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Executive summary and highlights

The Study Group on Multispecies Assessment in the Baltic (SGMAB) has now come to the end of its life span. SGMAB convened last time in November 2006 and was mainly tasked with: i) update and correct the multispecies database (i.e. catch in numbers, maturity ogives, mean weight at age) for the Eastern and Western Baltic to enable bi-annual key-runs for both areas; ii) develop, apply and validate enhanced multispecies models, e.g. the new Stochastic MultiSpecies model (SMS); iii) explore the effect of heterogeneous distribution of predator and prey on species interactions in the Central Baltic and investigate the need and possibilities to integrate this heterogeneity into multispecies models; and vi) implement and evaluate the suitable medium- to long-term projection methodology for simulation of stock and catch development under different fishery scenarios and management objectives.

The SGMAB recommend that a **Study Group on Baltic Fish and Fisheries Dynamics** (SGBFFD) will be established. This group should have a wider geographical and ecological remit than was the case for SGMAB and thus it will form an improved linkage between scientific activities within physical, chemical and biological oceanography, as well as fish stock assessment, which is a pre-requisite for the ICES Strategic Plan and BSRP goals of developing and implementing a holistic approach to ecosystem and fisheries management in the Baltic.

This new group is expected to provide an essential interface with the Study Group on Multispecies Model Development (WGMSAM) and will be responsible for performing multispecies assessments for the Baltic by utilizing the models developed in WGMSAM. One of the main goals of the Group is also to develop the methodology further to integrate environmental information in fish stock assessment and prediction tools and to implement these in the assessment of Baltic cod, sprat and herring stocks.

1 Introduction

1.1 Participation

Eero Aro (Co-chair)	Finland
Georgs Kornilovs	Latvia
Fritz Köster (Co-chair)	Denmark
Stefan Neuenfeldt	Denmark
Eske Teschner	Germany
Paula Urrutia	Chile

A detailed list of contact addresses are given in Appendix 1.

1.2 Terms of Reference

SGMAB meeting was planned to take place 9-12 May 2006 in connection to EU-project BECAUSE meeting 15-19 May 2006 in Helsinki, Finland. These meetings would have support each other in implementing SMS model into the Baltic Sea. New SMS model was expected to be operative in May 2006, but for the Baltic that was not the case for various reasons. Checking the data and updating data bases for the model took more time than expected during the spring and that's why it was decided to postpone SGMAB meeting to November. Other reason to postpone the meeting was that in May we were expecting very low participation. Having the meeting in November did not help in this respect either.

According to Resolution of ICES 2005/2/BCC07 and decision made in April 2006 the Study Group on Multispecies Assessment in the Baltic [SGMAB] (Co-Chairs: E. Aro, Finland, and F. Köster, Denmark) will meet in Helsinki, Finland, from 2–7 November 2006 to:

- a) review the progress of the stomach sampling program, its sampling protocols and set-up of formats for inclusion of new information in the international stomach content database;
- b) update and correct the multispecies database (i.e. catch in numbers, maturity ogives, mean weight at age) for the Eastern and Western Baltic to enable bi-annual key-runs for both areas)
- c) validate of the consumption rates for Eastern Baltic, cod considering the impact of low oxygen concentration, and revise the Western Baltic consumption rates;
- d) develop a concept for inclusion of environmental sensitive and spatially explicit stock recruitment relationships into multispecies predictions;
- e) include coupled weight at age, proportion of maturity at age and consumption process models in multispecies prediction models;
- f) coordinate and interlink the SG with multispecies and ecosystem modeling activities in the Baltic with relevant BSRP Study Groups, ICES multispecies groups and EU-projects.
- g) explore the effect of heterogeneous distribution of predator and prey on species interactions in the Central Baltic and investigate the need and possibilities to integrate this heterogeneity into multispecies models;
- h) develop, apply and validate enhanced multispecies models, e.g. the Stochastic MultiSpecies model (SMS);
- i) implement and evaluate the suitable medium- to long-term projection methodology for simulation of stock and catch development under different fishery scenarios and management objectives;

- j) Take into account the recommendations of the Study Group on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB).

SGMAB will report by 15 December 2006 for the attention of the Baltic Committee.

2 Background information on Baltic Sea multispecies assessment

2.1 Overview of Baltic Sea multispecies assessment

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. Presently the following multispecies assessments and data are available for the Baltic Sea according to ICES sub-divisions (Figure 1.3.1):

Baltic Main Basin: Years 1974-2005

- cod in Sub-divisions 25-29+32
- sprat in Sub-divisions 25-32,
- herring in Sub-divisions 25-29+32 including Gulf of Riga,

Western Baltic: Years 1977-1999

- cod in Sub-divisions 22+24 (sub-division 23 included in 1996-1999),
- sprat in Sub-divisions 22-24,
- herring in Sub-divisions 22-24 including Division IIIa.

Baltic Main Basin: Years 1976-2005, area dis-aggregated MSVPA by Sub-divisions:

- cod in Sub-divisions 25, 26 and 28
- sprat in Sub-divisions 25, 26 and 28
- herring in Sub-divisions 25, 26 and 28

The catch at age in numbers database for cod in the Baltic Main Basin (SD 25-32) for the years 1974-76 was based on very limited age distribution data, and most of the landings have been split into age groups based on the data from only one country. Several datasets concerning the age distribution of the landings that have been collected by national laboratories for 1977-85, but were not included in the database. The work for compiling these additional data series for 1974-85 has been ongoing and the data available have been included in corrected for into the database.

In the case of Main Baltic herring, the multispecies assessment unit is not directly comparable to the units used by the Baltic Fisheries Assessment Working Group in single species assessment, excluding Gulf of Riga herring from the multispecies assessment. As the sprat population in Sub-division 30 is low and in sub-division 31 almost non existing, the Baltic Main Basin stock estimates are basically also referring to Sub-division 25-29, and 32. Consequently the effect of ignoring the two Sub-divisions should not hamper a direct comparison between single species and multispecies assessment output in the case of sprat and cod in the Baltic Sea Main Basin.

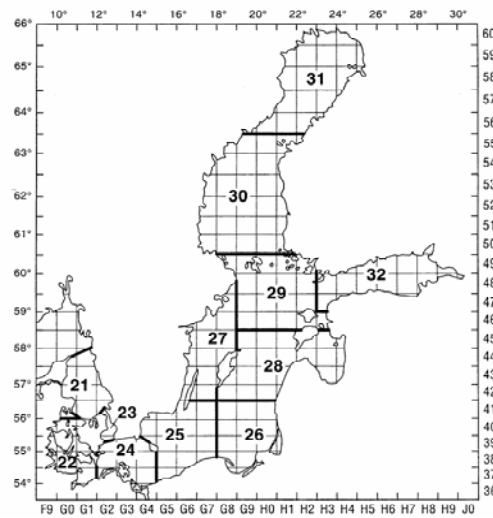


Figure 1.3.1. ICES Sub-divisions in the Baltic

2.2 Databases and supporting projects

Under the ICES framework the SGMAB has benefited from the activities of Baltic Fisheries Assessment Working Group (WGBFAS) and vice versa. WGBFAS has compiled the main input information needed for SGMAB since 1997, but some external work has been allocated to scrubbing the data for multispecies assessment purposes.

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 for cod. However there are still serious concerns about the functioning and the quality control of BITS (DATRAS) database held by ICES Headquarters. The database has not been in recent years in such form and shape that it is ready for use for various working groups and study groups for their assessment and extra analysis. This applies WGBFAS, WGBIFS and SGMAB meetings last three years.

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 (BAD1 and BAD2) can be used to establish a stock specific weight at age and abundance in more detailed form, however, not covering all quarters. This consequently requires modelling of seasonal growth to ensure complete seasonal coverage and correct mean weight at age by quarters to multispecies input.

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

Within European Union, SGMAB has benefited from results of number of completed and some of the 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.

European Union funded project BECAUSE (2004-2007, FP6 program under the title “Critical interactions between species and their implications for a precautionary fisheries management in a variable Environment - a Modelling Approach”) and PROTECT (2005-2008, “MPAs as a tool for ecosystem conservation and fisheries management”) play an important cooperative role in the multispecies work. BECAUSE covers the development of stochastic multispecies model for the entire Baltic Sea as well as coupling marine mammals and seabirds into the critical interactions. These critical biological interactions, which have a significant relevance for fisheries management and ecosystem functioning, are for example non-commercial top-predators, e.g. mammals and then important commercial species, e.g. cod/cod, cod/herring, cod/sprat, sprat/cod, seals/salmon interactions. In the new multispecies model (SMS model) it is possible to estimate high number of parameters and their variances.

The PROTECT program concentrates among other things to develop a suite of implementation, monitoring and assessment strategies in order to manage the fisheries impact on cod and clupeids stocks and the structure of upper trophic levels in the ecosystem.

At the beginning of year 2002 the European Union established a framework for the collection and management of data needed to evaluate the situation of the fishery resources and the fisheries sector in general and this sampling directive has been renewed for 2007-2013. In the Baltic Sea area the sampling directive is covering almost entire Baltic except the territorial waters of Russia which form round 8 % of the total Baltic area. In all EU countries round Baltic Sea, national programmes are defined for the collection and management of fisheries fish stock data. The programme cover the information strictly necessary for the scientific evaluations and moreover to define an extended Community programme which includes, in addition to the information of the minimum programme, 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 programme or under extended programme. Anyhow, the assessments of Baltic fish stocks will be very much dependent on these sampling schemes and minimum and extended programmes.

2.3 Justification for multispecies assessment in the Baltic Sea

It is likely 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 European Community and Government of Russia.

The maintenance of the data-base, data-base revision and updates, which incorporate basic multispecies products need input from various institutes and working and study groups. 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 has proven to be difficult because of lack of proper documentation and dis-aggregation of the primary data. The data base has been, however revised and completed now to the year 1974. The Eastern Baltic MSVPA covers years 1974-2005 and spatially dis-aggregated model years 1976-2005 for eastern Baltic. To update actual quarterly data-bases backwards to 1960's and early 1970's seems to be almost impossible and there are severe problems compiling quarterly catch at age and weight at age data by sub-divisions for Baltic herring and sprat.

There are considerable amounts of stomach content data for the 1960's and 1970's and this information would be very useful for estimation of consumption rates and understand cod cannibalism. Some new stomach data has been collected under the umbrella of BSRP (“Baltic Sea Regional Program” on Large Marine Ecosystems).

From inspection of the original stomach content data, cannibalism appears to be related to the prey sizes. 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 both in BECAUSE and BSRP.

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 2005. The results are sensitive to 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 Sub-divisions. 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 programme, which contain MSVPA and it's routines including the tuning module, have been run without problems. The present programme package enables for example WGBFAS to run MSVPA's on a regular basis and a practical user manual giving specification and documentation of the 4M package is 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 CORE, STORE and German GLOBEC projects, but the relationships between various processes and hydrodynamics need still some exploration.

Reference points, stated in terms of fishing mortality rates or biomass and management plans are key concepts in implementing precautionary approaches in fishery management. It has been agreed, but not fully under-stood, that reference points are effected by species interactions, and do hold only in the single-species context. For multispecies situations the sustainability concept seems to be difficult. If sustainability is considered as an ability of an ecosystem to maintain in a healthy state, the ecological processes and functions, biological diversity and productivity for very long time, then the key factors challenging the use of marine resources in a sustainable way must include anthropogenic forcing of ecosystem, e.g. habitat alteration and destruction, water quality impairment and global climate change. Reference points are far away from being adequately defined given the limited understanding of the processes in the environment, 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 versions of multispecies models (4M and SMS) are 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, 4M programme is not able to incorporate environmental processes into stock recruitment relation-ships, but SMS has that capability. The inclusion of environmental variability in

predictions is worthwhile when assess-ing the impact of various management and fishing strategies on the stock development under different environmental conditions.

3 Status of the multispecies database

3.1 Stock units

3.1.1 Stocks in the Central Baltic (Sub-divisions 25-32)

The stock units utilized in the present MSVPA for the Central Baltic are as presented in the section 2.1: i) cod in Sub-divisions 25-29+32, ii) sprat in Sub-divisions 25-32, and iii) herring in Sub-divisions 25-29, 32 (Gulf of Riga included). As the sprat population in Sub-division 30 and 31 is rather low (landings are less than 5000 t in most recent years), the stock estimate is basically also referring to Sub-division 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 Sub-division 30 and 31. Landings reported in these Sub-divisions 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 Sub-divisions 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.

3.1.2 Herring stock units in the Central Baltic

Until 2002 the herring stock assessment in the Central Baltic was based on Herring in the SD 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&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&32 including Gulf of Riga;
- 2) Herring in the SD 25-29&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&32 excluding Gulf of Riga and Herring in the Gulf of Riga. Such practice has been maintained in later 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&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 will deviate significantly from the Gulf of Riga. Therefore it is suggested also in MSVPA to use data of herring stock in SD 25-29&32 excluding Gulf of Riga, to be consistent in the 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& 32 excluding Gulf of Riga. Such data compilation for separation of these two herring units in the MSVPA could require approximately 1-2 months working time, to be allocated by the Leibniz Institute of Marine Sciences in Kiel and the Latvian Fish Resources Agency in Riga.

3.1.3 Stocks in the Western Baltic (Sub-divisions 22-24 and Division IIIa)

In previous MSVPA runs for the Western Baltic, following the stock units used by the single species assessment Working Groups, three different stocks are considered in the Western Baltic:

Cod in Sub-divisions 22-24

Sub-division 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 Sub-division 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 1998/ACFM:16). The exclusion before is expected to be of minor importance.

Herring in Sub-divisions 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 Sub-divisions 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 Sub-divisions 22-24

The data-base for sprat has been taken and implemented in a form as provided by the Baltic Fisheries Assessment Working Group for Sub-divisions 22-24 (including 23). The basic data-base of sprat consists of data for Sub-divisions 22-32 as a single stock.

3.2 Database updates

Before the meeting of the Study Group on Multispecies Assessment in the Baltic this year, the quarterly catch-at-age and weight-at-age data by Subdivisions for the eastern Baltic cod stock (SD 25-32) in the years 1974-1992 was revised. Several recovered data series were included, improving considerably the data coverage especially for the earliest years of the database. The included data were obtained from the national reports presented to ICES, from Kosior (1985, 1986) and Berner & Borrmann (1980, unpublished updates from the authors).

The need for better documentation of the existing multispecies database was emphasized. During the revision of the database this year, the originally applied data substitution and calculation procedures were recovered for the eastern Baltic cod for the years 1974-1992. Subsequently, the availability of original catch-at-age and weight-at-age data and substitutions by countries, Subdivisions and quarters were documented for this part of the database and are provided in Tables 2.3.1 and 2.3.2. For the other stocks and time-periods this task needs to be done in the future.

The detailed description of the new changes made in the catch-at-age and weight-at-age data for the eastern Baltic cod stock for 1974-1992 is given below.

Catch-at-age

1974 age distribution data (%) added: Poland SD 25 Q1 and SD 26 Q1; FRG SD 25-28 Q1-2; GDR SD 25 Q1-2 and SD 26 Q1-2 and USSR SD 26-32 Q1-4. For USSR only annual mean age distribution (%) for 1974 was available. Quarterly proportions of catch numbers were calculated based on information on quarterly age distribution and respective annual mean for 1975.

1975 age distribution data (%) added: Poland SD 25 Q1 and SD 26 Q1; FRG SD 25-28 Q1-2; GDR SD 25 Q1-2 and SD 26 Q1-2.

1976 age distribution data (%) added: Poland SD 25 Q1,Q2,Q3,Q4 and SD 26 Q1,Q2,Q3,Q4; FRG SD 25-28 Q1-2; GDR SD 25 Q1-2 and SD 26 Q1-2.

1974-1976 the catch numbers of USSR for SD 29 were calculated using USSR age composition data for SD 26-32 (Finnish data for SD 29-32 were applied in earlier version of the database) in order to keep consistency with the procedures applied for later years.

1977 age distribution data (%) added: Poland SD 25 Q1,Q2 and SD 26 Q1,Q2,Q4; FRG SD 25-28 Q1-2; GDR SD 25 Q1-2 and SD 26 Q1-2

The included age distribution data for 1974-1977 were only available as percentages, without respective information on weight at age. Mean weight-at-age for 1977 for respective quarters and Subdivisions from the MSVPA database was used to calculate catch numbers. USSR weight-at-age data for 1975 in respective quarters were used to calculate USSR catch numbers for 1974.

1978 age distribution data (%) added: Poland SD 25 Q1,Q2,Q3,Q4 and SD 26 Q1,Q2,Q3,Q4 ; FRG SD 25-28 Q1-2; GDR SD 25 Q1-2 and SD 26 Q1-2

1979 age distribution data (%) added: Poland SD 25 Q1,Q2,Q3,Q4 and SD 26 Q1,Q2,Q3,Q4; FRG SD 25-28 Q1-2

Mean weight-at-age in 1978 and 1979 in respective quarters and Subdivisions from the MSVPA database was used to calculate GDR and FRG catch numbers.

1980-1984 age distribution data (%) added: Poland SD 25 Q1 and SD 26 Q1

1985 age distribution data (%) added: Poland SD 26 Q1

Polish catch numbers for SD 25 in 1980-84 were calculated using mean weight-at-age from the MSVPA database in respective quarter and Subdivision.

Slight changes were made into substitution of lacking age composition data for 1980, 1981, 1983, 1985 in SD 25 in accordance to the substitution scheme (ICES CM 1997/J:2).

1985-1990 in the previous version of the database, Danish cod landings were treated in the substitution process as all taken in SD25, however these were split into Subdivisions some years after the first compilation of the MSVPA database (ICES CM 1999/H:5). Respective changes were now incorporated into substitution process.

1989 error in substitution process concerning Swedish catch numbers for SD 29 was corrected. Inconsistency in substitution process in relation to Polish catch numbers in Q3, Q4 in SD 26 was corrected.

