International Council for the Exploration of the Sea

CM 2004/R:24

Positive relationships between bottom trawl and acoustic data

D.J. Beare, D.G. Reid, T. Greig, N. Bez, V. Hjellvik, O.R. Godo, M. Bouleau, J. van der Kooij, S. Neville, S. Mackinson.

ABSTRACT

Demersal fish stock biomass is usually estimated using commercial landings data, 'tuned' by various types of survey data, usually trawl. When collecting fish data by trawl it is only possible to take relatively small numbers of samples, but each component of the catch can be measured and resolved to species. Acoustic data, on the other hand, are easy to collect since continuous sampling can be maintained at speed (10 knots) but discerning species and size structure from data is difficult. Here we investigate whether these two different measurements of the same quantity (fish abundance/biomass) are actually related to each other. To do this, databases were built that consisted of simultaneous acoustic and catch data collected during a trawl haul. These are described as 'on station data'. Both trawl haul and acoustic data were found to have high variances and direct correlation between them tended to be weakly positive, although the spatial and temporal trajectories captured by both the trawl and acoustic data were similar. The reasons for this apparent inconsistency are explained. In many situations, however, direct positive correlation was found; relationships perhaps strong enough to be extended to acoustic data collected between trawl stations, ie. 'underway data'. Factors leading to such situations are also described. Given the number and characteristics of the favorable cases, we go on to comment whether such relationships can realistically be used in the construction of combined trawl and acoustic indices and under which conditions.

Keywords: acoustics, trawls, fish, stock assessment.

D.J. Beare, D.G. Reid and T. Greig : Fisheries Research Services, Marine Laboratory, PO Box 101, Victoria Road, Torry, Aberdeen, Scotland AB9 9DB [tel :+44(0)1224 295314, email : d.beare@marlab.ac.uk].
N. Bez and M. Bouleau: Centre de Géostatistique, 35 Rue Saint Honoré, F-77305 Fontainebleau, France [tel: +33 1 64694700, fax: +33 1 64694705, e-mail: nicolas.bez@ensmp.fr, mireille.bouleau@ensmp.fr].
O.R. Godø and V.Hjellvik: Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway [tel: +47 55 23 85 00, fax: +47 55 23 85 31, e-mail: olavrune@imr.no and vidarh@imr
S. Mackinson, S. Neville and J. van der Kooij,CEFAS Lowestoft UK [tel. +44 1502 524295, fax. +44 1502 5242 95, emails : s.mackinson@cefas.co.uk, S.Neville@cefas.co.uk, J.Vanderkooij@cefas.co.uk]

1. INTRODUCTION

This work was inspired by the European Union funded project, CATEFA ('Combining Acoustic and Trawl data for Estimating Fish Abundance'). The principal objective of CATEFA was to develop and apply methodologies for the effective, simultaneous, use of both acoustic and trawl data from bottom trawl surveys which has been done successfully in Canadian waters (McQuinn *et al.* 1999). This is in recognition of the fact that bottom trawl surveys remain the most important, fisheries independent, data source used in stock assessment of commercial groundfish in European waters. A further motivation was that the relatively high sampling resolution of acoustic data, as compared to trawl data, in space and time should, potentially, be able to improve the precision and accuracy of bottom trawl surveys at little extra cost. Specifically, the project set out to determine statistical relationships between acoustic and trawl data at various levels of aggregation, the idea being that any relationships found could then be exploited in the calculation of new combined stock abundance indices which again could be tested within the stock assessment process.

It was originally intended that there would be no detailed ‘scrutiny’ of the echograms (Reid *et al.* 1998), which is time consuming and may require expert knowledge and an element of subjectivity (Petitgas *et al.* 2003). Instead, the acoustic data were divided into *ad hoc* depth layers which would then be related directly to the trawl data using a suite of statistical methods. The approach was adopted for reasons of practicality, connected with the ultimate goal of the project, ie. it should be possible to incorporate any useful extra information brought by the acoustics into abundance indices straightforwardly and objectively. The further, tantalising, prospect was that underway acoustic data might ultimately be used in the complete absence of trawls in much the same way as they are used in the assessment of pelagic stocks (Simmonds 2003). Abundance ‘indices’ are spatially weighted time-series, usually organised by age (Cook 1997) used by stock assessment scientists to ‘tune’ commercial catch-at-age data prior to Virtual Population Analysis (VPA) type stock assessments (Kimura 1986).

When work on the project began, it quickly became apparent that useful relationships between the simultaneously collected bottom trawl and acoustic data were difficult, although not impossible to find. In this paper, possible reasons for the weaknesses and strengths are explored and discussed using databases consisting of simultaneous trawl and acoustic data collected in the North Sea and Barents Sea. One intention is to emphasise positive aspects and to point out to the scientific community that combining acoustic data with trawl data for use in demersal stock assessment may not be outside the bounds of possibility.

2. METHODS

Data collected by Fisheries Research Services, Aberdeen (FRS) and the Institute of Marine Research, Bergen (IMR) were analysed during the current study. Exhaustive details, (e.g. descriptions of bottom detection algorithms) pertaining to the collection and preparation of the acoustic and trawl data used, are available in the first annual progress report of the CATEFA project (“The quality controlled data sets including meaningful sub-divisions for further analysis for the CATEFA project”) available by anonymous ftp from a remote server called cg.ensmp.fr. The file is a Microsoft Word document, D1.1.doc, in directory /pub/users/bez/CATEFA.

