably good fishing, both factors which lead to fewer reject comparisons.

The summarised results are collected in Tables 3, 4 and 5. In Table 3, "Eldjarn"'s autumn 1987 cruise, the data are grouped into deep and shallow water rather than being wholly in serial order. Recall that each line of Tables 3, 4 and 5 arises from a table such as Table 1.

4.1 Rejection of Poor Data

Situations with high integrator values and little catch are easily imagined, ground echo breakthrough (quite frequent) being the most likely. Sometimes ground breakthrough is obvious from watching the display, sometimes not so obvious. With cod and haddock near the bottom, total avoidance is unlikely. If there is nothing much indicated above headline height, low acoustic values can hardly justify effective trawl spreads well beyond the otterboard spread, much more likely is that the dead zone estimate is too low, because fish is too close to bottom. The other near bottom channels can give a clue to whether the QD channel readings are reliable, the "back up" from the (2-4 m) channel, and maybe the BCH channel. At relatively low abundance an echo count from the echogram may also be instructive.

The size and nature of the catch influences the decision of what comparisons to accept and what to reject. On a wide ranging survey with a considerable distance between trawl stations to catch only a handful of fish at a station, gives little confidence in what is being integrated, and a poor idea of what to use for a conversion factor. Occasionally, the mean length of the catch was so low that there was little likelihood of the numbers caught representing the abundance the trawl encountered, particularly with the bobbin gear. On the other hand, if trawl abundance and acoustic abundance are both low, and the echograms show little evidence of fish, accepting the comparison is not going to affect $\Sigma P_T/\Sigma P_A$ very much, and that it probably makes the variance worse is acceptable in that one would hardly expect good agreement at very low abundance, a point made by Ehrenberg and Lytle (1977).

The variance in the comparisons is obviously high even from a quick look at Tables 3, 4 and 5. Nothing is to be gained by including comparisons known or judged to be faulty. The reasons for rejection are outlined above and given again as notes and footnotes in the results tables.

5.0 EVALUATION OF RESULTS

5.1 Cases with nothing much above Headline Height

The most direct way to eliminate possible diving effect is firstly to consider only the cases where there is nothing or nothing much above the net to be driven down. Hauls "G.O. Sars" February 1987 No. 101, 106, 125, 128, "Eldjarn" September/October 1987 Nos. 593, 623, 627, 646, 592, 595, 597, 598, 599, 601, 602, 647, 649, and "Michael Sars" February 1988 Nos. 79, 93, are extracted from Table 3 to fulfill this condition. Comparing $P_T/P_{A(0\text{-}4)}$ gives a value 1.07 in the range from 0.76 to 1.51. This, if the acoustic values are accepted as correct, gives an effective spread of 27 m within the range of 19 to 38 m for the survey net with bobbin rigged groundrope.

Comparing $P_T/P_{A(0\text{-}14)}$ for the same hauls, and considering that the few fish above the net are driven down, gives equivalent values of 0.94 m in the range 0.69 to 1.28, not a very different range. At least one can say that an assumed average effective spread of 25 m is in reasonable agreement with acoustic abundance as derived using $T_S = 21.8 \text{ Log } L_{RMS} - 74.96$.

<u>5.1.1 Day v. night:</u>

These same data comprised 9 day and 10 night hauls. The day hauls give a mean $P_T/P_{A(0\text{-}4)}$ of 1.24, and the night hauls $P_T/P_{A(0\text{-}4)}$ a mean of 0.95. Pooling the variances and making a 2 tail t test does not show any significant differences between these day and night values. A 2 tailed test is used because day and night differences may move either way. The day and night difference may be just chance, or it could be due to increased gear efficiency by day if nothing is driven down, and/or due to some driving down by day. Alternatively, there could be more hidden in the dead zone by day, giving a low acoustic abundance estimate. The increased abundance $P_{A(0\text{-}14)}/P_{A(0\text{-}4)}$ is 1.14 by day and the same by night for these comparisons, so that in this case the last mentioned alternative looks unlikely. There are the difficulties that hauls where nothing is seen above headline height are too few, if hauls with a little above headline height are included, the effect of this may not be negligeable, and that the places and times are various so that gear efficiency can change anyway.

5.2 Considering all the Day and Night Comparisons in Table 3

A plot of the abundance values for the bobbin gear P_T v. $P_{A(0\text{-}4)}$ is given in Figure 7, this is plotted in logarithmic values since abundances range from below $10/(0.1\ nm)^2$ to around 2000. The 16 day plots comparison gives 1.80 in the range 1.21 to 2.67 with correlation coefficient R = 0.74. The correlation is based on the actual abundance values, not their logarithms. The 20 night plots comparison is 0.95 in the range 0.69 to 1.29. The night abundance comparison is lower, but the correlation at R = 0.96 is considerably better. A Student 2 tailed t test shows the difference to be quite significant (better than 2%).

Similarly, a plot of P_T v. $P_{A(0\text{-}14)}$ shown in Figure 8, gives a day comparison of 1.24 in the range 0.89 to 1.72, and a night comparison of 0.65 in the range 0.48 to 0.88. The correlation coefficient are day R = 0.95, night R = 0.94. Again, the difference between day and night is quite significant (better than 1%).

The correlation for P_T v. $P_{A(0\text{-}4)}$ by day is much the most ragged. At the same time $P_T/P_{A(0\text{-}4)}$ is giving a higher value than $P_T/P_{A(0\text{-}4)}$by night when the correlation is better. It can be argued that a major source of variance will be in the assessment of what is in the deadzone + backstep, and that this can well occur when fishing is best. Note how in Figure 7 the day plots of $P_T/P_{A(0\text{-}4)}$ are ragged at the top end, as well as the bottom end where raggedness may be expected anyway. Also if dead zone estimate is a source of variance, it will give less variance if the integration is made to a greater height, being a smaller proportion of the total.

If this is a major reason for the poor day, correlation of $P_T/P_{A(0-4)(day)}$, it appears to be less serious at night, because then the $P_T/P_{A(0-4)(night)}$ correlation is quite good.

Much of the best fishing took place predominantly on haddock at about 1 kg each. With fair to good fishing being at 1 tonne per hour and upwards, this corresponds on a swept area basis (25 m effective spread) to an abundance of about 250 fish/$(0.1 \text{ nm})^2$. Looking at Figures 7 and 8, and with the exception of the $P_T/P_{A(0-4)(day)}$ plot, the correlations look rather better from about 250 upwards. Incidentally, with a half hour tow at 3 knots, the trawl abundance so calculated is very close to half the catch, which is useful when considering Tables 3, 4 and 5.

Note that the $P_T/P_{A(0-4)(night)} = 0.95$ for all 20 hauls, whether there is fish to be seen above or not, is exactly the same value as that already obtained for the 10 hauls (included in the 20) where there was little or nothing seen above. This leads to comparing the 10 night hauls with much seen above $P_T/P_{A(0-4)(night)(much\ above)} = 0.94$ in range 0.68 to 1.31 with $P_T/P_{A(0-4)(night)(little\ above)} = 0.95$ in range 0.54 to 1.66. All but one of the night hauls with much above was in deep water. This does not prove that in deep water (over 250 m) there is no diving effect, but it points that way. The hauls were made in various places so that it is possible that diving effect at night could have taken place (increased availability to the trawl) and been compensated by a reduced trawl efficiency. If required to make the best current estimate of night trawl gear efficiency as a base line or anchor point, and with the reservation made in the previous sentence, this can be obtained based upon the 10 night hauls with little above and the 9 hauls in deep water with much above, to give $P_T/P_{A(0-4)(night)}$ 0.93 in range 0.68 to 1.27. Thus the average value is hardly changed from the hauls with little above, but the limits are improved on compared with the case with the 10 night hauls with little above.

The day comparisons tell a different story. $P_T/P_{A(0-4)(day)}$ for all hauls was 1.8, for hauls with little above it was 1.24. That the gear effectiveness has increased by day is hardly in doubt (day v. night comparison significant). Whether the increased effectiveness is due to increased gear efficiency, or due to increased availability due to diving effect, or due to both, remains unknown. It is suspected that the efficiency part is slightly less than 1.24, and that the balance up to 1.8 is due to availability. That the difference might be due to reduced acoustic efficiency by day is rather belied by the following. For all hauls, $(P_{A(0-14)(day)}/P_{A(0-4)(day)} = 1.45$, and for hauls with little above, $P_{A(0-14)(day)}/P_{A(0-4)(day)} = 1.13$. Any reduced acoustic estimate (low dead zone estimate) with little above would tend to raise $P_T/P_{A(0-4)(day)}$, and thus tend to mask the difference between the all huals case and the little above case.

5.3 Comparing Cases where the Echosounder Shows a Considerable Amount above Headline Height and where it does not

It would be better if these comparisons could be divided into deep and shallow water in trying to find if there is diving effect, but there are not enough data for this. It is taken that when there is little seen on the echosounder above headline height, the scope for any farther diving effect is small, so that it does not much matter whether the water is deep or shallow.

Using the method described in Figure 6, data are as follows:

Day	Case (1)	P_T	72, 503, 304, 19, 380, 1348, 334
	Much	$P_{A(0-14)}$	62, 375, 273, 141, 332, 794, 264
	above		$\log(\Sigma P_T/\Sigma P_{A(0-14)}) = 0.121 \pm 0.2826$
	Case (2)	P_T	610, 269, 67, 19, 118, 3, 7, 81, 210
	Little	$P_{A(0-14)}$	62, 375, 273, 141, 332, 794, 264
	above		$\log(\Sigma P_T/\Sigma P_{A(0-14)}) = 0.039 \pm 0.1409$

<u>Comparing (1) and (2)</u>

The difference is non-significant.

Case (3)	P_T	72, 503, 304, 19, 380, 1348, 334
Much	$P_{A(0-4)}$	583, 273, 80, 24, 53, 4, 8, 149, 91
above		$\log(\Sigma P_T/\Sigma P_{A(0-4)}) = 0.360 \pm 0.3393$
Case (4)	P_T	610, 269, 67, 19, 118, 3, 7, 81, 210
Little	$P_{A(0-4)}$	515, 224, 80, 23, 394, 7, 149, 78
above		$\log(\Sigma P_T/\Sigma P_{A(0-4)}) = 0.092 \pm 0.1662$

Comparing (3) and (4):

The difference is non-significant, but it is nearly so

$$t(0.10)(1)(14) < t = 1.524 < t(0.5)(1)(14)$$

That this is so is mainly due to 1 big haul.

Summarizing:

	DAY	
	Much above	**Little above**
$P_T/P_{A(0\text{-}14)}$	Case (1) 1.321	Case (2) 1.094
	$P_{A(0\text{-}14)}/P_{A(0\text{-}4)} = 1.73$	$P_{A(0\text{-}14)}/P_{A(0\text{-}4)} = 1.13$
$P_T/P_{A(0\text{-}4)}$	Case (3) 2.291	Case (4) 1.237

The only reason for (1) > (2) are chance (1 big haul) due to better gear efficiency on the grounds with much above. A too low dead zone estimate would be more likely to raise cases (2) and (4) than (1) and (3). If nothing is driven down, then (1) < (2), unless gear efficiency is better on grounds with little above.

Since there is no significant difference between (1) v. (2), and since the difference is in the wrong direction, it cannot be ruled out that much is driven down. There are 4 deep and 3 shallow hauls with much above.

If nothing is driven down, then (3) = (4) other than by chance or changes in gear efficiency. With (3) > (4), though this might be by chance due to one big haul and might be because gear efficiency happened to be better on the grounds with much above. The difference is non-significant, but one could not be at all confident in ruling out the possibility that fish are driven down.

Dividing hauls into deep and shallow water can even less lead to significant differences in the comparison, but can be instructive when summarized:

	SHALLOW Much above		SHALLOW Little above		DEEP Much above		DEEP Little above	
$P_T/P_{A(0-14)}$	(1) 0.88		(2) 0.96		(1) 1.46		(2) 1.13	
$P_{A(0-14)}/P_{A(0-4)}$		1.38		1.07		1.88		1.14
$P_T/P_{A(0-4)}$	(3) 1.21		(4) 1.03		(3) 2.74		(4) 1.29	

None of this leads to any feeling of certainty that fish is not being driven down by day. There is also no convincing demonstration that it is driven down, but it looks possible.

For the night hauls, all those with much to drive down were in deep water.

Night	Case (1) Much above	P_T	333, 317,393, 303, 2242, 1152, 610, 229, 173
		$P_{A(0-14)}$	328, 469, 994, 347, 2707, 2084, 1418, 794, 425
			$\log(\Sigma P_T/\Sigma P_{A(0-14)}) = -0.221 \pm 0.1242$
	Case (2) Little above	P_T	458, 338, 3, 57, 220, 13, 100, 198, 5, 26, 183
		$P_{A(0-14)}$	661, 351, 9, 157, 106, 61, 46, 128, 4, 14, 281
			$\log(\Sigma P_T/P_{A(0-14)}) = -0.055 \pm 0.2101$

<u>Comparing case (1) and (2)</u>:

The difference is not significant:

$$t(0.25)(1)(18) < t = 1.325 < t(0.10)(1)(18)$$

Case (3) Much above	P_T	333, 317, 393, 303, 2242, 1152, 610, 229, 173
	$P_{A(0-4)}$	234, 302, 686, 259, 1919, 1160, 817, 578, 265
		$\log(\Sigma P_T/P_{A(0-4)}) = -0.034 \pm 0.1195$
Case (4) Little above	P_T	458, 338, 3, 57, 220, 13, 100, 198, 5, 26, 183
	$T_{A(0-4)}$	578, 304, 8, 156, 81, 61, 46, 81, 4, 11, 233
		$\log(\Sigma P_T/P_{A(0-4)}) = 0.010 \pm 0.2295$

<u>Comparing case (3) and (4)</u>:

The difference in non-significant.

Summarizing:

	NIGHT	
	Much above	**Little above**
$P_T/P_{A(0-14)}$	Case (1) 0.601	Case (2) 0.881
	$P_{A(0-14)}/P_{A(0-4)} = 1.54$	$P_{A(0-14)}/P_{A(0-4)} = 1.16$
$P_T/P_{A(0-4)}$	Case (3) 0.925	Case (4) 1.024

Although (1) is not significantly less than (2), it is in the direction that indicates nothing much being driven down. Also (3) would have to be significantly greater than (4) to indicate diving effect. Generally, while not completely ruling out the possibility of diving effect at night, it does not look likely.

5.4 Frequency Distribution of Trawl and Acoustic Abundance

Frequency distributions present in another way data that has already been plotted as $\log P_T$ v. $\log P_A$, but they do emphasise rather different things. The frequency distribution of trawl and acoustic abundances, by day, by night, and combined, are shown in Figure 9. The hauls listed in Table 3 cover a wide range of fishing conditions and depths. At one end there were some trawl stations on survey where very few fish were present, at the other end were periods during mini-survey and comparative fishing when catches were good. Generally, the trawl abundance distribution appears as shifted to the right compared with acoustic abundance, rather more so by day than by night. That they have the same general shape is encouraging. The trawl curve can of course be moved left or right by basing the effective spread on a value other than 25 m. Similarly, the acoustic curve can be moved left or right by assuming a conversion factor based on other than $TS = 21.8 \log L_{RMS} - 74.96$.

