Report of the Workshop on Maturity Ogive Estimation for Stock Assessment (WKMOG)

3-6 June 2008
Lisbon, Portugal
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Executive summary

The European Union requires member states to collect maturity data under the Data Collection Regulation (DCR) but there are no agreed guidelines for calculating and reporting maturity estimates from the data collected. Therefore this workshop was proposed by the Planning Group on Commercial Catches, Discards and Biological Sampling (PGCCDBS 2007) as part of ongoing ICES work to improve data collection, methodology and quality assurance. The objectives were to establish, if not a common method for raising, at least a set of best practices to be used when producing estimates from maturity data and to give participants the opportunity to address specific issues related to their maturity sampling and estimation approaches.

The workshop met its Terms of Reference which, in brief, were: a) Review the data structures and agree on a format for analysis purposes; b) Investigate differences in raising procedures in use by different countries, compare results, identify advantages and limitations; c) Propose best practices for summarizing and reporting the results.

Guidelines

A set of guidelines for maturity sampling, estimation and reporting is given in the conclusions. These build on the work of the ICES Workshop on Sexual Maturity Sampling (WKMAT 2007) and complement the minimum international protocols for age and maturity calibration from PGCCDBS 2008. The guidelines include an interpretation of how to calculate DCR precision levels for maturity estimates, based on the mean confidence interval width, which was agreed among participants.

Data

The FishFrame/COST data format was selected and successfully used as an exchange format for maturity data. It has the benefits of being open source and actively maintained. Potential developments identified were: extending the code lists for Area and otolith side, modification to accommodate species with total weight by sex and an optional field for histological maturity. Code was developed to convert from DATRAS output format to the FishFrame/COST data format.

Methods

Currently accepted practice is to use Binomial generalized linear models (GLMs) with logistic link for maturity ogive modelling and Sex-Maturity-Age-Length-Keys for raising estimates. Methods were reviewed and detailed information on raising procedures and countries’ methods provided. Comparisons between different countries’ approaches showed results were very similar.

The report demonstrates how the GLM models can be used to evaluate differences between age classes, sexes, areas or years and suggests alternative approaches if model fit is poor. For example, standard logistic curves are demonstrated to give substantially biased estimates if skipped spawning is a significant issue. In this case, three-parameter logistic curves will be more suitable. The link between maturity estimates and stock assessment was also considered with illustrations of the effect on SSB of bias and variability in maturity estimates.

There is the opportunity to advance current practice by developing models that more fully include the sampling and spatial structure of the data. Also, several approaches of estimating precision for maturity-at-age are available but there is no widely-used method. Analytical approaches need testing and bootstrap procedures that resample
individual fish may violate the assumption of independent sampling units. Re-sampling stations is reasonable, although issues arise if estimates show spatial trends or correlations between stations.
1 Introduction

1.1 Terms of Reference

At the 95th Statutory Meeting of ICES (2007) it was decided that a Workshop on Maturity Ogive Estimation for Stock Assessment (WKMOG) (Chair: David Maxwell, UK) would be established. This met in Lisbon, Portugal from 3 to 6 June 2008, to:

a) Review the data structures commonly used at a national and international level and agree on a format for analysis purposes;

b) Investigate differences in raising procedures to maturity datasets in use by different countries, compare the results between methods and data sources, identifying the advantages and limitations of each procedure, consider proposals for such raising procedures;

c) Propose best practices for summarizing and reporting the results.

1.2 Participants

This workshop was attended by 15 people from six countries. Annex 1 presents a list of names and addresses of all participants.

1.3 Background

Since 2002 the European Union has required member states to collect maturity data under the Data Collection Regulation (DCR, EC Regulations No 1543/2000, No 1639/2001, and No 1581/2004). Consequently most countries collect maturity data, but may lack guidance in calculating and reporting maturity estimates. Therefore, the ICES Planning Group on Commercial Catches, Discards and Biological Sampling (PGCCDBS, ICES 2007a), under its remit to co-ordinate development of methods and guidelines for collection and provision of data for stock assessment purposes, proposed this workshop. The objective was to establish, if not a common method for raising, at least a set of best practices to be used when producing estimates from maturity data. In the process, countries would have a chance to learn how to resolve specific raising issues related to their maturity sampling programmes and to apply other, possibly new, methods to provide national maturity estimates.

1.4 Structure of the Report

The report broadly follows the Terms of Reference for the meeting.

Section 2 summarizes the presentations made to the workshop, which were a mixture of specific studies and more general topics.

Section 3 addresses ToR a), reviewing the FishFrame/COST data exchange format selected.

Section 4 covers ToR b), it includes summaries of methods from EU DCR Technical Reports and the published literature and detailed explanations of the methods available at the workshop. These methods are applied to a common dataset with reassuringly similar results. The section finishes with an exposition of raising maturity data by length and/or age and conclusions on the methods.

Section 5 discusses additional issues related to maturity estimation and includes numerical illustrations of the effect of skipped spawning on logistic models and
the effect of bias and variation in maturity estimates on spawning-stock biomass (SSB).

Section 6 addresses ToR c) by providing guidance on how to calculate an appropriate summary of precision to meet DCR reporting requirements.

Section 7 then summarizes the workshop’s conclusions and gives guidelines for collecting maturity data and estimating proportion mature.

Along with the references used in the report, Annex 5 gives a large collection of references related to maturity, grouped into topics. Four working papers, prepared by SFI Poland, containing photographic guidebooks of the main Baltic fish gonads’ development were also available to WKMOG. These guides are not included in the report because of their large file size and the methodological focus of the meeting but they can be obtained directly from Dr W. Grygiel (grygiel@mir.gdynia.pl).

2 Summary of Presentations

2.1 A brief overview of previous meetings
David Maxwell

This presentation set the scene for the workshop, highlighting key findings and themes from a selection of previous meetings: Workshop on Sampling strategies for age and maturity (Anon 1994), SGGROMAT (ICES, 2004a), WKMAT (ICES 2007b) and recent Maturity Staging Workshops (ICES 2007c, ICES 2007d, ICES 2007e)

2.2 Summary of Workshop on Sexual Maturity Staging of Cod, Whiting, Haddock and Saithe (WKMSCWHS), 2007.
Provided by Rikke Hagstrøm Bucholtz, presented by David Maxwell

A summary of the preparation, results and conclusions of the workshop was given. The conclusions included adding an extra stage for abnormal gonadal development to the maturity scale and replacing maturity sampling outside Q1 with extra sampling in Q1. WKMSCWHS also recommended that the spawning proportion replaces the proportion mature in the assessment of the spawning stock size. This has direct implications for fitting maturity ogives that are explored in Section 5.

2.3 Maturity ogive estimation
Lisa Readdy

Some recent literature on maturity ogive estimation was summarized. Methods used were mainly generalized linear modelling with logit link, bootstrapping and one example of tree-based models. The relationship between maturation and a range of biological and environmental variables have been investigated for specific stocks. During the meeting other participants greatly expanded the reference list to provide a topic-based list of relevant literature, see Annex 6.

2.4 Raising Maturity Data
Hans Gerritsen

A description was given of an application of GLM to maturity data and a model selection procedure that can help decide if terms like age, length and age*length interactions should be included in the model. This can be used to decide the
appropriate way to raise maturity data. The same approach can also be used to test for differences between the sexes or between areas.

For a number of stocks, various raising procedures were compared for bias and precision in the maturity-at-age estimates. Although some methods are more appropriate than others, the parameter and precision estimates were quite similar between the different raising procedures.

Details of the methodology and resulting work are included in Section 4.

2.5 Methods of investigations of the sexual maturity and sex ratio of the Baltic sprat, herring, cod and flounder inhabiting the southern Baltic, and the status of BITS/DATRAS database in Poland.

Włodzimierz Grygiel

The principal part of the presentation entitled: “Methods of investigations of the sexual maturity and sex ratio of the Baltic sprat, herring, cod and flounder inhabiting the southern Baltic, and the status of BITS/DATRAS database in Poland” (author - Włodzimierz Grygiel) was based on the text extracted from the Working Paper entitled “Methods and some results of investigations of the sexual maturity and sex ratio of the Baltic sprat, herring, cod and flounder”, and four other Working Papers prepared by the Sea Fisheries Institute in Gdynia (Poland) on the WKMOG session in Lisbon (3–6.06.2008). Topics of the presentation were:

- methods of the main commercial Baltic fish sexual maturity and sex ratio investigations,
- guidebooks for the Baltic sprat, herring, cod and flounder gonad’s maturity determination – examples,
- the status of BITS/DATRAS/FishFrame databases in Poland.

A summary of the work is given in Section 4 and the full Working Paper is given in Annex 6.

2.6 Maturity Ogives estimation - the Southern Stock of European hake (Merluccius merluccius) case

by P. Gonçalves, E. Jardim, M. Sainza, L. Silva, M. Santurtún and S. Cervino - presented by Patricia Gonçalves

Abstract:

European hake (Merluccius merluccius) is distributed in the North-eastern Atlantic. Being the Southern Stock of Hake distributed along the Atlantic coast of the Iberian Peninsula (ICES div. VIIIc and IXa). In this stock, the spawning-stock biomass (SSB) is currently assessed on an annual basis, using a sex combined maturity ogive based on macroscopic gonad identification. Since 2007, the proportion of mature estimates are weighted by the length composition of the stock as recommended by ICES WKMAT. The major issue with maturity data quality is the possibility of significant misclassification of maturing or resting fish as immature, which leads to an underestimation of SSB conducting to inadequate management options. Another possible error could be introduced by the variability associated with different observers classification from the data used to estimated SSB provide from different countries and therefore different institutes.

In order to achieve the percentage of resting females macroscopically classified as immature, the maturity stage of several gonads had been determined based on microscopic characteristics. The inter-institutes classification variability, had been
estimated using the results of a maturity stage calibration exercise realized during the ICES WKSHM with all the institutes involved on the southern stock assessment.

In the present study, we re-estimated the southern stock maturity ogives taking into account the error estimation given by immature/resting misclassification and by the inter-institutes maturity staging variability.

Further details from the presentation and resulting work are included in Section 4

2.7 INBIO: A simple tool to calculate biological parameters’ uncertainty

by P. Sampedro, M. Sainza and V. Trujillo – presented by Maria Sainza

We describe an automatic procedure to estimate uncertainty of some biological parameters: growth, maturation, sex-ratio and length-weight curves. A routine has been developed in R environment, which makes possible to fit the most usual models and to estimate the coefficient of variation for parameters by using the non-parametric bootstrap methodology. The approach is illustrated by an application for Southern Hake stock.

2.8 Latvian studies of fish maturation

Tatjana Baranova

The biological data of Baltic cod were collected since 1948 on the board of commercial vessels, from landings on the fishing factory and in 1958-1991 from research surveys on the board of research vessels. Latvian sampling before 1990s was carried out monthly in SD 25-32 of Baltic Sea. Samples from the BITS (DATRAS) research surveys in 1993-2007 were conducted in March and in November-December. Samples from the commercial fishery in 1995-2005 are collected monthly, in 2006-2007 – quarterly.

The biological data of flounder, herring and sprat were collected by the LATFRA in Riga (former Baltic Fishery Research Institute) since 1960’s. The determination of the maturity stages of cod, flatfish, sprat and herring in Latvia traditionally is carried out using the 6-stage scale of gonads development. The national maturity coding should be converted into the BITS 5-stages code before the data are submitted to the ICES databases (DATRAS, FishFrame) according to the conversion tables for maturity keys mentioned in the Manual for the Baltic International Trawl Surveys, 2007. This database contained catches data (year, month, subdivision, species composition), gear parameters, biological characteristics of fish of (length, weight, sex, maturity stage, age).

The data from cod commercial catches were collected on board of the commercial vessels, which applied commercial gears – gillnets and trawls and others presented in the international FishFrame database (Fisheries and Stock Assessment Data Framework) according to the Manual for FishFrame. Following types of data can be uploaded:

1) Records with detailed haul information
2) Length frequency data
3) Sex-maturity-age length keys.

The distribution of cod by maturity stages calculated for males and females in spring monthly was used for determination of spawning stock of cod and time of spawning. Usually the following indices were calculated:

1) The average maturity stage for mature males and females was calculated as mean stage of all stages of fish (stages from II to VI),
2) The share (% by number) of immature males and females,
3) The share of mature cod in different age groups (for determination of spawning stock),
4) The sex ratio (relation of male to female) in different age groups and total in spawning stock.

Annual maturity ogives separately for males and females are calculated for estimating the Spawning Stock Biomass (SSB).

**The maturation of cod and the time of spawning**

The irregular maturation of Eastern Baltic cod and long time spawning are adaptation features to unstable hydrological conditions in the Baltic. In the case of normal maturation the spawning of Eastern Baltic cod happens in March - May and matured fish concentrate on the Gotland spawning grounds. Strongly irregular and prolonged maturation of Eastern Baltic cod was observed from 1994. Due to prolonged maturation spawning period elongated till the end of summer

Prolonged maturation and summer spawning of cod in the Eastern Baltic are not extraordinary phenomena. Alike situation was observed in the end of 1940s and in the beginning of the 1950s as well as in the mid 1960s.

Due to late maturation it is not possible to determine maturity ogives and time of spawning from research surveys in spring as the Eastern Baltic cod in March only began to ripen. In 1995-2007 the largest amount of fish were on maturity stages 3-4 (BITS stage 2) on the Gotland spawning grounds.