2. 1. Acoustic data

FRS data were collected during routine trawl (1999-2003) surveys done in the first quarter of the year (usually the last half of January and the beginning of February). The surveys are done in the northern North Sea in an area bound by 56 to 62^{o}N and 5^{o}E to 3^{o}W (Fig. 1). The depth range of the FRS ‘on station’ hauls ranged between 45m and 150m with bottom temperatures ranging between 6°C and 9°C. The acoustic data were collected using a Simrad EK500 scientific echosounder with a 38kHz split-beam transducer mounted on a drop keel, allowing operation both between and on stations without degradation in the data due to platform attitude changes. The drop keel also allowed operation in the generally poor weather conditions encountered in this area at this time of year. Pulse length was set at

1ms, and the minimum detection level for the bottom, in decibels (dB), was the default value at –50.0 dB. Data were stored and then processed using SonarData Echoview© software, where Nautical Area Scattering Coefficient (NASC) values were exported at a 21cm vertical resolution and a horizontal resolution of 0.5 nautical miles. Original data were acquired at resolution thresholds of –120dB for later processing to –60, -70 & -80dB thresholds. Acoustic data were taken while trawling at *ca* 4 knots, and while steaming between stations at *ca* 10 knots. Elementary Sampling Distance Units (EDSU) – the horizontal (along track) bins for integration of the acoustic data - were set at approximately 2 nautical miles for data, collected while trawling ("on-station" data) and at 0.5 nautical miles for "underway" data. The FRS data were divided into 14 depth layers. Starting at the seabed, depth layers 1-10 were 1m wide, while layers 11-13 had a width of 10m. Two possible 'layer 1' datasets were available, depending on the bottom detection algorithm. This was, either the default sounder detected bottom, or alternatively the acoustic data were integrated with a 20cm 'backstep' from the seabed. The latter protocol was tried to avoid contamination with the seabed.

The Barents Sea (IMR) data were collected in a similar manner, also during routine surveys (1997-2002; Fig. 2). Overall, bottom depths were far greater in the Barents Sea and ranged between 55m and 700m, while sea bottom temperatures were lower (–1.8°C to 6.8°C) than those recorded from the North Sea. The Barents Sea surveys are also done in quarter 1, specifically during January and February. Spatial coverage has varied slightly between years but typically encompassed the area, 15^{o}E to 45^{o}E and 69^{o}N to 76^{o}N. A Simrad EK500 echosounder was also used in the Barents Sea, but the data were processed using Bergen Echo Integrator (BEI). Since the Barents Sea is much deeper than the North Sea the acoustic data were divided into 30 depth layers of equal width.

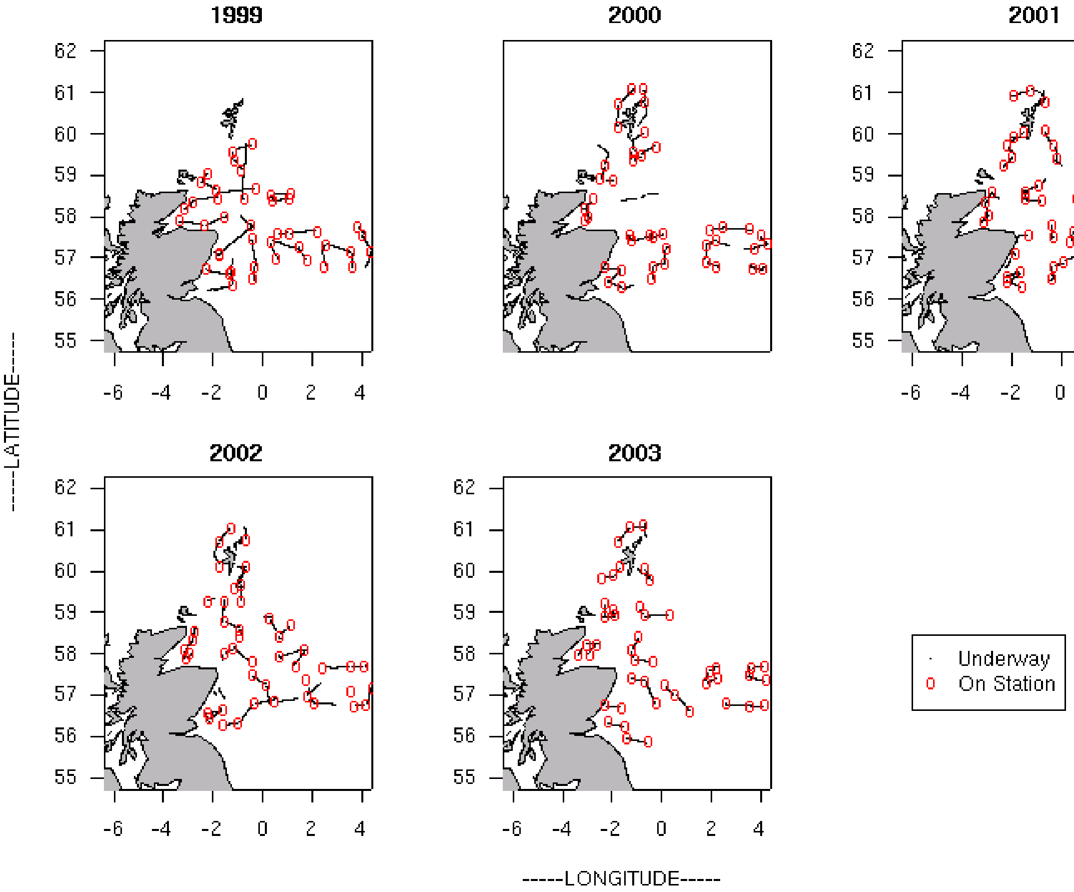

Figure 1. Location of the combined acoustic and trawl surveys done in the North Sea between 1999 and 2003.

