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Insight on fish reaction to the presence of trawl from the comparison of acoustic data recorded during and between trawl stations

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In many cases, people also collect acoustic data during bottom trawl surveys. The inclusion of acoustic recordings in the estimation process could potentially improve the precision and accuracy of the estimations if acoustic data collected between trawl stations are consistent with that collected during trawling operations. The present paper deals with this latter consideration. First, on station and underway acoustic data are compared using statistics computed globally over an entire survey area. This amounts to comparing the average vertical profiles, and the spatial structures of the acoustic data integrated over various combination of depth layers. Second, we focus on underway data recorded in the vicinity of stations, distinguishing between data recorded before and after the tows. The objective is to avoid masking possible differences due to spatial non homogeneity between on station and underway acoustic data.
Contrary to expectation, on station and underway acoustic data happen to be highly consistent and no systematic perturbation of the gear is observed at the study scale.

Key words : Trawl, acoustic, gear perturbation

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1 Introduction

Bottom trawl surveys are one of the key survey metiers used in the assessment of demersal fish stock around the world (Gunderson, 1993), and have been used for many years. More recently it has become possible to carry out combined acoustic and bottom trawl surveys e.g. in the Barents Sea (Aglen and Nakken, 1997; Korsbrekke et al., 2001) or to collect simultaneous acoustic survey data while carrying out a bottom trawl survey (Cachera et al., 1999; Krieger et al., 2001). In some cases the acoustic data are used to generate a secondary abundance index from the survey in addition to a trawl catch rate index, e.g., Barents Sea cod (Korsbrekke et al., 2001). Another approach would be to use the acoustic observations to provide more information e.g. on fish availability, or distribution away from the trawl station, to improve the precision and accuracy of the trawl based estimate. These two approaches were the basis for the EU funded (Framework Programme 5) project CATEFA (Combining Acoustic and Trawl data for Estimating Fish Abundance).

Two hypotheses need to be confirmed to allow this combination of acoustic and trawl survey data. The first is that the fishing gear and the acoustic devices are measuring or observing the same things. This would allow us derive a relationship between trawl catch and acoustic observations (Krieger et al., 2001; Hjellvik et al., 2003). This can be based on investigation of the catch data and the on-station acoustic record, and will be reported elsewhere. The second is that acoustic data collected away from the trawl stations is consistent with that collected during the trawling operations. The present paper deals with the second hypothesis.

There is considerable evidence that fish will show avoidance behaviour to the trawl/ vessel combination (Godø et al., 1999; Michalsen, 1999; Handegard et al., 2002; Kloser and Horne, 2003). During trawling, the vessels are generally moving at low speeds (e.g. around 5 knots) and, of course, towing a large and noisy net. Away from the trawl stations the vessel will be moving faster (usually over 10 knots) and without a net. There is mixed evidence of whether fish will also avoid in this situation (Mitson and Knudsen, 2003; Fréon and Misund, 1999; Fernandes et al., 2001). Different avoidance reactions and hence availability to the echosounder could have a significant impact on what is seen on the echogram. For the acoustic data away from the trawl stations to be useable in the context of improving trawl survey estimates or of combining the data, we must be sure that the echosounder is seeing the same population in both situations. The present paper uses data from a number of different trawl surveys in the North, Irish and Barents Seas (Fig.1a). It examines the relationship between on-station and between-station acoustic data at both the local level (i.e. immediately adjacent to the trawl station) and more globally for each survey.

2 Material

Twenty bottom trawl surveys with coincident acoustic measurements comprising of five different survey series were used in this analysis (Table 1 summarises the main characteristics of each surveys):

1- the ICES co-ordinated International Bottom Trawl Surveys (IBTS) in the North Sea. They follow a random design stratified by ICES rectangle (Fig. 1b). Trawls and acoustic data are only taken in daylight hours. The surveys used in this study were those carried out by CEFAS - Lowestoft (2000, 2001 and 2002), FRS - Aberdeen (1999, 2000 and 2002) and IFREMER - Boulogne (2002 and 2003). Each survey comprises between 60 and 80 hauls. The North Sea data showed the most skewed distributions with many low values and a few extremely high values. For the French data for instance, 65 % of the total back-scattering energy on-station was concentrated in 3 % of the stations.
2- the Northern Irish Bottom Trawl Surveys (NIBTS) in the Irish Sea. These surveys are mostly small (20 or 30 hauls). They follow a random sampling design stratified by depth and substrate (Fig. 1c). Depth varied between 25 and 150 m. Four surveys carried out by DARDNI - Belfast were available: autumn 1997, spring 2000, autumn 2001 and spring 2002. These surveys tend to have much more pelagic fish (herring and sprat) than the North Sea or Barents Sea.
3- the combined acoustic and bottom trawl surveys for cod and haddock in the Barents Sea – carried out by IMR Bergen. Sampling follows a regular grid with a haul every 20 n.mi. (Fig. 1d) The number of hauls varied between 200 and 300. Available surveys were 1997, 1998, 1999, 2000, 2001 and 2002.

For the purposes of this study, the acoustic back-scattering energies were converted to Nautical Area Scattering Coefficient - NASC (MacLennan *et al.*, 2002) and expressed in $m^2 \cdot n.mi^{-2}$. The integration threshold was set at -70dB. NASC values were available both during and between trawl stations. For the on-station NASC, integration was carried out for the whole trawling period. In general the tow lengths were standardised within each survey series. For each survey series, the NASC values between trawl stations were available at fixed Elementary Sampling Distance Units (ESDU). However these were different between survey series: 0.1 n.mi. for IFREMER data, 1 n.mi. for IMR data, and 0.5 n.mi. for the rest of the datasets (Tab. 1).

As the ESDUs were different from average tow lengths, between-station NASC values were converted (i.e. regularized) to produce ESDU as close to the tow average lengths as possible for each survey series, namely, 3 n.mi in the Irish Sea, 1 n.mi. in the Barents Sea, and 2 n.mi in the North Sea.

NASC values for each ESDU or trawl station were subdivided into a series of bottom referenced layers (Fig. 2): ten one-meter layers sequentially from the seabed followed by several ten-meters layers. A key step in the analysis was to check the accuracy of the sounder detected bottom, and where relevant to correct it. This was achieved using manual or semi-automated analyses implemented in the acoustic data analyses. In the latter case, the layer closest to the bottom included a backstep to avoid integrating seabed. The backstep varied between surveys and, in some cases, weather conditions. The value used for the first layer was standardised to one meter when appropriate. Acoustic data preparation was carried out using SIMRAD BI500 for Norwegian data, Movies Plus for French data and SonarDat EchoView 3.1 for all other data.

When appropriate, clear and well defined pelagic fish schools were excluded from the data.

3 Methods

3.1 Notations

The superscripts indicate whether the parameter concerns on-station (^{o}) or between-station (^{b}) data. For instance, the numbers of samples taken on-station and between-stations are denoted N^{o} and N^{b} . Nonetheless, the formulae are only given for the on-station data. They can be directly transposed to between-station data by changing the superscripts.