For assessment purposes the appropriate time of sampling is when it can be decided whether a fish will contribute in the current year to the spawning or not. In the last years we are forced to use data from commercial cod catches in spring-summer for determination of time of spawning. The peak of cod spawning in 1995-2004 was very clearly indicated on the basis of biological samples from commercial trawl catches on the Gotland spawning ground during March-August. Owing to the closure of the cod fishery in Baltic since 2005 (from May to September) it is not possible to precisely time the spawning of cod in Eastern Baltic.

**3 Review of Data Structure**

ToR a) Review the data structures commonly used at a national and international level and agree on a format for analysis.

The data collected by each of the countries participating in WKMOG follows the minimal requirements necessary to follow the data collections regulations; therefore the structures of the data are similar for biological sampling.

The datasets produced for analysis by non-assessment working groups and others do currently do not have a standard format. Therefore it was agreed that having a standard format fit for a wide range of uses, rather than just this workshop, was the best approach. Following discussion before the meeting and at PGCCDBS (ICES 2007a) the FishFrame/Cost format (Anon. 2008b) was agreed on as the most appropriate common format as it can be used for research survey biological data and is also structured to hold commercial biological data. The FishFrame format is an open source format developed for ICES and used successfully within the Baltic region. The format has also been adopted by the COST project (Anon. 2006. http://wwz.ifremer.fr/cost/cost_project).
For WKMOG the most important data is in the biological samples table. This table allows the calculation of basic maturity ogives using length and age, however, the following changes are necessary to fully accommodate the maturity data available:

- The biological samples (CA) table does not take account of histology results, these are necessary if a correction factor or calibration is required for the maturity stages. The subgroup has concluded that an extra, optional, field is necessary for the microscopic maturity stage results.
- The coding system used for rectangle and/or area for the Mediterranean countries would need to be incorporated (see annex 2). Spanish biological data does not record area for all species, in these cases distinguishing at stock level only.

Due to interpretation issues with the ‘length class’ field and its corresponding field ‘length code’, it was decided that a fuller explanation was required, i.e. in mm, Actual length or lower bound of length class i.e. 650 for 65-66 cm.

The other data tables also must be considered when raising the data. We concluded:

- The species list (SL) table should include a field for sex. This is necessary as some species of fish, such as flatfish and elasmobranchs, are sexed prior to weighing, particularly on research surveys. This extra field is necessary in order to raise the data correctly.

The field “otolith side” could include an option for when both otoliths are taken (as only one biological record per fish is expected) or when other calcified structures are used such as illicia spines or scales.

Converting an output data file, DATRAS, into another data file, COST/FishFrame is cumbersome and there is the potential to lose information such as where flat fish are sorted by sex prior to weighing. However, SAS code was successfully developed to convert from the DATRAS output into the FishFrame format and applied to data from the Baltic International Trawl Survey. This SAS code will be submitted to ICES with the meeting report or can be obtained from either of the participants from Cefas.

4 Methods of calculating maturity estimates

To investigate the differences in raising procedures for maturity datasets in use, three sources of information were studied: DCR Technical Reports, published literature and detailed descriptions of the methods used by the countries present at the meeting. Four sets of code currently in use by different countries were then applied to the same dataset, generating direct comparisons of the methods and their implementation.

4.1 Methods in DCR Technical Reports 2006

In order to study the methodology commonly used to estimate the maturity ogive and its precision, DCR Technical reports on 2006 from different countries (https://datacollection.jrc.ec.europa.eu/) were reviewed. However, only a subset of countries reported any methods for maturity estimation. Where details were given, two methods were mainly used: Generalised linear models (GLM), with binomial errors (logistic function), and Age-Length-Sex-Maturity Key (ALSMK). The number of countries using each of these two methods was roughly equal. The GLM approach typically produces an estimate of maturity-at-length (e.g. length at 50% mature), the ALSMK approach produces an estimate of maturity-at-age. Non-parametric
bootstrapping was reported as a method to obtain the precision for the maturity ogive estimation. Many countries’ technical reports referenced the recommendations on methods and reporting given in WKSCMFD (ICESb 2004) report.

4.2 Comparing methods of raising maturity data between countries

4.2.1 Sampling design

The most common approach to collecting data is two-stage sampling (e.g. Cochran 1977) where biological data are collected on a length-stratified basis and length-frequency distributions are obtained from random samples of the catch. A matrix of the catch numbers-at-age and length is estimated by applying an Age Length Key (ALK) to the length distribution of the catch. A length-based maturity ogive is then often applied to this matrix of catch numbers to estimate an age-based maturity ogive (proportion mature-at-age). The proportion of mature fish is usually defined as the proportion of fish that are likely to spawn in the current year, so fish that are not virgins but skip spawning are classified as immature.

4.2.2 Modelling maturity data

A number of methods for modelling maturity data were presented, the models used are summarized in Table 1 below.

Table 1. Maturity modelling methods used by five countries represented at WKMOG.

<table>
<thead>
<tr>
<th>Country</th>
<th>Model</th>
<th>Parameters</th>
<th>Precision estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEFAS, UK</td>
<td>GLM with logit link function</td>
<td>Length</td>
<td>Analytical using statistical weights</td>
</tr>
<tr>
<td>SFI, Poland</td>
<td>Linear regression on transformed data. Weighted by length distribution</td>
<td>Length</td>
<td>From model, L50 only</td>
</tr>
<tr>
<td>IPIMAR, Portugal</td>
<td>GLM / Generalized additive model (GAM) with logit link function</td>
<td>Length</td>
<td>From model</td>
</tr>
<tr>
<td>IEO, Spain</td>
<td>GLM with logit link function (INBIO)</td>
<td>Length, Age, Sex</td>
<td>Bootstrap: resample individual fish</td>
</tr>
<tr>
<td>MI, Ireland</td>
<td>GLM with logit link function</td>
<td>Length, Age, Sex, Area, Year</td>
<td>Bootstrap: resample sampling stations</td>
</tr>
</tbody>
</table>

Rather than using an ALK, the UK assigned weights to individual observations of age, maturity and length. The GLM was applied to weighted data and precision estimates were obtained analytically. Poland used a method described by Rickey (1995) to fit a logistic curve to the maturity-at-length data. Portugal used a GLM with a logit link function and has also developed code to apply a binomial Generalized additive model (GAM) to southern hake data. The GAM was applied in cases where the GLM did not provide a good fit for data with both sexes combined. Spain has developed an R-package called INBIO that fits a GLM and supplies bootstrapped precision estimates as well as a range of diagnostics plots. Ireland has developed code that fits GLMs and allows a number of terms to be tested for significance in the model. Possible terms to be included are Age, Sex, Area and Year. A more detailed summary of the procedures used by each country is provided later in this section.

All countries that presented their methods of raising maturity data used a logit transformation or logit link function to describe the proportion mature-at-length. Applying a linear regression on the transformed data is essentially the same as
applying a GLM with a logit link function although the two methods differ in the way the errors are handled. Error estimates of parameters like L50 (the length at 50% maturity) might also be obtained analytically using either method, although the methods have not been fully tested. The bootstrap procedure is reasonably straightforward to apply, however it requires the assumption that bootstrapping units are independent. This is not strictly the true, neither for sampling stations (used by Ireland as bootstrapping units) nor for individual fish (used by Spain).

During the workshop, each country applied their own code or package for estimating maturity ogives on the same dataset (Cadiz hake, 2007). The length at 50% maturity was estimated for males, females and the combined sexes. IPIMAR and MI achieved nearly identical results (within 0.01cm), the estimates for IEO were 0.5cm higher than the IPIMAR and MI results because the INBIO package corrects for the fact that the midpoint of length class j is j+0.5cm. SFI’s estimate of L50 for males was slightly larger as two outlying immature observations at 46 and 54cm were removed. The L50’s for females were within 0.5cm confirming that the approaches were very similar. Small differences were found between the use of 1cm length classes and the raw length data at 1mm resolution. When only maturity at length is required and data are available to 1mm there is no need to convert to length classes.

The results of estimating the L50 from the Cadiz hake dataset for each country are given below.

<table>
<thead>
<tr>
<th>L50</th>
<th>LENGTH IN 1CM SIZE CLASSES</th>
<th>LENGTH IN MM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IPIMAR</td>
<td>IEO</td>
</tr>
<tr>
<td>Both sexes</td>
<td>40.89</td>
<td>41.39</td>
</tr>
<tr>
<td>Females</td>
<td>42.95</td>
<td>43.44</td>
</tr>
<tr>
<td>Male</td>
<td>29.68</td>
<td>30.17</td>
</tr>
</tbody>
</table>

* two outliers excluded
* without 0.5cm correction factor

4.2.3 Methods – UK

The following extract from the UK DCR technical report on 2006 describes the methods used for raising maturity data and estimating precision.

Estimates of biological parameters by stock were calculated from a combination of the most appropriate datasets from UK (E&W), UK (NI) and UK(Scotland) research vessel surveys. The surveys apply two-stage, length-stratified sampling. A reasonably large number of fish are measured to produce a length distribution and biological parameters (age, maturity and sex) are recorded for a subsample of these fish. Therefore, calculations by age used statistical weights to account for the length distribution. The derivation of these weights is given at the end of the section.

Mean weight at length, weight-at-age and length-at-age and their CVs were estimated analytically from the data by length or age group using standard formulae. The median CV across all length groups or ages 0 to 9 was calculated and converted to a precision level using the approximation in the ICES WKSCMFD report (2004). For maturity at length and maturity-at-age, logistic maturity ogives were fitted, as generalized linear models (GLM). The maximum width of the 95% confidence interval was used to define the precision level. For sex ratio, the proportion of females at length or age was modelled using a generalized additive model (GAM) with binomial family and the amount of smoothing selected automatically. The
maximum width of the 95% confidence interval over the length groups containing the central 95% of the data or age groups 0 to 9 was used to define the precision level.

SAS v9.1 was used for all analysis except modelling the sex ratio where R v2.4.1 with package mgcv was used.

Definition of statistical weights used in calculations by age.

For each fish with biological data, define a raising factor:

(1) \[ r_g = \frac{ng}{mg} \]

where ng is the number of fish measured within a length group g, and mg is the number of fish subsampled in the same length group.

Calculate the sum of the raising factors for each age group a,

(2) \[ R_a = \sum_{g=a}^{\text{all}} r_g \]

where ai denotes the age of fish i.

Assign statistical weight, to fish i in length group g and age a

(3) \[ w_i = m_a \times \frac{r_g}{R_a} \]

where ma is the number of fish of age a with biological data.

For each age group the sum of statistical weights will equal the number of fish with biological data.

Code based on this method, under development within the COST project (Anon. 2006. http://wwwz.ifremer.fr/cost/cost_project), was tested on Polish and UK (England & Wales) data provided in the COST/FishFrame commercial format. The code was successfully implemented on both sets of data, and this will be taken forward and developed further by the COST project.

### 4.2.4 Methods – Poland

The principal part of the presentation entitled: “Methods of investigations of the sexual maturity and sex ratio of the Baltic sprat, herring, cod and flounder inhabiting the southern Baltic, and the status of BITS/DATRAS database in Poland” (author - Wlodzimierz Grygiel) was based on the text extracted from the Working Paper entitled “Methods and some results of investigations of the sexual maturity and sex ratio of the Baltic sprat, herring, cod and flounder”, and four others Working Papers prepared by the Sea Fisheries Institute in Gdynia (Poland) on the WKMOG session in Lisbon (3–6.06.2008). Topics of presentation were:

- methods of the main commercial Baltic fish sexual maturity and sex ratio investigations,
- guidebooks for the Baltic sprat, herring, cod and flounder gonad’s maturity determination – examples,
- the status of BITS/DATRAS/FishFrame databases in Poland.

In 1999, the ICES Study Group on Baltic Herring and Sprat Maturity (SGBHSM) and the ICES Working Group on Baltic Fisheries Assessment (WGBFAS) initiated the international investigations of maturity ogives as well as the sex ratio (separately by sex and the ICES Subdivisions) with regard to the age and length structure of the Baltic herring and sprat.
In 2000-2001, the Sea Fisheries Institute (SFI) in Gdynia with close cooperation of the aforementioned ICES WGs realized an own, study project concerns the sexual maturity and sex ratio of the Baltic clupeids, based on historical and contemporary materials.

Reason for the realization of above-mentioned international investigations was the fact that over the 1974-1999 period the ICES working groups estimated e.g. the Baltic herring (with the exception of the ICES Subdivisions 30 and 31) and sprat stocks size using constant, fixed and combined sex maturity data at age groups and the ICES Subdivisions. This parameter was not verified until 2000.

Similar international investigations of the Baltic cod were initiated on the beginning of 1990s. In the first half of 1990s the SFI in Gdynia carry out the separate study of the southern Baltic cod and flounder maturation, sex ratio and fecundity.

At present time modified the 9-stages Maier's scale is applied by the SFI in Gdynia for the Baltic fish biological analyses, and abnormally developed gonads are recorded as the stage 9, which can be converted to adequate stage 6 - according to the new ICES gonads development scale. The Baltic main commercial fish gonads developmental stages were determined by visual, macroscopic identification, without histological validation.

The following periods were designated as representative of the prespawning and at very beginning of spawning seasons for the main southern Baltic fish:

- herring – from January to April,
- sprat – from February to May,
- cod – February-March,
- flounder – January-February.

The Baltic clupeids, cod and flounder with gonads in maturity stages III and IV on the Maier’s scale, achieved in the above-mentioned periods were classified as the sexually mature fraction, which were potentially ready for spawning in a given season. The investigations were based on samples collected within the Polish parts of the ICES Subdivisions 25 and 26, mostly during research surveys type BITS (the Baltic International Trawl Surveys), conducted in February/March 1980-2004 and, to a lesser degree, on materials from the commercial fishing fleet catches and landings not sorted according to fish size groups.