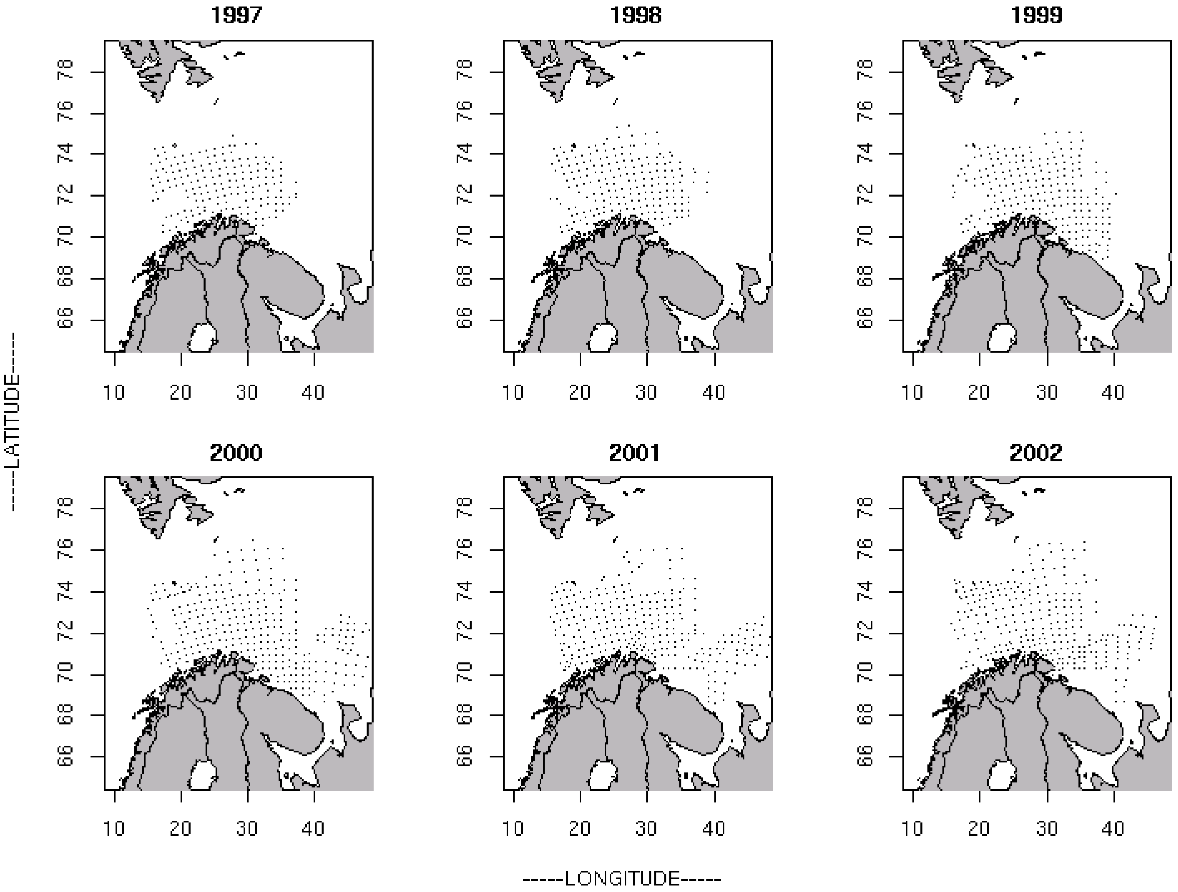

Figure 2. Location of the Barents Sea data (only 'on-station' data displayed).

2. 2. Trawl data

The fish caught during each tow provided five quantities per species; number caught, root mean square length, mean target strength, mean weight and equivalent NASC (ENASC). Equivalent NASC was calculated from the trawl length-frequency data as

(1) $$ENASC = 4\pi \cdot 1852^2 A^{-1} \sum_{L=1}^{\max} n_L (L+0.5)^2 10^{TS/10}$$

where L is fish length in cm, n_L number of length L fish, A is the swept area in m^2 and TS is the target strength. This was done so that the acoustic and trawl data could be quantified and compared on the same unit of measurement. Eight species occurred commonly enough in the North Sea surveys to be treated individually. These were; haddock, whiting, norway pout, herring, sprat, common dab, long rough dab and grey gurnard. In addition, three categories were defined according to habit; demersal, pelagic and flatfish. The piscean fauna of the Barents Sea was quite different to that of the North Sea, and the following species were the most important; cod, haddock, redfish, saithe, polar cod, capelin, herring and blue whiting. [Note: two species (cod & haddock) were common to both FRS and IMR survey areas].

2.3. Data analyses

The following two main approaches were taken to compare on station trawl data and acoustic data.

2.3.1. Relating acoustic data and trawl data directly to each other

In the first instance ENASCs (NASCs; see MacLennan et al., 2002 for a full description) from the trawl length-frequency data for each species were simply plotted against NASCs from acoustic data by depth layer. [Note: during analyses NASC data were log-transformed because of skew frequency distributions]. An example of this approach, together with correlation coefficients (*r*) can be seen in Figure 3. It suggests weak to non-existent relationships between the trawl and acoustic data sources and is unlikely to be useful for our purposes. For norway pout in the North Sea 2003 survey (Fig. 3), correlations are very low (r=0.41) even close to the seabed. The explanation for the lack of a relationship is that each acoustic NASC value potentially comprises an aggregation of species; whereas the trawl ENASC data are resolved to species. To be useful it was therefore decided to partition the acoustic NASC value according to the estimated proportion of each species in each local trawl haul according to,

$$(2) \qquad PNASC_{layer} = NASC_{layer}\left(\frac{ENASC_{cod}}{ENASC_{total}}\right)$$

where $ENASC_{total}$ is the total ENASC from the relevant trawl haul. As an illustration, if there were 50% cod by ENASC in a particular haul, then only 50% of the relevant acoustic NASC would be used. This latter approach resulted in considerable improvement in direct correlations between trawl and acoustic data (Fig. 3), e.g. for norway pout in the 2003 North Sea survey, *r* rose from 0.41 to 0.85. In fact this approach is equivalent to what is done during a standard acoustic biomass surveys for pelagic fish species such as herring and is perhaps not surprising (Bailey *et al.* 1998; Maravelias *et al.* 1996; Simmonds *et al.* 1992).

The trawl data consist of only one layer, while the acoustic data were available for 14 (North Sea) or 30 (Barents Sea) different layers. In order to see which acoustic layer was related most strongly to the trawl ENASCs, correlation coefficients were extracted and plotted against the central point of each depth layer (e.g. Fig 4).

