Modelling study of catchability properties of research and commercial trawls to identify sources of uncertainty in resource surveys indices

Kasatkina S. and V. Ivanova

ABSTRACT

Data from trawl sampling performed in the acoustic survey polygon are traditionally used to estimate age structure of fish population as well as to estimate conversion factors (as fish backscattering cross-sectional area summed over its length frequency distribution) for converting integrated volume backscattering area to area fish density. This fact is important for estimating abundance indices by age groups from acoustic survey and application of these indices for VPA tuning. Catchability characteristics (differential catchability and codend selectivity) of several types of research and commercial mid-water trawls are discussed in relation to fishing Baltic herring and sprat. Calculations were made by simulating method applying the models of the probability-statistical theory of fishing systems and information on the trawls design and the distribution pattern of fish aggregations fished. Trawl catchability were incorporated into the Baltic acoustic survey data processing. The influence of the trawl catchability characteristics on the reliability of abundance values was traced by estimating fish length distributions, mean weighted target strength and abundance by age groups. The authors discuss the obtained results in context of using acoustic data from research vessels and commercial vessels for supporting fisheries management assessment.

Keywords: abundance indices, acoustic surveys, Baltic Sea, trawl selectivity and differential catchability, research and commercial trawls, modeling.

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INTRODUCTION

Research surveys provide the most important information for estimating abundance indices and their dynamics description in commercial fish population used in tuning the stock assessment models (ADAPT, Gavaris, 1988), (XSA, Shepherd, 1991, 1999), (ICA, Patterson, 1994).

Collection of data on length, species and weight structure of fish population constitute the essential part of any research survey, and as a result, a fishing gear becomes an integral tool of both trawl and acoustic surveys. Each trawl is characterized with catchability characteristics (total catchability and differential catchability, including codend selectivity) determined primarily by the fishing gear construction and biometric parameters of the fish body (Kadilnikov, 2001). At the same time, at present catchability characteristics are not considered in procedures of research survey data processing. Errors in abundance indices estimates related to using the
trawl samples data remain outside researchers’ attention and have not been integrated into the total survey variance estimate.

As is known, the fish stocks assessment models apply research survey data, fishery statistics (catches and fishing effort) and biological statistical information (length, age and weight structure of catches and several another biological indices). Therefore, differences in catchability characteristics of research and commercial trawls may become one of the major sources of uncertainty in the stock assessment models.

The problem of different catchability characteristics of commercial and research trawls is also important in connection to the recent development of acoustic surveys fulfilled at commercial vessels. Such surveys are carried out in addition to the regular resource surveys for the purpose of a special monitoring in the fishing areas and provision of additional data for stock assessment models (ICES, 2007).

The research trawl catchability characteristics are especially important in the international surveys carried out by several vessels from different countries. While the international trawl surveys, as a rule, are carried out using an appropriate standard fishing gear, vessels participating in the international acoustic surveys use mid-water trawls of different designs, e.g. the Baltic International Acoustic Surveys (ICES, 2008). At the same time, the trawl samples data provide the most important information for converting the acoustic index NASC into abundance indices by age groups used in tuning stock assessment models.

In this paper catchability characteristics of mid-water trawls used in commercial fishery and in acoustic surveys of the Baltic sprat and herring are comprised. The authors also demonstrate the impact of selectivity and differential catchability of the research trawl on the acoustic survey results, tracing this impact through the procedures of the data processing, including determination of length and age catch structures, estimation of the target strength, biomass and abundance indices of fishes by age groups.

MATERIAL AND METHODS

Estimation of the trawl catchability characteristics was made using the models of probability-statistical theory of commercial trawls, developed in AtlantNIRO under the leadership of Yu.Kadilnikov (2001). Applicability of this theory to the assessment of trawl catchability and codends selectivity in fishing slow-moving and fast moving species was demonstrated on the basis of good convergence between the modeling and experimental data (Kasatkina, 1989; Zimarev et al, 1991; Kadilnikov et al, 1997; Sergeev and Feldman, 2001).

**Simulation of the trawl catchability characteristics**

Selectivity of codends was estimated on the basis of their technical characteristics and biometric parameters of the fish body (Kadilnikov, 2001; Sergeev and Feldman, 2003).