The NASC values observed at sample number i are denoted $s_A^o(x_i, y_i, k)$ or $s_A^o(i,k)$ in short for $i \in \left[1, N^o\right]$. The longitude and latitude (x_i, y_i) are expressed in degrees. The number and the thickness of the depth layers are k and t_k. Given the data preparation protocol :

$$0 \le t_1 \le 1$$
$$t_k = 1 \text{ m} \quad \text{for } k = 2,...,10$$
$$t_k = 10 \text{ m} \quad \text{for } k \ge 11$$

When appropriate, data were standardised by the layer's height and converted into a Nautical Volumetric Scattering Coefficient s_V expressed in $\text{m}^2\cdot(\text{n.mi}^{-2}\cdot\text{m}^{-1})$:

$$s_V^o(i,k) = \frac{s_A^o(i,k)}{t_k}$$

To account for differences in the vertical distribution of NASC values, layers were eventually grouped into a set of "bottom" and "mid water" layers, that is, from the bottom to a given height and above that height. For the Barents Sea area, given the large average depth and the order of magnitude of the trawl height efficiency, the first 100 m of the water column, that is the first 19 layers, were split into groups below and above 40 meters (i.e., layer number 13):

$$s_A^o(i, \mathit{0\text{-}40}) = \sum_{k=1}^{13} s_A^o(i,k) \quad \mathit{and} \quad s_A^o(i, \mathit{40\text{-}100}) = \sum_{k=14}^{19} s_A^o(i,k)$$

For the other areas (North Sea and Irish Sea), the threshold was 10 meters.

3.2 Global statistics

3.2.1 Vertical profiles

For each survey, we computed the average vertical profiles for both on-station and between-stations NASC:

$$s_V^o(\square,k)=\frac{\sum_{i=1}^{N^o} s_V^o(i,k)}{N^o}$$

This allows visual comparison of vertical fish distributions seen on-station and between-station.

3.2.2 Horizontal structures

3.2.2.1 Global index of Collocation

The match between the two spatial distributions was evaluated using a Global Index of Collocation – GIC (Bez and Rivoirard, 2000). This index is based on the centre of mass and inertia of each spatial distribution. The centre of mass, for say, the on-station bottom layers in the Barents Sea ($CoM_{0\text{-}40}^o$), is computed assuming equal weight for each sample which corresponds to a regular sampling pattern:

$$CoM_{0\text{-}40}^o=\left(\frac{\sum_{i=1}^{N^o} s_A^o(i,0\text{-}40)\cdot x_i}{\sum_{i=1}^{N^o} s_A^o(i,0\text{-}40)}\quad,\quad\frac{\sum_{i=1}^{N^o} s_A^o(i,0\text{-}40)\cdot y_i}{\sum_{i=1}^{N^o} s_A^o(i,0\text{-}40)}\right)$$

The centre of mass is a vector of coordinates giving the mean location of the population in terms of longitude and latitude. The inertia

$$I_{0\text{-}40}^o=\frac{\sum_{i=1}^{N^o} s_A^o(i,0\text{-}40)\cdot\left((x_i-CoM_{0\text{-}40}^o)^2+(y_i-CoM_{0\text{-}40}^o)^2\right)}{\sum_{i=1}^{N^o} s_A^o(i,0\text{-}40)}$$

is expressed in surface units (typically square nautical miles) and quantifies the spatial dispersal of the population. The Global Index of Collocation (GIC) is:

$$GIC_{0\text{-}40}=1-\frac{(CoM_{0\text{-}40}^o-CoM_{0\text{-}40}^b)^2}{(CoM_{0\text{-}40}^o-CoM_{0\text{-}40}^b)^2+I_{0\text{-}40}^o+I_{0\text{-}40}^b}$$

It quantifies the amount of spatial overlap between the two populations. It ranges from 1 for fully spatially overlapping distributions to 0 when the two populations are distinct. It decreases quickly with spatial overlap. A GIC of less than 0.8 indicates a poor overlap.

3.2.2.2 Variograms

Spatial structures of the vertically integrated NASC values were compared in more detail using variography (e.g. Rivoirard et al., 2000). The aim was to compare the spatial structures, and not to make any estimation. We were therefore able to use the following log transformation:

$$\log\left(1+\frac{s_A^o(i,\square)}{m}\right)$$

where m is the mean of the data. This transformation introduces bias but does not preclude comparisons of spatial structures. It ensures that zero values remain zero after transformation. It reduces the differences between (relative to the mean) large data values. Compared to a simple log transformation $\log\left(1+s_A^o(i,\square)\right)$, it reduces the distortion of (relative to the mean) low data values. Finally, it is insensitive to a change in units for the original variable. For example, if NASC were expressed in $km^2 \cdot n.mi^{-2}$ instead of in $m^2 \cdot n.mi^{-2}$, this transformation would be unchanged while $\log\left(1+s_A^o(i,\square)\right)$ would be modified.

As we had to compare two sets of data with significantly different sample numbers (a few tens for on-station data and few hundreds for between-station), we would not expect variances to be the same (especially when dealing with skewed data). Therefore, we compared normalised variograms, i.e. variograms divided by their variance. Sills, where they were found, would be one. In two instances, a poor match was observed between the variograms of on-station and between-station data. The impact of extreme values were then investigated by excluding some of the largest data.

Normalised variograms were averaged by series of surveys using a weighted average by the number of pairs used at any distance lag, so that one variogram is produced per survey series.

3.3 Local statistics : before, during and after trawl

To test for the existence of small scale perturbations due to trawling operations (positive or negative), we focused analyses on the comparison between observations made during trawling and those made just before and afterwards. The objective was to test the null hypothesis (H0) that on-station and between-station NASCs were observations of the same phenomenon.

A window was defined to select between-station data just prior and just after each trawl station This window had to be small enough to provide local statistics but large enough to include sufficient observations. This compromise eventually led us to choose 3 nautical miles in most cases.

Bottom and mid-water layers have been summarized by a biomass information i.e. the NASC values integrated over the corresponding layers and, a vertical information i.e. the altitude of the centre of mass of the energy of the corresponding layers. The null hypothesis is then evaluated with regards to these two criteria for bottom and mid-water layers separately.

Assuming that the consistency between observations made before, during and after trawling is independent of the year, surveys of a given series are combined in order to increase the number of comparisons and to enhance statistical conditions.

Correlations between acoustic observations realized before, during and after the trawl stations are analyzed with reference to the correlation that exists between two successive between-station observations taken some distance away from the stations, i.e. where no trawl effect can occur. If there is a strong spatial structure, two successive between-station values will be, on average, similar due to their spatial proximity. In this case, before, during and after trawling observations will have to be very similar to accept H0. On the contrary, if the spatial structure is weak, the mean difference between two successive between-station values will be large and we will accept H0 even if a large, but equivalent, discrepancy exists between observations made before, during and after trawling. For each survey, we have thus randomly selected pairs of successive between-station data, so that three pairs of observations are available each time from which the following differences were computed: *during - before, during – after*, and, *random1 – random 2*.

Given that observations are paired, a one sample test on the paired differences is preferred to a two sample test on the difference on the means. The Wilcoxon test is used as the distributions of the paired differences are strongly non-gaussian. The p-value indicates the probability, under H0, that the mean difference exceeded the observed value. So, the larger the p-value, the most likely the mean difference equals zero, that is the better on-station and between-station data match. For tests with a 10% risk, p-values smaller than 0.10 leads to rejection of H0 and to the conclusion that on-station and between-station parameters are different.