2.3.2. Relating trawl and acoustic data to spatial and temporal information

Relationships between the two measurements of fish biomass were further explored by examining the dependence of the on station acoustic and trawl data as functions of four other covariates: longitude, latitude, sea bottom depth and the time of day. Visual methods were initially used as exploratory tools. Finally the relationships were summarised using regression models fitted using the statistical software package ‘R’. For details see, www.cran.r-project.org. Non-linear dependence was quantified within the models using spline smooth terms available in the ‘R’ library, ‘splines’ (Hastie & Tibshirani 1990).

3. RESULTS

3.1.1. Relating acoustic data and trawl data directly to each other

The CATEFA project generated a large amount of data for surveys done across Europe. The variability inherent in these types of data, the range of hydrographic situations and species assemblages make it very difficult to find common trends and make useful summaries. For the purposes of this study a few examples have been selected to emphasise what we believe to be important aspects. For the North Sea data, direct linear correlations between the trawl data and acoustic data were generally weak, even when the acoustic NASCs were partitioned according to the trawl data. There were some examples (see Figs 3 & 4) where relationships were strong and linear, particularly for norway pout, for which a correlation coefficient of r=0.93 was calculated for bottom layer 1 with no backstep (see Fig. 3). For the more important demersal species like cod, haddock and whiting, however, correlations were normally below r=0.4 implying weakly linear positive relationships (Figs 3 & 4). Connections between trawl and partitioned acoustic data were far stronger in the Barents Sea. One of the weakest relationships, found in the 1997 database, is that for cod (r=0.53 for the 0m to 10m layer) and is plotted in Figure 5. For most of the other species recorded in the Barents Sea (see Fig. 5) correlation coefficients for the bottom most layers were usually above r=0.8 (Fig. 6). Correlation between acoustic and trawl data fell with distance from the seabed in both the North Sea and Barents Sea (Figs 4 & 6). The detailed shape of this pattern was highly variable, depending on the particular species and associated behavioural factors, but a sharp fall in correlation as distance from the seabed increased, followed by a more gradual decline was very typical.

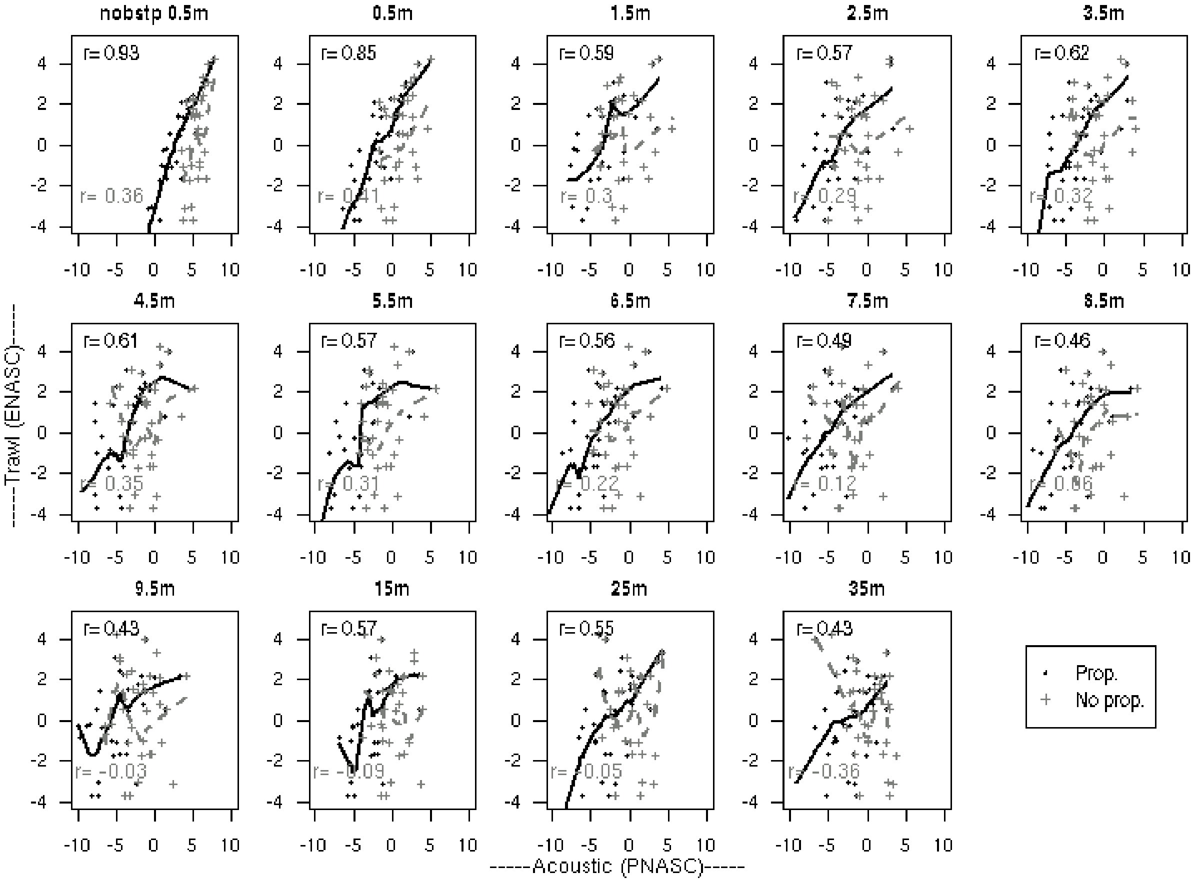

Figure 3. North Sea 2003 survey: relationship between acoustics and trawl for norway pout. NASC (black dots and lines) and PNASC (grey crosses and broken lines) plotted against ENASC. In both datasets, trends are summarised with smooth functions.