The ratio of trawl/acoustic abundance comparisons is also given a frequency distribution by day, night, and combined, as seen in Figure 10. The percentage of values $P_T/P_{A(0-4)}$ coming within the simple ratio 1.6:1 either way is 47%, and within the ratio 2.5:1 either way is 72%. That is percentage of comparisons considered as valid. If the chances of getting reasonable agreement between trawl and acoustic abundance at a single trawl station are no better than an even break, this must surely hold some message for survey procedures. The shift farther to the right of the $P_T/P_{A(0-4)}$ frequency curve by day, as before demonstrates either an increase in trawl effectiveness whether better efficiency or better availability, or else a corresponding under estimate of acoustic abundance by day.

5.5 Comparisons for "G.O. Sars" Bobbin Trawl (poorly spread), February 1988

All comparisons are in deep water in the Nysleppen area, and all indicated plenty of fish (mostly haddock), a considerable proportion of it above headline height, as seen on the echosounder.

The plots of $\log P_T$ v. $\log P_{A(0-4)}$ for day and night, taken from Table 4, can be seen in Figure 11. The day plot is not correlated, R = 0.026 based on the abundances (not their logarithms). This is worse than the rather poor day correlation already found in Figure 7. The night correlation is R = 0.93.

Average $P_T/P_{A(0-4)}$ is 1.35 in the range 0.72 to 2.51 by day
$P_T/P_{A(0-4)}$ is 0.72 in the range 0.58 to 0.89 by night
$P_T/P_{A(0-4)}$ is 0.89 in the range 0.67 to 1.19 combined

The combined (day and night) value 0.89, when compared with the combined value of 1.15 from Table 3 (all comparisons), reflects though not accurately the rather poor fishing performance of "G.O. Sars" on this occassion with the faultily rigged otterboards. The catch rate ratio "G.O. Sars" when compared with "Michael Sars" and "T.O. Senior" using the bobbin gear, was about 60%. In spite of the poor confidence limits for the day comparisons, there is a significant difference between the day and night comparisons.

$$t(0,05(2)(19) < t = 2.27 < t(0.02)(2)(19)$$

As before, it is uncertain whether this increase by day is due to better day gear efficiency, increased availability with diving effect, or even reduced acoustic abundance. Since there were no cases with nothing much seen above headline height, the question cannot be taken farther. The day comparisons are much more ragged.

Here there is a possibility to check how far day and night differences in $P_T/P_{A(0-4)}$ might be due to differences in day and night acoustic conversion factor, there being on this mini-survey enough day and night hauls in one area to check this. Dealing only with hauls in depths around 360 m, day hauls 96, 97, 103, 110 and 111 and night hauls 98, 99, 100, 105, 106, 107, 108 and 109 gave:

	Mean P_T	Cod/haddock ratio	CF cod	CF haddock	$P_T/P_{A(0-4)}$	$P_T/P_{A(0-4)}$*
DAY	358	1/4.8 numbers	523	750	1.91	1.85
NIGHT	347	1/6.5 numbers	582	803	0.73	0.75

The * refers to the values of $P_T/P_{A(0-4)}$ if combined day and night values CF cod 550 and CF haddock 779 are used. Thus, in this instance, the effect of not differentiating between night and day acoustic conversion factors is slight, masking a little, but not hiding a big difference in the day and night ratio of $P_T/P_{A(0-4)}$ due to the other reasons discussed.

The correlations $P_T/P_{A(0-22)}$ are R = 0.24 day also bad and R = 0.98 night. The night correlation $P_T/P_{A(0-22)}$ is a little better than the night correlation $P_T/P_{A(0-4)}$. A visual presentation of this is given in Figure 12 with its plotted comparisons of $P_T/P_{A(0-22)}$.

5.6 Comparisons for Rockhopper Gear

5.6.1 Some different results

At first, when combined day and night values for $\Sigma P_T/\Sigma P_A$ were computed for the rockhopper gear, the overall results was reasonably enough in line with what was expected from the comparative fishing results, but, comparing the day and night effect, seemed to lead to quite surprisingly opposite effects from the bobbin gear. The reasons became apparent when Figure 13 was plotted and sorted out into the different surveys and mini surveys. The simple lesson is: do not start by shovelling data into the number crusher. Figure 13, taken from Table 5, shows a strong concentration of night comparisons far to the left of the 1:1 line, and this predominantly comes from the "Eldjarn" October 1986 cruise both on the wider survey and the mini cruise, when night fishing was particularly good, and also particularly good in relation to what appeared available by echosounding.

The "Eldjarn" October 1986 mini survey looks like a special case, and with its good catches it bulks large in the rockhopper comparisons. All the "Eldjarn" results from this cruise are from shallow water. On the mini survey the night catches are better than the day, but since the night catches were all done first, it is uncertain whether this was a day/night effect, or just that the fishing was decreasing. The day ratios of P_T/P_A were by no means poor. To begin with, in the night comparisons, there looks to be a lot of fish immediately above headline height, see $P_{A(0-15)}$ and $P_{A(0-4)}$ for hauls No. 460, 461 in Table 5. The acoustic conversion factors for "Eldjarn" were calculated separately for each haul, and in the mini survey area were 852, 770 and 796 for the day hauls, and 1025, 956, 854 and 862 for the night hauls representing smaller fish (mostly haddock). Using a combined day and night CF would raise P_A by day, thus lowering P_T/P_A and vice-versa by night. This falsely farther separates the day and night plots of P_T/P_A. Note that this is not at all the same effect as discussed in section 5.5.

The other group is for "Michael Sars" in February 1988 around Nysleppen. The hauls made by "Michael Sars", fishing with bobbin gear in this area, are also marked on Figures 7 and 8. The "G.O. Sars" results on Figures 11 and 12 are all from this area, and all show the same general tendency for higher $\Sigma P_T/\Sigma P_A$ by day. Average catch rates were either better or much the same by day. There is doubt about the one haul made by each of the boats in 270 m depth, "G.O. Sars" Haul No 112, "Michael Sars" Haul No 89. Catch rates were very different, and some of the acoustic data missing or doubtful.

5.6.2 With little seen above headline height

Analysis is again started with cases where there is little recorded above headline height.

By day hauls were "Eldjarn" October 1986: 441, 442, 446, 456, 478; "G.O. Sars" February 1987: 150, 152; and by night "Eldjarn" October 1986: 443, 444, 463, 467. This gives:

$\Sigma P_T/\Sigma P_{A(0-4)}$	day	= 0.712 in range 0.438 to 1.158
	night	= 3.71 not enough to judge limits
	combined	= 1.377 in range 0.783 to 2.422,

also:

$\Sigma P_T/\Sigma P_{A(0-15)}$	day	= 0.654 in range 0.404 to 1.058
	night	= 2.95 not enough to judge limits
	combined	= 1.223 in range 0.715 to 2.092.

Compared with the corresponding figure of 1.24 and 0.95 for the bobbin trawl, these rockhopper figures of 1.38 and 1.22 seem reasonable. Engås, Jacobsen and Soldal (1988) gave catch ratios rockhoppers/bobbin of 1.56 for cod above 35 cm, and 1.18 for haddock above 35 cm. The echo-integrator cannot distinguish cod from haddock, and as for fixing the ratio, comparative fishing is the far better way to do it. With the provisos mentioned before, the best current estimate (day and night combined) for effective spread of the rockhopper gear from the acoustic comparisons would be 34 m with nothing driven down, and 31 m if the little seen above headline height were driven down.

5.6.3 Correlation differences

For all rockhopper day comparisons $P_T/P_{A(0-4)(day)}$, the correlation coefficient R = 0.811, is better than was found with either of the cases using bobbins. The correlation coefficient $P_T/P_{A(0-15)}$, R = 0.76, is rather worse than for $P_T/P_{A(0-4)}$, which is again different from either of the cases with the bobbin gear. These observations rather count against putting much blame for the poor day correlations with the bobbin gear as being due to erratic dead zone + backstep estimates, and suggests that in quite large measure it could be due to erratic escapes at the bobbin groundrope. There have also been reports of less erratic commercial fishing with the rockhopper gear.

There is little point in considering any overall night correlation when it falls into such different groups as the "Eldjarn" mini survey and the "Michael Sars" ("G.O. Sars", "T.O. Senior") mini survey. In Figure 13, the night "Eldjarn" mini survey comparisons are fairly well grouped, and as a separate group the "Michael Sars" night comparisons do not look too bad grouped either. Interestingly, these groupings look worse in Figure 14, where the plot is $\Sigma P_T / \Sigma P_{A(0-15)}$.

5.6.4 Night and day, shallow water

The "Eldjarn" October 1986 cruise is the only one with fairly extensive fishing in shallow water, and at least some of these had few echoes seen above headline height. There are not enough hauls for statistical analysis, but a summary can give some pointers.

Day, shallow, much above:	P_T	787, 201
	$P_{A(0-4)}$	213, 148
	$P_{A(0-15)}$	314, 199
Day, shallow, little above:	P_T	19, 120, 102, 224, 397
	$P_{A(0-4)}$	54, 82, 121, 145, 338
	$P_{A(0-15)}$	54, 83, 121, 145, 430

Summarizing:

	DAY, shallow	
	Much above	**Little above**
$P_T/P_{A(0-15)}$	Case (1) 1.93	Case (2) 1.03
	$P_{A(0-15)}/P_{A(0-4)} = 1.42$	$P_{A(0-15)}/P_{A(0-4)} = 1.13$
$P_T/P_{A(0-4)}$	Case (3) 2.73	Case (4) 1.16

Comparing (1) with (2) and (3) with (4) does not discourage the idea that something could be driven down.

Night, shallow, much above:	P_T	1222, 846
	$P_{A(0-4)}$	289, 266
	$P_{A(0-15)}$	915, 713
Night, shallow, little above:	P_T	179, 200, 671, 948
	$P_{A(0-4)}$	62, 62, 256, 159
	$P_{A(0-15)}$	64, 63, 341, 210

Summarizing:

NIGHT, shallow

	Much above	Little above
$P_T/P_{A(0-15)}$	Case (1) 1.27	Case (2) 2.95
	$P_{A(0-15)}/P_{A(0-4)} = 2.93$	$P_{A(0-15)}/P_{A(0-4)} = 1.26$
$P_T/P_{A(0-4)}$	Case (3) 3.73	Case (4) 3.71

Comparing (1) with (2) and (3) with (4) does not lend support to the diving concept. However, there is something odd about values of 3 to nearly 4 in cases (1) and (2), which indicate effective spreads of 3 to 4 times normal, well beyond otterboard spread it would seem. It might be chance, but each of the 4 hauls tells the same story. This did not occur in the day comparisons with little above.

5.6.5 Night and day, deep water

If there is little to drive down anyway, it should not matter much whether comparisons are from deep or shallow water. In deep water, there are two more day comparisons with little above from "G.O. Sars" February 1987 to add in haul nos. 150 and 152.

Day, deep, little above:	P_T	shallow data + 244, 239
	$P_{A(0-4)}$	shallow data + 444, 705
	$P_{A(0-15)}$	shallow data + 495, 728
Day, deep, much above:	P_T	234, 992, 218, 517, 1421
	$P_{A(0-4)}$	190, 593, 114, 412, 2151
	$P_{A(0-15)}$	258, 4361, 603, 2655, -

Summarizing:

	DAY, deep	
	Much above	**Little above**
$P_T/P_{A(0-15)}$	Case (1) 0.25	Case (2) 0.65
	$P_{A(0-15)}/P_{A(0-4)} = 3.88$	$P_{A(0-15)}/P_{A(0-4)} = 1.09$
$P_T/P_{A(0-4)}$	(Case 3) 0.97	Case (4) 0.71

Comparing (1) with (2) and (3) with (4), if there is any indication at all of diving in this it looks slight.

Night, deep, little above:		have only shallow water data to use
Night, deep, much above:	P_T	424, 328, 169, 263, 183, 303, 369
	$P_{A(0-4)}$	562, 204, 129, 274, 224, 241, 318
	$P_{A(0-15)}$	1019, 1029, 482, 1339, 923, 1096, 894

Summarizing:

	NIGHT, deep	
	Much above	**Little above**
$P_T/P_{A(0-15)}$	Case (1) 0.30	Case (2) 2.95 or use 1
	$P_{A(0-15)}/P_{A(0-4)} = 3.47$	$P_{A(0-15)}/P_{A(0-4)} = 1.26$ or 1
$P_T/P_{A(0-4)}$	Case (3) 1.04	Case (4) 3.71 or use 1

Comparing (1) with (2) and (3) with (4), there is hardly an indication of diving, even if values like 1 and 1 are substituted in cases (2) and (4).

6. DISCUSSION

6.1 Efficiency, Effectiveness and Availability

In considering trawl efficiency, it is availability of the fish immediately in front of the gear that has to be considered. Thus the natural abundance may be disturbed by the passage of the ship and the approach of the gear. The vertical fish profile may be disturbed from the natural and the horizontal distribution may also have a disturbed profile.

Number of encounters = $Y_b \cdot V \cdot t \cdot N \cdot F_{V3} \cdot F_{H3}$, also $N_3 = N \cdot F_{V3} \cdot F_{H3}$, where Y_b = otterboard spread, V = speed, t = time, N = abundance (fish/unit area) in the natural state, F_{V3} is the vertical availability coefficient at the gear, and F_{H3} is the horizontal availability coefficient at the gear.

Since Efficiency = catch/encounters, catch = $Y_b \cdot V \cdot t \cdot N \cdot F_{V3} \cdot F_{H3}$ · Efficiency also. This is not to say that Efficiency is independent of speed any more than Y_b, F_{V3} and F_{H3} are or may be independant of speed.

Since Catch = qEN and Effort E = t, it follows that q the Effectiveness = $Y_b \cdot V \cdot F_{V3} \cdot F_{H3}$ · Efficiency (units m^2/s). The term q may also be called catchability (catching ability), but it is not a coefficient. Effectiveness is a more general term than efficiency. It includes efficiency as well as availability (vertical and horizontal), as well as the swept area ($Y_b \cdot V \cdot t$). Thus a wider and higher opening gear might be expected to be more effective (have greater catchability), even though it might be less efficient. Effectiveness is considered as dealing with the whole water column. Efficiency operates on what is made available to the gear (encounters). Efficiency is the simpler concept and is dimensionless. Effectiveness is the area above the seabed that is effectively cleared of fish in one unit of effort (time), as such it is closely associated with local fishing mortality.

Thus effectiveness q = C/E · 1/N or C/N · 1/E. The first of these equations expresses an effective gear as being one which has good catch per unit effort (CPUE) at low local abundance. The second expresses it as one which creates a high local fishing mortality for low effort. It also follows that when two gears are being compared in terms of CPUE, it is their effectiveness (catchabilities) that are being compared.

6.2 Vertical Availability

It is possible that ship noise or ship lights and the trawl warp may disturb the natural vertical profile as shown in Figure 15, which is something like the picture presented by Ona in various discussions. There is a vertical profile of fish in the undisturbed condition, there may be another under the ship, and yet a third by the time the otterboards reach the fish.

