Baltic Committee

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Report of the

Study Group on Multispecies Assessment in the Baltic

Charlottenlund, Denmark
2–4 April 2003

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Palægade 2–4 DK–1261 Copenhagen K Denmark

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1 INTRODUCTION

1.1 Participation

A list of the participants and invited experts can be found in Annex 1 of the report.

1.2 Terms of Reference

According to C.Res 2002/2H02, the Study Group on Ecosystem and Multispecies Predictions [SGMPB] was renamed the Study Group on Multispecies Assessment in the Baltic (SGMAB), (Co-Chairs E. Aro (Finland), (eero.aro@rktl.fi) and F. Köster (Denmark) (fwk@dfu.min.dk) and will meet in Charlottenlund, Denmark from 2–4 April 2003 to:

a) update the multispecies database and produce basic key runs of MSVPA;
b) evaluate options for the best mechanism to undertake the work performed in a);
c) develop, apply and validate of multispecies prediction models taking into account environmental processes affecting predator-prey relationships, growth and maturation.

SGMAB will report by 11 June 2003 for the attention of the Baltic Committee. It will also make its report available to WGBFAS.

1.3 Background

In the Baltic Sea, the interacting fish community in the open sea is dominated by three species namely cod, herring, and sprat. The abundance of cod stock in the Main Basin is currently low, herring stocks are decreasing, and the sprat stock is at high level. The effect of cod on prey species (herring and sprat) is now low level. Multispecies interactions are present and they will become important, when predator population recovers. While cod biomass is low, there is the potential for herring and sprat to have an adverse effect on cod recruitment, through consumption of eggs and larvae.

The multispecies interactions in the Baltic are rather clear and strong, Thus it is relative easy to demonstrate how species interactions effect our assessments of the state of the stocks and our perception of the interactions.

Baltic multispecies assessment process started about 20 years ago and presently the following multispecies assessments and data are available for the Baltic Sea according to ICES Subdivisions (Figure 1.3.1):

- Baltic Main Basin: Years 1974–2001
  - cod in Subdivisions 25–29+32
  - sprat in Subdivisions 25–32,
  - herring in Subdivisions 25–29+32,
- Western Baltic: Years 1977–2001
  - cod in Subdivisions 22+24 (Subdivision 23 included in 1996–2001),
  - sprat in Subdivisions 22–24,
  - herring in Subdivisions 22–24 including Division IIIa.
- Baltic Main Basin: Years 1974–1999, area dis-aggregated MSVPA:
  - cod in Subdivisions 25, 26 and 28
  - sprat in Subdivisions 25, 26 and 28
  - herring in Subdivisions 25, 26 and 28

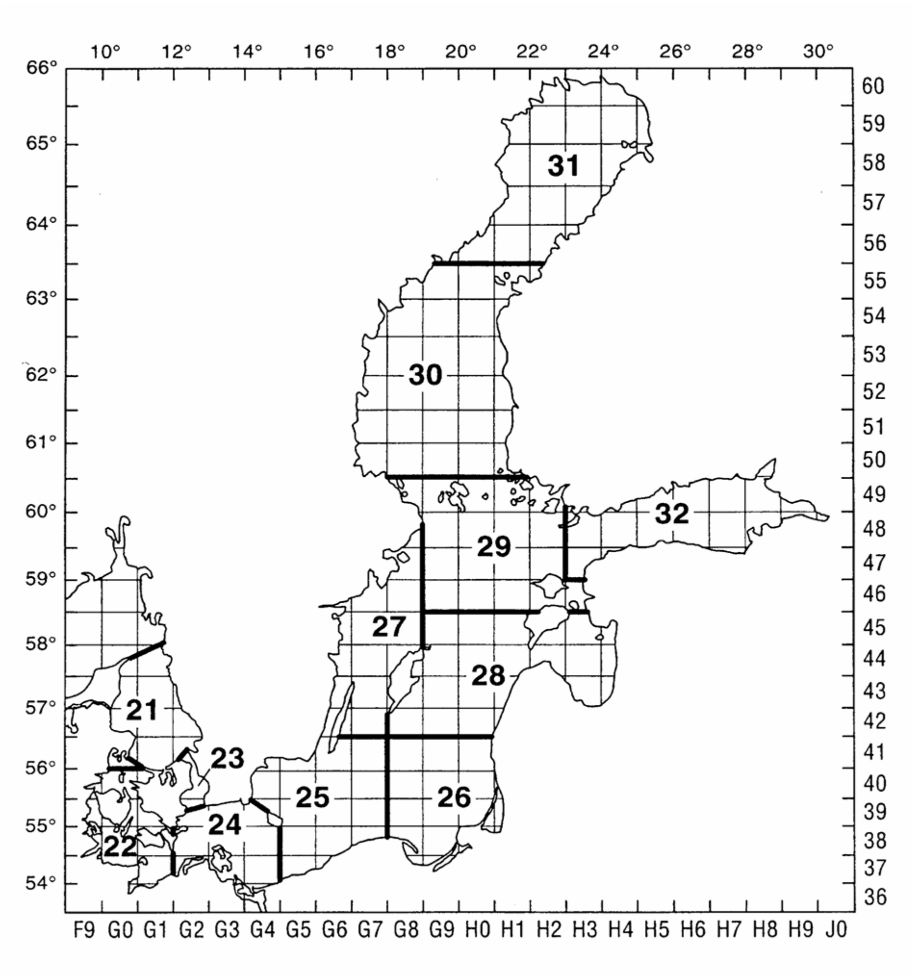

Figure 1.3.1. ICES Subdivisions in the Baltic.

In the case of Main Baltic herring, the assessment unit is directly comparable to the units used by the Baltic Fisheries Assessment Working Group, although in their 2001 meeting WGBFAS used new stock assessment units for Baltic herring in the Main Basin. As the sprat population in Subdivision 30 is rather low and in Subdivision 31 almost non-existing, the Baltic Main Basin stock estimates are basically also referring to Subdivisions 25–32.

Consequently the effect of ignoring the two Subdivisions should not hamper a direct comparison between single species and multispecies assessment output in the case of cod and sprat.

1.4 Supporting projects and background information

Under the ICES framework the SGMAB has benefited from the activities of Baltic Fisheries Assessment Working Group (WGBFAS). WGBFAS compiles the main input information needed for SGMAB since 1997, which is appreciated.

The WGBIFS (Baltic International Trawl Surveys Working Group) reports information on weight at age in the stock for cod based on 1st quarter and 4 quarter bottom trawl surveys and compiles the information for VPA tuning files from the surveys.

Data on abundance of herring and sprat as well as data on weight at age in the stock is available from international hydroacoustic surveys, which are conducted “annually” in September/October. Both these data sets can be used to establish a stock specific weight at age data-base, however, not covering all quarters, which consequently requires modelling of seasonal growth to ensure complete seasonal coverage.

There have been activities on modelling growth, sexual maturation and egg production in relation to food consumption, food availability and environmental conditions, especially temperature in the framework of STORE and SAP (Sustainable Fisheries), which have been used by SGMAB.

The work of the SGMAB depends upon the results of various European Union funded projects and some of ICES Study Groups and Working Groups. Within European Union, SGMAB has benefited from results of number of other, either completed or ongoing projects and study projects. Such projects are CORE (Cod Recruitment, completed at the end of 1997), ISDBITS (International Standardization of Baltic Bottom Trawl Surveys, completed in March 2001), BALTDAT (Baltic International Hydroacoustic Surveys, completed in March 2001), BITS (Baltic International Trawl Survey Database, completed in April 2001) and IBSSP (International Baltic Sea Sampling Project I-II, completed in July 2001) and STORE (Environmental and fisheries influences on fish stock recruitment in the Baltic Sea) completed in 2002.

All these are linked to this Study Group and the Study Group is fortunate to have the possibility to use their results.

At the beginning of year 2002 the European Union established a new framework for the collection and management of data needed to evaluate the situation of the fishery resources and the fisheries sector in general. In EU countries national programs are defined for the collection and management of fisheries fish stock data. The programs cover the information strictly necessary for the scientific evaluations and moreover to define an extended Community program which includes, in addition to the information of the minimum program, information likely to improve in a decisive way the scientific evaluations. There are also possibilities to include some extra sampling schemes on special issues on minimum program or under extended program. Anyhow, the assessments of Baltic fish stocks will be very much dependent on these sampling schemes and minimum and extended programs.

1.5 Overview of Baltic Sea multispecies modelling

It is obvious that there is a need for specific work to keep the capability of running updated multispecies models for the Baltic within the ICES community and to ensure further progress in multispecies modelling in the Baltic. Updated multispecies model results are used by WGBFAS annually and the new predation mortalities are used for Baltic herring and sprat assessments. These single species assessments for cod, herring and sprat are presently the basis for management advice for IBSFC and European Community.

The maintenance of the data-base, data-base revision and updates, which incorporate basic multispecies products, needs input from the Danish Fisheries Research Institute. Backwards extension of the MSVPA to periods before 1977 with the aim to enlarge the time series on stock developments especially for stock-recruitment modelling purposes is possible and in fact this has been completed now to the year 1974. The Eastern Baltic MSVPA covers years 1974–2002 and spatially dis-aggregated model years 1974–1999.

To update databases backwards to 1960s and early 1970s may be possible, but there might be severe problems compiling quarterly data by Subdivisions. In this process the most obvious limiting factor will be the poor quality quarterly catch at age and weight at age data, especially before 1974.

There are considerable amounts of stomach content data for the 1960s and 1970s and this information would be very useful for estimation of consumption rates and understand cod cannibalism. We can foresee that no new stomach data will be sampled in high numbers in the nearest future.

From inspection of the original stomach content data, cannibalism appears to be related both to the prey sizes and spatial overlap. However, cannibalism is most likely also related to shifts in the distribution of predator and prey in response to changes in hydrographical conditions, resulting in pronounced changes in the spatial overlap of predator and prey. This part of exploratory work is ongoing and there are plans to tackle these issues both in European Union Framework 6 program under the title "*Critical interactions between species and their implications for a precautionary fisheries management in a variable Environment - a Modelling Approach*" and under GEF funded project "*Baltic Sea Regional Program*" on Large Marine Ecosystems.

Our predictive models are sensitive to structural uncertainty. For example, with inclusion of weight at age and maturity at age being dependent on the food supply, the projected medium-term yield at various combinations of fishing effort directed to both cod and clupeids stocks change considerably in comparison to ordinary standard multispecies predictions.

Spatially dis-aggregated MSVPA runs have been updated for the Central Baltic up to 1999. The results support the theory that passive transport of youngest life stages of cod and migration by juveniles into/out of their nursery areas as well as spawning migrations of adults between different Subdivisions are likely to occur. The intensity between years varies and there is not for time being clear estimates throughout the years and nor spawning seasons about the extent of these movements. Similarly for herring and sprat, the MSVPA output do not match the distribution pattern obtained from research surveys, indicating conflicting results caused probably by migration and movements. However, the integrated results over the whole area coincide with the results of the assessed stock.

The 4M program, which contain MSVPA and it's routines including the tuning module, have been run without problems. The present program package enables for example WGBFAS to run MSVPA's on a regular basis. An updated user manual giving specification and documentation of the 4M package is also available.

For development, application and validation of different types of multispecies prediction models, one of the key elements seems to be environmental variability. For example Baltic cod recruitment, feeding, growth and maturation processes are very much influenced by the heterogeneity of the physical environment.

In the Baltic Sea environmental variability is strongly linked to the meteorological-, hydrological-, and hydrographical processes and their interaction. As a result, the impact or change of one factor may well be correlated with that of others. How they interact has been considered in some occasions in CORE and STORE projects, but the relationships between various processes and hydrodynamics need still some exploring.

Baltic Sea oceanographic data usually consist of indices that reflect and integrate multiple processes. They often contain indices that reflect the influence of remote forcing over a broad geographic area, direct measurements that reflect measured variables on a local scale or predicted elements generated from detailed models of an specific area. The use of these indices instead of local observations is often the result of limited monitoring resources or limited knowledge at the local scale. How to use these values or indices properly should also be explored.

Reference points, stated in terms of fishing mortality rates or biomass and management plans are key concepts in implementing a precautionary approach. It has been agreed, but not fully understood, that reference points should be regarded as signposts giving information of the status of the stock. It has been possible to develop rather clear concepts and a "quantitative framework" with reference points and management models for single stock sustainability and precautionary. For multispecies situations the sustainability concept seems to be very different and difficult. Although Baltic Sea is considered to be a simple ecosystem, there is still little clarity on the conceptual level given the complexity and natural variability of that environment. Reference points are far away from being defined given the limited understanding of the processes in the environment, of the effects of human interaction and of what comprises a perturbation of the environment which is unsustainable or perhaps irreversible.

Medium- to long-term projection methodology is a problem for single species approach and for multispecies as well. However, the present version of 4M program package is able to handle a variety of stock recruitment relationships with and without stochasticity, as well as stochastic recruitment derived from normal or log-normal distributions. However, the program is not able to incorporate environmental processes into stock recruitment relationships. The inclusion of environmental variability in predictions is worthwhile when assessing the impact of various management and fishing strategies on the stock development under different environmental conditions.

2 STATUS OF THE MULTISPECIES DATABASE

2.1 Stocks in the Central Baltic (Subdivisions 25–32)

The stock units utilized in the present MSVPA for the Central Baltic are:

i) Cod in Subdivisions 25–29+32

ii) Sprat in Subdivisions 25–32

iii) Herring in Subdivisions 25–29, 32 (Gulf of Riga included).

As the sprat population in Subdivision 30 and 31 is rather low (landings are less than 5000 t in most recent years), the stock estimate is basically also referring to Subdivision 25–29+32. To estimate the predation mortality on these stocks, the cod assessment unit was adjusted accordingly, thus not considering part of the stock in Subdivisions 30 and 31. Landings reported in these Subdivisions are in general less than 1% and in maximum 3.5% of the total catch from the Central Baltic. Consequently the effect of ignoring the two Subdivisions should not hamper a direct comparison between single species and multispecies assessment output. For sprat, the multi- and single species assessment units are not directly comparable, as in the latter the sprat stock in entire Baltic is treated as a single stock unit.

Herring stock units in the Central Baltic:

Until 2002 the herring stock assessment in the Central Baltic was based on Herring in the SDs 25–29 and 32. Additionally an assessment of Herring in the Gulf of Riga has been performed to evaluate the stock development trends and provide catch options for this local herring stock. Assessment of herring in SD 25–29 and 32 without Gulf of Riga has been performed irregularly based on request from IBSFC. In 2002 the Main Basin herring stock assessment has been made on 3 different units:

1) Herring in the SD 25–29 and 32 including Gulf of Riga;
2) Herring in the SD 25–29 and 32 excluding Gulf of Riga;
3) Herring in the Gulf of Riga.

Due to complexity of stock structure and that stock development trends in the Gulf of Riga and in the Main Basin are opposite; ACFM advice was based on assessments of Herring in SD 25–32–29 and 32 excluding Gulf of Riga and Herring in the Gulf of Riga. It is assumed that such practice will be maintained for coming assessments.

SGMAB so far used in the multispecies assessment and predictions in the Baltic the combined main basin herring stock data e.g., Herring in SD 25–29 and 32 including Gulf of Riga. As the herring in the Gulf of Riga presently constitute approximately 1/3 of all herring stocks, the growth of sea and gulf herring differs and there are no cod in the Gulf of Riga the estimated natural mortality for herring in the open sea can deviate significantly from previously used. Therefore it is suggested also in MSVPA to use data of herring stock in SD 25–29 and 32 excluding Gulf of Riga, to be consistent in future with WGBFAS practice. However, during SG meeting it was not possible to compile the new set of quarterly dis-aggregated data for herring in the SD 25–29 and 32 excluding Gulf of Riga. Such data compilation for separation of these two herring units in the MSVPA could require approximately 1–2 months. Data could only be prepared for next Study Group meeting. This should be done by Institute of Marine Research in Kiel and Latvian Fisheries Research Institute in Riga.

2.2 Stocks in the Western Baltic (Subdivisions 22–24 and Division IIIa)

As in previous MSVPA runs for the Western Baltic and according to the units used by the single species assessment Working Groups three different stocks were considered in the Western Baltic:

Cod in Subdivisions 22–24. Subdivision 23 was up to 1995 not included in the assessment of the western cod stock. This corresponds to the procedure conducted by the Baltic Fisheries Assessment Working Group. Reasons were mainly that commercial catches were not sampled and application of the age-structure of the neighbouring Subdivision 24 was difficult, due to different fishing practise in the Sound (ban of trawl fishery). Since 1996, however, a sampling scheme of commercial catches was introduced and the data was included into the assessment (ICES 1998a/ACFM:16). The exclusion before is expected to be of minor importance.

Herring in Subdivisions 22–24 and Division IIIa. The herring shows a complex distribution pattern. The major spawning grounds are found around Rügen and in the Greifswalder Bodden. After spawning on their feeding migration (as 2 years of age and in proportions increasing with age) the herring enter Division IIIa through the Sound and Belt Sea and spread out into the Western part of Skagerrak and the Eastern North Sea. Towards the end of the summer the herring aggregate in the Eastern Skagerrak and Kattegat before they migrate to the main wintering areas in the southern part of Kattegat, the Sound and the Western Baltic. Due to this migration out of Subdivisions 22–24 only a fraction of the total herring stock is preyed upon by the Western cod stock in the 2nd and 3rd quarter. This must be kept in mind when looking at the predation mortality from the MSVPA, which may be biased downwards (at least for herring age-group 2+), as only some part of the predation mortality is accounted for due to the described distribution pattern of herring.

Sprat in Subdivisions 22–24: The Baltic Sea sprat inhabits the Baltic Sea from the Belt Seas and western Baltic (Subdivisions 22 and 24) up to the Quark area in the north (Subdivision 30) and to the north-eastern part of the Gulf of Finland (Subdivision 32). There are three different sprat stocks in the Baltic and the mixing with the Kattegat and Skagerrak stocks is considered to be very low, although there is no significant difference in morphometric characters and in the vertebrae counts. The mixing is mainly prevented by the gradient and differences in many abiotic factors between the western Baltic and the Kattegat. The identification of the sprat stocks in the Baltic has been carried out by the differences in otolith structure, meristic and morphometrical characters, growth patterns and also by the hydrological conditions in the Baltic Basins. In multispecies assessment, sprat stock inhabiting the Belt Seas, western Baltic and the area west of Bornholm Island (Subdivisions 22–24) is included into the database. However, the boundaries between the neighbouring stocks are not very clear and the mixing of stocks during feeding and wintering is apparent, which should be kept in mind, when multispecies assessment results are considered.

2.3 Database update (catch at age and weight at age in the Central Baltic)

Period 1974–1992

During the meetings of the Study Group on Multispecies Model Implementation in the Baltic (ICES 1997/J:2 and ICES 1999/H:5) and the Study Group on Multispecies Predictions in the Baltic (ICES 2001/H:4) revised and corrected quarterly catch at age and weight at age in the catch data per Subdivision were compiled for cod, sprat and herring in the Central Baltic for the period 1974–1992. This enables multispecies assessments to be carried out for stock units defined as appropriate, i.e., presently those used by the Baltic Fisheries Assessment Working Group.

Period 1992–2002

Data for all three species were provided in the needed form by the Baltic Fisheries Assessment Working Group in most recent years, for minor deviations between the single- and multispecies database see ICES (1999b/H:5). As in previous years, the data for the most recent year of the assessment year was implemented into the multispecies data-base as provided by the Baltic Fisheries Assessment Working Group up to 2001 (ICES 2002/ACFM:17). Data for 2002 will be included in close co-operation and in the frame of the Baltic Fisheries Assessment Working Group to be held at ICES headquarters April 2003.

General

The revision of the data-base needs allocation of additional effort. Work is needed especially for compilation of the new set of quarterly dis-aggregated data for herring in the SD 25–29 and 32 excluding Gulf of Riga (see Section 2.1.1) and for the years at the beginning of the time-series. For these still data exist in various national laboratories and with respect to potential corrections for age-reading discrepancies in cod. Furthermore, no discard estimates are yet included in the data. A necessary step after incorporation of all available information and re-computation of quarterly data per Subdivision according to the agreed substitution scheme (ICES 1997/J:2), is a further validation of the assessment data by comparison of SOP-values to actual reported landings. Based on this validation, a final revision of the data-base has to be conducted, before handing over the data-base to the Baltic Fisheries Assessment Working Group.

2.4 Database update (catch at age and weight at age in the Western Baltic)

Cod and sprat stocks. The data-base was updated from 1998–2001. For these years data was implemented into the multispecies data-base as provided by the Baltic Fisheries Assessment Working Group for Subdivisions 22–24 (including 23).

Herring stock. Herring catch at age and weight at age data were revised for the period 1991–2002, applying the data provided by the Herring Assessment Working Group for the Area South of 62°N meeting in 2003. Nevertheless, the revision of the data-base needs allocation of additional effort, especially to conduct a detailed comparison between the “old” and the updated dataset.

2.5 Stomach content information

The stomach content data-base contains the major part of the information available for the period 1977–1993. Stomach sampling activity has been very limited in most recent years, and this data material has not been incorporated into the database so far. Likewise available information for the period 1974–1976 has not been included in the database. Backwards extension of the MSVPA to periods before 1974 with the aim to enlarge the time series on stock developments especially for recruitment modelling purposes is in principal possible, as considerable amounts of stomach content data exist for the 1960s and 1970s. However, the limiting factor of such an extension will probably be the insufficient reliability of quarterly catch at age and weight at age data available.

2.6 Possible data improvements

The revision of the catch at age and weight at age data-base according to quarter and Subdivision for the period 1974–92, handled by the Institute of Marine Sciences in Kiel, needs allocation of additional effort. Work is needed especially for compilation of the new set of quarterly dis-aggregated data for herring in the SD 25–29 and 32 excluding Gulf of Riga (see Section 2.1.1) and for the years at the beginning of the time-series. A further necessary step after incorporation of all available information and re-computation of quarterly data per Subdivision according to the agreed substitution scheme, is a validation of the assessment data, e.g., by comparison of SOP-values to actual reported landings in smallest time and area units available. This procedure (see ICES 1999/H:5 and ICES 1997/J:2) allows to identify major discrepancies between the present single- and the new multispecies database, caused by either computation errors or substitution of missing information with unsuitable or erroneous data. Based on this validation, a final revision of the data-base has to be conducted, before handing over the end product to the Baltic Fisheries Assessment Working Group, which should take care of an annual update, as already started in 1997.

During its meeting in 1998 the Baltic Fisheries Assessment Working Group (ICES 1998/ACFM:16) has started a compilation of available weight at age in the stock data for cod, based on 1st quarter bottom trawl surveys. Similarly, data on weight at age in the stock for herring and sprat are available from international hydroacoustic surveys conducted annually in September/October. Both data sets can be used to establish a stock specific weight at age data-base, however, not covering all quarters, which consequently requires modelling of seasonal growth to ensure complete seasonal coverage.

The stomach content data-base contains the major part of the information available for the covered time period 1977–1993, and as stomach sampling activity has been very limited in most recent years, only limited effort for an update of the data-base is required for most recent years. However, inclusion of earlier data covering, e.g., 1974–1976, may be worthwhile as a as considerable amounts of stomach content data exist for the 1960s and 1970s. Further backwards extension of the MSVPA to periods before 1974 with the aim to enlarge the time series on stock developments especially for recruitment modelling purposes is in principal possible. However, the limiting factor of such an extension will be the insufficient reliability of quarterly catch at age and weight at age data available, especially before 1974. Maintenance of the data-base needs limited input from the Danish Fisheries Research Institute presently holding the data-base.

3 MSVPA KEY RUN FOR 1974–2001 IN THE BALTIC MAIN BASIN

The 4M software package (Vinther *et al.,* 2001) was applied to make a MSVPA “key-run” for cod, sprat and herring in the Central Baltic for the period 1974–2001. This run estimates natural mortality for use in the single species assessment WG.

3.1 MSVPA set-up

Following basic input data have been used for the MSVPA key-run:

- catch at age and weight at age in the catch and in the stock for 1974–2000 as outlined in ICES (2001/H:04), data for 2001 were taken from ICES (2002/ACFM:17)
- quarterly cod stomach content data (1977–1993) by Subdivision as revised previously (ICES 1997/J:2), intra-cohort cannibalism of cod was excluded by changing prey age to predator age minus 1 and omitting cod in 0-group cod stomachs,
- maturity ogives for cod in different Subdivisions represent averages over the periods 1980–1984 (applied also prior 1980), 1985–1989, 1990–1994 and annual data for 1995–1999 for combined sexes as presented in single species assessment (ICES 1998/ACFM:16; ICES 2000/ACFM:14), and for 2000 and 2001 an average over the years 1997–1999 as utilized by the Assessment WG (ICES 2002/ACFM:17); for herring maturity ogives were used as given in ICES (1998/ACFM:16) being constant over the entire period, - suitability sub-model as introduced in ICES (1992/Assess:7), for sprat maturity ogives were used as given in ICES (2002/ACFM:17)
- quarterly consumption rates for cod as revised in ICES (2001/H:04),
- residual mortalities of 0.2 per year, equally distributed over quarters,
- a constant biomass of other food,
- oldest age-groups in the analyses were: 8+ for cod, 8+ for herring and 7 for sprat.

The terminal F-tuning of MSVPA was performed with the new 4M-programme routine developed and implemented iteratively running XSAs and MSVPAs (Vinther, 2001). XSA settings were identical to the ones used in assessment runs by Baltic Fisheries Assessment Working Group (ICES 2002/ACFM:17). Fishing mortalities in the terminal year for the 0-groups (and the 1-group for cod) are not estimated in the XSA tuning and values were given such that the final estimated MSVPA stock numbers for herring and sprat were close to the average values estimated in period 1998–2000.

For cod the terminal F were derived by relating the BITS abundance index for age-group 2 to the earlier MSVPA output.

3.2 Results of the key run for 1974–2001

Cod

The main results of the MSVPA key-run for the Central Baltic are given in summary Figures 3.1–3.3. The spawning stock biomass of Eastern Baltic cod derived by the MSVPA run shows a pronounced increase from 1977 to 1980, remaining on a high level during the first half of the 1980s, afterwards declining to a low level in 1992, showing a restricted intermediate increase in the mid 1990s being presently on the historic minimum. This is well in agreement with the respective estimates from single species VPA (ICES 2002/ACFM:17), see Figure 3.4. Higher deviations between standard and multispecies SSB estimates are obvious for the beginning of the 1980s. These differences are caused by lower mean weight at age in the stock applied in the MSVPA runs, as derived stock numbers are rather similar for age-groups 2+. Furthermore, it should be mentioned that in the MSVPA runs catch at age from Subdivisions 30 and 31 were not included, which were higher in the 1980´s compared to later years. After 1993, when the input data sets deviate only to a minor extent, the estimated biomass values are very well in agreement. Repeating the exercise for recruitment estimates at age 2 showed a good agreement between MSVPA and single species output (Figure 3.5). Fishing mortality rates determined by MSVPA and the standard assessment show similar time patterns, with the single species assessment estimating in general slightly higher values with some exceptions, e.g., 2001 (Figure 3.6). An exceptional high fishing mortality in the MSVPA output in 1989 is probably caused by missing records in the catch data set for age-group 7 in the 3rd and 4th quarter of 1990, although in the same cohort in previous and following years catches were recorded. As a result fishing mortality in age-group 6 in the 4th quarter 1989 exceeded 1.5.

Correspondingly the mean fishing mortality in 1990 from MSVPA is somewhat lower than in the single species VPA. Predation mortalities of 0-, 1- and 2-group cod (Figure 3.7) are in the same order of magnitude than derived by earlier MSVPA runs. The intensity of cannibalism on 0-group cod in 1974–1976, is somewhat astonishing, as the predator abundance is considerably lower than in early 1980s. Estimated predation mortalities of 1- and 2-group cod follow more closely the development of the predator stock size.

Comparing the old MSVPA key-run (ICES 2001/H:04) with the present one revealed slight deviations between cod biomass and recruitment during the 1990s (Figures 3.8–3.10) which are due to the tuning procedure.

Sprat

The estimated spawning stock biomass of sprat shows a pronounced decline from the mid 1970s to the early 1980s, a trend that is slightly less pronounced in the standard assessment (Figure 3.4). In fact the mid 1970s show deviations between both assessments, i.e., in 1974 and 1975 the MSVPA based estimates are considerably higher than the standard XSA output. The subsequent increase of the spawning stock from the late 1980s to historically high levels of around 2 million t in 1997 is shown by both assessments, with the MSVPA estimating slightly higher SSB values. The described deviations between spawning stock biomass values are caused by different weight at age, as determined stock numbers are rather similar from 1977–1999. Deviations in 1974–1976 are in contrast not entirely explained by deviations in weight at age, but by differences in catch at age, being higher in the multispecies database in 1974 and 1975.

Correspondingly deviations in sprat recruitment estimates are apparent especially for these early years as well as in the latest years of the time series (Figure 3.5). Here the MSVPA recruitment is lower compared to the standard assessment. The MSVPA derived fishing mortality rates follow rather well the general trend in F estimates from the standard XSA (Figure 3.6), with some higher deviations in the periods 1976–1980 and 1989–1992 as well as in 1999 and 2000. Predation mortalities of sprat showed a continuous decline from mid 1970s to early 1990s being rather constant afterwards (Figure 3.7).

Generally the SSB values of sprat from the new MSVPA run are higher when compared to the earlier analysis (Figure 3.8). This discrepancy is due to the adoption of new maturity ogives from the Baltic Fisheries Assessment Working Group (ICES 2002/ACFM:17).Differences in recruitment and fishing mortality during the late 1990s are the result of a different tuning procedure (Figures 3.9 and 3.10).

Herring

Spawning stock biomass estimates of Central Baltic herring derived by the MSVPA key-run show a continuous decline (Figure 3.4), which is however to a large extend caused by reduction in weight at age. Single–species values are generally lower than the MSVPA derived, being a result of different age-specific weight input. Recruitment at age 1 derived by the MSVPA shows a high level in the early 1980s and a declining trend afterwards. (Figure 3.5). Larger deviations between single and multispecies assessment are encountered for the early years of the time-series, which are probably due to the poor data quality in either or one of the time series. The estimated fishing mortality rates obtained from MSVPA and standard assessment are rather similar, with largest deviations in 1978 and 1979, as well as in 1999 to 2001 (Figure 3.6). Predation mortality follow closely the time trend described for sprat. However, a substantial difference between the species is, that predation mortalities of adult herring is very low, reaching seldom 0.1 per year (Figure 3.7).

Major differences between old and new multispecies assessments for herring were only visible for recruitment and fishing mortality in the latest years, which are a result of the tuning procedure (Figures 3.9 and 3.10).

Natural mortalities

Natural mortalities estimated by MSVPA are routinely used in the single assessment (ICES 2001b/ACFM:18). The values estimated by the last iteration of the multispecies tuning are presented in Tables 3.1–3.3.