1990 age distribution data (%) added: USSR SD 26-32 Q1,Q2,Q3,Q4 and Poland SD 26 Q1

Polish catch numbers were calculated using mean weight-at-age from the MSVPA database in respective quarter and Subdivision.

1991 errors in calculating Polish and Swedish catch numbers for SD 25 and 26 were corrected.

Weight-at-age

1978- 1979 data added: Poland SD 25 Q1,Q2,Q3,Q4

1980- 1985 data added: Poland SD 26 Q1

1990 data added: USSR SD 26-32 Q1, Q2, Q3, Q4

1986 error in calculating mean weight-at-age in SD 25 was corrected.

1991 error in calculating mean weight-at-age by Subdivisions was corrected.

Mean weight-at-age by Subdivisions in these years where new data were added was recalculated following the same procedure originally applied in database compilation (see Table 2.3.2 for documentation of the procedure).

The time series of mean weight-at age by quarters for the total stock in SD 25-32 (the mean weight-at-age of Subdivisions weighted by respective catch numbers) in 1974-91 was recalculated, due to changes both in weight-at-age and in catch numbers.

Table 2.3.1. Availability of original quarterly age composition data and respective substitutions for cod (SD 25-32) by Subdivisions and countries. Shaded areas mark the availability of the original data. General substitution scheme is presented in ICES CM 1997/J.2, additional details of the procedures are described in the footnotes of the table. The format e.g. 1.II.Q indicates that data are available separately for these quarters, while the format 1.II.Q refers to one dataset representing given quarters.

Year	SD	SWE	DK	FRG	GDR	POL	USSR	FAR	FIN
1974	25	FRG/GDR/POL	FRG/GDR/POL	FRG SD 25-28 1.II.Q ¹	GDR SD 25 1.II.Q	POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q ²		
1974	26			FRG SD 25-28 1.II.Q ¹	GDR SD 26 1.II.Q	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q ²		
1974	27	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1974	28	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1974	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1975	25	FRG/GDR/POL	FRG/GDR/POL	FRG SD 25-28 1.II.Q	GDR SD 25 1.II.Q	POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q ²		
1975	26			FRG SD 25-28 1.II.Q ¹	GDR SD 26 1.II.Q	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q ²		
1975	27	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1975	28	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1975	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1976	25	FRG/GDR/POL	FRG/GDR/POL	FRG SD 25-28 1.II.Q	GDR SD 25 1.II.Q	POL SD 25 1.II.III.IV.Q	FRG/GDR/POL		
1976	26			FRG SD 25-28 1.II.Q ¹	GDR SD 26 1.II.Q	POL SD 26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q ²		
1976	27	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1976	28	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1976	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1977	25	FRG/GDR/POL	FRG/GDR/POL	FRG SD 25-28 1.II.Q	GDR SD 25 1.II.Q	POL SD 25 1.II.IV.Q	USSR SD 26-32 1.II.III.IV.Q		
1977	26			FRG SD 25-28 1.II.Q ¹	GDR SD 26 1.II.Q	POL SD 26 1.II.IV.Q	USSR SD 26-32 1.II.III.IV.Q		
1977	27	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1977	28	SWE SD 25					USSR SD 26-32 1.II.III.IV.Q ²		
1977	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1978	25	FRG/GDR/POL	FRG/GDR/POL	FRG SD 25-28 1.II.Q	GDR SD 25 1.II.Q	POL SD 25 1.II.III.IV.Q	FRG/GDR/POL		
1978	26			FRG SD 25-28 1.II.Q ¹	GDR SD 26 1.II.Q	POL SD 26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q ²		
1978	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1978	28	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1978	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1979	25	POL/FRG	POL/FRG	FRG SD 25-28 1.II.Q	POL/FRG	POL SD 25 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1979	26	USSR/POL		FRG SD 25-28 1.II.Q ¹	USSR/POL	POL SD 26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q		
1979	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1979	28	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1979	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1979	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q

Year	SD	SWE	DK	FRG	GDR	POL	USSR	FAR	FIN
1980	25	DK/FRG/POL	DK SD 25-32 1.II.Q	FRG SD 25-28 1.II.Q ¹		POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q		
1980	26	USSR		FRG SD 25-28 1.II.Q ¹	USSR/POL	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1980	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1980	28	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1980	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1980	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1981	25	DK/FRG/POL	DK SD 25-32 1.II.Q	FRG SD 25-28 1.II.Q		POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1981	26	USSR/POL			USSR	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q		
1981	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1981	28	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1981	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1981	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1982	25	FRG/DK/POL	DK SD 25-32 1.II.Q	FRG SD 25-28 1.II.Q ¹		POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1982	26	USSR/POL		FRG SD 25-28 1.II.Q ¹	USSR	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q		
1982	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1982	28	SWE SD 25 / SD26			USSR		USSR SD 26-32 1.II.III.IV.Q ²		
1982	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1982	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1983	25	DK/FRG/POL	DK SD 25-32 1.II.Q	FRG SD 25-28 1.II.Q		POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1983	26	USSR/POL		FRG SD 25-28 1.II.Q ¹	USSR/POL	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q		
1983	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1983	28	SWE SD 25 / SD26			USSR		USSR SD 26-32 1.II.III.IV.Q ²		
1983	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1983	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1984	25	DK/FRG/POL	DK SD 25-32 1.II.Q	FRG SD 25-28 1.II.Q		POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1984	26	USSR/POL		FRG SD 25-28 1.II.Q ¹	USSR/POL	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q		
1984	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1984	28	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1984	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1984	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1985	25	DK/FRG	DK SD 25-32 1.II.Q	FRG SD 25-28 1.II.Q		POL SD 25 IQ	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1985	26	USSR/POL		FRG SD 25-28 1.II.Q ¹	USSR/POL	POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q		
1985	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1985	28	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1985	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1985	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q

Year	SD	SWE	DK	FRG	GDR	POL	USSR	FAR	FIN
1986	25	DK/FRG/POL	DK SD 25-32 1.II.III.IV.Q	FRG SD 25-28 1.II.Q		POL SD (25)-26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1986	26	USSR/POL	DK SD 25-32 1.II.III.IV.Q ¹	FRG SD 25-28 1.II.Q ¹	USSR/POL	POL SD (25)-26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q		
1986	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1986	28	SWE SD 25 / SD26	DK SD 25-32 1.II.III.IV.Q ¹				USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1986	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1986	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1987	25	DK/POL	DK SD 25-32 1.II.III.IV.Q	FRG SD 25-28 1.II.Q		POL SD (25)-26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1987	26	USSR/POL	DK SD 25-32 1.II.III.IV.Q ¹	FRG SD 25-28 1.II.Q ¹		POL SD (25)-26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q		
1987	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1987	28	SWE SD 25 / SD26	DK SD 25-32 1.II.III.IV.Q ¹	FRG SD 25-28 1.II.Q ¹			USSR SD 26-32 1.II.III.IV.Q ²		
1987	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1987	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1988	25	DK/FRG/POL	DK SD 25-32 1.II.III.IV.Q	FRG SD 25-28 1.II.Q	DK/POL	POL SD (25)-26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1988	26	USSR/POL	DK SD 25-32 1.II.III.IV.Q ¹	FRG SD 25-28 1.II.Q ¹		POL SD (25)-26 1.II.III.IV.Q	USSR SD 26-32 1.II.III.IV.Q		
1988	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1988	28	SWE SD 25 / SD26	DK SD 25-32 1.II.III.IV.Q ¹	FRG SD 25-28 1.II.Q ¹			USSR SD 26-32 1.II.III.IV.Q ²		
1988	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1988	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1989	25	DK/FRG/POL	DK SD 25-32 1.II.III.IV.Q	FRG SD 25-28 1.II.III.Q	DK/FRG/POL	POL SD (25)-26 1.II.Q	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1989	26	USSR/POL	DK SD 25-32 1.II.III.IV.Q ¹	FRG SD 25-28 1.II.III.Q ¹		POL SD (25)-26 1.II.Q	USSR SD 26-32 1.II.III.IV.Q		
1989	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1989	28	SWE SD 25 / SD26	DK SD 25-32 1.II.III.IV.Q ¹				USSR SD 26-32 1.II.III.IV.Q ²		SWE SD 25 / SD26
1989	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1989	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1990	25	DK/FRG	DK SD 25-32 1.II.III.IV.Q	FRG SD 25-28 1.II.Q		DK/FRG			
1990	26	USSR/POL	DK SD 25-32 1.II.III.IV.Q ¹	FRG SD 25-28 1.II.Q ¹		POL SD 26 IQ	USSR SD 26-32 1.II.III.IV.Q	USSR/POL	
1990	27	SWE SD 25 / SD26					USSR SD 26-32 1.II.III.IV.Q ²		
1990	28	SWE SD 25 / SD26	DK SD 25-32 1.II.III.IV.Q ¹				USSR SD 26-32 1.II.III.IV.Q ²		SWE SD 25 / SD26
1990	29	FIN					USSR SD 26-32 1.II.III.IV.Q ²		FIN SD 29-32 1.II.III.IV.Q
1990	32						USSR SD 26-32 1.II.III.IV.Q		FIN SD 29-32 1.II.III.IV.Q
1991	25	SWE SD 25-31 1.II.Q	DK SD 25-32 1.II.III.IV.Q	FRG SD 25-28 1.II.III.IV.Q		POL SD 26 1.II.IV.Q ³			
1991	26	f. USSR/POL (FRG ⁴)		FRG SD 25-28 1.II.III.IV.Q ⁵		POL SD 26 1.II.IV.Q	f. USSR SD 26-32 1.II.III.IV.Q	f. USSR/POL	
1991	27	SWE SD 25 / SD26							
1991	28	SWE SD 25 / SD26					f. USSR SD 26-32 1.II.III.IV.Q ⁶		SWE SD 25 / SD26
1991	29	FIN							FIN SD 29-32 1.II.III.IV.Q
1991	32								

Year	SD	SWE	DK	FRG	GDR	POL	USSR	FAR	FIN
1992	25	DK/POL	DK SD 25-32 1.II.III.IV.Q	DK/POL		POL (25)-26 1.II.III.IV.Q			
1992	26	POL		POL		POL (25)-26 1.II.III.IV.Q	POL	POL	
1992	27	SWE SD 25 / SD26							
1992	28	SWE SD 25 / SD26							
1992	29	FIN							SWE SD 25 / SD26
1992	32								

¹ the age distribution data that refer to several Subdivisions (e.g. SD 25-28) were applied on catches of a given country in all respective Subdivisions, but in substitution procedure these were included only in SD 25

² only annual mean age distribution data were available for 1974; quarterly shares were calculated based on information on quarterly and annual mean age distribution in 1975. These calculated age distributions were applied for USSR catches in all Subdivisions, but not included in substitution procedure

³ the age distribution data that refer to several Subdivision (e.g. SD 26-32) were applied for catches of a given country in all respective Subdivisions, but in substitution procedure these were included only in SD 26

⁴ FRG 1I.Q data were applied only for FRG catches, not included in substitution procedure

⁵ applied only for Polish catches

⁶ FRG age distribution data were applied in substitution procedure only for 1I.Q, in the other quarters these data are applied only for FRG catches

Table 2.3.2. Availability of original weight-at-age data and respective substitutions by Subdivisions and quarters (see the footnote* of the table for description of calculation procedures). Shared areas mark the availability of the original data. The format e.g. I-IIQ refers to one series of data representing given quarters.

Year	Quarter	25	26	27	28	29	32
1977	I	POL SD 25-26	USSR SD 26-32	POL/USSR ¹	POL/USSR ¹	FIN SD 29-32	FIN
1977	II	POL SD 25-26	USSR SD 26-32	POL/USSR ¹	POL/USSR ¹	FIN SD 29-32	FIN
1977	III	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1977	IV	POL SD 25-26	USSR SD 26-32	POL/USSR ¹	POL/USSR ¹	FIN SD 29-32	FIN
1978	I	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1978	II	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1978	III	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1978	IV	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1979	I	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1979	II	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1979	III	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1979	IV	POL SD 25	USSR SD 26-32 / POL SD 26	USSR/POL SD 25-26	USSR/POL SD 25-26	FIN SD 29-32	FIN
1980	I	FRG SD 25-28 I-IIQ	USSR SD 26-32 / POL SD 26	FRG/USSR/POL	FRG/USSR/POL	FIN SD 29-32	FIN
1980	II	FRG SD 25-28 I-IIQ	USSR SD 26-32	FRG/USSR	FRG/USSR	FIN SD 29-32	FIN
1980	III	FRG SD 25-28 I-IIQ	USSR SD 26-32	FRG/USSR	FRG/USSR	FIN SD 29-32	FIN
1980	IV	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1981	I	FRG SD 25-28 I-IIQ	USSR SD 26-32 / POL SD 26	FRG/USSR/POL	FRG/USSR/POL	FIN SD 29-32	FIN
1981	II	FRG SD 25-28 I-IIQ	USSR SD 26-32	FRG/USSR	FRG/USSR	FIN SD 29-32	FIN
1981	III	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1981	IV	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1982	I	FRG SD 25-28 I-IIQ	USSR SD 26-32 / POL SD 26	FRG/USSR/POL	FRG/USSR/POL	FIN SD 29-32	FIN
1982	II	FRG SD 25-28 I-IIQ	USSR SD 26-32	FRG/USSR	FRG/USSR	FIN SD 29-32	FIN
1982	III	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1982	IV	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1983	I	FRG SD 25-28 I-IIQ	USSR SD 26-32 / POL SD 26	FRG/USSR/POL	FRG/USSR/POL	FIN SD 29-32	FIN
1983	II	FRG SD 25-28 I-IIQ	USSR SD 26-32	FRG/USSR	FRG/USSR	FIN SD 29-32	FIN
1983	III	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1983	IV	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1984	I	FRG SD 25-28 I-IIQ	USSR SD 26-32 / POL SD 26	FRG/USSR/POL	FRG/USSR/POL	FIN SD 29-32	FIN
1984	II	FRG SD 25-28 I-IIQ	USSR SD 26-32	FRG/USSR	FRG/USSR	FIN SD 29-32	FIN
1984	III	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1984	IV	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1985	I	FRG SD 25-28 I-IIQ	USSR SD 26-32 / POL SD 26	FRG/USSR/POL	FRG/USSR/POL	FIN SD 29-32	FIN
1985	II	FRG SD 25-28 I-IIQ	USSR SD 26-32	FRG/USSR	FRG/USSR	FIN SD 29-32	FIN
1985	III	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1985	IV	USSR	USSR SD 26-32	USSR	USSR	FIN SD 29-32	FIN
1986	I	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1986	II	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1986	III	DK SD 25-32 / POL SD 25-26	USSR SD 26-32	DK/POL/USSR	DK/POL/USSR	FIN SD 29-32	FIN
1986	IV	DK SD 25-32 / POL SD 25-26	USSR SD 26-32	DK/POL/USSR	DK/POL/USSR	FIN SD 29-32	FIN
1987	I	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1987	II	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1987	III	DK SD 25-32 / POL SD 25-26	USSR SD 26-32	DK/POL/USSR	DK/POL/USSR	FIN SD 29-32	FIN
1987	IV	DK SD 25-32 / POL SD 25-26	USSR SD 26-32	DK/POL/USSR	DK/POL/USSR	FIN SD 29-32	FIN
1988	I	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1988	II	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1988	III	DK SD 25-32 / POL SD 25-26	USSR SD 26-32	DK/POL/USSR	DK/POL/USSR	FIN SD 29-32	FIN
1988	IV	DK SD 25-32 / POL SD 25-26	USSR SD 26-32	DK/POL/USSR	DK/POL/USSR	FIN SD 29-32	FIN
1989	I	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1989	II	DK SD 25-32 / FRG SD 25-28 / POL SD 25-26	USSR SD 26-32	DK/FRG/POL/USSR	DK/FRG/POL/USSR	FIN SD 29-32	FIN
1989	III	DK SD 25-32 / FRG SD 25-28	USSR SD 26-32	DK/FRG/USSR	DK/FRG/USSR	FIN SD 29-32	FIN
1989	IV	DK SD 25-28	USSR SD 26-32	DK/USSR	DK/USSR	FIN SD 29-32	FIN
1990	I	DK SD 25-32 / FRG SD 25-28	USSR SD 26-32	DK/FRG/USSR	DK/FRG/USSR	FIN SD 29-32	FIN
1990	II	DK SD 25-32 / FRG SD 25-28	USSR SD 26-32	DK/FRG/USSR	DK/FRG/USSR	FIN SD 29-32	FIN
1990	III	DK SD 25-32	USSR SD 26-32	DK/USSR	DK/USSR	FIN SD 29-32	FIN
1990	IV	DK SD 25-32	USSR SD 26-32	DK/USSR	DK/USSR	FIN SD 29-32	FIN
1991	I	DK SD 25-32 / FRG SD 25-28 I-IIQ / SWE SD 25-31 I-IIQ	USSR SD 26 / POL SD 26	DK/GE/SWE/USSR/POL	DK/GE/SWE/USSR/POL	FIN SD 29-32	FIN
1991	II	DK SD 25-32 / FRG SD 25-28 I-IIQ	USSR SD 26 / POL SD 26	DK/GE/USSR/POL	DK/GE/USSR/POL	FIN SD 29-32	FIN
1991	III	DK SD 25-32 / FRG SD 25-28 III-IVQ / SWE SD 25-31 III-IVQ	USSR SD 26	DK/GE/SWE/USSR	DK/GE/SWE/USSR	FIN SD 29-32	FIN
1991	IV	DK SD 25-32 / FRG SD 25-28 III-IV Q	USSR SD 26 / POL SD 26	DK/GE/USSR	DK/GE/USSR	FIN SD 29-32	FIN
1992	I	DK SD 25-32 / POL SD 25	DK/USSR SD 26	DK/POL / T USSR	DK/POL / T USSR	FIN SD 29-32	FIN
1992	II	DK SD 25-32 / POL SD 25	DK/POL	DK/POL	DK/POL	FIN SD 29-32	FIN
1992	III	DK SD 25-32 / POL SD 25	DK/POL	DK/POL	DK/POL	FIN SD 29-32	FIN
1992	IV	DK SD 25-32 / POL SD 25	DK/POL	DK/POL	DK/POL	FIN SD 29-32	FIN

*when weight-at-age data for a given Subdivision were available from more than one country, these were averaged, weighted by total catch numbers of respective countries (e.g. while calculating mean WAA in SD 25 based on the data from two countries referring to SD 25-32 and SD 25-26, these data were averaged, weighting with catch numbers of these countries in SD 25-32 and in SD 25-26, respectively). Weight-at-age in Subdivisions where no data were available (non-shaded areas in the table) were calculated as the average of the other Subdivisions inside the areas SD 25-28 and SD 29-32, weighted by total catch numbers of these countries where weight data were available (as described above).