The differential catchability of the trawl, i.e. the trawl catchability in relation to fishes of different species and length, is considered as a random value varying from 0 to 1 and characterizing the relationship between fish number in the catch and fish abundance in front of the trawl. Fig 1 shows the scheme of events sequence leading to the occurrence of fish in front of the trawl into the trawl activity zone and further to the codend (Kadilnikov, 2001).
Zone of B trawl activity to be considered as a part of space within which fish must have other than 0 probability to be caught for an effective time of fishing gear run:

a) with fish confused movement

\[ B = l_T \cdot h \cdot \tau \cdot v \]  

where \( l_T \) is trawl horizontal opening;
\( h \) is vertical zone of trawl activity;

\( h = H, \) for \( h_T \geq H \)
\( h = h_T, \) for \( h_T \leq H \)

\( H \) is depth of fish distribution level;
\( h_T \) is trawl vertical opening
\( v \) is trawling speed
\( \tau \) is trawling duration.

b) with fish directed movement

\[ e = \begin{cases} 
  l_T \cdot (V - V_p \cos \alpha) & \text{if } 0 < V \cos \alpha < V_p \\
  V \cos \alpha & \text{if } V \cos \alpha < 0 \\
  0 & \text{if } V \cos \alpha \geq 0 
\end{cases} \]  

where \( V_p \) is velocity of fish movement,
\( \alpha \) is angle between direction of fish movement and that of trawl clockwise towing.

According to Fig.1, the trawl differential catchability is represented by the probability of the complex events:

\[ P = P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \cdot P_7 \cdot P_8 \cdot P_9 \cdot P_{10} \]  

where \( P \) is differential catchability;

\( P_1 \) is probability of entering the fish between trawl headline and footrope;
\( P_2 \) is probability of entering the fish between trawl boards;
\( P_3 \) is probability of catching the fish along trawling route;
\( P_4 \) is probability of the fish entering between trawl wings, with the assumption that events 1,2,3 had happened;
\( P_5 \) is probability of the fish entering into the trawl mouth, with the assumption that events 1,2,3,4 had happened;
\( P_6 \) is probability of the fish entering in zone fished with small meshed part of trawl, with the assumption that events 1,2,3,4,5 had happened;
\( P_7 \) is probability of fish retention by trawl when towing, with the assumption that events 1,2,3,4,5,6 have happened;
\( P_8 \) is probability of fish retention with trawl bag netting (selectivity of trawl bag), with the assumption that events 1,2,3,4,5,6,7 had happened;
\( P_9 \) is probability of fish retention by trawl while haul back, with the assumption that events 1,2,3,4,5,6,7,8 had happened;
\( P_{10} \) is probability of fish retention by trawl for the time interval from the moment of the last shoal entering to the moment of trawl haulback.

Probabilities \( P_1 \) – \( P_{10} \) are expressed by analytical functions of the following characteristics of behavior of fish species, parameters and constructive trawl elements:

- distribution of fish aggregation depths,
- size of schools,
- biometric indices of fish species,
- spatial distribution pattern characteristics of fish schools,
- parameters of trawl vertical and horizontal opening in different netting zones;
- mesh bar and angles of its meridian opening in different netting zones
- angles of attack of cables, ropes and netting of trawl,
- other.

The above considerations indicated that in this work the differential catchability formed by the entire trawl construction (from the boards to the codend inclusive) is assessed, while in most publications the trawl mouth catchability is traditionally considered.

Characteristics of the fished aggregations spatial distribution were estimated on the basis of the acoustic data. (Kadilnikov, 2001; Kasatkina et al, 2005), including:

- a relative density of school settlement in 3-dimensional space, (ratio of sum of school volumes to the volume of those swarms habitat);
- a three-dimensional density of school field, (number of schools in a unit of their distribution water volume);
- a relative density of school settlement in 2-dimensional space (ratio of sum of school
- a two-dimensional density of school field (number of school in a unit of their distribution area or number of school in unit transect distance).

All mathematic equations used in estimation of catchability, characteristics of school spatial distribution are given in number of publications (Kadilnikov et al., 1989; Kasatkina et al, 2005).

**Biometric indices of the Baltic Sea clupeids**

Analysis of herring and sprat biometric indices was performed on the basis of the data obtained in subdivision 26 of the Baltic Sea. Biometric characteristics of two fish species (maximum perimeter of fish body girth, maximum body height and width) were estimated on the basis of 1200 measurements of herring and 600 measurements of sprat. The equal number of males and females were measured for each species.

**Fishing gear**

The trawl fishery for herring and sprat in the Baltic Sea is carried out by trawlers of different type using fishing gears of different design. In this work the analysis of catchability characteristics of commercial trawls was fulfilled for two fishing systems (vessel-fishing gear) most commonly used in fishery:

- Trawler with the main engine of 300 h.p. (trawler of type 1)
  Trawl PT 55/260m (trawl of type 1), trawling speed is about 3.1 knots.
- Trawler with the main engine of 1000 h.p. (trawler of type 2)
  Trawl PT 60/240 m (trawl of type 2), trawling speed is about 3.8 knots.

for the cases when these fishing gears were rigged with codends of 20mm, 18 mm, 16 mm, 12mm, 10mm, 8 mm in mesh opening.

