Introduction

In the Baltic International Acoustic Surveys (BIAS), target-strength (TS) estimates for herring (Clupea harengus membras) and sprat (Sprattus sprattus) are based on the traditional function: 

$$TS = 20 \log L - 71.2 \text{ dB}$$

(where $L$ is the fish length in centimetres), established ~25 years ago, but with no indication of its accuracy (ICES, 1983). Further, in situ TS measurements made during the past seven years established higher values for the parameter $B_{20}$ in the general function $TS = 20 \log L + B_{20}$. These $B_{20}$ values are within the range $-68.9$ to $-63.6 \text{ dB}$ (Ona et al., 2001; Ona, 2003; Didrikas and Hansson, 2004; Peltonen and Balk, 2005). Modelling has also demonstrated high TS values for herring comparable with these in situ results (Fassler et al., 2007; Gorska, 2007).

The assumption of particular acoustic properties for the Baltic Sea clupeids underlies the current practice of TS estimation for herring and sprat, based on the function cited earlier (ICES, 2006, 2008). However, up to now that assumption lacks support either by experimental or modelling studies or by comparative analyses of the biological characteristics of the two fish species as acoustic targets.

Conversely, the urgency for further studies of the Baltic clupeid TS is also dictated by the need to assess the TS functions together with relevant statistics. The latter are essential to present-day measurements of TS, because they are an important component of the overall uncertainty of the acoustic-survey results (Demer, 2006; Kasatkina and Gasyukov, 2006; Woillez et al., 2006).

In view of this problem, proposals to improve the clupeid TS estimates used in the BIAS are discussed in this paper. The results of in situ TS measurements for herring and sprat are presented, with analyses comparing these results with the biometric characteristics of the two species. A simulation method is used to incorporate the uncertainty in TS estimates into the acoustically derived abundance indices to compare the statistical features of the abundance indices based on the traditional and new TS functions.

Material and methods

In situ TS measurements

In situ TS measurements were made on board the RV “Atlantida” during acoustic surveys conducted in the Baltic Sea during 2003–2005. The echosounder (Simrad EK 500, 38 kHz, split-beam transducer type ES38) was run continuously during the surveys, so acoustic data were available for each trawl station.

Single-target echoes from free-swimming fish, identified by trawling as herring or sprat, were collected and processed using SonarData Echoview software. The echosounder was calibrated using a standard target at the start of each cruise. The target-position information provided by Echoview was used to locate the target in range and off-axis angles. Single-target echo detections from fish were filtered to retain only those from targets $<1^\circ$ off the central axis of the transducer. Then, the TS was compensated to provide values that the target would have exhibited on the axis.

The sonified, dispersed aggregations recorded at depths from 15 to 70 m were fished using a midwater trawl PT/TM 70/300...
Biometric data of herring and sprat were collected on board the RV “Atlantida” during acoustic surveys in the Baltic Sea in 2003–2005. The features used for biometric comparison of the two species were as follows:

(i) the fish weight–length relationship based on data from 2000 individuals, and
(ii) the maximum body girth, maximum body height, and weight based on data from 1200 herring and 600 sprat.

**Biometric indices of Baltic Sea clupeids**

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Simulation model to estimate uncertainty in acoustically derived, abundance indices

Simulating the effect of uncertainty in acoustically derived, abundance indices was based on the method of Kasatkina and Gasyukov (2006) for quantifying and summarizing components of the overall uncertainty in sampling surveys. The spatial variability of the nautical-area-scattering coefficient ($s_i$) of the fish-species composition and their size structure within the surveyed area and the uncertainty of the TS were chosen as the main sources of uncertainty. Vessel avoidance as an issue in Baltic surveys was not considered. The effects were simulated independently using a bootstrap resampling technique to reveal the spatial variability and a Monte Carlo simulation for the TS-defining parameters.

The suggested simulation method was also based on the current algorithms of BIAS data processing (ICES, 2002). In this case, the stratum density was estimated from the mean $s_{i0}$ and the mean backscattering cross sections ($\sigma$) within the stratum, where $\sigma$ is calculated by inverting the TS functions, and weighting by the length and species compositions obtained from all trawl stations in the stratum:

$$\sigma = \sum_i f_i \sigma_i = \sum_i f_i \sum_j f_{ij} \sigma_{ij},$$

where $\sigma_{ij}$ is the backscattering cross section of the $j$th length class of species $i$, and $f_{ij}$ is the respective frequency, whereas $f_i$ is the frequency of species $i$ in the stratum.

Sprat and herring abundances were estimated by splitting the total abundance according to the species frequency in the stratum, because $N_i = Nf_i$.

The input data for the simulation were the following.