4 Cod stomach content data

4.1 Background information on cod stomach data

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 1960's and 1970's. 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.

Regular sampling of the cod stomachs is being performed in Latvian Fish Resources Agency (LATFRA). In recent years the stomach samples were collected in bottom trawl surveys (BITS) in Subdivisions 26 and 28 in March and November. Stomachs of cod greater than 20 cm were sampled in 2000-2005. The stomachs were collected from the bottom trawl (TV3-520). Stomachs for the pelagic cod were sampled during acoustic survey in May and October 2005. The number of stomachs sampled was 104 and 30 respectively. Cod stomachs were collected from catches of pelagic trawl which is used in hydro-acoustic surveys and is targeting concentrations of pelagic fishes. In total in BITS and hydro-acoustic surveys 2571 stomachs have been analysed and are reported to the data-base. The cod stomachs were taken from the biological analyses of the cod catch and preserved in the 70-80% ethyl alcohol.

In laboratory each stomach was inspected individually. Each prey in a stomach was identified to the lowest possible taxonomic level. Digested herring and sprat was separated based on the morphology of their vertebra. For the intact or slightly digested fish the length (total length in mm) was measured. For the digested clupeids the length of the fish was guessed from what was left. These fishes could be later classified as belonging to different size classes (herring: <10cm, 10-15, 15-20 and >20cm and sprat <10, 10-15cm).

The database files give information about the cod stomach content on herring, sprat, cod, other fishes, *Mesidotea entomon* and other invertebrates. Furthermore, information about the length, weight of the prey fish species is included. The stomachs content data were compiled in reporting forms agreed upon by the Study Group on cod stomach data for Baltic (C.M. 1989/J: 2). All information is given per sub-division and per month. There are two types of files. The first one contains general information about stomach content in weight and stomach content per prey item in weight (g) per one cod of a certain length group. The second prey (clupeids) length file gives information on prey length, prey weight and prey number in given length or size class. The prey (clupeids) length for March and November are reported in two separate files.

The Latvian data have been processed using the same stomach content analyses method and reported in the same format as the data for years 1977-1989.

Cod stomachs were also collected by Sea Fisheries Institute (MIR) in Gdynia Poland during three national surveys when approx. 200 stomachs were collected in each of them. The collected cod stomachs were sent to LATFRA where they were analysed and the results submitted to MIR. Other national laboratories have not informed SGMAB whether they collected cod stomachs in 2005-2006.

It is known that regular cod stomach sampling is performed also by AtlantNIRO in Kaliningrad Russia. However, information on these activities was not available to SGMAB.

Sea Fisheries Institute (MIR) is planning to start regular collection of cod stomach samples as well as their analysis. In this connection specialist from MIR visited LATFRA for one week cod stomach analysis training courses which were conducted by Dana Uzars. The expenses of training courses were covered by Baltic Sea Regional Project (BSRP).

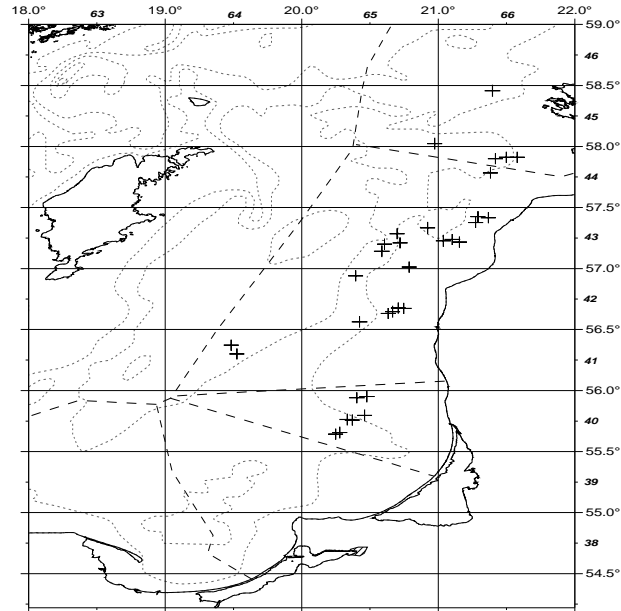


Figure 4.1.1. Sampling areas for cod stomachs by Latvia in 2000-2005

5 Validation of consumption rates for eastern baltic cod and the impact of low oxygen concentration

5.1 Consumption Rates

Gastric evacuation models used for the Baltic Sea and North Sea to estimate consumption rates consider environmental temperatures and predator weights as additional variables (Temming 1996) but do not account for a potential impact of ambient oxygen saturation on gastric evacuation of Baltic cod. Both bottom trawl surveys and hydroacoustic investigations have shown that cod is exposed to low oxygen concentrations in the deeper basins of the Central and Western Baltic Sea (Tiews 1982, 1984, 1986; Tomkiewicz *et al.*, 1998). Furthermore, physiological investigations could show a significant influence of oxygen concentration on metabolism of fish (Brett, 1979; Jobling, 1994). Low oxygen saturation leads to a loss in appetite which is reflected by both reduced stomach contents as well as reduced gastric evacuation (Brach, 1999). Preliminary experiments on the impact of lower oxygen concentrations on the gastric evacuation rate indicated differences in the decrease of stomach content over time in reduced oxygen conditions (Brach, 1999).

5.1.1 Description of the present evacuation and consumption model

Temming and Andersen (1994) developed an evacuation model based on the general model of gastric evacuation, modified by Temming (1996). Extensive data obtained from stomach evacuation experiments were utilized to estimate the model parameters adequately (Temming, 1996), allowing to compute age-specific consumption rates in dependence of stomach content, predator weights and ambient temperatures.

Quarterly consumption per age-group in a given year was calculated as:

$$K_q = R' * W^C * e^{A*T} * S_{corr}^B * 24 * 91 * k$$

This procedure includes a correction for empty stomachs described in ICES (1999H:5). In the central Baltic the evacuation model was used with the general temperature coefficient $A = 0.13$ (ICES, 1997/J:2) and the prey specific coefficients $B=0.511$, $R'=0.00504$ and $C=0.295$. Average age-specific quarterly consumption rates were estimated by subdivision as described in ICES (1999/H:5).

5.1.2 Development of an alternative evacuation and consumption model

An alternative evacuation model was developed, which should account for a slower stomach evacuation rate under reduced oxygen concentrations, as found in laboratory experiments (Brach 1999). These experiments indicated a significant impact of oxygen saturation on the residual amount of food in the stomach within the course of 36 hours after food ingestion. Exponential decay functions were fitted to the experimental data (Fig. 5.1.1) and from these functions the stomach evacuation rates per hour were calculated for different oxygen conditions (Fig. 5.1.2a).

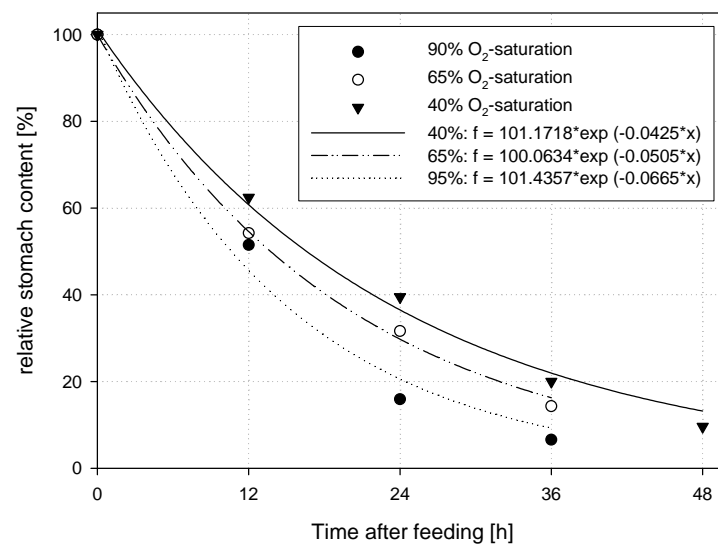


Fig. 5.1.1. Oxygen-dependant stomach evacuation. Fitted exponential functions to the results of Brach (1999).

Caused by a limited amount of data points and the risk of under- or overestimation of consumption at different saturation levels using a simple linear regression, we decided to establish a linear relationship with structural interruption at 65% oxygen saturation. Furthermore both functions were scaled to give $f(y_{\leq 35})$ an intercept of 1, i.e. assuming no influence on the evacuation rate at 100% oxygen saturation (Fig. 5.1.2b).

Resulting linear functions were:

$$y_{\leq 35} = 1 + (-0.0017 x) \quad \text{for } x \leq 35$$

$$y_{> 35} = 1.4325 + (-0.0141 x) \quad \text{for } x > 35$$

These determined functions with the structural interruption at 35% reduction in oxygen saturation (expressed as % reduction from full saturation) were incorporated as a multiplicative term and formed the new, oxygen-sensitive conceptual consumption model:

$$1: \quad K_q = R' * ((1 + (a_{\leq 35} * S_a)) * W^C * e^{A*T} * S^B * 24 * k * 91) \quad \text{for } x \leq 35$$

$$2: \quad K_q = R' * ((1.4325 + (a_{> 35} * S_a)) * W^C * e^{A*T} * S^B * 24 * k * 91) \quad \text{for } x > 35$$

With the reduction in ambient oxygen concentration S_a in %

and the determined oxygen coefficient
0.0141.

$$a_{\leq 35} = -0.0017 \text{ \& } a_{> 35} = -$$

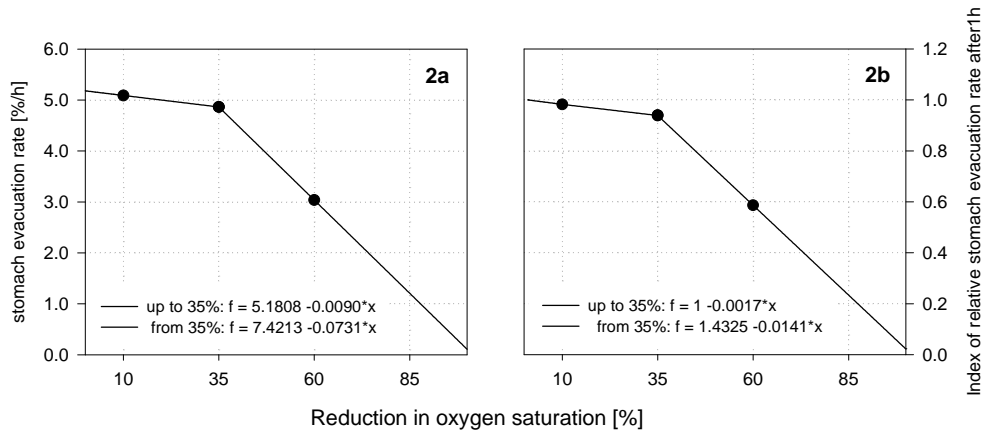


Figure. 5.1.2: Relative stomach evacuation rate of cod (a) and index of relative stomach evacuation rate of cod after 1h (b) in relation to ambient oxygen saturation (expressed as % reduction from full saturation).

5.2 Input Data for Consumption Rates Models

5.2.1 Ambient temperatures and oxygen saturations

Ambient temperatures were calculated based on the ICES hydrographic database. For the period 1976-2005 quarterly mean temperatures were calculated for considered ICES-Subdivision (25, 26 and 28). In a first step mean temperatures were calculated for depth strata and afterwards weighted ambient temperatures were obtained by accounting for the distribution of cod over depth strata (from BIT-Survey). The relative depth-specific distribution of cod was determined for 3 different groups independently (i) cod age-class 1, (ii) cod age-class 2 and (iii) cod age 3+. Mean weighted oxygen saturations were calculated accordingly.

In the standard MSVPA setup the distribution patterns of cod are derived from an analysis of the Baltic International Trawl Survey (BITS) database which is based on catches of the 1st quarter. The derived distribution is then kept constant for the rest of the year.

When preparing the input data for the analysis in intersessional work, BITS-data for the years 2004 and 2005 there not available. Because of an exceptional inflow situation in 2003, we assumed the hydrographical situation in 2001 and 2002 to correspond with the situation in 2004 and 2005. Thus, mean temperature per depth strata and quarter over the years 2001 and 2002 were applied as input for 2004 and 2005 (see Figs. 5.2.1-5.2.3).

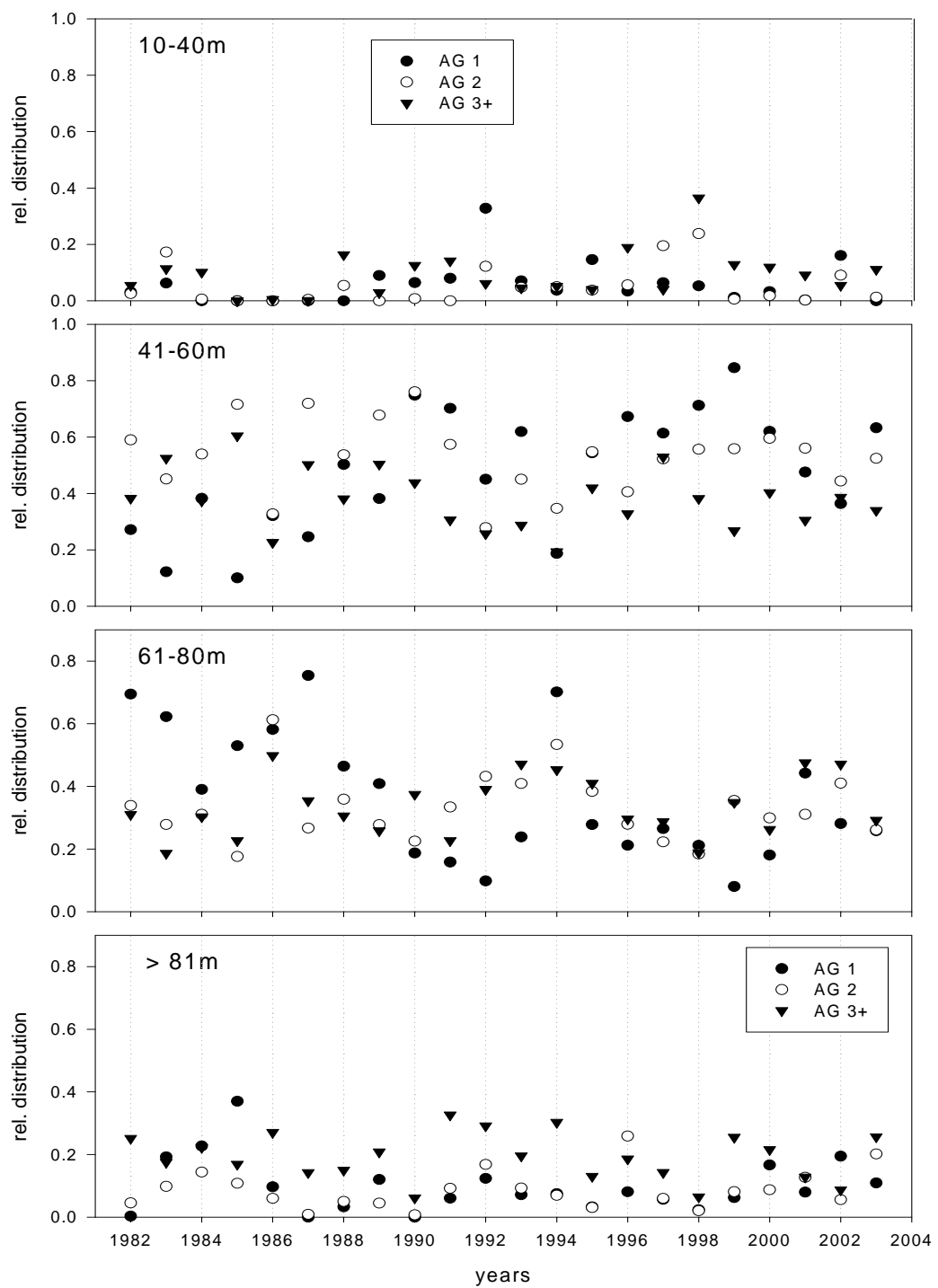


Figure 5.2.1: Relative depth distribution of cod in different depth strata in SD 25 based on BITS-data analysis