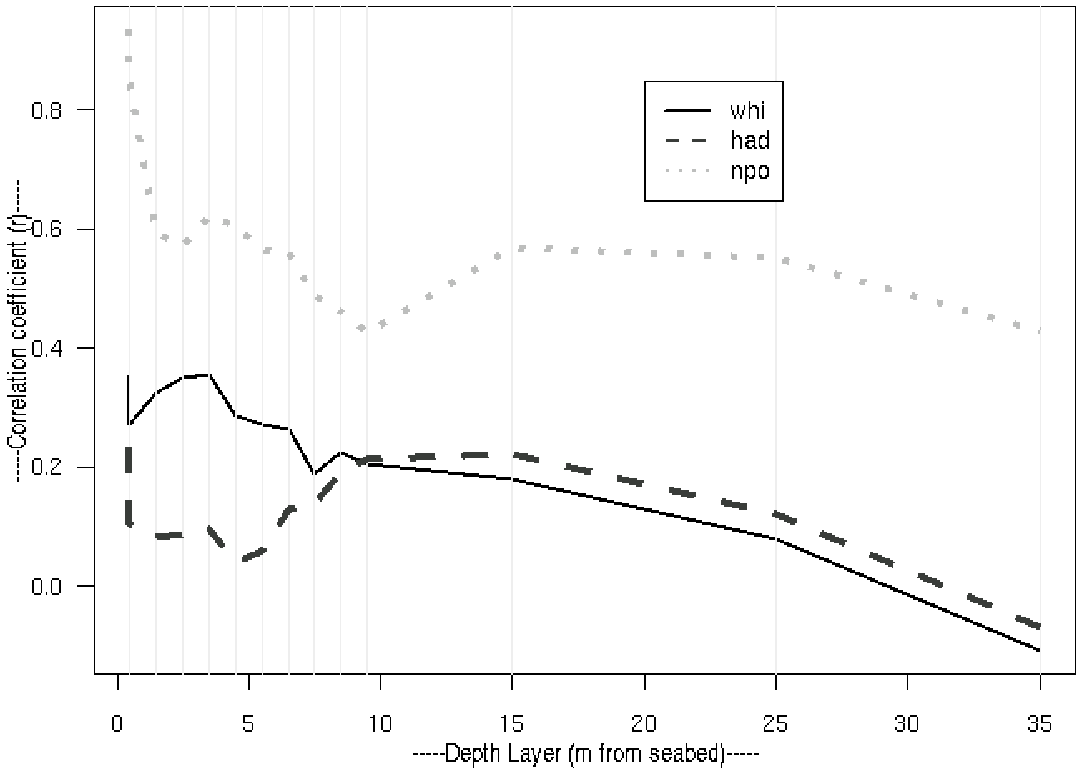

Figure 3. North Sea survey 2003: correlation coefficients reflecting the relationship between trawl data (ENASC) and acoustics (PNASC) for three demersal species (had=haddock, sai=saithe, npo=norway pout).

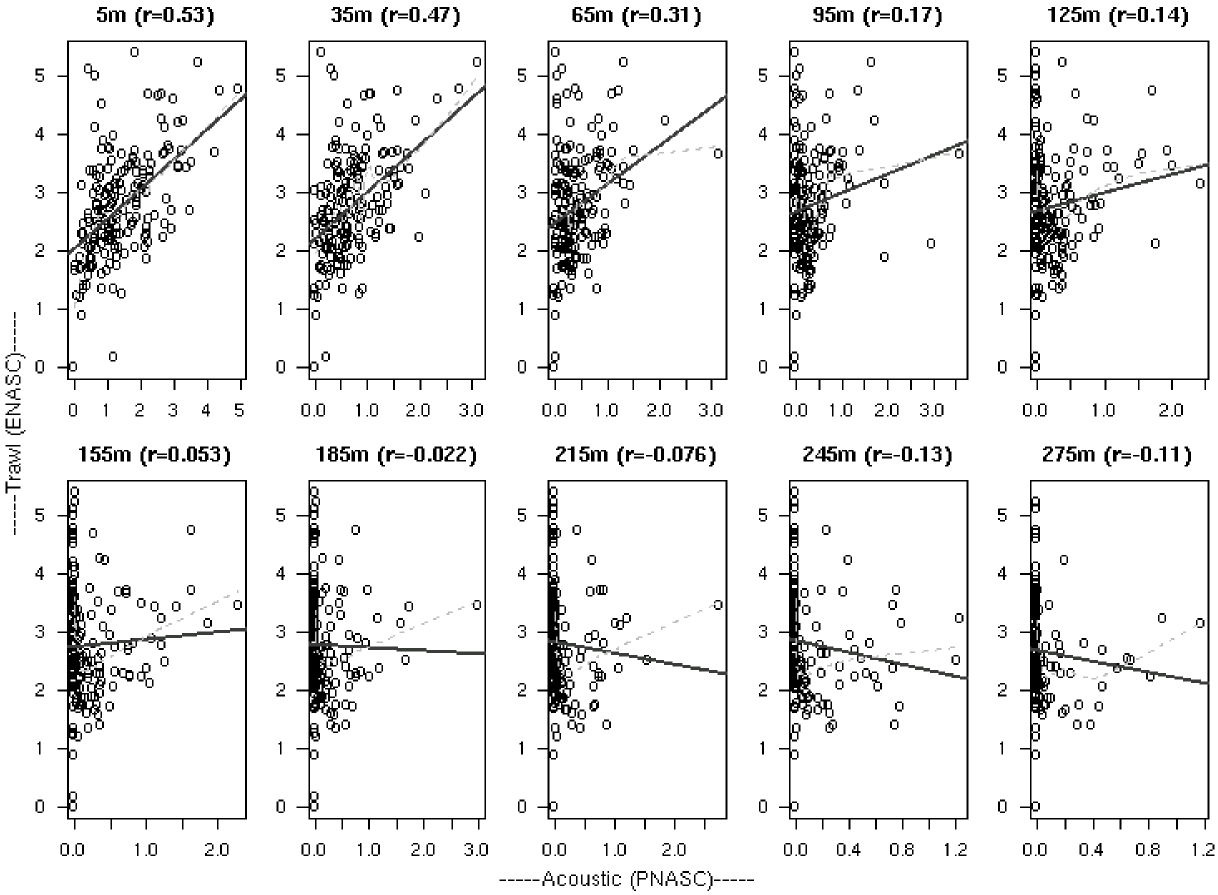

Figure 5. Barents Sea 1997 survey: relationship between acoustics and trawl for cod. PNASC (see equation 2) plotted against ENASC. The solid lines are regression lines. The relationships are further summarised with a smooth functions (grey broken lines) and correlation coefficients (in parentheses).