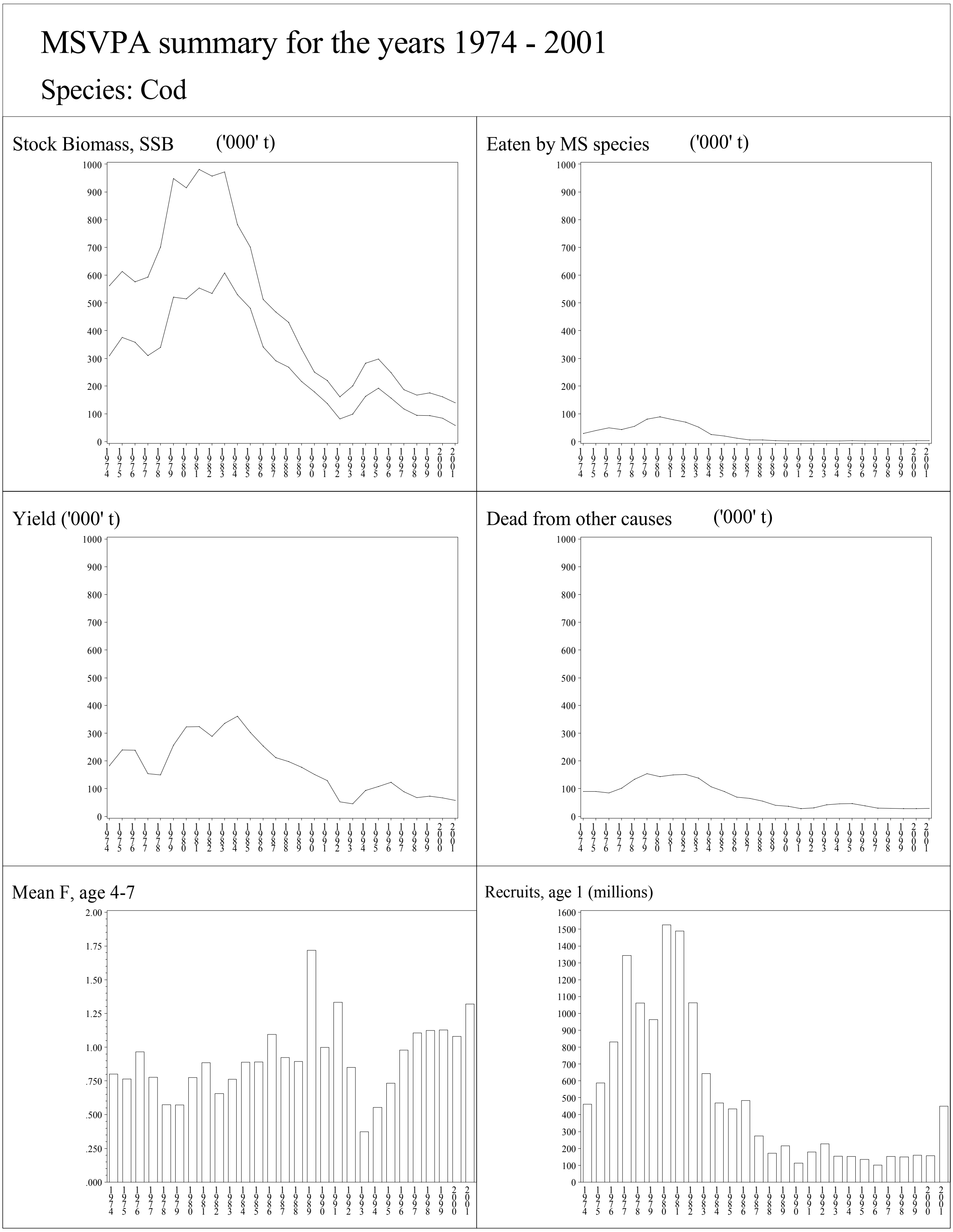

Figure 3.1. Key-run summary for cod.

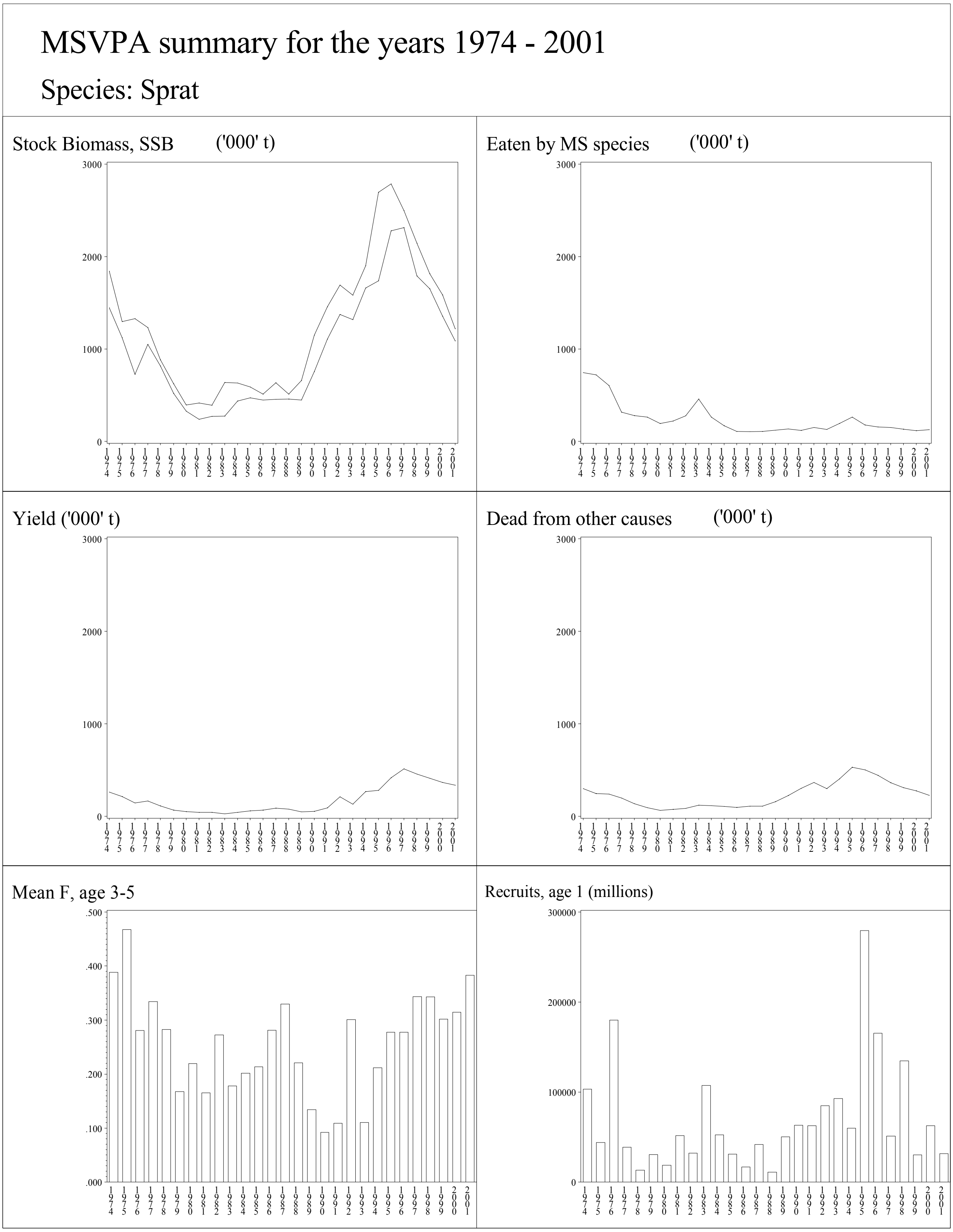

Figure 3.2. Key-run summary for sprat.

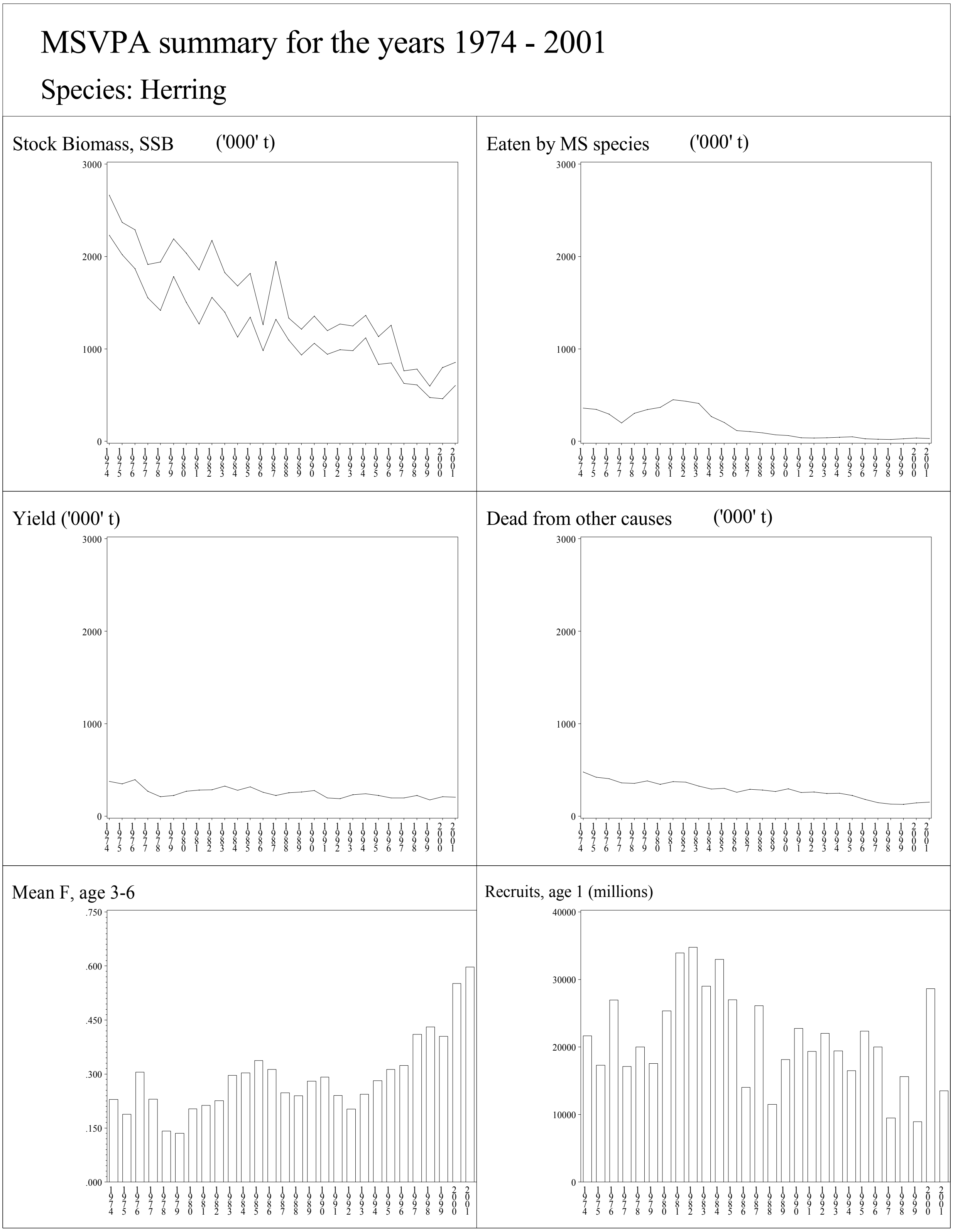

Figure 3.3. Key-run summary for herring.

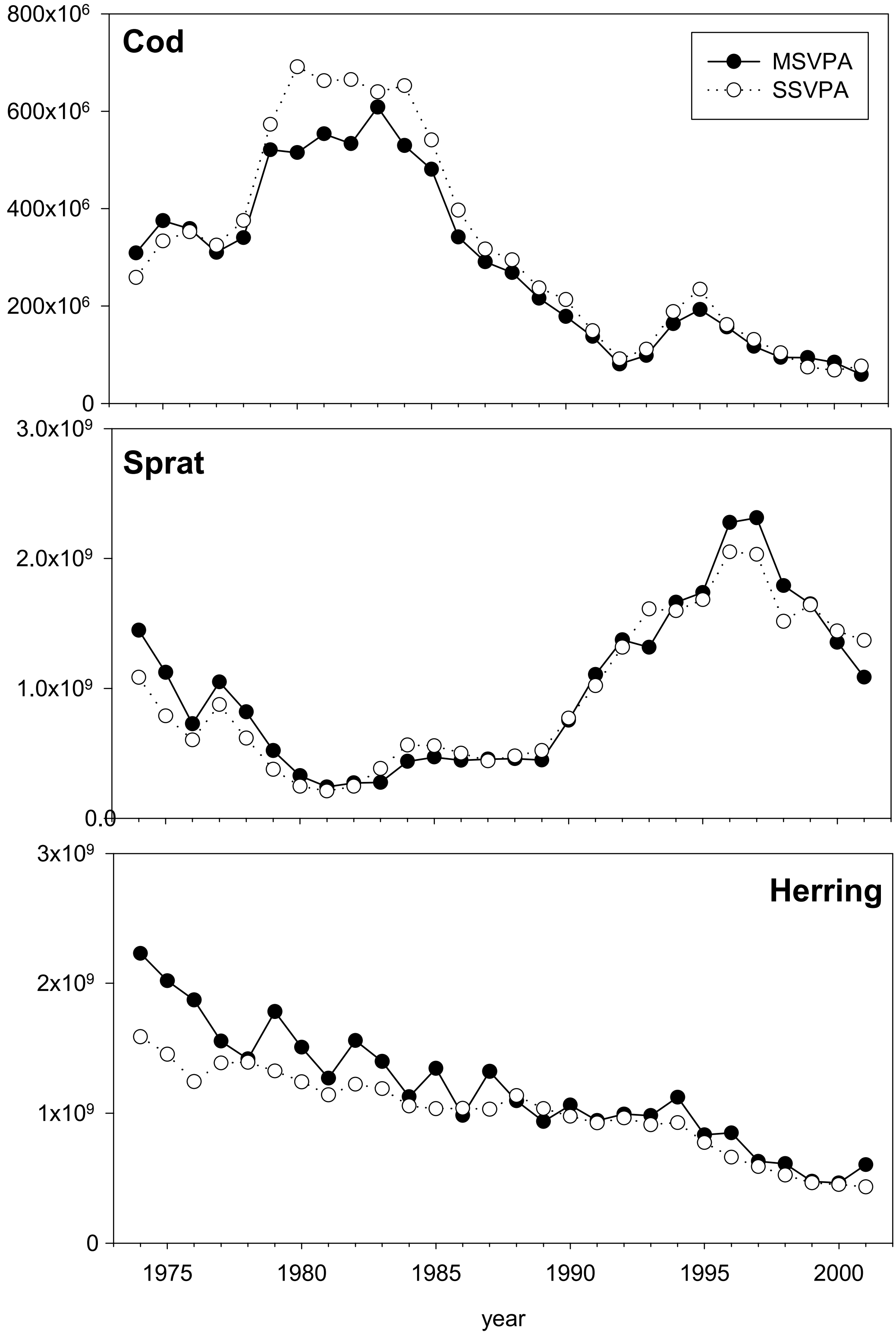

Figure 3.4. Times-series of spawning stock biomass (SSB, 1st quarter) of cod, herring and sprat in the Central Baltic Sea derived from MSVPA and standard assessment (SVPA).

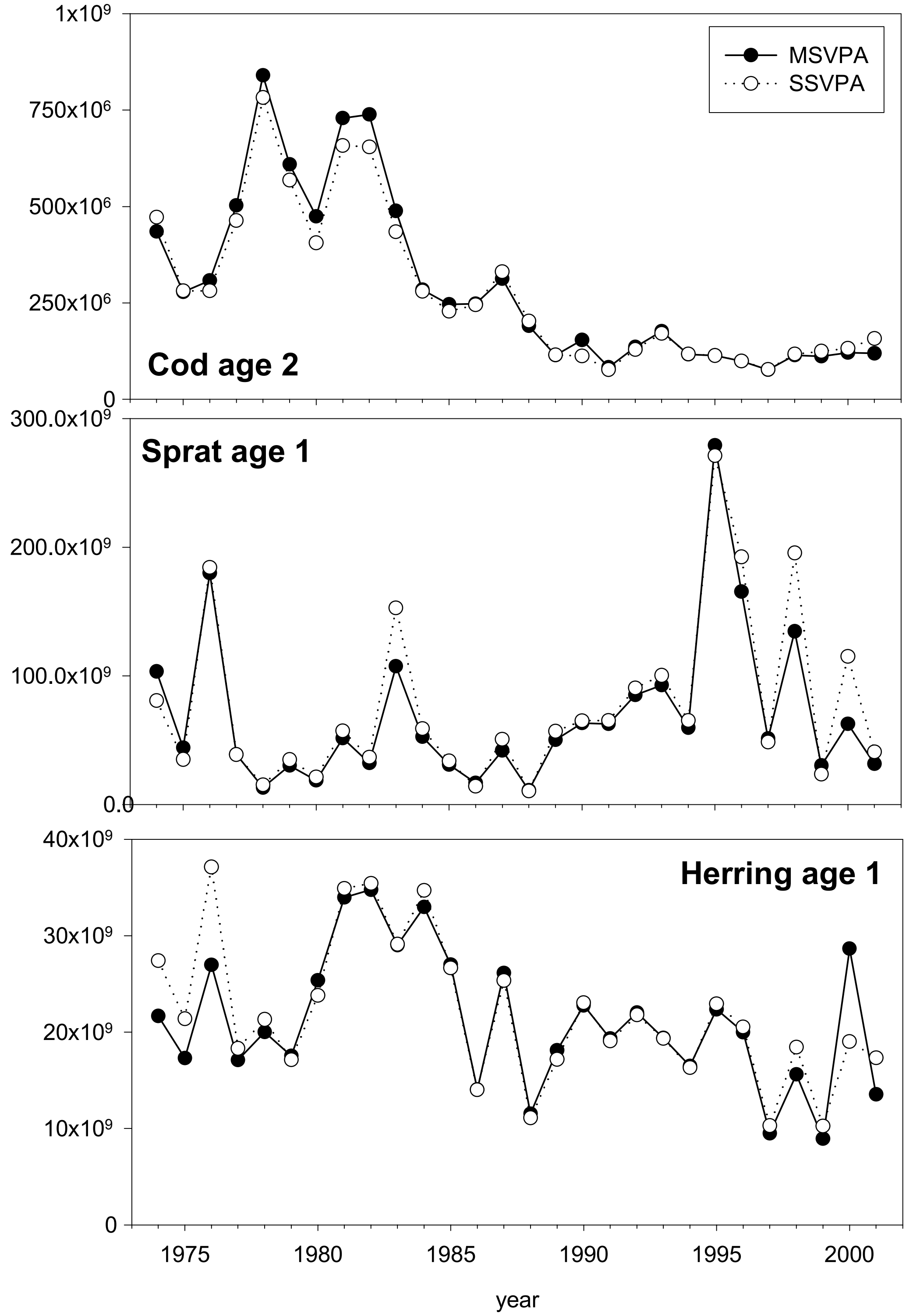

Figure 3.5. Time-series of recruitment estimates (1st quarter) of cod, herring and sprat in the Central Baltic Sea derived from MSVPA and standard assessment (SSVPA).

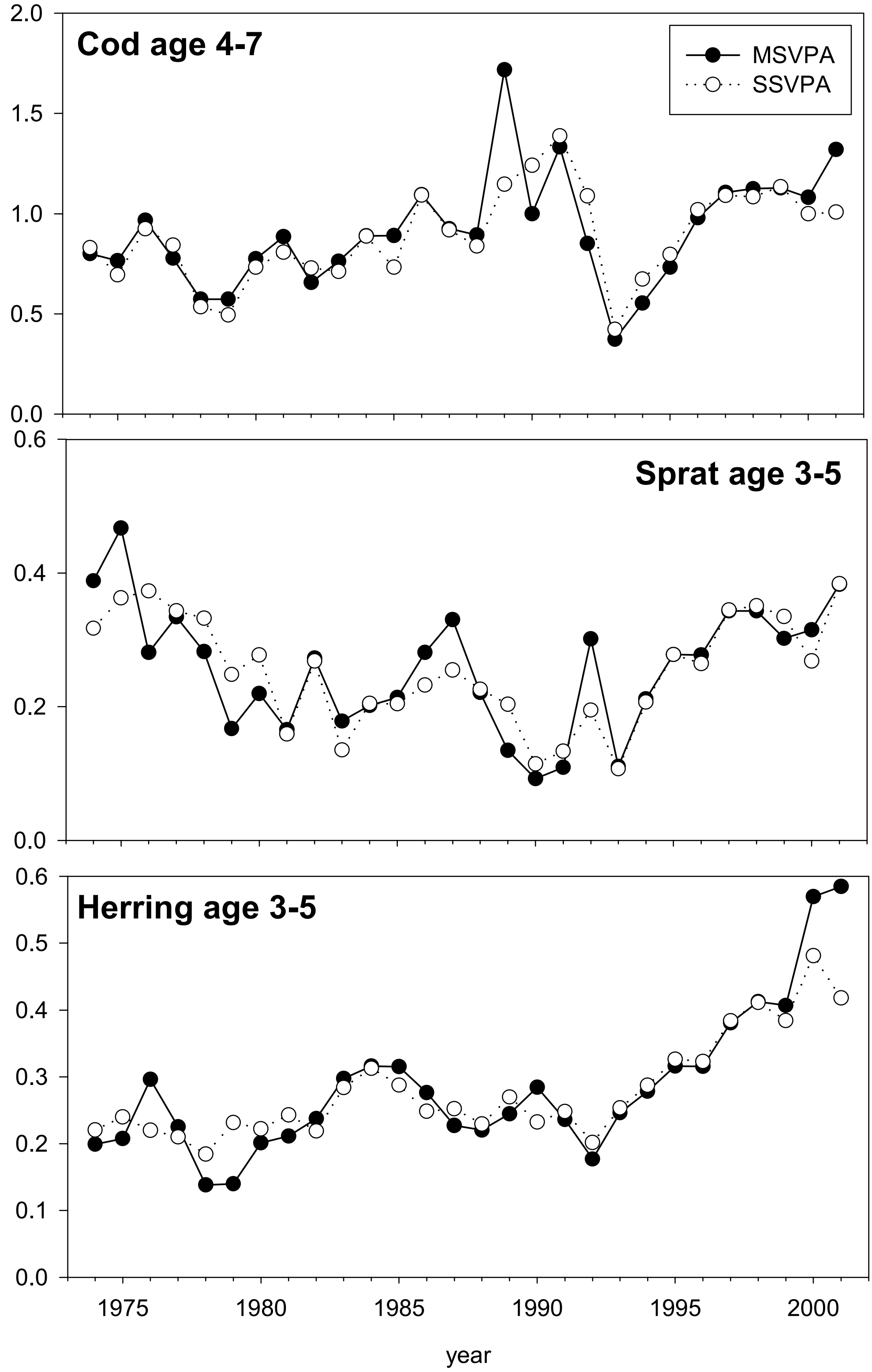

Figure 3.6. Time-series of annual fishing mortalities of cod, herring and sprat in the Central Baltic Sea derived from MSVPA and standard assessment (SSVPA).

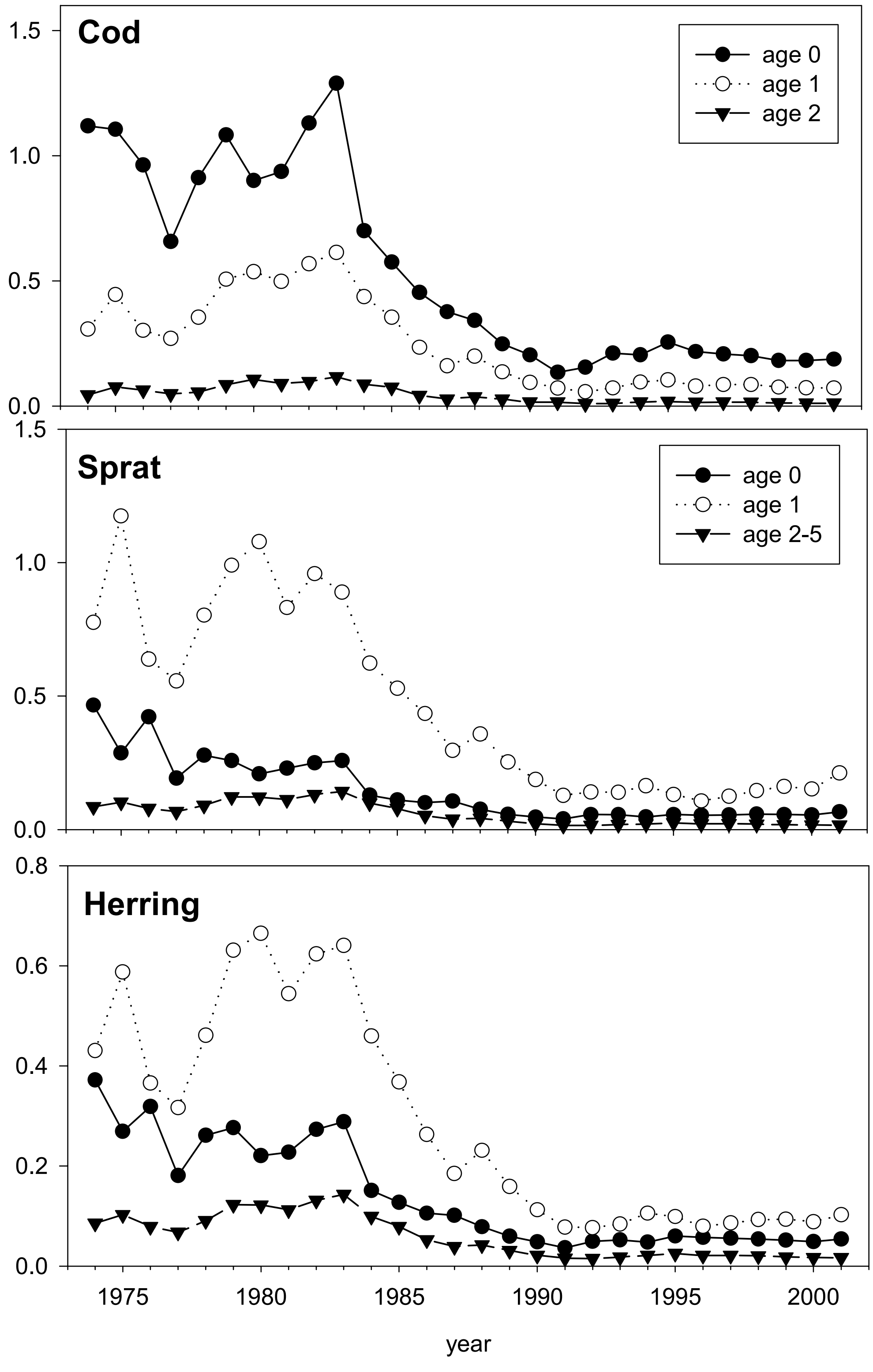

Figure 3.7. Time-series of annual predation mortalities of cod, sprat and herring in the Central Baltic Sea derived from MSVPA.

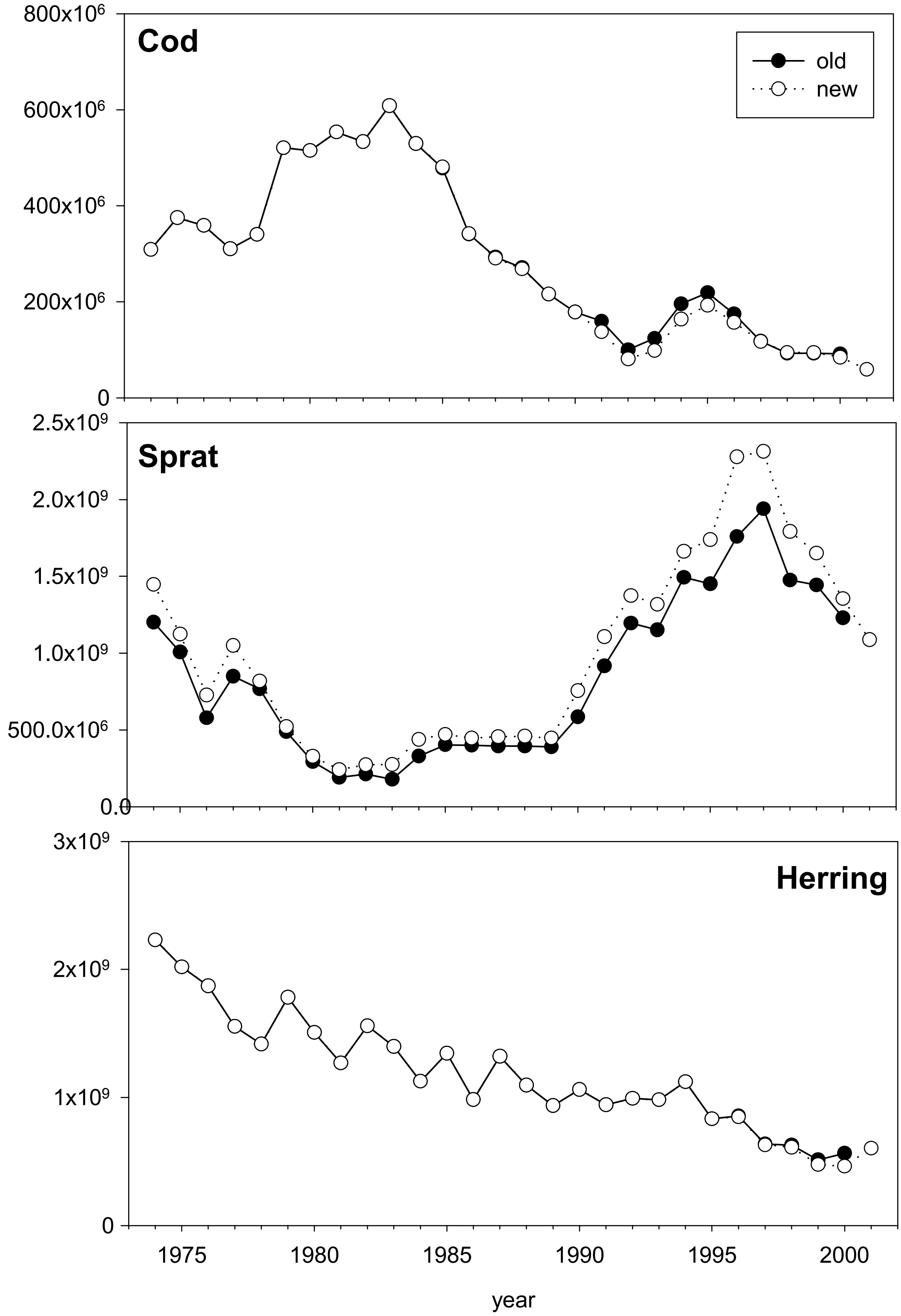

Figure 3.8. Times-series of spawning stock biomass (SSB, 1st quarter) of cod, herring and sprat in the Central Baltic Sea derived from the old and new MSVPA run.