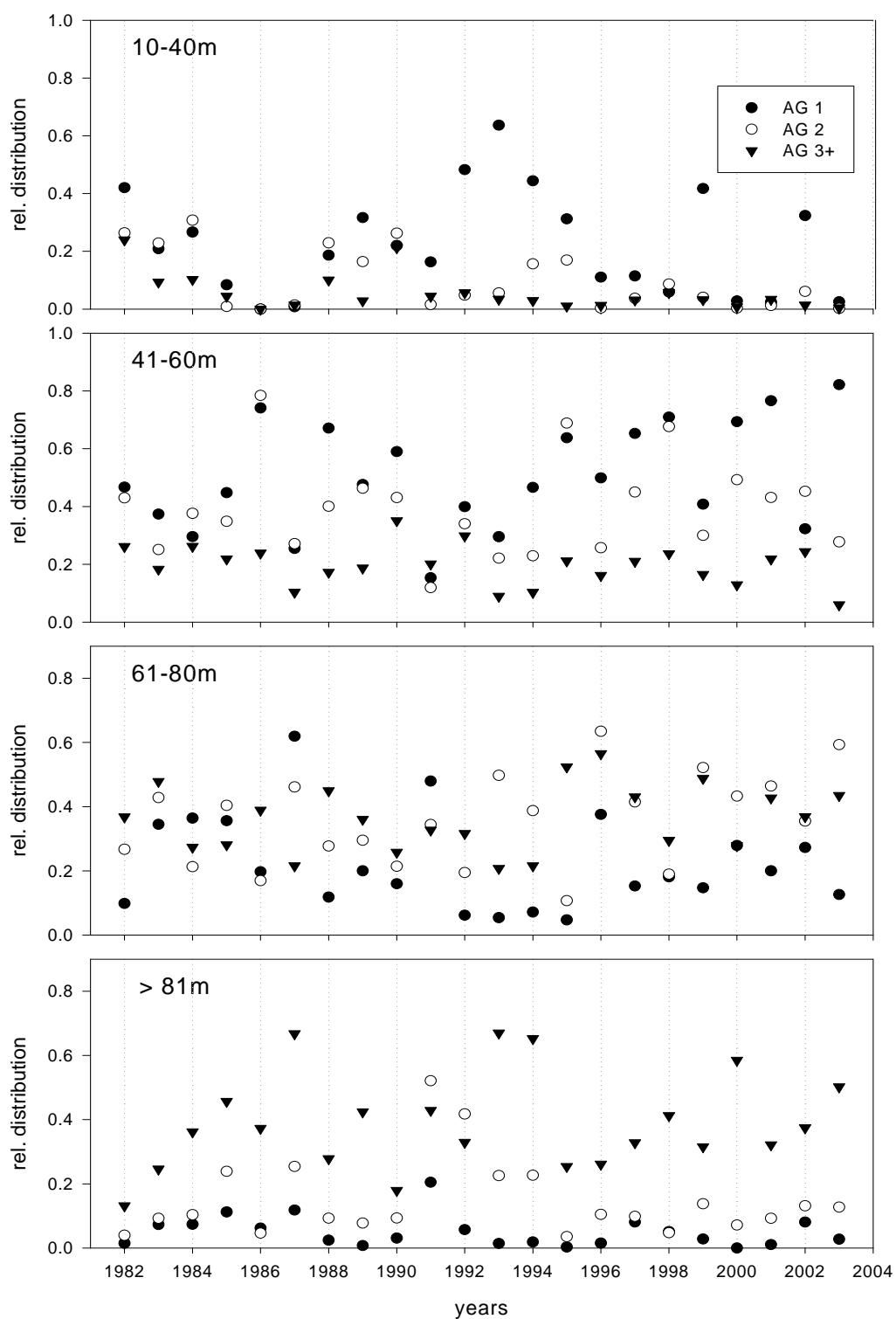


Figure 5.2.2: Relative depth distribution of cod in different depth strata in SD 26 based on BITS-data analysis

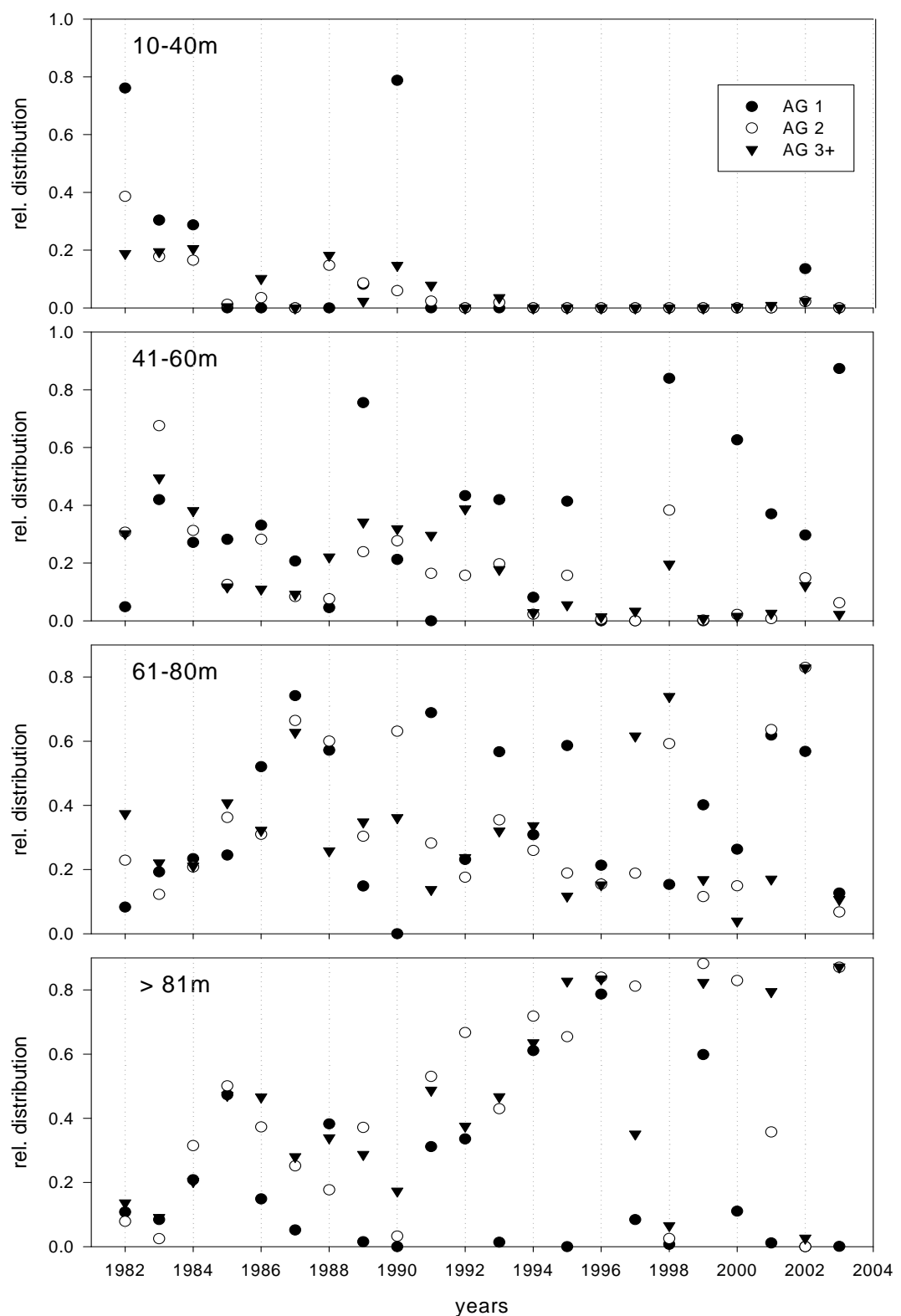


Figure 5.2.3: Relative depth distribution of cod in different depth strata in SD 28 based on BITS-data analysis

5.2.2 Stomach content data and other input data

Quarterly cod stomach content data according to Sub-division as revised in ICES (1997/J:2) were utilized as input. Via stomach content (S), subdivision (SD), year (Y) and the predator

weights (W), lacking stomach contents were estimated by following model fitted to the available data set ($r^2 = 0.92$, however artificially inflated as no intercept incorporated):

$$\text{Log}(S) = 0.0993984 * \text{SD} - 0.00272192 * Y + 0.834113 * \text{Log}(W)$$

Weights at age in the stock according to Subdivision and quarter were applied as in the standard estimation procedure in earlier years.

5.3 Estimation of consumption rates

For both described evacuation models quarterly, age-specific consumption rates of cod were calculated with ambient temperature and oxygen, predator weights and stomach content data. Afterwards a comparison of estimated consumption rates after Temming (1996) and the new approach for each sub-division was conducted.

Results of the comparison between the estimated 'standard' individual consumption rates and the developed alternative consumption model taking into consideration the influence of ambient oxygen saturation are presented in Figures 5.3.1. – 5.3.3. Presented are absolute differences between the two calculated consumption rates (gram per fish) for each age-group, Subdivision, year and quarter.

Several general trends are obvious:

An increase of the absolute differences between both computed consumption rates with increasing age. This general trend can be attributed to an increase in the weight-at-age of cod, as weight is one of the parameter needed for consumption estimates.

Higher differences in consumption rates are observed more frequently at the end of the time-series. This effect can probably be linked to generally decreased oxygen levels in cod habitat in more recent years.

Seasonal differences in consumption rates, with highest discrepancies in the 4th quarter, revealing a combined effect of weight, oxygen conditions and temperature, all needed as input variables for consumption estimates.

In SD 25 maximal differences between consumption rates varied between 433.4 g in the 1st quarter to 1520.8 g in the 4th quarter (Figure. 5.3.1). In SD 26 maximal differences between consumption rates were in the order of 618.1 g in the 1st quarter to 1034.0 g in the 4th quarter (Figure 5.3.2) and in SD 28 maximal differences amounted to 1943.4 g in the 1st quarter and 2028.5 g in the 4th quarter (Figure 5.3.3).

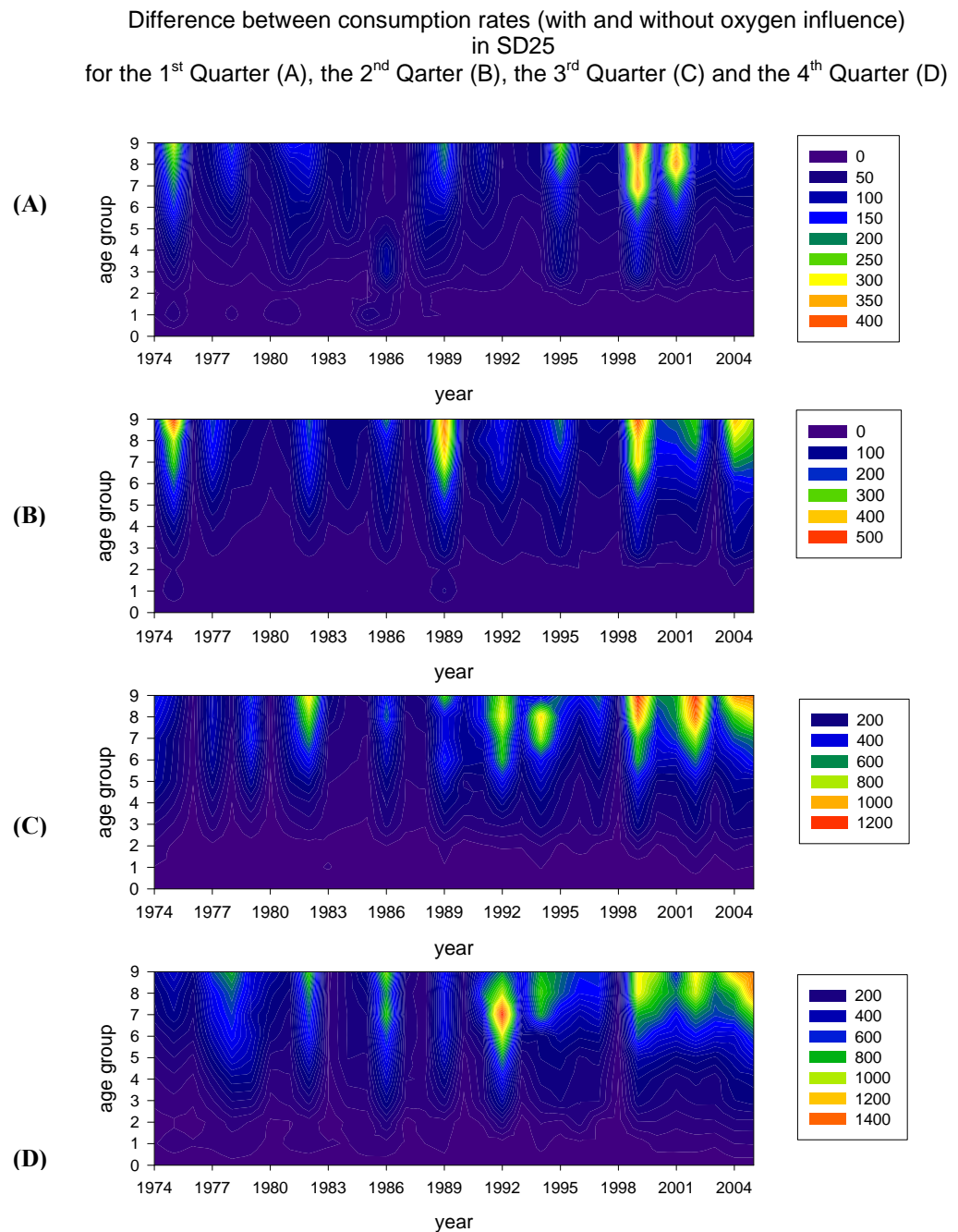


Figure 5.3.1: Absolute difference between individual consumption rates (with and without oxygen influence) in SD25 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D) in 1974-2005. Values are given as g per fish; Note the different scales.

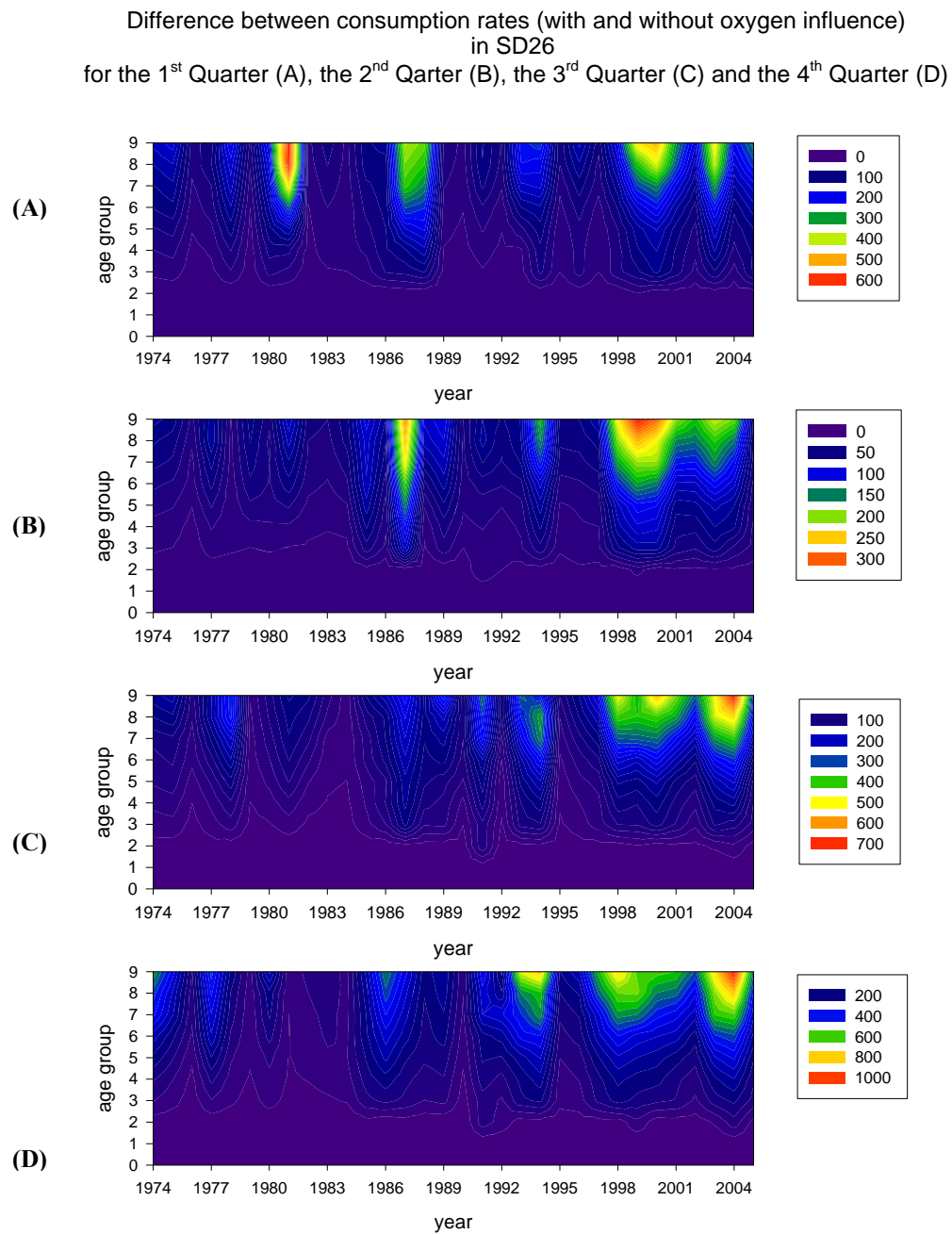


Figure 5.3.2: Absolute difference between individual consumption rates (with and without oxygen influence) in SD25 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D) in 1974-2005. Values are given as g per fish; Note the different scales.