At this stage, if the vertical availability profile is known (No./$(0.1 \text{ nm})^2$ within narrow depth layers), then the vertical availability coefficient up to headline height follows, and so (ignoring for the moment horizontal availability) does the number of encounters within otterboard spread. Trawl efficiency can then be considered in terms of gear herding; avoidance and escapement.

There is no doubt that changes in vertical profile do sometimes occur. Take for instance day pelagic trawling for blue whiting (*Micromesistius Poutassou*) on the Porcupine Bank, when as evidenced by the netsonde the fish have been observed concentrated below the net at a lower depth than seen on the echosounder. Pay out more warp and the fish descend again until finally they can be driven close to bottom and captured. The least doubtful situation when bottom trawling for cod and haddock, is when reasonable abundance is observed up to headline height and none or little above it, but it is not good when fish is so close to the bottom that the dead zone + backstep estimate is faulty, erratic or impossible.

6.3 Horizontal Availability

Everything read about ploughing effect or change in horizontal distribution due to a vessels approach has concerned pelagic fish, but there has been comment that it might affect demersal fish also. A common assumption has been that a single furrow is ploughed in the path of the vessel, the fish taking avoiding action, moving to port or starboard of the vessel away from the wavefront of the approaching noise source. The assumption seems questionable. Firstly is the question of how well fish can detect the direction of the noise generator outside the near field, or whether they respond more to sound intensity, which would only the same directional response if the polar intensity-diagram is spherical or hemispherical.

Figure 16 is taken from Urick (1967), roughly converted to metre, and the scale moved laterally so that the main source of low frequency noise, the propeller, becomes the zero point on both axes. The polar diagram is far from hemispherical, being something like a butterfly's wings in the horizontal plane, the wings closing downward and coming together in the vertical plane. Ideally, it is a toroid or doughring closed at the centre round the propeller. The point to note is that zones of relative silence are in front of and behind the vessel, also to the outside of the lobes of the butterfly wings. If fish movement is toward lower sound intensity, then two furrows would be ploughed in front of the forward lobes of the butterfly wings and some considerable distance apart.

The responses of pelagic herring and sprat discussed by Misund and Aglen (1989), in that the fish tended to zig zag in front of the vessel, there being three areas of concentration ahead of and to either side of the vessel, also their report of horizontal swimming speed, increasing significantly with horizontal distance vessel-to-school within the range 25-330 m, all fit better with the idea of a dual furrow than a single one.

What effect might a dual furrow have on demersal fish? In shallow depths, the butterfly wings are folded downward to but a limited extent and the two furrows still far apart. Looking at Figure 16, it could roughly be said that the range, propeller to the foremost part of the lobes, is equal to the distance bewteen these foremost parts. Take for example the maximum reaction range as 250 m, then the furrows are also 250 m apart. If the depth is 125 m, then the furrows are $(250^2 - 125^2)^{1/2} = 217$ m apart. This is well beyond the otterboard spread of even very long sweep trawls. As the depth increases, the furrows come closer together, eventually merging at the maximum reaction range.

If there is any two furrow ploughing effect due to propeller noise, it is likely to increase horizontal availability as the vessel approaches. When the vessel is overhead, some scattering might occur, but as much backwards as to the sides, and thereafter those temporarily scattered to the sides would be again concentrated toward the centre line with gradually decreasing intensity.

6.3.1 Are there any signs of changes in horizontal availability?

Recall the one set of really perplexing results when by night in shallow water the rockhopper trawl/acoustic abundance ratio was of order 3 with little or nothing seen above headline height, making the trawl seem abnormally efficient. It could as well be that the acoustic abundance was abnormally low. This would be like a temporary low abundance hole immediately under the ship that has filled by the time the trawl arrives, and in these shallow depths the otterboards were only 3 or 4 minutes behind the propeller. In the single furrow model, the hole fills in by natural redistribution. In the two furrow model, there is impulsion to fill in the hole. If this hole occurs, why only at night?

At this point a reconsideration of all the shallow water results in Tables 3 and 5 seemed in order. There are no shallow water results in Table 4. Results are only chosen where there is little or nothing above, so that there is little chance of confusing possible diving effect with ploughing effect. Looking at Table 5, there are two more rockhopper comparisons which were rejected, "Eldjarn" October 1986, haul Nos. 445 and 455. Both of these are night hauls, and give abnormally high values of P_T/P_A. The rejected day haul No. 447 perhaps tells something of the story when even $P_T/P_{A(0\text{-}15)} = 2$. From Table 3, and now taking shallow to be less than 150 m to correspond with the rockhopper shallow water results. The day hauls with little above, "Eldjarn" October 1987, hauls Nos. 598, 602, 610, 648, 649, show a generally show a low value of $P_T/P_{A(0\text{-}4)} = 0.41$. Even including hauls 437, 597 and 648, where there is more to drive down, does not lead to a high value of $P_T/P_{A(0\text{-}4)}$ or $P_T/P_{A(0\text{-}14)}$. By night, however, hauls 599, 601, 619, 620, 647 value over 2. Adding in also hauls 578 and 592 with more above, does not change the picture that P_T/P_A remains high, however, it is judged.

The story looks the same, shallow water (here < 150 m), night, nothing much seen above headline height, high values of P_T/P_A. The question of why is unresolved.

6.4 Day and Night differences

Day and night differences in the trawl/acoustic abundance relationship were found, sometimes as quite significant differences. Generally by day the trawl/acoustic abundance ratio is found to be higher, but with the bobbin gear the day relationship is much more variable, and on one cruise did not correlate at all. The night relationship is generally found to correlate better. Correlation is only one statistical test; at constant fish abundance the ratio trawl/acoustic abundance is unlikely to correlate, but the value $\Sigma P_T/\Sigma P_A$ could nevertheless be within close statistical limits.

There is some indication of the rockhopper day correlation being better than for the bobbin gear, possibly because of less variable escape at the groundrope. On one cruise in October 1986 with the rockhopper gear, the night ratio of trawl/acoustic abundance was higher than by day, and this was associated also with good night fishing, mainly on haddock, during a mini survey. Earlier in the same cruise on the wider survey and then for cod, the night ratio was also better than the day ratio with the catch rates just about equal day and night. On another mini survey, it followed the more normal pattern. Taking a single haul at a station is not going to tell much about what is happening, and without knowing what is happening there are strong chances of misinterpretation.

If catches show a markedly different cod/haddock ratio by day and night and/or if length/frequencies of either species are markedly different in day and night hauls, acoustic conversion factors should be modified accordingly. Failure to do this can either mask or falsely accentuate real differences in day and night gear effectiveness. Potentially the effect of ignoring any size dependant day and night change in acoustic conversion factor could be considerable. For a wider range of relevant situations, see Engås and Soldal (1990).

The reasons for the generally higher day ratio of trawl/acoustic abundance is not completely clear. It could be in part due to diving effect by day; it occurs also (less significantly) when there is little seen on the echosounder above headline height. That sweeps are more effective by day (Dickson and Engås 1989), is surely part of the reason.

It is suspected but remains unknown that the effect is partly masked by an increased net efficiency at night.

6.5 Cases with little seen above Headline Height

This represents the nearest that has been reached to a trawl/acoustic abundance comparison with minimum possibility of extranous effects. There are not enough occasions when there is absolutely nothing seen above headline height. Such occasions would in any case be the ones where the dead zone + backstep estimate was the most suspect and cause the most variance. The day/night effect appears to remain with generally day giving the slightly higher trawl/acoustic abundance ratio, but the differences cannot be shown to be significant. The reasons for the possible day/night difference and the difficulties of explanation remain as in section 6.4 above, with the important difference that any possible diving effect is much reduced.

The trawl/acoustic abundance comparison for the bobbin gear is close to 1:1, possibly slightly more by day and slightly less by night. The rockhopper gear gives a slightly higher value than the bobbin gear. The bobbin gear with the poorly spread otterboards a rather lower value. All this is in order and accords roughly with independant comparative fishing experiments.

If one has confidence in the target strength relationship $TS = 21.8 \; LogL_{RMS} -74.96$ for cod and haddock, also that the corrections to the nominal solid beam angle ψ are correct, then it is possible to be confident that the nominal value of 25 m effective spread is quite reasonable for the sampling trawl with bobbins. The slightly higher value of 27 m might be better and higher again for the rockhopper gear. The relative values are better set by comparative fishing. The 27 m is an attempt to set a rough anchor point (zone), representing a value for cod and haddock together, and of the most frequent midling size. When it comes to arranging effective spread (or trawl efficiency) by species and length group from comparative fishing results, there are other constraints as well as the guidance of an anchor zone.

6.6 Allocating Variance between Trawling and Acoustics

The mean value which is the most reliable is not the above 1.07:1 composite day and night ratio, but the night deep water value of 0.93:1 (see section 5). These average values have wide confidence limits, and they must lack any precision on a haul by haul basis. The 95% confidence limits of the 0.93 are from 0.68 to 1.27. Part of the variance is in the nature of trawling and part in the nature of the acoustics. There is little saying which has the greater variance. Looking at Figure 9 might suggest that acoustic abundance is rather less variable because the acoustic plots are more peaked and rather lower at the extremes. This, however, is likely the result of being more ready to reject extremes of acoustic data than trawl data. To a trawlerman fish is, afterall, real fish, while echoes are only a semblance of fish. Allocating all the blame to trawl variance in the above case gives effective spreads ranging from 17 to 32 m (arising from range 0.68 to 1.27 above). This is quite credible, ranging from less than the headline spread to more than half the otterboard spread. However, if half the blame is put on acoustic variance, the above confidence limits can be considered to arise from a pooled variance and worked backwards to the variance and confidence limits for each part. Thus, the trawl effective spread range is bettered to 19 m to 29 m, while the acoustic range confidence is degraded to become from 0.8 to 1.25 instead of taken as true. Would the acoustic experts like to claim any better accuracy for a near bottom abundance estimate? This would seem rather more realistic than blaming all the variance as being due to either trawling or acoustics. The mean value within these ranges are the geometric means (because based on logarithms).

It must be re-emphasised that the above represents the best night deep water estimates for the bobbin gear. The day estimates can be expected to be higher, but considerably more variable.

6.7 Diving Effect

Tests made to determine whether there is any diving effect suffer from the disadvantage that without direct means of observations, they rely on dividing cases, into where there is a considerable amount of fish seen on the echosounder to be above headline height, and where there is not. One has to divide this into day and night, and farther attempts to subdivide results into deep and shallow water leave too little data in some groups. Since also the times and places where much is seen above and little is seen above have usually to be different, one is not sure how much one is comparing different availabilities and how much different trawl efficiencies. The expected changes in gear efficiency are, however, a good deal less than the potential changes in availability.

By night in deep water over 250 m, and even into shallower water, there was no indication from the tests made that diving effect was at all likely to have occured. Moreover, whether there is much seen above headline height or not, the mean ratio $P_T/P_{A(0\text{-}4)}$ stays at 0.93 to 0.95 for the bobbin gear, which is another sign that potential availability is not changed into actual availability.

By day, and perhaps moreso in shallower water, there were indications that diving effect might well have occured. There was, however, not enough certainty to reject the null (Ho) hypothesis that it did not occur.

Does it take more than sound stimulation alone to cause significant movement response? Is it related to fish being able to see each other? At the greatest abundance occurring, the fish would have been 5 m apart and most commonly at nearly three times that distance (from Figure 9).

6.8 Sources of Error and Variance

Possible sources of error like acoustic calibration and T.V.G. are so far as possible taken care of and hopefully small. It is not so sure that the corrections made for solid beam angle with depth are as yet well taken care of, and they could be responsible for bias in the acoustic results. If such bias is discovered, at least these acoustic abundances could be recalculated (as has been done once already). Sundry errors most occur because the raw data are written down from a video screen, and can only to a limited extent be checked on the printout. This can no doubt be improved with the new EK500, better software, and more printout, specially designed for trawl stations, rather than making do with adaptions of procedures essentially designed for acoustic survey only. There must be a small residual bias in trawl abundance because the distance of tow is taken from gear on bottom to start heaving on the winch. The trawl net will come some distance more before it leaves bottom, rough estimate of error at 200 m depth, less than 5% in a half hour tow.

An estimate of trawling variance in best conditions has already been given. From comparative fishing results it should be possible to obtain independant information. The trawling variance, however, comes from 3 sources, availability vertically, availability horizontally (patchiness or clustering), and trawl efficiency. In order to be left with an estimate of variance of the last, it is necessary to collect it for the first two. This can be done while trawling, and independantly by making repeat runs over interesting fish concentrations.

Bottom breakthrough is a frequent cause of data rejection, and is usually obvious enough, but undetected it must be a sometime source of error. The old QM method with the analogue output was good in this respect, because one could see the jumps due to ground breakthrough and eliminate them as in Figure 17. Data processing is supposed to make some such adjustment when the results of the last distance interval are displayed, but it is not clear how this is done, and it can hardly be completely effective.

One can also rely on some guidance from the QD channel printout, and on the 2-4 m channel used as backup. Any bottom breakthrough that remains biasses the results one way, a falsely high acoustic abundance estimate lowering the trawl/acoustic abundance ratio, making the trawl appear less efficient than it must be.

A bias in the opposite direction arises from the conversion factor obtained from trawl sampling. At the time of comparative fishing with "Anny Kræmer", the rockhopper conversion factor was some 15% higher than from the bobbin trawl selection range. The real conversion factor must be higher again though by less than another 15%. The results from Table 3 arises mostly from bobbin gear derived conversion factor, the last part though is rockhopper derived because comparative fishing experiments were ongoing. Tables 4 and 5 are derived from rockhopper length selections. The bias makes the trawl appear more efficient than it really is. The particular bias is one it is hoped can soon be allowed for.

Variance must arise in the dead zone + backstep estimate, even if the average extrapolation were the correct one. Information from the trawl is little more than qualitative, e.g. a fair catch and nothing seen on the echosounder and echointegrator indicates it must have been in the dead zone. The only way to come at it would seem to be alternative estimates of what is in the dead zone like the 2-4 m backup and maybe a revised BCH channel, then see how they relate. A useful suggestion came from Jin (1990), which is that instead of extrapolating the last channel, which includes the dead zone and backstep, one should use 2 or 3 narrow preceding channels to predict the trend (probably increasing) into the dead zone and backstep zone.

6.9 Possible Improvements

6.9.1 Instruments, data processing and presentation

There are several improvements to the present system that would not appear too hard to make. Special attention should be paid to trawling stations, so that they can be printed out in suitable format with 0.1 or 0.3 nm intervals. All the bottom locked channels should be printed out, not just the BAR (QD) and BCH. It would also seem better to lock more channels to bottom on the printout. At present, if one wants to cover the whole water column, there is a "grey zone" where bottom locked and pelagic channels overlap, and it takes time and care to ensure that everything is counted once, and that there is not an overlap zone that is counted twice or not at all. It would seem quite feasible to make the dead zone and backstep extrapolations in real time and print out the estimated M value. It would be of considerable help to be able to choose two backstep values and print out the results from both.