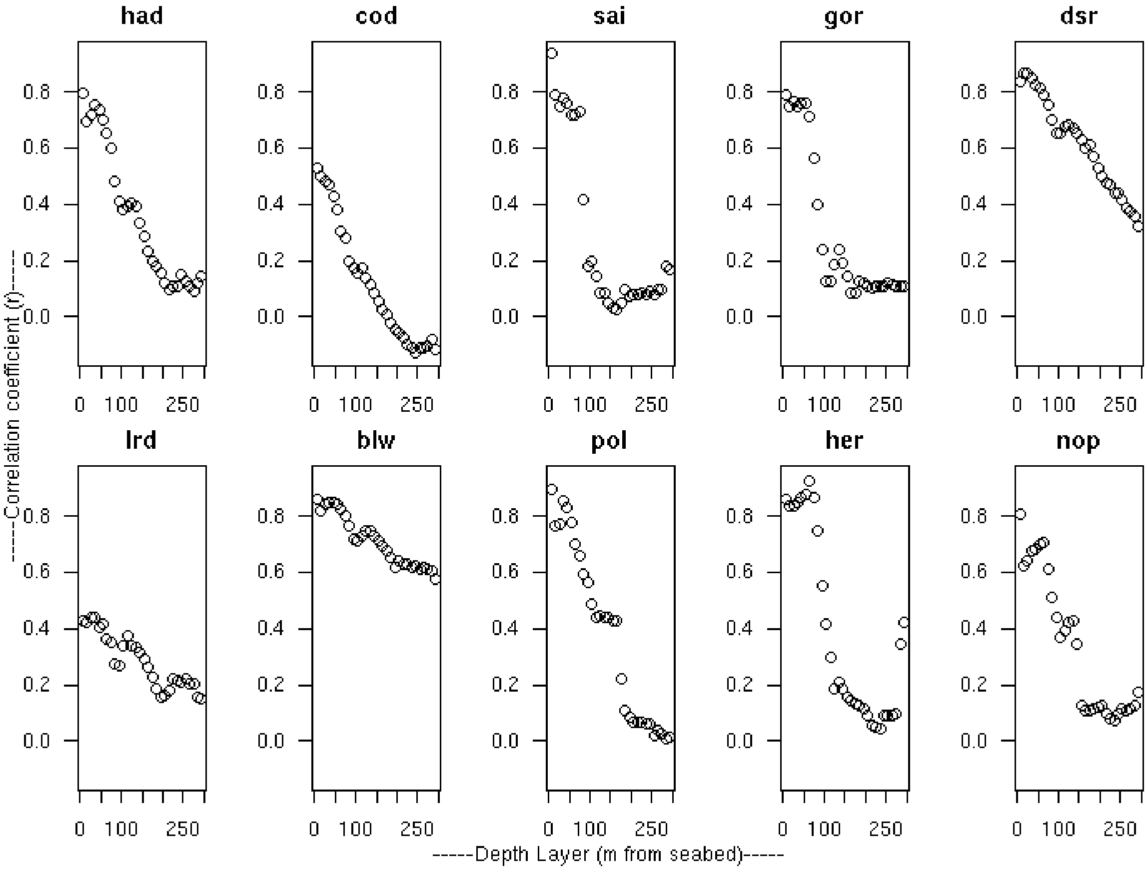

Figure 4. Barents Sea 1997 survey: correlation coefficients reflecting the relationship between ENASC and PNASC as a function of height above the bottom for 10 species (had=haddock, cod=cod, sai=saithe, gor=golden redfish, dsr=deepsea redfish, lrd=long rough dab, blw=bluewhiting, pol=pollack,her=herring and nop=norway pout).

3.1.2. Relating trawl and acoustic data to spatial and temporal information

The *direct* relationships between trawl and acoustic data were weak, especially in the North Sea. In spite of this observation, both acoustic and trawl data reflected very similar patterns of fish abundance when examined along spatial (longitude, latitude & bottom depth) and temporal (time of day) trajectories instead. In the North Sea, haddock abundance increases steadily between bottom depths of *ca* 50m and 120m and then falls away steadily (Fig. 7) and this feature is reflected by both the trawl and acoustic datasets. Furthermore, the absolute levels of NASC are very similar indicating that the acoustics and trawls are genuinely measuring the same quantity and that the equivalent NASC calculation is useful.

In the Barents Sea connections between the acoustic data and trawl data, when observed as functions of location and time of day, were even more compelling (Fig. 8). Both fish biomass measurement methods show that haddock abundance falls with distance North (latitude) and increases with distance west (longitude) until *ca* 30°E when it declines. The pattern of depth dependence, with a peak at *ca* 300m bottom depth, was also very similar in shape (Fig. 8). A slight difference in haddock diel patterns of abundance was observed.