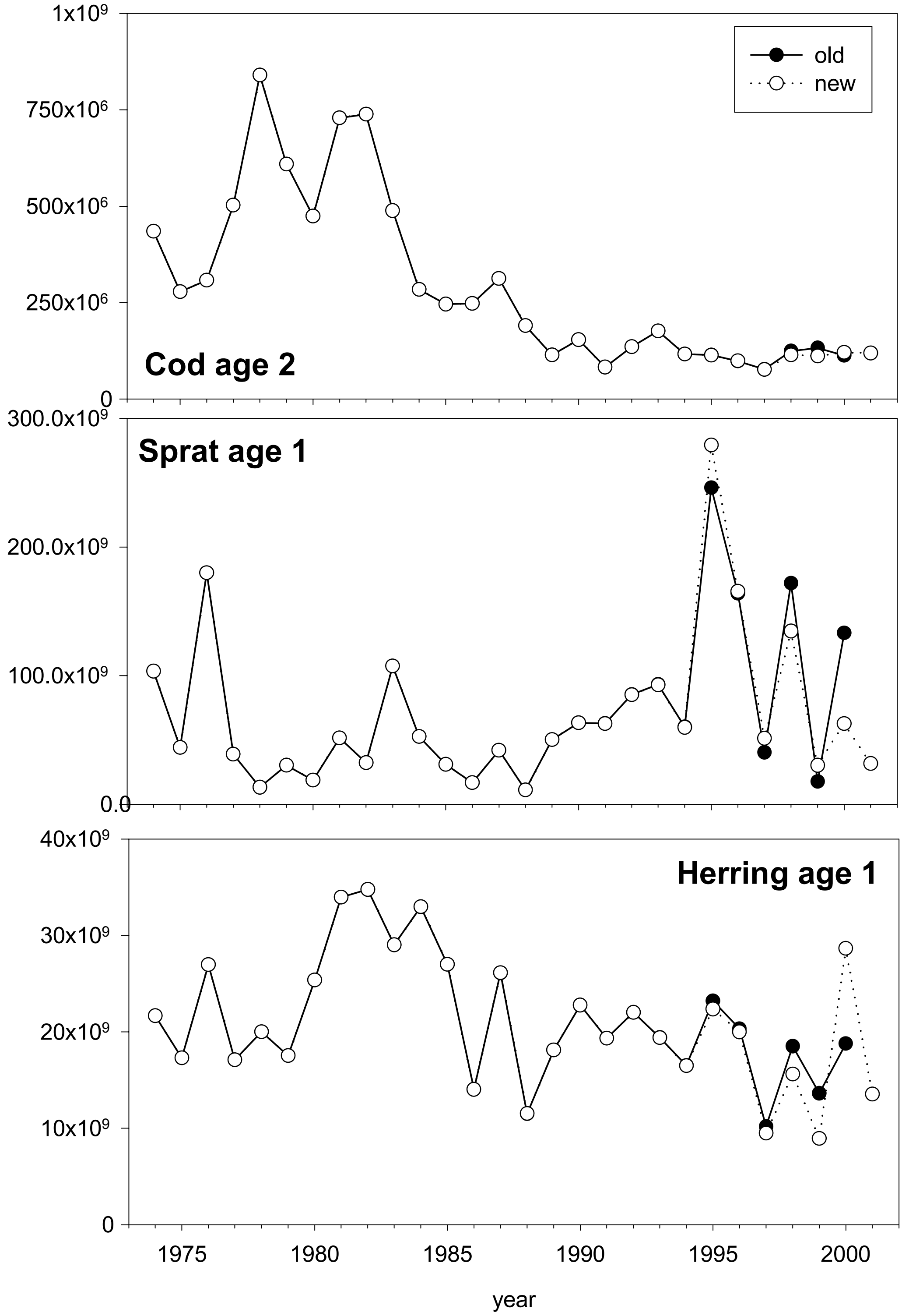

Figure 3.9. Time-series of recruitment estimates (1st quarter) of cod, herring and sprat in the Central Baltic Sea derived from the new and old MSVPA run.

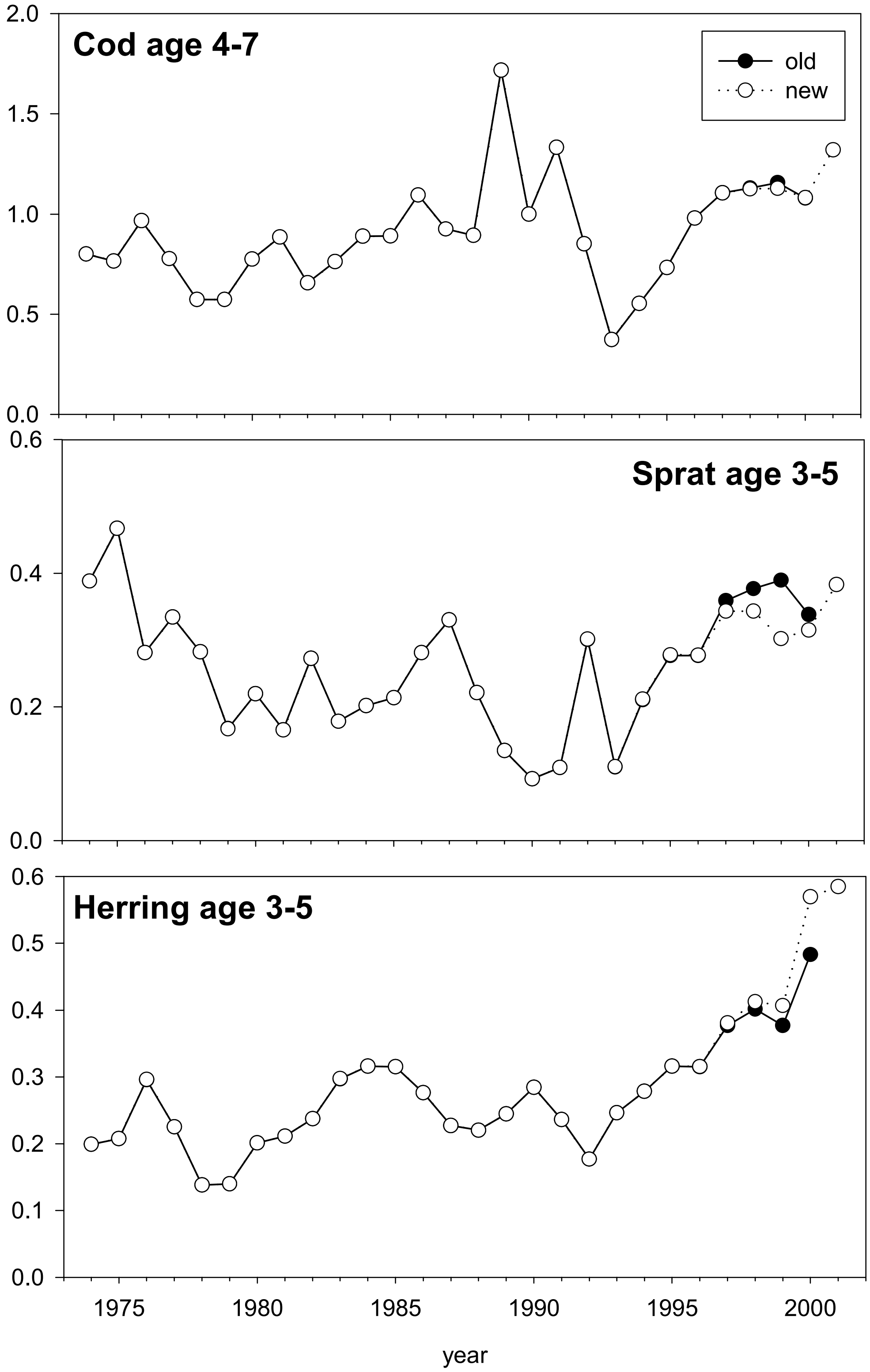

Figure 3.10. Time-series of annual fishing mortalities of cod, herring and sprat in the Central Baltic Sea derived from the new and old MSVPA run.

Table 3.1. Annual M2 for cod in the Central Baltic.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1974	0.2439	0.2044	0.2007	0.2000	0.2000	0.2000	0.2000
1975	0.2762	0.2086	0.2014	0.2001	0.2000	0.2000	0.2000
1976	0.2630	0.2086	0.2017	0.2001	0.2000	0.2000	0.2000
1977	0.2484	0.2061	0.2011	0.2001	0.2000	0.2000	0.2000
1978	0.2547	0.2063	0.2011	0.2001	0.2000	0.2000	0.2000
1979	0.2847	0.2095	0.2016	0.2001	0.2000	0.2000	0.2000
1980	0.3061	0.2127	0.2020	0.2001	0.2000	0.2000	0.2000
1981	0.2888	0.2121	0.2023	0.2001	0.2000	0.2000	0.2000
1982	0.2964	0.2122	0.2023	0.2002	0.2000	0.2000	0.2000
1983	0.3161	0.2150	0.2028	0.2002	0.2000	0.2000	0.2000
1984	0.2872	0.2126	0.2024	0.2002	0.2000	0.2000	0.2000
1985	0.2763	0.2113	0.2023	0.2002	0.2000	0.2000	0.2000
1986	0.2429	0.2051	0.2009	0.2001	0.2000	0.2000	0.2000
1987	0.2278	0.2040	0.2008	0.2001	0.2000	0.2000	0.2000
1988	0.2367	0.2050	0.2010	0.2001	0.2000	0.2000	0.2000
1989	0.2268	0.2039	0.2008	0.2001	0.2000	0.2000	0.2000
1990	0.2151	0.2016	0.2003	0.2000	0.2000	0.2000	0.2000
1991	0.2150	0.2025	0.2006	0.2000	0.2000	0.2000	0.2000
1992	0.2081	0.2008	0.2001	0.2000	0.2000	0.2000	0.2000
1993	0.2086	0.2009	0.2002	0.2000	0.2000	0.2000	0.2000
1994	0.2132	0.2014	0.2002	0.2000	0.2000	0.2000	0.2000
1995	0.2170	0.2020	0.2004	0.2000	0.2000	0.2000	0.2000
1996	0.2135	0.2015	0.2002	0.2000	0.2000	0.2000	0.2000
1997	0.2164	0.2022	0.2004	0.2000	0.2000	0.2000	0.2000
1998	0.2142	0.2019	0.2004	0.2000	0.2000	0.2000	0.2000
1999	0.2116	0.2014	0.2003	0.2000	0.2000	0.2000	0.2000
2000	0.2106	0.2013	0.2002	0.2000	0.2000	0.2000	0.2000
2001	0.2114	0.2012	0.2002	0.2000	0.2000	0.2000	0.2000

Table 3.2. Annual M2 for sprat in the Central Baltic.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1974	0.9758	0.5944	0.4732	0.4488	0.5330	0.4875	0.5475	0.5475
1975	1.3753	0.7656	0.5817	0.5338	0.6469	0.6123	0.7031	0.7031
1976	0.8413	0.5313	0.4226	0.3988	0.4744	0.4598	0.5234	0.5234
1977	0.7565	0.4989	0.4160	0.3841	0.4410	0.4340	0.4926	0.4926
1978	0.9999	0.6476	0.5301	0.4765	0.5575	0.5405	0.6126	0.6126
1979	1.1873	0.8062	0.6544	0.5710	0.6836	0.6924	0.7894	0.7894
1980	1.2713	0.8527	0.6832	0.5802	0.6984	0.7444	0.8529	0.8529
1981	1.0236	0.7083	0.5771	0.5131	0.6071	0.6180	0.7149	0.7149
1982	1.1511	0.7960	0.6533	0.5663	0.6714	0.6835	0.7929	0.7929
1983	1.0848	0.7902	0.6392	0.5749	0.7079	0.7044	0.8185	0.8185
1984	0.8208	0.6335	0.5300	0.4679	0.5472	0.5777	0.6651	0.6651
1985	0.7273	0.5399	0.4551	0.4087	0.4740	0.4993	0.5696	0.5696
1986	0.6321	0.4483	0.3824	0.3524	0.3984	0.4001	0.4476	0.4476
1987	0.4932	0.3735	0.3290	0.3112	0.3442	0.3370	0.3694	0.3694
1988	0.5526	0.4217	0.3615	0.3362	0.3796	0.3789	0.4148	0.4148
1989	0.4470	0.3542	0.3140	0.2930	0.3224	0.3268	0.3535	0.3535
1990	0.3817	0.3052	0.2768	0.2650	0.2855	0.2824	0.2999	0.2999
1991	0.3229	0.2697	0.2497	0.2428	0.2564	0.2575	0.2702	0.2702
1992	0.3352	0.2664	0.2481	0.2399	0.2512	0.2510	0.2605	0.2605
1993	0.3355	0.2782	0.2558	0.2505	0.2678	0.2562	0.2692	0.2692
1994	0.3595	0.2956	0.2688	0.2597	0.2800	0.2749	0.2896	0.2896
1995	0.3333	0.2837	0.2620	0.2543	0.2748	0.2733	0.2895	0.2895
1996	0.3076	0.2653	0.2499	0.2426	0.2582	0.2589	0.2718	0.2718
1997	0.3255	0.2720	0.2534	0.2461	0.2621	0.2642	0.2784	0.2784
1998	0.3388	0.2790	0.2570	0.2502	0.2664	0.2638	0.2779	0.2779
1999	0.3600	0.2861	0.2616	0.2535	0.2700	0.2658	0.2789	0.2789
2000	0.3475	0.2817	0.2578	0.2514	0.2683	0.2611	0.2740	0.2740
2001	0.4095	0.3053	0.2726	0.2634	0.2834	0.2746	0.2906	0.2906

Table 3.3. Annual M2 for herring in the Central Baltic.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1974	0.6355	0.3367	0.2915	0.2588	0.2575	0.2398	0.2344	0.2106
1975	0.7945	0.3585	0.3103	0.2739	0.2716	0.2491	0.2422	0.2129
1976	0.5712	0.3193	0.2866	0.2581	0.2552	0.2389	0.2327	0.2099
1977	0.5202	0.2981	0.2742	0.2506	0.2488	0.2350	0.2287	0.2087
1978	0.6651	0.3373	0.2988	0.2656	0.2635	0.2451	0.2375	0.2114
1979	0.8366	0.3828	0.3360	0.2906	0.2853	0.2606	0.2497	0.2149
1980	0.8683	0.3794	0.3355	0.2912	0.2844	0.2596	0.2487	0.2145
1981	0.7455	0.3591	0.3230	0.2858	0.2822	0.2571	0.2466	0.2140
1982	0.8261	0.3862	0.3453	0.3006	0.2963	0.2696	0.2560	0.2169
1983	0.8455	0.4043	0.3572	0.3092	0.3056	0.2748	0.2622	0.2188
1984	0.6645	0.3377	0.3118	0.2787	0.2740	0.2524	0.2415	0.2123
1985	0.5729	0.3109	0.2894	0.2631	0.2595	0.2423	0.2339	0.2101
1986	0.4662	0.2767	0.2592	0.2411	0.2395	0.2283	0.2231	0.2070
1987	0.3865	0.2575	0.2431	0.2295	0.2287	0.2204	0.2167	0.2051
1988	0.4319	0.2627	0.2463	0.2319	0.2305	0.2211	0.2173	0.2052
1989	0.3584	0.2447	0.2339	0.2233	0.2220	0.2154	0.2125	0.2037
1990	0.3107	0.2314	0.2228	0.2155	0.2151	0.2105	0.2089	0.2027
1991	0.2754	0.2216	0.2163	0.2114	0.2108	0.2077	0.2063	0.2019
1992	0.2728	0.2210	0.2149	0.2097	0.2091	0.2066	0.2055	0.2017
1993	0.2808	0.2253	0.2176	0.2119	0.2121	0.2083	0.2072	0.2022
1994	0.3025	0.2292	0.2209	0.2142	0.2139	0.2095	0.2081	0.2025
1995	0.2999	0.2345	0.2269	0.2189	0.2184	0.2130	0.2110	0.2034
1996	0.2806	0.2294	0.2231	0.2159	0.2154	0.2112	0.2093	0.2028
1997	0.2870	0.2296	0.2233	0.2162	0.2155	0.2113	0.2093	0.2028
1998	0.2892	0.2281	0.2212	0.2148	0.2145	0.2103	0.2085	0.2026
1999	0.2925	0.2265	0.2186	0.2124	0.2120	0.2085	0.2071	0.2022
2000	0.2872	0.2257	0.2181	0.2123	0.2121	0.2084	0.2071	0.2022
2001	0.3075	0.2294	0.2199	0.2132	0.2129	0.2089	0.2076	0.2023

4 PRELIMINARY MSVPA KEY RUN FOR 1974–2002 IN THE BALTIC MAIN BASIN

Because SGMAB met before WGBFAS in Charlottenlund (Denmark, 02. – 04. April 2003) the group performed updated MSVPA-runs for the Central Baltic including only 2001 as terminal last year. As input data for 2002 were not available during the meeting, SGMAB decided to run a MSVPA-run including 2002 during the WGBFAS meeting.

Due to the problems with the assessment of the cod stock in the Central Baltic (see Section 3), the MSVPA-run was performed using a preliminary set of settings for the XSA-tuning module for the MSVPA only.

Thus small discrepancies were encountered when comparing single- and multispecies assessments results (see below). An update of the presented MSVPA-run using the settings of the latest XSA-run for Central Baltic cod will be conducted intersessionally by members of SGMAB. Nevertheless MSVAP-derived natural mortalities only marginally deviate from former runs and are available for single-species assessments (Table 4.1).

Due to the problems in the assessment of the cod stock, no multispecies predictions could be performed during the meeting. Extensive medium-term projections were performed by SGMAB and will be further conducted intersessionally.

4.1 MSVPA-run for 1974–2002

The 4M software package (Vinther *et al.*, 2001) was applied to make a MSVPA-run for cod, sprat and herring in the Central Baltic for the period 1974–2002. This run estimates natural mortality for use in the single species assessment WG.

4.2 MSVPA set-up for 1974–2002

Following basic input data have been used for the MSVPA-run:

- catch at age and weight at age in the catch and in the stock for 1974–2000 as outlined in ICES (2001/H:04), data for 2001 were taken from ICES (2002/ACFM:17) and for 2002 from newly compiled international data
- quarterly cod stomach content data (1977–93) by Subdivision as revised previously (ICES 1997/J:2), intra-cohort cannibalism of cod was excluded by changing prey age to predator age minus 1 and omitting cod in 0-group cod stomachs,
- maturity ogives for cod in different Subdivisions represent averages over the periods 1980–84 (applied also prior 1980), 1985–89, 1990–94 and annual data for 1995–99 for combined sexes as presented in single species assessment (ICES 1998/ACFM:16; ICES 2000/ACFM:14), and for 2000 to 2002 an average over the years 1997–1999 as utilized by the Assessment WG (ICES 2002/ACFM:17); for herring maturity ogives were used as given in ICES (1998/ACFM:16) being constant over the entire period, suitability sub-model as introduced in ICES (1992/Assess:7), for sprat maturity ogives were used as given in ICES (2002/ACFM:17)
- quarterly consumption rates for cod as revised in ICES (2001/H:04),
- residual mortalities of 0.2 per year, equally distributed over quarters,
- a constant biomass of other food,
- oldest age-groups in the analyses were: 8+ for cod, 8+ for herring and 7 for sprat.

The terminal F-tuning of MSVPA was performed with the new 4M-programme routine developed and implemented iteratively running XSAs and MSVPAs (Vinther, 2001). XSA settings were identical to the ones used in assessment runs by Baltic Fisheries Assessment Working Group (ICES 2002/ACFM:17). Fishing mortalities in the terminal year for the 0-groups (and the 1-group for cod) are not estimated in the XSA tuning and values were given such that the final estimated MSVPA stock numbers for herring and sprat were close to the average values estimated in period 1999–2001. For cod the terminal F were derived by relating the BITS abundance index for age-group 2 to the earlier MSVPA output.

4.3 Results of the preliminary MSVPA-run for 1974–2002

Cod

The main results of the MSVPA key-run for the Central Baltic are given in summary Figures 4.1–4.3. The spawning stock biomass of Eastern Baltic cod derived by the MSVPA run shows a pronounced increase from 1977 to 1980, remaining on a high level during the first half of the 1980s, afterwards declining to a low level in 1992, showing a restricted intermediate increase in the mid 1990s being presently on the historic minimum. This is well in agreement with the respective estimates from single species VPA (see Figure 4.4). Higher deviations between standard and multispecies SSB estimates are obvious for the beginning of the 1980s. These differences are caused by lower mean weight at age in the stock applied in the MSVPA runs, as derived stock numbers are rather similar for age-groups 2+. Furthermore, MSVPA runs did not include catch at age from Subdivisions 30 and 31, which were higher in the 1980´s compared to later years. After 1993, when the input data sets deviate only to a minor extent, the estimated biomass values are very well in agreement. Repeating the exercise for recruitment estimates at age 2 showed a good agreement between MSVPA and single species output. A minor deviation occurred in 2001, which is a result of problems in the XSA-settings used for tuning the MSVPA. Fishing mortality rates determined by MSVPA and the standard assessment show similar time patterns, with the single species assessment estimating in general slightly higher values.

Sprat

The estimated spawning stock biomass of sprat showed a pronounced decline from the mid 1970s to the early 1980s, a trend that is slightly less pronounced in the standard assessment (Figure 4.4). In fact the mid 1970s show deviations between both assessments, i.e., in 1974 and 1975 the MSVPA based estimates are considerably higher than the standard XSA output. The subsequent increase of the spawning stock from the late 1980s to historically high levels of around 2 million t in 1997 is shown by both assessments, with the MSVPA estimating slightly higher SSB values. The described deviations between spawning stock biomass values are caused by different weight at age, as determined stock numbers are rather similar from 1977–1999. Deviations in 1974–1976 are in contrast not entirely explained by deviations in weight at age, but by differences in catch at age, being higher in the multispecies database in 1974 and 1975. Correspondingly deviations in sprat recruitment estimates are apparent especially for these early years as well as in the latest years of the time series. Here the MSVPA recruitment is lower compared to the standard assessment. The

MSVPA derived fishing mortality rates follow rather well the general trend in F estimates from the standard XSA, with some higher deviations in the periods 1976–1980 and 1989–1992 as well as in 1999 and 2000.

Herring

Spawning stock biomass estimates of Central Baltic herring derived by the MSVPA key-run show a continuous decline (Figure 4.4), which is however to a large extend caused by reduction in weight at age. Single–species values are generally lower than the MSVPA derived, being a result of the Gulf of Riga herring, presently still incorporated in the MSVPA, while excluded in the single-species assessment. Further a different age-specific weight input between the assessment input data contributed to the discrepancies. Recruitment at age 1 derived by the MSVPA shows a high level in the early 1980s and a declining trend afterwards. Larger deviations between single and multispecies assessment are encountered for the early years of the time-series, which are probably due to the poor data quality in either or one of the time series. The estimated fishing mortality rates obtained from MSVPA and standard assessment are rather similar, with largest deviations in 1978 and 1979, as well as in 1999 to 2002.

Natural mortalities

Predation mortalities of 0-, 1- and 2-group cod (Figure 4.5) are in the same order of magnitude than derived by earlier MSVPA runs. The intensity of cannibalism on 0-group cod in 1974–1976, is somewhat astonishing, as the predator abundance is considerably lower than in early 1980s. Estimated predation mortalities of 1- and 2-group cod follow more closely the development of the predator stock size. Predation mortalities of sprat showed a continuous decline from mid 1970s to early 1990s being rather constant afterwards. Predation mortalities of herring follow closely the time trend described for sprat. However, a substantial difference between the species is, that predation mortalities of adult herring is very low, reaching seldom 0.1 per year.

Natural mortalities estimated by MSVPA are routinely used in the single assessment. The values estimated by the last iteration of the multispecies tuning are presented in Tables 4.1–4.3.

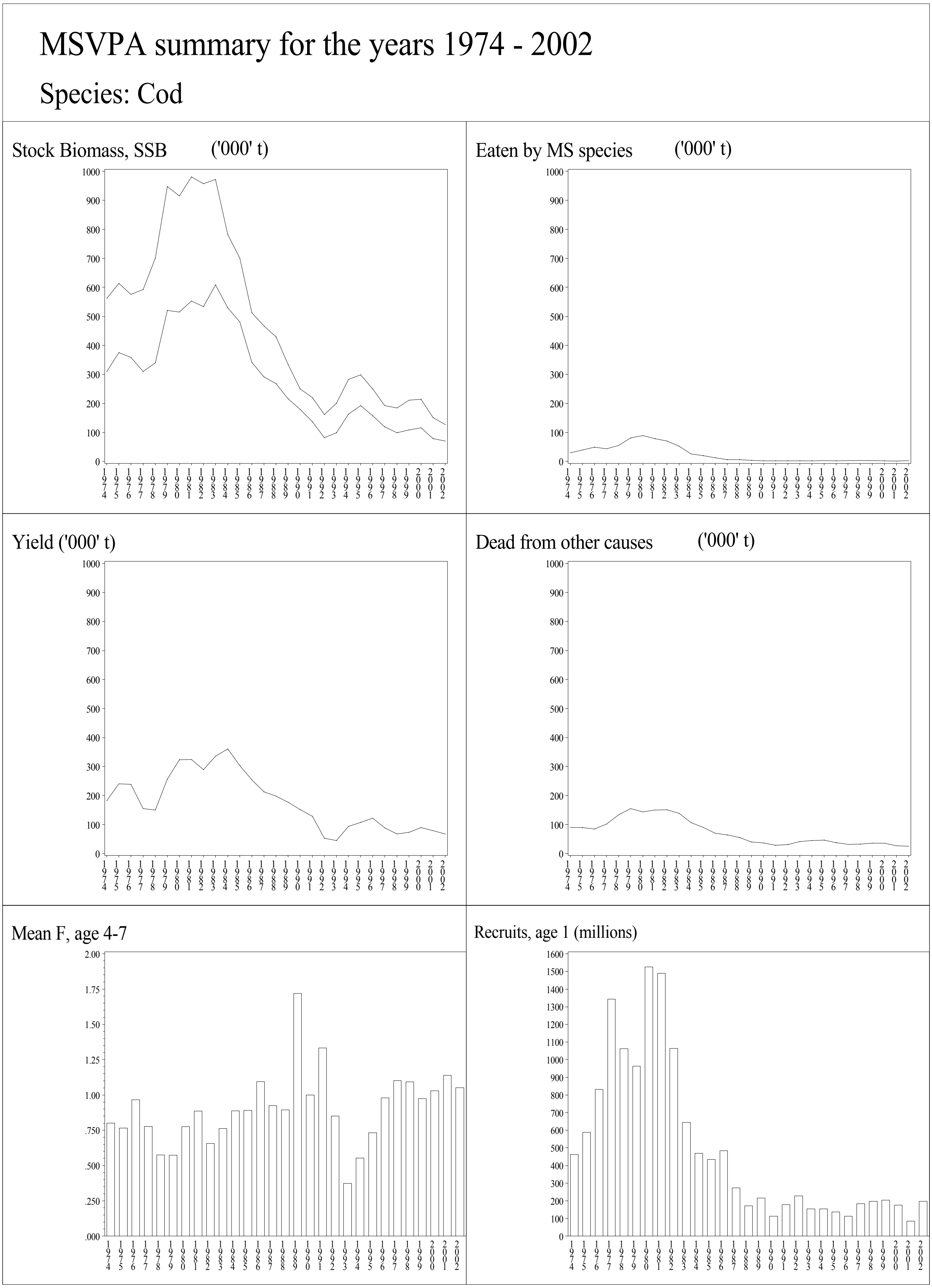

Figure 4.1. MSVPA-run summary for cod.

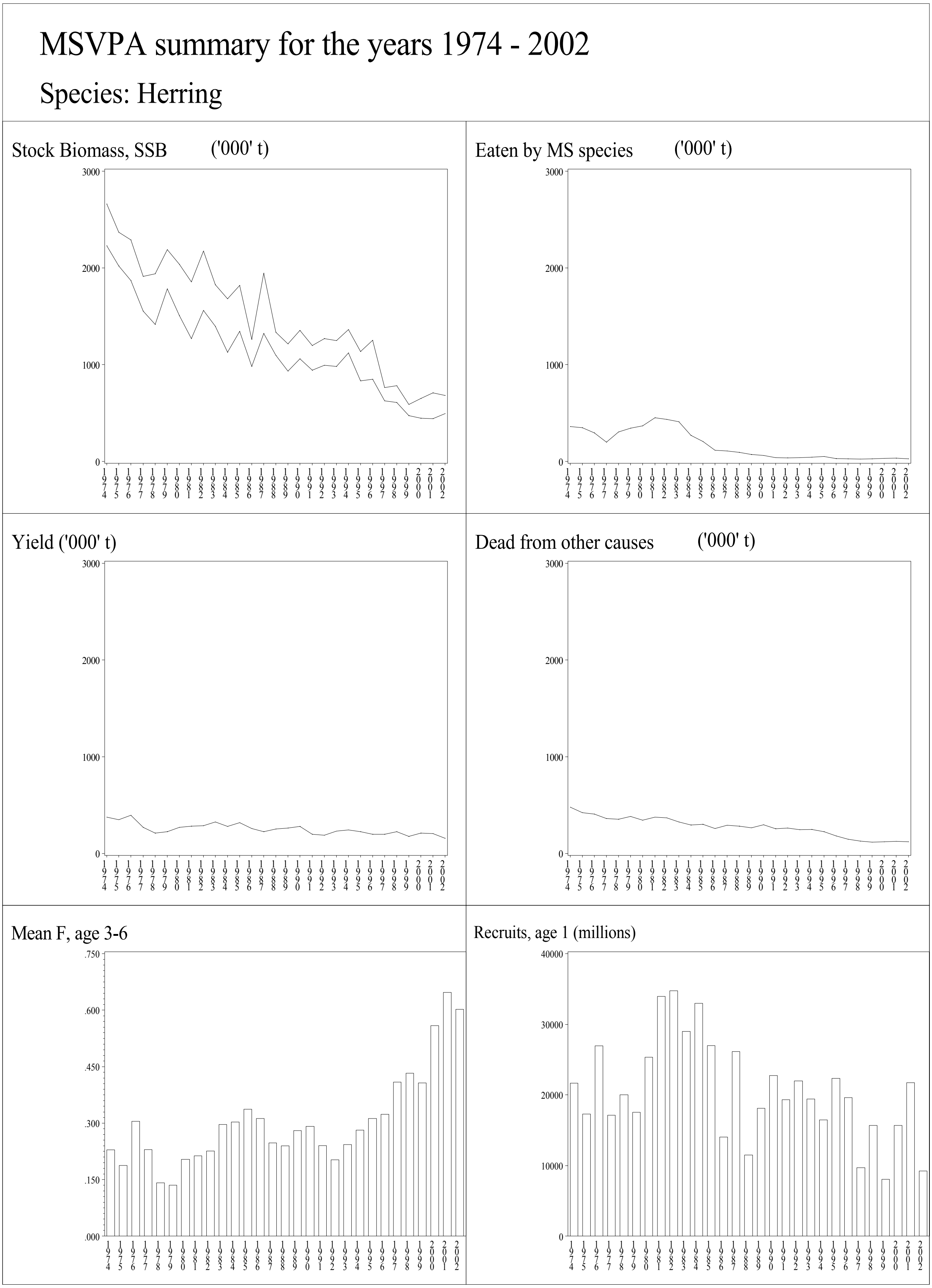

Figure 4.2. MSVPA-run summary for herring.

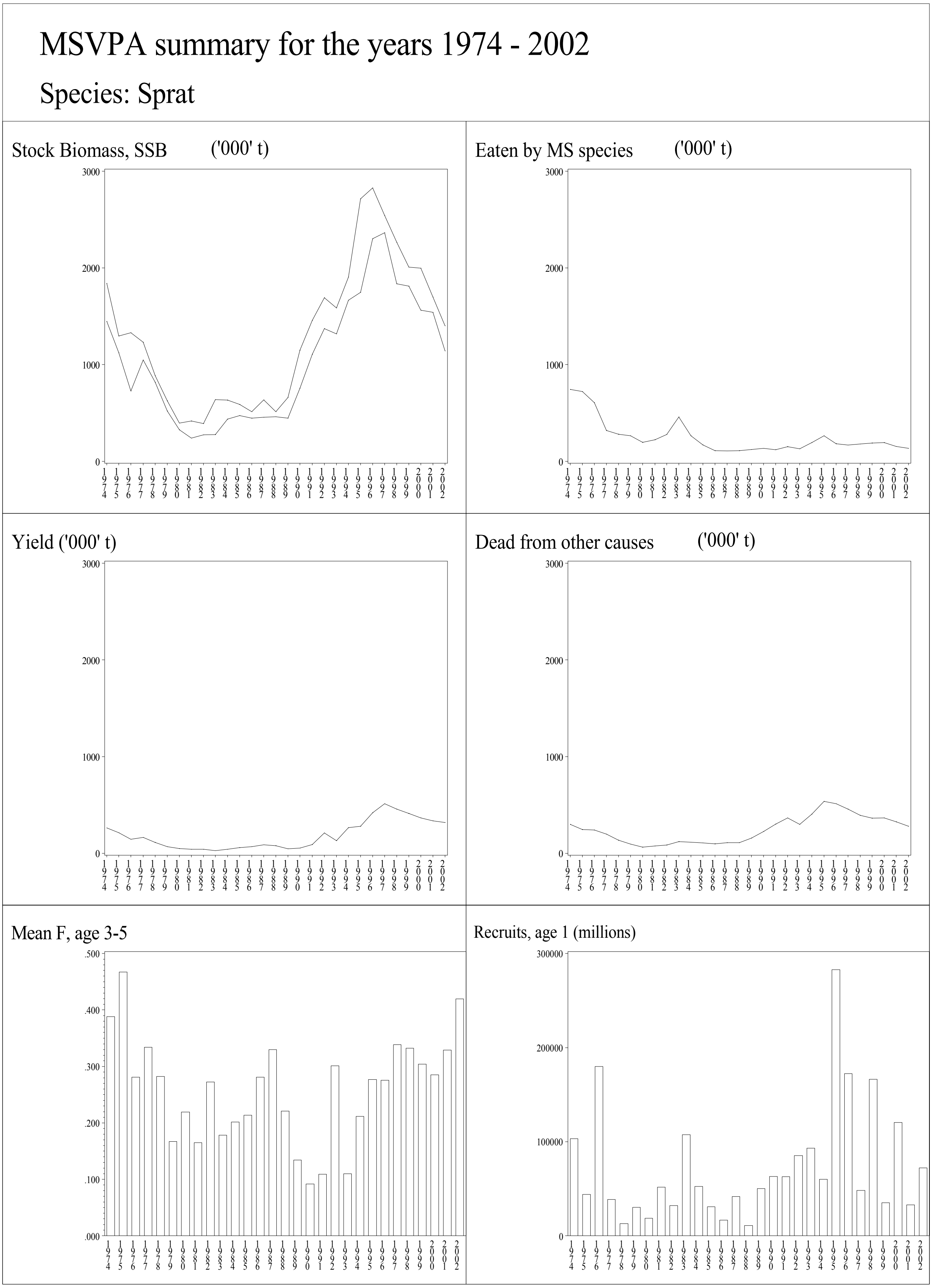

Figure 4.3. MSVPA-run summary for sprat.