Difference between consumption rates (with and without oxygen influence)
in SD28
for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

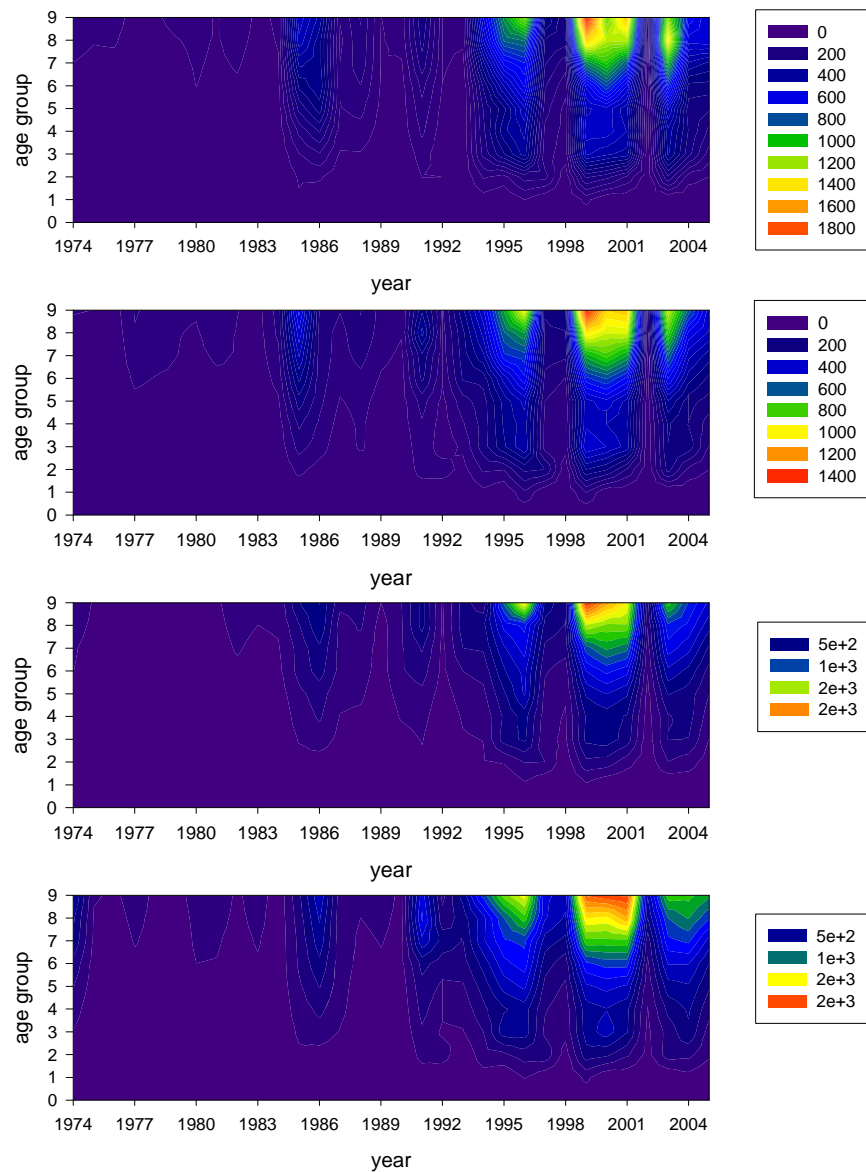


Figure 5.3.3: Absolute difference between individual consumption rates (with and without oxygen influence) in SD25 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D) in 1974-2005. Values are given as g per fish; Note the different scales.

6 Weight at age, sex ratios and proportion of maturity at age

6.1 Eastern Baltic cod

6.1.1 Background information

Weight at age in the commercial catch is assumed to be equal to weight at age in the stock, as survey based age specific weight are available only from the 1. quarter bottom trawl survey since 1983 and from 4. quarter surveys implemented in the 1990's. Due to size selection by commercial gears in young age-groups 0 to 2, period specific (before 1989 and after 1990) average weight at age in the stock compiled by ICES (1999/H:05) were applied for these age-groups.

Concurrently to the decline in stock size of cod during the 1980's an increase in weight at age is indicated in both the commercial and the surveys based data sets until the beginning the 1990's, followed by a decline in age specific weight during the 1990's, which however started earlier in the commercial data and did in both data sets not continue for oldest age-groups in the 2nd half of the 1990's (Figure 6.1.1). A considerable inter-annual variability in weight at age is encountered especially in these older age-groups, which may indicate inadequate sampling or problems in age determination (e.g. Bagge *et al.* 1994).

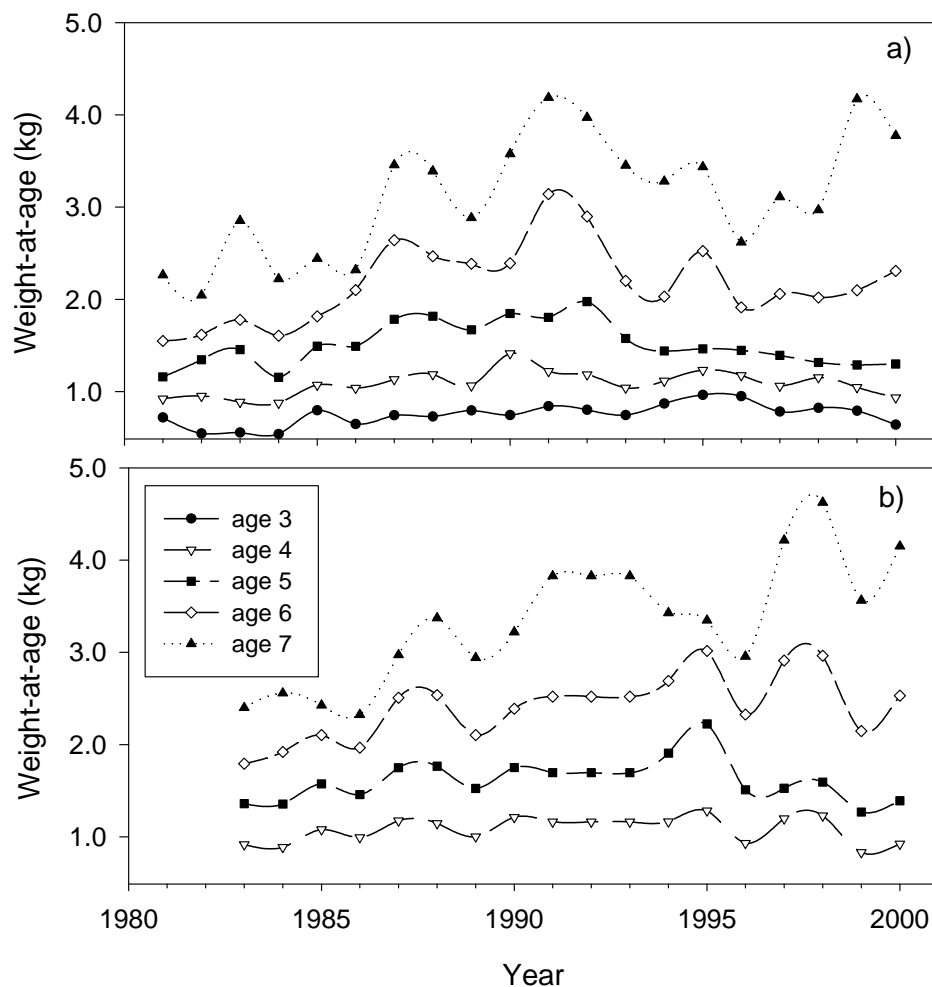


Fig. 6.1.1 Average weight at age of cod in the central Baltic (1. quarter) as obtained from sampling the commercial fishery (a) and from the 1. quarter BITS survey (b).

The average weight at age deviate in different Sub-divisions with significantly higher values in Sub-division 25 compared to 26 (Kruskal Wallis, $p < 0.02$ for age-groups 3-7), while weight at in Sub-division 28 are on an intermediate level, not being significantly different from both other areas (Figure 6.1.2).

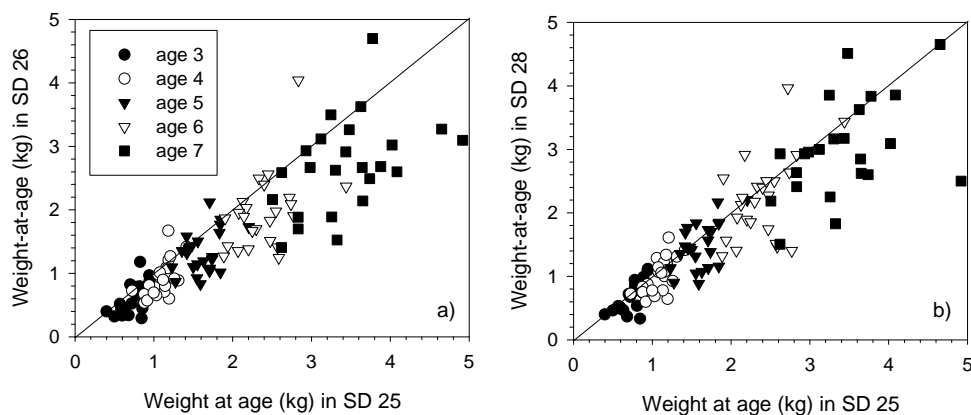


Figure 6.1.2. Average weight at age in the catch (1. quarter 1976-1999) in Sub-division 26 vs. 25 (a) and in Sub-division 28 vs. 25 (b).

Fitting exponential functions to quarterly weight at age data for several cohorts did not reveal any consistent significant difference in growth rates between areas and periods, however, the intercepts showed significant variation in space and time. This may again be caused by deviations in age reading by the various countries sampling different areas of the Baltic. However, even within Sub-divisions, i.e. areas in which the age-determination was performed in a more consistent way, significant time trends in weight at age 3 are encountered (Fig. 3). This may indicate that increasing weight at age throughout the 1980's and early 1990's are not caused by increasing growth rates of adult, but of juvenile cod. However, increased mesh sizes in the directed trawl fishery and an increasing fishing effort with gill-nets at the end of the 1980's may have contributed to the observed trend in increasing weight at age 3. In contrast, the decline in weight at age during most recent years may be explained by a successive shift in main spawning activity from spring to summer month (Wieland *et al.* 2000), reducing the length of the first growth season and by this size at first over-wintering. This has lead to the hypothesis that these late spawned juveniles are unable to catch up in size compared to earlier born cohort affecting the entire individual growth history (Larsson and Eriksson 1996).

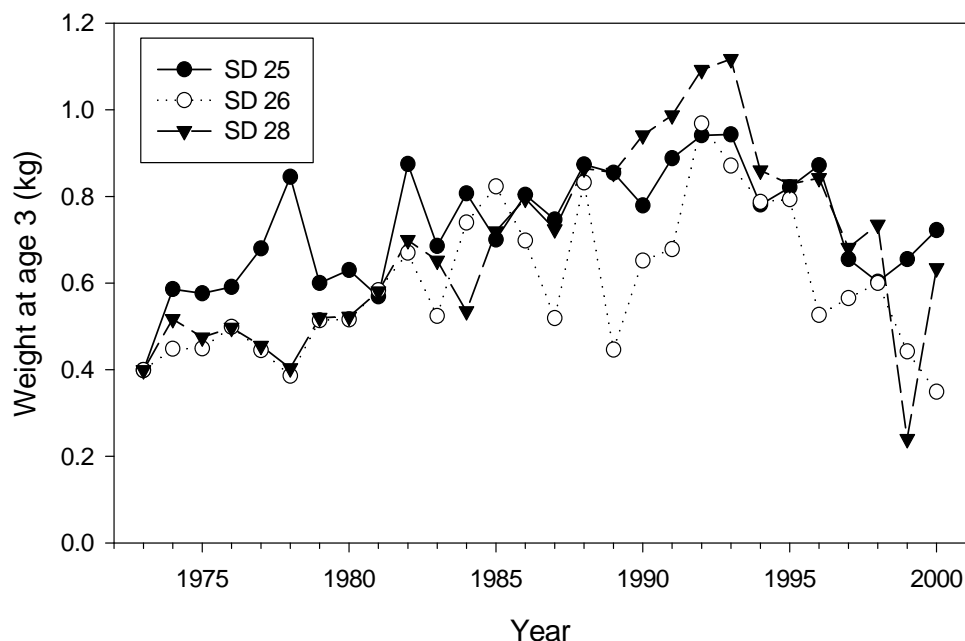


Fig. 6.1.3. Average weight at age 3 of cod (1. quarter) in different Sub-divisions as obtained from sampling the commercial fishery.

These interpretations are not in line with the traditional view, that growth of Baltic cod is density dependent and affected by the availability of food resources (Baranova and Uzars 1986, Baranova 1992) as well as by hydrographic conditions (Aro 2000). These processes have been put forward as explanation of variation in weight at age also in other cod stocks and it appears to be likely that a combination of various processes act in a non-linear way, which makes any consistent analysis of weight at age data extremely difficult (see Bagge *et al.* 1994 for further discussion on Baltic cod).

Growth and thus weight at age is in various fish species sex specific, e.g. North Sea plaice. Further evidence exists, that growth differs also between immature and mature fish (STORE 2003). While the latter is probably of limited importance for the estimation of the spawning stock biomass in fish stocks consisting of several adult age-groups, the sex specific growth has implications for the calculation of the female spawning stock biomass and the potential egg production of the stock.

Growth affects not only the size at age, but also the likelihood of attaining sexual maturity at a given age or size (e.g. Dragesund *et al.*, 1980; Hutchings, 1997). A declining age and length at sexual maturity has been observed for most gadoid stocks in the Northwest Atlantic since the 1970's (Trippel *et al.*, 1997), but also for stocks in the Northeast Atlantic (e.g. Jørgensen, 1990). This has been explained by higher growth rates and better nutritional condition at smaller size, due to increased food supply per individual at low stock levels (Trippel, 1995). However, a genetic selection of early maturing fish under heavy fishing pressure is another potential explanation (Trippel, 1995).

An analysis of sex specific proportions of sexually mature individuals at age (maturity ogive) and sex ratios of cod derived from the 1. quarter International Baltic Trawl Survey (Tomkiewicz *et al.* 1997) revealed: i) a dominance of females with increasing age (Figure 6.1.4), ii) that the age at which sexual maturation occurs, increases with distance from Kattegat and the Danish Straits, especially for females (Figure 6.1.5), iii) that males generally mature at a younger age than females (Figure 6.1.5), and iv) that maturity at age shows significant temporal variability (Figure 6.1.6).

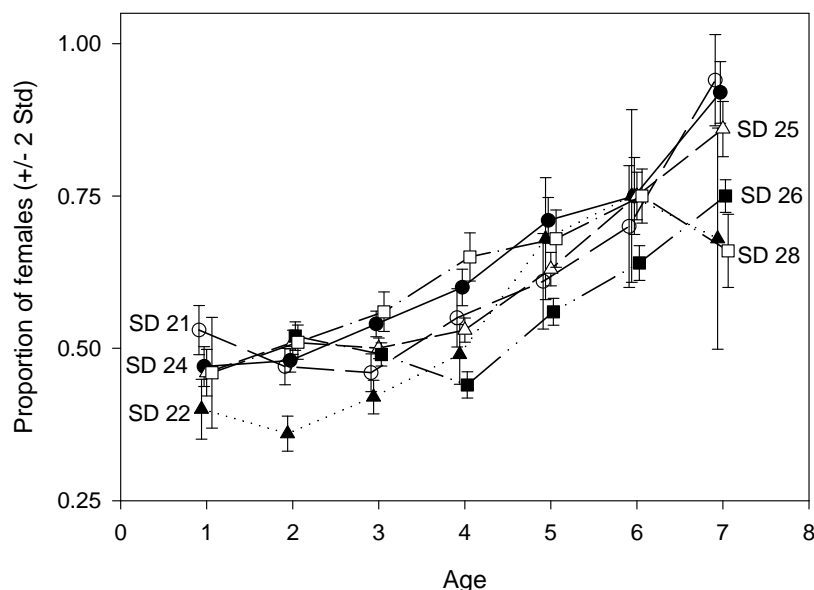


Figure 6.1.4. Average cod sex ratio at age in different Sub-divisions 1980-1996 (data Tomkiewicz unpubl., computation as in STORE 2003).

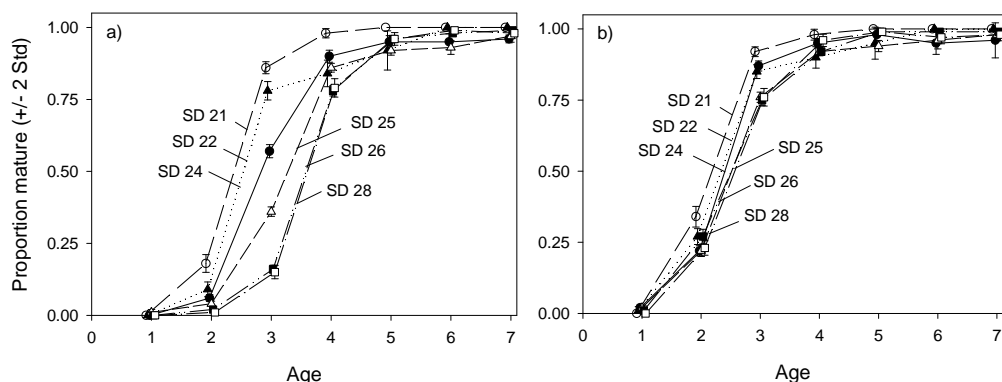


Figure 6.1.5. Average cod maturity ogives of females (a) and males (b) in different Sub-divisions 1980-1996 (data Tomkiewicz unpubl., computation as in STORE 2003).

Cardinale and Modin (1999) found a positive relationship between the size of attaining maturation in males and females and the SSB implying some form of density dependence. However their maturation data is restricted to the Swedish economic zone, comprising mostly samples from Sub-division 27 not consisting any major spawning ground, which were then compared to the total stock development in the Central Baltic. Utilizing basin specific data for female cod in Sub-division 25 for year-classes 1980-1995, neither cohort strength nor deviations in prey biomass or growth rates do explain the large variability in proportions being mature at age 3 and 4 (Figure 6.1.6). Nevertheless, there appears to be a general trend of attaining sexual maturity at an earlier age concurrently to reduced year-class strength and increasing prey biomass resulting in higher prey availability per unit of cod biomass. Some cohorts show considerable deviations in the proportions attaining maturity at an age of 3 and 4, e.g. year-class 1990 was only to 12% mature at an age of 3 but already 94% at an age of 4. This type of variability is presently extremely difficult to explain and attempts to resolve the interacting processes as feeding intensity, assimilation, metabolism, transformation and

excretion, with all rates being controlled by ambient temperature and prevailing oxygen conditions, requires either experiments under controlled conditions.