The BCH channel does not at present seem to be giving useable information. The depth above bottom at which integration starts, can presumably be treated as a variable backstep (ping by ping), and what is extrapolated as being in the dead zone + backstep shell calculated in real time. It could also be useful to know the average value and variance of this "backstep" over the last distance interval. If this does not yield useful information, the channel could be used for something else.

Nominal bottom is declared as half way between the threshold and the discriminator voltage setting, back tracking from the latter. It would presumably not be much more difficult to declare nominal bottom as halfway between the times taken to reach discriminator value and the threshold. This is not the same thing unless the voltage rise between the two is linear. Often the bottom slope is steeper near the threshold end. The nominal bottom might then be marginally less deep, but one might be able to use a lower backstep value without running into bottom integration problems.

It would be useful to have a graphical output for each distance interval, something like the old QM analogue integrator, so that one could actually see what was happening about unwanted bottom integration. Possibly this can be done even now from what is stored on magnetic tape, but it could be useful to see it while trawling.

Some of the problem is in deciding where bottom actually begins, and it is believed that this may be more accurately defined by the new split beam echosounder.

One must hope that the relationship between the nominal solid beam angle and the actual solid beam angle related to threshold can be more completely resolved, and corrections more routinely applied.

6.9.2 Procedures

Much has been gained by the mini surveys stitched into the periods of general survey, and it is to be hoped they can continue. It is hoped this report has shown that much more may be gleaned from an acoustically backed trawl station than just the length and species composition and biological investigation of the catch. The spatial fish distribution, horizontal and vertical, how it changes by day and night, and how it is related to the catch, are surely worth a few hauls on any interesting concentration encounted in a wide survey.

7. CONCLUSIONS

- With bobbin trawl gear the trawl/acoustic abundance correlation is much better at night. This is more likely to be mainly due to escape reactions at the groundrope than due to dead zone estimate error, because the amount of fish in the dead zone can often be large at night also.

- The day trawl/acoustic abundance correlation is better with rockhopper gear. This reinforces the point made immediately above.

- There is a demonstrable need to differentiate between acoustic conversion factors (m^2/nm^2 to number of fish/nm^2) by day and by night.

- There was no sign of diving effect by night, which does not necessarily mean that the possiblity can be excluded.

- The more stable night conditions made it possible to set an approximate value for night trawl effective spread, provided that acoustic conversion factors based on target strength from root mean square fish length are correct. This accorded well with the 25 m assumed for the bobbin gear in trawl surveys, and is a useful cross check when determining size selectivity for this arctic survey trawl (next report).

- Having in the trawl an alternative and not necessarily less accurate way of estimating near bottom cod and haddock abundance has highlighted the necessity to use and improve on suitable equivalent beam angle correction on the acoustic side.

- By day the increased (often significantly different) trawl/acoustic abundance cannot be well allocated between greater availability to the gear and increased gear efficiency. The increase often looks too big to be the latter alone. There were not enough cases with nothing seen above headline height to obtain a good baseline for day gear efficiency, cases with little seen above having to suffice. While day increased availability due to diving effect could not be proven, it looks quite likely.

- Combined trawl gear and acoustic analysis at trawl stations looks rewarding enough, but establishing more routine and less laborious procedures are a necessary con-commitment to farther work.

8. REFERENCES

Blindheim, J., P.K. Eide, H.P. Knudsen and G. Vestnes, 1982. A ship-borne data logging and processing system for acoustic fish survey. *Fish.Res.*, *1*: 141-153.

Dickson, W. and A. Engås, 1989. Change in length composition of different species with doors and sweeps on and off bottom. *ICES WG, Fish.Techn.Fish Behav., Dublin, April 24-26, 1989.*

Ehrenberg, J.E. and D.W. Lytle, 1977. Some signal techniques for reducing the variance in acoustic stock abundance estimates. *Rapp.P.-v.Réun.Cons.int.Explor.Mer*, *170*: 205-213.

Engås, A., J.A. Jacobsen and A.V. Soldal, 1988. Catch comparison between rockhoppers and bobbins groundgear on the Norwegian bottom sampling trawl. *Coun.Meet.int. Coun.Explor.Sea, 1988*/B:31.

Engås, A., J.A. Jacobsen and A.V. Soldal, 1988. Diurnal changes in bottom trawl catches and vertical fish distribution. *Coun.Meet.int.Coun.Explor.Sea, 1988*/B:32.

Engås, A. and A.V. Soldal, 1990. Diurnal and seasonal variations in bottom trawl catches of cod and haddock. *Rapp. P.-v. Réun.Cons.int.Explor.Mer* (in press).

Foote, K.G. 1988. Acoustic sampling volume versus equivalent beam angle. *Coun.Meet.int. Coun.Explor.Sea, 1988*/B:5.

Gulland, J.A. 1987. Statistical aspects of comparative fishing trials. *FAO/UNDP/TA, Rep.No. 2277-2*, pp. 349-354.

Jin, X. 1990. Acoutic Estimation of near seabed fish abundance. Dept.Fish.Biol., University Bergen, mimeo.

Misund, O.A. & A. Aglen, 1989. Swimming behaviour of schooling herring and sprat as recorded from a survey vessel. *ICES WG, Fish.Techn.Fish Behav., Dublin, April 24-26, 1989.*

Mitson, R.B. 1982. Acoustic detection and estimation of fish near the seabed and surface. *Symposium on fisheries acoustics, Bergen, Norway, 21-24 June 1984.*

Ona, E. 1987. The equivalent beam angle and its effective value when applying an integrator threshold. *Coun.Meet.int.Coun.Explor.Sea, 1987*/B:35.

Ona, E. 1988. Manual for bruk av bunnkanal, backstep, dødsonekorreksjon, luftabsorbsjonskorreksjon under flerbestandstoktet 1988. Mimeo.

Urick, R.J. 1967. *Principles of underwater sound for engineers.* MacGraw-Hill Book Co., New York, 1967.

AKNOWLEDGEMENTS

In leading cruises and in making this work possible, thanks are due to O.R. Godø. To the acoustic engineers aboard the research vessels for the trouble they took, I would like to express my appreciation to K.A. Hansen in particular for explaining the working of the system and for help in avoiding some of the pitfalls, similarly to P. Bangstad and E. Ona for guidance and suggestions, lastly to those in FTFI who helped with computer programming.

Table 1. Data sheet for trawl hauls, and example.

Station No. BT 97 Date: 17.02.88
Gear: Campelen 1800
Bobbins
40 m sweeps
Position: N 71°34' E 26°38'
GMT: 12.03

Log	574.6	575	576	576.1	1.5 mile Total M		Mtot m²/(nm)²		
10-200		27	28				27.5		cod 136
200-250		30	60 from				45		haddock 938
250-300		48	56 printout				52		sebastes 1441
300-350		392	144				268		
350-400						Average depth 349 m			
22-14	14.8	27.7	50.2	4.3	67.4		44.9		
14-10	12.1	15.9	17.1	2.8	23.7		15.8	60.9	
10-6	12.9	17.9	12.1	1.1	18.2		12.1		
6-4	6.9	9.3	3.7	1.2	7.3	KF	4.9		
4-2	7.5	11.7	3.4	1.3	8.9	2.15	5.9	28.1	12.7
BCH	1.5	2.3	6.2	1.2	8.2				
BAR (QD)	82	82.6	9	5	14.6	2.28	22.2		

Backstep 1 m

$P_{A(0-4)}$ 153/(0.1 nm)²
$P_{A(0-22)}$ 576/(0.1 nm)²
$P_{T(25\ m)}$ 530/(0.1 nm)²

Table 2. Gulland's method of comparing A and B when the ratio of A/B can swing about to be considerably greater and less than 1:1. The particular example is for $P_T/P_{A(0-4)}$ with bobbin gear and 40 m sweeps at night. It shows only the last 7 of a print out of 20 comparisons. Columns A and B include the values entered and their running sums on alternate lines.

OBS	A	B	SumA/SumB	LogSum	A/B	Log(A/B)=X
	2738	2799	0.978	-0.010		
14	26	11			2.364	0.3736
	2764	2810	0.984	-0.007		
15	2242	1919			1.168	0.0676
	5006	4729	1.059	0.025		
16	1152	1160			0.993	-0.0030
	6158	5889	1.046	0.019		
17	610	817			0.747	-0.1269
	6768	6706	1.009	0.004		
18	229	578			0.396	-0.4021
	6997	7284	0.961	-0.017		
19	183	233			0.785	-0.1049
	7180	7517	0.955	-0.020		
20	173	265			0.653	-0.1852
	7353	7782	0.945	-0.025		

	X**2	Conf.lim.	From	To
14	0.1396	0.1853	0.642	1.507
15	0.0046	0.1727	0.711	1.575
16	0.0000	0.1615	0.721	1.517
17	0.0161	0.1562	0.710	1.434
18	0.1617	0.1509	0.679	1.360
19	0.1110	0.1430	0.687	1.328
20	0.0343	0.1367	0.690	1.294

Answer: Antilog = -0.025 ± 0.1367 or 0.945 in range 0.690 to 1.294

Table 3. P_T trawl abundance estimate, P_A acoustic abundance estimate, bottom 4 and bottom 15 m. Haul by haul data, with 40 m sweeps and bobbin groundrope.

	D/N	Haul No.	P_T	$P_{A(0-4)}$	$P_{A(0-15}$	Depth	Notes
Eldjarn Oct. -86	o	437	72	47	62	140	
G.O. Sars Feb. -87	o	100	503	296	375	339	
	o	101	610	515	583	348	
	o	102	304	92	273	312	
	•	104	333	234	328	340	
	•	105	317	302	469	339	
	•	106	458	578	661	346	
	•	107	393	686	994	334	
	o	124	397	84	100	350	Note A
	o	125	269	224	273	335	
	•	127	303	259	347	322	
	•	128	338	304	351	337	
	•	129	335	1687	1712	349	Note B
Eldjarn Sep/Oct -87	o	576	213	47	65	237	Note A
	o	593	67	80	80	330	
	o	607	302	35	50	272	Note A
	•	608	4	37	47	353	Note C
	o	613	2	260	279	241	Note C, E
	o	614	2	116	199	261	Note C, E
	o	623	19	23	24	242	
	•	627	3	8	9	285	
	o	634	1	88	89	356	Note C
	o	645	22	301	302	271	Note D
	•	646	57	156	157	239	
	•	578	290	14	72	145	Note A
	•	592	220	81	106	124	
	•	595	13	61	61	195	
	•	596	12	194	195	216	Note B
	o	597	118	39	53	126	
	o	598	3	4	4	98	
	•	599	100	46	46	116	
	•	600	198	81	128	209	
	•	601	5	3	4	80	
	o	602	7	7	8	75	
	o	603	19	211	211	182	Note D
	o	610	19	111	141	103	
	•	619	6	0	0	65	
	•	620	3	0	0	58	
	o	621	1	36	36	175	Note D, small fish <30 cm
	•	647	26	11	14	124	
	o	648	380	230	332	61	
	o	649	81	149	149	112	
M. Sars Feb. -88	o	74	1348	327	794	360	Mostly haddock
	•	75	2242	1919	2707	360	Mostly haddock
	•	76	1152	1160	2084	360	Mostly haddock
	•	77	610	817	1418	360	Mostly haddock
	•	78	229	578	794	360	Mostly haddock
	•	79	183	233*	281	360	Mostly haddock
	o	93	210	78*	91	260	Mixed cod and haddock
	o	94	334	189	264	260	Also some saithe
	•	97	173	265	425	260	Also some saithe

Note A indicates rejection because trawl effective pathwidth would be so much greater than otterboard spread if either $P_{A(0-4)}$ or $P_{A(0-15)}$ were representative.

Note B indicates rejection because of ground echo breakthrough. Much in dead zone seems likely.

Note C indicates rejection because of so small catch that there is uncertainty of what is being integrated.

Note D indicates rejection because not enough echoes outside of QM channel to be sure of QM channel being meaningful.

Note E indicates that mean length of fish in catch is so low that there is small likelyhood of numbers caught representing abundance.

* indicates where "backup" extrapolation from 2-4 m channel was used.

Table 4. P_T trawl abundance, P_A acoustic abundance, bottom 4 m and bottom 22 m. Haul by haul data with 40 m sweeps and bobbin groundrope. Hauls 96 to 111 mostly haddock. Hauls 113 to 120 cod and haddock mixed, also some saithe.

	D/N	Haul No.	P_T	$P_{A(0-4)}$	$P_{A(0-22)}$	Depth	Notes
G.O. Sars Feb. -88	o	96	773	199*	452	347	
	o	97	530	153	576	349	
	●	98	573	1153*	1788	361	
	●	99	942	1345*	2916	355	
	●	100	454	408	1342	351	
	●	101	-	-		370	Trawl not on bottom
	●	102	-	-		375	Trawl not on bottom
	o	103	95	144*	284	352	
	o	104	243	212	455	372	
	●	105	263	192*	238	374	
	●	106	143	144*	278	372	
	●	107	98	92	226	355	
	●	108	169	230	396	359	
	●	109	136	138	286	363	
	o	110	131	60*	176	350	
	o	111	375	391	1032	363	
	o	112	153	-		270	No realistic acoustic values
	●	113	140	432	526	259	
	●	114	173	274	439	268	
	o	115	153	65	112	286	
	o	116	172	-	-	283	No realistic acoustic value
	o	117	191	627	999	263	
	●	118	80	84	116	261	
	●	119	231	270	349	266	
	●	120	152	172	247	265	

Note A indicates rejection because trawl effective pathwidth would be so much greater than otterboard spread if either $P_{A0-4)}$ or $P_{A(0-15)}$ were representative.

Note B indicates rejection because of ground echo breakthrough. Much in dead zone seems likely.

Note C indicates rejection because of so small catch that there is uncertainty of what is being integrated.

Note D indicates rejection because not enough echoes outside of QM channel to be sure of QM channel being meaningful.

Note E indicates that mean length of fish in catch is so low that there is small likelyhood of numbers caught representing abundance.

* indicates where "backup" extrapolation from 2-4 m channel was used.

Table 5. P_T trawl abundance, P_A acoustic abundance, bottom 4 m and bottom 15 m. Haul by haul data with 40 m sweeps and rockhopper groundrope.