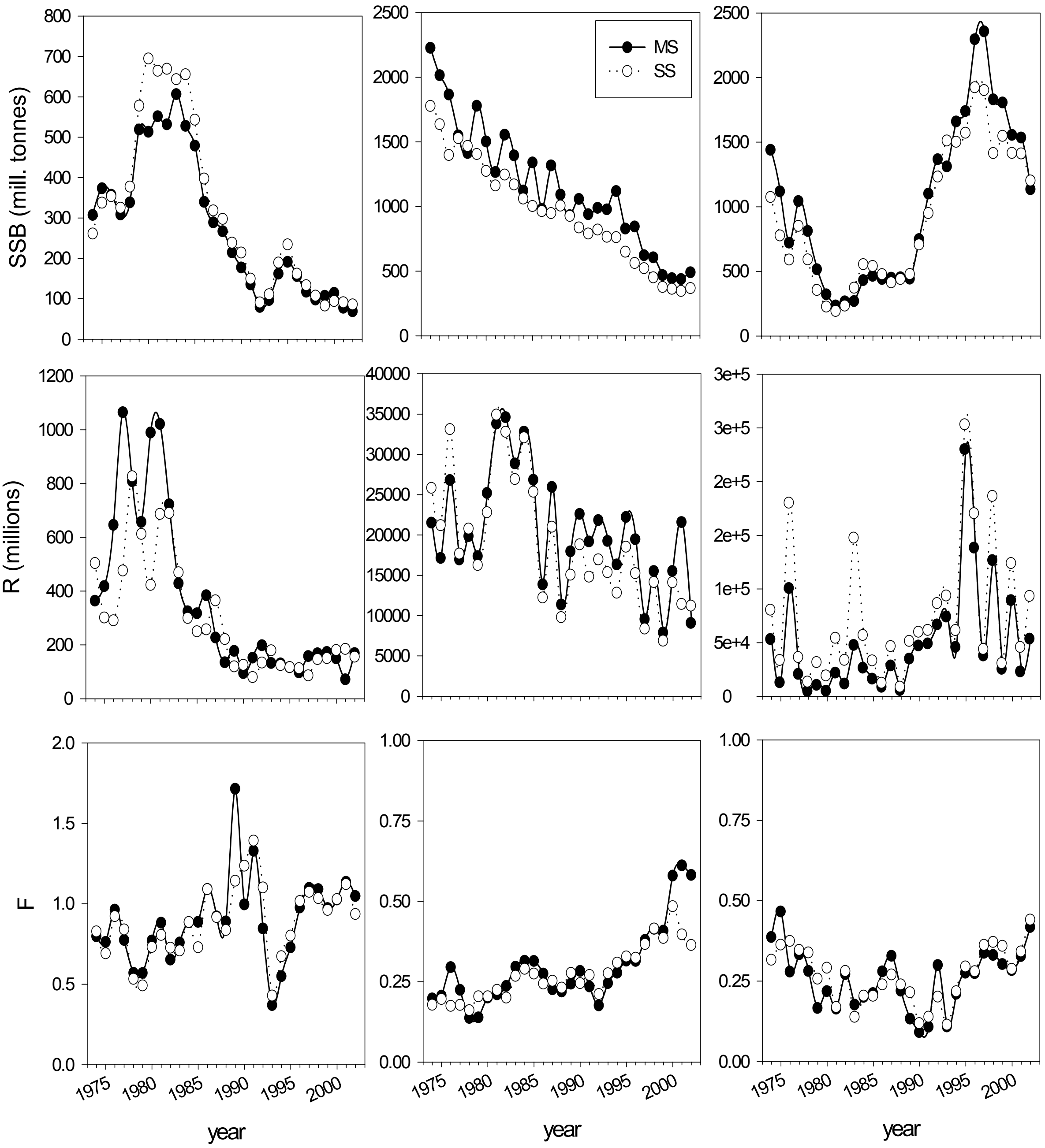

Figure 4.4. Comparison of multispecies (MS) and single-species assessments (SS) of cod (left column), sprat (middle column) and herring (right column). R – recruitment age 1 in 1 st quarter for sprat and herring, age 2 for cod; annual F ages 3–5 for sprat and herring, ages 4–7 for cod.

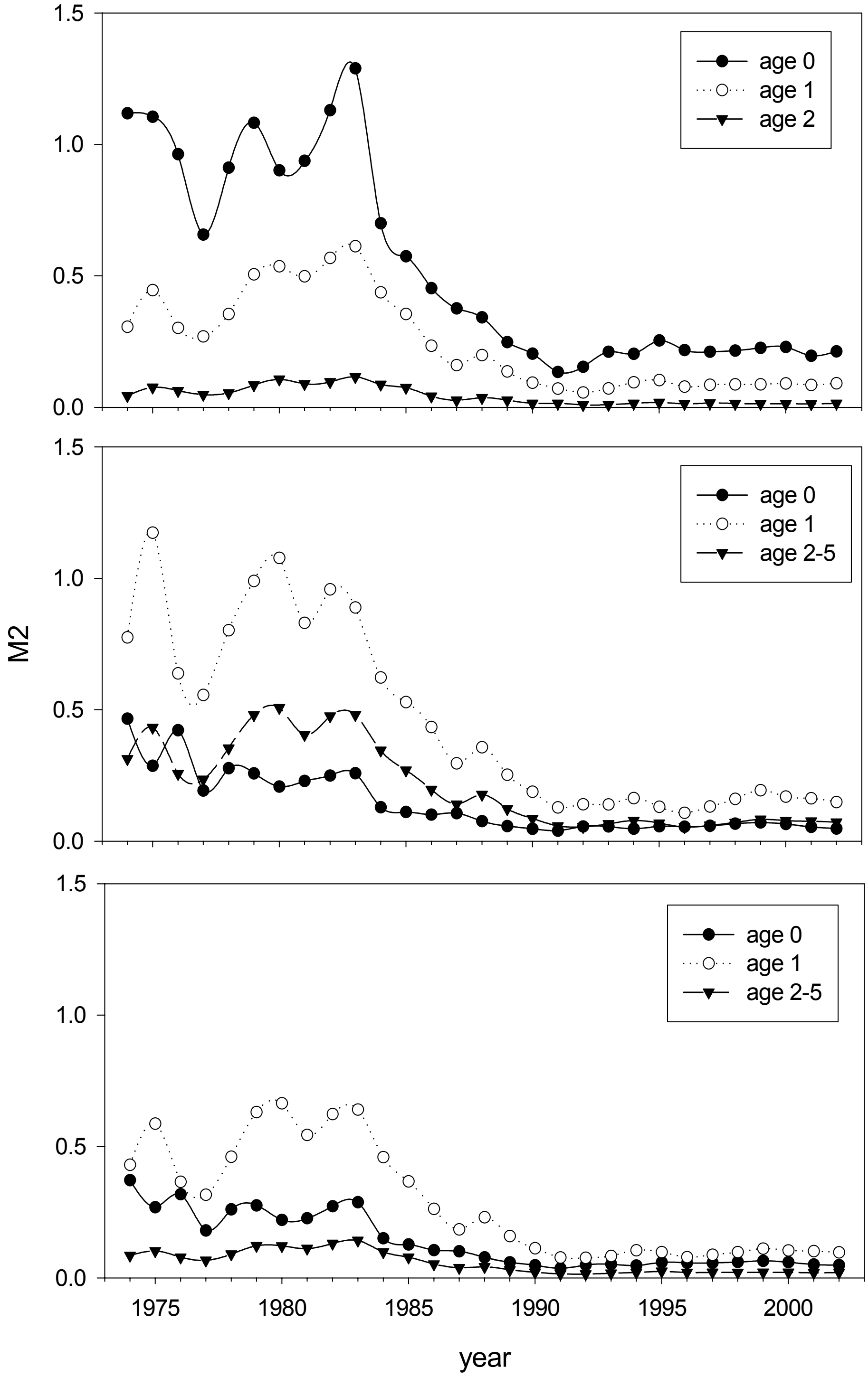

Figure 4.5. MSVPA-derived annual predation mortalities of cod (upper panel), sprat (middle panel) and herring (lower panel).

Table 4.1. Annual M2 for cod in the Central Baltic.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5
1974	1.1186	0.3064	0.0437	0.0044	0.0007	0.0000
1975	1.1055	0.4453	0.0758	0.0086	0.0014	0.0001
1976	0.9631	0.3021	0.0627	0.0085	0.0017	0.0001
1977	0.6571	0.2695	0.0481	0.0061	0.0011	0.0001
1978	0.9119	0.3547	0.0546	0.0063	0.0011	0.0001
1979	1.0825	0.5061	0.0845	0.0095	0.0016	0.0001
1980	0.9012	0.5364	0.1062	0.0127	0.0020	0.0001
1981	0.9374	0.4980	0.0891	0.0121	0.0023	0.0001
1982	1.1301	0.5678	0.0966	0.0122	0.0023	0.0002
1983	1.2892	0.6128	0.1160	0.0150	0.0028	0.0002
1984	0.6999	0.4371	0.0864	0.0125	0.0024	0.0002
1985	0.5745	0.3545	0.0744	0.0109	0.0022	0.0001
1986	0.4534	0.2338	0.0416	0.0050	0.0009	0.0001
1987	0.3760	0.1602	0.0268	0.0038	0.0008	0.0001
1988	0.3419	0.1985	0.0361	0.0049	0.0010	0.0001
1989	0.2478	0.1359	0.0267	0.0039	0.0008	0.0001
1990	0.2039	0.0939	0.0152	0.0016	0.0003	0.0000
1991	0.1345	0.0710	0.0151	0.0025	0.0006	0.0000
1992	0.1538	0.0563	0.0091	0.0009	0.0001	0.0000
1993	0.2112	0.0716	0.0100	0.0011	0.0002	0.0000
1994	0.2038	0.0949	0.0151	0.0018	0.0003	0.0000
1995	0.2540	0.1032	0.0181	0.0023	0.0004	0.0000
1996	0.2173	0.0786	0.0135	0.0015	0.0002	0.0000
1997	0.2111	0.0853	0.0161	0.0021	0.0004	0.0000
1998	0.2159	0.0872	0.0144	0.0019	0.0004	0.0000
1999	0.2259	0.0874	0.0136	0.0016	0.0003	0.0000
2000	0.2294	0.0908	0.0137	0.0016	0.0003	0.0000
2001	0.1961	0.0850	0.0131	0.0015	0.0003	0.0000
2002	0.2125	0.0913	0.0151	0.0019	0.0004	0.0000

Table 4.2. Annual M2 for sprat in the Central Baltic.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
1974	0.4656	0.7752	0.3946	0.2735	0.2505	0.3323	0.2889	0.3516
1975	0.2864	1.1736	0.5656	0.3819	0.3358	0.4464	0.4139	0.5082
1976	0.4218	0.6380	0.3304	0.2222	0.1996	0.2735	0.2605	0.3268
1977	0.1923	0.5563	0.2986	0.2158	0.1850	0.2403	0.2345	0.2951
1978	0.2775	0.8021	0.4483	0.3306	0.2786	0.3572	0.3418	0.4166
1979	0.2578	0.9897	0.6072	0.4553	0.3737	0.4839	0.4947	0.5955
1980	0.2077	1.0777	0.6563	0.4860	0.3843	0.5008	0.5493	0.6622
1981	0.2292	0.8306	0.5127	0.3805	0.3174	0.4098	0.4230	0.5238
1982	0.2490	0.9582	0.6003	0.4566	0.3708	0.4736	0.4880	0.6018
1983	0.2580	0.8887	0.5927	0.4411	0.3786	0.5089	0.5082	0.6271
1984	0.1288	0.6225	0.4341	0.3304	0.2695	0.3471	0.3790	0.4686
1985	0.1110	0.5285	0.3400	0.2550	0.2095	0.2735	0.2993	0.3711
1986	0.1007	0.4341	0.2491	0.1828	0.1534	0.1983	0.2003	0.2487
1987	0.1063	0.2959	0.1747	0.1297	0.1123	0.1445	0.1375	0.1706
1988	0.0758	0.3573	0.2242	0.1633	0.1382	0.1810	0.1810	0.2181
1989	0.0571	0.2522	0.1571	0.1160	0.0950	0.1242	0.1290	0.1569
1990	0.0469	0.1874	0.1085	0.0792	0.0673	0.0879	0.0849	0.1035
1991	0.0399	0.1279	0.0729	0.0520	0.0449	0.0590	0.0603	0.0739
1992	0.0559	0.1403	0.0697	0.0508	0.0422	0.0540	0.0546	0.0655
1993	0.0554	0.1393	0.0810	0.0580	0.0527	0.0701	0.0595	0.0741
1994	0.0471	0.1633	0.0985	0.0712	0.0620	0.0821	0.0784	0.0950
1995	0.0560	0.1306	0.0824	0.0613	0.0541	0.0738	0.0734	0.0908
1996	0.0548	0.1073	0.0646	0.0493	0.0424	0.0574	0.0586	0.0720
1997	0.0578	0.1315	0.0739	0.0545	0.0474	0.0634	0.0653	0.0803
1998	0.0664	0.1604	0.0892	0.0641	0.0566	0.0741	0.0708	0.0867
1999	0.0706	0.1935	0.1047	0.0753	0.0656	0.0854	0.0805	0.0970
2000	0.0653	0.1692	0.0973	0.0696	0.0624	0.0824	0.0749	0.0913
2001	0.0541	0.1630	0.0948	0.0681	0.0604	0.0793	0.0740	0.0890
2002	0.0481	0.1486	0.0896	0.0645	0.0566	0.0766	0.0732	0.0888

Table 4.3. Annual M2 for herring in the Central Baltic.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1974	0.3719	0.4304	0.1353	0.0905	0.0581	0.0567	0.0393	0.0340	0.0105
1975	0.2693	0.5874	0.1567	0.1090	0.0730	0.0707	0.0485	0.0417	0.0127
1976	0.3186	0.3658	0.1177	0.0854	0.0573	0.0543	0.0383	0.0322	0.0098
1977	0.1806	0.3164	0.0971	0.0733	0.0500	0.0481	0.0345	0.0284	0.0086
1978	0.2609	0.4608	0.1361	0.0978	0.0649	0.0627	0.0446	0.0371	0.0113
1979	0.2761	0.6309	0.1813	0.1347	0.0897	0.0843	0.0599	0.0492	0.0147
1980	0.2204	0.6646	0.1783	0.1346	0.0905	0.0836	0.0591	0.0483	0.0144
1981	0.2272	0.5438	0.1585	0.1224	0.0853	0.0817	0.0567	0.0463	0.0140
1982	0.2729	0.6233	0.1852	0.1444	0.0999	0.0955	0.0690	0.0556	0.0168
1983	0.2881	0.6405	0.2024	0.1556	0.1080	0.1043	0.0739	0.0615	0.0186
1984	0.1507	0.4594	0.1357	0.1099	0.0772	0.0725	0.0513	0.0407	0.0121
1985	0.1273	0.3675	0.1086	0.0870	0.0612	0.0576	0.0408	0.0328	0.0098
1986	0.1055	0.2626	0.0749	0.0573	0.0396	0.0380	0.0271	0.0222	0.0067
1987	0.1015	0.1846	0.0565	0.0418	0.0285	0.0277	0.0196	0.0161	0.0049
1988	0.0786	0.2309	0.0619	0.0454	0.0312	0.0297	0.0205	0.0169	0.0051
1989	0.0594	0.1589	0.0445	0.0337	0.0230	0.0217	0.0152	0.0124	0.0037
1990	0.0481	0.1124	0.0317	0.0229	0.0156	0.0152	0.0105	0.0089	0.0027
1991	0.0365	0.0778	0.0222	0.0167	0.0116	0.0110	0.0078	0.0064	0.0019
1992	0.0491	0.0762	0.0223	0.0161	0.0106	0.0100	0.0072	0.0060	0.0018
1993	0.0524	0.0837	0.0267	0.0189	0.0129	0.0130	0.0090	0.0078	0.0024
1994	0.0475	0.1053	0.0304	0.0224	0.0155	0.0151	0.0105	0.0088	0.0027
1995	0.0596	0.0983	0.0345	0.0273	0.0193	0.0188	0.0134	0.0112	0.0034
1996	0.0574	0.0791	0.0289	0.0228	0.0157	0.0151	0.0110	0.0092	0.0028
1997	0.0576	0.0878	0.0298	0.0232	0.0160	0.0153	0.0112	0.0092	0.0028
1998	0.0605	0.0983	0.0304	0.0225	0.0155	0.0151	0.0107	0.0089	0.0027
1999	0.0649	0.1115	0.0324	0.0228	0.0151	0.0146	0.0103	0.0087	0.0027
2000	0.0600	0.1047	0.0316	0.0226	0.0155	0.0153	0.0106	0.0090	0.0028
2001	0.0514	0.1020	0.0293	0.0206	0.0139	0.0136	0.0094	0.0080	0.0025
2002	0.0487	0.0977	0.0299	0.0223	0.0155	0.0151	0.0105	0.0089	0.0027

5 STOCK-RECRUITMENT RELATIONSHIP OF COD

5.1 Modified conventional stock-recruitment relationship exercise

For reliable predictions, one of the key relationships is stock-recruitment. The WGMAB considered one possible approach to describe cod recruitment in the eastern Baltic cod stock subdivisions 25–32 on the base of the modified conventional relations “stock – recruitment” with accounting environment factors.

Two hypotheses are essential in this model:

- Parameters of the stock-recruitment relationship are variable in time, and recruitment values generate two formations – high one and low one both with full range of spawning biomass variations (Solari *et. al.,* 1997), (Jarre-Techman *et.al.,* 2000)
- The values of these parameters depends on the environment factors which can be characterized by reproductive volumes and can be described by a smooth function of their value.

The linearized models by Ricker and Beverton-Holt were used. Then parameters of the models can be estimated by rather flexible approach based on application of the generalized linear model (GLM) (MacCullagh, and Nelder, 1989), (O’ Brien,1999) and generalized additive models (Hastie and Tibshirani, 1990), (Gasyukov *et al.,* 2000).

The traditional Ricker’s model (Ricker, 1975) is as follows:

$$R = \alpha \cdot Ssb \cdot \exp(-\beta \cdot Ssb) \qquad (1)$$

while the model by Beverton and Holt (Beverton and Holt, 1957) is

$$R = \alpha \cdot Ssb / (1 + \beta \cdot Ssb) \tag{2}$$

where R - recruitment estimate;
Ssb - spawning biomass;
α and β are unknown parameters of the model.

The linearized model by Ricker has the following form (Hilborn and Walters, 1992)

$$\log(R_y / Ssb_y) = a + \beta_1 \cdot Ssb_y \tag{3}$$

where $a = \log \alpha$,
$\beta_1 = -\beta$.

Assuming the symbols by MacCulagh and Nelder (1989) or (S-Plus, 1999), this model is formulated in GLM terms as following:

$$\eta(\mu) \sim Ssb,$$

where μ is a mean value of R_y / Ssb_y at the level of Ssb_y,
$\eta(\mu)$ is a link function.

For the complete GLM task it is necessary to specify the family of the distribution functions as well as to determine the relation between variance of μ and the value of μ.

The similar equations may be written for Beverton-Holt model:

$$\frac{1}{\mu} = \beta_1 + в \frac{1}{Ssb}, \ \eta(\mu) = 1/\mu \tag{4}$$

and

$$\eta(\mu) \sim \frac{1}{Ssb}.$$

The way to include the environmental variables (V) into the Ricker's model implies the following formulation of the model:

$$R = \alpha \cdot Ssb \cdot \exp(-\beta \cdot Ssb) \cdot \exp(\gamma \cdot v), \tag{5}$$

where γ - constant coefficient.

The respective GLM form is as follows

$$\eta(\mu) \sim Ssb + V. \tag{6}$$

Another way provides the replacement of the constant term of equation (3) with the smooth parametric or non-parametric function of the environmental variables:

$$\eta(\mu) = -1 + f(v) + Ssb \qquad (7)$$

Smoothing sp lines $s(v)$, the function of local-weighted regression loess (S-Plus, 1999), polynomial may be used as such smooth functions.

Beverton-Holt's model with variable coefficients is as follows:

$$\eta(\mu) = -1 + f(v) + b \cdot 1/Ssb \qquad (8)$$

If spare terms are additionally included into equations (7) and (8) they may be pooled with $f(V)$ function. The resulting function will be a smooth function of variable V.

The estimates of cod stocks in subdivisions 25 – 32, obtained by the working Group in April 2000 (ICES, 2000) for the period from 1996 to 1999 has been used in this exercise. The values were estimated with XSA method (Darby, Flatman, 1994) on the basis of age composition of age groups 2 – 8+ catches and abundance indices of age group 2 – 8 bases on the trawling surveys for 1982 – 2000 (Sparholt and Tomkiewicz, 1998).

The following data were used as the environmental indices (reproductive volumes):

- the time series for 1966 – 1996 obtained by Latvian scientists (Latvian estimates) in Bornholm area;
- the time series for 1966 – 1996 obtained by German scientists (Kiel estimates) in Bornholm area;
- the time series for 1966 – 1996 obtained in the southern Gotland Deep.

The description of these indices is presented in MacKenzie *et. al.* (2000) and Jarre–Teichmann *et.al.* (2000).

The exercise based on the model with the mixed effects showed, that it is possible to subdivide the data to two classes: the first one includes years with law values of reproductive volumes, the second one includes mean and high their values. Using the new hypothesis that environment factors in the next year after spawning influents the recruitment gives possibility to subdivide the data to classes the first of which includes data for 1966–1980 years and the second includes 1981–1999 years.

Statistical properties recruitment and spawning biomass estimates from XSA obtained by bootstrap clarified the final version of the Ricker's model in the next form.

For the first class:

$$\begin{aligned} &gam(R/Ssb \sim +1 + poly(V_1, 2) + s(V_2, df = 1) + Ssb, \\ &family = robust(quasi(link = \log, \mathrm{var}iance = mu)), data = ...) \end{aligned} \qquad (9)$$

For the second class

$$\begin{aligned} &gam(R/Ssb \sim +1 + s(V_1, df = 1) + s(V_2, df = 1) + Ssb, \\ &family = robust(quasi(link = \log, \mathrm{var}iance = mu)), data = ...) \end{aligned} \qquad (10)$$

In these equations V_1 is the reproductive volume in the spawning year, V_2 - the same parameter in the year next to the spawning. Introduction of non – parametric components into the model is significant. ANOVA shows that the values of reproductive volumes in the next year after spawning significantly improve both models. Standard deviation between "observed" (XSA) recruitment values and those calculated with model (9) for the first class amounts to 77.1*10^3 (124.0*10^3 in the traditional model) and for the second class – 32.1*10^3 (49.2*10^3 in the traditional model).

The same presentation for the Beverton – Holt's model has the next form.

For the first class

$$gam(\frac{1}{R} \sim +1 + poly(V_1,2) + s(V_2, df = 1) + \frac{1}{Ssb},$$
$$family == robust(quasi(link = \log, \text{var}iance = mu)),$$
$$data = ...) \qquad (11)$$

For the second class

$$gam(1/R \sim +1 + S(V_1, df = 1) + S(V_2, df = 2) + 1/Ssb,$$
$$family == robust(quasi(link = \log, \text{var}iance = mu)),$$
$$data = ...) \qquad (12)$$

That Beverton–Holt's classical model describes recruitment dynamics worse that Ricker's model: the standard deviation amounted to 397.7*10^3 (124.0*10^3) in the first class and 143.6*10^3 (49.2*10^3) in the second class (in brackets is shown Ricker's model estimate). The accuracy of estimates accounting the reproductive volumes is slightly lower: 80.0*10^3 (77.1*10^3) – in the first class; 48.9*10^3 (32.1*10^3) – in the second class.

The main result of this exercise are models (9) and (10) for eastern Baltic cod stock assessment and recruitment estimation using reproductive volumes. The result of the latter (10) application is comparable to the accuracy of estimates obtained on the basis of eggs production (Jarre-Teichmann, *et al*. 2000).

One of probable applications of the model is specification of recruitment and the younger age groups abundance estimated for 2 – 3 last years. According to bootstrap estimations these values are characterized with the coefficient of variance more than twice exceeding those for other fishing years. The estimates may be made more precise using "shrinkage" procedure by means of averaging two values with different weights for each year: XSA estimate of age group 2 abundance with weight multiplier estimated by a standard error obtained using bootstrap or delta – method and recruitment estimate and its standard error, obtained using the model (9) and (10). This in its turn, will allow to specify the abundance estimates of age – groups 2 and 3 for the first year after the terminal one.

There are also other possibilities for application of the above model. One possibility may be that, the value of the recruitment in one or two projection years is adjusted if there is new information on reproductive volume during standard spring survey and then developed a method to calculate and estimate reproductive volumes for summer months.

6 LONG-TERM FORECASTS FOR COD, HERRING AND SPRAT

The 4M forecast software was used to evaluate different scenarios. For all scenarios the mean weight in the sea, the residual natural mortalities and food rations were kept constant in the prediction and derived from the average values for 1995–2001 from the key run. Stochastic recruitment was estimated from the key-run for 1974–2001.For eastern Baltic cod, the following input values and parameters were used for 2002–2031:

1) F *status quo*
2) Food suitabilities were estimated from MSVPA using stomach data from the period 1984–1993.
3) Default settings:
    - Mean weight in the sea, residual natural mortalities and rations were average values from 1995–2001 and they were kept constant in the predictions
    - Exploitation pattern was taken as average for 1999–2001
    - F level was taken as average for 1999–2001
    - Recruits as log-normal using cod data for 1982–1999 year classes (poor recruitment phase)
4) Stock-recruitment relationship:

    Ricker, Sprat 1974–1999 (modified to maximum recruitment at 2 million tons)

Ricker, Herring1974–1999

5) Food suitabilities were estimated from VPA runs with stomach data 1984–93 (bad environment phase)

6) Initial stock numbers for prediction were taken from the key-run for 1974–2001

For predictions, the following scenarios were considered:

Scenario 1. Fsq:

All defaults were used

Scenario 2. Fpa

F-level taken as Fpa:

cod:	0.60 (age groups 4–7)
herring	0.19 (age groups 3–7)
sprat	0.40 (age groups 3–5)

Scenario 3. Improved cod exploitation pattern and change in minimum landing size

In this scenario we assumed improved cod exploitation pattern to be caused by BACOMA selection panel and associated minimum landing size change from 35 cm to 38 cm (implemented 01.01.2003) according to IBSFC resolution.

For cod, improved exploitation pattern of Fpa:

Age group	**F**
2	0.029
3	0.225
4	0.301
5	0.672
6	0.597
7	0.829
8	0.832
Fbar (4–7):	0.599

Scenario 4. Improved cod exploitation pattern and F½pa for cod and sprat

Exploitation pattern for cod as in 3)
F level cod and sprat: Fpa*0.5
F level herring: Fpa

Scenario 5. Improved cod exploitation pattern and Fpa all species

Exploitation pattern for cod as in 3)
F level all species: Fpa

The results of long-term simulations are given in Figures 6.1–6.5.

The results show that continuing with *status quo* fisheries, cod SSB will remain well below Bpa and only slightly above Blim in the long-term. Baltic herring SSB will decrease very much to a level of 120, 000 tonnes and there will no be any sustainable fishing possibilities in the future. However, because of low abundance of cod stock, sprat SSB will increase above 750 000 tonnes in the long term (Figure 6.1).

Fpa forecast (Figure 6.2) indicates that especially Baltic herring stock will benefit and SSB will increase to about 1 million tonnes in the long term. Cod stock does not show, however any sign of recovery on this option.

Improving cod exploitation pattern by decreasing fishing mortality especially in age groups 2 and 3 and increasing minimum landing size to 38 cm and keeping fishing mortality at Fpa for cod and Fsq for herring and sprat, does not help either cod stock to recover and there is high probability that cod stock will remain at low level in long term (Figure 6.3).

Using better exploitation pattern for cod and halving fishing mortality for cod and sprat and continuing Fpa for herring, there is high probability that cod stock will increase at or above Bpa in the long term and Baltic herring and sprat will increase well above Bpa. This option eventually mean catch rates about 75, 000–100, 000 tonnes for cod in the long term.

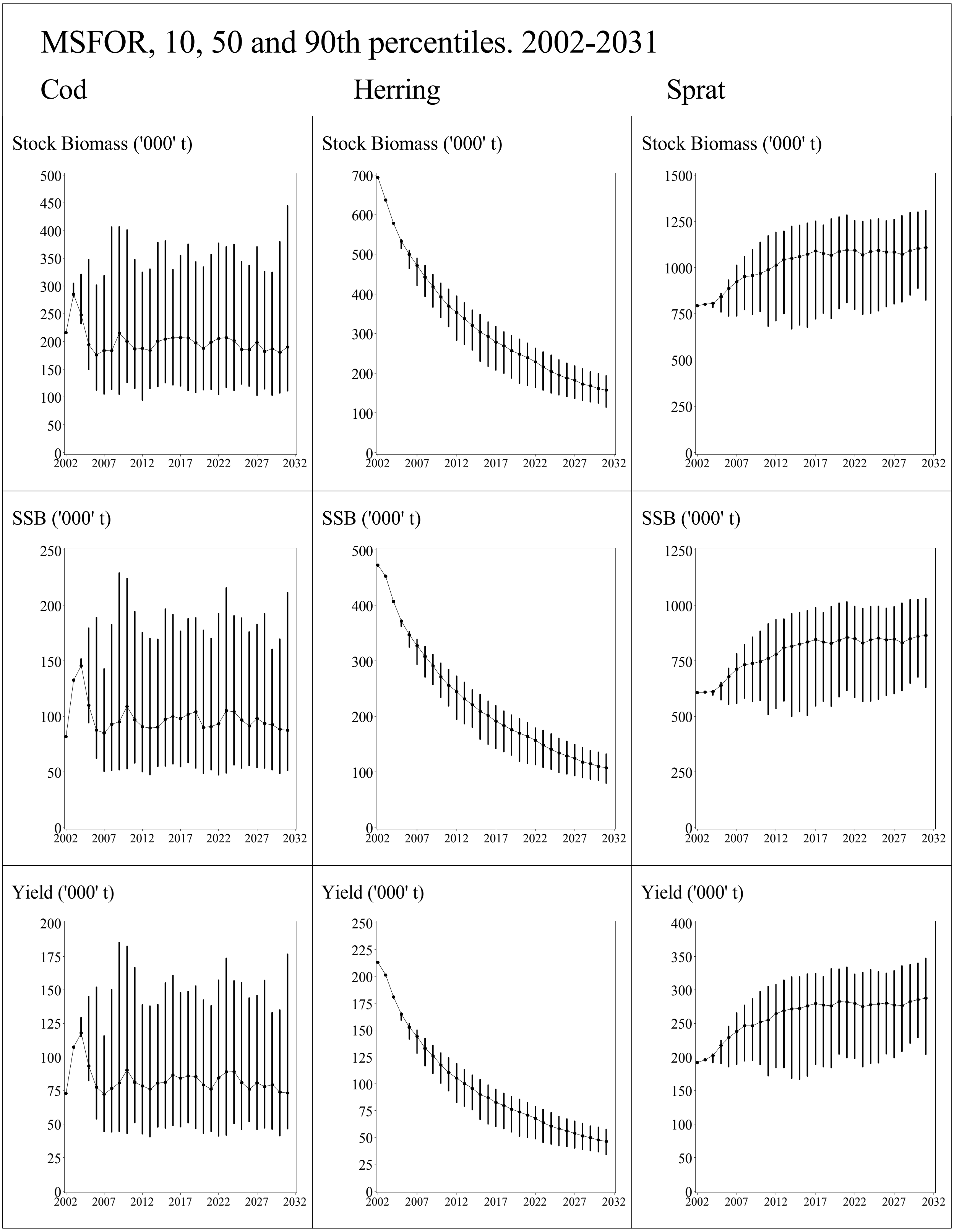

Figure 6.1. *Status quo* forecast.