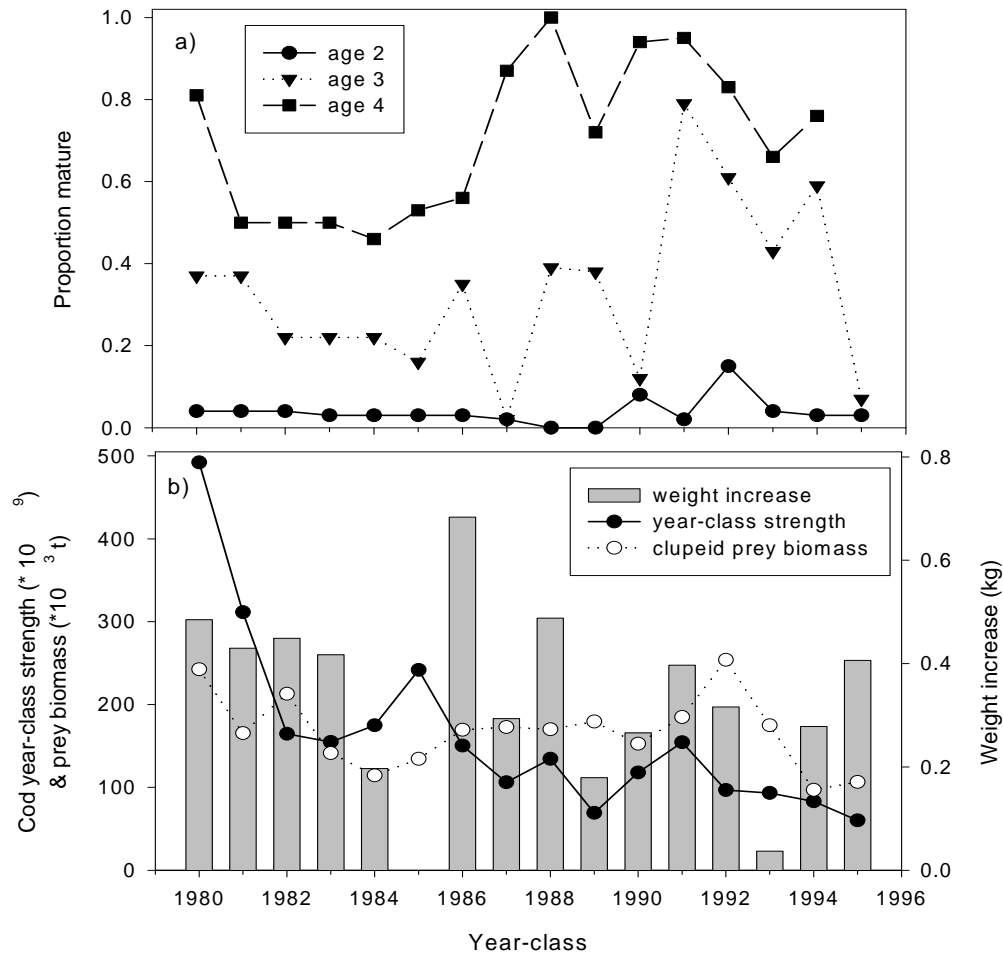


Figure 6.1.6. Average proportion of female cod attaining sexual maturity at age 2, 3 and 4 in year-classes 1980-95 (for years 1982-84 and 1985-87 averages otherwise yearly data applied) in Sub-division 25 (a); cohort strength at age 1 of year-classes 1980-95, clupeid prey availability (biomass of sprat and juvenile herring in autumn of years cod cohort were 3 years old) and weight increase from mid of 3rd to mid of 1st quarter of 3 to 4 year old cod (b).

As consequence of the limited understanding of processes affecting sexual maturation in Baltic cod, sexual maturation, are parametrized in the MSVPA, utilizing sex specific maturity ogives either for 5 years periods if the data coverage was questionable or annual data. For prediction purposes, maturity is normally set constant, but Gislason (1999) modelled maturity ogives in dependence of weight at age assuming maturity at age of being related to body weight by a sigmoid relationship.

In summary it can be stated, that weight at age in eastern Baltic cod has changed over time, increasing concurrently to a decrease in stock size throughout the 1980's and decreasing throughout the 1990's despite remaining low stock size. Furthermore, weight at age in different Sub-divisions of the Baltic differs. An analysis of compiled weight at age data from commercial fisheries, revealed that these temporal and spatial variations are related to deviating weight at age of the youngest fish considered in the analysis, i.e. age-group 3, while differences between growth rates of older fish were limited, both in a temporal and in a spatial comparison. The significant deviations in weight at age 3 may indicate a bias introduced by

inconsistent age-readings conducted by various laboratories covering different areas of the Baltic and within single laboratories over time. Other explanations, however, are also not unlikely, first of all the growth of juvenile fish may have changed over time as a consequence of the shift in spawning time from spring to summer month reducing the first growth season considerably. This process would explain the reduction in weight at age encountered throughout the 1990's. Secondly, increased mesh sizes in the trawl fishery directed to cod and an increasing fishing effort with gill-nets may have contributed to the observed trend in increasing weight at age 3 throughout the 1980's, which is obvious for all major Sub-divisions in the central Baltic. However, a decline in weight at age during the 1980's is as well obvious from the BITS survey, confirming the traditional view, that growth of cod is density dependent and affected by the availability of food resources as well as by hydrographic conditions.

The sex ratio in the cod stock changes with age and ages at attaining sexual maturity are significantly different between sexes and areas and show additionally considerable year to year variability. Thus, the quantity of the egg production of Baltic cod depends on the age structure of the stock, on the location and the time period in question. The factors driving the variability in sexual maturation success are similarly to processes affecting growth poorly understood, as various behavioural and metabolic processes interact with different environmental variables. A statistical analysis as conducted for weight at age is furthermore hampered by the limited amount of reliable data on proportion of sexual maturity at age.

6.1.2 Statistical analysis of weight at age

The main purpose of this exercise was to develop a simple tool for scenario-dependent predictions of weight at age. Temporal and spatial variations are related to deviating weight at age of the youngest fish considered in the analysis, i.e. age-group 3, while differences between growth rates of older fish were limited, both in a temporal and in a spatial comparison (see above). For this reason, the statistical analysis of weight at age was divided into (a) a regression model for the weight at age 3, and (b) estimating von Bertalanffy growth parameters independent of external forcing for age groups 4+.

Weight at age 3 was modelled using weight in the catch data and MSPVA-abundances of age 3 cod and the aggregated clupeid abundances. For the 'early spawning' scenario, the weights in the period when the cod actually had been spawned late were scaled up according to the average weight during the period when the cod had been spawned early. Vice versa, for the 'late spawning' scenario the weight in the periods when the cod actually had been spawned early were scaled down to according to the average weight during the period when the cod had been spawned late. Data from 1991 to 1993, when the spawning stock was mainly composed of cod that had been spawned early but themselves were late spawners were excluded from the analysis.

A simple model was fitted to the cod weight at age 3 data:

$$w(3) = \frac{w(3, \max)}{1 + \exp(\gamma(CLU - CLU_{0.5}))}$$

In this model, $w(3, \max)$ is the asymptotic weight at age 3, $w(3)$ where a further increase of CLU (the number of clupeids per cod) will not lead to an increase in cod age 3 weight. $CLU_{0.5}$ is the half-saturation constant, and γ encompasses all processes involved in the conversion from prey availability per cod to weight.

The model explained 82% of the variability of $w(3)$ for both scenarios (Fig. 6.1.7) and was highly significant ($P < 0.001$). The residuals for both scenario models were normally distributed (Shapiro-Wilk test, $P > 0.05$).

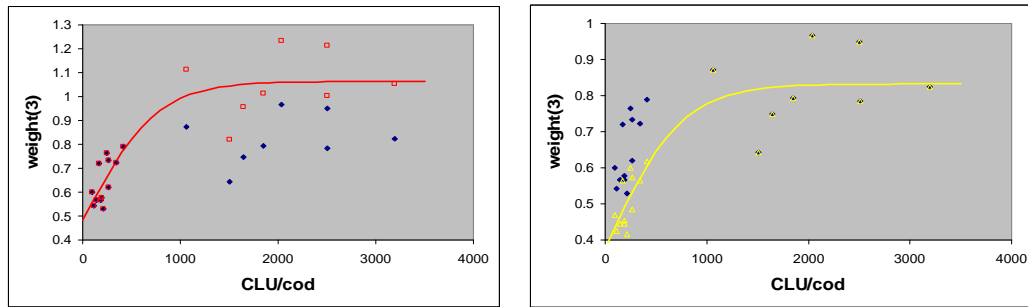


Fig 6.1.7. Weight at age 3 (weight(3)) versus clupeids available per cod (CLU/cod) for the early spawned scenario (A) and the late spawned scenario (B). The solid points represent the raw weight in the catch data. In A the late spawned cod weight has been scaled up, and in B the early spawned cod weight has been scaled down (for further explanations please see the text).

For both scenarios, γ was estimated to -0.002819 ± 0.001264 (s.e.) and $CLU_{0.5}$ was estimated to 65.03931 ± 72.3974 (s.e.). The maximum weight at age 3 was for the ‘early spawning’ scenario estimated to 1.063 ± 0.043 kg, and for the ‘late spawning’ scenario to 0.833 ± 0.034 kg.

Weight at age 4+ was predicted using March survey data for ages 4 to 7 in a Ford-Walford plot. In the Ford-Walford plot usually Length at age $a+1$ is plotted on the y-axis against length at age a on the x-axis. Hence, $L(t+1) = aL(t) + b$. When growth data are given in terms of weight, fitting of growth curves is most easily done by using the cube-root of the weight as an index of length, fitting this to the von Bertalanffy growth model based equations of growth in length, and finally cubing to return to weight. No further coefficients were used here in the weight to length conversion for the Ford-Walford plots (Fig. 6.1.8) corresponding to different scenarios. For the ‘early spawned’ scenario (data from 1983 to 1990), a was estimated to 0.9088 ± 0.04044 (s.e.), and the intercept b was estimated to 0.2344 ± 0.04700 (s.e.) ($r^2 = 0.96$, $P < 0.0001$). For the ‘late spawned’ scenario (data from 1994 to 2004), a was estimated to 1.0419 ± 0.06492 (s.e.), and the intercept b was estimated to 0.1025 ± 0.07547 (s.e.) ($r^2 = 0.89$, $P < 0.0001$). The estimated parameters for ages 4+ for the different spawning scenarios did hence not differ significantly. A combined regression for both scenarios yielded $a = 0.9968 \pm 0.04461$ (s.e.) and $b = 0.1455 \pm 0.05186$ (s.e.) ($r^2 = 0.90$, $P < 0.0001$). The analysis might be improved, especially when the VB parameters $L(\text{inf})$ and k are to be estimated, by including older age groups which have not been available during the meeting.

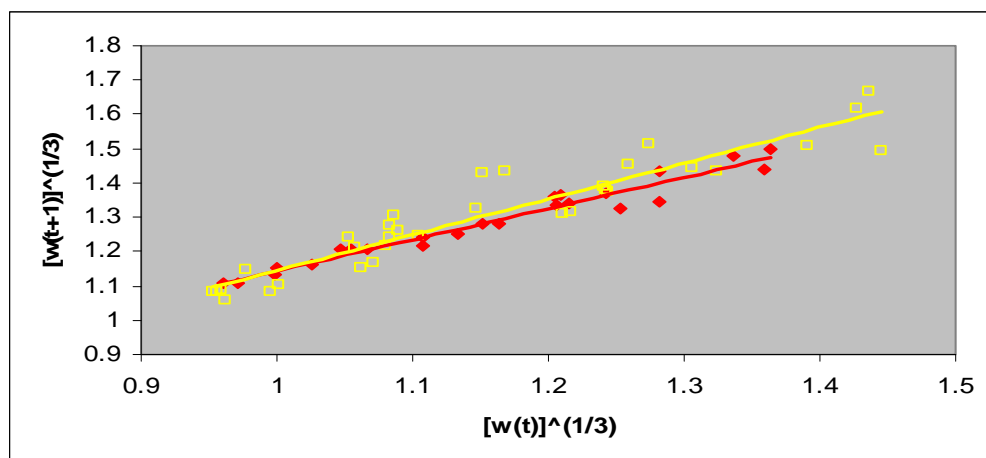


Figure 6.1.8. Weight-based Ford-Walford plot for the ‘early spawned’ (diamonds) and the ‘late spawned’ (squares) scenarios. See text for further details.

Using the number of clupeids per cod as a measure for prey availability, weight at age 3 in the first quarter of the year can be predicted based on the above mentioned relations. Weight at

age 4 can be predicted based on weight 3 and the parameters estimated by the Ford-Walford plot. Subsequently, weight at age 5+ in the first quarter of the year can also be predicted based on the F-W plot.

What lacks is the seasonal development of weight at age for the two scenarios. The seasonal development of weight at age is displayed for the two scenarios using the same periods as for the F-W plot in Figure 6.1.9. As a starting point for predictions, the seasonal trend can be derived by scaling the quarter 1 values to the other quarters using this scenario-specific seasonal development. Late spawners cannot reconstitute their weight after spawning during one year growth period. The weight deficiency is carried through the winter season.

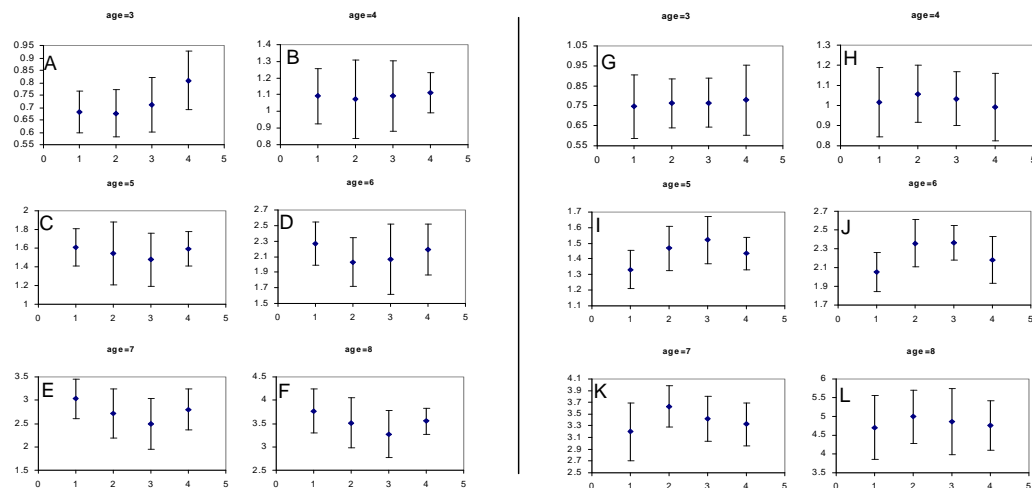


Figure 6.1.9. Quarterly (x-axis) development of weight at age for the 'early spawned' scenario (A-F) and the 'late spawned' scenario (G-L). For further explanations please refer to the text.

6.2 Central Baltic herring and sprat

6.2.1 Background information on herring and sprat

Central Baltic herring showed a decline in weight at age by more than 50% in all age-groups from the beginning of the 1980's to the end of the 1990's. A similar decrease has been observed for Baltic sprat, only starting later, i.e. from early 1990's to 1998 with indications of a reverse trend for both species in most recent years (Figure 6.2.1).

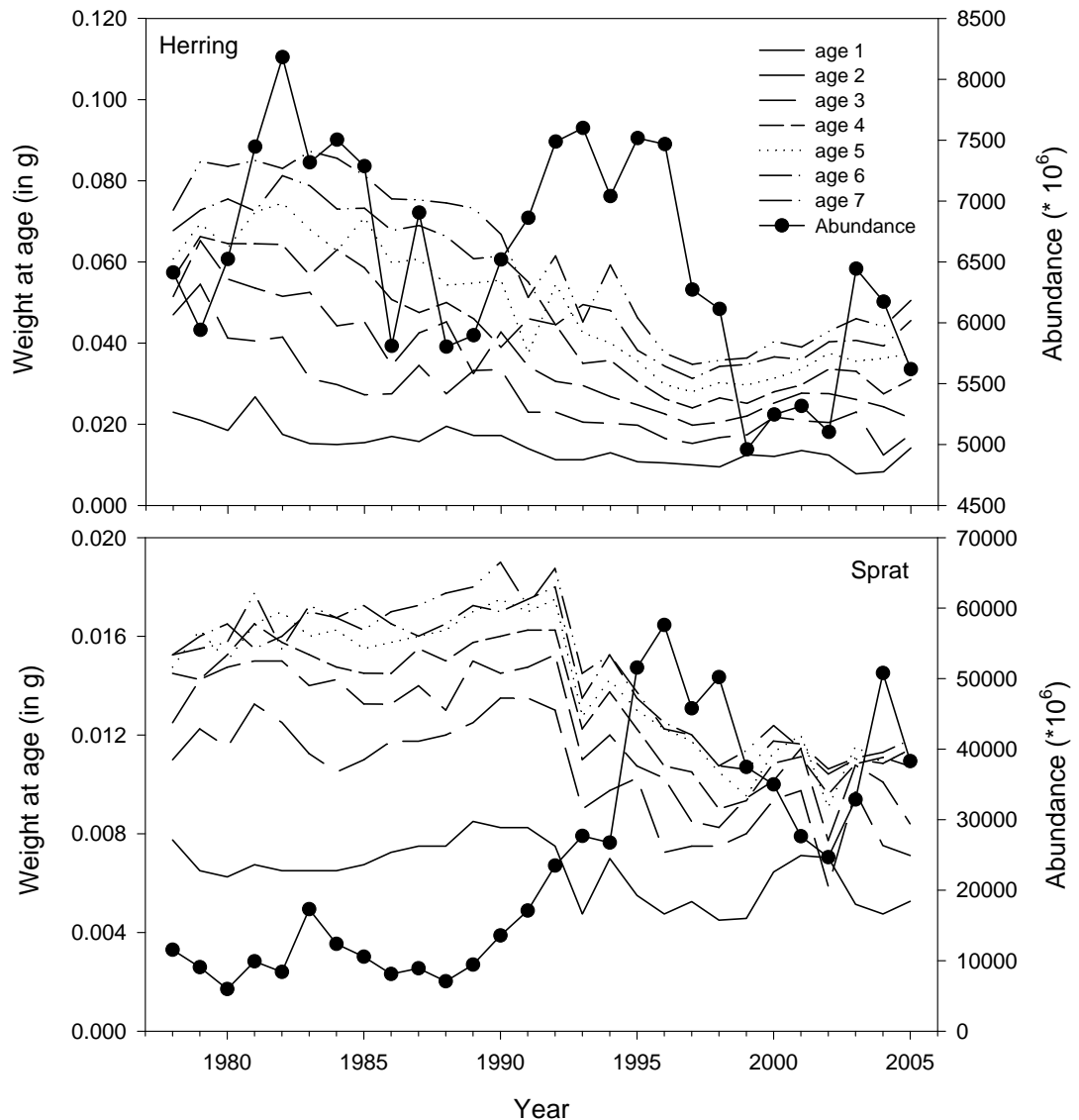


Figure 6.2.1. Average weight at age in the catch of herring and sprat and corresponding stock size (age 1+) in the central and entire Baltic (1.quarter).