Catchability characteristics of the research trawl were considered by the example of the trawl PT 70/370m (Fushing system III in Table 1) for the cases of rigging with different codends (with mesh opening 20 mm, 16 mm, 10 mm). The impact of the trawl differential catchability on the acoustic survey results were simulated with two options of herring and sprat abundance indices by age groups on the basis of:

- length and species composition of catches
- length and species composition of fish aggregations in front of the trawl.
The fish length and species composition in catch was modeled on the basis of predetermined length and species composition in the fished aggregations (i.e. in front of the trawl) following the analytical models (Kadilnikov, 2001).

**RESULTS AND DISCUSSION**

**Selectivity**
Trawl codend selectivity is the most important component of fishing gear differential catchability. Relationships of the trawl codend selectivity on its mesh size and fish biometric indices is demonstrated by the simulation results (Fig. 2, 3). Herring and sprat biometric parameters used in simulation are shown in Fig. 4, 5.

Calculated fish lengths (Fig.2, 3, Table 2) are close to the values obtained in experimental works for herring and sprat of the Eastern Baltic Sea, not only at the point of 50% retention, but also at other characteristic points of selectivity curves (Ivanova et al, 2002). This evidences that the estimated values are reliable.

Changes of fish biometric characteristics result in changes of the trawl codends selectivity in the case of the same mesh size. Comparative estimation of codends selectivity (Fig.3) were carried out by the example of changes in herring body parameters observed during 1996 and 1998 (Fig. 4), which indicated that probability of herring retention by codends was higher in 1996 than in 1998 (Fig. 3). The length of fish at 50% retention was 12.8 cm for codends with the mesh size 16mm, 13.8 cm and 14.3 cm for the mesh size 18 mm based on the data for 1996 and 1998 respectively, and 15.3-15.5 cm for the codends with the mesh size 20 mm (Table 2, Fig. 3).

As appears from the above considerations, inter-annual and inter-seasonal changes of fish body biometric parameters may result in changes of the trawl codend selectivity. For the Baltic International Acoustic Surveys this problem is especially important in view of considerable decrease of herring and sprat weight by age groups observed during the latest 30 years (ICES, 2007; Kasatkina, 2007). The latter fact evidences changes of fish biological and biometric characteristics. Therefore, it could be expected that codend selectivity of the research trawls used by the vessels-participants of BIAS has not remained constant during several years.

**Fish length and species composition in catch. Differential catchability of trawls.**
Fish length and species composition and catch size per haul are the most important catch characteristics. Specificity of these characteristics formation is considered on the basis of simulation data.

The modelling was aimed to estimate length and species compositions of catches using the predetermined those compositions in fished aggregation (i.e. in front of trawl active zone). Taking into account the importance of recruitment indices estimating, it is assumed that the significant proportion of small fish in fished aggregations (Fig.6, 7). It also assumed that the fished aggregations consist of 40% of sprat and 60% of herring (by abundance). Modelling results of fished the same predetermined aggregations by different trawl constructions (Table 1) are shown in Fig.6-8, Table 3.

It is revealed that length and species composition of catches are determined by the trawl differential catchability, which is formed by the entire trawl construction, including codend selectivity. However, the catch structure depends on the codend selectivity to the great degree
and on the vessel and trawl type to the less degree. The latter fact is demonstrated by estimations of length and species catch composition during fishing the same fish aggregation with different fishing system types (Table 1) rigged with codends of the same mesh size (Fig. 6,8, Table 3).

Changing the codend mesh size considerably affects the fishing gear differential catchability. By the example of fishing the same fish aggregation with the trawl TP 70/370m, rigged with codends with different mesh size (20mm, 16mm and 10mm), it is demonstrated that length and species composition of catches appeared incomparable (Fig.6, Table 3). During fishing the mixed aggregation (40% of sprat, 60% of herring) the catch species composition varied within 36%-87% for herring and 64 %-13% for sprat depending on the codend mesh size (Table 3).

Unlike the fish length-species composition in catches, the catch size depends considerably on the vessel and trawl type (Table 3).

The most important result of the above presented data is the fact that the catch length-species structure considerably differs from that in the fished aggregation due to availability of the fishing gear differential catchability (Figs. 6-8). Therefore:

- trawls differential catchability is the source of uncertainty of the catch length-species composition in inventory surveys;
- selection of the trawl construction and codend will to a significant extent affect the results of research surveys;
- standard fishing gears should be used in international surveys.