3.4 Coordinates transformations

The computation of GIC or variogram and the selection of between-station observations nearby stations are based on geographical distances. Samples were then projected on a plan prior to the computations. Depending on the area, the algorithm is a gnomonic projection with a centre at E30^{o}00 for the Barents Sea data or a simple cosine transformation for the North Sea and the Irish Sea data.

4 Results

4.1 Vertical profiles

A clear and consistent trend exists across surveys and survey series in the vertical acoustic profiles (Fig. 3, 4 and 5). In general the mean NASC value is highest in the deepest one metre layer, and then reduces in a broadly exponential fashion over the next five to nine meters. Above this, the mean NASC is either relatively constant or decreases steadily. This is the case for both on-station and between-station data. Importantly, the differences between years are reflected consistently for on-station and between-station data. For instance in the FRS data (Fig. 4a) the increase in mean NASC between 4 and 7 m in 2003 is replicated in both on-station and between-station profiles. Similarly, the unusual increase in mean NASC over the first 2 metres in the CEFAS data for the 2002

February survey occurs in both (Fig. 4b). Additionally, there is no general pattern of on-station or between-station being systematically larger than the other. For the Irish Sea where a lot of the energy comes from fish schools, this trend only appears after dense (pelagic) school echo traces have been filtered out from the analyses (Fig. 5). If these are retained, they result in a more bell-shaped vertical profile with the maximum energy being on average a few meters above the bottom.

4.2 Global Index of Collocation

In 75% of the case studies (Fig. 6), GICs are above 0.9. This means that the spatial distributions described by on-station NASC are similar to the between-station NASC. In only two cases, the GIC was much lower (around 0.6) due to the large distances between the centres of mass with regards to the respective dispersion of each population (i.e. inertia).

No systematic difference is observed between the ” bottom” and ”mid-water” layers. On average, ”mid-water” GICs are smaller than those of ”bottom” layers. However, this difference was not significant (Student test: p.value = 0.57).

4.3 Variograms

The match between the (log-transformed) variograms computed for on-station and between-station data is very good for the Barents Sea surveys (Fig. 7a). For the other survey series (Fig. 7 b-e), a reasonable match is observed. However, in two cases (IBTS from FRS and IFREMER), this was only obtained after respectively 5% and 2% of the most extreme values were removed. In any case, the between-station data allowed resolution of the short scale spatial structures that are inaccessible with the on-station data alone. These structures are made of a nugget effect that explains 40 % of the total variability (whatever the survey series) and of a structure of 200 n.mi for the Barents Sea surveys, and approximately 50 n.mi for the others.

4.4 Correlation before/during/after trawl

The cumulative histograms of the paired differences of the total energy of bottom and mid-water layers are symetrical with long and heavy tails (Fig. 8). The medians are systematically 0, but the means often depart from 0. For example, the difference between before and during trawl data for FRS survey series had a median of 0 but a mean of 150 $m^2 \cdot n.mi^{-2}$ (Fig. 8, second column, lower panel).This was the result of a very few negative values. For bottom layers, NASC integrations were generally higher during the tow than before or after. However, these means were not significantly different from 0 in most cases (2 p-values out of 10 below 0.1). The picture was somewhat different for the mid-water layers. The NASC values were alternatively smaller and larger during trawling and the Wilcoxon tests often lead to a rejection of H0 (solid symbols on Fig. 8), i.e. that total NASC observed in mid water was not the same before, during and after the trawl. Interestingly, the differences between randomly selected off station data showed the same symetrical and skew distributions and were considered equal to 0 for all except one case (QUB mid-water layers).

Differences in altitudes of the centre of mass from NASC values showed weaker tails than for the integration values, especially for bottom layers (Fig. 9). Medians and means often coincided and were equal to zero. For the bottom layers, the majority of the observed differences is less than 1 meter. Wilcoxon p-values were all larger than 0.1 indicating a strong confidence in accepting H0, except in one case (FRS, difference between before and during trawling). This latter case was the sole case where the median is not zero. Here again, the differences between randomly selected off station data showed the same distributions and were considered equal to 0 for all cases except for the QUB mid-water layers.

5 Discussion

The main aim of the present analysis was to investigate the potential for using acoustic data recorded during bottom trawl surveys to improve our understanding of what happens between trawl stations. To this end we have examined the hypothesis that acoustic data collected away from the trawl stations was consistent with that collected during the trawling operations. Rather than examine one survey with a particular format, we chose to study a series of different surveys ranging from the Barents Sea to the North and Irish Seas, to attempt to identify broad trends in this type of data. The major discrepancy between the data sets was in the numbers of data points available on-station and in the proportion of stations connected with acoustic transect. The Barents Sea surveys include between 200 and 300 trawl stations per survey, whereas in the North and Irish Seas surveys include between 13 and 80 stations. In addition, as IBTS data are only taken in daylight hours, the last station of given day and the first one of the following day are not connected by acoustic transects (Fig. 1 b). As a consequence relationships between on-station and between-station observations are likely to be more apparent for the Barents Sea than for any of the other surveys.

The first type of analysis was a straightforward global comparison using all the available data, for the pooled NASCs by layers for the on-station and between-station data. The general pattern was broadly consistent across all the surveys. The bulk of the acoustic energy was found in the deepest layers in the water column: the back-scattering energy reduces exponentially as the range from the seabed increases and then stabilises somewhere between 5 and 10 m off the bottom. More importantly, the pattern is similar for both on-station and between-station data. Where differences occurred they were not systematic, as on-station integrated data could be both greater or less than between-station data. Furthermore, where deviations from the general pattern occurred in a particular survey, they were seen in both on-station and between-station data. This founds the use of bottom and mid-water layers further in the analysis.

The Global Indices of Collocation (GICs) confirmed the subjective appraisal of the vertical profiles. For the bottom layers, only one survey out of twenty showed a poor match, and this had low station numbers (N^o =46). Slightly poorer results were obtained for the mid water layers, with five out of the twenty surveys having low GIC values. NASC values were generally much lower in the mid water layers and also much more variable so this outcome is not surprising.

The variograms allowed a more detailed study of the spatial structures associated with the on-station and between-station data. For the Barents Sea data, the relatively high number of stations allowed the generation of good quality variograms for on-station and between-station data. These variograms were highly similar. For the other surveys, the variograms were less well behaved, reflecting the smaller number of samples relatively to the sampling area and the large skewness of the data. However they were also similar provided that some extremes values were removed in two cases. Because of the normation, we only compared the shape of the variograms and not their absolute level. The variance of the between-station data is indeed often larger than the variance of the on-station data because the chance to encounter the rare extreme fish concentrations is larger with few thousands samples than with few tens or hundred samples. However, the strong similarity between the shapes of the variograms makes it possible to use the short scale structures provided by the between-station data to define a variogram model. It is worth reminding here that the variograms were computed with log-transformed, and sometimes thresholded, data. Without these data transformations, variograms were most of the time unexploitable. These non linear transformations induce bias and the variograms obtained in this analysis can not be directly used for estimation purposes. Both the log-transformation and the selection of a certain quantile (95, 98 or 100%) of the data, aim at reducing the impact of the extreme data. This was the price to get consistent on-station and between-station observations. In other words, what makes between-station acoustic data statistically different from the on-station acoustic data is only the occurrence of extreme data. The bulk of the distributions match well.