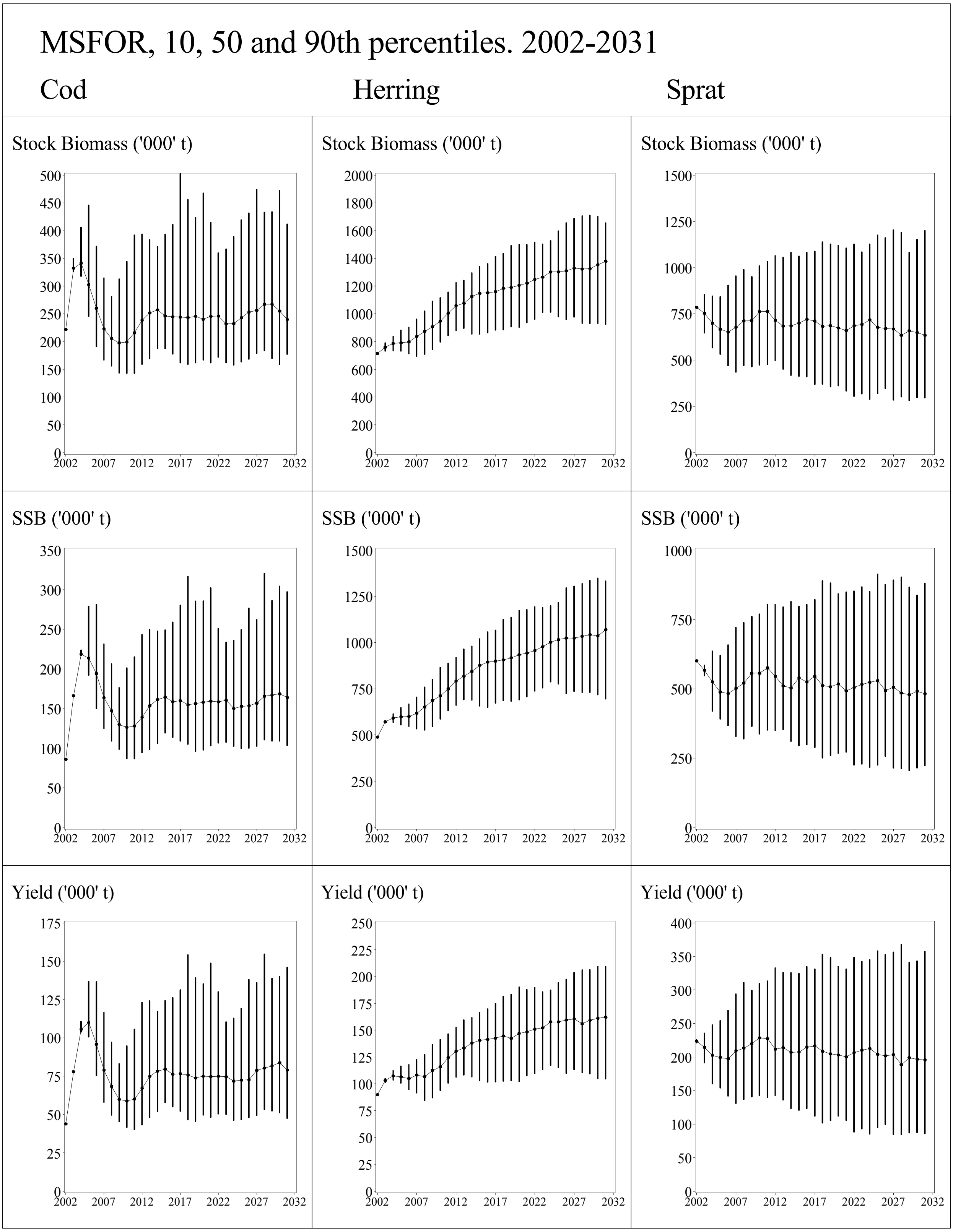

Figure 6.2. Fpa forecast.

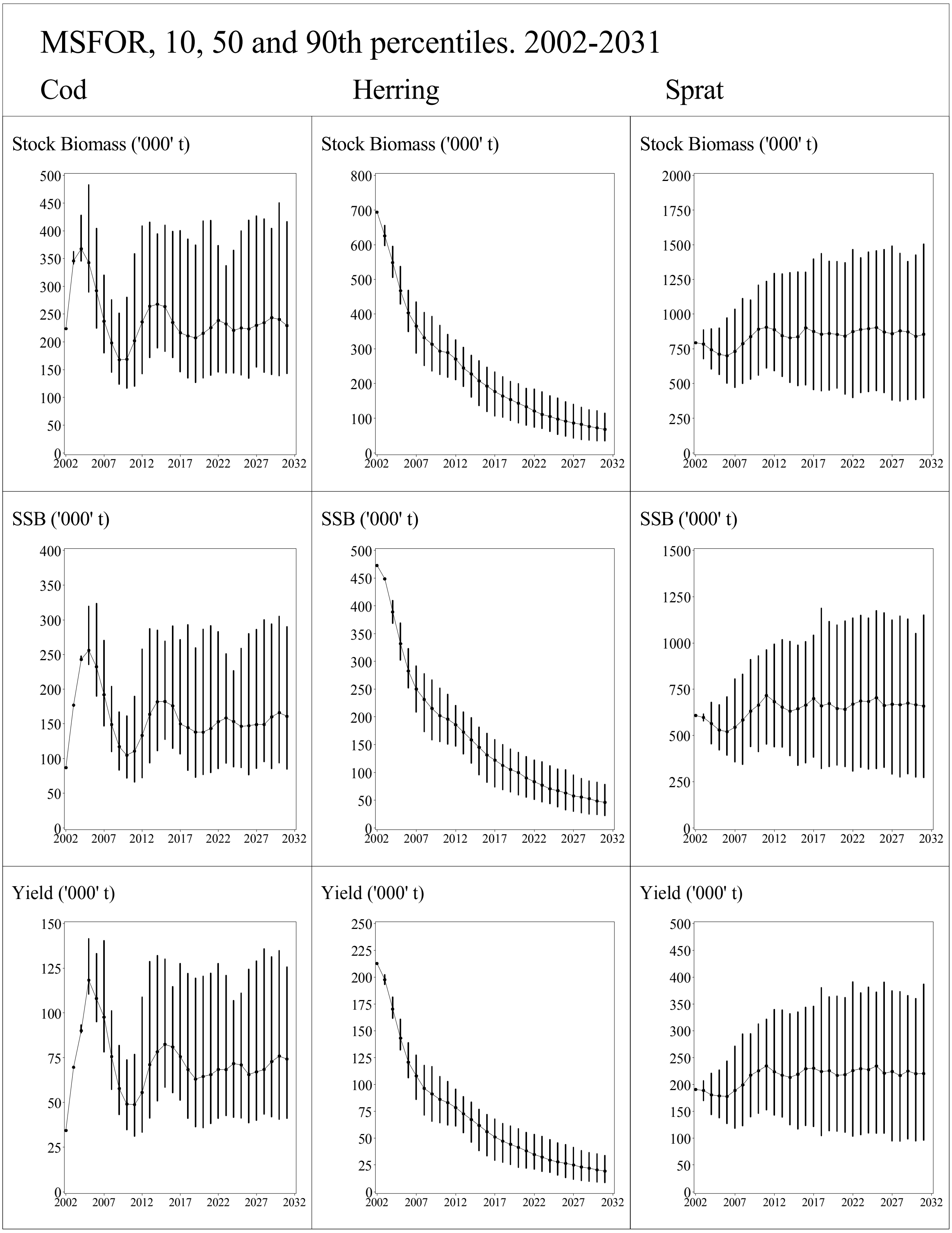

Figure 6.3. Cod improved exploitation pattern, F level=Fpa. *Status quo* F for herring and sprat.

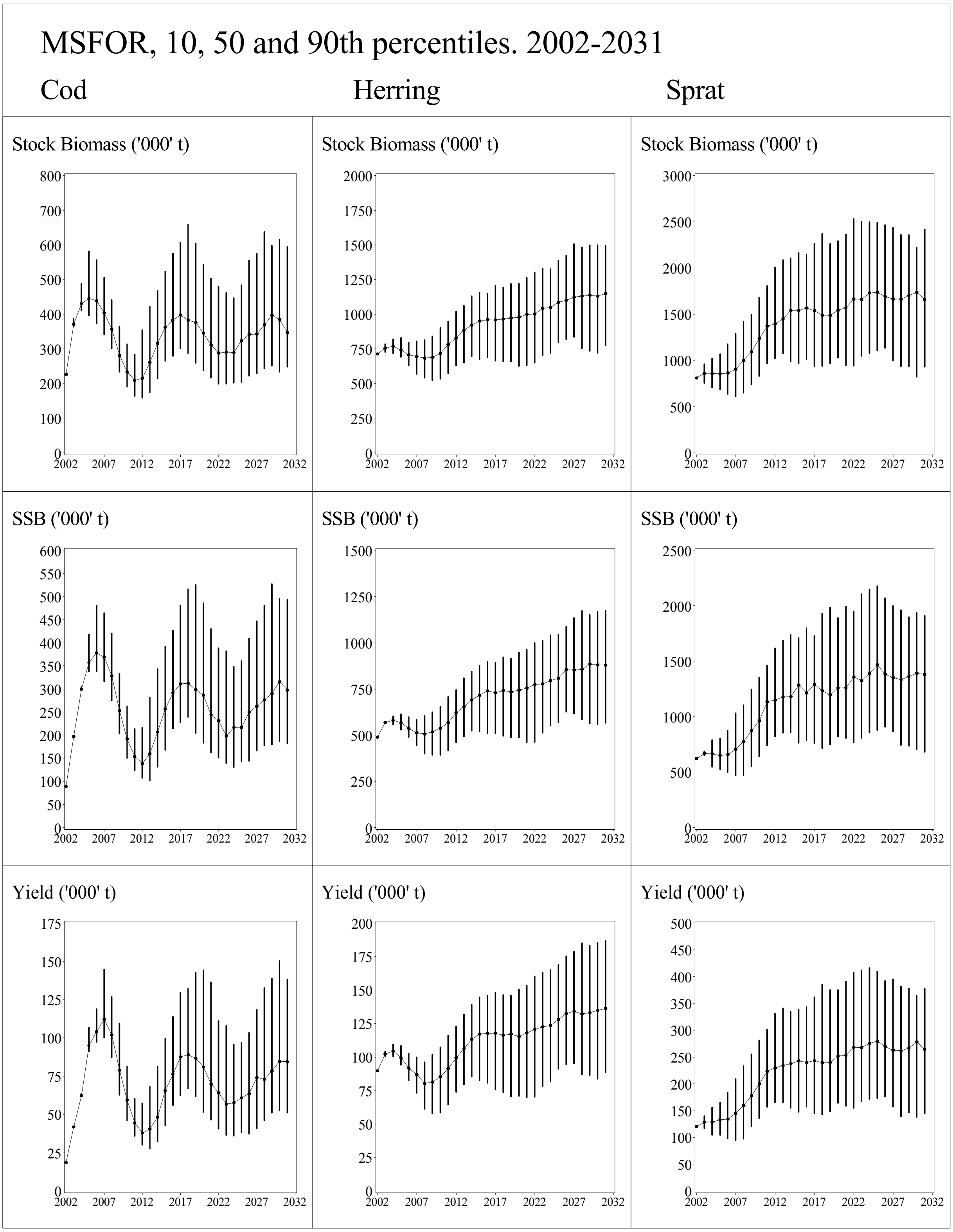

Figure 6.4. Cod improved exploitation pattern, F level= ½ Fpa. Herring F=Fpa. Sprat F=½Fpa.

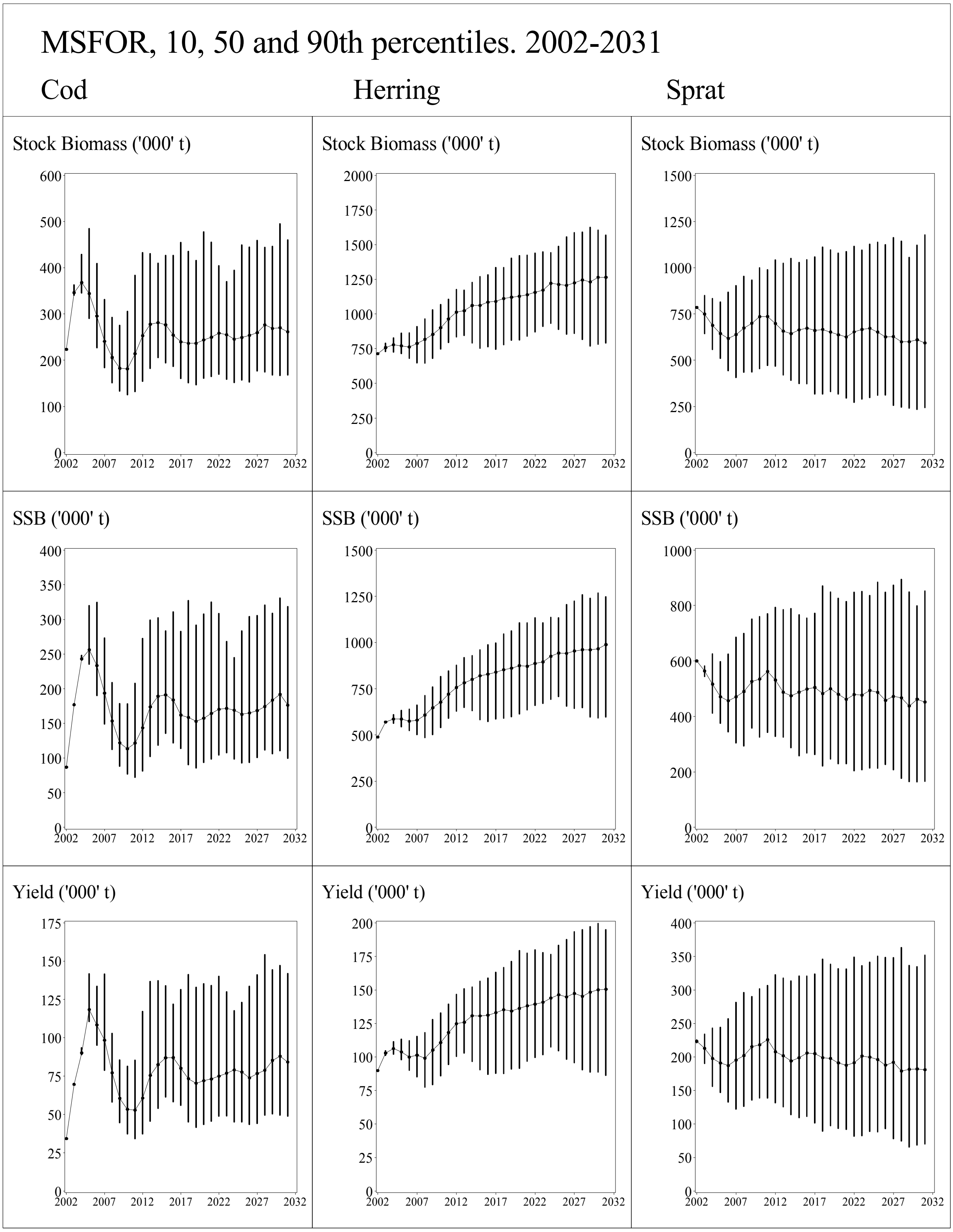

Figure 6.5. Cod improved exploitation pattern, F level= Fpa. Herring F=Fpa. Sprat F=Fpa.

7 LONG-TERM SIMULATIONS AND ENVIRONMENT

7.1 Long-term simulations with environmentally driven cod recruitment

Long-term multispecies simulations were conducted with a spreadsheet prediction model developed by Gislason (1999). The model is based on the MSFOR concept and operates with an annual time step utilizing MSVPA results. The model was modified in two ways: first an environmentally sensitive cod recruitment model was incorporated allowing prediction of cod, sprat and herring stock dynamics in the Central Baltic in dependence of environmental conditions affecting cod recruitment. Secondly, density dependent weight at age for cod were implemented as an alternative to constant weight at age and growth dependent on food availability as implemented by Gislason (1999).

7.2 Stock recruitment relationships

Based on exploratory statistical analysis conducted within the STORE project significant variables influencing survival of cod early life stages and varying systematically among spawning sites were incorporated into stock-recruitment models, first for major cod spawning sites and then combined for the entire Central Baltic. Variables identified included: potential egg production by the spawning stock (Kraus *et al.*, 2002), abiotic conditions affecting survival of eggs (Köster *et al.*, 2001b), prey availability for first feeding larvae (Hinrichsen *et al.*, 2002) and cannibalism on 0- and 1-group specimen, the latter simulated in the traditional MSFOR procedure. Predictions were started for the year 1998 with stock sizes as obtained from the MSVPA, with the female biomass in each year derived from predicted stock sizes, weight at age and maturity ogives (see below). Sex ratios at age were assumed to be constant, calculated as averages over the time period 1977–1997.

To estimate area-specific seasonal potential egg production (PEP) by the spawning stock (Figure 7.1), female SSB according to Subdivision were multiplied by relative individual fecundity values. Utilisation of relative instead of absolute age-specific fecundity is justified by the fact, that this measure is independent of body size in Baltic cod (Kraus *et al.*, 2000) and thus can be applied to the spawning stock without considering the size/age structure. Relative fecundity (PRF) was predicted from a relationship to clupeid prey availability, defined as biomass of sprat and juvenile herring (ages 0–2) per predator biomass in the fourth quarter preceding the spawning season (Kraus *et al.*, 2002):

$PRF_y = \exp(6.23 + 0.02 * P_y)$

with Py being the prey availability index of year y. Relationships between PEP and independent estimates of potential and realised seasonal egg production as obtained from ichthyoplankton surveys in Subdivision 25 were highly significant, indicating that PEP is an accurate measure of egg production (Kraus *et al.*, 2002).

In the predictions, the distribution of the spawning effort in the three Subdivisions is accounted for by a distribution factor D_y determined as follows

$B_{i,y}$ The proportion of the overall spawning stock which spawns in area i in year y

$P_{i,y}$ The relative productivity of spawning in area i in year y.

All of these values are expressed as proportions scaled between 0 and 1. The distribution effect in year y, D_y is then defined as:

$$D_y = \sum_{i=1}^{i=I} B_{i,y} P_{i,y}$$

where I is the total number of areas. The PEP in year y and area i is then obtained by multiplying by D_y. No direct information is available on the historic distribution of the stock between spawning areas at spawning time, but area-disaggregated, multispecies assessments (Köster *et al.*, 2001a) give an approximate measure of the relative size of each of these spawning units. These measures show a pronounced increase with stock decline in Subdivision 25 and a vice versa trend in Subdivision 28, while the corresponding measure in Subdivision 26 is more stable (Table 7.1). By regressing the values for Subdivision 25 and 28 against spawning stock biomass and allocating the remaining proportion to Subdivision 26, relative distributions were predicted in dependence of stock development.

For estimating egg survival rates in relation to variable oxygen conditions, incubation experiments were conducted under controlled temperature conditions within the CORE project. The experimental set-up is described by Wieland *et* *al.* (1994) for the first series of experiments conducted in 1991/1992 and for the second series in 1995–1998 by Rohlf (1999), the latter with a slightly modified experimental set-up utilising a water re-circulation and not a flow through system. In all experiments egg batches from single females caught by trawling in the Bornholm Basin were fertilised by several males. Subsets of these egg batches were incubated at different oxygen concentrations and the viable hatch, i.e., larvae surviving through the yolk-sac stage, were expressed relative to the proportion surviving at normoxic conditions to separate the oxygen effect from other causes of mortality.

To estimate the fraction of cod egg production surviving during main spawning times in each year, in the following called OES (Figure7.2), the predicted vertical distribution of cod eggs in 5 m depth intervals relative to water density (see below) and the oxygen concentration at each depth interval derived from the ICES hydrographic database were coupled to the oxygen concentration/cod egg survival relationship derived from the incubation experiments. To model the vertical distribution of eggs, the observed distribution of the youngest egg stage (IA) obtained from vertically resolving ichthyoplankton sampling in April to July 1986 to 1996 (Wieland and Jarre-Teichmann, 1997) was examined in relation to water density profiles by fitting a parabolic function to the log relative distribution data:

$$\text{LOGe}(IA_z) = a + b * r_z + c * r_z^{\,2}$$

where $\text{LOGe}(IA_z)$ and r_z are the natural logarithm of the relative abundance of stage IA eggs and the water density in the depth interval z, respectively. However, in the Bornholm Basin it has been observed that cod eggs are less buoyant after inflows when higher salinity occurs in the bottom water (Wieland and Jarre-Teichmann, 1997). Hence these hydrographic situations were modelled separately. In order to adjust for this change in buoyancy, we defined inflow situations in the Bornholm Basin by the depth at which the oxygen concentration reached 2 ml * l^{-1} (inflow > 85 m) and by the average salinity within the reproductive volume (stagnation S < 13.5 psu). Furthermore, upon inspection of the data, a seasonal effect in the vertical distribution of cod eggs was detected. Hence, the following yearly hydrographic and spawning situations were defined to group the data: a) stagnation/early spawning, b) stagnation/late spawning, c) inflow/early spawning and d) inflow/late spawning. For both other spawning areas, i.e., Subdivisions 26 and 28, the stagnation scenario was applied throughout, as salinity values never exceeded the threshold set for the Bornholm Basin. However, the shift in spawning time was considered. As the current models do not take into account temperature, also known to affect the vertical distribution (Wieland and Jarre-Teichmann, 1997), a correction was made for low temperatures (< 1.7°C) by transferring the predicted relative abundance of eggs to the next deeper water layer (5 m intervals).

The major prey of first feeding cod larvae in the Baltic are calanoid copepod nauplii, specifically nauplii of *Pseudocalanus elongatus* (Voss *et al.*, 2002; Hinrichsen *et al.*, 2002). However, not only the abundance of nauplii in larval dwelling depths also the capture success define larval feeding intensity. To accommodate for this, the product of nauplii or alternatively *P. elongatus* nauplii abundance at spawning time (e.g., 2nd quarter up 1990 and 3rd quarter 1991–1999) in 25–50 m depths were compiled and multiplied by the turbulent velocity, being a measure of capture success (Figure. 7.3). Age-group 0 recruitment in the different Subdivisions were derived by area dis-aggregated MSVPA runs described above. This early juvenile stage was utilised to minimise the effect of mortalities on later juveniles independent of the hydrographic situation, e.g., cannibalism.

The influence of oxygen concentration on the proportion of viable hatch in relation to the surviving fraction at norm-oxic conditions derived from controlled laboratory experiments showed that oxygen concentrations above the threshold level of 2 ml * l^{-1} utilised in the definition of the RV, still have a pronounced impact on the egg survival (CORE 1998). At about 4 ml O_2/l only half of the egg production survives, while at above 6 ml O_2/l the effect of the oxygen concentration diminishes. In order to apply the fitted sigmoid oxygen – egg survival relationship ($r^2 = 0.95$) to estimate the fraction of the egg production surviving in each spawning season, the vertical distribution of eggs was modelled in relation to the ambient density. The explained variance in the relative distribution of egg stage IA ranged between 72 and 82% for the four environmental scenarios considered, with the least explained variability for the inflow/spring spawning scenario (STORE 2003).

Coupling predicted vertical distributions, measured oxygen concentrations and the laboratory derived survival relationship revealed a time series of oxygen related egg survival fractions (OES) for each Subdivision (Figure 7.2). Clearly egg survival was regularly highest in the Bornholm Basin, though highly variable (10–91%), with the Gdansk Deep and the Gotland Basin sustaining in maximum 16 and 8% egg survival. Obvious are also low egg survival periods, i.e., 1981–1982 and 1986–1990, visible in all areas. This corresponds to results obtained by Hjerne *et al.* (2003) applying experimentally derived egg buoyancies.

Regressing recruitment at age 0 against the potential egg production in Subdivision 25 revealed a significant relationship ($p = 0.031$), however, explaining only 20% of the variance in reproductive success. Utilizing the product of egg production and egg survival factor revealed a substantially improved relationship ($p = 0.003$, $r^2 = 0.33$), with however still large negative residuals in 1983 and 1994–1996 and a positive residual in 1976. In contrast for Subdivision 26 already the potential egg production is highly significantly related to recruitment ($p = 0.0001$, $r2 = 0.52$) and multiplying it with the egg survival factor improves the relationship only slightly ($r^2 = 0.54$). In Subdivision 28, potential egg production explains 62% of the variability in recruitment, while including the oxygen related survival factors reduced the explained variation substantially ($r^2 = 0.42$). Here inclusion of the reproductive volume in a linear multiple regression analysis according to the approach conducted by Köster *et al.* (2001b) behaves better (RV: $p = 0.019$, PEP: $p < 0.0001$, $r^2 = 0.68$).

Introducing additionally the variable prey availability (product of turbulent velocity (T) and *Pseudocalanus* nauplii abundance (P_p) as an additional variable into a multiple linear regression does improve the fit of the model in all areas considerably, SD25: PEP*OES: $p < 0.021$, P_p * T: $p <0.0001$, $r^2 = 0.69$; SD26: PEP*OES: $p < 0.015$, P_p * T: $p = 0.0003$, $r^2 = 0.71$; SD28: PEP*OES: $p < 0.035$, P_p * T: $p = 0.0001$, $r^2 = 0.67$. Utilizing the total nauplii abundance (P_n) instead of the *Pseudocalanus* nauplii abundance improves the multiple regressions models further: SD25: PEP*OES: $p < 0.014$, P_n * T: $p <0.0001$, $r^2 = 0.75$; SD26: PEP*OES: $p < 0.013$, P_n * T: $p = 0.001$, $r^2 = 0.72$; SD28: PEP*OES: $p < 0.006$, P_n * T: $p <0.0001$, $r^2 = 0.71$. Autocorrelation in the residuals was indicated by the DW statistics for SD 26 and 28, while the earlier model including *Pseudocalanus* nauplii revealed no indication of autocorrelation in the residuals. Adding additional physical variables to the relationships, i.e., an area specific upwelling index as a proxy for primary production and the BSI index, as proxy for transport from western to eastern spawning areas, did not improve the explained variance in recruitment, with none of the additional variables being significant. An exception is the egg predation index (Köster *et al.*, 2001b) being a measure of the predation pressure on cod eggs by clupeids, which is significant for Subdivision 25, but does not improve the fit of the model substantially. Based on these exploratory results, following stock recruitment model for the entire Central Baltic was constructed:

$$R_0 = a + b * \sum PEP_i * OES_i + c * T * P_p$$

with:

PEP_i:	Potential egg production in Subdivision i
OES_i:	Oxygen related egg survival fraction in Subdivision i
T:	average turbulent velocity in the Central Baltic during and after peak spawning time
P_p:	prey availability as *Pseudocalanus* nauplii (alternatively total nauplii) per m^3
a, b, c:	regression coefficients

The statistical model is highly significant (PEP*OES: $p = 0.010$, T * P_n: $p <0.0001$, $r^2 = 0.73$) with a slight trend for auto correlated residuals (DW = 1.15) underestimating the recruitment in the beginning of the time series (Figure 7.4) a trend even more pronounced when replacing P_p by P_n (DW = 0.97), though the explained variance is even higher (PEP*OES: $p = 0.008$, T * P_n: $p <0.0001$, $r^2 = 0.76$).

To test the stability of the model to adding/removing new data the first model was refitted to data series encompassing 1976–1995 (removing the most recent period of low recruitment) and 1980–1999 (removing a period of high recruitment 1976–1978, with missing data in 1979). In the first case the model underestimated most recent recruitment, in fact predicting negative recruitment with observed recruitment however being inside the 95% prediction limit of the mean (Figure 7.5). Similarly the second model underestimated recruitment in early years of the time series, a tendency already visible in the model established on basis of the entire time series (at least for 1977 and 1978). This time the observed values are well outside the 95% prediction limits of the mean.

Following the approach by Köster *et al.* (2001b) predicting recruitment for single Subdivisions and then integrating the results, with predicted negative recruitment set to zero is naturally more stable (Figure 7.6), explaining 78% of the variance in recruitment at age 0. Performing the above test shows also that recruitment in the years excluded is predicted better (Figure 7.7). However, observed recruitment values in 1976–1978 are still outside the prediction limits of the mean. Nevertheless, the latter stock recruitment model was used in the performed simulations.

In the presented stock recruitment relationships an oxygen related egg survival factor (OES) replaces the reproductive volume (RV) or the sum of oxygen in the reproductive volume (ORV) utilised before to establish stock recruitment models for cod in the Central Baltic (Sparholt, 1996; Jarre-Teichmann *et al.*, 2000; Köster *et al.*, 2001b). As prerequisite for the development of the OES, the vertical distribution of cod eggs has been predicted for different environmental scenarios, i.e., early and late spawning as well as stagnation and inflow situations. The latter differentiation accounts for the observation that the buoyancy of cod eggs in the Baltic is reduced when ripening of adults and release of eggs takes place at increased salinities (Wieland and Jarre-Teichmann, 1997). A dependence of egg buoyancy on the timing of peak spawning has been described before (Köster *et al.*, 2001b), but is difficult to explain at present. As the deviation between early and late spawning in stagnation periods is rather limited, the classification impacts only on 1993 and 1994, with higher buoyancy than predicted for the scenario inflow/early spawning. An overestimated buoyancy would normally result in an overestimated oxygen related egg survival, however, after inflow events intermediate oxygen minima may occur within the halocline. Exactly this happened in 1993 (Wieland and Jarre-Teichmann, 1997), meaning that the oxygen related egg survival may be underestimated by the applied procedure in this year. In contrast, for 1994 application of both scenarios resulted in rather similar survival rates, as the oxygen concentration was constant in 55–65 m in which 76% of the eggs were floating.

The low survival rates derived for the eastern spawning areas in Subdivisions 26 and 28 are somewhat astonishing. According to the model applied only 6–37% of the eggs produced were able to obtain neutral buoyancy in the Gdansk Deep, while the percentage in the Gotland Basin was higher, i.e., 22–52%, due to the greater depths of the basin. As the hydrographic conditions in the bottom water of the Gotland Basin is less favourable than in the Gdansk Deep this does, however, not translate into a higher egg survival. In the Sub-division 26, survival rates were between 0.3 and 15.5% with on average 4.6%, while the corresponding figures in Subdivision 28 are 0.03–5.6% with an average of 0.7% (Figure 7.2). High abundances of larvae in eastern spawning areas as obtained by ichthyoplankton surveys in the 1970s being in a comparable magnitude than in Subdivision 25, are difficult to explain from the estimated egg production and survival rates. However, the estimated survival rates correspond very well to the survival estimates derived by Hjerne *et al.* (2003), based on experimentally derived female size – egg buoyancy relationships using results also from experiments conducted at Gotland, i.e., in low salinities. Hjerne *et al.* (2003) estimated egg survival rates 0–15% with an average of 2.6% in Subdivision 26 and 0–6.5% and on average 0.7% in Subdivision 28.