The above considerations are of utmost importance for the International Baltic Acoustic Surveys, where different fishing gears with different mesh size in codends are used. (ICES, 2008)

**The impact of trawl differential catchability on acoustic survey results**

Table 4 and Fig. 9 show the modeling results on acoustically-derived abundance indices by age groups depending on the research trawls used for biological sampling during acoustic survey.

The following input data were used in these assessments: the mean NASC index in the survey polygon and the area of this polygon (predetermined data of Russian survey 2003 in subdivision 26); the length and species composition of catches taken in the survey polygon. The length and species compositions in catch and respective length and species composition in front of trawl shown in Fig.6 were used in this study. It is assumed that the mixed aggregation of herring and sprat was fished with the research trawl TP 70/370m, rigged with codends with different mesh size. The age structure of species was determined using fish length-age keys, provided in reports of WGBIFS-2003.

According to Table 4 and Fig. 9, incorporation of the trawl differential catchability into the procedures of acoustic survey data processing results in changes of the following:

- fish length and age structure in the survey polygon;
- estimates of target strength as the basis of conversion factors (as fish backscattering cross-sectional area summed over its length frequency distribution) for converting integrated volume backscattering area to area fish density (ind./m$^2$);
- indices of the total fish abundance and abundances of each species;
- relationship between abundance indices by age groups and estimates of the youngest age group, which are used as recruitment indices (0-group of sprat and 1 year-group of herring).
As appeared, the abundance indices by age groups estimated from the acoustic surveys data may provide non-realistic description of their dynamics due to the fishing gear differential catchability. This fact is of utmost importance, when abundance indices are used in VPA tuning (e.g. with XSA (Shepherd, 1999)), affecting the trends in abundance dynamics during the recent years close to the terminal year. For the Baltic International Acoustic Surveys this problem is especially important in view of changes of herring and sprat biological characteristics observed during the latest 3 decades and usage of different fishing gears at vessels-participants of BIAS.

Moreover, the modelling results indicate that using a standard fishing gear in research surveys (both trawl and acoustic) allows obtaining the trawl samples with the assumption of similar differential catchability of the fishing gears used. However, the uncertainty in estimates of abundance indices by age groups resulted from non-considered the trawl differential catchability will remain. Therefore, temporal dynamics of abundance indices, including recruitment indices, may considerably differ from the actual dynamics.

Another important result of this study is the fact that commercial and research trawls should have different differential catchability primarily due to different requirements to codend selectivity. For research trawls the optimal representation of all age groups in catches, especially small fish forming recruitment, is required. For commercial trawls the mesh size is determined by the Fishery Rules. This fact should be taken in account in applying the acoustic survey results and observations from commercial fishing vessels.

CONCLUSION

The differential catchability of a fishing gear is one of the major sources of uncertainty in estimates of abundance indices by age groups obtained from research surveys data. Consideration of fishing gear differential catchability allows obtaining more realistic estimates of abundance indices and their temporal dynamics, thereby providing the most important information for stock-assessment models.
REFERENCES


### Table 1. Fishing system

<table>
<thead>
<tr>
<th>Fishing system</th>
<th>Commercial vessel</th>
<th>Trawl</th>
<th>Codend Mesh size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fishing system I</td>
<td>Trawler with engine power of 300hp (trawler type I)</td>
<td>RT 55/620m (trawl type 1) towing with speed of 3.1 knots</td>
<td>8mm, 10mm, 12mm, 16 mm, 18mm, 20mm</td>
</tr>
<tr>
<td>Fishing system II</td>
<td>Trawler with engine power of 1000 hp (trawler type II)</td>
<td>RT 60/240m (trawl type II), towing with speed about 3.8 knots</td>
<td>8mm, 10mm, 12mm, 16 mm, 18mm, 20mm</td>
</tr>
<tr>
<td>Fishing system III</td>
<td>Trawler with engine power of 2000ph (trawler type III)</td>
<td>RT 70/370m (trawl type III) towing with speed about 3.8 knots</td>
<td>10mm, 16mm, 20mm</td>
</tr>
</tbody>
</table>

### Table 2. Selectivity of trawl codends in the herring and sprat fishery in 1996 and 1998.

<table>
<thead>
<tr>
<th>Codend Mesh size, mm</th>
<th>Herring</th>
<th>Sprat</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>$k_s=3.948$</td>
<td>$k_s=3.898$</td>
</tr>
<tr>
<td>18</td>
<td>$k_s=4.069$</td>
<td>$k_s=3.913$</td>
</tr>
<tr>
<td>16</td>
<td>$k_s=4.086$</td>
<td>$k_s=4.078$</td>
</tr>
<tr>
<td>12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 3. Modelling estimates of fish length and species compositions in hauls when the same mixed aggregations were fished by different fishing system.