The final step in the analysis was to examine the relationship between on-station and between-station data in the areas close to each of the hauls. For this comparison we only used between-station data immediately adjacent to those hauls. The null hypothesis that the average difference in biomass or height of the centre of mass for observation made before, during or after trawling (split into bottom and mid water layers) was null has been tested using a Wilcoxon test. This test indicates that the acoustic observations made before, during and after the trawl stations are more consistent for bottom layers than for mid water layers and are more consistent for depth criteria than for the total energy criteria. However, despite it is non parametric, the Wilcoxon tests can be considered as fragile, and care must be taken in relying on the p-values alone. For example, the p-values of a one sample test made on simulated data from of a centred gaussian distribution homogeneously range from 0 to 1 despite the true mean is zero. We thus complemented the Wicoxon test by a resampling exercise which indicated that both before and during trawling data, and during and after trawling data are not more different than two successive randomly selected between-station data (the distributions of their differences are strongly similar).

Most critically for the purposes of this analysis, the inference that we see similar energy values on-station and between-stations suggests that we were looking at the same fish assemblages in the two situations. However, there is some evidence in the literature of fish avoiding research vessels during trawling (Godø et al., 1999; Handegard et al., 2002; Wilson pers. comm.). Avoidance can be both vertical, as in diving or horizontal, as in moving out of the path of the trawl. Based on the current evidence, it would appear that both horizontal and vertical avoidance were not a major problem in the context of the present surveys. If fish were moving out of the path of the vessel and of the trawl, we would expect a reduction in NASC during trawling. Fish diving would tend to increase tilt angle and hence reduce target strength (MacLennan et al., 1987; McQuinn and Winger, 2003; Kloser and Horne, 2003). They may also move into the acoustic dead zone (Ona and Mitson, 1996; Lawson and Rose, 1999) and be inaccessible to the echosounder. In the present study, the non significant but systematic increase of NASC value in the "bottom" layers during trawling is associated neither to a corresponding systematic decrease of NASC values in the "mid-water" layers, nor to a change in height of the mean energy in any of the "bottom" or "mid-water" layers. This suggests that none of the above mentioned avoidance behaviours are operating in these situations.

There is ample evidence that vertical zonation of gadoid fish can vary throughout the day or year (Alderstein and Ehrich, 2003; Casey and Myers, 1998; Godø and Michalsen, 2000; Michalsen et al., 1996; Pedersen, 2000; Pillar and Barange, 1997). In the present analyses this would not be expected to have a major impact. Apart from the Barents Sea surveys, the trawls are all taken in daylight. For the pooled analyses we have combined data for all times of day. For the before-during-after studies each haul is matched to adjacent between-station data taken at the approximately the same time, thus reducing the impact of dial changes. Each survey is generally taken at the same time of year, thus reducing seasonal effects.

6 Conclusion

The final conclusion from the study must be that in general the hypothesis that acoustic data collected away from the trawl stations was consistent with that collected during the trawling operations is acceptable. Individual survey series showed some exceptions but the general picture was positive. The example for the Barents Sea shows what can be achieved with a more substantial data set, where in all cases the on-station and between-station data were consistent for all indicators and methods. The cases of poor fit in the other survey series can be explained by the sparcity and the skewness of the data.

In conclusion, the study suggests that the acoustic observations collected on-station and between trawl stations on a bottom trawl survey can be treated as observations of the same phenomenon . If it can be established that there is also a useable relationship between catch and on-station acoustics (as illustrated by Cachera et al 1999 and Krieger et al 2001) then there should be scope to use between-station acoustics to enhance the quality of trawl survey indices.

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Figure 8 Difference between the total NASC observed before, during and after trawling. Comparison with two randomly selected successive between station observations. Each panel represents the cumulative distribution of the pair differences for each survey series. The x-axis represents differences of NASC in $m^2 \cdot n.mi.^{-2}$. The y-axis represents the frequency. Distinction between “bottom” layers (lower panels) and “mid water” layers (upper panels). P-values of the Wilcoxon tests are represented : symbols are located at the observed mean difference. Solid symbols represent values smaller than 0.1. Values larger than 0.1 are represented by empty symbols with a proportional size.

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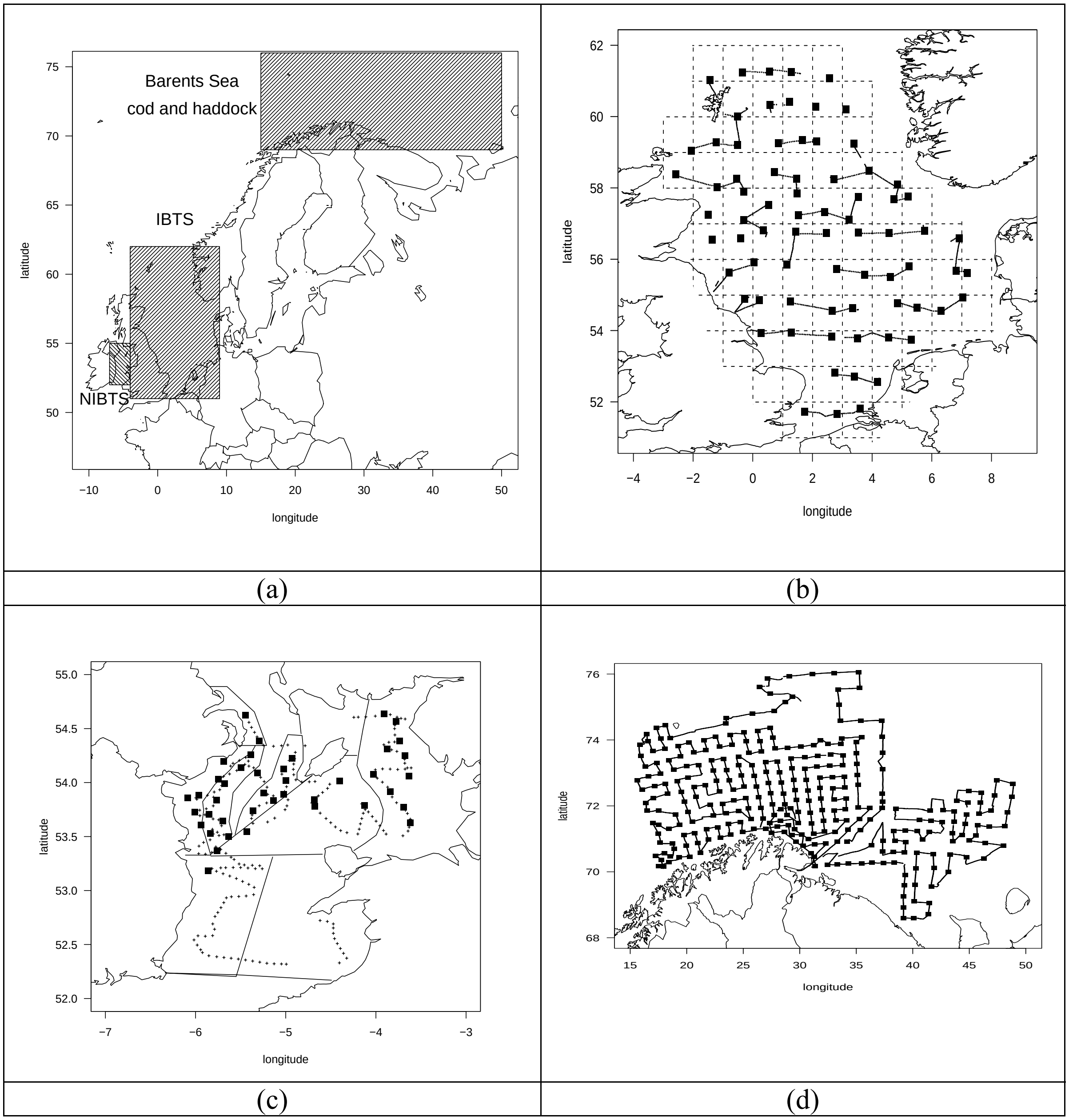