As larger females produce on average more buoyant eggs (Nissling and Vallin, 1996), a substantial changes in the spawning stock size/age structure will affect the vertical distribution of cod eggs, a process presently not considered in the applied statistical model. Similarly a potential dependence of egg size on female condition is not considered in the present models. A decline in egg size with continuation of spawning activity has been described for Baltic cod (Vallin and Nissling, 2000) as well as for other cod stocks (e.g., Kjesbu, 1989; Trippel, 1998). First time spawners show in general a decrease of egg size right from the beginning of the spawning activity, while repeat spawners show a parabolic shape in egg size with a peak relatively early in the spawning season (Kjesbu *et al.*, 1996; Vallin and Nissling, 2000). In addition spawning activity of larger females starts earlier than of smaller ones (Baltic: Tomkiewicz and Köster, 1999; other stocks: Kjesbu *et al.*, 1996; Trippel *et al.*, 1997). In the present analyses, the vertical egg distribution was in general sampled in May and in July. In years classified as early spawning situations this represents peak and late spawning activity, while in years classified as late spawning situations, this corresponds to early and peak spawning. This introduces a bias to higher buoyancy in late spawning years, which is however only indicated for the inflow scenario, i.e., 1993 and 1994.

As the specific gravity of cod eggs increases with age, older eggs occur deeper in the water column than younger eggs (Wieland *et al.*, 2000a), but this is obvious from our data only for periods characterised by high salinity (>16 PSU in the bottom water), with the centre of mass of egg stage III being on average 2.3 m deeper than the corresponding depths for stage IA. This implies that the oxygen related egg survival up to stage III may be overestimated in periods of relatively high salinity and pronounced gradients in oxygen concentration, i.e., post-inflow years 1977, 1995 and 1996. When applying the statistical models in other areas of the Baltic, the inflow scenario might be omitted, as salinities above 16 psu are extremely seldom encountered.

Calculation of PEP used in the present analysis assumes that the female spawning stock biomass coupled to observed relative fecundity is an unbiased measure of the actual egg production in the field. This assumption is justified by a high correlation between the production estimate of stage IA cod eggs from ichthyoplankton surveys conducted in Subdivision 25 in 1986–1999 and the corresponding PEP (Kraus *et al.*, 2002). The reason for utilisation of PEP instead of the realised egg production is the restricted time series available for the latter, covering basically only the prolonged stagnation period since mid of the 1980s interrupted by one major Baltic inflow in 1993 (Matthäus and Lass, 1995).

To obtain an indication of the sensitivity of the parameter estimates and the predictive power, the models were re-fitted over different shorter time periods and then model predictions were compared with the excluded year's observations. The exercise clearly demonstrated that the models derived for the different Subdivisions are not sensitive to the exclusion of periods from the parameter estimation procedure. The models were able to capture the trend of high recruitment during the late 1970s and early 1980s relatively well and the low recruitment in the early 1990s very well. However, if observed high recruitment values during the 1970s were excluded from the time series utilized for parameter estimation, a substantial underestimation of recruitment in early years was obvious.

Recruitment was log-normal rather than normally distributed. Thus, multiplicative instead of additive processes may in some of the models be more appropriate (Sparholt 1996). Additionally, established multiplicative models explained more of the variance in recruitment in Subdivision 28. However, the log-transformed model did not exhibit better predictive power and consistently underestimated recruitment at high reproductive success in the beginning of the time series in all areas.

The stock-recruitment models established here explain a considerable part of the variability encountered in cod recruitment in the Baltic Sea. The remaining variability may be due to a number of processes not included in the present exercise such as egg fertilization (Vallin *et al.* 1999) and the influence of parental (age/size structure, condition) on egg and larval characteristics (buoyancy, survival probability, e.g., Marshall *et al.* 1998; Trippel 1998), but also uncertainties in the way variables are assumed to represent processes of interest. A number of potential improvements of the stock-recruitment models are possible through the better resolution of the influences of a number of key variables. Here, the most promising potential candidates are: a) including variations in buoyancy of eggs spawned by first time and repeat spawners (Vallin *et al.* 1999), b) resolving the vertical distribution of cod eggs in relation to oxygen concentration in eastern spawning areas and c) including the effects of hydrodynamic processes on the horizontal and vertical overlap of predator and prey also including cannibalism.

The spatially dis-aggregated approach presented here, allows an investigation of the impact of different stock components on the reproductive success of cod in the Central Baltic. This is a necessary prerequisite for area based fisheries management, i.e., an area closure within the Bornholm Basin during cod spawning time recommended by the International Baltic Sea Fisheries Commission.

Sprat recruitment and herring recruitment were predicted from a Ricker stock and recruitment relationship (Ricker, 1954):

$$N(0,y) = R1\, SSB(y) \exp(-R2\, SSB(y))$$

where $R1$ and $R2$ are species specific constants determined from the recruitment and SSB estimated in the retrospective part of the models. For both clupeids the data contained little information about the shape of the stock recruitment curve. Initial parameter estimates resulted in recruitment maxima far outside the observations and produced unlikely predictions of virgin stock biomass. The parameters were therefore selected so that the maximum of the stock recruitment curve corresponded to the point defined by the average SSB and average recruitment over the period from 1977 to 1995.

7.3 Growth

Weight at age of cod show a considerable increase since the beginning of the 1980s concurrently to decreasing stock sizes (Figure 7.8). Thus, weight at age groups 3 and older were predicted from age-specific relationships between weight and stock size in the year-class in the mid of the preceding year. Outlying values for age group 5–8 in 1992 were excluded from the regressions, being highly significant in all age groups (Figure 7.9), i.e., r^2 between 0.65 and 0.78. An exception is age group 8 explaining less variability ($r^2 = 0.41$). Weight at age 0 to 2 were set constant according to ICES (1999/H:5), reflecting two periods of different levels in weight at age, i.e., 1977–1989 and 1990–1997. As demonstrated by ICES (1999), weight at age in the catch (being the basis of the multispecies weight at age database) is not representative for juvenile weight at age in the stock. Thus, average juvenile weight at age in the stock were applied corresponding to the procedure in ICES (1999/H:5).

Alternatively, the more sophisticated coupling of cod growth and the amount of available food as developed by Gislason (1999) was applied. Weight at age is assumed to equal weight at age in the cohort during the preceding year plus a growth term. The growth term depends on whether the amount of available food in a particular year is above or below the average. Thus, in years where there is more than average food available growth will be faster than average. In years with less food available growth will be slower. Weight at age of cod is thus described by:

$$\overline{w}(a+1, y+1) = \overline{w}(a,y) + \frac{Avail(a,y)}{\overline{Avail(a)}}\left[\overline{\overline{w}_{obs}(a+1)} - \overline{\overline{w}_{obs}(a)}\right]$$

where:

$Avail(a,y)$: Amount of food available to cod age group a in year y
$\overline{w}(a,y)$: Average weight of cod age group a in year y

and

$$\overline{Avail(a)} = \frac{\sum_{y=1}^{ny} Avail(a,y)}{ny}$$

$$\overline{\overline{w}_{obs}(a)} = \frac{\sum_{y=1}^{ny} \overline{w}_{obs}(a,y)}{ny}$$

$\overline{w}_{obs}(a,y)$: Average observed weight at age of cod age group a in year y
ny: Number of years over which the calculations are performed

Food consumption is calculated by assuming constant conversion efficiency at age:

$$R(a,y) = \frac{\overline{w}(a+1,y+1) - \overline{w}(a,y)}{CE(a)}$$

where:

$R(a,y)$: Per capita food consumption of cod age group a in year y
$CE(a)$: Conversion efficiency. Proportion of total food intake that is converted to somatic growth for cod age group a

In a model where growth and food intake depends on the amount of available food, it is inconsistent to assume that the biomass of other food is constant and does not respond to changes in predation. The model was therefore extended by a simple description of the dynamics of other food in which the biomass of other food was made a function of the predator's intake.

The total intake of other food of type b, is calculated by the model from:

$$Cons(*,b,y) = \sum_a Cons(a,y)Food(a,b,y) = \sum_a R(a,y)\overline{N}(a,y)\frac{Suit(a,b)\overline{B}(b,y)}{Avail(a,y)}$$

where

$Food(a,b,y)$: The proportion of other food of type b in the food of cod age group a in year y
$Suit(a,b)$: Suitability of other food of type b to predation by cod age group a
$\overline{N}(a,y)$: Average number of fish alive in age group a during year y
$\overline{B}(b,y)$: Average biomass of other food of type b in year y

The average biomass of other food of type b was assumed to decline exponentially as a function of the amount eaten:

$$\overline{B}(b,y) = \exp\left[K(b) - L(b)Cons(*,b,y)\right]$$

where

$\overline{B}(b,y)$: Average biomass of other food of type b in year y

$K(b)$: Constant expressing the log of the biomass of other food type b when predation is zero, corresponding to the unexploited biomass in a surplus production model

$L(b)$: Constant expressing the amount of change in log biomass of other food per unit of predator consumption

7.4 Maturity ogives

The forecast model takes changes in maturity at age of cod into account by introducing a sigmoid relationship between the proportion mature and body weight:

$$PM(a,y) = (1 - \exp(-PM1 * \overline{w}(a,y)))^{PM2}$$

where $PM1$ and $PM2$ are constants determined by non-linear regression of proportion mature versus observed weights at age. The non-linear regression used to estimate the parameters in the equation describing the proportion mature at age explained 99% of the variance in the data.

7.5 Other input data

The forecasts were run with MSVPA output according to Gislason (1999) covering the period 1977–1997, ensuring comparability of the earlier and new runs with an environmentally sensitive stock recruitment relationship and density dependent growth for cod introduced. Catch at age, terminal fishing mortalities, proportion mature at age, single species total natural mortality and weight at age for herring and sprat for running the MSVPAs and for sprat and herring related input into the predictions were taken from ICES (1997a).

The quarterly values were averaged for each year to produce annual mean weights at age and annual stomach content at age. Consumption rates by cod were estimates via food conversion efficiencies for different age groups as determined by ICES (1992).

In the stomach content database, all food items except cod, herring and sprat are lumped together in one category of Other Food. However, the species composition of this category is not the same for large and small cod. For cod >50 cm (age group 4+) it consists almost exclusively of a large isopod, *Saduria entomon*, while for smaller cod other invertebrates are also included (Sparholt 1994). Initial attempts to model cod growth with only one category of Other food proved unable to describe the changes in the growth of older cod, and it was therefore decided to split Other food into *Saduria* and other invertebrates. First, it was assumed that other food of age 4+ cod contained only *Saduria*. Secondly, for ages 1–3, it was assumed that *Saduria* constituted the same proportion of the diet as for older cod and that the remainder of the Other food category consisted of other invertebrates. In the MSVPA the biomass of *Saduria* was set to 4 million tons and the total amount of 'other invertebrates' to 10 million tons. In the MSVPA modelling growth in dependence of prey availability, these biomasses were used to calculate *K(b)*. In both the MSVPA and MSGVPA alternative biologically plausible values for the biomass of 'other invertebrates' and *Saduria* produced virtually identical results confirming the insensitivity of the models to the input biomass of other food. The observed weight at age for the 0-group and for all age groups in 1977 was used as the starting values in the growth model incorporated in the MSGVPA.

Average suitability coefficients in the two multispecies versions (Gislason and Sparre 1987) were estimated from all available stomach content data in an iterative procedure as explained in Magnusson (1995). The parameters, $L(b)$, used to describe the change in the biomass of invertebrates and *Saduria* in the MSGVPA were estimated by minimizing the sum of squares of deviation between observed and estimated weight at age in the model.

The *status quo* fishing mortality used in the prediction was calculated by rescaling the average exploitation patterns to the fishing mortality in 1996, the last year of the retrospective analysis.

7.6 Identification of future environmental conditions from historic time series

Several data series of variables identified to affect the reproductive success of cod and sprat in the Central Baltic have been established throughout most recent years. These encompass area aggregated data series covering the period 1966–1999 and area dis-aggregated time series for the period 1976–1999 including:

1) Realized egg production and surviving egg production of cod in Subdivision 25 from ichthyoplankton surveys.
2) Egg survival probabilities in relation to hydrographic conditions.
3) Meso-zooplankton abundance according to species and stage resolved for different water layers.
4) Atmospheric forcing conditions, e.g., the BSI and related transport indices for main spawning and post-spawning periods.
5) Measures of small scale turbulence, i.e., turbulent velocities in main depths of larval occurrence.
6) Physical environmental conditions, i.e., average salinity, temperature, oxygen concentration and density profiles according to quarter or main spawning period.
7) Quarterly up-welling and downwelling indices, as measures of production.

Environmental input data for the long-term projections were derived by combining different fragments of the historical time series (2, 3 and 5) representing either extreme events such as major inflows (e.g., as in 1976 or 1993), or more usual hydrographic situations during stagnation (end of the 1980s second half of the 1990s) or inflow periods (e.g., end of the 1970s/beginnging of the 1980s).

7.7 Fisheries management scenarios

In the long-term simulations performed the same F was applied as in the simulations conducted by Gislason (1999) to ensure direct comparability. The average F values were 0.67 for cod, which is considerably lower than the present status-quo F, being only slightly higher than F_{pa} (0.6). For sprat the assumed average F was 0.32, which corresponds well to the average F over the period 1999–2001 (0.33) (ICES 2002/ACFM:17). For herring the assumed F of 0.27 is considerably lower than the average F in the period 1999–2001 (0.44), but higher than F_{PA} (0.17).

7.8 Long-term projection results

Long-term simulation results (yield, SSB, consumption, food composition at the end or the prediction period) obtained by Gislason (1999) applying the traditional MSVPA and the MSGVPA, in which growth depends on the availability of suitable prey biomass, are presented in Figures 7.10 and 7.11. In Figures 7.12 and 7.13 the output of the extended model (with environmentally driven recruitment, growth and maturation process models) is illustrated, assuming unfavourable and favourable environmental scenarios for cod recruitment, respectively. For environmental conditions in 1997–1999 the actual monitored values were applied in both cases, followed by the time series 1984–1999 (unfavourable condition) and 1969–1983 (favourable conditions) repeated up to a prediction period of 43 years.

The first impression when comparing the scenario prediction output is that the difference in cod SSB between poor and favourable environmental conditions is not as pronounced as to be expected, although the scenarios differ in their recruitment estimates. If the implementation is correct, this might indicate that the biological regulation mechanisms (density dependent weight affecting egg production and cod cannibalism) potentially compensate for environmental variability.

In contrast to the original predictions a considerable fluctuation is obvious for all stocks. Under both scenarios, the sprat stock declined drastically within the first prediction years, which corresponds also to the original prediction output of Gislason (1999). However, while sprat recovers to some degree in the original prediction it continues to decline in the new runs, with a crash after 10 years in the prediction with good environmental conditions for cod recruitment. Herring behaves more stable in the predictions, but a significant decline is obvious for the high cod stock scenario. Here the decline is clearly coupled to an increase in predator abundance and consumption (Figure 7.13).

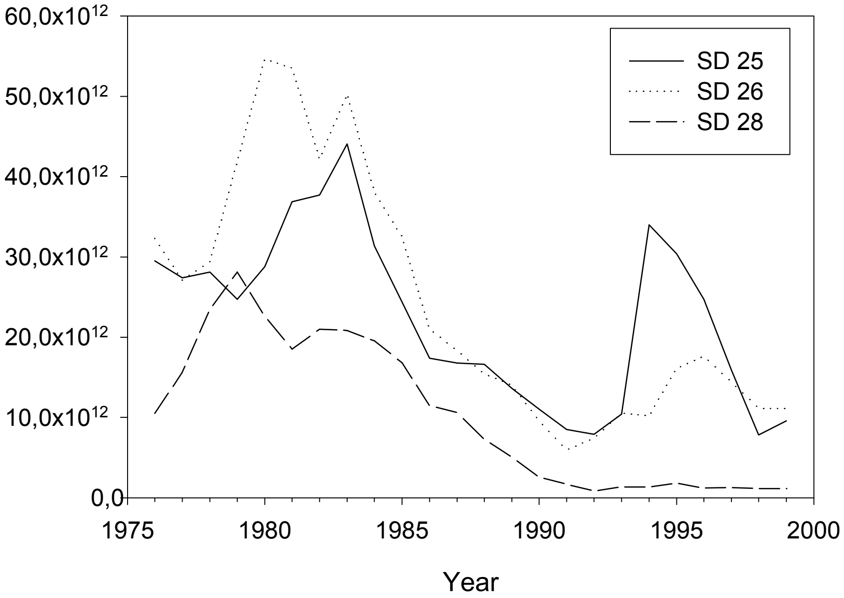

Figure 7.1. Potential egg production by cod in Subdivision 25, 26 and 28.

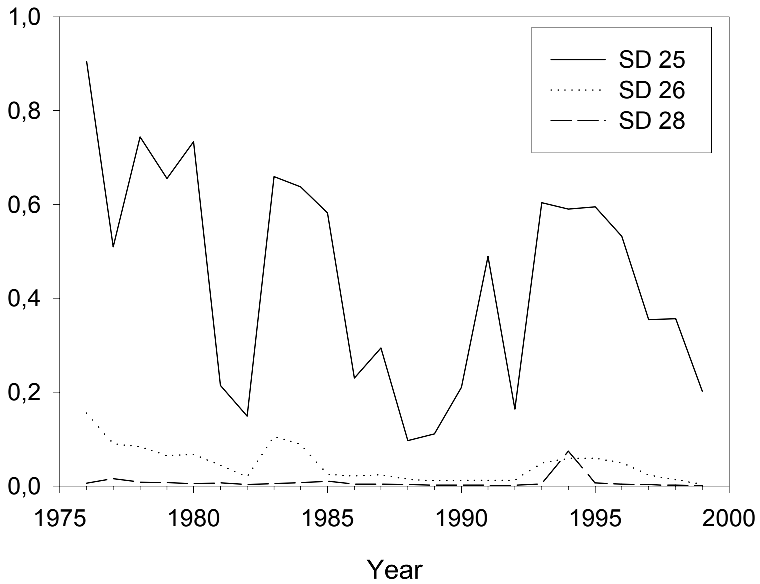

Figure 7.2. Oxygen related cod egg survival factor (OES) in Subdivision 25, 26 and 28.

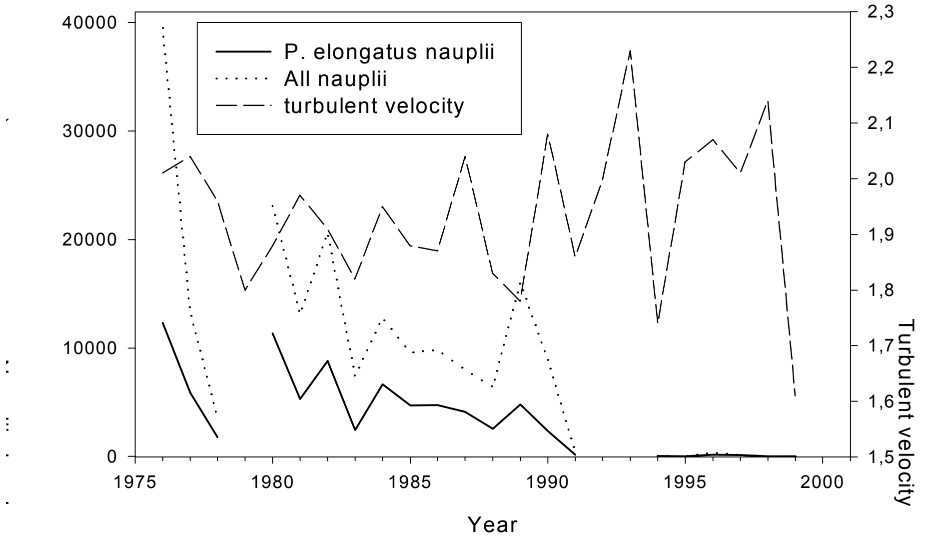

Figure 7.3. Time series of copepod nauplii and *P. elongatus* nauplii abundance at spawning time and turbulent velocity in the Central Baltic.

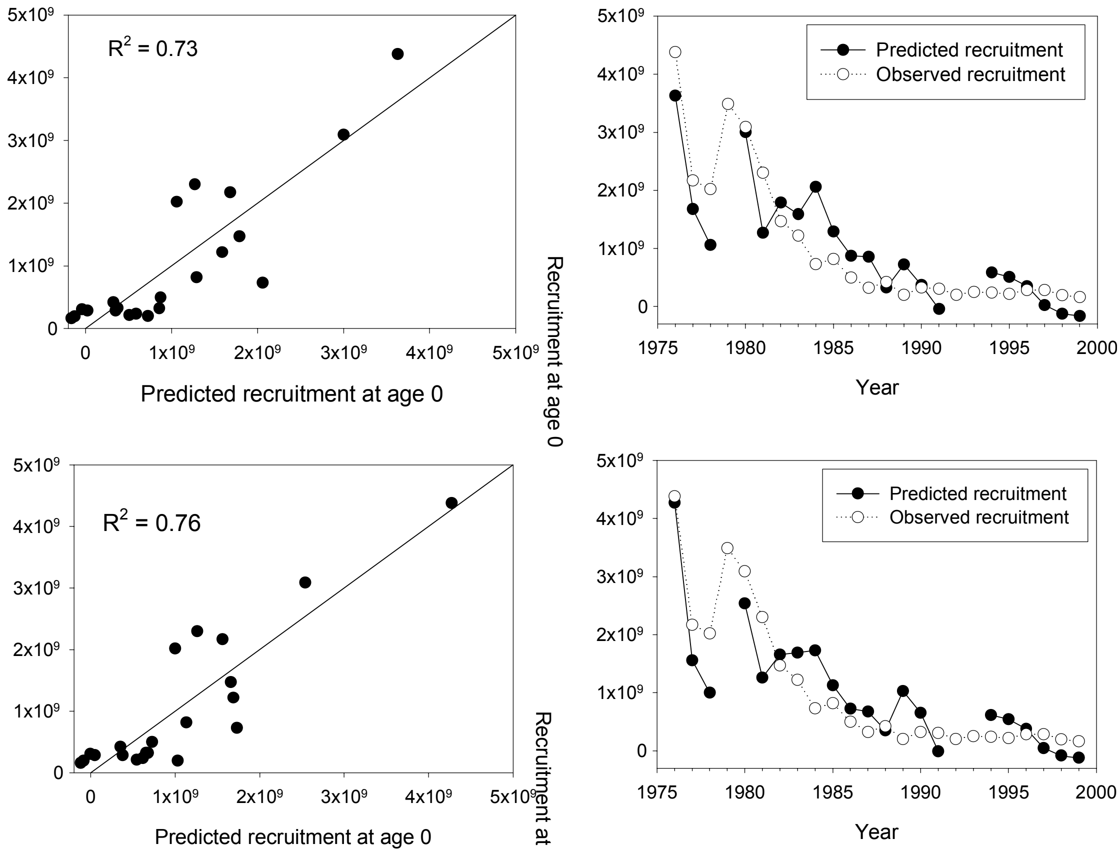

Figure 7.4. Observed vs. predicted recruitment at age 0 based on multiple linear regression model incorporating potential egg production times oxygen related egg survival (as sum over products for Subdivisions) and prey availability (product of turbulent velocity and *Pseudocalanus* nauplii (upper panel) and total nauplii abundance (lower leve)) as variables.

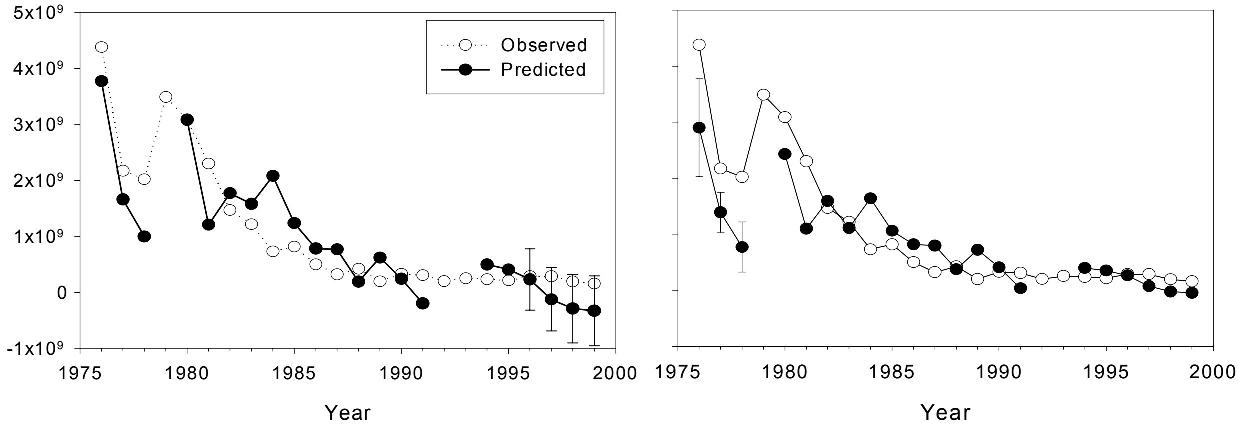

Figure 7.5. Observed and predicted recruitment at age 0 based on multiple linear regression model incorporating potential egg production times oxygen related egg survival (as sum over products for Subdivisions) and prey availability (product of turbulent velocity and *Pseudocalanus* nauplii) as variables, with model fitted to data covering 1976–1995 (left panel) and 1980–1999 (right panel) with remaining years predicted, error bars correspond to the 95% confidence limits of the predicted means.

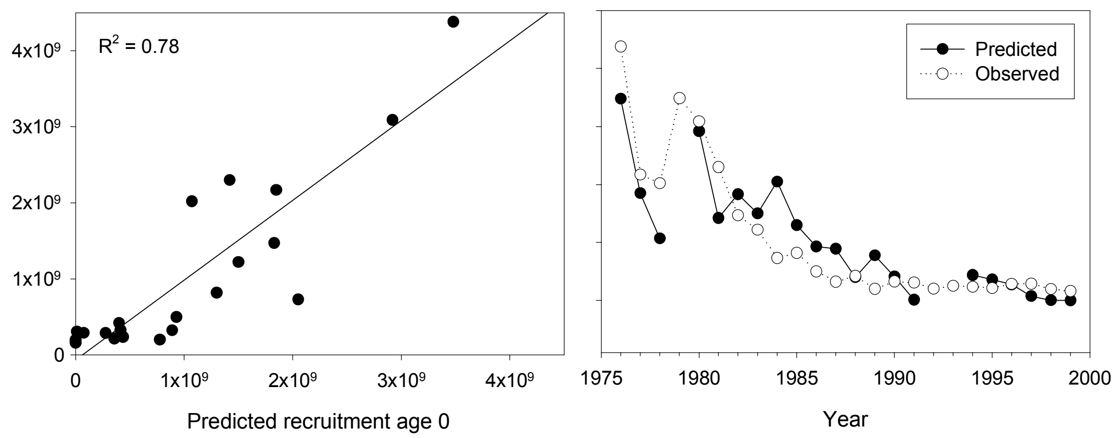

Figure 7.6. Observed vs. predicted recruitment at age 0 based on multiple linear regression models for each Subdivision incorporating potential egg production times oxygen related egg survival and prey availability (product of turbulent velocity and *Pseudocalanus* nauplii) as variables, and subsequently integrated over areas.

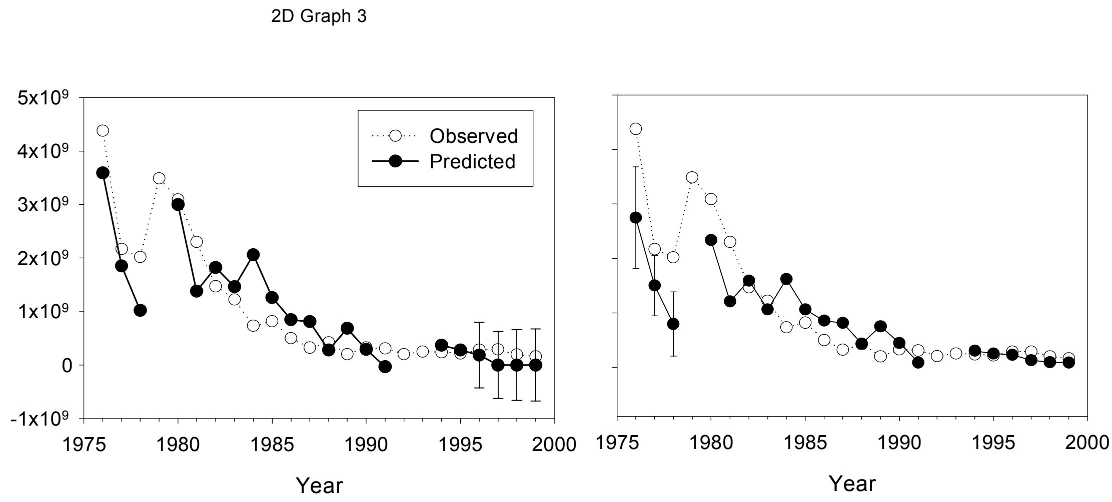

Figure 7.7. Observed and predicted recruitment at age 0 based on multiple linear regression models for each Subdivision incorporating potential egg production times oxygen related egg survival and prey availability (product of turbulent velocity and *Pseudocalanus* nauplii) as variables, integrated subsequently over areas, with model fitted to data covering 1976–1995 (left panel) and 1980–1999 (right panel) with remaining years predicted, error bars correspond to the 95% confidence limits of the predicted means.

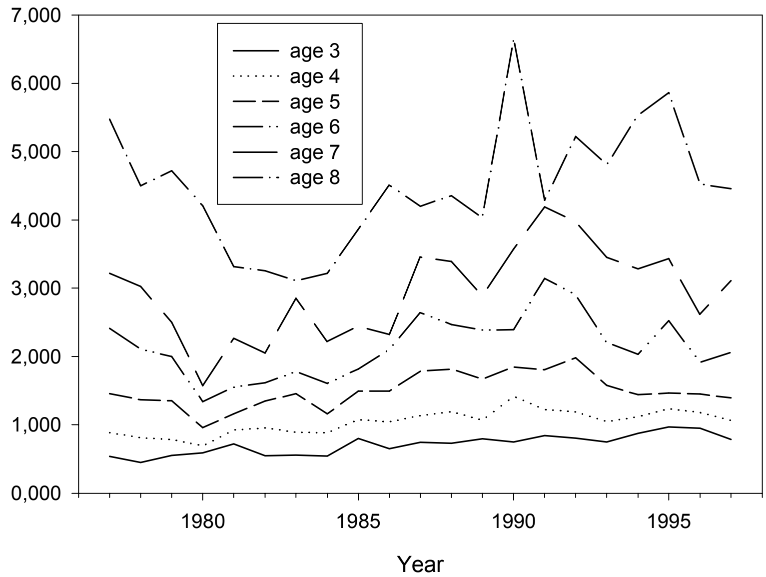

Figure 7.8. Average weight at age of Eastern Baltic cod 1977–1997 based on data from the multispecies database as utilized by Gislason (1999).