In the final stages of constructing sprat, herring, cod and flounder databases, the Polish data on fish’s gonad maturity were converted to the five-degree ICES scale, previously recommended by the ICES BIFSWG and SGBHSM.

The length distribution and age structure of Baltic clupeids were determined separately for males and females of the southern coast spring-spawning herring population and sprat. The age composition of clupeids was based on the “length-age keys”, which were prepared for particular years and each basin of the southern Baltic. The numerical share of sexually mature males and females at age groups resulted from raising procedure applied between the level of fish biological analyses (number of fish at a given age and length classes) and length measurements (frequency of given length classes).

The initial stage in the preparation of the Baltic clupeids maturity logistic curves was the regression analysis (linear model) and analysis of variance of the logarithm of the percentage of mature herring and sprat specimens vs. length classes. Calculations were performed separately according to sex, groups of years (1980-2000) and the
southern Baltic basins. A simple statistical model of herring and sprat maturity ogives vs. length classes was formulated during the final stage of the work. A modified logistic curve (non-linear regression; Rickey 1995) was applied for plotting the fish maturity ogive, well-fitted according to the following formula:

\[
Y = \left( \frac{1}{1 + e^{(a + bX)}} \right) \cdot 100
\]  

(4)

where: \( Y \) – percentage of the number of mature specimens, \( X \) – length class, \( e \) – base of the natural logarithm, and \( a \) and \( b \) – constant coefficients of the equation initially calculated from linear regression (\( y = a + bx \)).

Two examples of the logistic curves (maturity ogives) of the southern Baltic sprat and herring sexual maturation in the 1980s and the 1990s vs. length classes (Grygiel and Wyszyński 2003a) were presented.

In the regression analysis used, the value of the natural logarithm from the reverses of the dependent variable was provided instead of variable \( Y \) according to the following formula:

\[
Y' = \ln \left( \frac{1}{Y - 1} \right)
\]  

(5)

The length at which 50% of the fish population achieved first sexual maturity was calculated according to following formula (Seber 1982):

\[
L_{50\%} = -\frac{a}{b}
\]  

(6)

where: \( L \) – length (cm), \( a \) and \( b \) – the coefficients of regression analysis cited above.

The results presented in Grygiel and Wyszyński (2002, 2003a) papers indicate that there is a greater proportion (numerical percentage) of sexually mature the southern Baltic herring (excluding age group 1) and sprat in younger age groups than was assumed by the ICES working groups up to 2000.

In the second parts of presentation, 11 examples (photos) of the Baltic sprat, herring, cod and flounder different stages of gonads development was illustrated.

In the third parts of presentation, the status of BITS/DATRAS/FishFrame databases transferred to ICES by Poland was discussed during the “ICES Workshop on an evaluation and improvement of the BITS/DATRAS data quality assurance” (Gdynia, 31.01 - 03.02.2006) and was described in the “Addendum 2 to the ICES WGBIFS Report 2006”; ICES CM 2006/LRC:07 Ref. ACFM, BCC, RMC.
4.2.5 Methods - Portugal

Method to estimate the maturity ogive for Southern Stock of Hake

European hake (*Merluccius merluccius*) is distributed in the North-eastern Atlantic. Being the Southern Stock of Hake distributed along the Atlantic coast of the Iberian Peninsula (ICES div. VIIIc and IXa). In this stock, the spawning-stock biomass (SSB) is currently assessed on an annual basis, using a sex combined maturity ogive based on macroscopic gonad identification. Since 2007, the proportion of mature estimates is weighted by the length composition of the stock as recommended by WKMAT (ICES 2007b). Data was collected by the three institutes in charge of this stock (AZTI, IEO and IPIMAR), during the spawning season - from December until May. Length class intervals of 1 cm were used and mature fish was considered as those either maturing (presence of oocytes), spawning, spent or resting.

The maturity data quality could be compromised by the misclassification of maturing or resting fish as immature (ICES 2007c), which leads to an underestimation of SSB resulting in inadequate management options. In hake we cannot macroscopically distinguish between immature and resting females, only histology can allow the correct classification of resting females. Based on that, one recommendation of the ICES WKMSHM has been to collect immature/resting female gonads for histology purposes in a length class basis to estimate a correction factor that could be applicable to the macroscopic data. However, taking into account that in the peak of the spawning season mature females are active, if we reduced our sampling period, the number of resting females would be minimal. During the same workshop a maturity staging calibration exercise with fresh hake specimens was carried out, the results reveal that there is some variability on gonads classification between institutes that are using the same macroscopic maturity stage key.

The maturity data used for maturity ogive estimation should be committed by: the misclassification of maturing or resting fish as immature; the variability associated with different observers classification, once the data used to estimated SSB for the southern stock of hake has provided from different countries and different institutes (ICES 2007c); or the differences in maturity behaviour (L50 and SSB) by area.

In the present study, we re-estimate the southern stock maturity ogive:

- for the original data
  using the original data but applying the correction factor given by histology (on April and May data) and the correction factor based on the calibration exercise realized during the ICES WKMSHM
- for the main spawning period (January to May)
  using the main spawning period data but applying the correction factor based on calibration exercise realized during the ICES WKMSHM

The percentage of resting females macroscopically classified as immature has been estimated by applying histology to determine the maturity stage of several gonads based on microscopic characteristics (Table 2). The between-institute classification variability had been estimated using the results of a maturity stage calibration exercise realized during the ICES WKMSHM with all the institutes involved in hake southern stock assessment (Table 3).

The maturity ogives estimation method applied on the assessment is the following:

\[ Oc = p_f O_f + (1-p)f O_m \]
Oc = sex combined maturity ogive
Of = females maturity ogive
Om = males maturity ogive
pf = proportion of females

\[
\text{var}(\text{Oc}) = \text{var}(\text{pf})*[\text{Of}^2 + \text{var}(\text{Of}) + \text{Om}^2 + \text{var}(\text{Om})] + \text{pf}^2*\text{var}(\text{Of}) + \text{var}(\text{Om})]
\]

(Note that the final term in this variance equation requires checking)

A GLM with a binomial error distribution and a logit link was fitted to the proportion of fish mature (m) by length (cm). The model has the general form:

\[
\log(E[m]) = a + bl
\]

where \(a\) and \(b\) are the intercept and slope of the ogive. Estimates of the length at 50% maturity (L50) and of the slope of the ogive at L50 were derived from the model parameters as

\[
L50 = -\frac{b}{a}.
\]

The L50 results estimated by different data, reveals that when the correction factors are applied this value increase (Figure 1) which seems to indicate that the immature/resting misclassification and the classification variability between institutes seems to have impact on maturity estimation.
Figure 1. The length class (cm) at which 50% of the individuals are mature (L50), for the maturity ogive estimated by institute with original data, original data applying the correction factors (given by histology and calibration exercise), main spawning season data and main spawning season applying the correction factor given by calibration exercise. AZTI (+), IEO (+), IEO_Cádiz (+) and IPIMAR (+) results.

The main conclusions are:

- To estimate the misclassification percentage, all the institutes involved in providing data for the assessment should collect histological samples of gonads from both sexes, across the length range of fish and throughout the spawning season.
- Inter and intra-institutes calibration exercises should be carried out on a regular basis to assess discrepancies.
- Making improvements to maturity data collection and using correction factors that adjust for maturity sampling errors are useful ways to improve the accuracy of the L50 and SSB estimates.
Table 2. The percentage of resting females by length class (cm) that has been classified macroscopically as immature, this error estimation is based on histological observations. The number of individuals is the number of total individuals by length class analysed by histology at different macroscopic maturity stages.

<table>
<thead>
<tr>
<th>Lt (cm)</th>
<th>sex</th>
<th>AZTi</th>
<th>IEO</th>
<th>IPiMAR</th>
<th>IEO_Cadiz</th>
<th>Indiv. (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>f</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>f</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.24</td>
<td>21</td>
</tr>
<tr>
<td>35</td>
<td>f</td>
<td>0</td>
<td>0.7</td>
<td>0</td>
<td>0.35</td>
<td>14</td>
</tr>
<tr>
<td>40</td>
<td>f</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>4</td>
</tr>
<tr>
<td>45</td>
<td>f</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>50</td>
<td>f</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>m</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>35</td>
<td>m</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

Table 3. The percentage of females in each length class (cm) that has been classified as mature and according to the agreed stage (given by the all participants on the WKMSHM calibration exercise) are immature.

<table>
<thead>
<tr>
<th>Year</th>
<th>Lt (cm)</th>
<th>Sex</th>
<th>error (%)</th>
<th>Indiv. (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>21 – 25</td>
<td>m</td>
<td>0.000</td>
<td>10</td>
</tr>
<tr>
<td>2007</td>
<td>26 – 30</td>
<td>m</td>
<td>0.000</td>
<td>14</td>
</tr>
<tr>
<td>2007</td>
<td>31 – 35</td>
<td>f</td>
<td>0.286</td>
<td>7</td>
</tr>
<tr>
<td>2007</td>
<td>31 – 35</td>
<td>m</td>
<td>0.045</td>
<td>22</td>
</tr>
<tr>
<td>2007</td>
<td>36 – 40</td>
<td>f</td>
<td>0.039</td>
<td>25</td>
</tr>
<tr>
<td>2007</td>
<td>36 – 40</td>
<td>m</td>
<td>0.000</td>
<td>33</td>
</tr>
<tr>
<td>2007</td>
<td>41 – 45</td>
<td>m</td>
<td>0.000</td>
<td>8</td>
</tr>
<tr>
<td>2007</td>
<td>41 – 45</td>
<td>f</td>
<td>0.026</td>
<td>39</td>
</tr>
<tr>
<td>2007</td>
<td>46 – 50</td>
<td>f</td>
<td>0.000</td>
<td>21</td>
</tr>
<tr>
<td>2007</td>
<td>46 – 50</td>
<td>m</td>
<td>0.000</td>
<td>3</td>
</tr>
<tr>
<td>2007</td>
<td>51 – 55</td>
<td>f</td>
<td>0.000</td>
<td>18</td>
</tr>
<tr>
<td>2007</td>
<td>56 – 60</td>
<td>f</td>
<td>0.000</td>
<td>8</td>
</tr>
<tr>
<td>2007</td>
<td>61 – 65</td>
<td>f</td>
<td>0.000</td>
<td>4</td>
</tr>
<tr>
<td>2007</td>
<td>71 – 75</td>
<td>f</td>
<td>0.000</td>
<td>2</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td></td>
<td></td>
<td>212</td>
</tr>
</tbody>
</table>

4.2.6 Methods - Spain

Sampedro P., Sainza M. and Trujillo V. “INBIO: A simple tool to calculate biological parameters’ uncertainty”

Description of an automatic procedure to estimate uncertainty of some biological parameters: growth (by length/or weight), maturation (by length/or age), and length–weight relationship. A routine has been developed in R environment, which makes possible to fit the most usual models and to estimate the coefficient of variation for parameters by using the non-parametric bootstrap methodology.

The non-parametric bootstrap method consists in generate B bootstrap samples, in our case 1000 replicates, by resampling with replacement the original data. Then all statistics for each parameter can be calculated from each bootstrap sample.

The statistics adopted for each estimate were: median and coefficient of variation (relative variation, estimation error).
For all the estimates has been plotted their probability profiles ("density’s functions") and some plots of model’s residuals (model error) to check visually: autocorrelation, homo/hetero-cedasticity, outliers and/or extreme values (maybe, observation errors?), linearity and normality.

Models and fits adopted were:

- Growth at age (vs. Length and Weight):
  von Bertalanffy. Non-linear estimation w. minimum least squares (G-N)
- Maturity (Length and Age):
  GLM. Logistic function. Binomial errors w. maximum log-likelihood fit.
- Length - Weight Relationship:
  Standard. Non-linear estimation w. minimum least squares (G-N)
- Sex-ratio (Length and Age):
  No Model. Percentage by length and age. Cubic spline to plot

The approach is illustrated by an application for Southern stock of hake.

This tool is simple and powerful and it can be used for many purposes and give us an easy and quick way to produce estimates for the main biological parameters and their associated variability and bias.
Example Output - Estimates of maturity parameters’ uncertainty at age

Species: Southern hake, sex combined

ORIGINAL DATA: RESULTS OF GLM

Call:

glm(formula = mat ~ age, family = binomial(link = logit), data = mad.eda.dat)

Deviance Residuals:

Min     1Q Median 3Q     Max
-2.9741 -0.9382 -0.4987 1.1260 2.3662

Coefficients:

Estimate Std. Error z value Pr(>|z|)  
(Intercept) -3.09405  0.15939 -19.41 <2e-16 ***  
Age 0.71472  0.03947  18.11 <2e-16 ***

Signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 2714.5 on 2005 degrees of freedom
Residual deviance: 2266.2 on 2004 degrees of freedom
AIC: 2270.2; Number of Fisher Scoring iterations: 4

ESTIMATED PARAMETERS

<table>
<thead>
<tr>
<th>Original</th>
<th>Boot</th>
<th>CV boot</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0</td>
<td>-3.0941</td>
<td>-3.1052</td>
</tr>
<tr>
<td>B1</td>
<td>0.7147</td>
<td>0.7175</td>
</tr>
<tr>
<td>A50</td>
<td>4.3290</td>
<td>4.3214</td>
</tr>
</tbody>
</table>
Figure 3. Plot of deterministic and stochastic models, residual’s patterns for maturity at length and age and probability profiles (density functions) and q-q plot for L_{50} and A_{50}.