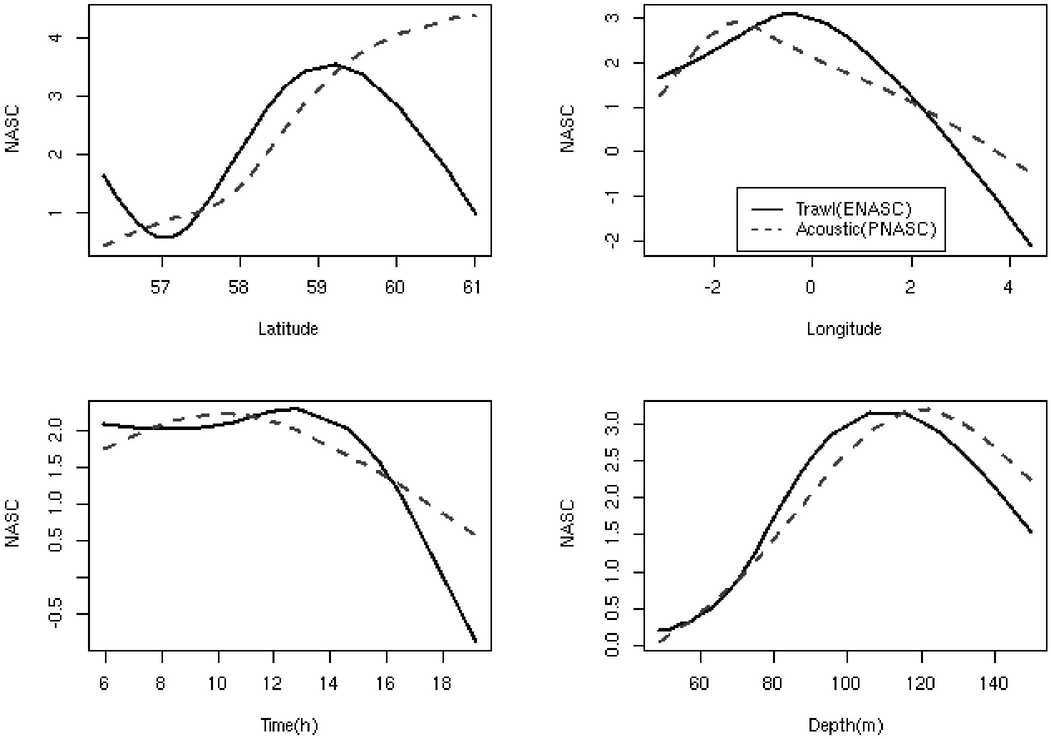

Figure 5. North Sea data 2002: relationship between two measures of haddock abundance (solid line=trawled ENASC, broken line=acoustic PNASC) and latitude, longitude, time of day and depth.

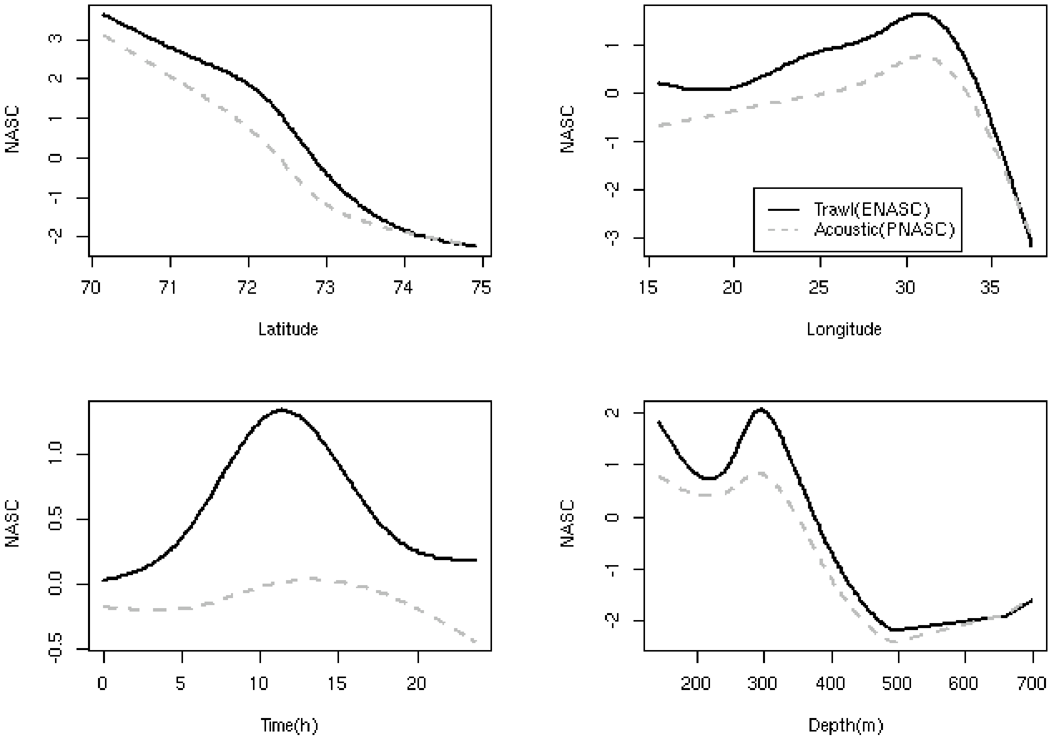

Figure 6. Barents Sea data 1997: relationship between two measures of haddock abundance (solid line=trawled equivalent NASC, broken line=acoustic proportional NASC) and latitude, longitude, time of day and depth.

4. DISCUSSION

The present study set out to determine links between simultaneously collected trawl and acoustic data. We have demonstrated that an *ad hoc*, objective layering treatment of the acoustic data, coupled with information on species composition from trawls, can result in strong, positive linear relationships between trawled equivalent NASCS and acoustic proportional NASCs for demersal species such as cod and haddock. Our analyses also indicate that improved quantification of trawl data by acoustic data may not be possible in the context of the annual demersal stock assessment process (Anonymous 1997). We have shown that, for reasonable, positive relationships to emerge, assumptions relating to the proportion of each fish species in the trawl need to be extended to the acoustics. Until robust methods for extrapolating these proportions into unsampled areas are developed, the use of underway acoustic data by themselves, for the quantification of complex demersal fish stock assemblages remains risky. It should also be noted that when echograms are scrutinised very carefully some puzzling conclusions emerge. It is often possible to observe haddock and whiting in the trawl but nothing whatsoever on the associated echotrace (Godo *et al.* 2004). It is then necessary to enquire why partioned NASCs improve correlations between trawl and acoustic data. Positive acoustic NASCs are always observed, due to plankton etc., and zeros are never recorded. Hence when proportions (from trawls) are assigned, for example, as species *A* to an acoustic NASC, correlations improve despite the fact that no species *A* were seen on the echosounder.

If methods to extrapolate species compositions reliably become available, then it may be possible to establish relationships between trawl and acoustic data that lead to improved abundance indices. This, though, will also depend on the species in question, and where the data were collected. In the Barents Sea, for example, the connections were far stronger than in the North Sea, although even the relatively high correlation coefficients of r=0.8 translate into low R^2 values of 0.64. Prediction intervals (Ott 1988) from such relationships/models will, therefore, be far higher than one would want from a calibration of this type.