The results of a preliminary analysis on herring growth conducted during the 2005 SGMAB meeting demonstrated that clupeids number (hypothesis of density dependence) explained the largest part of the variance of herring condition (ICES 2005/H:06). Low growth rates appear to be associated to periods of large stock size of clupeids confirming that competition between clupeids influence herring growth (Cardinale and Arrhenius, 2000). Möllmann *et al.* (2005) found the strongest correlations among annual and winter and spring sprat stock sizes with herring and sprat conditions, indicating the importance of competition with the sprat stock for the growth of both fish species. In winter, and especially in spring, when the diet overlap between both species is most pronounced, both species compete for *Pseudocalanus acuspes*. This may have resulted in reduced herring growth when *Pseudocalanus* sp. abundance decreased during the 1980s. During the early 1990s when competition was highest due to the small *Pseudocalanus* stock and the large sprat stock, sprat growth also decreased. The importance of density-dependence for sprat condition is indicated by the relatively low stomach contents of main food sources during the 1990s, although zooplankton availability increased, i.e. of *T. longicornis*, *Acartia* spp. and cladocerans. This occurred in parallel with

the drastic increase in sprat stock size during the 1990s, suggesting strong density-dependent growth.

An analysis of herring maturity ogives based on the data from Study Group on Baltic Herring and Sprat Maturity (ICES CM 2002/ACFM:21) showed that the proportion mature at age varies from year to year and between the Sub-divisions. Maturity at age of coastal spring spawning herring (1980-1999) and sprat (1980-2001) in the Bornholm Basin and the Gdansk Deep (only the Polish EEZ of the ICES Sub-divisions 24+25 and 26) showed considerable changes during the last two decades (ICES 2005/H:06). Along with the decrease of the mean weight at age of herring the proportion mature at age 2 decreased from 80 to 75% in the Bornholm Basin and from 92 to 82% in the Gdansk Basin.

Food availability, especially *Pseudocalanus acuspes*, also has been hypothesized to be crucial for the growth of sprat (Cardinale *et al.*, 2002; Möllmann *et al.*, 2004). However, in contrast to herring, Möllmann *et al.* (2005) found the changes in the mesozooplankton community not fully reflected in sprat diets. While the decrease in *Pseudocalanus* abundance is visible in the spring diet, the increase of *T. longicornis* and *Acartia* spp. as well as cladocerans during the 1990s was not observed. Although *Pseudocalanus* is the main food source also for sprat at the beginning of the year, it is not as important as for herring over the whole season (Möllmann *et al.*, 2004). In summer after spawning, sprat move into shallower water, where they feed mainly on *T. longicornis* (Möllmann *et al.*, 2004). The increase in abundance of *T. longicornis*, therefore probably compensated for the decreased availability of *Pseudocalanus*.

From the available annual maturity data of sprat in Sub-division 25 from 1976-1987, a high variability in the proportion being sexually mature is obvious for sprat up to 11 cm length with an extremely early maturation in 1980 and a late in 1987. In terms of variability in age-specific proportions, this translates into a high variability in age-group 1, while age-group 2 is in general to more than 90% mature, with the exception of 1987 (Figure 6.2.2).

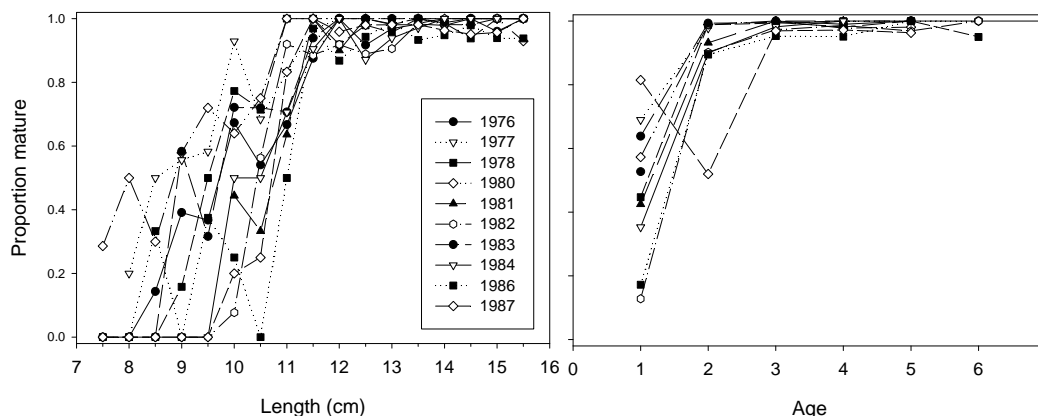


Figure 6.2.2. Proportion mature sprat in different length (a) and age-groups (b) from Sub-division 25 in April-June 1976-1987 (ICES Maturity group last meeting).

Utilizing these yearly maturity ogives to calculate the spawning stock results in pronounced deviations compared to estimates based on the standard average maturity ogive invariate over time. Especially in 1983, 64% of the 1-year old sprat was sexually mature, which together with a high recruitment of the 1982 year-class resulted in a doubled SSB estimate. In other years the SSB was between 3 and 35% higher than determined with the constant maturity ogive. These results indicate, that this standard procedure may in fact introduce a considerable error in the estimation of the spawning stock biomass, however, less severe than in the case of

cod where in general more than one age-group show a high variability in sexual maturation success.

Polish investigations showed for sprat at age 1 an increase of the mean proportion mature from the 1980's to 1990's, increasing in the Bornholm Basin from 26 to 38% and in the Gdansk Basin from 14,5 to 18% (ICES 2005/H:06). Analysis of the Bornholm Basin sprat maturation by individual years shows that there was not a linear trend but there were periods with high (1982-1984, 1991-1992 and after 1996) and low (1985-1988 and 1993-1995) proportions mature at age 1.

An analysis of the proportion mature at sprat age 1 from Latvian commercial catches revealed that significant changes during a year take place concurrently to changes of the proportion of age-group 1 in the catch, which increases during a year up to 10 times. This may indicate that in the first half of the year the largest part of 1 year old sprat stays separately from the adult stock closer to the coast. Thus the proportion of mature 1 year old sprat is estimated from a small part of the stock likely overestimating the proportion mature. Besides this, the analysis of proportion mature of 1 year old sprat indicated significant negative relationship with the stock size and year class strength. This indicates that the total spawning stock biomass is unlikely to be significantly affected by different shares of age group 1 being sexually mature. Moreover, there are also indications that in the mature 1 year old sprat the proportion of males is higher than for females confirming results from STORE (2003). The latter needs additional data analysis.

WGBFAS in 2002 was aware that the statistical analysis of herring and sprat maturity can be much improved. In the analysis binomial errors should be assumed and sample size taken into account. In addition, factors such as sex, survey time (ranged from February/March to June), country, and possibly some environmental variables could be included into the maturity model. WGBFAS decided that until the results of further analyses are not available, the overall averages of GLIM estimates i.e. 17 and 93% mature at age 1 and 2 ICES (2002/ACFM:17), respectively are applied for sprat maturity at ages 1 and 2, a practise also SGMAB has adopted for the MSVPA key runs.

6.2.2 Statistical analysis of weight at age

Highly significant relationships between clupeid stock size and weight at age of herring and sprat may be utilized for prediction purposes (e.g. Möllmann *et al.* 2005). Relating the weight at age of herring according to quarter with the clupeid stock size (age 1+) in a given year 1978-2005 yielded highly significant relationships presented in Table 6.2.1. The slope and explained variance of the relationships increases with age and quarter, i.e. the effect of density dependence gets more pronounced and detectable with age and in the 3rd and 4th quarter (Figure 6.2.3). The fit for age-group 1 in quarter 1 and 2 appears to be insufficient to use the relationship in forecasts and thus utilisation of historical averages is suggested.

Table 6.2.1 Regression of herring weight at age according to quarter against clupeid stock size (herring and sprat abundance in age 1+, start of year in 10^{12}), parameter estimates, significance level and r^2 value.

AGE	QUARTER	INTERCEPT	SLOPE	P	R2
1	1	0.0134826	-0.0138608	0.023	0.183
	2	0.0109887	-0.0139291	0.007	0.247
	3	0.0316440	-0.0678390	<0.001	0.526
	4	0.0275386	-0.0568572	<0.001	0.692
2	1	0.0355438	-0.0557731	<0.001	0.510
	2	0.0346398	-0.0641133	<0.001	0.452
	3	0.0558003	-0.1329730	<0.001	0.653
	4	0.0419482	-0.0930671	<0.001	0.611
3	1	0.0523378	-0.0857708	<0.001	0.536
	2	0.0494144	-0.0898512	<0.001	0.550
	3	0.0663611	-0.1516990	<0.001	0.687
	4	0.0516069	-0.1113400	<0.001	0.621
4	1	0.0643689	-0.1041680	<0.001	0.543
	2	0.5896330	-0.1046160	<0.001	0.724
	3	0.0740845	-0.1578990	<0.001	0.721
	4	0.0633509	-0.1389390	<0.001	0.661
5	1	0.0750914	-0.1181700	<0.001	0.537
	2	0.0655799	-0.1102400	<0.001	0.627
	3	0.0785176	-0.1575700	<0.001	0.704
	4	0.0704804	-0.1491640	<0.001	0.685
6	1	0.0844332	-0.1338730	<0.001	0.624
	2	0.0729277	-0.1205210	<0.001	0.705
	3	0.0886283	-0.1805170	<0.001	0.728
	4	0.0774275	-0.1596500	<0.001	0.746
7	1	0.0959021	-0.1564360	<0.001	0.618
	2	0.0814138	-0.1329460	<0.001	0.683
	3	0.0957561	-0.1876110	<0.001	0.692
	4	0.0869982	-0.1851790	<0.001	0.724

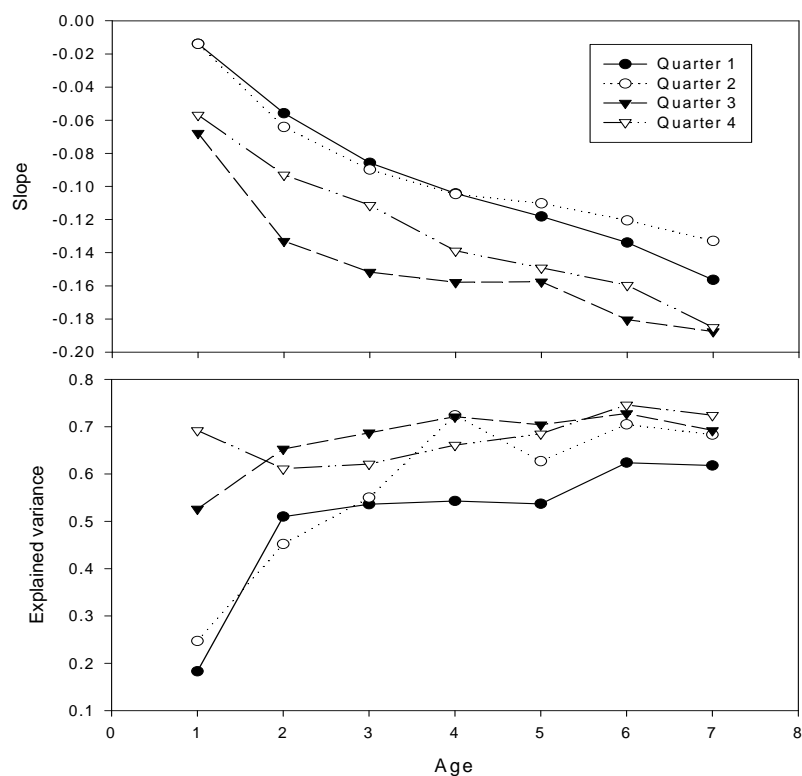


Fig.6.2.3 Slope and r^2 -value for regression of herring weight at age against clupeid stock size.

For sprat the corresponding analysis with sprat stock size as explanatory variable, revealed statistical models presented in Table. 6.2.2. Sprat instead of clupeid stock size was chosen because there is no indication that herring abundance has an impact on sprat growth, while the opposite appears to be the case.

Table 6.2.2 Regression of sprat weight at age according to quarter against clupeid stock size (sprat abundance in age 1+, start of year in 10¹²), parameter estimates, significance level and r² value.

AGE	QUARTER	INTERCEPT	SLOPE	P	R2
1	1	0.0047945	-0.0040470	0.006	0.253
	2	0.0048559	-0.0022905	0.173	0.070
	3	0.0091039	-0.0110303	<0.001	0.396
	4	0.0117707	-0.0213510	<0.001	0.528
2	1	0.0115826	-0.0111756	<0.001	0.402
	2	0.0121451	-0.0147642	<0.001	0.555
	3	0.0127530	-0.0194673	<0.001	0.432
	4	0.0140849	-0.0244936	<0.001	0.475
3	1	0.0142085	-0.0143039	<0.001	0.529
	2	0.0143086	-0.0172884	<0.001	0.514
	3	0.0150103	-0.0227593	<0.001	0.586
	4	0.0158758	-0.0258359	<0.001	0.576
4	1	0.0156057	-0.0158929	<0.001	0.457
	2	0.0154288	-0.0165919	<0.001	0.473
	3	0.0162627	-0.0238589	<0.001	0.737
	4	0.0166898	-0.0251142	<0.001	0.593
5	1	0.0165224	-0.0154014	<0.001	0.428
	2	0.0168374	-0.0192080	<0.001	0.522
	3	0.0167115	-0.0222856	<0.001	0.537
	4	0.0173279	-0.0260968	<0.001	0.563
6	1	0.0172348	-0.0159211	<0.001	0.448
	2	0.0169857	-0.0180232	<0.001	0.440
	3	0.0174002	-0.0243158	<0.001	0.682
	4	0.0171892	-0.0233545	<0.001	0.528
7	1	0.0176052	-0.0173374	<0.001	0.449
	2	0.0172090	-0.0180133	<0.001	0.386
	3	0.0189497	-0.0262989	<0.001	0.667
	4	0.0177975	-0.0264807	<0.001	0.561

As shown for herring, the slope and explained variance of the relationships increases with age and quarter, i.e. also in sprat the effect of density dependence gets more pronounced and detectable with age and in the 3rd and 4th quarter (Fig. 6.2.4).

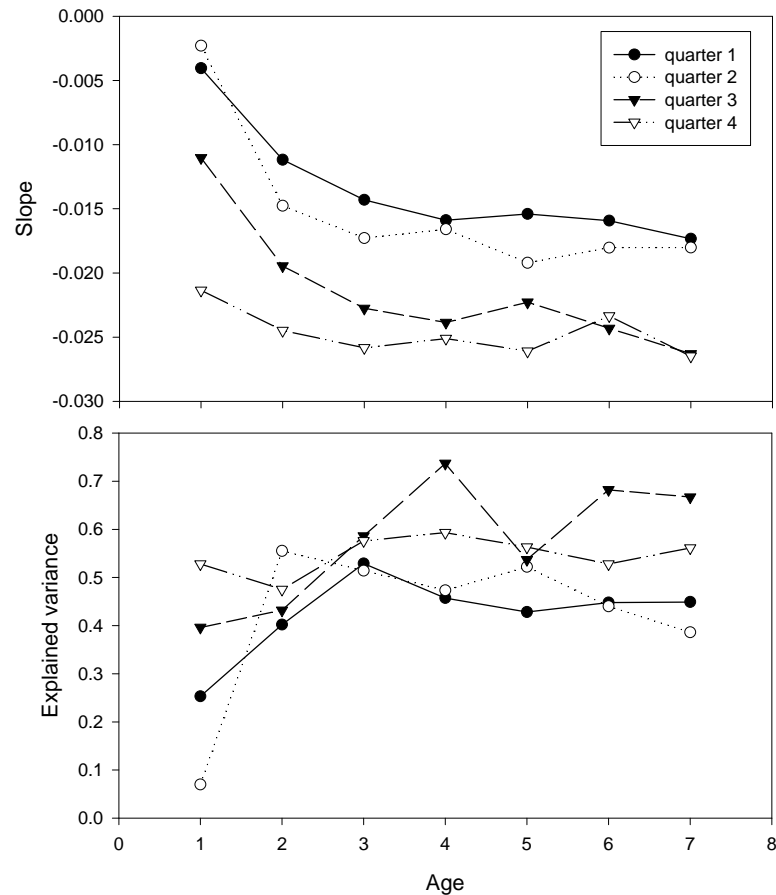


Fig. 6.2.4 Slope and r^2 -value for regression of sprat weight at age against sprat stock size.