	D/N	Haul No.	P_T	$P_{A(0-4)}$	$P_{A(0-15)}$	Depth	Notes
Eldjarn Oct. -86	o	441	19	54	54	161	
	o	442	120	82	83	124	
	•	443	179	62	64	137	with Anny Kræmer
	•	444	200	62	63	123	with Anny Kræmer
	•	445	126	18	20	181	with Anny Kræmer, Note A
	o	446	102	121	121	124	with Anny Kræmer
	o	447	215	13	104	104	big clupms 4-8 m
	•	455	124	18	18	126	Note A
	o	456	224	145	145	64	wide survey ends
	•	460	1222	289	915	79	mini survey, mostly haddock
	•	461	846	266	713	78	
	•	463	671	256	341	75	
	•	467	948	159	210	76	
	o	473	787	213	314	83	some big clumps 0-17 m
	o	478	397	338	430	84	
	o	479	201	148	199	80	mini survey ends
G.O. Sars Feb. -87	o	134	234	190	258	350	
	o	138	403	57	71	345	Note A
	•	142	248	1954	2142	350	Note B
	o	148	274	1966	1966	340	Note B
	o	150	244	444	495	333	
	o	152	239	705	728	360	
M. Sars Feb. -88	o	81	992	593	4361	360	with G.O. Sars + T.O. Senior
	•	82	424	562	1019	360	
	•	83	328	204*	1028	360	with G.O. Sars + T.O. Senior
	•	84	169	129	482	360	with G.O. Sars + T.O. Senior
	•	85	263	274	1339	360	with G.O. Sars + T.O. Senior
	•	86	183	224	923	360	with G.O. Sars + T.O. Senior
	o	87	218	114*	603	360	with G.O. Sars + T.O. Senior
	o	88	517	412	2655	360	with G.O. Sars + T.O. Senior
	o	89	1421	2151	missing	273	with G.O. Sars + T.O. Senior, some doubt
	•	90	303	241*	1096	260	with G.O. Sars + T.O. Senior
	•	91	369	318*	894	260	with G.O. Sars + T.O. Senior

Note A indicates rejection because trawl effective pathwidth would be so much greater than otterboard spread if either $P_{A(0-4)}$ or $P_{A(0-15)}$ were representative.

Note B indicates rejection because of ground echo breakthrough. Much in dead zone seems likely.

Note C indicates rejection because of so small catch that there is uncertainty of what is being integrated.

Note D indicates rejection because not enough echoes outside of QM channel to be sure of QM channel being meaningful.

Note E indicates that mean length of fish in catch is so low that there is small likelyhood of numbers caught representing abundance.

* indicates where "backup" extrapolation from 2-4 m channel was used.

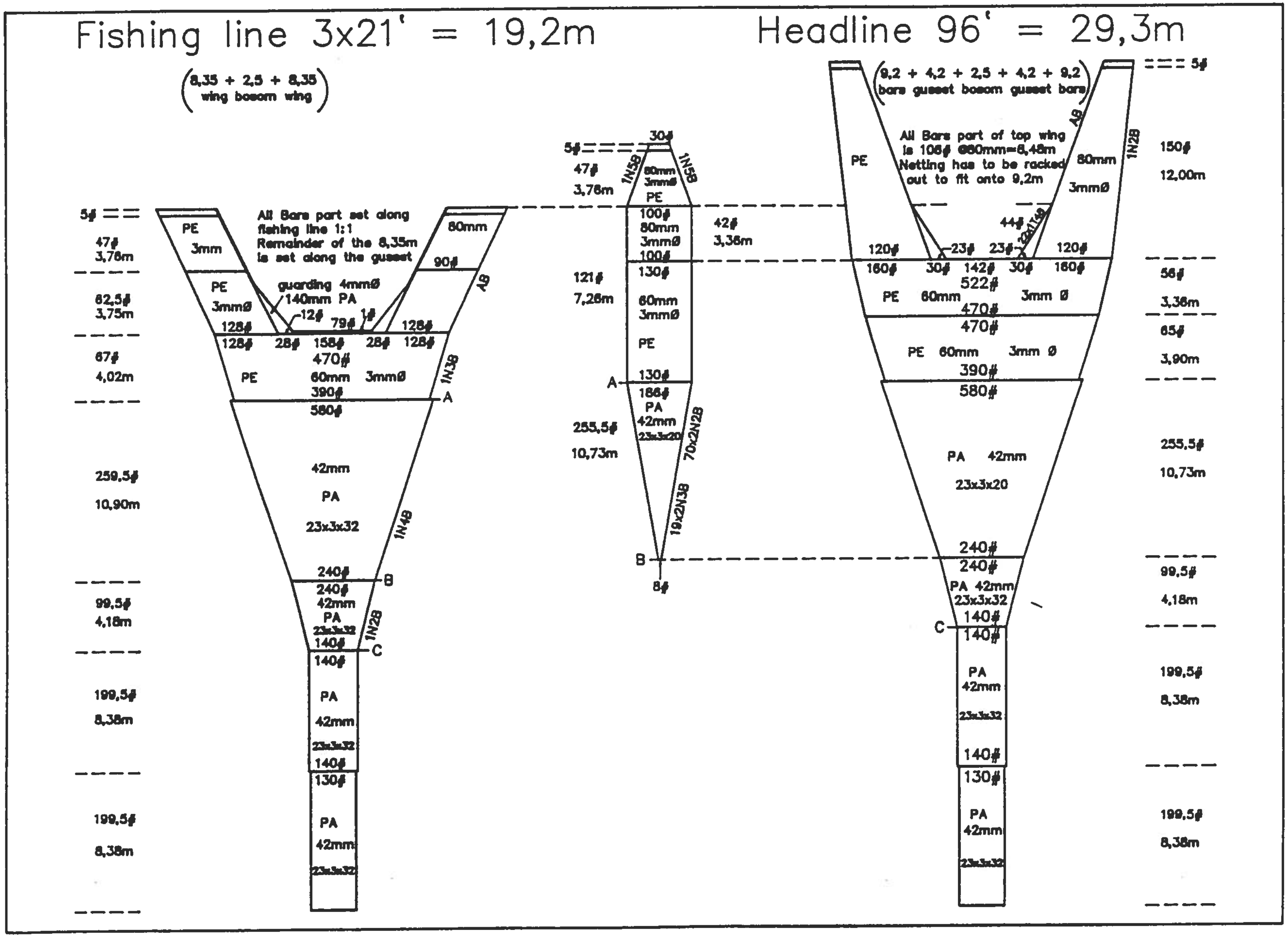


Figure 1. **Design of Campelen 188 trawl as used in Arctic survey.**

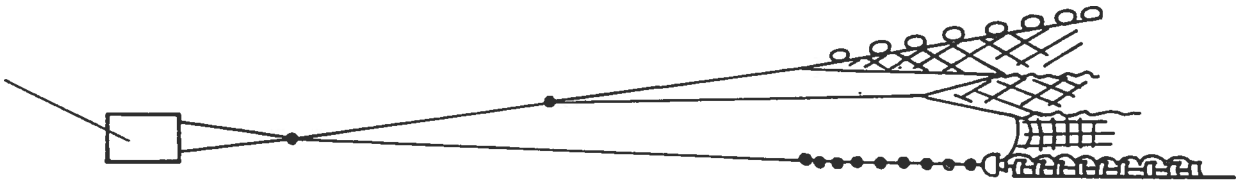


Figure 2. Rigging of Arctic survey trawl.

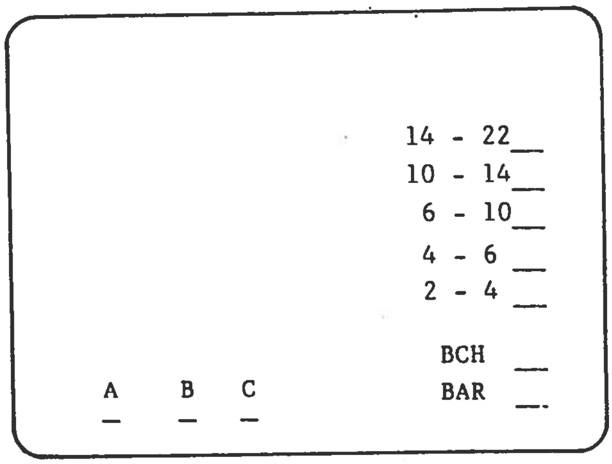


Figure 3. Schematic drawing of video display, showing the bottom locked channels. As well as displaying what is being integrated in the current distance interval (usually 1 nm), what was integrated in the last mile is also displayed.
A: shows the lowest height nearest above bottom at which Threshold was exceeded in the last distance interval
B: shows the current (last ping) height nearest above bottom at which Threshold was exceeded.
C: shows the highest height nearest above seabed at which Threshold was exceeded in the last distance interval.
A, B, and C refer to the BCH channel only.

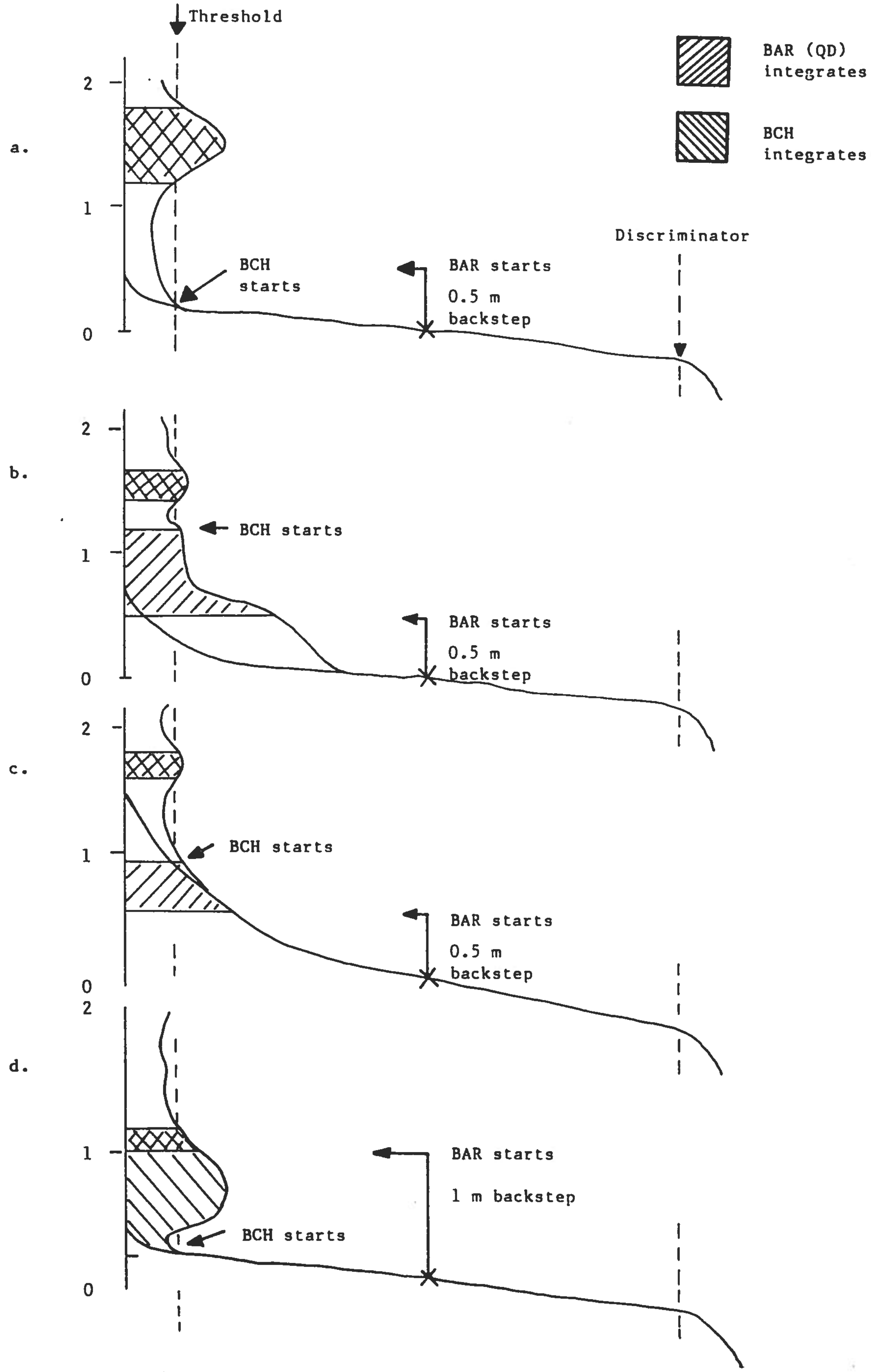
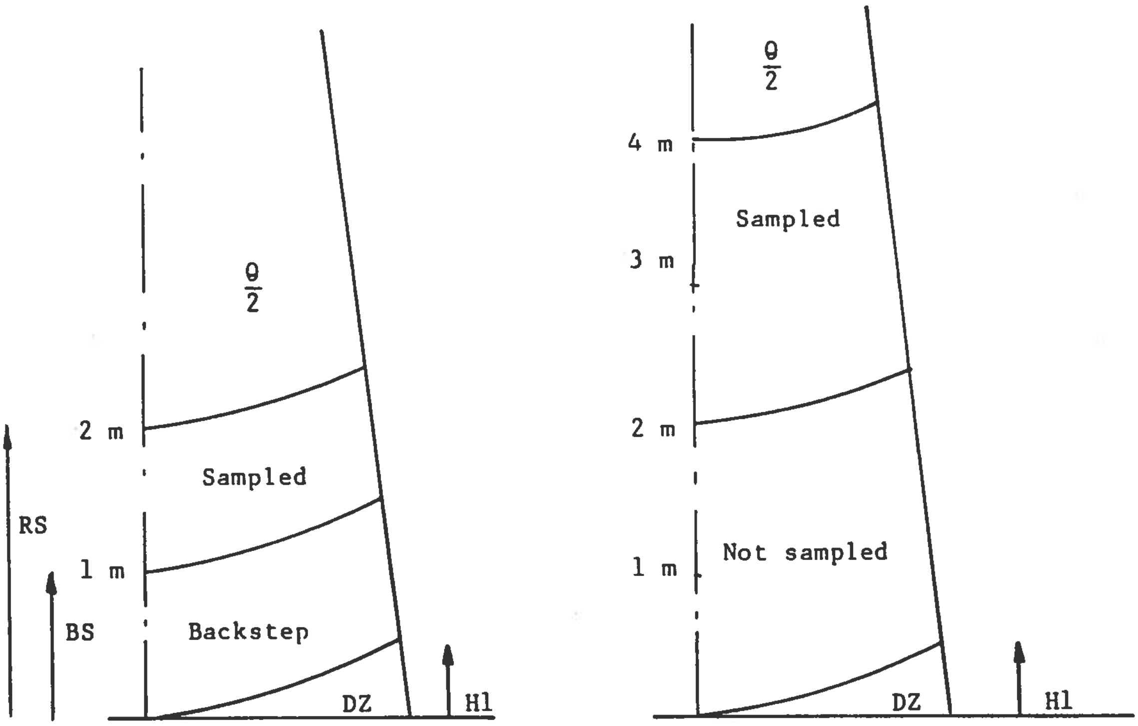


Figure 4. The figure shows what the two different bottom channels, the BAR (QD) and the BCH do and do not integrate. Nominal bottom is set at a voltage halfway between the Threshold and the Discriminator values. The BAR (QD) backstep is counted from there (at a later date nominal bottom was programmed to be at the discriminator voltage, now somewhat reduced). The BCH channel begins to integrate from where the signal drops below threshold for the first time.
A: both channels integrate the same, neither integrate ground.
B: the most common situation, BAR (QD) integrating much more fish than BCH, but also a little ground.
C: is the bad situation where BAR (QD) integrates much ground as well as a little fish.
D: is the uncommon situation where BCH integrates more fish than BAR (QD).