(i) Variable data:
   (a) the TS functions with mean and standard deviation (s.d.) estimates of $B_{20}$; a normal distribution of $B_{20}$ is assumed,
   (b) $s_i$ values along each acoustic transect, and
   (c) length frequencies for all fish species, weighted by the total catch at each trawl station.

(ii) Fixed data:
   (a) length–weight functions for each species or the weights obtained for each length class,
   (b) geographic area covered by the acoustic survey, and
   (c) number of realizations in the simulation process (500 realizations).

Algorithm for the simulation

**Step A.** For each stratum:

(a) the value of $B_{20}$ was simulated according to the normal (Gaussian) distribution,
(b) the set of $s_i$ values was simulated according to the empirical distribution in the stratum,
(c) for each length class, the number of fish “caught” at a trawl station was simulated according to the empirical distribution in the stratum,
(d) the length frequency sets formed at each station and frequencies for each length group were determined, and (e) weighted-mean TS values were estimated, and mean density, abundance, and biomass estimates were calculated.

**Step B.** The abundance and biomass in the studied area were estimated based on the stratified-sampling technique.

**Step C.** Steps A and B were repeated to produce the given number of realizations.

**Step D.** The statistical characteristics of abundance and biomass (mean values, variances, standard errors, coefficients of variation, and 95% confidence intervals) were estimated from the set of realizations obtained.

As an example, the simulation method was applied to estimate the statistics of fish-abundance indices in ICES Subdivision 25 (Baltic Sea), using data from the BIAS in 2004–2006.

**Results**

**TS–length relationships**

Bootstrap distributions for \( B_{20} \), based on linking observed *in situ* TS distributions with fish length frequency distributions obtained from catches, are given in Figure 1.

The estimates obtained for herring \( (B_{20} = -67.55 \text{ dB}, \text{s.d.} = 0.26 \text{ dB}) \), sprat in 2003 \( (B_{20} = -73.33 \text{ dB}, \text{s.d.} = 0.20 \text{ dB}) \), and sprat in 2005 \( (B_{20} = -71.9 \text{ dB}, \text{s.d.} = 0.39 \text{ dB}) \) differ from the \( B_{20} = -71.2 \text{ dB} \) currently used in the BIAS. Specifically, important differences were found between the TS functions applying to herring and sprat.

The *in situ* data also revealed that \( B_{20} \) is between \(-73 \) and \(-72 \text{ dB} \) for young herring smaller than 16 cm. These values are comparable with those obtained for sprat of all lengths from 6 to 15 cm. In view of this finding, the wisdom of using the same TS function for sprat and young herring should be considered.

Differences between some biometric characteristics of the two species, revealed by the survey data in 2003–2005, are indirect evidence in support of this hypothesis. Statistics of the parameters in the relationship \( W = aL^b \) between fish weight \( (W, \text{ g}) \) and fish length \( (L, \text{ cm}) \) and the relationship \( P = CL^d \) between the maximum perimeter of the fish body \( (P, \text{ cm}) \) and fish length are illustrated in Tables 1 and 2. The relationships for the two herring groups (young and adult fish) differ, whereas those of sprat and young herring are comparable (Tables 1 and 2). Thus, sprat and young herring are characterized by similar values of body perimeter and weight at the same length.

**Uncertainty in acoustically derived abundance indices**

The model results for ICES Subdivision 25 were obtained using the traditional \( B_{20} = -71.2 \text{ dB} \) and our alternatives for Baltic Sea clupeids, as suggested above \( (B_{20} = -73.33 \text{ dB}, \text{s.d.} = 0.20 \text{ dB} \) for fish \(<16 \text{ cm} \) in length; \( B_{20} = -67.55 \text{ dB}, \text{s.d.} = 0.26 \text{ dB} \) for fish \( >16 \text{ cm} \) ). Confidence limits on the traditional \( B_{20} = -71.2 \text{ dB} \) are unknown (ICES, 1983), so a standard deviation of 0.5 dB was assumed for modelling purposes.

The uncertainty in acoustically derived abundance indices varies considerably by year (Table 3). The uncertainty in TS is an important component of the overall variance of the abundance indices (Figure 2).
indices by fish group, including those of recruits, i.e. 0-group for sprat and age-1 group for herring (Figure 3).

**Discussion**

The TS function obtained for herring is characterized by \( B_{20} = -67.55 \text{ dB} \) (s.d. = 0.26 dB), which is 4 dB higher than the traditional \( B_{20} = -71.2 \text{ dB} \) that has been applied for the past 20 years in the BIAS. The obtained \( B_{20} \) is consistent with the above-mentioned results of *in situ* TS measurements and modelling reported by various authors in the past 7 years. Therefore, our results are further confirmation that current practice in the BIAS considerably underestimates the TS of herring.