4.2.7 Methods - Ireland

Most countries use only length as an explanatory variable when modelling maturity; however some examples of Irish fish stocks showed that within length classes, age can play a significant role in predicting the proportion mature (Figure 4). Therefore, it is recommended that the factor age is included in an initial model and tested for significance. (see Text box 1 for an example with R code). The same approach can be used to test for significant differences between the sexes or between areas.
If this procedure is used, it is essential the model diagnostics are examined to check for model fit, overdispersion etc (e.g. Collett 2003). If the data are presented to the model as a matrix with the number of mature and immature fish at each length class, the model diagnostics are easier to interpret than those of a model that uses the maturity state of individual fish as the response variable (as in the example below).

If it is found that the model does not adequately fit the data, one might consider using a GAM, as is applied to estimate annual maturity ogives for the southern hake at the WGHMM. In the case of southern hake, the logistic model does not fit the maturity ogive for the combined sexes very well, but it does provide a good fit for the males and females separately. In this case it might be worthwhile investigating the use of a multinomial model (with four levels: female-mature; female-immature, male-mature and male-immature, rather than the two levels of the binomial model: mature and immature, (see Gerritsen et al., 2006; ICES J. Mar. Sci., 63(6) for a description of the multinomial model).

The occurrence of skipped spawning might also result in a bad fit, see section 5.4 on skipped spawning for more details.

**Text box 1**

The following R code is an example of an initial maximal model (model0) that includes *age*, *length* and an *age*\**length* interaction. The simulated data are presented to the model as three columns of observations on individual fish. The function `step()` applies a stepwise selection procedure that drops the least significant term and tests for a significant increase in deviance. If this term is not significant, another term is dropped until no more terms can be dropped without significantly deteriorating the fit of the model. The output of the `step()` function (model1) is the minimum adequate model, the model with the ‘optimum’ number of terms (balancing the degrees of freedom with the model deviance).

```r
# simulate some data (badly)
len=sample(0:50,1000,replace=T)
age=rbinom(1000,5,len/50)
mat=rbinom(1000,1,1/(1+exp(-0.25*len-age+10)))

# fit maximal model
model0 = glm(mat~len*age,family="binomial")

# select minimum adequate model
model1=step(model0)
```

The same procedure can be applied to test for significant differences between the sexes, areas or years by including these terms in the original model. If the terms are dropped in the stepwise model selection procedure, they are not significant. (for example: `step(glm(mature~length*age*sex*area,"binomial")`) It is recommended that these variables are tested for significance if they are available.

**Figure 4** shows the minimum adequate model (the model that includes all significant terms) for four stocks sampled in Irish waters. (see Annex 3 for R-code to produce these plots) The factor age was a significant term for three of the four stocks shown here. Age data are not always available for all maturity records for some countries. However it is recommended that the age-effect is investigated for observations where maturity, length and age are available, even if this is only a subset of the data.
4.3 Raising maturity data

This section is based on the presentation “Raising maturity data” given by Hans Gerritsen during the working group.

Morgan and Hoelig (1997; http://journal.nafo.int/J21/vol21.html) describe an unbiased method for estimating maturity-at-age from length-stratified data. Following their notation, the proportion mature-at-age $M_a$ can be estimated as follows:

$$M_a = \frac{\sum_{j=1}^{J} \bar{p}(j) \bar{p}(a \mid j) \bar{p}(m \mid a, j)}{\sum_{j=1}^{J} \bar{p}(j) \bar{p}(a \mid j)} \quad (11)$$

where

- $\bar{p}(j)$ is the estimated fraction of the catch that was length $j$. (relative length frequency distribution of the catch)
- $\bar{p}(a \mid j)$ is the proportion of the sampled fish in length category $j$ which is age $a$. (Age-Length Key)
- $\bar{p}(m \mid a, j)$ is the proportion of the sampled fish at age $a$ which are mature in the length category $j$. (maturity ogive for each age class)
- $J$ is the number of length classes.

This approach has the same result as using a Maturity-Age-Length-Key. The raw data are usually used to estimate the proportions in the equation above, however these proportions can also be supplied by models like those described in the previous section. This can be advantageous if there are missing values in the maturity data.

In cases where length is the only significant term in the glm (e.g. horse mackerel in Figure 4), or if age data are not available for all the maturity observations, the equation can be slightly simplified by substituting $\bar{p}(m \mid a, j)$ for $\bar{p}(m \mid j)$ which is the proportion of sampled fish which are mature in the length category $j$. (the length-based maturity ogive):

$$M_a = \frac{\sum_{j=1}^{J} \bar{p}(j) \bar{p}(a \mid j) \bar{p}(m \mid j)}{\sum_{j=1}^{J} \bar{p}(j) \bar{p}(a \mid j)} \quad (12)$$

In cases where age is the only significant term (e.g. cod in Figure 4) an unbiased estimate of the proportion mature-at-age can be obtained simply by estimating the average proportion mature for each age class of the sampled fish:

$$M_a = \bar{p}(m \mid a) \quad (13)$$

4.3.1 Precision and bias

The effect of estimating maturity-at-age using a maturity ogive that includes both length and age (Equation 11), using a length-based maturity ogive (Equation 12) or
directly estimating maturity-at-age from the length-stratified data (Equation 13) was investigated by estimating the precision of the maturity-at-age estimates using a non-parametric bootstrap procedure which used the sampling stations as bootstrapping units and resampled the length-frequency data together with the maturity and age data (as these were not collected independently). The standard error was estimated from the standard deviation of the bootstrap estimates of the proportions mature-at-age (500 bootstrap iterations). Estimates of maturity-at-age using Equation 11 were considered unbiased. Relative bias for the other methods was estimated as the difference between the estimates of Equation 11 and those of Equations 12 or 13.

Figure 5 indicates that, although the raising procedures given by Equations 11, 12 and 13 differ conceptually, the parameter estimates are quite similar: the bias is usually less than 10%. Additionally, the precision estimates were very similar between the methods. Therefore it appears that one method is not necessarily superior, however, the modelling procedure has shown that the most appropriate method varies between stocks.

4.4 Summary of raising procedure

1) Fit maximal glm with all available variables (Length, Age, Sex, Area, Year)
2) Check model diagnostics for fit and over-dispersion
3) If the glm does not provide a good fit, other appropriate models include:
   • gam
   • multinomial model (e.g. Gerritsen et al., 2006)
   • any other curve might be fitted using maximum likelihood which can account for the binomial nature of the data (e.g. Gerritsen et al., 2003)
4) If glm provides good fit, use stepwise procedure to select the minimum adequate model. All the terms that remain in the model are significant. This indicates whether maturity should be raised separately for the sexes, by area or by year. It also indicates which of Equations 11 to 13 is the most appropriate way to raise the data.
Figure 4. The minimal adequate models for four stocks sampled in the waters around Ireland. The coloured numbers represent the proportion mature at length for each age class. The coloured lines represent the predicted proportions mature at length for each age class. The model parameters are given in the title of each plot.
Figure 5. Bias relative to equation 11 and precision of maturity-at-age of four stocks sampled around Ireland. Estimates using Equation 11 (maturity-at-age and length; red), Equation 12 (maturity at length only; green) and Equation 13 (maturity-at-age only; blue). The thick lines represent the most appropriate raising procedure as determined by the stepwise selection procedure of the GLM.
4.5 Methods from the literature

As with the DCR Technical reports and methods presented at the workshop, Binomial GLMs with logistic link are most commonly found in the published literature on maturity studies. In addition to this we note the following approaches.

4.5.1 Probabilistic Maturation Reaction Norms (PMRNs)

PMRNs describe an organism’s probability of maturing as a function of its age and size. They are useful for studies of changes in maturation and the effects of biological or environmental factors and can be used as part of process-based dynamical models. Dieckmann and Heino (2007) provide further details and an easily accessible review of the topic. PMRNs differ from maturity ogives as they describe the probability of becoming mature while maturity ogives describe the probability of being mature. Therefore PMRNs do not provide a direct input to the stock assessment methods commonly in use at ICES assessment working groups and we did not apply them to the case study in Section 4.2.2. However, researchers studying maturation and scientists collecting maturity data should be aware of the approach, its benefits and data requirements, especially as PMRNs are Environmental indicator 4) “Maturation of exploited fish species” in Appendix XIII of the new EC DCR (Draft Commission Regulation (EC) No 199/2008).

4.5.2 Regression Trees

Vitale et al. (2006) give an example of regression tree analysis applied to maturity data. This approach defines groups of observations with similar proportions mature using length classes, biological and environmental variables. The final number of groups is decided based on a trade-off between increasing the model complexity and improving the fit. As the method does not assume a parametric relationship between length and proportion mature it can be a useful tool for exploratory analysis and could be used to assess if using a logistic curve is reasonable or if less regular patterns of, e.g. mature at length, are present.

4.5.3 Limitations of GLM and potential developments

The methods used by most countries (GLMs and estimates by individual length or age classes from SMALKs) are based on an assumption that the individual observations of maturity are independent. (The exception in Table 1 is the approach where stations are bootstrapped). Generally, the sampling structure, i.e. the fishing hauls or market samples, is not taken into account, although maturity at length of fish from the same haul are likely to be more similar than for fish from different hauls. Using stratification and ensuring that sampling programmes have representative coverage of the population partially mitigate this issue but there is clearly scope to develop models that incorporate sampling and spatial structure.

GLM models that include random effects (GLMMs) are now available (e.g. Venables and Dichmont, 2004) so it should be possible to develop models where proportion mature is related to length through a logistic model that also accounts for the two levels of variability in the data, hauls and individuals within hauls. Similarly, model-based spatial statistics (Diggle and Ribeiro 2007) for Binomial data are becoming more accessible through software such as the geoRglm package in R, so there is the potential to include spatial structure in the model error structure. Ultimately an assessment model that integrates different sources of sampling data (in a similar manner to Hirst et al. (2005) for catch-at-age) to estimate the numbers immature and mature in the population as part of the assessment, would be desirable.
4.6 Conclusions

The review of the methods used by different countries yielded the following conclusions and raised a number of questions, which are considered in Section 5.

- Logistic models are almost universally used to model maturity data. The literature provides alternative approaches (e.g. Trippel and Harvey, 1991), although with the advent of freely available statistical platforms like R, Generalized Linear Modelling (GLM) seems to be the most popular approach.
- If the models provide a good fit, they can be used to evaluate if differences exist between age classes, sexes, areas or years. However, the usefulness of the model is contingent on the fit of the model. If the model fit is poor, other approaches like gam, multinomial models (e.g. Gerritsen et al., 2006) or any other curve fitted using maximum likelihood that acknowledges the binomial nature of the data (e.g. Gerritsen et al., 2003) can be used.
- The raising procedure used did not affect the parameter or error estimates to a great extent for the stocks examined.
- There is scope to develop and apply models that include the sampling and spatial structure of the data as GLMs are limited by the assumption that individual observations are independent.
- There is no widely agreed method of estimating errors for maturity data. Analytical approaches need to be developed and tested further before they can be adopted. Bootstrapping procedures assume that the bootstrapping units are independent. If individual fish are resampled this assumption might be violated as parameters of fish from the same haul are likely to be correlated. If sampling stations are used as bootstrapping units, a similar problem arises if the data show spatial trends or correlations between stations.

5 Additional questions

5.1 Should survey or commercial data be used for maturity ogives?

The workshop thought this issue was case-specific and agree with SGGROMAT (ICES 2003) that the presence of both survey and commercial information can be beneficial. Survey data have advantages due to being collected under more controlled conditions from a known design, while commercial data are important to obtain maturity ogives of species with a protracted spawning season where it would be difficult for survey data to cover the spawning season or whole stock area. In all cases it is vital to use knowledge of the fishery and population dynamics, such as migration, to decide on the appropriateness of each data source.

Different fishing gears will have different size selectivity but it is less obvious if maturation stage will directly affect selectivity or if commercial and survey data from the same region and season will show meaningful differences in maturity. One possible concern is that within the same local area commercial fishing might target spawning aggregations while a survey would not. If both survey and commercial data are available for the same region and season then the effect of ‘data source’ can be assessed by including it as a factor in a glm for proportion mature. However, often only one source of data is available, due to practical reasons or it being considered uneconomical to collect similar data from two sources at the same time. A limited
comparison tried at the workshop was inconclusive but there is potential to develop it.

The workshop felt that the maturity sampling guidelines from WKMAT covered the use of survey and commercial data but suggested an alternative phrasing, which is included as points 1) and 2) of the extended guidelines in Section 7.

5.2 If differences exist between areas, how do we weight the maturity data from each area?

This issue was raised by the WG on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM) but may be relevant elsewhere, particularly where several institutes collect data on the same stock. The possibility of spatial differences or differences in spawning season within the stock distribution area should be checked to avoid bias in the maturity ogive.

If large differences in maturity exist between areas then first the assumption that the areas cover a single-stock should be confirmed. Where this is true and a combined estimate for the whole stock is required then the maturity ogives by area should be weighted using the best available information. If there is sufficient catch and tuning index information to estimate population numbers by area these should be used. Alternatively, if the whole stock area is covered by a survey, the different areas should be weighted by the catch rate in each area (i.e. a stratified design). If neither of these options are available then a proxy measure for abundance may have to be used to combine the areas, for example, commercial cpue, surface area or even expert opinion.

5.3 Are annual estimates or average values across years more appropriate?

Differences between years in maturity estimates can be caused by many factors: (i) Sampling variability; (ii) Age and maturity stage estimation uncertainty; (iii) changes in the coverage of the population due to survey changes or variability in targeting practices of commercial fisheries; (iv) genuine changes in maturation caused by population effects, human activities and environmental factors.