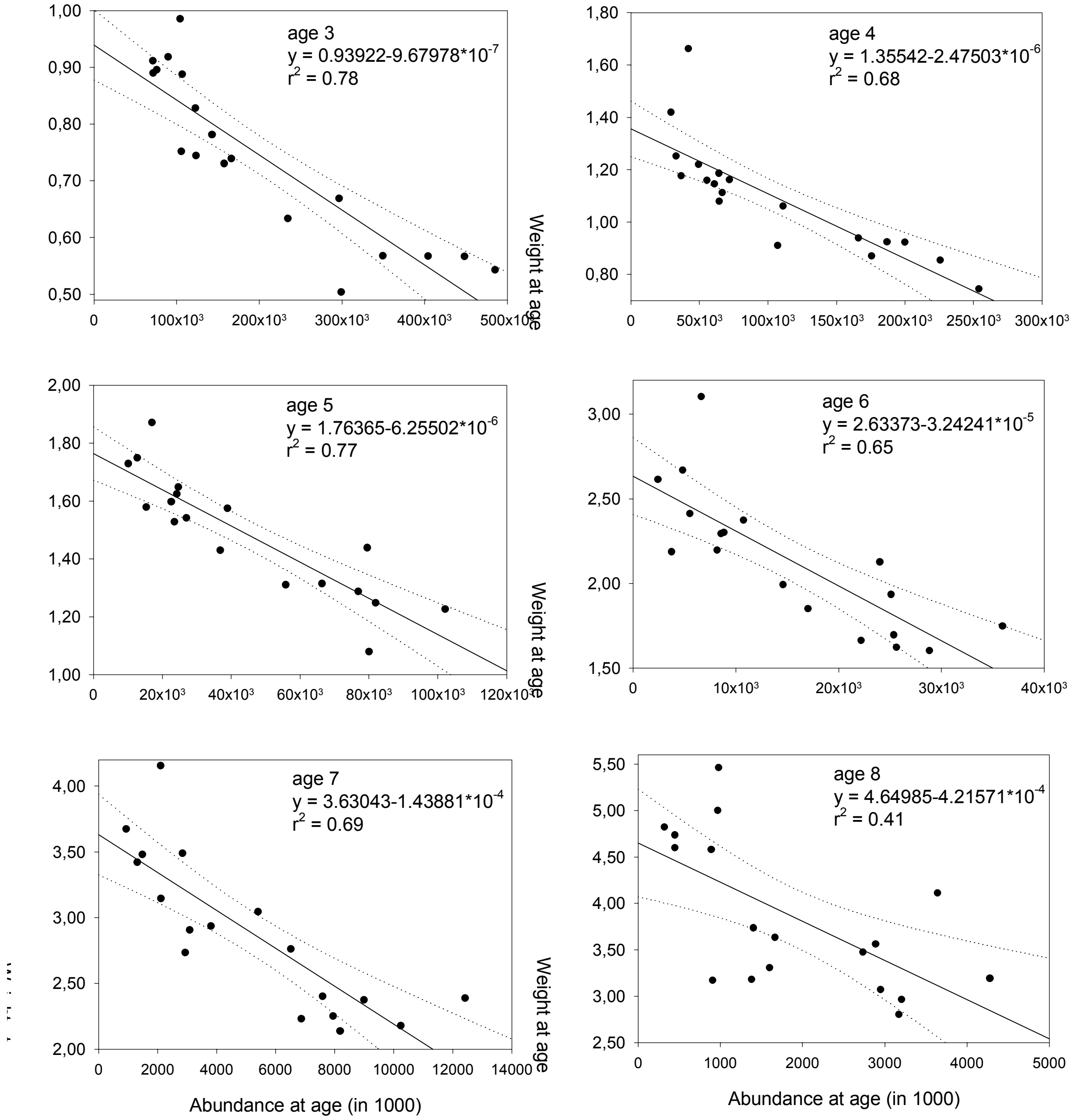

Figure 7.9. Linear regressions between cod weight at age against year class abundance in the mid of the preceding year.

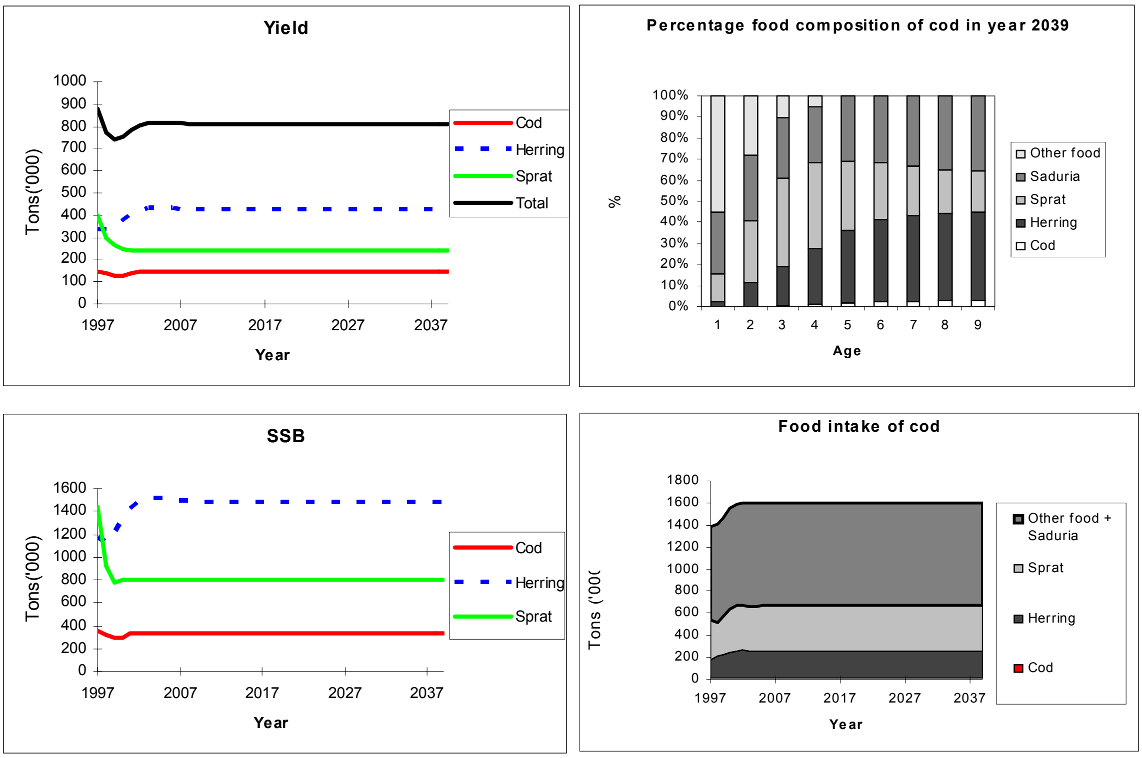

Figure 7.10. Summary of the MSGVPA prediction runs as used and presented in Gislason (1999), including cod growth dependence on suitable prey biomass.

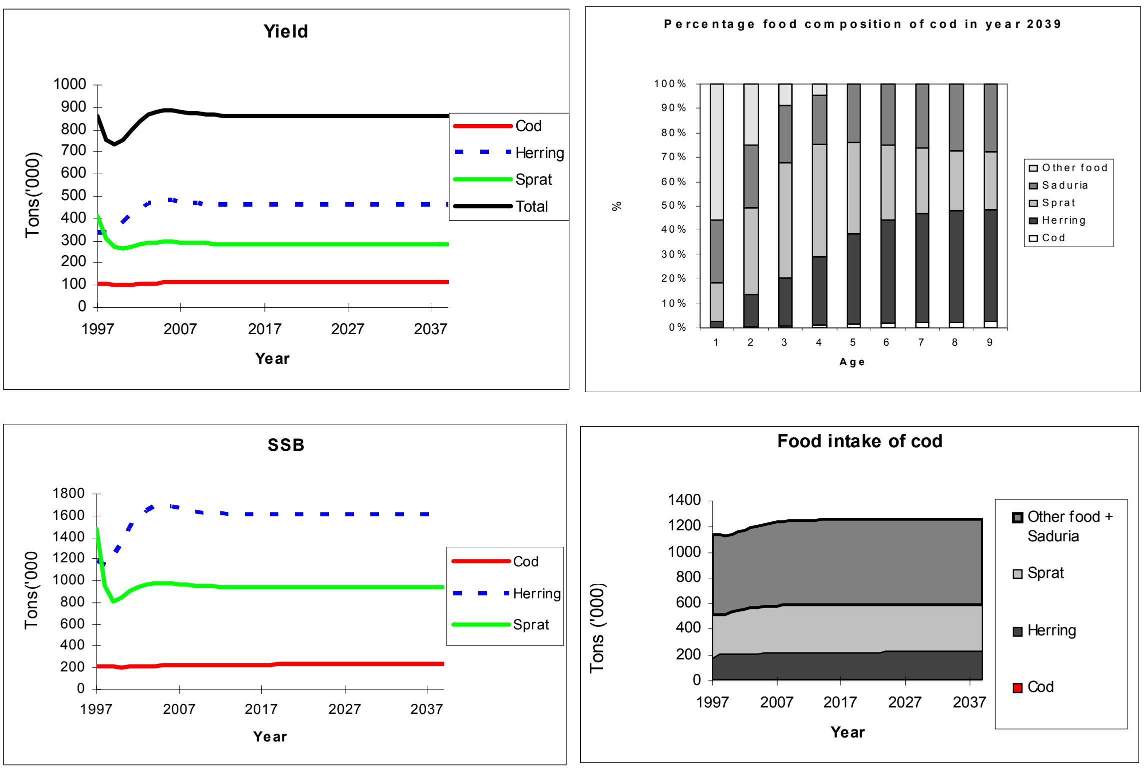

Figure 7.11. Summary of the MSVPA prediction runs as used and presented in Gislason (1999).

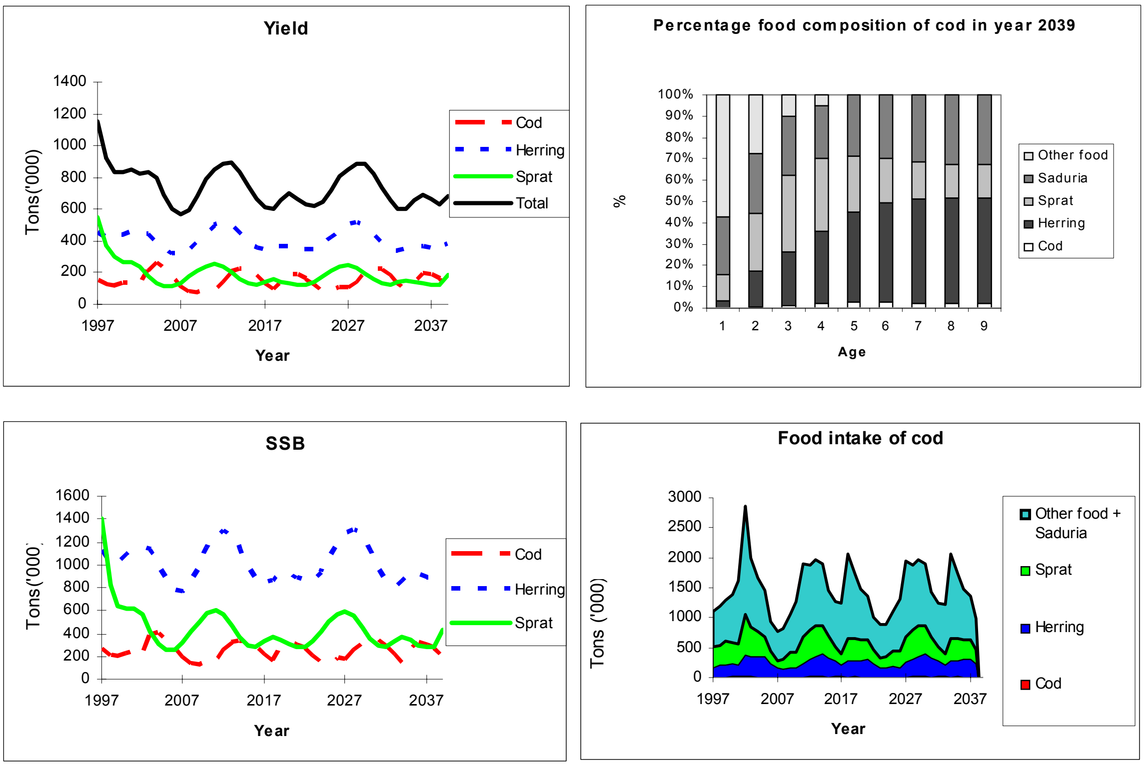

Figure 7.12. Summary of the extended MSVPA prediction runs assuming poor environmental conditions for cod recruitment (using environmental data from 1984 to 1999 respectively).

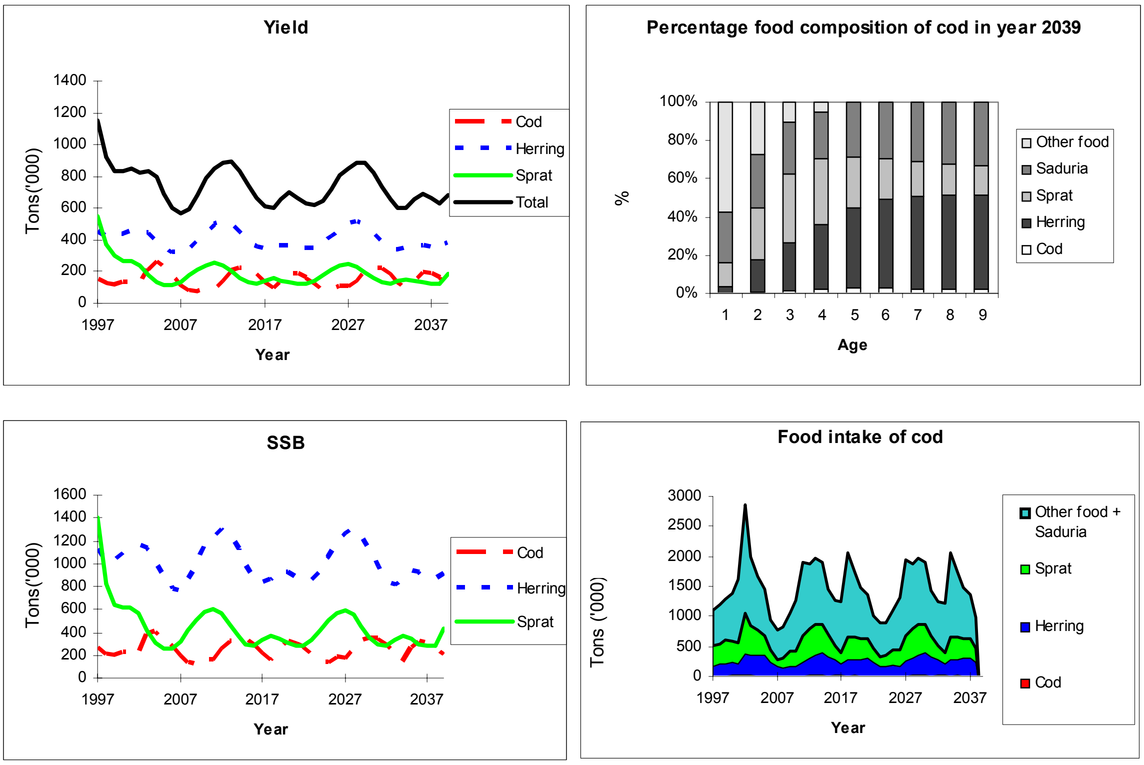

Figure 7.13. Summary of the extended MSVPA prediction runs assuming favourable environmental conditions for cod recruitment (using environmental data from 1969 to 1983 respectively).

Table 7.1. Estimated $B_{i,y}$, Proportions of overall spawning stock of cod spawning in each Subdivision of the Baltic Sea, 1977–1997. Italics indicate assumed values.

Year	SD25	SD26	SD28
1977	0.36	0.41	0.23
1978	0.32	0.43	0.26
1979	0.30	0.50	0.20
1980	0.40	0.44	0.16
1981	0.39	0.42	0.19
1982	0.42	0.40	0.17
1983	0.38	0.42	0.20
1984	0.40	0.41	0.19
1985	0.45	0.36	0.19
1986	0.47	0.38	0.16
1987	0.50	0.38	0.11
1988	0.55	0.35	0.10
1989	0.59	0.35	0.06
1990	0.57	0.34	0.09
1991	0.52	0.44	0.04
1992	0.60	0.37	0.03
1993	0.70	0.26	0.04
1994	0.57	0.39	0.03
1995	***0.62***	***0.34***	***0.04***
1996	***0.62***	***0.34***	***0.04***
1997	***0.62***	***0.34***	***0.04***

8 MULTISPECIES STOCK PRODUCTION MODEL

An alternative to the standard MSVPA are multispecies production models: the example of such a model is the multispecies model of Schaefer (e.g., Sullivan, 1991). Such models, although not so realistic as age-structured models, are generally less data demanding, and may be especially useful when the age structure of the stocks is unknown. Horbowy (1996) developed a new multispecies stock-production model, deriving it from the age-structured multispecies model of Andersen and Ursin (1977). The multispecies interactions in the model are constrained to the impact of predator stock on survival of prey components – the growth rate of predator is not affected by prey biomass, similar as in MSVPA. The advantage of Horbowy's approach is that some of the model parameters, having specific biological meaning, can be estimated outside the model. The model allows for the estimation of the dynamics of stock biomass and multispecies interactions given catches, predator stomach contents, and indices of recruitment and fishing effort. The model was applied for simulation of the dynamics of the Baltic fish stocks, producing results comparable with those obtained from age-structured assessment models. The basic shortcoming of the model was its applicability to fully exploited part of the stocks only, while multispecies effects for young fish (usually less exploited or unexploited) may be important and usually are more pronounced. Therefore, a new formulation of the multispecies production model was developed incorporating the dynamics of young fish (STORE; 2003)

The basic equation of the multispecies stock-production model of Horbowy (1996) is:

$$\frac{dB_s}{dt} = (v_s h_s w_s^{-1/3} - q_s E_s - M1_s - k_s - \sum_{r=1}^{n} h_r w_r^{-1/3} \frac{G_r^s B_r}{\sum_{i=1}^{n} G_r^i B_i + OT}) B_s \quad [1]$$

where

v, h, k = parameters of the von Bertalanffy`s growth equation generalized by Andersen and Ursin (1977), v is the fraction of eaten food assimilated for growth,

E = fishing effort,
q = catchability coefficient,
M1 = coefficient of natural mortality caused by other reasons than predation,
w = mean weight of fish in the population,
G_r^s = suitability of prey s to predator r,
OT = “other food”
s, r = populations,
n = number of populations.

Assuming the term in the brackets as constant or having small variability in a time interval (t, t + dt), model [1] can be approximated by

$$B_s(t+dt) = B_s(t)\exp[a_s(t)dt], \qquad [2]$$

where

$$a_s(t) = v_s h_s w_s^{-1/3} - q_s E_s - M1_s - k_s - \sum_{r=1}^{n} h_r w_r^{-1/3} \frac{G_r^s B_r}{\sum_{i=1}^{n} G_r^i B_i + OT}$$

If recruitment takes place at time t+dt, equation [2] will assume the following form

$$B_s(t+dt) = B_s(t)\exp[a_s(t)dt] + R_s \qquad [3]$$

where R is the biomass of the year class recruited to the population.

This model has been applied for fully exploited part of the populations because fishing mortality in the model is age independent. To cover non-exploited (young) ages in the modelled populations additional equations were developed and employed in the model. It was assumed that younger ages are not exploited or the exploitation is so low that it can be neglected. The dynamics of the not exploited part of the population is presented by

$$N_{si}(t+dt) = N_{si}(t)\exp[-(M1_{si} - \sum_{r=1}^{n} h_r w^{-1/3} \frac{G_r^s B_r}{\sum_{i=1}^{n} G_r^i B_i + OT})dt] \qquad [4]$$

$$B_{si}(t) = N_{si}(t) w_{si}(t)$$

where

N_{si} – number at age i in population s,
w_{si} – mean weight at age i in population s.

In equation [4] the Σ term expresses the predation mortality. The part of the oldest non-exploited (young) age which survived to the exploited (adult) age quits the non-exploited component and enters the exploited component of the population as recruitment denoted by R_s in equation [3].

Recruitment to the non-exploited component of the population is modelled as $R_0 = uR_{index}$

where u is parameter, and R_{indeks} – is an index of recruitment to non-exploited component.

The Baltic Sea has a relatively simple system of trophic levels, which facilitates the modelling of the multispecies interactions. The main predator cod feeds mainly on herring, sprat and invertebrates. Thus, in the model interactions between man (catches), cod, herring, sprat and a component called "other food" are estimated. The stocks of cod, herring and sprat consist of two components in the model: young fish and adult fish. Adult components consist of cod at age 3 and older, and herring and sprat at age 2 and older, while young components are represented by age groups 1–2 for cod and age groups 0–1 for herring and sprat. The fishery in the model operates on adult components only. The following species interactions are modelled:

- ·predation of adult cod on herring, sprat, young cod, and "other food",
- ·predation of young cod on sprat (both young and adult), young herring, and "other food".

The "other food" is composed of invertebrates and fish of minor importance.

The model has been applied to eastern Baltic cod stock (Subdivisions 25–32), central Baltic herring (Subdivisions 25–29+32) and sprat (Subdivisions 22–32). In simulations the years 1982–2001 were covered, as data from the international acoustic surveys on herring and sprat have been available since 1982 (STORE 2003).

In the 1980s and 1990s a marked decline in growth rate of Baltic herring was observed. This phenomenon was simulated in the model by presenting an anabolism coefficient h as linear function of time.

The parameters v, h, k, M1, w, OT were estimated from the available data (outside the model) or assumed basing on literature. The parameters G, q, u, and B0 (B0 is initial biomass needed to solve equation [3]) were found by minimizing the sum of squares of differences of logged observed and estimated in the model: catches, food composition, and initial biomasses

$$SS(G,q,u,B0) = \sum_{i,t} \lambda_Y (\ln Y_{it} - \ln \underline{Y}_{it})^2 + \sum_{i,t} \lambda_{sc} (\ln SC_{it} - \ln \underline{SC}_{it})^2 + \sum_{i} \lambda_{B0} (\ln B0_i - \ln \underline{B0}_i)^2 \quad [5]$$

where Y and Y, SC and SC denote model and observed catches and stomach content, respectively. The index i refers to species (cod, herring, sprat) and t is year (1982–2001). The parameters λ represent statistical weights being inverse of variance associated with successive terms. The λ were estimated in an iterative way assuming initial values (usually 1), and using in subsequent models runs the estimates of λ from preceding run. Parameters G are determined relative to a constant multiplier, so the highest was allotted 1, and other G values were estimated relative to that. The model was developed as a spreadsheet in EXCEL and SOLVER module was used for the minimisation of the sum of squared residuals [5].

9 GROWTH CHANGES IN BALTIC SEA CLUPEOIDS

Drastic changes in the weight-at-age (WAA) of herring, one of the most important commercial fishes the Baltic Sea, have been observed since the late 1980s (Parmanne *et al.*, 1994; Cardinale and Arrhenius, 2000). This decrease was observed in almost all age groups and in all open areas of the Central Baltic, with the exception of the most northerly (Cardinale and Arrhenius, 2000). The low WAA has dramatic effects on the biomass and further on the catches of herring (ICES, 2002). Additionally the bad condition of the fish (i.e., low fat content) has important implications on the marketing for human consumption (Raid and Lankov, 1995).

Recently three different hypotheses have been put forward to explain the decrease in WAA of Baltic herring, which involve (i) a reduction in selective predation of cod on smaller herring (Sparholt and Jensen, 1992; Beyer and Lassen, 1994), (ii) an influx of slow-growing individuals from the northern areas (ICES, 1997a, b), and (iii) a real decrease in growth rates due to changes in stock size and feeding environment.

The latter hypothesis has been addressed by Flinkman *et al.* (1998) showing changes in WAA in the Northern Baltic to be related to the mesozooplankton species composition. For the Central Baltic Horbowy (1997) modelled growth of herring in relation to the biomass of *Mysis mixta*. Similarly Szypula *et al.* (1997) stressed the importance of the fraction of macrozooplankton in the diet of planktivores. Contrary, a series of works pointed towards the outstanding importance of *Pseudocalanus elongatus* for nutrition of Baltic herring (Davidyuk *et al.*, 1992; Naglis and Sidrevics, 1993; Davidyuka, 1996).

During the present study group meeting new evidence from the Central Baltic as well as for the Gulf of Finland has been presented showing a chain of events relating variability in climate, salinity and *P. elongatus* abundance to changes in diet and condition/growth of herring. Similarly sprat growth was hypothesized to suffer from the same mechanism in the last decade (Cardinale *et al.* 2002; Möllmann *et al.* submitted). Below we present short summaries of the studies and discuss possibilities for incorporation of clupeid-zooplankton interactions in Multispecies Models.

9.1 Growth changes in the Central Baltic

A chain of events relating variability in climate, salinity and *P. elongatus* abundance to changes in diet and condition of herring in the Central Baltic Sea has been demonstrated (Möllmann *et al.* 2003b). The effect of climate on Baltic salinity has been described before using the Baltic Sea Index (BSI, Lehmann *et al.*, 2002). Clearly a change in the atmospheric forcing occurred in the recent two decades from an average negative state of the climate index during the 1980s to a positive one in the 1990s (Figure 9.1, Möllmann *et al.* 2003b). This resulted in increased rainfall and runoff and eventually in decreased salinity (Vuorinen *et al.*, 1998; Hänninen *et al.*, 2000). Increased runoff leading to sea level variations may explain the absence of major inflow events to the Baltic since the 1980s especially influencing deep water salinity (Matthäus and Schinke, 1994).

A decrease in *P. elongatus* abundance, especially during the 1990s, occurred in parallel to salinity (Figure 9.2, Möllmann *et al.* 2003b). The effect of ambient salinity conditions is most pronounced during peak reproduction in spring, and obviously maturation and reproduction processes were mostly affected as indicated by significant Pearson correlation coefficients with C6 and N stages (Möllmann *et al.*, 2003a). Clearly the decrease of *P. elongatus* abundance is reflected in the amount of this copepod found in the diet of herring (Davidyuk *et al.*, 1992; Naglis and Sidrevics, 1993; Davidyuka, 1996, Möllmann and Köster, 1999; 2002) and resulted in a decrease of the total average stomach content of herring (Figure 9.3, Möllmann *et al.* 2003b). The amount of *P. elongatus* in the spring herring diet was further correlated to condition of the clupeid in all subsequent seasons, indicating the importance of *P. elongatus* for herring growth (Table 8.1, Möllmann *et al.* 2003b). The analysis supports the hypothesis that a change in the feeding environment has caused not only an apparent, but a real decrease in growth of Baltic herring. Further it showed that the amount *P. elongatus* available to individual herring in spring is key to the decrease in growth. This hypothesis is supported by the coincidence of the main reproduction season of *P. elongatus*, providing the largest stock of older stages with a high energy content, with the return of herring from their coastal spawning grounds (Aro, 1989). Our analysis showed that herring in spring are in bad condition after spawning, and when they re-enter their feeding areas in the deep Baltic basins, have to refill their energy depots. They feed in the region of the permanent halocline during day-time (Köster and Schnack, 1994), where they encounter mainly older stages of *P. elongatus*, due to the ontogenetic vertical distribution of the copepod (Möllmann and Köster, 2002). With the decrease of the *P. elongatus* stock also condition of herring worsened with important consequences for the fisheries yield and marketability of the low conditioned fish (Raid and Lankov, 1995).

Analyses on the feeding ecology of sprat indicate a similar mechanism to be responsible for the decrease in growth during the 1990s. Also for this species the decrease in the fraction of *P. elongatus* in the stomachs during the last decade is visible (Möllmann *et al.* submitted).

9.2 Growth changes in the Gulf of Finland

Herring growth has fluctuated remarkably during the last few decades in the Gulf of Finland. In the end of the 1970s herring weight-at-age (WAA) started to increase but ten years later the growth slowed down. In the 1960s and early 1970s herring weight-at-age was only slightly higher than in the end of the 1990s (Figure 9.4, Rönkkönen *et al.*, submitted).

Herring growth in the Gulf of Finland may have been limited by the availability of suitable type of plankters (as suggested by Flinkman *et al.* 1998) or by other energetically valuable food animals (mysids, amphipods -- Lankov and Kukk 2002), because there was a difference in zooplankton community structure between the period of slow growth of herring and the period of fast growth (Figures 8.5 and 8.6). When herring has grown well, the large-sized *P. elongatus* has been the dominating species both in zooplankton (Fig. 8.2) and in herring diet (Raid and Lankov 1995, Möllmann and Köster 1999, Rönkkönen *et al.*, submitted). In contrast, during the period of slow growth, the proportions of *Acartia* spp., *E. affinis* and *B. longispina* have been greater (Rönkkönen *et al.*, submitted). *Acartia* spp. is a small species and *E. affinis* is also alert to hydrodynamic signals (Viitasalo *et al.* 2001) and may therefore be difficult prey for herring. The decrease in the biomass of *P. elongatus* and an increase of the share of small *B. longispina* and *Acartia* spp. and the difficulty of catchable *E. affinis* may have worsened herring feeding conditions during the low salinity period. Because there is a highly significant positive correlation between herring weight-at-age, especially with 1–2 year old herring, or growth rates of the year-classes and salinity (Figure 9.7., Rönkkönen *et al.*, submitted), this correlation may give a possibility to predict herring growth in the Baltic Sea, since it has been suggested that the salinity level of the Baltic Sea can be predicted from climatic trends (Hänninen *et al.* 2000).

9.3 Possible incorporation of clupeid-zooplankton interactions in Multispecies Models

Above summarised studies demonstrated the relationship between climate changes, salinity and the standing stock of the copepod *P. elongatus*. Furthermore the importance of this copepod for growth and condition of herring could be shown and potentially exist for sprat as well. Further, variability in temperature may effect standing stocks of other copepods (e.g., *Acartia* spp.) which will contribute to variability in clupeid growth and condition. A further step to include environmental processes into stock assessment could be the inclusion of this knowledge into the multispecies framework. This could be realized by a growth model for herring (and sprat) dependent on the food supply and the stock size (including the competing predator sprat) to be used in multispecies predictions applying different environmental scenarios with respect to salinity and temperature. Furthermore, age of reaching sexual maturity may depend on growth rates and environmental conditions, e.g., temperature. This may explain considerable variability of the proportion being mature at age 1 at least for sprat. Coupling of food availability, growth and maturation considering hydrographic conditions may be introduced in environmentally sensitive stock recruitment relationships used in multispecies predictions.

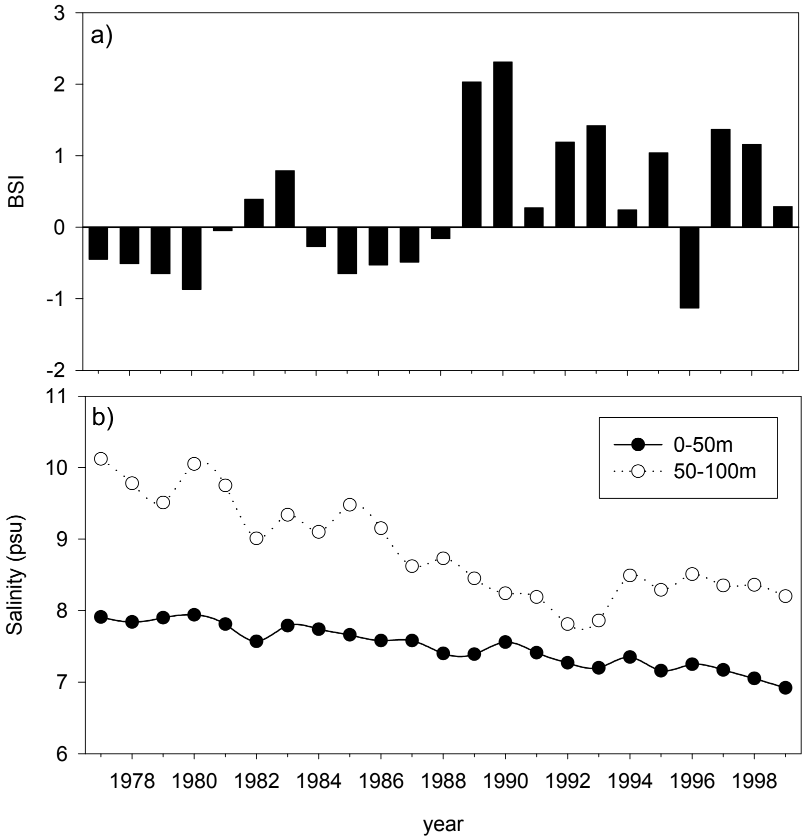

Figure 9.1. Time-series of the Baltic Sea Index BSI (a) and average spring salinities in the layers of 0–50m and 50–100m (b).