Conversely, the results suggest appreciable differences between the \( B_{20} \) values for sprat (mean \( B_{20} \) = -71.9 to -73.33 dB, s.d. = 0.20–0.39 dB) and herring (mean \( B_{20} \) = -67.55 dB, s.d. = 0.26 dB), which are explained by the different biometric characteristics of the two species.

The results from the TS measurements reveal that the traditional \( B_{20} \) measure used for estimating TS both for herring and sprat is wrong. Alternative TS functions for the Baltic Sea clupeids need to be considered.

The biometric indices of the two species are similar within the length range 6–16 cm, which includes all sizes of sprat, whereas those of adult herring >16 cm in length differ. This suggests the possibility of adopting two TS functions for Baltic Sea clupeids. These would be applied to the length range from 6 to 16 cm, including young herring and all sizes of sprat, and lengths >16 cm for adult herring only.

We believe that adopting a separate TS function for sprat and young herring will give more reliable abundance indices for fish <16 cm, which comprise the bulk of Baltic Sea clupeid stocks. For example, these small fish contributed more than 86% of the total herring and sprat abundance during autumn 2007 (ICES, 2007).

Furthermore, application of the new TS functions will change the absolute values and uncertainties of the abundance indices, and their annual rate of change. This is highly relevant to the use of abundance indices for VPA tuning, for instance by the XSA method of Shepherd (1999), which depends on the index trends in the most recent years. An important consequence is the change in the estimated quantities of younger fish used as recruitment indices: 0-group for sprat and age-1 group for herring and sprat abundance in the Baltic

| Table 3. | Statistics of acoustically derived abundance indices for Baltic Sea clupeids obtained with the traditional \( B_{20} = -71.2 \text{ dB} \) (s.d. = 0.5 dB), indicated as I variant, and with our alternatives indicated as II variant (\( B_{20} = -73.33 \text{ dB}, \text{s.d.} = 0.20 \text{ dB for fish} <16 \text{ cm and} \ B_{20} = -67.55 \text{ dB}, \text{s.d.} = 0.26 \text{ dB for fish} >16 \text{ cm})

<table>
<thead>
<tr>
<th>Survey 2004</th>
<th>Survey 2005</th>
<th>Survey 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fish abundance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>31 147.7</td>
<td>26 532.9</td>
</tr>
<tr>
<td>s.d.</td>
<td>3 118.1</td>
<td>2 259.5</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.10</td>
<td>0.09</td>
</tr>
<tr>
<td>Lower limit (95% CI)</td>
<td>25 081.2</td>
<td>22 532.8</td>
</tr>
<tr>
<td>Upper limit (95% CI)</td>
<td>37 598.1</td>
<td>31 358.4</td>
</tr>
<tr>
<td>Sprat abundance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>25 055.2</td>
<td>21 306.4</td>
</tr>
<tr>
<td>s.d.</td>
<td>2 743.4</td>
<td>2 201.5</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.11</td>
<td>0.10</td>
</tr>
<tr>
<td>Lower limit (95% CI)</td>
<td>20 010.9</td>
<td>17 270.3</td>
</tr>
<tr>
<td>Upper limit (95% CI)</td>
<td>30 641.9</td>
<td>26 018.3</td>
</tr>
<tr>
<td>Herring abundance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>6 092.5</td>
<td>5 226.6</td>
</tr>
<tr>
<td>s.d.</td>
<td>880.9</td>
<td>567.3</td>
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<tr>
<td>Coefficient of variation</td>
<td>0.14</td>
<td>0.11</td>
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<tr>
<td>Lower limit (95% CI)</td>
<td>4 538.8</td>
<td>4 128.4</td>
</tr>
<tr>
<td>Upper limit (95% CI)</td>
<td>8 000.3</td>
<td>6 407.3</td>
</tr>
</tbody>
</table>

The fish quantities are in millions of fish. CI, confidence interval.
herring. As for total abundances, the temporal dynamics of recruitment-abundance indices may also change compared with traditional calculations. The application of new TS–length functions based on our results should allow a more realistic assessment of herring and sprat abundances for each age group, by year.

Conclusions
The current TS value used for the BIAS acoustic estimate of herring and sprat abundance is a significant source of uncertainty in the surveys. Using different TS functions for large and small fish, with young herring and sprat included in the latter group, seems to be more appropriate. Introducing such TS functions in the BIAS analysis should improve the reliability of abundance indices for young, recruiting fish, and should allow more realistic estimates of each age group by year, so providing vital information for tuning stock-assessment models.

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References


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