To reduce the effect of sampling variability it may be appealing to use average values based on several years rather than annual estimates, however, averages may be less responsive if genuine annual changes occur. For North Sea cod, Reeves and Pastor (2007) report that using average values for weight-at-age smoothes out observed annual variations but can lead to substantial deviations between the assumed and actual values if there are multiyear trends. The same is true for maturity estimates. Figure 6 illustrates this point, showing how the 3-year average (mean of current year and two previous years) lags behind the observed data. For points in a historical time-series taking averages centred on the year of interest e.g. \((y(t-1) + y(t) + y(t+1)) / 3\), will reduce this effect, although this is clearly not possible for the latest year in the time-series.

As with the choice of data source, knowledge of the stock and sampling must be used to guide the interpretation of annual changes in proportion mature and to judge if they are sampling artefacts, for example, if spawning occurred unusually late relative to survey timing.

The list of literature provided in Annex 7 contains a significant number of publications reporting noticeable changes in maturity over relatively short time-scales. This fact combined with the lag effect meant that, in general, the workshop was cautious about using averages and preferred annual estimates to be the default
option where possible. However, it is important to realize that using annual estimates is not currently an option some stocks as maturity data are only collected every three years. For these stocks changing to annual estimates would imply a significant increase in sampling effort.

**Age 3 data with 3-year average**

![Graph showing age 3 data with 3-year average](image)

Figure 6. Southern Hake, proportion mature at age 3 (open circles and black line) and 3 year average (thicker red line) defined as \( (y_t + y_{t-1} + y_{t-2}) / 3 \).

When a time-series of biological data is available, a factor for year and a year:length interaction can be included in analysis described in Section 4.2.7 to quantify differences in maturity at length across years. How much these terms alter the predictions should be considered, not just their statistical significance.

Alternatively, if only the time-series of proportions at age is known then it may be possible to judge the relative strength of trends, between year and within year variation by fitting smooth curves to the time-series of maturity estimates and then assessing the degree of smoothing and the slope. Figure 7 and Figure 8 show the Southern Hake data with a smooth curve fitted. Proportions mature were converted to numbers using \( n=20 \) or \( n=100 \) as an illustrative number of fish maturity staged each year. A smoothing spline with binomial errors was fitted to the time-series using the function \( s( ) \) in the R package mgcv. The amount of smoothing was selected automatically by generalized cross-validation (Wood, 2006). For \( n=100 \) the fitted curve, with 8.9 equivalent degrees of freedom (edf) for 26 data points, appears to smooth the data a similar amount to the 3 year average. However, the curve is steep in the latest years and the predicted value for 2008 is 0.1 greater than the observed value for 2007, suggesting that the recent trend makes using annual estimates a better
option. For \( n=20 \), the curve is smoother (4.6 edf) indicating that sampling variability is a larger component of the between year changes and there is more support for using an average or smoothed value.

This idea is an exploratory analysis that has not been fully evaluated so we recommend further investigation before it used. For example, in this case, the smoother never tracked the peak in 1996 regardless of how high the number of maturity staged fish was set.

![Age 3 data and smooth curve assuming 100 fish maturity staged each year](image)

**Figure 7.** Southern Hake, proportion mature at age 3 (open circles and black line) and smooth curve (blue, thicker line) fitted assuming 100 fish maturity staged each year. Point represented by blue square shows predicted value for year 2008.
5.4 **What is the effect of skipped spawning on maturity ogive fitting?**

The Workshop on maturity staging cod, whiting, haddock and saithe (ICES 2007d) reported that a substantial proportion of mature Baltic cod can skip spawning and also found evidence of skipped spawning in other stocks. Therefore they recommended that the spawning proportion replaces the maturity ogive (proportion mature) in the assessment of the spawning stock size.

When fitting a logistic curve to maturity data, one of the underlying assumptions is that the proportion modelled will reach the maximum value of one as length increases. The presence of skipped spawning invalidates this assumption. Figure 9 demonstrates the lack of fit using logistic curves on dummy datasets that include skipped spawning and Table 4 presents the mean and maximum absolute bias (abs(observed – fitted value)) for the example. In general the bias will depend on the length range sampled, number samples in each length group and pattern of maturity at length. For this example, the bias is noticeable at 10% skipped spawning and substantial for 20% skipped spawning.

To estimate spawning proportion when there is skipped spawning an alternative to the logistic is required and several options are available. Individual estimates by length class remain valid although they do not make use of the trend in the data. A non-parametric curve or simply including polynomial terms (length²+length³) in a glm will provide a reasonable approximation within the observed length range.
(Collett 2003). However, it may be more theoretically justified to use an extension of the logistic curve that includes a parameter for the asymptote. The three parameter logistic can be written as:

\[ y = \frac{a}{1+\exp(b - c \times \text{length})} \]

where \(a\) defines the asymptote and \(b/c\) is the length at \(a/2\).

It should be possible to fit this, accounting for the Binomial nature of the observations, by using maximum likelihood estimation.

Figure 9. Deteriorating fit of a logistic curve to maturity data with a percentage of skipped spawners, i.e. with an asymptote less than one.

Table 4. Mean and maximum absolute bias from fitting a logistic glm to data generated with a three-parameter logistic curve, \(y=a/(1+\exp(b - c \times \text{length})\), asymptote \(a\) defined by \(\%\) skip spawning, \(b=0.6, c=0.22\).

<table>
<thead>
<tr>
<th>% SKIP SPAWNING</th>
<th>BIAS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>.203</td>
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<tr>
<td>30</td>
<td>.100</td>
<td>.203</td>
<td>.203</td>
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5.5 What is the Effect of Maturity Estimates on Assessments?

Even where assessments that do not use regularly updated maturity estimates, it remains relevant to understand the potential links in the assessment system and relate the properties of the maturity data to the outputs it could affect. It is also important to realize that many other studies and models of fish stocks use the maturity and SSB estimates reported, e.g. Andrews et al. (2006).

In ICES stock assessment models, maturity ogives have no effect on the estimates of stock numbers; they enter the assessment process through the calculation of spawning-stock biomass (SSB) for each year:
SSB = sum over ages [weight-at-age * stock numbers at age * proportion mature at age]
(stock numbers may also be adjusted for mortality within the year up to spawning period).

The variance of SSB will involve a weighted average of the maturity-at-age variances and the effect of bias in the proportion mature at age \( a \) will depend on the weight and numbers at age \( a \). A few examples investigating changes in maturity estimates are available in the literature, e.g. for North Sea cod, Cook et al. (1999) showed that using a more realistic set of maturity estimates altered the scale of SSB values but did not substantially change the trajectory over time. Here we show how the effects on SSB can easily be investigated, and then we consider the use of SSB.

5.5.1 Effect on SSB - Examples using FLR code

The R package FLR (Kell et al. 2007, http://flr-project.org) provides a convenient framework to investigate the effects of variation and bias in maturity estimates as it contains suitable data structures with example stock data, relevant functions and a flexible development environment. Annex 6 provides code, developed at this workshop, which simulates bias and variances in a set of maturity-at-age estimates then calculates SSB for the new data. Bias is defined either in relative or absolute terms, i.e. new proportion mature = \( \hat{p} \) + relative bias*\( \hat{p} \) or new proportion mature = \( \hat{p} \) + absolute bias. Variance is incorporated simply by simulating from a Normal distribution with specified standard deviation and no correlation between ages. Any simulated proportions less than 0 are set to 0 and any greater than 1 set to 1.

Figure 10 shows the effect of bias on the Plaice IV stock data provided as part of the FLCores package. This has 45 years of data (1957-2001) with a time-invariant maturity ogive of proportion mature 0 at age 1, 0.5 at ages 2 and 3 and 1 at ages 4-15. We assumed that proportions of 0 and 1 will always be estimated reliably and varied the estimates at ages 2 and 3 between 0 and 1. The effect on SSB for a particular year depends on the distribution of stock weight by age in that year. On average SSB changed by 5.4% for each 0.1 change in proportion mature for ages 2 and 3, with a smallest change of 2.4% for 1967 and the maximum effect, in 1999, was a considerable 11.9% change in SSB for each 0.1 change in proportion mature.

To investigate the effect of variation in proportion mature, the interpretation of EU DCR precision levels in Section 6 was applied to both the Plaice IV and Southern Hake stocks. Three levels of variation relating to DCR precision levels 3 (the best) to 1, were applied to maturity estimates for ages 2 and 3 for Plaice IV and ages 2 to 5 for Southern Hake. 1000 simulations were run, SSB calculated for each and the CV (standard deviation from iterations / mean) of the SSB reported (Table 5). Figure 10 illustrates the process, showing boxplots of the 1000 simulated SSB values for each year, when the standard deviation for maturity estimates was based on precision level 2. This indicates that the overall trends in SSB in this example can still be observed and Table 5 suggests that if the target of DCR level 3 can be achieved then the effect of variation in maturity estimates on SSB will be tightly controlled. (Although finding will always be stock specific and depends on the assumptions of the simulation.)
Table 5. Effect of variation in maturity estimates on SSB.

<table>
<thead>
<tr>
<th>Stock</th>
<th>CV of SSB</th>
<th>Precision level</th>
<th>Min (best year)</th>
<th>Mean</th>
<th>Max (worst year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaice IV</td>
<td>3 (sd set to 0.05/1.96)</td>
<td>0.4</td>
<td>1.0</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>(1957-2001)</td>
<td>2 (sd set to 0.1/1.96)</td>
<td>0.9</td>
<td>2.0</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 (sd set to 0.25/1.96)</td>
<td>2.1</td>
<td>5.1</td>
<td>11.9</td>
<td></td>
</tr>
<tr>
<td>S. Hake</td>
<td>3</td>
<td>0.9</td>
<td>1.8</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>(1982-2007)</td>
<td>2</td>
<td>1.8</td>
<td>3.5</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>4.0</td>
<td>8.2</td>
<td>15.6</td>
<td></td>
</tr>
</tbody>
</table>

Effect of bias in maturity estimates on SSB, Plaice Sub-Area IV

![Boxplots showing range of results from 45 years (1957-2001).](image)

Figure 10. Effect on SSB of changing proportion mature at ages 2 and 3 from 0.5, for Plaice in Sub-Area IV. Boxplots show range of results from 45 years (1957-2001).
Effect of variation in maturity on SSB, Plaice Sub-Area IV

Figure 11: Effect on SSB of random variation in proportion mature at ages 2 and 3, for Plaice in Sub-Area IV. Variation defined as Normal mean 0, sd 0.1/1.96 from an interpretation of DCR precision level 2. Boxplots show range of results from 1000 simulated values.

5.5.2 Effect on Assessment Outputs

Once SSB has been calculated, assessments use it to make forecasts, set biological reference points through the stock-recruitment relationship and judge where the stock is in relation to these reference points. To judge the overall effects of maturity estimates and their effect relative to other components of the assessment process it will be appropriate to test a designed set of hypotheses with management strategy evaluation simulations (De Oliveira et al. 2008). This fell outside the scope of the workshop and the time available. However, a number of projects are using management strategy evaluation and if there is the opportunity to investigate this further following the workshop any relevant findings will be reported to PGCCDBS in 2009.

6 Summarizing and reporting maturity estimates

Term of Reference c) was to “propose best practices for summarizing and reporting the results”. For the countries present, the main requirement to summarize and report maturity estimates comes from the EC Data Collection Regulation. This was discussed by the workshop and a consistent interpretation reached.
**Number of samples**

Reporting the sample size is a basic requirement of any analysis and this is true for the DCR Technical Report where the number of maturity samples (individual fish) achieved is reported in Table 11.3. This number is the total amount of fish maturity staged and is appropriate for the DCR report as it shows the data available and the annual sampling effort. However, maturity estimates may not use all the samples reported, e.g. may only use one survey, so when considering a specific set of maturity estimates the number samples used to produce those estimates should be reported.

**Precision**

Draft Commission Regulation (EC) No 199/2008 states:

*Chapter III, B2*

4.3. *For maturity, fecundity and sex ratios, a choice may be made between reference to age or length, provided that Members States which have to conduct the corresponding biological sampling have agreed the following:*

*(a) For maturity and fecundity, precision of level 3 must be achieved within the age and/or length range, the limits of which correspond to a 20 \% and 90\% of mature fish; where precision level 3 is defined as:*

*Chapter II, 4(c) Level 3: level making it possible to estimate a parameter with a precision of plus or minus 5\% for a 95\% confidence level.*

Currently (June 2008) Level 2 is defined as +/- 10\% for a 95\% confidence level and Level 1 as +/- 25\%, but this is likely to change to Level 2 +/- 25\% and Level 1 as +/- 40\%.

To be general this definition uses the term parameter but we understand that 4.3(a) refers to the estimates of proportion mature here. Because maturity estimates are already proportions there are two possibilities for ‘plus or minus 5\%’, either a percentage e.g. 0.5* +/- 5\% = 0.475 to 0.525 or as five percentage points e.g. 0.45 to 0.55. The second choice was agreed as it produces similar requirements for high and low proportions and is a more realistic requirement for low values of proportion mature.

For estimates of proportions the confidence interval will not necessarily be symmetric, so +/-5\% can be interpreted as a confidence interval width of 10 percentage points or, equivalently, a proportion of 0.1. This requirement does not directly convert a CV, unlike the requirement for catch-at-age estimates (WKSCFMD, ICES 2004).

Using maturity estimates also raises the issue of how to summarize a vector of precision estimates by length or age, as the phrase “within the age and/or length range” can be interpreted in more than one way. The options considered by WKSDFD (ICES 2005) were reviewed and it was agreed that using the mean of the confidence interval widths was sensible for maturity estimates. Requiring all estimates within the specified age or length range to have the required precision was considered too demanding and asking for only the best estimate within the range to meet the requirement was potentially misleading. Reporting the range of precision levels achieved was also discussed and considered to be a useful option to report alongside the mean level.