(a)

(b)

(c)

(d)

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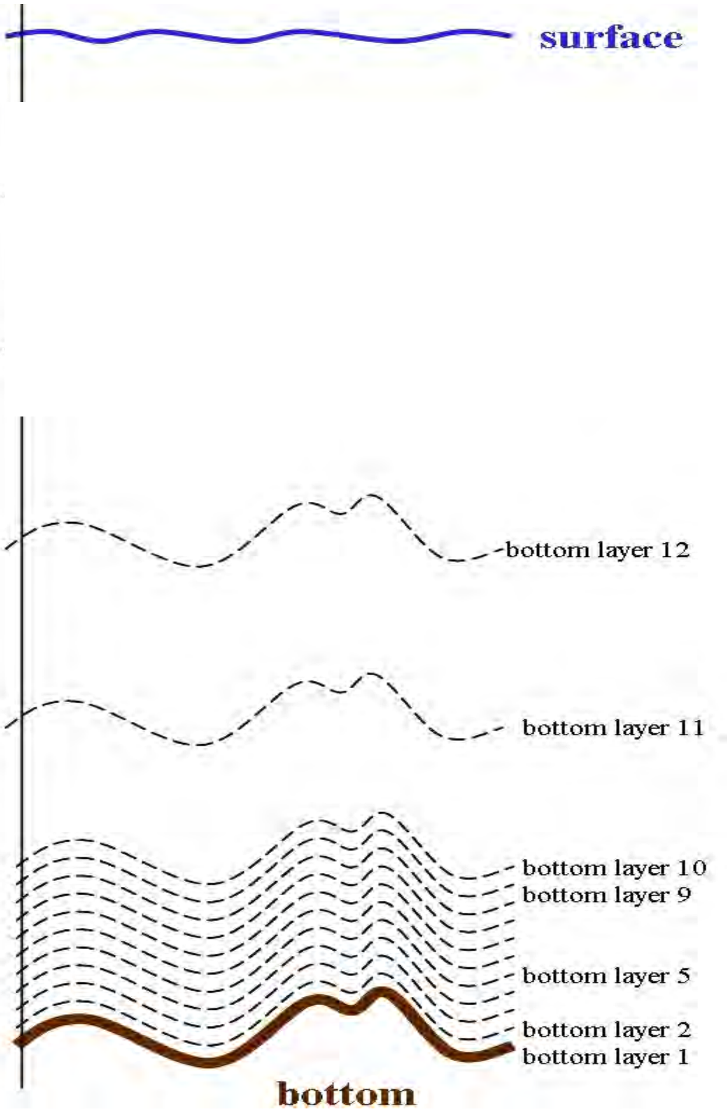

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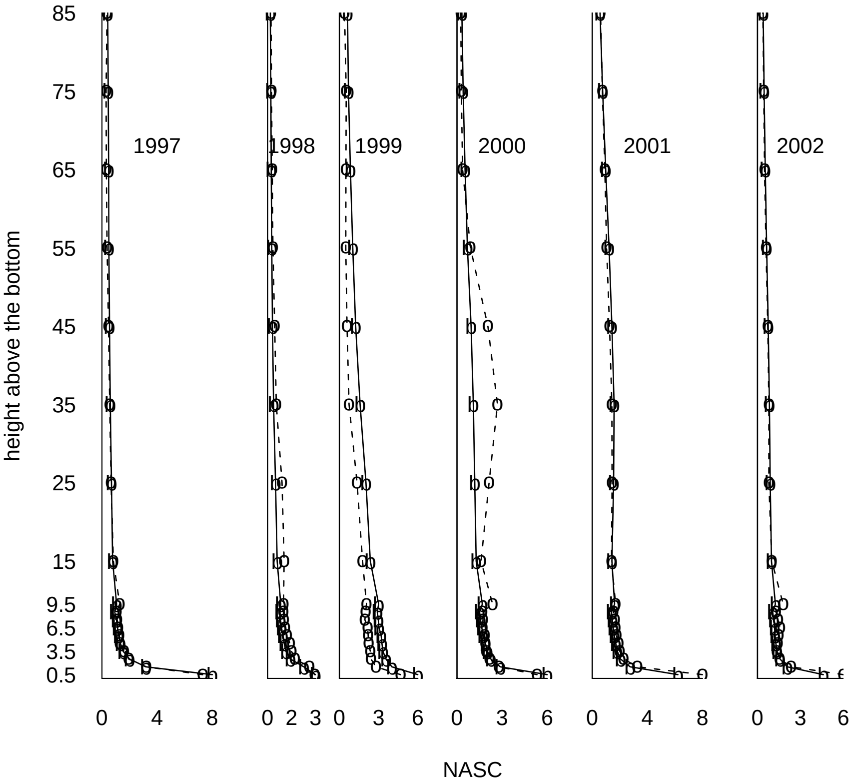