BAR (QD) channel 0-2 m with 1 m backstep

2-4 m channel used as backup

Frustom height $H1 = R(1-\cos\frac{\theta}{2})$

Bottom of frustom diameter $FBD = 2R.\tan\frac{\theta}{2}$

Top of frustom diameter $FTD = 2(R-H1).\tan\frac{\theta}{2}$

Frustom volume $VF = 0.268\ H1(FBD^2+FTD^2+FBD.FTD)$

Cap volume $VC = (\pi/3)(H1)^2(3R-H1)$

Volume of dead zpne $VDZ = VF-VC$

Volume of backstep $VRS1 = (2/3).\pi(R^3-(R-BS)^3).(1-\cos\frac{\theta}{2})$

Volume of rangeshell sampled $VRS2 = (2/3).\pi((R-BS^3-(R-RS)^3).(1-\cos\frac{\theta}{2})$

Correction factor = (volume sampled+volume not sampled)/(volume sampled)

KF = (VRS2+VRS1+DZ(/)VRS2)

Figure 5. Near bottom range shells with dead zone and backstep. It is seen that a 0-2 m bottom channel with a 1 m backstep is going to have a correction factor greater than 2 for extrapolating to estimate what is in the whole 0-2 m range shell plus dead zone. The 2-4 m range shell may also be considered as a 0-4 m channel with a 2 m backstep and used as "back up" if there is ground breakthrough in the 0-2 m channel.

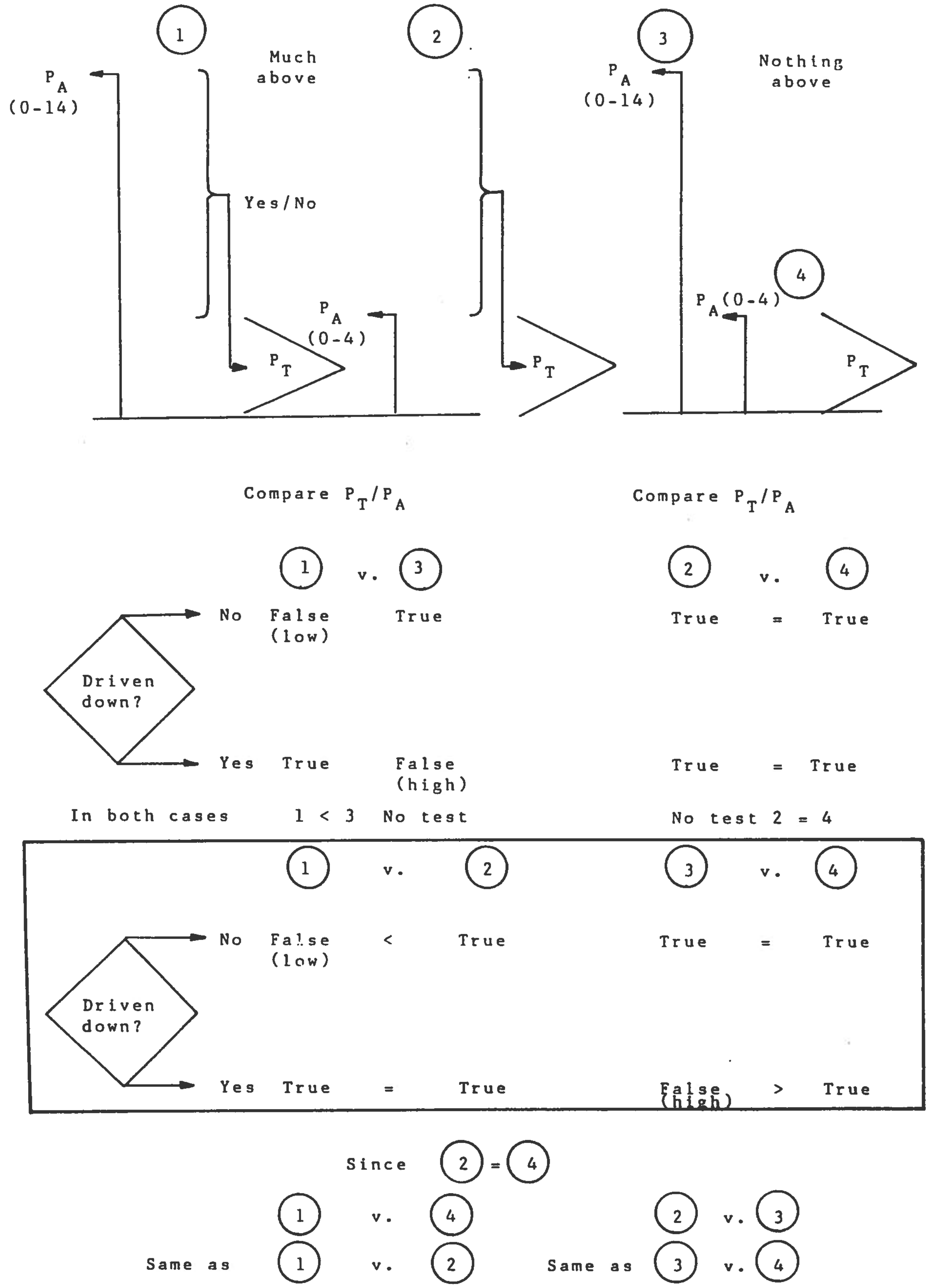


Figure 6. An idealized decision making process to decide whether fish dive down to trawl level. Integration is made from 0-4 m, the headline height, and also 0-14 m. Cases are divided into hauls with much above and cases with nothing above the net. In practice it is not quite so simple.

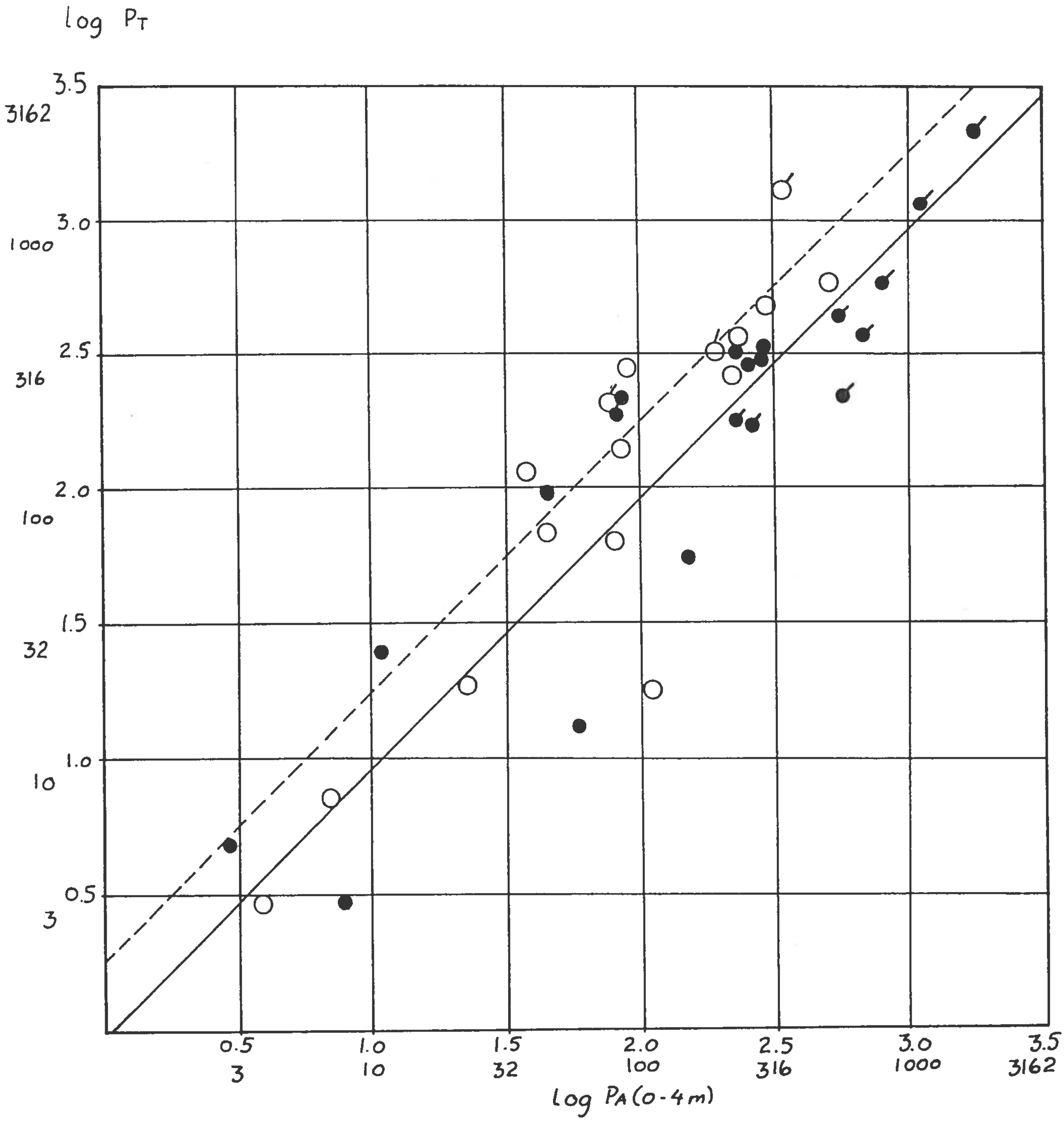


Figure 7. Plot of trawl abundance v. acoustic abundance in bottom 4 m for all bobbin trawl hauls. Those made by "Michael Sars" on mini survey Feb. -88 are marked with a tick, haddock predominating.

By day $\log(P_T/P_{A(0-4)}) = 0.256 \pm 0.171$
correlation R = 0.74

By night $\log(P_T/P_{A(0-4)}) = -0.025 \pm 0.137$
correlation R = 0.96

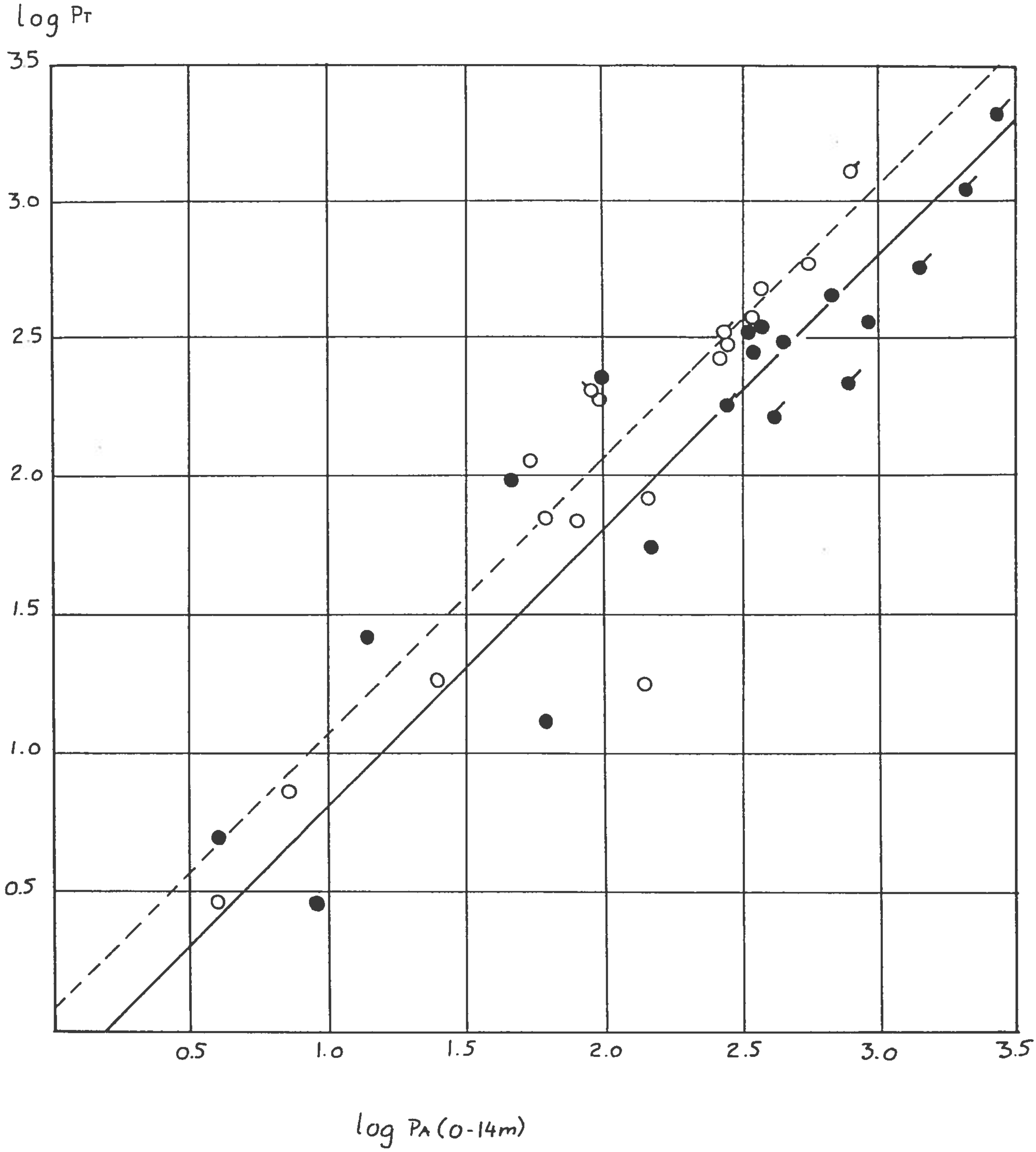


Figure 8. **Plot of trawl abundance v. acoustic abundance in bottom 14 m for all bobbin trawl hauls. Those made by "Michael Sars" on mini survey Feb. -88 are marked with a tick, haddock predominating.**

By day $\log(P_T/P_{A(0\text{-}14)}) = 0.093 \pm 0.142$
correlation $R = 0.95$

By night $\log(P_T/P_{A(0\text{-}14)}) = -0.190 \pm 0.132$
correlation $R = 0.94$