Using the range containing 20\% to 90\% of mature fish was considered sensible, as precision for proportions close to 0 and 1 is generally very good. However, the workshop participants were unaware of the reason for the exact choice of limits.
The mean confidence interval can be calculated as a weighted mean using the catch numbers. Where this has been used, in general the weighted mean gave slightly better precision than the mean as ages with greater catch numbers had greater sample numbers.

A reason for using the weighed mean is that the main use of maturity ogives for stock assessment is to calculate SSB and the variance in SSB will be similar to a weighted average of the variance in proportion mature, if variance in the other terms and covariances are ignored. As stock numbers are not generally available, catch numbers are a proxy for them. Overall it was decided that using the weighted mean was acceptable but not an essential requirement.

When maturity estimates are calculated by length class, the width of the length class affects the number of observations and therefore the precision level achieved. It is widely recognized that very good precision could be achieved at the expense of poor accuracy. Therefore, the supporting information must report the width of the length classes used.

6.1 Guidelines for reporting

In summary, to report precision for estimates of proportion mature the workshop considered good practice to be:

- Report the number of maturity staged fish used to calculate the estimates.
- When length classes are used in the calculation, report the width of length classes used.
- Calculate mean confidence interval width for the age and/or length range which correspond to a 20% and 90% of mature fish,
- For DCR purposes half the mean confidence interval width directly converts a precision level,
  - if half confidence interval width is less than 0.05 then the precision level is 3
  - if half confidence interval width is less than 0.25 then the precision level is 2
  - if half confidence interval width is less than 0.4 then the precision level is 1

*This is based on likely new definitions: Level 3 making it possible to estimate a parameter with a precision of plus or minus 5% for a 95% confidence level, Level 2 as +/- 25% and Level 3 as +/- 40%.

- Optionally: Report the range of precision levels achieved as well as the mean level.

7 Conclusions and Recommendations

7.1 Data and Methods

The FishFrame / COST data format is a suitable exchange format for maturity data, as it can accept survey or market sampling records, is open source and actively maintained. We recommend that the developers consider: extending the code lists for Area and otolith side, modifying the SL table to include sex and an optional field for histological maturity.
Logistic models fitted by Generalized Linear Modelling (GLM) are the most popular approach to model maturity data.

If the models provide a good fit, they can be used to evaluate if differences exist between age classes, sexes, areas or years.

If the model fit is poor, other approaches such as GAM, multinomial models (e.g. Gerritsen et al., 2006) or any other curve fitted using maximum likelihood that acknowledges the binomial nature of the data (e.g. Gerritsen et al., 2003) can be used.

Logistic curves can give substantially biased estimates if skipped spawning is a significant issue (>10% for illustrative data considered). A three-parameter logistic curve is likely to be suitable in this case.

There is scope to develop and apply models that include the sampling and spatial structure of the data as GLMs are limited by the assumption that individual observations are independent.

The raising procedure used did not affect the parameter or error estimates to a great extent for the stocks examined.

There is no widely agreed method of estimating errors for maturity-at-age. Analytical approaches need to be developed and tested further. Bootstrapping procedures assume that the bootstrapping units are independent. If individual fish are resampled this assumption might be violated as parameters of fish from the same haul are likely to be correlated. Re-sampling stations is reasonable, although a similar problem will arise if estimates show spatial trends or correlations between stations.

If large differences in maturity exist between areas and a combined estimate for the whole stock is required then the maturity ogives by area should be weighted using the best available information, preferably stock numbers or survey catch rates.

Measures of variability and bias in maturity estimates, for example from the results of a maturity staging workshop, can be converted to the effect on spawning-stock biomass using code provided. For Plaice in Sub-Area IV, the average SSB change was 5.4% for each 0.1 change in proportion mature at ages 2 and 3. For the two examples studied, maturity estimates with DCR precision level 3 gave little variation in SSB (mean CV<2%).

7.2 Guidelines for collecting maturity data and estimating proportion mature

The following guidelines incorporate and extend those from WKMAT (ICES 2007b)

1) For survey data to be used in a maturity index of the spawning stock, the survey must be conducted at the right time compared to the spawning period and have adequate coverage. If survey data are not available at the right time then histologically validated maturity data obtained outside spawning season can be used, although this should be confirmed on a stock-by-stock basis.

2) Where valid (see 3) maturity data are available from market samples they can be used to estimate maturity. This is mainly the case for species with a protracted spawning season where survey data do not cover the whole spawning season or stock area. Also, if survey and market data do not show systematic differences they can be used together.

3) Maturity data from market samples should be collected during the whole prespawning (for determinate species) or spawning (for indeterminate
species) season on a métier based sampling programme, and cover the whole stock distribution area.

4 ) As with market samples, on-board samples should be collected on a métier base to avoid gear and fleet selectivity effect and in the correct time and spatial frame compared to spawning.

5 ) If possible, maturity staging should be done on board the survey vessel.

6 ) A comprehensive illustrated manual should be available for all stocks requiring maturity observations.

7 ) Macroscopic maturity scales used should be validated, either histologically or by another appropriate way.

8 ) Plot and map the data collected to assess differences by source, strata, location and time.

9 ) Length stratified maturity data should be weighted by the length distribution. If samples are collected on a random scheme or the stock is assessed on a length basis, no weighting according to the length distribution is required.

10 ) If the fish maturation process is dependent on age and/or sex as well as length then a Sex-Maturity-Age-Length-Key (SMALK) should be used. Age reading precision is important in this context.

11 ) If the stock shows a sexual difference in maturity a female maturity ogive should be used, or the effect of combining both sexes considered in detail.

12 ) If the maturity data are modelled, a Binomial GLM with logit link is current standard practice. Alternative approaches should be compared against this baseline approach.

13 ) Check appropriate model diagnostics.

14 ) Report the number of maturity staged fish used to calculate the estimates. If length classes are used, report the width of length classes.

15 ) When maturity estimates (as proportions) are reported to DCR specifications, calculate the mean confidence interval width for the age and/or length range which correspond to a 20 % and 90% of mature fish. Convert this to a precision level using:

- if half confidence interval width is less than 0.05 then the precision level is 3
- if half confidence interval width is less than 0.25 then the precision level is 2
- if half confidence interval width is less than 0.4 then the precision level is 1

*This is based on likely new definitions: Level 3 making it possible to estimate a parameter with a precision of plus or minus 5% for a 95% confidence level, Level 2 as +/- 25% and Level 3 as +/- 40%.

Optionally, report the range of precision levels achieved as well as the mean level.
8 References


Anon. 2008b. FishFrame 5.0 / COST 1.0 Exchange format specifications.


DCR Technical Reports from different countries: https://datacollection.jrc.ec.europa.eu/


# Annex 1: List of participants

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<thead>
<tr>
<th>Name</th>
<th>Address</th>
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<td>Tatjana Baranova</td>
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</tbody>
</table>
Annex 2: SAC-GFCM Geographical Sub-Areas in the Mediterranean

The SAC-GFCM (Scientific Advisory Committee of the General Fisheries Commission for the Mediterranean) divided the Mediterranean and Black Sea Area (FAO Area 37) into the 30 Geographical Sub-Areas (GSAs) listed below:
1. Northern Alboran Sea
2. Alboran Island
3. Southern Alboran Sea
4. Algeria
5. Balearic Islands
6. Northern Spain
7. Gulf of Lions
8. Corsica Island
9. Ligurian and North Tirrenian Seas
10. South Tirrenian Sea
11. Sardinia Island
12. Northern Tunisia
13. Gulf of Hammamet
14. Gulf of Gabes
15. Malta Island
16. South of Sicily
17. Northern and Central Adriatic Sea
18. Southern Adriatic Sea
19. Western Ionian Sea
20. Eastern Ionian Sea
21. Lybia
22. Aegean Sea
23. Crete Island
24. South of Turkey
25. Cyprus Island
26. Egypt
27. Levant
28. Marmara Sea
29. Black Sea
30. Azov Sea
Annex 3: R-code to plot maturity-at-age and length

Below is some code developed by the MI in Ireland that plots the proportions mature at each age and length class (Figure 4, section 4)

```
# simulate some data (badly)
len=sample(0:50,1000,replace=T)
age=rbinom(1000,5,len/50)
mat=rbinom(1000,1,1/(1+exp(-0.25*len-age+10)))

# plot function
mat.plot=function(len,age,mat,model.type=0,main='',xlim,...){
  # len is a vector containing the lengths of individual fish
  # age is a vector containing the age classes of individual fish
  # mat is a vector containing 0 or 1 for immature/mature fish
  if(model.type==0)
    model=step(glm(mat~len*as.factor(age),'binomial'))
  if(model.type==1) model=glm(mat~len*as.factor(age),'binomial')
  if(model.type==2) model=glm(mat~len+as.factor(age),'binomial')
  if(model.type==3) model=glm(mat~len,'binomial')
  if(model.type==4) model=glm(mat~as.factor(age),'binomial')
  mal=tapply(age,list(len,age,mat),length)
  mal=ifelse(is.na(mal),0,mal)
  pmal=mal[,2]/(mal[,1]+mal[,2])
  lengths=as.numeric(rownames(pmal))
  ages=colnames(pmal)
  title=paste(main,model$call[2],sep='\n')
  if(missing(xlim)) xlim=range(lengths)
  plot(NULL,xlim=xlim,ylim=c(0,1),xlab='length (mm)',ylab='Proportion mature',main=title,...)
  for(i in ages){
    text(lengths,pmal[,i],i,col=i)
    len.i=as.numeric(names(na.omit(pmal[,i])))
    len.pred=min(len.i):max(len.i)
    pred=predict(model,newdata=data.frame(len=len.pred,age=i),type='response')
    lines(len.pred,pred,col=i,lwd=2)
  }
  mat.plot(len,age,mat,model.type=0,main='simulated data')
```

Annex 4: R-code to simulate the effect on SSB of bias and variation in maturity-at-age estimates

```r
# setGeneric("MCmat", function(object, ...) standardGeneric("MCmat"))
setMethod("MCmat", signature("FLStock"),
  function(object, iters, B, stdev, biastype="absolute"){
    require(MASS)
    #------------------------------------------------------------
    # formula:
    # relative bias: B = (That-T)/T <=> That = B*T+T
    # absolute bias: B = That-T <=> That = B+T
    #------------------------------------------------------------
    mat <- mat(object)
    dnms <- dimnames(mat)
    dnms$iter<-1:iters
    # check error and bias vectors
    if(! (biastype %in% c("absolute","relative"))) stop('biastype must be "absolute" or "relative"')
    if(length(B)!= length(dnms[[1]])) stop("Your bias vector does not match the ages on the maturity ogive")
    if(length(stdev)!=length(dnms[[1]])) stop("Your stdev vector does not match the ages on the maturity ogive")
    # introduce bias
    m <- c(mat)
    if(biastype=="relative") m <- m*B+m
    if(biastype=="absolute") m <- B+m
    # simulate variance, currently assumes no covariance
    m <- mvrnorm(iters, m, diag(rep(stdev, times=length(m)/length(stdev))^2))
    # avoid 0<mat>1
    m[m<0]<-0.0
    m[m>1]<1.0
    # back to FLStock
    attr(object, "stoch") <- data.frame(B=B, stdev=stdev)
    attr(object, "mat.orig") <- mat
    mat(object) <- FLQuant(c(t(m)),dimnames=dnms)
    object
  })

# convenience function to tabulate results
setGeneric("ssbtab", function(object, ...) standardGeneric("ssbtab"))
setMethod("ssbtab", "FLQuants", function(object){
  nms <- names(object)
  lst <- lapply(object, c)
  df <- as.data.frame(do.call("cbind", lst))
  names(df) <- nms
  row.names(df) <- dimnames(object[[1]][[1]][[2]])
  df
})

# alternative ssb function to deal with iterations,
# note does not include in-year mortality
setMethod("ssb", "FLStock", function(object){
  it <- dim(mat(object))[6]
})
```
```r
sn <- propagate(stock.n(object), it)
sw <- propagate(stock.wt(object), it)
quantSums(sn*sw*mat(object))
}

### Examples
library(FLCore)
load("RData.shke")

# original maturity ogive and catch weight
mat(stk0i)
catch.wt(stk0i)

# how to create new maturity matrix,
# set relative bias vector, stdev and iters
it <- 1
rB <- c(0,0,0,0.3,0,0,0,0,0) # 30% relative increase for age 3
aB <- c(0,0,0,0.1,0,0,0,0,0) # 10 percentage point increase for age 3
stdev <- rep(0,9) # new maturity matrices
stknew <- MCmat(stk0i, it, rB, stdev=stdev, biastype="relative")
mat(stknew)
stknew <- MCmat(stk0i, it, aB, stdev=stdev, biastype="absolute")
mat(stknew)

# run a simulation
it = 1000
B <- rep(0,9) # no bias
# from interpretation of DCR level 3
stdev = c(0,0, rep(0.05/1.96 , 4),0,0,0)
stknew <- MCmat(stk0i, it, B, stdev=stdev, biastype="absolute")

# some plots
bwplot(data~factor(age)|factor(year), data=mat(stknew))
bwplot(data~factor(year), data=ssb(stknew))

# summaries
stknew.ssb <- FLQuants{
  ssb=ssb(stk0i),
  ssbmean=apply(ssb(stknew),2,mean),
  ssbnnew=apply(ssb(stknew),2,median),
  ssbblow=apply(ssb(stknew),2,quantile, probs=0.05),
  ssbbhigh=apply(ssb(stknew),2,quantile, probs=0.95),
  ssbstdev =apply(ssb(stknew),2,sd)
}

xyplot(data~year, groups=qname, data=stknew.ssb, type="l", auto.key=T, col=c(2,1,1,1), lty=c(1,2,2,1))

# table output
ssb.tab <- ssstab(stknew.ssb)
ssb.tab$cv = 100 * ssb.tab$ssbstdev / ssb.tab$ssbmean
ssb.tab
summary(ssb.tab3$cv)
```
Annex 5: References regarding maturity

Below is a list of references concerning issues that are raised in the report, the references are grouped under the following headings: References concerning geographic variation in maturity; temporal variation in maturity; methods and models; validation of maturity; variables influencing maturity and other relevant references.