<table>
<thead>
<tr>
<th>Mesh size of trawl codends</th>
<th>Species compositions in hauls from different fishing systems</th>
<th>Fishing system type I v=3.1 knots</th>
<th>Fishing system type II v=3.8 knots</th>
<th>Fishing system type III v=3.8 knots</th>
<th>Fished aggregation (before trawl)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>sprat</td>
<td>herring</td>
<td>sprat</td>
<td>herring</td>
<td>sprat</td>
</tr>
<tr>
<td>20</td>
<td>14.5</td>
<td>85.5</td>
<td>11.8</td>
<td>88.2</td>
<td>13.1</td>
</tr>
<tr>
<td>16</td>
<td>49.9</td>
<td>40.1</td>
<td>40</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>63.8</td>
<td>36.2</td>
<td>40</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

% of each species by abundance

<table>
<thead>
<tr>
<th>Catch (number species)</th>
<th>20</th>
<th>110860</th>
<th>114340</th>
<th>147300</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td></td>
<td>349900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>966250</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Modelling impact of research trawl catchability on acoustically-derived fish abundance. It is assumed that biological sampling in the survey area was taken by research trawl (fishing system III) using codends with different mesh size. Fish length and species compositions in the surveying area are shown in Fig.7.

<table>
<thead>
<tr>
<th>Fishing system</th>
<th>NASC m³/nm²</th>
<th>Area nm²</th>
<th>Sigma</th>
<th>Fish composition, %</th>
<th>Abundance, mln sp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>herring</td>
<td>sprat</td>
</tr>
<tr>
<td>Fishing system III mesh size 10mm</td>
<td>500.0</td>
<td>5877.7</td>
<td>0.000132782</td>
<td>36.2</td>
<td>63.8</td>
</tr>
<tr>
<td>Fishing system III mesh size 16mm</td>
<td>500.0</td>
<td>5877.7</td>
<td>0.000212466</td>
<td>50.1</td>
<td>49.9</td>
</tr>
<tr>
<td>Fishing system III mesh size 20mm</td>
<td>500.0</td>
<td>5877.7</td>
<td>0.000267675</td>
<td>88.2</td>
<td>11.2</td>
</tr>
<tr>
<td>Fished aggregation</td>
<td>500.0</td>
<td>5877.7</td>
<td>0.00016</td>
<td>60.0</td>
<td>40.0</td>
</tr>
</tbody>
</table>
Fig. 1. the scheme of events sequence leading to the occurrence of fish in front of the trawl into the trawl activity zone and further to the codend (Kadilnikov, 2001).
Fig. 2. Selectivity of trawl codends with different mesh size (8mm, 10mm, 12mm) in relation to sprat.

Fig. 3. Selectivity of trawl codends with different mesh size (16mm, 18mm and 20mm) in relation to herring. Red and blue curves are based on fish biometric parameters obtained in 1998 and 1996 respectively.
Fig. 4. Biometric parameters for the Baltic herring body. Red and blue curves are based on fish biometric parameters obtained in 1998 and 1996 respectively.

Fig. 5. Biometric parameters for the Baltic sprat body.
Fig. 6. Modeling fish length compositions in the trawl hauls. It is assumed that the same mixed fish aggregation (red curve) were fished by different fishing systems (table 1) applying codends with the same mesh size of 20mm. Species compositions in hauls obtained by each fishing system are shown in Table 3.
Fig. 7. Modeling fish length compositions in the trawl hauls. It is assumed that the same mixed fish aggregation (red curve) were fished by fishing system III (table 1) applying codends with the different mesh size (10mm, 16mm and 20mm). Species compositions in hauls are shown in Table 3.
Fig. 8. Modeling fish length compositions in the trawl hauls. It is assumed that the same mixed fish aggregation were fished by different fishing systems (table 1) applying codends with the different mesh size (18mm and 12 mm). Length compositions for sprat and herring in the fished aggregation are shown by red curves in Fig. 6, 7.
Fig. 9. Estimates of acoustically-derived abundance indices by age groups based on modelling results. It is assumed that acoustic surveys were accompanied by scientific trawls with different catchability. The abundance indices based on length-species compositions in hauls and those based on length-species compositions in fished aggregations are comprised. The said fish length and species compositions are shown in Fig. 7.