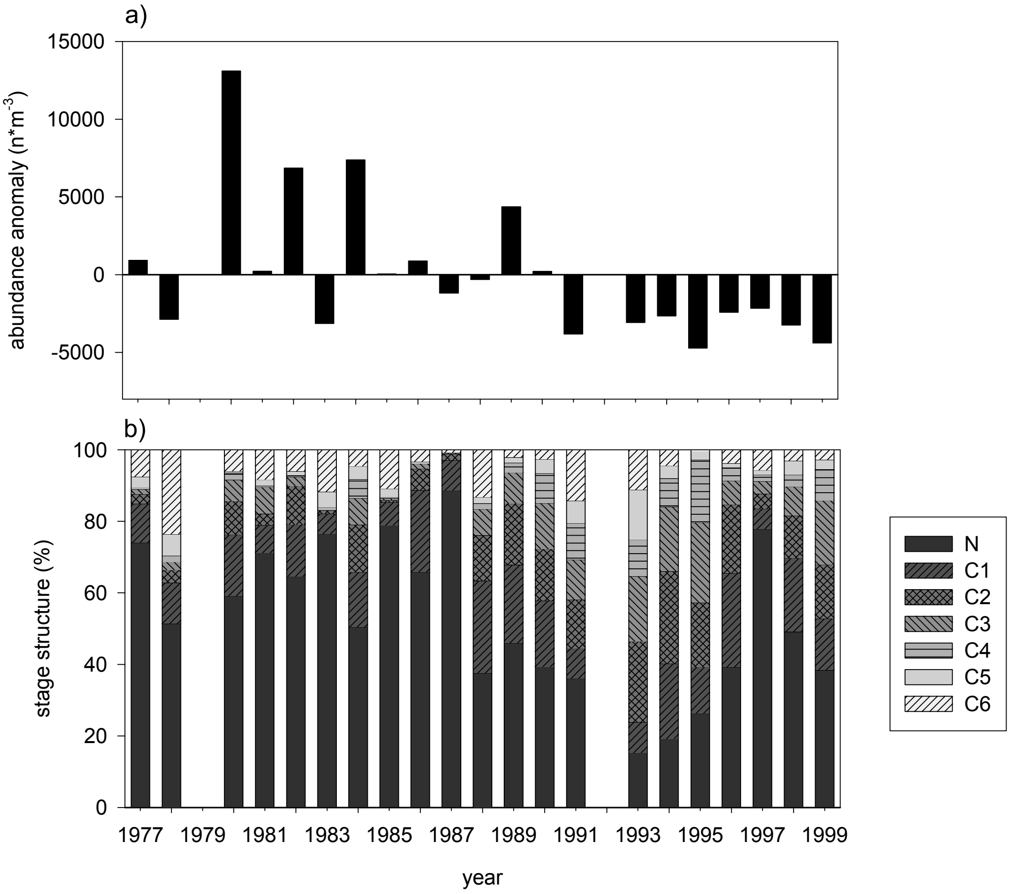

Figure 9.2. Time-series of total abundance anomalies (a) and stage-structure (b) of *Pseudocalanus elongatus* in spring.

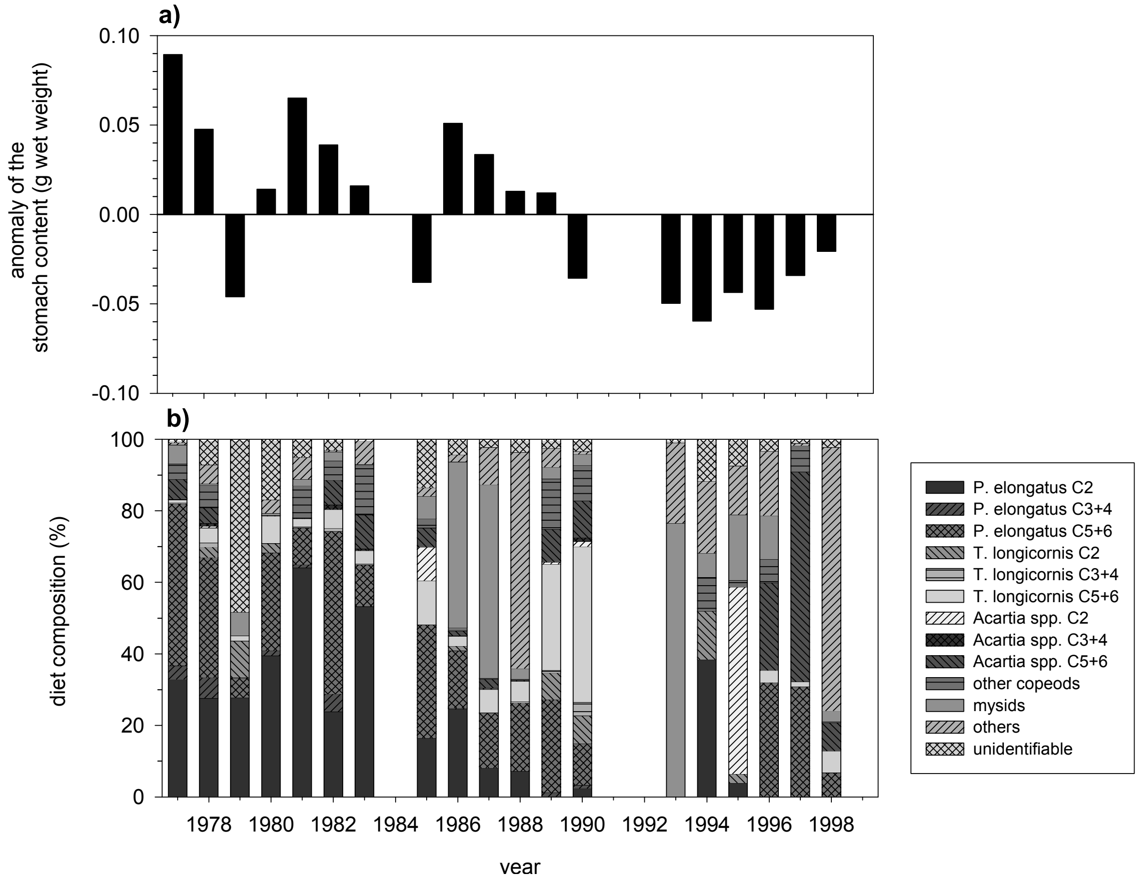

Figure 9.3. Time-series of total stomach content anomalies (a) and diet composition (b) of herring in spring.

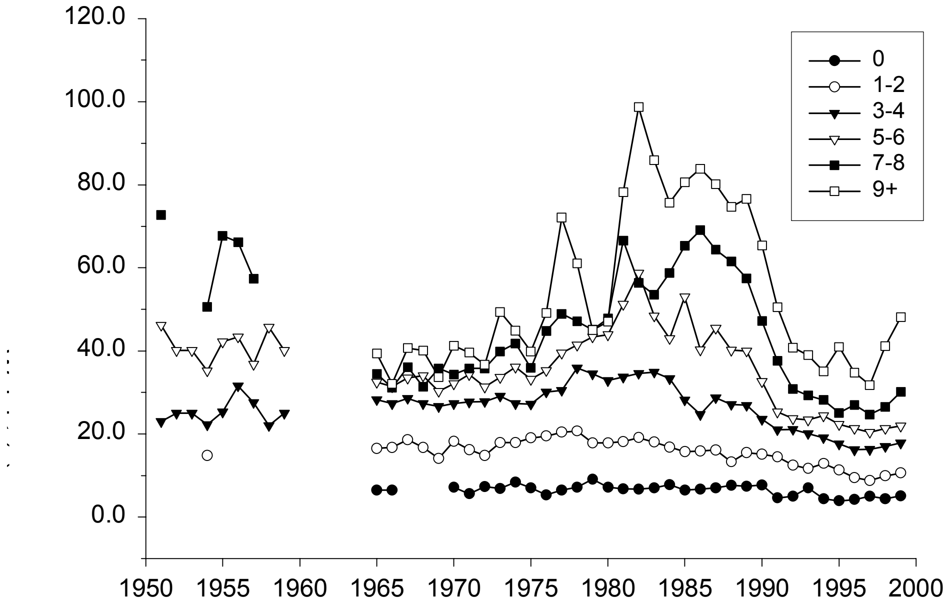

Figure 9.4. Herring weight-at-age in the Gulf of Finland. No data for the years 1960–1964.

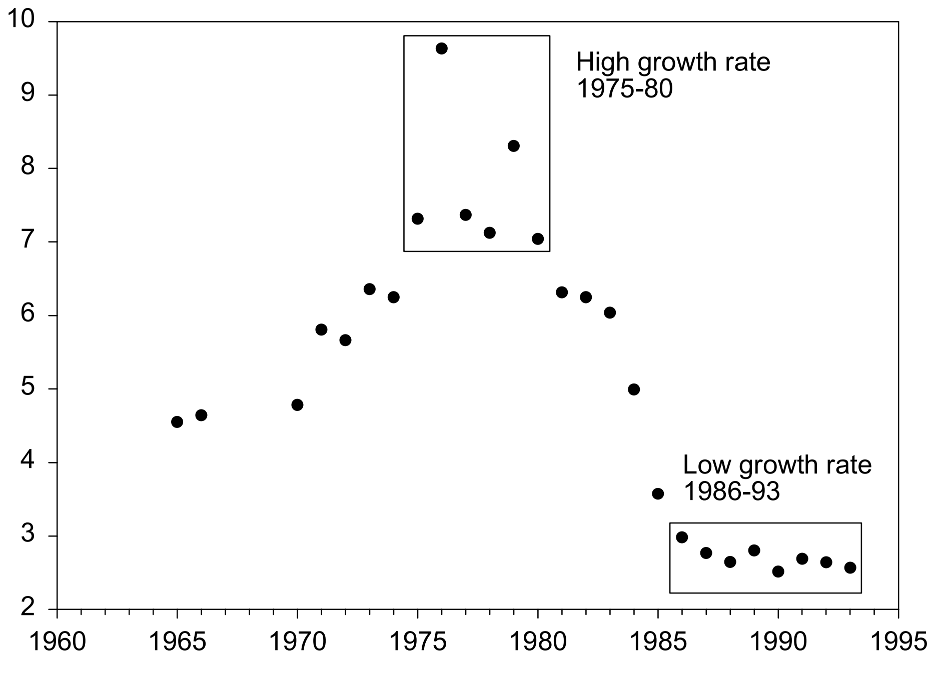

Figure 9.5. Growth rates (k) of Baltic herring year-classes. Highest (years 1975–80) and lowest (years 1986–93) growth rates are surrounded with a box. The average zooplankton biomass structure during these years is shown in Figure 9.6.

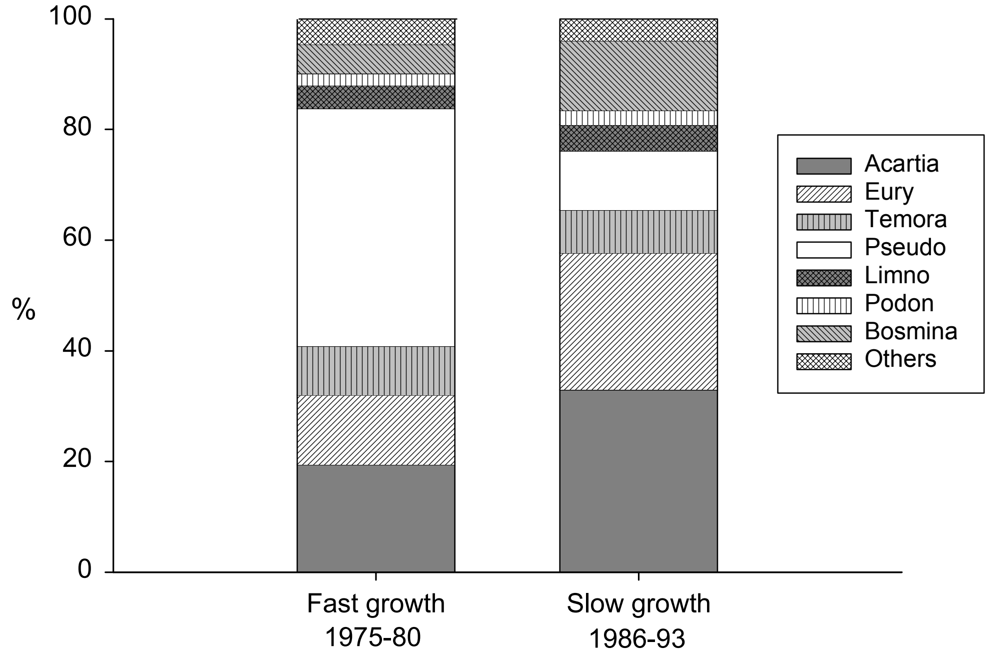

Figure 9.6. Zooplankton biomass structure (in %) in the Gulf of Finland during high (1975–80) and low (1986–93) growth rate (cf. Fig. 9). Acartia = *Acartia* spp., Eury= *Eurytemora affinis*, Temora = *Temora longicornis*, Pseudo = *Pseudocalanus minutus elongatus*, Limno = *Limnocalanus macrurus*, Podon = *Podon intermedius*, Bosmina = *Bosmina longispina maritima*. "Others" = *Centropages hamatus*, Cyclopoida, *Pleopsis polyphemoides* and *Evadne nordmanni*.

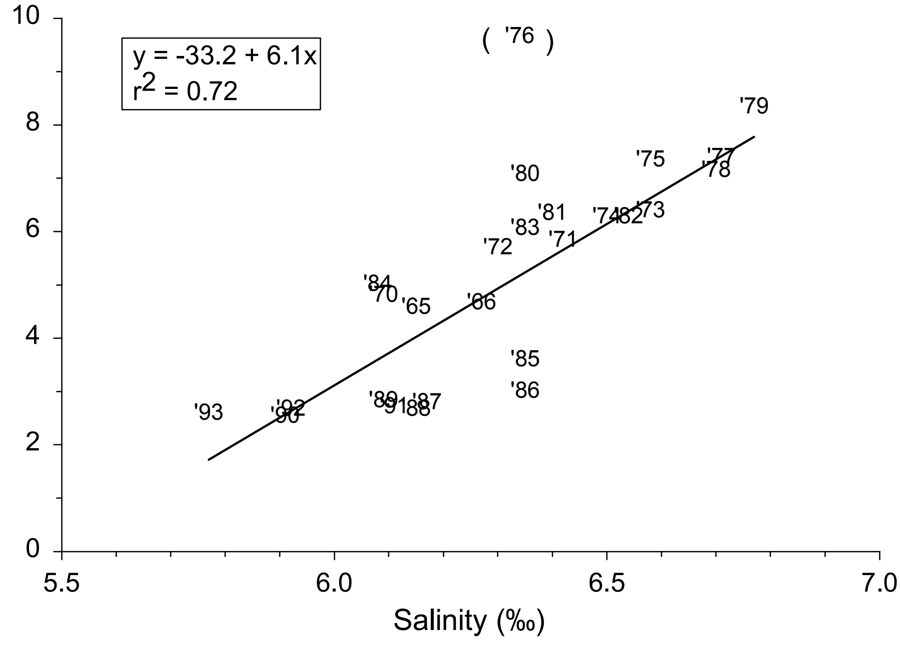

Figure 9.7. Growth rate (k) of herring year classes plotted against salinity in the Gulf of Finland. Linear regression line has been added. Outlier, not included in the regression, indicated with brackets.

Table 9.1. Correlation tests between amount of *Pseudocalanus elongatus* in stomachs of herring in spring, and seasonal time-series of condition using log and smoothed (three-point running mean) time-series. N = number of data points, N^{eff} = "effective" number of degrees of freedom, r = Pearson correlation coefficient, p = associated probability (α).

Condition	**P. *elongatus***			
	N	**N^{eff}**	**r**	**P**
Spring[1]	22	12	0.13	0.563
Summer[1]	22	11	0.76	<0.01**
Autumn[1]	22	14	0.51	0.016*
Winter[13]	22	11	0.54	0.009
Spring[2]	20	5	0.80	<0.01*
Summer[2]	20	6	0.88	<0.01**
Autumn[2]	20	7	0.69	<0.01*
Winter[13]	20	5	0.71	<0.01

[1] log time-series
[2] smoothed time-series
[3] time-series shifted one year ahead
*significant at 0.05 and ** at 0.01 level

10 COOPERATION AND COORDINATION OF FUTURE WORK BETWEEN SGMAB AND BSRP

The following gives a short list of those tasks, which SGMAB has planned to address in the incoming years:

1) Technically oriented activities:

a) validation, maintenance and update of the various input data-bases (meeting in 2003 and future work)

2) Scientifically oriented activities:

a) Development and incorporation of models on growth, maturation and egg production coupled to food availability and environmental conditions (meeting 2003 and future work)
b) Modelling of suitability coefficients considering environmental factors triggering predator/prey overlap, which should include an investigation of the occurrence and intensity of prey switching. (meeting 2003 and future work)
c) Additionally a consideration of spatial differences in mortality, growth and maturation rates, and area specific variability in reproductive success and recruitment due to differences in environmental conditions (output from CORE and STORE; future work)

3) Management oriented activities:

a) Implementation of suitable medium- to long-term projection methodology for simulation of stock and catch development under different fishery actions (meeting 2003 and future work)
b) Management options and environmental scenarios, which includes the evaluation and set-up of suitable biological reference points (meeting 2003 and future work)

Firstly there is a need for data-base revision, update and maintenance. Baltic Fisheries Assessment Working Group has compiled available weight at age in the stock data for cod, based on 1st quarter bottom trawl surveys. Data on weight at age in the stock for herring and sprat are available from international hydroacoustic surveys conducted "annually"/semi-annually in September/October and results are reported to WGBIFS and WGBFAS. Both data sets can be used to establish a stock specific weight at age data-base, however, not covering all quarters, which consequently requires modelling of seasonal growth to ensure complete seasonal coverage. It is obvious that no new stomach data is available or data is very limited, and the stomach content data-base contains the major part of the information available for the covered time period 1977–97.

For modelling growth, sexual maturation and food consumption there are several avenues to proceed. Firstly we may try to explain historical variation in weight at age observed for cod, herring and sprat in the Baltic and taking into especially temperature and trying to account size selective predation by cod and fishing activity as a cause of apparent changes in growth rates. Secondly validation of spatial, temporal and age-specific variation in determined individual consumption rates in relation to environmental parameters.

Our predictive models in ICES are sensitive to structural uncertainty. With inclusion of weight at age and maturity at age being dependent on the food supply, the projected medium-term yield at various combinations of fishing effort directed to both cod and clupeids stocks change considerably in comparison to ordinary standard multispecies predictions.

In general, very incomplete information on the impact of growth and nutritional condition on maturation processes and egg production is presently available and SGMAB should explore possibilities to include these issues into the predictive models.

Selection of the suitability sub-model has only limited impact on the population dynamics of major prey species and independent of the model in use relative stock developments will be similar, as long as suitability coefficients are kept constant over time. For prey species like herring and sprat being encountered by the predator regularly in considerable quantities, independent of time and place, the assumption of a constant suitability appears to be an acceptable simplification.

For cod cannibalism, which shows considerable fluctuations in intensity, both available suitability sub-models overestimate the predation mortality acting on juvenile cod in the majority of years and underestimate the predation mortalities in the few years with relatively high occurrence of cod in cod stomachs.

Spatially disaggregated MSVPA runs has been conducted for the Central Baltic and hopefully SGMAB is able to update these runs between meetings. The results have shown that passive transport of youngest life stages of cod and migration by juveniles into/out of their nursery areas as well as spawning migrations of adults between different Subdivisions are likely to occur. Similarly for herring and sprat, the MSVPA output did not match the distribution pattern as obtained from research surveys, also indicating migratory behaviour.

The medium-term/long-term predictions is one of the main issues in SGMAB 2003 meeting. The present version of the 4M programme package is able to handle a variety of stock recruitment relationships with and without stochasticity, as well as stochastic recruitment derived from normal or log-normal distributions.

Medium- to long-term projections in contrast to short-term predictions depend heavily on the recruitment model used. In ICES standard projections, recruitment is in general modelled via traditional stock-recruitment relationships and in the Baltic this avenue seems to be a "*cul-de-sac*" in multispecies context Recruitment in the Baltic depends on a combination of environmental conditions, spawning stock characteristics and species interactions among other things. Thus it can be expected that the predictive power of ICES standard approach is somewhat limited. So where SGMAB likes to? The following summarizes some ideas:

The environmental issues have been tackled in recent years in many aspects, analyzed and compiled by STORE project. The inclusion of environmental parameters into the population dynamics apply especially for Baltic cod and sprat, but Baltic herring is somewhat out of focus here.

At least the following issues are of importance in MSVPA predictions:

Recruitment models need to be expanded to incorporate most important processes affecting the reproductive success. Among the factors and processes to be considered are:

a) size, structure and condition of the spawning stock and its viable egg production,
b) temporal and spatial distribution of spawning effort,
c) impact of physical/chemical conditions on fertilisation, egg development, hatching success and larval survival,
d) food availability for larvae and juveniles in terms of quantity and quality, and
e) predation pressure on all juvenile life stages

In order to have enhanced/modified predictions, SGMAB has faced many problems. The following is just a short list of the most relevant at this context:

a) Various combinations of processes act in different species and even between different stocks of one species. Which are the most vital ones?
b) Changes in major environmental conditions may prove to be impossible to predict (like inflows in general), even a generation time ahead, leading to the conclusion that stochastic approaches may be the only way to proceed.
c) In connection to egg production ICES has considered the quantity, but we should also look in more detail the quality of the egg production. How to incorporate this one?
d) For egg and early larval survival, temperature may be especially important to consider in northern or southern areas of the distribution range, while salinity and oxygen cause problems mainly in stratified systems. This addresses the importance of spatially disaggregated updated MSVPA runs.
e) Predation mortality on early life stages is in general not well understood and will hamper predictions if a substantial and variable impact on survival rates occurs. How to deal with this one?
f) What is the functional response of predators and the role of temporal/spatial overlap between predator and prey under varying environmental forcing conditions?
g) How the abundance of herring and sprat as well as data on mean weight at age in the stock are relevant for predictions (seasonal growth) to ensure complete seasonal coverage
h) How the environmental parameters and biotic environment influence growth, sexual maturation and egg production of pelagic species i.e., sprat and herring and how to incorporate these parameters in short-, medium and long-term predictions

The cooperation and coordination of work between SGMAB and BSRP have following elements. When looking BSRP implementation plan and the objectives of various components' aims, the following may be good candidates for supplying extra information to Baltic Sea multispecies/ecosystem management process:

a) Better temporal and spatial coverage of hydrography (coarse and fine scale) and assessment of plankton community (pelagic fish growth and feeding).
b) Better acoustic estimates of pelagic species abundance and spatial distribution
c) GIS Data Center and GIS-database
d) Development of environmental-fisheries integrated models for management
e) Development of ecosystem health indicators versus indices
f) Coordination of joint abundance surveys including stomach sampling (landings sampling(?) and survey sampling
g) Objective to move from single species assessment/management to multispecies assessment/management
h) Workshops to develop management models and indicators for sustainable fisheries (both open sea and coastal)
i) Coordination of Baltic Sea multispecies issues (BSRP, ACFM, ACE, BC, SGMAB, WGBFAS, 6th Framework Task 8)
j) Promoting the use of Baltic herring and sprat for human consumption (dioxine issues?); EU regulation and exceptions until 2006)

The above list is far from complete and contains mainly Component 1 and its sub-task plus combining obvious results in the project implementation plan. There must be many other combinations of tasks as well especially between coastal area-open sea interaction. Under BSRP it is now proposed to establish a new Study Group under Baltic Committee, which will handle according to Baltic Sea Regional Program Implementation plan many aspects of fish ecology, biology and fisheries as well as integrated environmental-fisheries aspects. This is a good idea and SGMAB has included a recommendation for coordination and distribution of work between SGMAB and the new fisheries SG under Baltic Committee. The recommendation is included in Section 11.

11 RECOMMENDATIONS

SGMAB has benefited from and is dependent very much on the activities outside ICES framework. The timing of these activities and results obtained will thus define very much the future activities of SGMAB.

SGMAB has requirements to complete some tasks each year. For example updating and compiling the basic information for multispecies database and estimation of predation mortalities (M2) and run necessary key runs used by Baltic Fisheries Assessment Working Group. Therefore it is **recommended** that SGMAB will continue its work.

In ICES, the Baltic multispecies modelling and related issues are tackled presently only by SGMAB. However, this is going to change in 2003 when GEF (Global Environmental Facility) funded Baltic Sea Regional Program is in full operation. Under that program it is proposed to establish a new Study Group under Baltic Committee, which will handle, according to Baltic Sea Regional Program Implementation Plan many aspects of fish ecology, biology and fisheries as well as integrated environmental-fisheries aspects.

SGMAB support the idea of establishing a new Study Group and SGMAB **recommends** that the coordination and distribution of tasks for SGMAB and the new SG should be made according to those lines presented in Section 9 in this report. SGMAB **recommends** that for the new fisheries Study Group, the BSRP Fisheries Coordination Centre in Riga should make a proposal to the Study Group Chair for approval of Baltic Committee and ICES ASC.

To incorporate environmental variability and spatial heterogeneity in fish stock modelling in the Baltic, SGMAB proposes and **recommends** that at least the following tasks should be included into the terms of reference of the new group. These are in good accordance with SGMAB future plans and BSRP Implementation Plan:

- A review of existing knowledge on environmental processes, which are affecting fish stock dynamics in both in open sea and coastal areas
- Determine those oceanographical processes and their temporal and spatial variability in the Baltic, which are affecting the distribution and productivity of the fish
- Determine those physical and biological processes in the open sea-coastal interaction, which have relevance for fish population dynamics.
- Integrate the above mentioned processes into the enhanced assessment models for commercial fish stocks and new models of coastal fish community structure

.In it's next meeting SGMAB will allocate more effort for modelling of fish growth, sexual maturation and egg production in relation to food consumption, food availability and environmental conditions, especially temperature, with objectives to use these in fisheries management. For constructing environmentally based short-term prediction and medium- to long-term projection models, available information on environmental processes affecting the population dynamics of Baltic herring should be reviewed in order to complete the review on cod, sprat and herring.

For SGMAB **recommends** that:

The **Study Group on Multispecies Assessment in the Baltic** [SGMAB] (Co-Chairs, E. Aro, Finland, and F. Köster, Denmark) will work by correspondence in 2004 to prepare and plan a meeting in Riga, Latvia from 9–13 May 2005 to:

a) update the multispecies key runs up to 2004 covering both Western and Eastern Baltic by appropriate units;
b) review, revise and update the multispecies database (i.e., catch in numbers, maturity ogives, mean weight at age, stomach data etc) and consider the historical trends and changes in mean weight at age of key species (cod, sprat and herring);
c) review the available information on environmental processes, which are affecting the temporal and spatial changes in Baltic herring population dynamics;
d) develop, apply and validate enhanced multispecies models for assessment and prediction i.e., stochastic Multispecies model, to predict weight at age and proportion of maturation at age, potentially depending in a feed back loop on prey availability as well as environmental conditions;
e) validate the revised consumption rates (by quarter of years), which presently contain inter-annual and spatial variability in stomach content, predator weight and ambient temperature;
f) consider how the results of the Study Group on "Fisheries Ecology Issues in the BSRP (SGFEI)" can be incorporated into the work programme of this Study Group.

SGMAB will report by 11 June 2004 for the attention of the Baltic Committee.

Supporting Information

Priority:	The activities of this Study Group will produce updated information issues of predator-prey relationships in the Baltic as well as evaluation of usability of single species precautionary reference points in multispecies context which should be considered to have high priority in future management advice.
Scientific Justification:	As approved in 1999 and 2001 Study Group will concentrate initially on issues related to historical stock developments as well as on medium- to long-term multispecies prediction methodology. Group has considered multispecies prediction models and has taking into account some environmental processes, which are affecting growth, maturation and subsequent recruitment success.
Relation to Strategic Plan:	The elaboration and development of our knowledge of the stock structure, dynamics, and trophic relationships.
Resource Requirements:	For the 2005 meeting (9–13 May) Computer and printing facilities as well as copy machine should be made available from organising institute (Riga, Latvian Fisheries Research Institute).
Participants:	In order to have full participation and the latest information available at the meeting it is necessary to have the meeting after the WGBFAS meeting in 2005 and meeting should not be arranged back to back to WGBFAS.
Secretariat Facilities:	None
Financial:	No direct costs to ICES
Linkages to Advisory Committees:	ACFM, The quality of stock assessments and management advice of Baltic herring, sprat and cod stocks.
Linkages to other Committees or Groups:	WGBFAS, WGBIFS, Resource Management Ctte, SGFEI
Linkages to other Organisations:	IBSFC
Cost Share	ICES 100%

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ANNEX 1: LIST OF PARTICIPANTS AND THEIR CONTACT ADDRESSES

The Study Group on Multispecies Assessment in the Baltic [SGMAB]

DIFRES, Charlottenlund, Denmark, 2–4 April 2003

NAME	ADDRESS	TELEPHONE	FAX	E-MAIL
Eero Aro **(Co-Chair)**	Finnish Game and Fisheries Research Institute Pukinmäenaukio 4, P.O. Box 6, FIN-00721 Helsinki **FINLAND**	+358 205 751 253	+358 205 751 201	eero.aro@rktl.fi
Fritz Köster **(Co-Chair)**	Danish Institute of Fisheries Research Charlottenlund Castle 2920 Charlottenlund **DENMARK**	+45 33 963 300	+45 33 963 333	fwk@dfu.min.dk
Valeri Feldman	Atlantic Research Institute of Fisheries and Oceanography (AtlantNIRO) 5 Dmitriy Donskoy Street Kaliningrad **RUSSIA**	+007 0112 552 369	+007 0112 552 369	feldman@atlant.baltnet.ru
Pavel Gasyukov	Atlantic Research Institute of Fisheries and Oceanography (AtlantNIRO) 5 Dmitriy Donskoy Street Kaliningrad **RUSSIA**	+007 0112 225 257	+007 0112 219 997	pg@atlant.baltnet.ru
Christian Möllmann Invited Expert	Danish Institute of Fisheries Research Charlottenlund Castle 2920 Charlottenlund **DENMARK**	+45 33 963 458	+45 33 963 333	cmo@dfu.min.dk
Stefan Neuenfeldt	Danish Institute of Fisheries Research Charlottenlund Castle 2920 Charlottenlund **DENMARK**	+45 33 963 396	+45 33 963 333	stn@dfu.min.dk
Maris Plikshs	Latvian Fisheries Research Institute Daugavgrivas Street 8 LV 1007, Riga **LATVIA**	+371 7610766	+371 7616946	maris@latfri.lv

NAME	ADDRESS	TELEPHONE	FAX	E-MAIL
Sanna Rönkkönen Invited Expert	Finnish Institute of Marine Research P.O. Box 33 FIN-00721 Helsinki **FINLAND**	+358 9 61394409	+358 9 613 94494	Sanna.ronkkonen@fiMrfi
Brian MacKenzie Invited Expert Part-time	Danish Institute for Fishery Research Charlottenlund Slot DK-2920 Charlottenlund **DENMARK**	+45 33 96 34 03	+45 33 96 34 34	brm@dfu.min.dk
Morten Vinther	Danish Institute of Fisheries Research Charlottenlund Castle 2920 Charlottenlund **DENMARK**	+45 33 96 33 56	+45 33 96 33 33	mv@dfu.min.dk
Rudi Voss	Institute of Marine Science Düsternbrooker Weg 20 24105 Kiel **GERMANY**	+49 431 600 4557	+49 431 600 4553	rvoss@ifm.uni-kiel.de