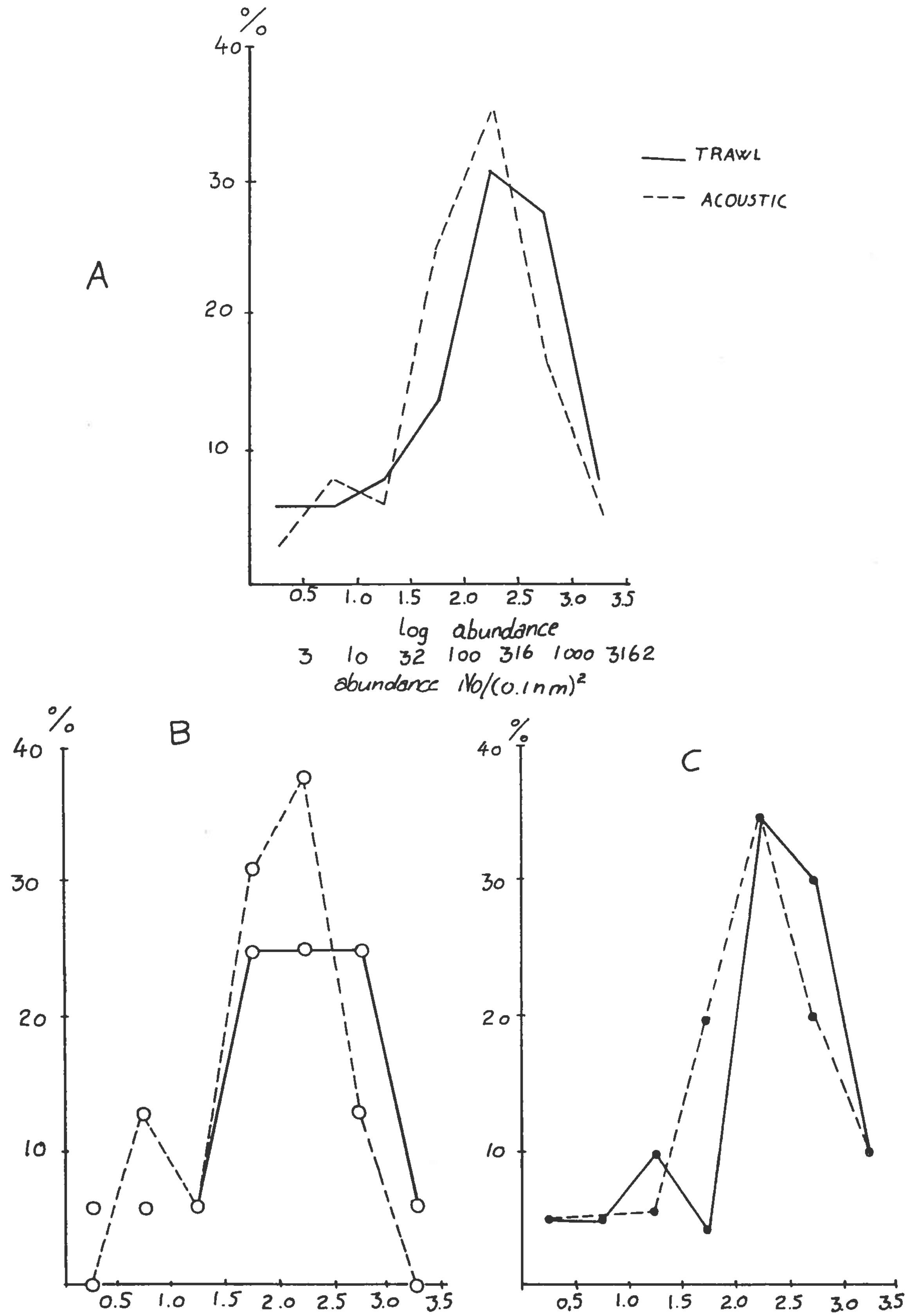


Figure 9. Frequency distribution of trawl abundance P_T and acoustic abundance $P_{A(0-4)}$ for the bobbin trawl.
A: combined day and night
B: day
C: night
Trawl abundance is shifted to the right especially by day.

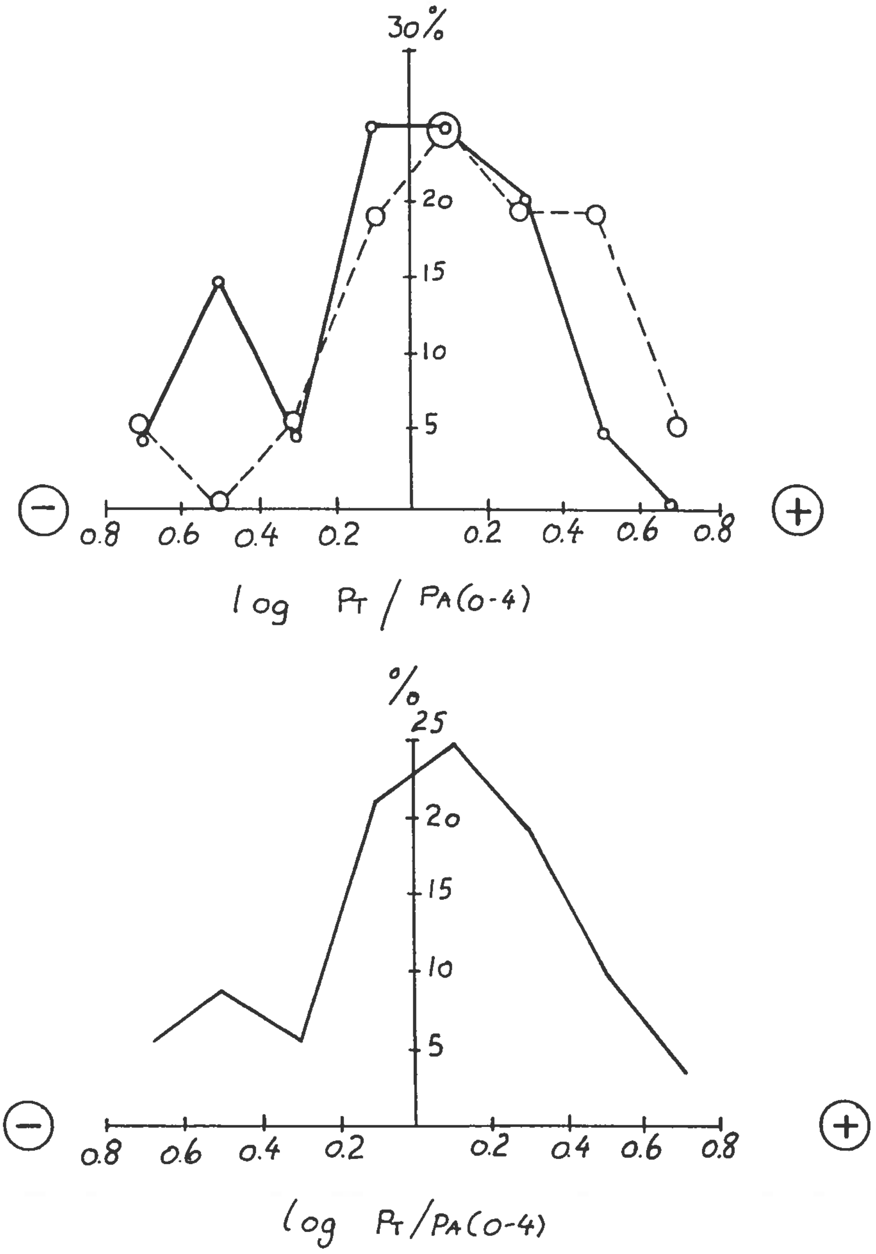


Figure 10. **Frequency distribution of trawl/acoustic abundance comparisons for bobbin gear, 47% of comparisons are within 1.6:1, 72% are within 2.5:1.**

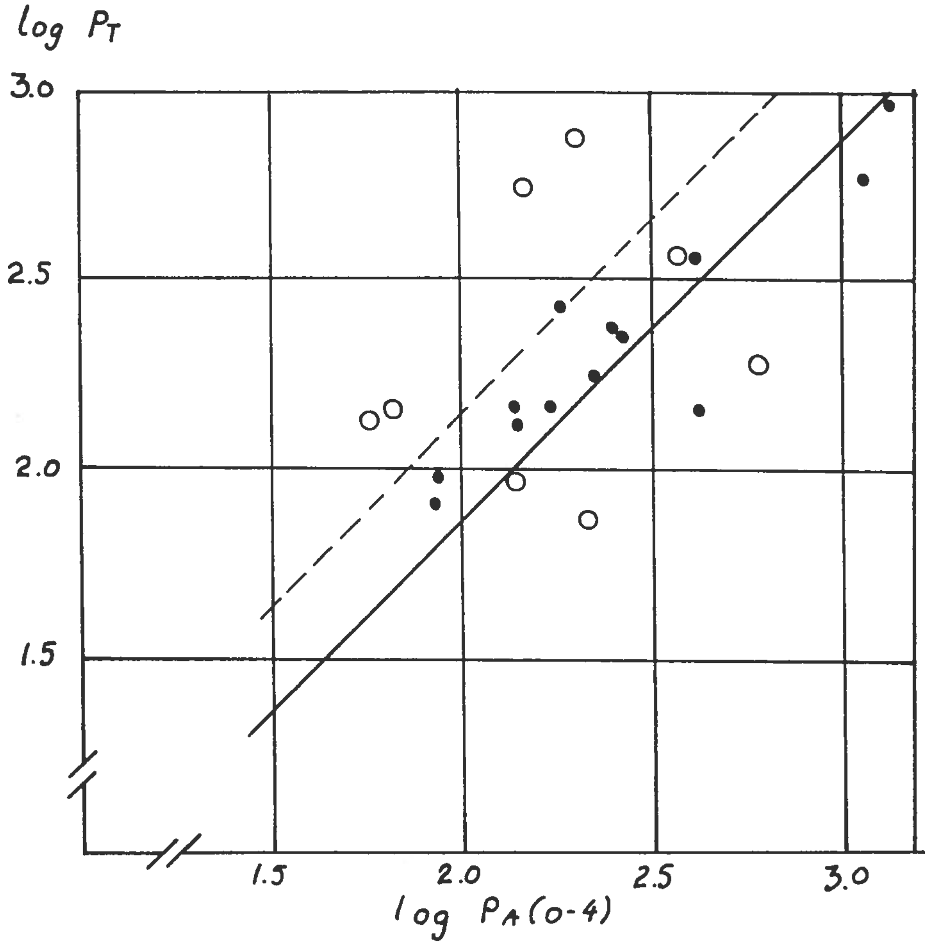


Figure 11. Plot of comparisons P_T v. $P_{A(0-4)}$ for stations in the mini survey "G.O. Sars" Feb. -88. Note particularly the lack of day correlation compared with the night correlation. The otterboards were poorly spread, and notice the correspondingly lower level of the comparisons compared with Figure 7. Haddock predominated, especially in the hauls at 360 m depth.

By day $\log(P_T/P_{A(0-4)}) = 0.129 \pm 0.270$
correlation $R = 0.03$

By night $\log(P_T/P_{A(0-4)}) = -0.142 \pm 0.092$
correlation $R = 0.93$

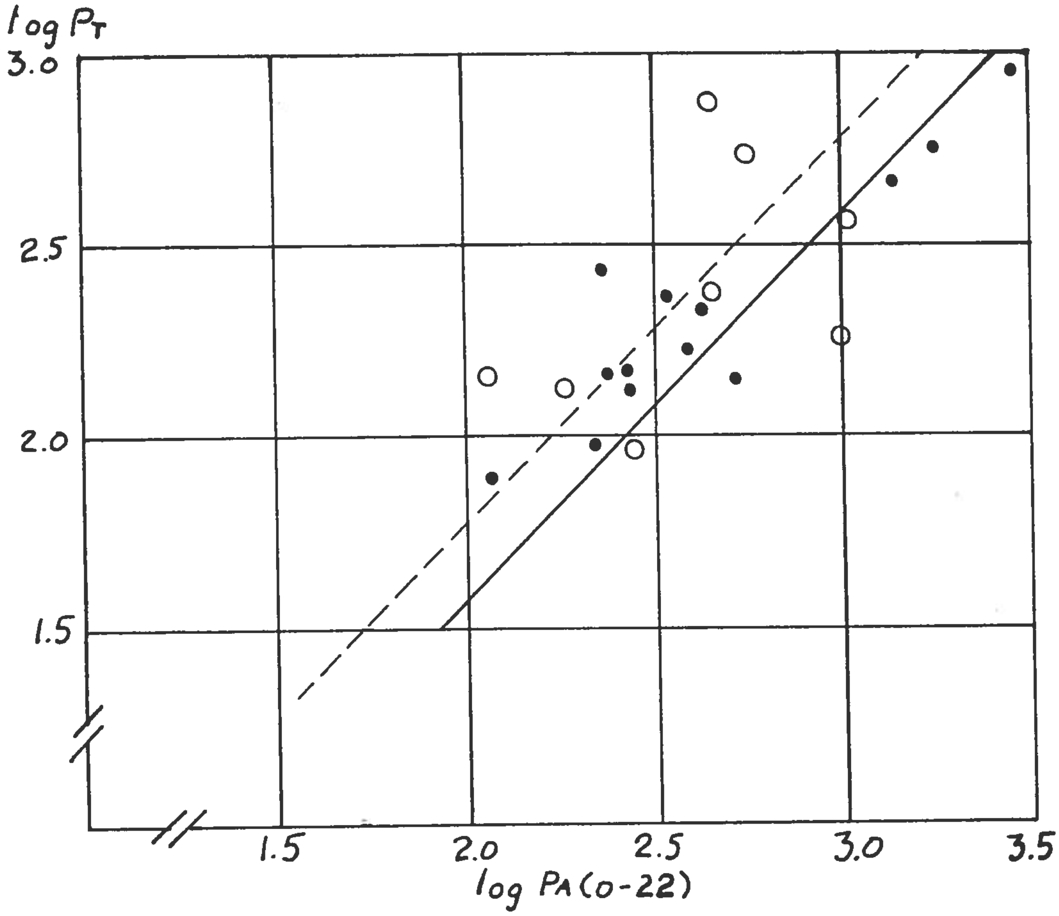


Figure 12. Plot of comparisons P_T v. $P_{A(0-22)}$ for stations in the mini survey "G.O. Sars" Feb. -88.
Note that day correlation is still poor, the night correlation rather good.