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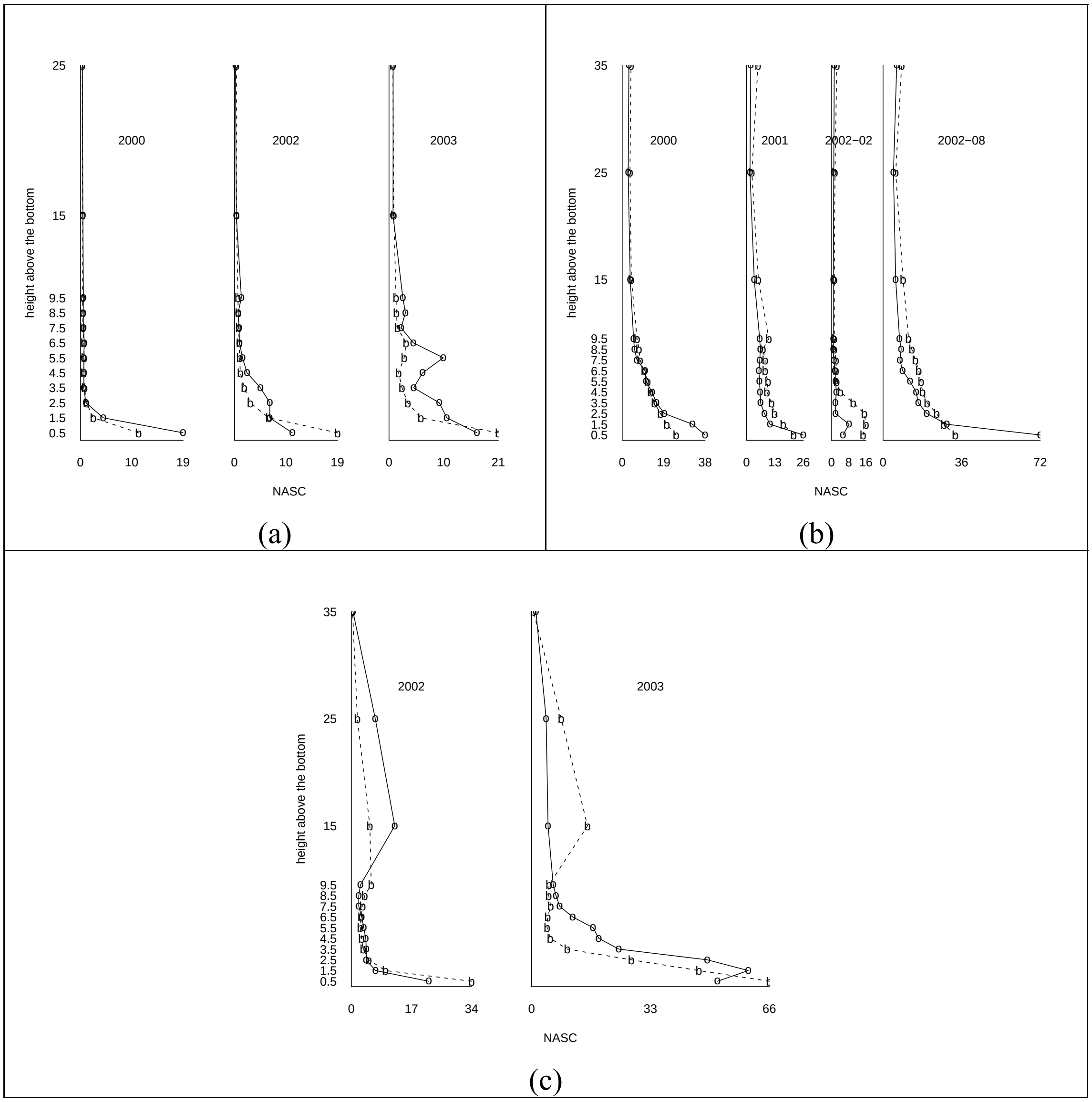

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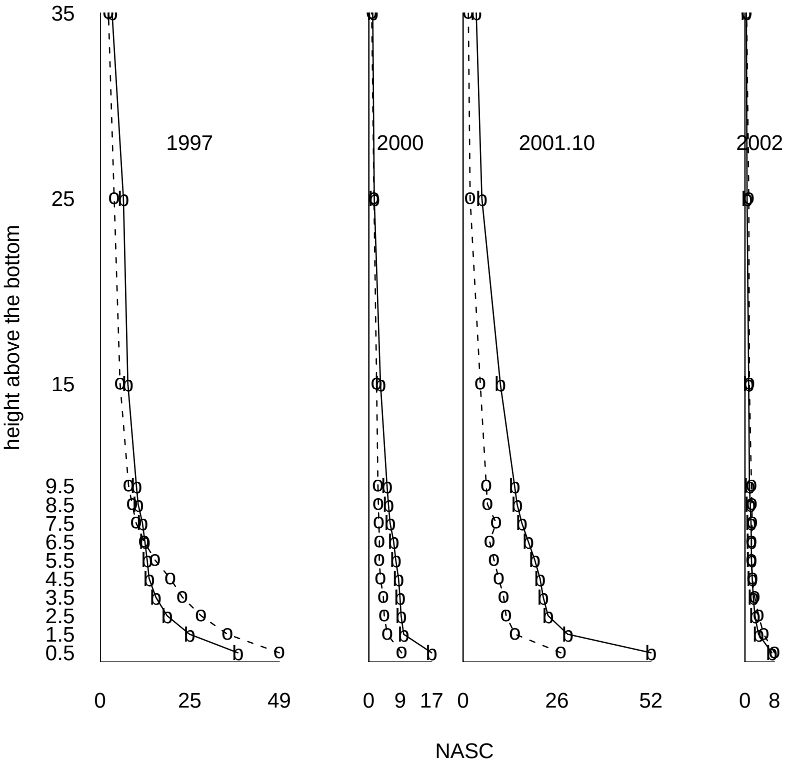

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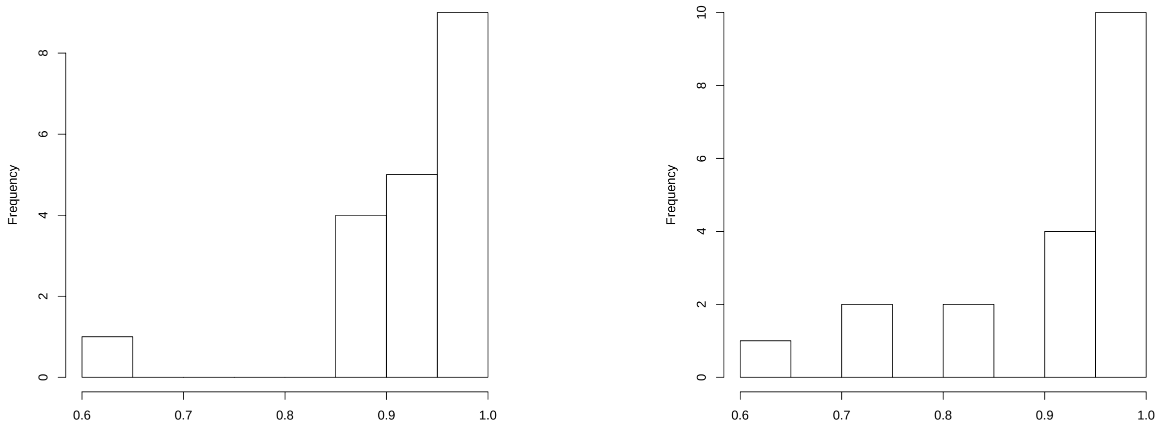