There are a variety of reasons why relationships in the Barents Sea were stronger than those observed in the North Sea. The Barents Sea data were far richer spatially with between 150 and 200 stations available (Fig. 2) whereas each North Sea survey comprised only between 40 and 50 stations (Fig. 1). The Barents Sea is also much deeper than the North Sea, so signals due to fish abundance are more pronounced and easier to detect. The depth range (50m to 700m) for haddock, for example, in the Barents Sea is far greater than in the North Sea (50m to 200m) so there will be more variation due to depth and the signal will be relatively more straightforward to reveal.

Direct relationships between trawl and acoustic data were weak, especially in the North Sea, while indirect relationships were often very similar. By the term ‘indirect’ we mean the independent connections between the trawl and acoustic data and other information such as location. This phenomenon is observed because both trawl and acoustic data are ‘noisy’ or variable. This high variability can be caused by a range of complex factors. The echosounder may not follow the path of the trawl exactly; or perhaps a fish school sampled acoustically might move out of the trawl path altogether so the two measurement tools might not actually be sampling the same groups of fish. A consequence is that when the data from each source are simply plotted pairwise against one another, the high degree of variation around each datum obscures the connection. When, however, the same two datasets are ‘ordered’ according to other important information such as depth, and a trend estimated, the signals can be surprisingly similarly shaped in spite of the noise (see Figs 7 & 8). The next question is whether this information can be incorporated into the calculation of new abundance indices. The lines displayed (Figs 7 & 8) are fitted values from regression models and are thus ‘smooth’ and highly autocorrelated by definition. Although these model outputs are strongly related to each other (Fig. 8), it is unlikely that one would be able to predict one from the other because the smoothness of each dataset violates statistical assumptions such as that of ‘independence’. Further work in this direction may, however, be worthwhile.

In conclusion, there is no doubt that the trawls and acoustics are measuring a quantity that is reflected by both. Until reliable algorithms for identifying species from acoustics are developed, however, it seems unlikely that acoustic data can or will be used to improve demersal survey abundance indices in areas other than the Barents Sea. Much of the work done on combined acoustic and trawl datasets has concentrated on the differences in the data collection methods, and how these expose different behaviour by fish (Aglen *et al.* 1999; Michalsen *et al.* 1996). It maybe that future investigations that focus, instead, on revealing behavioural and relative catchability differences (Hjellvik *et al.* 1999) may ultimately be more useful in stock assessment.

4. REFERENCES

Aglen A., Engaas A., Huse I., Michalsen K. & Stensholt B. K. (1999) How vertical fish distribution may affect survey results. *ICES Journal of Marine Science* 56: 345-360.

Anonymous (1997) Report of the working group on the assessment of northern shelf demersal stocks. ICES, Copenhagen.

Bailey M. C., Maravelias C. D. & Simmonds E. J. (1998) Changes in the spatial distribution of autumn spawning herring (*Clupea harengus* L.) derived from annual acoustic surveys during the period 1984-1996. *ICES Journal of Marine Science* 55: 545-555.

Cook R. M. (1997) Stock trends in six North Sea stocks as revealed by an analysis of research vessel surveys. *ICES Journal of Marine Science* 54: 924-933.

Godo O. R., Hjellvik V., Greig A. & Beare D. (2004) Can subjective evaluation of echograms improve correlation between bottom trawl and acoustic densities? In: *ICES Annual Science Conference, Vigo.* ICES C.M. 2004/R:23.

Hastie T. & Tibshirani R. (1990) *Generalized Additive Models*. Chapman & Hall, London.

Hjellvik V., Godø O. R. & Tjoestheim D. (1999) Modelling diurnal variation in bottom trawl catches and potential application in surveys. In: *Proceedings of International Council for the Exploration of the Sea* (ed. ICES) pp. 28 pp. ICES, Copenhagen (Denmark), Stockholm (Sweden).

Kimura D. K. (1986) Variability, tuning and simulation for the Doubleday-Deriso Catch-at-age model. *Canadian Journal Fisheries & Aquatic Sciences* 46: 941-949.

Maravelias C. D., Reid D. G., Simmonds E. J. & Haralabous J. (1996) Spatial analysis and mapping of acoustic survey data in the presence of high local variability: geostatistical application to the North Sea herring. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 1497-1505.

McQuinn I. H., Simard Y., Stroud W. F., Beaulieu J. L., McCallum B. & Walsch S. (1999) An adaptive integrated acoustic-trawl survey on Atlantic cod. In: *Proceedings on International Council for the Exploration of the Sea* (ed. ICES) pp. 22 pp. ICES, Copenhagen (Denmark), Stockholm (Sweden).

Michalsen K., Godø O. R. & Fernoe A. (1996) Diel variation in the catchability of gadoids and its influence on the reliability of abundance indices. In: *Proceedings of an ICES International Symposium held in Aberdeen, Scotland, 12-16 June 1995, 389-395* (ed. D. N. Maclennan). ICES Journal of Marine Science, Aberdeen (UK).

Ott L. (1988) *An introduction to statistical methods and data analysis*. PWS-KENT Publishing Company, Boston.

Petitgas P., Masse J., Beillois P., Lebarbier E. & Le Cann A. (2003) Sampling variance of species identification in fisheries acoustic surveys based on automated procedures associating acoustic images and trawl hauls. *ICES Journal of Marine Science* 60: 437-445.

Reid D. G., Fernandes P. G., Bethke E., Couperus A., Goetze E., Hakansson N., Pedersen J., Staehr K. J., Simmonds E. J., Toresen R. & Tortensen E. (1998) On visual scrutiny of echograms for acoustic stock estimation. *ICES CM/J:3*.

Simmonds E. J. (2003) Weighting of acoustic- and trawl-survey indices for the assessment of North Sea herring. *ICES Journal of Marine Science* 60: 463-471.

Simmonds E. J., Williamson N. J., Gerlotto F. & Algen A. (1992) Acoustic survey design and analysis procedure: A comprehensive review of current practice.