References concerning geographic variation in maturity


Dominguez-Petit, R., Korta M., Murua H., Saborido-Rey F., Quincoces I., Sainza M. and M. Santurtún 2005. Variability in size at maturity European hake (Merluccius merluccius) at Bay of Biscay and Galician Coast. Poster presented at the ICES ASC, Aberdeen, UK.


References concerning temporal variation in maturity


References concerning methods and models


Grygiel, W., K. Radtke and T. Nermer 2006. The southern Baltic cod, clupeids and flounder sexual maturation; the status of BITS/DATRAS database in Poland. Working paper on the ICES Workshop on an evaluation and improvement of the BITS/DATRAS data quality. Gdynia, 31.01 - 03.02.2006; 4 pp., mimeo.


**References concerning validation of maturity**

Bromley, P. 2000. Growth, sexual maturation and spawning in central North Sea plaice (Pleuronectes platessa L.), and the generation of maturity ogives from commercial catch data. Journal of Sea Research, 44 (2000); 27-43.


References concerning variables influencing maturity


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Szypuła, J. 1992. Seasonal changes of feeding, condition and gonad maturity of herring in Dziwnów Region. Scientific scripts of Agriculture Academy in Szczecin, Sea Fisheries and Fish Food Technology XIX, No. 150: 45-57 [in Polish].


Other references


BIOSDEF, 1998. Biological Studies of Demersal Fish. Final Report to the Commission of European Communities, Parts I and III.


METHODS AND SOME RESULTS OF INVESTIGATIONS OF THE
SEXUAL MATURITY AND SEX RATIO OF THE BALTIC SPRAT,
HERRING, COD AND FLOUNDER

by
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INTRODUCTION

As a consequence of changes in the seawater temperature, salinity and food resources, the percentage of maturing herring and sprat from different year classes can change in separate populations, but also in relation to sex in the same population (Koshelev 1971, Polivajko 1982, Szypuła 1992). The results obtained by Grygiel and Wyszyński (2002, 2003a) indicate that in the 1980-2001 period the differentiation in sexual maturation of the southern Baltic herring and sprat in relation to the age and length structure of the exploited stocks, sex, year groups and regions is mostly due to variation in ecological conditions, to selected biotic and abiotic parameters and the specificity of species inhabiting the western and eastern parts of the southern Baltic Sea. The results of regression analysis indicate that the percentage of mature young sprat was statistically significantly dependent on seawater and air temperatures (in the first quarter) and on sprat stock abundance in age group 1. The same was also found between the percentage of young herring from the spring spawning population, which were spawning for the first time and the mean length, and weight of fish (in the first quarter).

Mild winters may have modified the maturation of fish - spawning started earlier and more fish spawned earlier than normal, for example as in 1990 with herring in the northern Baltic (Rajasilita et al. 1996). The influence of the season in which the first spawning in the life cycle of a given population of fishes take place is usually retained in their "memories" in the following years of life, e.g. in Baltic herring for 3-4 years (Anokhina 1969). In herring from northern seas, e.g. those from the White Sea, a loss of separateness of spawning seasons often takes place (Cheprakova 1971).

According to some authors, the process of fish sexual maturation is connected with the following:

- growth rate of fish length and weight, but not their age (Lapin and Jurovitskij 1959);
- minimum weight and age and geographical location of spawning grounds, e.g. in reference to plaice from the North Sea - this process is susceptible to annual changes (Bromley 2000);
- age, rather than length, e.g. in reference to cod from the Irish Sea (Armstrong et al. 2001).

The simple relationship between fish maturity and age group is characteristic for a population and not for specimens of a given species (Lapin and Jurovitskij 1959).

In publications from the past fifty years, prevailed the opinion that the numerical share of males and females in samples of commercially exploited fish stocks, including Baltic herring, were temporally and geographically differentiated (Woźniak 1956, Strzyżewska 1969, Parmanne 1990, Feldman et al. 2000, Kaljuste and Raid 2002). D'Angelo and Bowen (1985)

There are a few examples of publications from the last 25 years, which report results of investigations on Baltic herring and sprat sexual maturation and sex ratio versus age and length (Shirokov 1990, Wyszyński 1997, Feldman et al. 2000, Reglero and Mosegaard 2001, Grygiel and Wyszyński 2002, 2003a, 2003b, Kaljesté and Raid 2002). Data on the sex ratio and sexual maturity of the stock of a given species has a decided impact on establishing the optimum level of the fishing mortality coefficient and the age at first capture and, when supplemented with data on female fecundity, they become a measure of the potential reproductive capability of a given fish stock (Berner and Vaske 1981).

In 1999, the ICES Study Group on Baltic Herring and Sprat Maturity (SGBHSM) and the ICES Working Group on Baltic Fisheries Assessment (WGBFAS) initiated the international investigations of maturity ogives as well as the sex ratio (separately by sex and the ICES Sub-divisions) with regard to the age and length structure of the Baltic herring and sprat (Anon. 1998, 1999, 2001a, 2001b). In 2000-2001, the Sea Fisheries Institute (SFI) in Gdynia with close cooperation of the aforementioned ICES WGs realised an own study project concerns the sexual maturity and sex ratio of the Baltic clupeids, based on historical and contemporary materials (Grygiel and Wyszyński 2002, 2003a, 2003b). Reason for the realisation of above-mentioned international investigations was the fact that over the 1974-1999 period the ICES working groups estimated e.g. the Baltic herring (with the exception of the ICES Sub-divisions 30 and 31) and sprat stocks size using constant, fixed and combined sex maturity data at age groups and the ICES Sub-divisions. This parameter was not verified until 2000 (Anon. 2001a, Grygiel and Wyszyński 2002, 2003a, 2003b, Grygiel et al. 2006).

Similar to clupeids, the international investigations of the Baltic cod were initiated on the beginning of 1990s (Anon. 1994, 1999, Tomkiewicz et al. 1997) however, the SFI in Gdynia jointed this work at the end of 1990s. On the beginning of 1990s the separate study of cod maturation and sex ratio, based on the materials collected in the Gdansk Deep within the period 1965-1990 was also realised in Poland by Kosior and Skólski (1992), Kosior (1994) and Kosior et al. (2001).

In the first half of 1990s the SFI in Gdynia carry out also investigations of the southern Baltic flounder fecundity and gonads maturity changes (Kosior et al. 1996a, 1996b, Draganik and Kuczyński 1997).

**MATERIALS AND METHODS**

Maturity ogives, that separates juvenile (immature) and adult (mature) specimens and representing the proportion of mature fish in each age group (length class) are applied in traditional assessments of the spawning (parents) stocks biomass (SSB), and to back-calculate stock size from spawning stocks biomass estimates derived from eggs production studies (Horwood 1993a, 1993b). Recently it is recommended by the ICES WG (Anon. 2008) that the 'spawning proportion' replace the 'maturity ogive' in the assessment of the spawning stock size. The spawning proportion is estimated as the proportion of fish sampled in stages 2-4/1-6 (acc. to the new ICES 6-stages scale of fish gonads development; Anon. 2008).
After a review of the relevant literature, and based on author (Grygiel 1987, Grygiel and Wyszyński 2002, 2003a, 2003b) own investigations, the periods from January to April and from February to May were designated as representative of the pre-spawning and spawning seasons for herring and sprat in the southern Baltic, respectively. The Baltic clupeoids, cod and flounder with gonads in maturity stages III and IV on the Maier’s scale were classified as the sexually mature fraction, which were potentially ready for spawning in a given season.

The southern Baltic herring and sprat sexual maturity and sex ratio investigations conducted by the SFI in 1980-2001 were based on samples collected mostly during research surveys type BITS (Baltic International Trawl Surveys) and, to a lesser degree, on materials from the catches and landings of the commercial fishing fleet. Bromley (2000), Armstrong et al. (2001), Kraus and Köster (2001), Reglero and Mosegaard (2001), Kaljuste and Raid (2002) have applied the same system of fish sampling for investigations of the maturity ogives. It should be added that for separate investigations of the Baltic sprat maturity, realised under the UNCOVER study project, the Polish materials were collected in the period 2002-2004 and elaborated with the same methods (Grygiel 2008a).

In the case of the southern Baltic cod, the materials collected by the SFI during the BITS surveys in February/March 1990-2002, were the keystone of maturity ogives and the sex ratio investigations (K. Radtke [2008] – the SFI in Gdynia, personal communication).

The Baltic flounder sampling by Kosior et al. (1996a, 1996b) and, Draganik and Kuczyński (1997) took place within the Polish parts of the ICES Sub-divisions 25 and 26, in the pre-spawning season of 1993 and 1995, i.e., January – February, when gonads of the majority of the females reach maturity stage IV (acc. the 8-stages Maier’s scale). A totally of 339 pairs of ovaries were collected and grouped by 1-cm length-classes, somatic weight and age groups were also determined. Length of the examined flounder specimens ranged from 22 to 45 cm in the ICES Sub-division 25, and from 20 to 45 cm in the ICES Sub-division 26. Somatic weight ranged from 100 to 1300 g. The examined females belonged to age groups 3-10.

The P20/25 herring bottom trawl with a 6-mm mesh bar length in the codend was applied in the Polish research catches. A lack of data for clupeids from some years was compensated with material from Polish commercial catches, which were not sorted according to fish size groups. For example, most of the data from April and May originated from the Baltic commercial small mesh size trawl catches. Treschov and Shevtsov (1978) and Shevtsov (1982), who conducted investigations of the selectivity of commercial sprat trawls applied in the Baltic fishery, concluded that trawls with the popular 20-mm mesh size in the codend are characterized by relatively low selectivity (76.8% of young specimens were retained, on average).

At least two random samples of herring and sprat per month in the pre-spawning and at the beginning of spawning season and the ICES Sub-division, with no preference to fishing location, were examined. The geographical distribution of herring and sprat sampling over the 1980-2001 periods is presented in Figure 1 (Grygiel and Wyszyński 2003a, 2003b). In some years, the number of fish (especially sprat) collected for biological analysis was not numerous and, equally importantly, the share of young specimens was low. Thus, for example, the sprat data from the Bornholm Basin in 1994 are incomplete due to the lack of fish from age group 1, samples from 1984-1985 are not numerous, and in 1987 and 1999 the fraction of young fish (<9.5 cm length) was relatively small. The samples of herring from the Bornholm Basin collected
between 1985-1989 originated mostly from commercial catches, which explains why the share of young specimens (<16 cm length) was insignificant in comparison with the samples from the Gdansk Basin.

Samples of clupeids were taken from separate geographical strata (the ICES Subdivisions) and were stratified by the length classes, i.e. of 0.5-cm in the case of clupeids and 1.0-cm in the case of cod and flounder. The analysed fish were weighed to within 0.1 gram (clupeids) or 1.0 gram (cod and flounder), and their age was determined by examining the otoliths morphological macrostructure. During the standard ichthyological analyses, fishes were also sexed and the eight-degree Maier’s scale (Maier 1906) was used to describe the maturity stages of the Baltic herring, sprat, cod and flounder specimens. The Baltic main commercial fish gonads developmental stages were determined by visual, macroscopic identification without histological validation.

In the final stages of constructing the southern Baltic clupeids and cod databases, the Polish data on fish’s gonad maturity were converted to the five-degree ICES scale previously recommended by ICES BIFSWG and SGBHSM (Anon. 1999, 2000). The scheme of this transformation is given below:

<table>
<thead>
<tr>
<th>ICES (BIFSWG) scale</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>immature (I+V)</th>
<th>mature (II+III+IV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maier’s scale</td>
<td>I</td>
<td>III-V</td>
<td>VI-VII</td>
<td>VIII</td>
<td>II</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the framework of fish biological analyses, made by the SFI in the recent two years and very occasionally also in the past, the morphological abnormally developed fish gonads (e.g. due to disease – atresia or intersexes, resulted among others from the ecological stress or pesticide) were also recorded (Photo 1-3; see also separate guidebooks). At present time modified the 9-stages Maier’s scale is applied by the SFI in Gdynia for the Baltic fish biological analyses, and abnormally developed gonads are recorded as the stage 9, which can be converted to adequate stage 6 - according to the new ICES gonads development scale. During the last working session of the ICES PGCCDBS in Nicosia (Anon. 2008) was underlined the need of additional biological investigations of fish with ‘abnormal’ gonads. Stages 5 (resting/skip of spawning) and 6 (abnormal) will be applicable as ecosystem state indicators. Stages 5 and 6 do not contribute to the spawning stock and viable egg production.

Length (longitudo totalis) measurements of 104,072 herring and 61,176 sprat and the ichthyological analyses of 13,915 herring and 12,067 sprat specimens from the southern Baltic and the period of 1980-2001, formed the Polish database (prepared in the Excel spreadsheet format) for the calculations of the Baltic clupeids maturity ogives and sex ratio (Grygiel and Wyszyński 2003a, 2003b). The range of recognized clupeids age groups was as follow:

- males of herring: 1–10 and of sprat: 1–9;
- females of herring: 1–12 and of sprat: 1–11.