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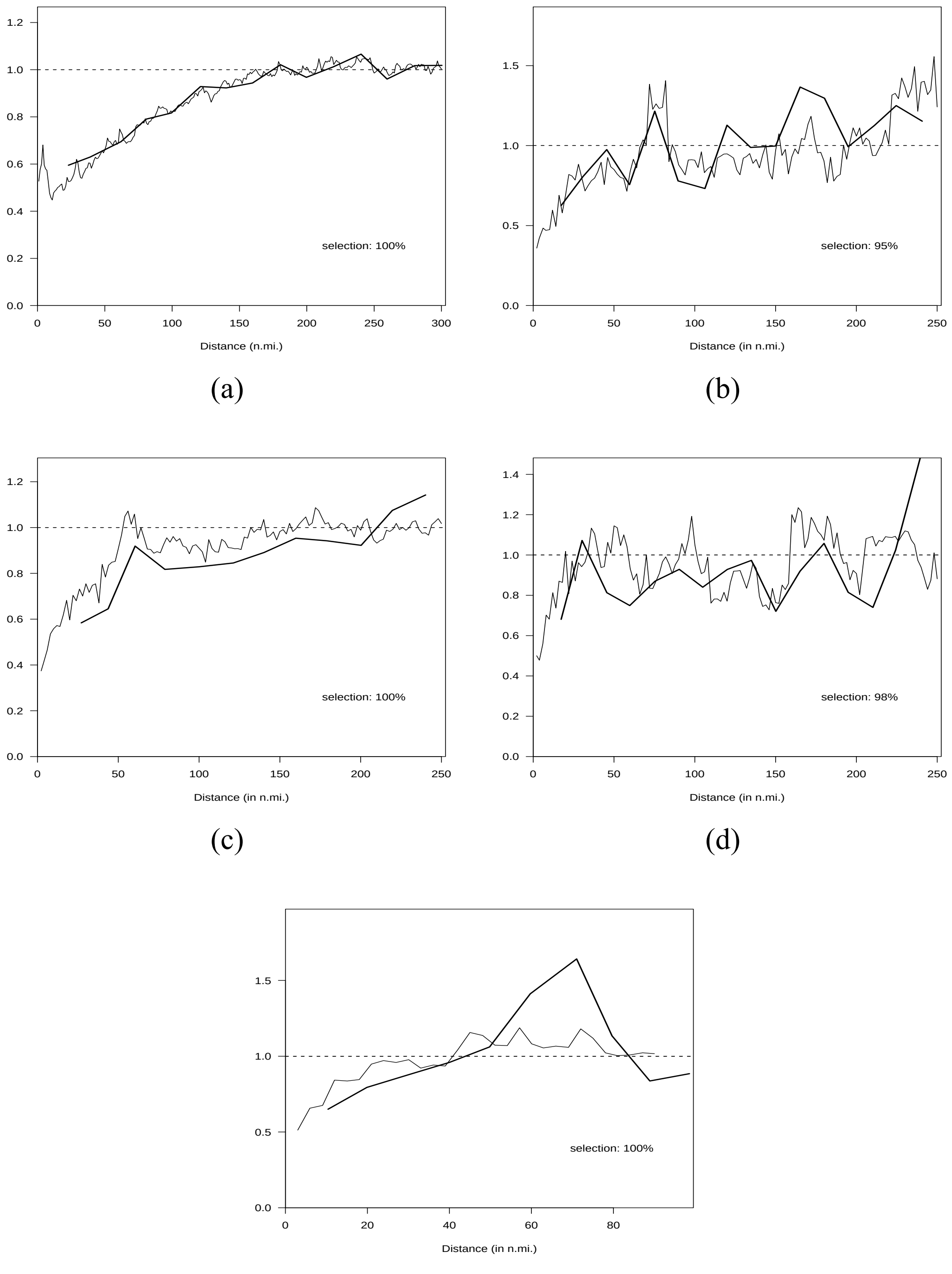

(a) (b)

(c) (d)

(e)

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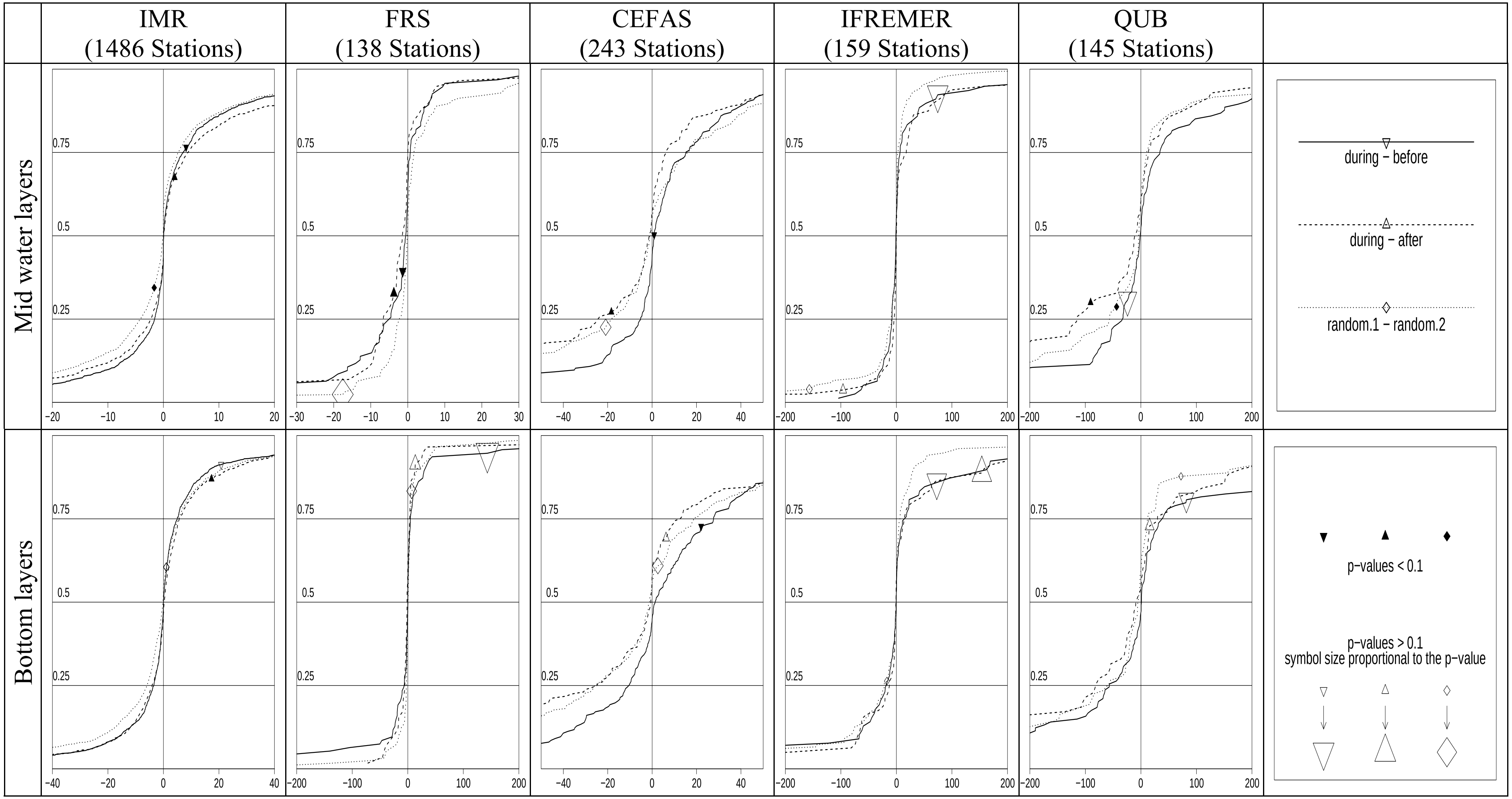