By day $\log(P_T/P_{A(0-22)}) = 0.215 \pm 0.230$
correlation R = 0.24

By night $\log(P_T/P_{A(0-22)}) = -0.411 \pm 0.094$
correlation R = 0.98

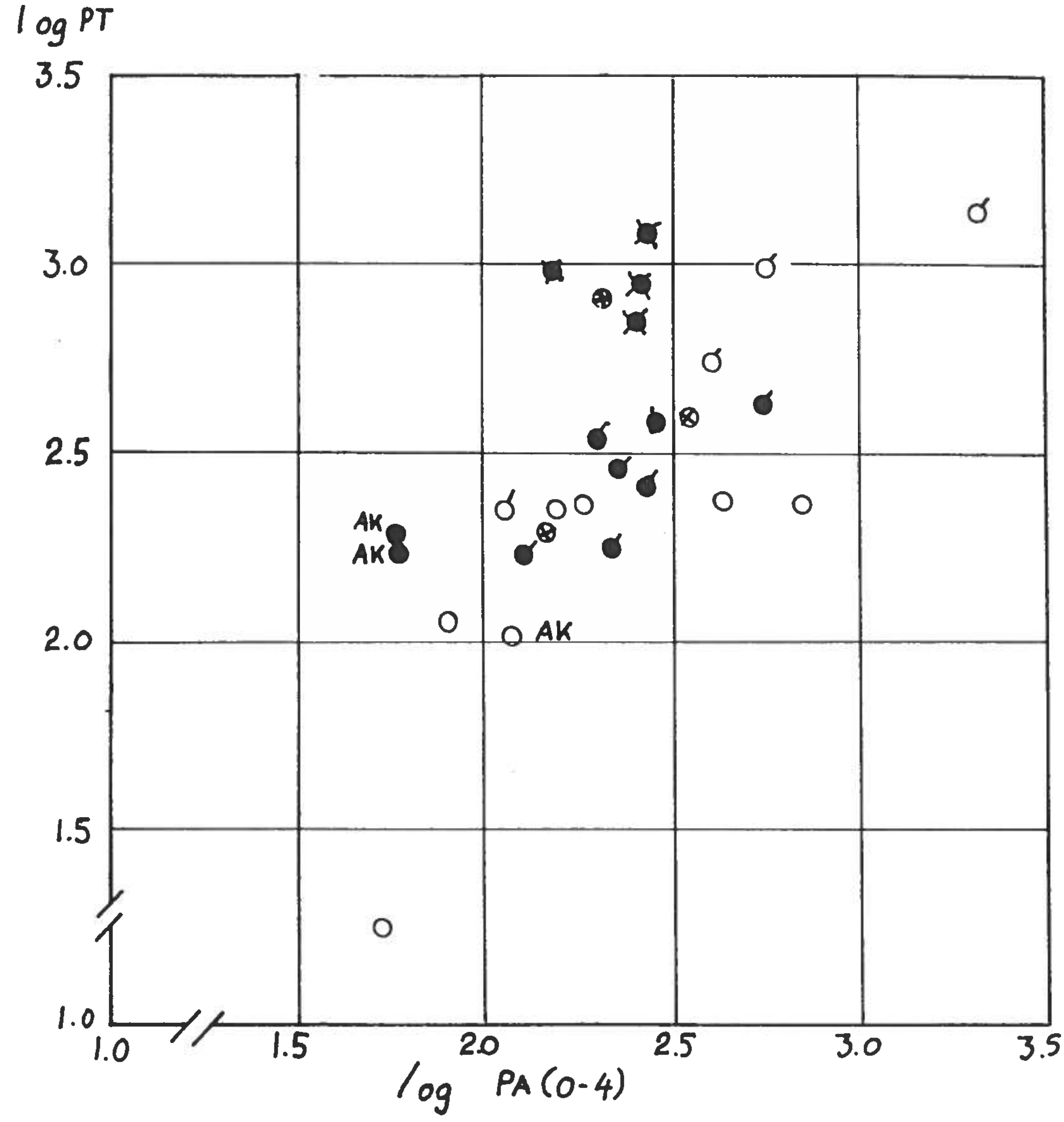


Figure 13. Plot of camparisons P_T v. $P_{A(0-4)}$ with rockhopper gear. Stations marked with x represent "Eldjarn" mini survey Oct. -87 with good night fishing (mostly haddock). Stations marked AK were together with "Anny Kræmer" (all cod), and stations ticked were "Michael Sars" mini survey Feb. -88 (mostly haddock). See text for details.

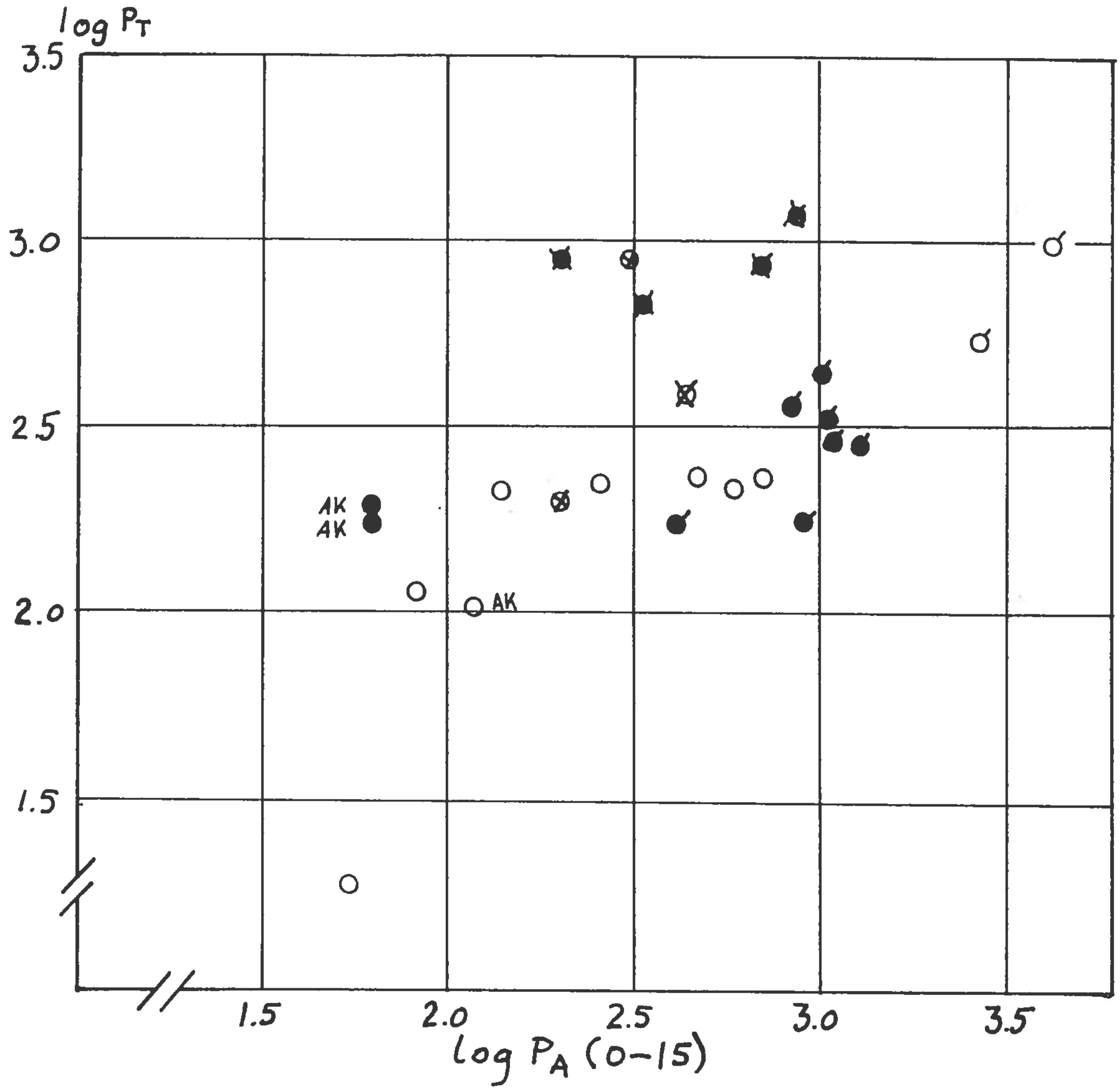


Figure 14. Plot of comparisons P_T v. $P_{A(0\text{-}15)}$ with rockhopper gear. Other information is as on Figure 13.

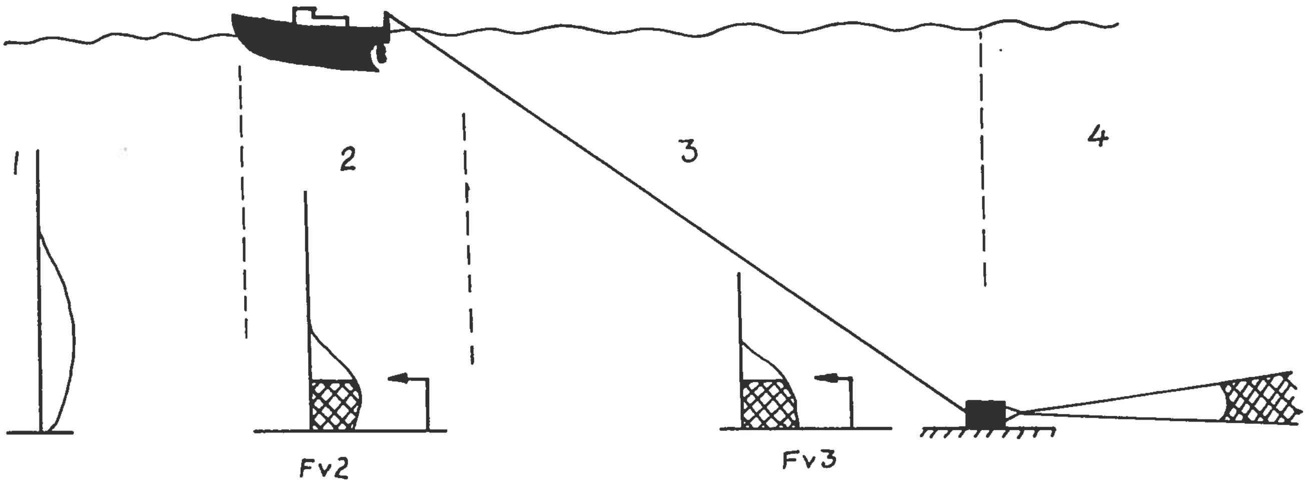


Figure 15. Four regions of fish response to an approaching ship and trawl after suggestions by E. Ona. The undisturbed vertical profile of the fish abundance can be as in zone 1 before the approach of the ship, what is seen on the echosounder and integrated can be as in zone 2 under ship. There could be more change in zone 3, so that by the time the otterboards approach the fish, there is another vertical profile with another vertical availability coefficient FV3, which determines the number of fish encounters to the gear. Vessel noise, vessel lights, and warp, may all have an effect. Zone 4 is the region of herding and avoidance.

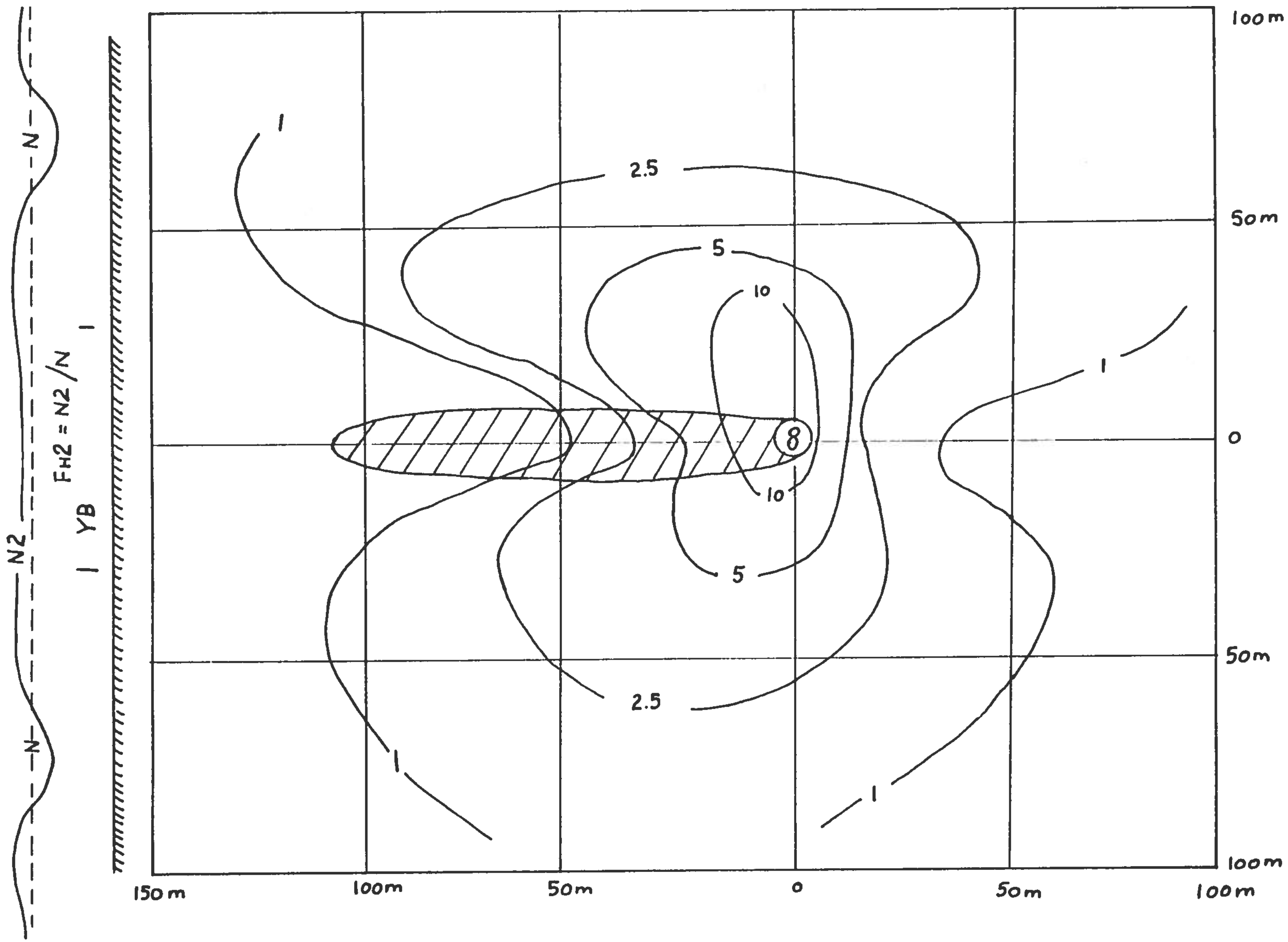


Figure 16. Noise field from a ship, mainly propeller noise, redrawn from Urick (1967). A freighter at 8 knots. Contours are pressures in dyne/cm² in a 1 Hz band, measured in octave band 2500 to 5000 Hz. Under the ship the butterfly wings fold downwards. There are areas of relative silence in front of and behind the ship. If there is "ploughing" effect it seems likely to cause a double furrow, the depleted zones being outside otterboard spread and possibly some build up in the trawl path.

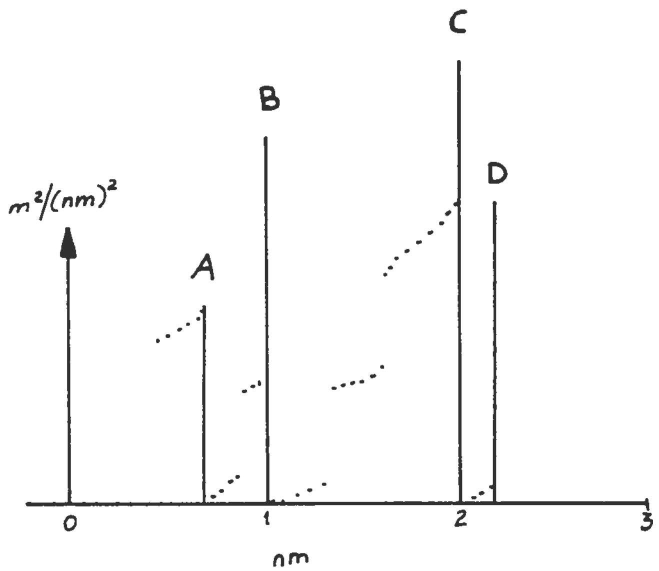


Figure 17. With the old QM analogue integrator output, it was possible to see ground echo breakthrough in the form of jumps in the trace.
A: is the reset at the start of the two
B: is the next mile marker
C: is the next mile marker
D: is the reset at the end of the tow, totalling 1.5 nm from A to D.
The possibility of some similar type of display from the BAR (QD) channel would be helpful.