In the next step of Baltic clupeids maturation study the length distribution and age structure were determined separately for males and females of the southern coast spring spawning herring population (usually dominated in the Polish commercial catches) and sprat, caught in the pre-spawning and at the beginning of spawning seasons (1980-2001) within the Polish EEZ. The age composition of clupeids was based on the “length-age keys”, which were prepared for particular years and each basin of the southern Baltic. It should be emphasized that the “length-age keys” were used to split out herring and sprat length distributions by sex in order to obtain sex specified maturity ogives. Moreover, the numerical share of sexually mature
males and females at age groups resulted from raising procedure applied between the level of fish biological analyses (number of fish at a given age and length classes) and length measurements (frequency of given length classes).

The collection of herring and sprat materials designed to the further analyses was grouped according to the geographical locations of two main the southern Baltic basins, i.e. the Bornholm Basin (ICES Sub-divisions 24+25) and the Gdansk Basin (the ICES Sub-division 26; Fig. 1). Moreover, materials were aggregated by years, according to the results of optical analysis of the mean weight at age fluctuation, and herring and sprat stocks size (biomass and abundance) changes. The long-term (1980-2001) changes in the proportion of mature clupeids at age groups in the Bornholm Basin were also analysed (Grygiel and Wyszyński 2003a, 2003b).

The initial stage in the preparation of the Baltic clupeids maturity logistic curves was the regression analysis (linear model) and analysis of variance of the logarithm of the percentage of mature herring and sprat specimens versus length classes. Calculations were performed separately according to sex, groups of years (1980-2000) and the southern Baltic basins. The regression analysis parameters show statistically significant relationships between clupeids length growth and the percentage of mature specimens. One of these parameters, the correlation coefficient \( r \) ranged from 0.78 to 0.88 for herring and from 0.64 to 0.91 for sprat. Moreover, the probability level (for constant coefficients \( a \) and \( b \)) was considerably below the critical level \( p = 0.05 \).

A simple statistical model of herring and sprat maturity ogives versus length classes was formulated during the final stage of the work (Grygiel and Wyszyński 2003a). A modified logistic curve (non-linear regression; Rickey 1995) was applied for plotting the fish maturity ogive, well-fitted according to the following formula:

\[
Y = \left( \frac{1}{1 + e^{(a + bX)}} \right) \cdot 100 \quad (1)
\]

where: \( Y \) – percentage of the number of mature specimens, \( X \) – length class, \( e \) – base of the natural logarithm, and \( a \) and \( b \) – constant coefficients of the equation initially calculated from linear regression \( y = a + bx \). Two examples of logistic curves of clupeids sexual maturation in the 1980-2000 period in relation to length classes are presented in Figures 2-3. For the Baltic flounder, a similar maturity ogive example is presented in Figure 4.

In the regression analysis used, the value of the natural logarithm from the reverses of the dependent variable was provided instead of variable \( Y \) according to the following formula:

\[
Y' = \ln\left( \frac{1}{Y - 1} \right) \quad (2)
\]

The length at which 50% of the fish population achieved first sexual maturity was calculated according to following formula (Seber 1982):

\[
L_{50\%} = \frac{-a}{b} \quad (3)
\]

where: \( L \) – length (cm), \( a \) and \( b \) – the coefficients of regression analysis cited above.

The indicatory mean length at first sexual maturity \( (L_{50\%}) \) is a component of the protection length of a given species. These data refer to the critical level of a 50% numerical
share of mature fish in samples, which accede to first spawning in a life cycle of the very same length.

Linear regression analysis was also applied by Grygiel and Wyszyński (2003a) to the variables - percentage of mature herring from age group 2 and sprat from age groups 1 and 2, caught in the Bornholm Basin (1980-2001) versus their mean mass, length, body condition coefficient (K), stock size (abundance) as well as mean air and seawater temperatures.

**SOME RESULTS OF THE STUDY OF MATURITY AND SEX RATIO**

The results presented in Grygiel and Wyszyński (2002, 2003a) papers indicate that there is a greater proportion (numerical percentage) of sexually mature the southern Baltic herring (excluding age group 1) and sprat in younger age groups than was assumed by the ICES working groups up to 2000. For example, with herring from age groups 2 and 3 the differences were 5-22% and 8-10%, respectively, and with sprat from age groups 1 and 2 the differences were 15-38% and 21-30%, respectively (see table below).

<table>
<thead>
<tr>
<th>Age groups &gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Herring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the authors’ data</td>
<td>0</td>
<td>75-80, Bornholm Basin</td>
<td>98-100</td>
<td>100</td>
</tr>
<tr>
<td>ICES data</td>
<td>0</td>
<td>70</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td><strong>Sprat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the authors’ data</td>
<td>26-38, Bornholm Basin</td>
<td>91-100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>ICES data</td>
<td>0</td>
<td>70</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

The investigations conducted by Grygiel and Wyszyński (2002, 2003a) indicate that in comparison to the 1980s, the mean percentage of sprat males and females (combined) from age group 1 acceding to the first spawning increased in the 1990s from 25.8 to 38.4 in the Bornholm Basin, while a lower range (from 14.5 to 18.2%) was noted in the Gdansk Basin. As the herring growth rate in weight decreased in 1980-1999, the mean percentage of mature males and females (combined) from age group 2 acceding to first spawning decreased from 79.5 to 74.8 in the Bornholm Basin and from 91.8 to 82.2 in the Gdansk Basin. The mean value of this variable decreased from 88.1 to 80.3% in all the investigated areas. The proportion of mature males and females of herring from age group 2 was about 7-19% higher, on average, in the Gdansk Basin (in the examined groups of years) in comparison to the Bornholm Basin. These results differed from the data used by ICES working groups in 1974-2000.

The decline of the southern Baltic herring mean weight at age in the 1980-1999 periods was accompanied by a decrease in the length of first sexual maturation in both males and females. In comparison to the 1980-1984 period, the indicatory length (\(L_{50}\% \) - 50% of specimens are mature) of herring decreased by an average of 2.55 cm from 1993-1999, i.e. from 19.7 to 16.7 cm in the Bornholm Basin and from 18.4 to 16.3 cm in the Gdansk Basin. In comparison to the 1980s, the decline in sprat indicatory length in the 1990s was an average of 0.25 cm, i.e. from 9.84 to 9.66 cm in the Bornholm Basin and from 9.74 to 9.45 cm in the Gdansk Basin.

More detailed analysis of the yearly data (1980-2001) for herring from age group 2 and sprat from age group 1, caught in the Bornholm Basin, indicates that the change in the fraction of mature fish was not linear, but was approximately sinusoidal in shape with a marked growth tendency, e.g. in sprat from 1982-1984, 1991-1992 and especially after 1996. A considerable
The percentage of mature southern Baltic herring and sprat specimens is length dependent, and this percentage increases successively in length classes. The results obtained by Grygiel and Wyszyński (2002, 2003a) indicate that there are statistically significant relationships between these variables (best fitted according to the linear model in regression analysis applied). Similar analyses of results for Baltic herring and sprat were not found in the literature, although results obtained by Torstensen (1998) demonstrate that the maturation of sprat from Norwegian fjords is also length dependent. The length at 50% maturity was 9.3 cm. Sprat from this region normally mature as 1-year-olds at a minimum length of 8.0-9.0 cm. They spawn during the same season as older fish, but a little later.

The results of Grygiel and Wyszyński (2003b) studies indicate that the sex ratio of herring and sprat from the southern Baltic in the 1980-2000 period underwent short- and long-term changes with regard to both the region of occurrence and the age and length of the fish. The range of age groups and length classes of herring and sprat females in relation to those of the males was higher in the 1980-2000 period. Females dominated numerically in the older age groups and the largest length classes. Males of the species studied mature for spawning more quickly than do the females in a given season, and their average length and age at first sexual maturity is lower than it is for females (Grygiel and Wyszyński 2003a). This is why in the spawning grounds clupeids males are potentially available for fisheries exploitation earlier, and their life cycle is shorter than that of females.

The mean numerical share of herring females during almost whole study period was quite similar in the Bornholm and Gdansk basins at 52.7 and 50.7%, respectively, with 51.3% noted for the entire study area of the southern Baltic (Grygiel and Wyszyński 2003b). Differences in the sex ratio of sprat between the eastern and western regions of the Baltic and the groups of years (1980-2000) were clearer than for herring. The highest percentage of sprat females was noted in the Bornholm Basin in 1991-1992 at 62.2%, while the lowest percentage of them was noted in the Gdansk Basin at 43.4%. The average percentages of sprat females throughout the 21 years of the study in the two basins were nearly the same - 51.7 and 51.6%, respectively. In turn, the average numerical share of females in samples from the Bornholm Basin ranged from 28.4 to 68.4%.

It should be emphasized that the average share of sprat females somewhat increased in the 1990s in comparison to the 1980s from 48.4 to 54.4% in the Bornholm Basin and from 50.3 to 52.6% in the Gdansk Basin. The biomass and abundance of the Baltic sprat spawning stock was lower in the 1980s and higher in the 1990s than the long-term average. The comparison of the data above indicates that in the 1980-2000 period the sex ratio of herring from the southern Baltic was more stable than that of sprat (Grygiel and Wyszyński 2003b).

The results of the study of changes in the sex ratio of sprat, obtained by Grygiel and Wyszyński (2003b), indicate that females had a numerical prevalence in practically all age groups in both of the studied Baltic basins. The increase in the percentage of sprat females from age 1 to 9 in the Bornholm Basin was much clearer than for herring. There was an increase in the relative share of females in the larger length classes – in spring-spawning herring above 21.5 cm, and in sprat above 12.0 cm, sampled in the period 1980-2000. All of the females of both species from these length classes spawned. The numerical prevalence of
males over females was noted primarily in the smallest length classes – 6.5-12.0 cm for herring and 5.5-7.0 cm for sprat. Nearly 100% of the herring males larger than 19.0 cm and females larger than 20.0 cm and sprat males ≥ 10.0 cm and females ≥ 11.0 cm were mature (Grygiel and Wyszyński 2002, 2003a).

Polish investigations of the Gdansk Deep cod maturation and sex ratio in the period 1965-1990 conducted by Kosior and Skólski (1992), Kosior (1994) and Kosior et al. (2001) pointed out that the proportion between the sexes at age groups and years studied was diversified. Assuming an equal proportion of males and females in the stock, irrespective of its age composition, has found no confirmation in practice. That is why, when estimating the reproductive potential of the stock for a longer period, age and sex structures in each calendar year studied as well as a fecundity corresponding for females of each age-group for a given year have to be taken into account. Estimated by the above-mentioned author’s curves of cod maturity versus length show that in the second half of 1980s in the comparison with year 1965 the length at which 50% of cod females attained sexual maturity increased from 36.1 to 41.0 cm.

Draganik and Kuczyński (1997) studied the influence of the southern Baltic flounder gonad maturation in the pre-spawning season of 1993 and 1995 on the condition factor and gonadostomic index. Kosior et al. (1996a, 1996b) investigated reproduction of the southern Baltic flounder in relation to some somatic factors. The aims of research were analyses of the maturation cycle of flounder and determination of the “first maturity” age. The smallest fish found at maturity stage IV were:

- in 1993, in the ICES Sub-division 26: 19 cm female, 17 cm male;
- in 1995, in the ICES Sub-division 25: 23 cm female, 20 cm male;
- in 1995, in the ICES Sub-division 26: 20 cm female, 15 cm male.

According to Kosior et al. (1996a, 1996b), development of flounder gonads is like follows - in January, most of fish were at maturity stage IV (Maier’s scale), in March, males and females at the spawning stage VI were observed. From May to July occurred flounder with recovering stage of gonads (Maier’s 8th stage). The next, new cycle of flounder reproduction began in August (the Gulf of Gdansk) and September (the Bornholm Basin). The length at first maturity, at which 50% of fish is being to spawn for the first time, was 22.5 cm for males and 18.5 cm for females (Fig. 4).

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Figure 1. Location of herring and sprat sampling as well as the hydrological and meteorological stations in the southern Baltic (within the Polish EEZ) in 1980-2001.
Figure 2. Maturity ogives of the sprat males and females caught in the Bornholm Basin (A) and the Gdansk Basin (B) in the 1980s and 1990s vs. length classes (Grygiel and Wyszyński 2003a).
Figure 3. Maturity ogives of herring, caught in the Bornholm Basin and the Gdansk Basin in selected groups of years vs. length classes of males and females (Grygiel and Wyszyński 2003a).
Figure 4. Maturity ogive of the southern Baltic flounder (Kosior et al. 1996).

Photo 1. The Baltic sprat abnormal development of gonads – an example of maturity stage 9. Male with length 12.0 cm, catch date: 15.05.2008, the r.v. "Baltica", the ICES rectangle 41G8. Coexistence of gonads in stage V with a fully standard size (A) and stunted gonad in stage III-IV (B; Grygiel 2008b).
Photo 2. The Baltic herring abnormal development of gonads – an example of maturity stage 9. Female – fish with length 25 cm and weight 110 g; gonads: weight 18 g (Wyszyński 2008). Coexistence of gonads in stage VII (A) and fully developed, however lumpy (clotty; B) and not attended the spawning in given season or even at all (Wyszyński 2008).

Photo 3. The Baltic cod abnormal development of gonads – an example of maturity stage 9. Female – fish with length 58 cm, catch date: May 2008; commercial vessel; ICES rectangle 38G9. Coexistence of gonads in stage III (A) and under resorption (B; Radtke 2008).