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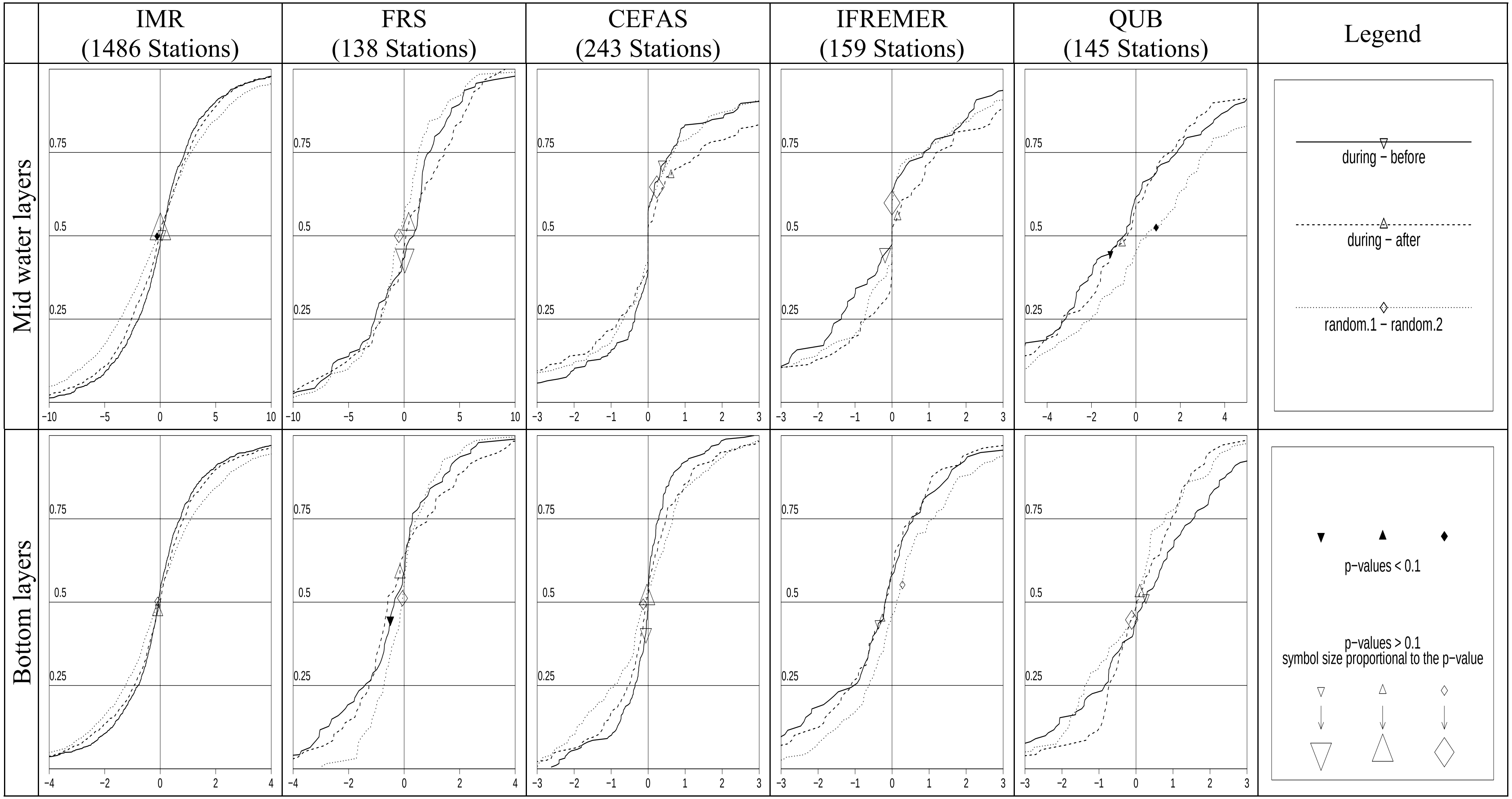

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Table 1. Main characteristics of the various survey used in the analyses.
ESDU : Elementary Sampling Distance Unit

Area	Source/Survey series	year	month	Number of stations	Mean towed distance (n.mi.)	Original ESDU (in n.m.)	Number of between station data (after regularization)	Height used to split vertical profiles (m)	depth range	GIC ”bottom” layers	GIC ”bottom” layers
Barents Sea	IMR	1997	02- 03	176	1.50	1	5209	40	143 – 699	0.98	0.95
	IMR	1998	02	198	1.53	1	5135	40	63 – 720	0.9	0.85
	IMR	1999	01- 02	223	1.49	1	5567	40	104 – 480	0.99	0.97
	IMR	2000	01- 02	302	1.42	1	7680	40	58 – 550	0.98	0.99
	IMR	2001	01- 03	300	1.49	1	7666	40	55 – 487	0.97	0.96
	IMR	2002	01- 03	287	1.44	1	7383	40	63 – 542	0.98	0.98
North Sea	FRS	1999	01- 02	44	1.8	0.5	468	10	45 – 150	0.6	1
	FRS	2000	01- 02	46	2.01	0.5	351	10	48 – 144	0.89	0.74
	FRS	2002	01- 02	47	1.98	0.5	430	10	49 – 150	0.9	0.98
	CEFAS	2000	08 - 09	71	1.98	0.5	1038	10	24 – 178	0.99	0.99
	CEFAS	2001	08 - 09	70	2.01	0.5	883	10	24 – 211	0.99	0.84
	CEFAS	2002	02	23	1.98	0.5	1140	10	24 – 84	0.93	0.97
	IFREMER	2002	02	77	1.83	0.1	440	10	9 – 88	0.9	0.95
	IFREMER	2003	02	82	1.89	0.1	722	10	14 – 90	0.93	0.75
Irish Sea	QUB	1997	10	13	3.00	0.5	84	10	25 – 103	0.98	0.91
	QUB	2000	3	37	2.90	0.5	110	10	26 – 106	0.99	0.95
	QUB	2001	10	34	2.70	0.5	236	10	23 – 90	0.94	0.99
	QUB	2002	3	41	2.85	0.5	173	10	24 – 102	0.93	0.98

Table 2. P-values of the Wilcoxon tests on the mean paired differences of NASC and centre of mass of the NASC values observed before, during and after trawling. Comparison with two randomly selected successive between station observations.

	NASC						Mean energy height					
	"Bottom" layers			"mid-water" layers			"Bottom" layers			"mid-water" layers		
	b-d	a-d	r_1-r_2	b-d	a-d	r_1-r_2	b-d	a-d	r_1-r_2	b-d	a-d	r_1-r_2
IMR	0.11	0	0.16	0	0	0	0.1	0.39	0.17	0.25	0.98	0.03
FRS	0.9	0.24	0.22	0	0	0.89	0.01	0.2	0.23	0.65	0.38	0.16
CEFAS	0.02	0.19	0.46	0.05	0.05	0.47	0.44	0.7	0.25	0.28	0.15	0.72
IFREMER	0.93	0.92	0.12	0.98	0.21	0.18	0.17	0.11	0.12	0.44	0.2	0.79
QUB	0.67	0.32	0.1	0.85	0.03	0.03	0.19	0.35	0.57	0.03	0.18	0.08