7 Environmental sensitive and spatially explicit stock recruitment relationships for Eastern Baltic cod

7.1 Background information

Based on exploratory statistical analysis conducted by ICES (2003/H:03) for the eastern Baltic cod, significant variables influencing survival of early life stages were incorporated into stock-recruitment models. All processes were as far as possible spatially resolved, as it has been recognised that environmental conditions in major spawning areas and thus reproductive success differs (e.g. MacKenzie *et al.*, 2000; Köster *et al.*, 2001a). Single ICES Sub-divisions 25, 26, and 28 are assumed to represent the major spawning areas of the Bornholm Basin, Gdansk Deep and Gotland Basin, respectively. Fitting of the statistical models was conducted first for these major spawning sites and then combined for the entire central Baltic. The conducted analysis revisits spatially explicit environmentally sensitive stock recruitment models established by Köster *et al.* (2001a), but it is based on enhanced process understanding, especially in relation to the impact of food availability on the larval stage, new and updated time series for all variables and extended statistical analysis. Variables identified included: potential egg production by the spawning stock, abiotic conditions affecting survival of eggs and prey availability for first feeding larvae (Köster *et al.* 2005). To account for cannibalism the stock recruitment relationships were fitted to 0-group abundance from area disaggregated MSVPA output (ICES 2001/H:04). Time series of standing stocks and production rates of various life stages and their survival utilised in the present analysis are presented in Köster *et al.* (2005).

Reproductive effort: potential egg production

Basin specific estimates of female spawning stock biomass (SSB) at spawning time, i.e. mid of May 1976-1990 and beginning of July 1991-1999, are available from area dis-aggregated MSVPA runs for Sub-divisions (SD) 25, 26 and 28 encompassing the period 1976 to 1999 (for technical set-up of MSVPA see ICES, 2001/H:04). The corresponding seasonal potential egg production (PEP) by the spawning stock was estimated by multiplying the female SSB according to SD by relative individual fecundity values predicted from a relationship to clupeid prey availability (Kraus *et al.*, 2002) applying MSVPA derived area specific abundances of clupeids as prey.

Realised egg production and survival

Mean annual egg abundance values, representing main spawning time, are available for the three spawning areas from ichthyoplankton surveys conducted in the period 1976-1999. Egg stage specific abundances available for most years in combination with ambient temperatures formed the basis for determining average daily egg production according egg stages I to IV.

To estimate the fraction of egg production surviving the hydrographic conditions at incubation depths in each year (OES), the predicted vertical distribution of cod eggs relative to water density and the oxygen concentration derived from the ICES hydrographic database were coupled to an oxygen concentration-egg survival relationship.

Predation by sprat has a significant impact on cod egg survival in spring and early summer, while later in the cod spawning season herring is the principal predator (Köster and Möllmann, 2000). Apart from intra-annual trends, spatial variation in the intensity of egg predation occurs, with consumption in the Gdansk Deep and Gotland Basin being considerably lower than in the Bornholm Basin. For this reason, predation on eggs was considered as mortality source for the latter area only.

Cod egg predation intensity was modelled as linearly related to cod egg abundance considering the vertical predator/prey overlap. In combination with daily egg consumption rates of individual predators and predator populations sizes from area dis-aggregated MSVPA downscaled to the Bornholm Basin, the predation pressure by clupeid populations was determined for the period 1976-1999. Similar to the approach in Köster *et al.* (2001a), the predation pressure was expressed relative to the maximum value determined (RPP), assuming a minimum survival of 5% in the year of maximum predation (PES).

Larval survival

The major prey of first feeding cod larvae in the Baltic are calanoid copepod nauplii, due to the pronounced spatio/temporal overlap with cod larvae especially nauplii of *Pseudocalanus acuspes* (Voss *et al.*, 2003). The importance of *Pseudocalanus* nauplii for cod larval growth and survival was tested with a coupled hydro-/trophodynamic individual-based model (Hinrichsen *et al.*, 2002b). In the present analysis, total and alternatively *Pseudocalanus* nauplii food availability is computed as average abundance over the entire water column from Latvian zooplankton monitoring in the 2nd quarter 1976-1991 and 3rd quarter 1994-1999 (Möllmann *et al.*, 2000).

Apart from prey availability and encounter, capture success may define larval feeding intensity. To accommodate this, in the present study the product of nauplii abundance during main spawning time and pursuit success was utilized as a measure of prey availability. Pursuit success probability has been calculated by utilizing a regression model for describing the influence of turbulent velocity on larval feeding success (MacKenzie and Kjørboe, 2000). This pursuit success model requires as input estimates of turbulent kinetic energy dissipation rate (from wind data time series) and prey separation distance (from prey field data). Successful

pursuit probabilities have been calculated specifically for this study for early (April-May), summer (June-July) as well as for later hatched larvae (August-September) for 30 m depths.

A time series of larval survival rates is not available for the eastern Baltic cod stock. However, mortality measures were derived by relating recruitment at age 0 to surviving egg production, either modelled as the product of PEP and OES or directly observed as average daily egg stage III production.

Juvenile abundance and survival

Age-group 0 recruitment values for the different SDs were derived by area dis-aggregated MSVPA runs (ICES 2001/H:04). The early juvenile stage was utilised instead of age-group 2 available from regular stock assessments to minimise the effect of cannibalism (Uzars and Plikshs, 2000) on the perception of reproductive success.

Jarre-Teichmann *et al.* (2000) demonstrated that the cumulative wind energy at peak spawning time impacts on cod recruitment success. The suggested process being a transport of larvae and pelagic juveniles to coastal nursery habitats favourable for recruitment during periods of high wind energy and a retention in the central basins during periods of low wind stress of variable wind direction (Hinrichsen *et al.* 2001). Köster *et al.* (2001a) modified the cumulative wind energy measured on the island of Christiansø in the northwestern Bornholm Basin into a larval transport index.

In the present study we applied a larger scale atmospheric variable as a measure of transport, assumed to be representative for the entire Central Baltic, i.e. the Baltic Sea Index (BSI), covering as well a longer period of time, i.e. a three month period from peak spawning time to account for juvenile transport. Lehmann *et al.* (2002) defined the BSI index as the difference of normalised sea level pressure anomalies between Oslo (Norway) and Szczecin (Poland). For example, a positive BSI corresponds to an anomalous sea level pressure difference with westerly winds over the Central Baltic, in near surface layers leading to transport towards the east. In contrast, a negative BSI corresponds to easterly winds, favouring currents towards the west near the sea surface.

Environmentally sensitive stock recruitment relationships

The basis for developing environmentally sensitive stock-recruitment relationships for Baltic cod is the identification of causal relationships between survival rates of different early and juvenile life stages, environmental factors and species interactions (Köster *et al.* 2005). In the present study, simple and multiple linear regression techniques were applied to test for the relationships between various variables and based on significant results, stock-recruitment models with combinations of different factors were constructed.

Area specific data were used when available and if substantial spatial variation was encountered (Köster *et al.*, 2005). Specifically, the oxygen related egg survival (OES) and the relative predation pressure were considered to be area specific as strongly dependent on hydrographic conditions. By utilising the sum of $PEP * OES * PES$ over Sub-divisions, with PES being 1 in the Gdansk Deep and the Gotland Basin and thus assuming no predation mortality, the surviving potential egg production is represented by one variable. This combines the reproductive effort and egg survival, but being area specific. In contrast, the available zooplankton data did not allow construction of an area specific measure of prey availability, but is calculated as an average per quarter over all areas to minimise the impact of small-scale variability resulting in quite noisy local estimates. Similarly, the applied atmospheric variable BSI as a measure of transport is assumed to be representative for the entire Central Baltic.

The identification of variables to be included in stock-recruitment models was conducted by a combination of step-wise regression and ranking of best best-subsets of explanatory variables. First the effect of modifying PEP for oxygen and predation related egg survival was explored by testing all possible area and variable combinations for significance and contribution to explained variance. In a second step, the effect of including different representations of prey availability as an additional variable was tested for each area, retaining alternatively PEP or modified PEP for oxygen and predation related egg survival. Based on the resulting significant best performing variables, stock recruitment relationships were constructed for the entire central Baltic acknowledging spatial variability in significant processes and variables.

Recruitment in Baltic cod is ln-normal rather than normal distributed (Shapiro-Wilks test) and ln-transforming dependent and independent variables lead to multiplicative stock recruitment models with ln-normal error structure. Köster *et al.* (2001b) acknowledged that this type of model performs statistically better and is also biologically more sensible than additive models. The argumentation to prefer nevertheless additive models was that multiplicative models did not exhibit better predictive power and consistently underestimated recruitment at high reproductive success (Köster *et al.* 2001b). In the present analysis we test for this difference in predicting extreme recruitments with a subset of best performing stock recruitment models.

The parameters of these statistical models are based on the entire time series of data available. However, in order to obtain an indication of the sensitivity of parameter estimates for model configurations having best predictive capabilities and to evaluate the accuracy of model predictions for time periods not represented by the model, the first four and five years of data, i.e. years with high reproductive success, were excluded and the models re-fitted utilizing only data sets 1979 to 1995 and 1980 to 1995 for parameter estimation. Predictions from the re-fitted models were then compared with observations for 1976 to 1979/1980. A similar test was performed for the periods 1995/1996 to 1999 utilizing data sub-sets covering the periods 1976 to 1995 and 1976 to 1996.

7.1.1 Exploratory analysis

The potential egg production (PEP) in SD 25 is significantly related to the realised average daily production of the youngest egg stage I. PEP is, however, only weakly related to the production of egg stage III, unless multiplied by the oxygen related (OES) and the predation related egg survival (PES). This indicates that PEP is an adequate measure of egg production and that OES and PES capture major processes affecting egg mortality. A similar test of PEP and egg survival is not possible for the other spawning areas, as a time series of stage specific egg production data does not exist. However, comparison to larval abundance is possible. While PEP is only weakly correlated to larval abundance, the relationship between PEP*OES and larval abundance is highly significant confirming that OES captures a significant fraction of the egg mortality.

PEP is as well significantly related to 0-group recruitment in all SDs, however in SD 25 explaining only limited variability in recruitment (Tab. 7.1.1). Utilising PEP*OES and especially PEP*OES*PES as independent variable improves the relationships substantially, while this is not the case in eastern SDs. Linear relationships between the same variables, but ln-transformed explain recruitment in general better (Tab. 7.1.1). A positive effect of including OES is obvious for SD 26, otherwise the most simple model, i.e. PEP as variable only, explains variability in recruitment best. From these tests it can be concluded that the potential egg production is in all areas significantly related to recruitment, but that including factors representing the egg survival alone do not improve the relationships substantially. Furthermore, ln-transformation of variables revealed the better fit to the data.

Late egg stage production in SD 25, used as a measure of larval production is significantly related to recruitment at age 0. When including prey availability as either Pseudocalanus or all

nauplii as additional variable in a multiple regression, the explained variance in recruitment increased considerably. A similar test is not possible for the other spawning areas, as a time series of stage specific egg production data does not exist. However, comparison to egg abundance is possible. While recruitment is only weakly correlated to egg abundance, the relationship improves significantly if prey availability is included as additional variable, which is in line with coupled tropho-/hydrodynamic model results demonstrating that nauplii availability affect early cod larval survival (Hinrichsen *et al.*, 2002b).

To test for the form of the relationship between larval survival and food availability, recruitment per unit of egg production (PEP) as a measure of larval survival was related to food availability in a linear, an asymptotic and an exponential relationship. Independent whether the abundance of *Pseudocalanus nauplii* (Pp) or of all nauplii (Pn) represented prey availability, the linear relationship performed best in all areas (Tab. 7.1.1).

As the contribution of egg survival factors OES and PES in explaining recruitment variability was inconclusive when considering together with the potential egg production PEP alone, all possible combinations of egg production, egg survival and food availability were tested against recruitment. Utilising the various variables representing food availability (Pp, Pn, Pp*T and Pn*T) together with PEP in a multiple linear regression revealed improved r^2 -values compared to those obtained when utilising PEP alone. However, PEP is a none significant variable in SD 25 and only partly significant in SD 26, i.e. when using Pn instead of Pp. This is in contrast to the result for the ln-transformed models. Here PEP is in general significant, but food availability only in SD 25 and partly in SD 26 (Tab. 7.1.1).

The difference between including pursuit success (T) as factor in the prey availability was found to be marginal, in both the un- and ln-transformed relationships (Tab. 7.1.1). As inclusion of the factor always improved the overall fit of the model in the un-transformed mode, in subsequent more complex relationships always Pp*T or Pn*T were applied as food availability.

Modifying PEP for egg survival in the multiple regressions together with food availability, revealed improvements in the un-transformed relationship in all tested variable combinations (Tab. 7.1.1). Surviving egg production (PEP*OES or PEP*OES*PES) and prey availability (Pp*T or Pn*T) are always significant ($p < 0.05$) and Mallows Cp suggests to retain both variables in all combinations (check). The overall model fit was always best when applying Pp in the food availability, although partial coefficients of determination were not always confirming the better performance of Pp. The Durban Watson (DW) statistics indicated serial autocorrelation in residuals for SD 26.

For SD 25 and SD 26 the ln-transformed models behaved similar to the un-transformed, with complex models having the overall best fit, all variables being significant, and Pp*T behaving best as food availability (Tab. 7.1.1). The latter is in contrast to SD 28, where using Pn in the food availability resulted in highest r^2 -values. For this area all variables are significant in all combinations, but most variability in recruitment is still explained by a simple relationship to PEP. Furthermore, the DW-statistics indicates autocorrelation in the residuals for the complex model, which however, is even more pronounced in the simple model. A tendency to autocorrelation in the residuals is as well encountered in the other areas, especially when Pp*T is applied as food availability.

Including the transport index BSI in these complex models as additional variable or replacing nauplii abundance as food availability by BSI did not improve any of the statistical models, with BSI always being insignificant and Mallows CP suggestion removal of the variable in all cases (Tab. 7.1.1).

Testing for the effect of inclusion of egg predation in SD 25 by including RPP as additional variable (un- and ln-transformed respectively) revealed according to Mallows Cp that

predation adds significant information to the models, however, PEP*OES losing its significance.

Table 7.1.1 Exploratory analysis of recruitment (age 0 from MSVPA 1976-1999) variability in different ICES Sub-divisions 25, 26 and 28. If for the independent variable a log-transformation is indicated, the transformation was also applied to the dependent variable.

INDEPENDENT VARIABLE	25	26	28
Ln PEP	0.36**	0.53***	0.84***
Ln (PEP*OES)	0.34**	0.70***	0.71***
Ln (PEP*PES)	0.25*		
Ln (PEP*OES*PES)	0.24*		
PEP	0.20*	0.52***	0.62***
PEP*OES	0.33**	0.52***	0.45***
PEP*OES*PES	0.42***		
Ln PEP	0.55* ²	0.63* ²	0.80*** ²
Ln Pp	**	*	-
Ln PEP	0.59**	0.50**	0.80***
Ln Pn	***	-	-
Ln PEP	0.51 ²	0.63*	0.80*** ²
Ln Pp*T	**	*	-
Ln PEP	0.59**	0.51**	0.80***
Ln Pn*T	***	-	-
Ln Pp*T vs. R/PEP	0.19 ²	0.22* ²	0.22* ²
Pp*T vs ln(R/PEP)	0.38**	0.31**	0.44**
Pp*T vs R/PEP	0.47***	0.47***	0.57***
Pn*T vs R/PEP	0.50***	0.45***	0.56***
Ln Pn*T vs R/PEP	0.29*	0.18	0.24*
Pn*T vs ln(R/PEP)	0.38**	0.25*	0.33**
PEP	0.57	0.65	0.66*
Pp	***	**	**
PEP	0.55	0.63*	0.65**
Pn	***	**	**
PEP	0.59	0.66	0.67*
Pp*T	***	***	**
PEP	0.58	0.64*	0.66**
Pn*T	***	**	**
Ln (PEP*OES)	0.61** ²	0.82*** ²	0.73** ²
Ln Pp*T	***	**	*
Ln (PEP*OES)	0.66***	0.75*** ²	0.81*** ²
Ln Pn*T	***	*	**
Ln (PEP*OES*PES)	0.70*** ²		
Ln Pp*T	***		
Ln (PEP*OES*PES)	0.69***		
Ln Pn*T	***		
Ln (PEP*OES)	0.66	0.67	0.72*
Ln BSI	-	-	-
Ln Pp*T	-	-	-
Ln (PEP*OES)	0.43*	0.58* ²	0.77**
Ln BSI	-	-	-
PEP*OES	0.68*	0.72* ²	0.67*
Pp*T	***	***	***
PEP*OES	0.66*	0.65*** ²	0.64*** ²

INDEPENDENT VARIABLE	25	26	28
Pn*T	***	**	***
PEP*OES*PES	0.74**		
Pp*T	***		
PEP*OES*PES	0.38*** ²	0.47*** ²	0.41*** ²
BSI	-	-	-
PEP*OES*PES	0.76**	0.71* ²	0.67* ²
Pp*T	***	***	***
BSI	-	-	-
PEP*OES*PES	0.71**		
Pn*T	***		

* p<0.05, ** p<0.01, ***p<0.001

¹ Cp suggest exclusion of variable

² DW suggests autocorrelation of residuals

7.1.2 Stock recruitment relationships

Based on results of conducted exploratory analyses statistical stock recruitment models can be constructed as simple multiple linear regressions for the different SDs. Variables included are the potential egg production modified by oxygen and predation related egg survival (PEP*OES*PES) and Pseudocalanus nauplii availability modified by turbulent velocity dependent pursuit success (Pp*T):

$$R_i = a_i + b_i * PEP_i * OES_i * PES_i + c_i * T * P_p$$

In a second step stock recruitment relationships in this model 1 can be calculated for the entire eastern Baltic stock as sum over SDs with:

$$R = \sum \max(0, R_i)$$

Alternatively the statistical model may be fitted directly fitted to all SDs at once (model 2):

$$R = a + b * (\sum PEP_i * OES_i * PES_i) + c * T * P_p$$

with: R_i : Recruitment at age 0 in SD i

PEP_i : Potential egg production in SD i

OES_i : Oxygen related egg survival fraction in SD i

PES_i : Predation related egg survival fraction in SD i, with PES = 1 in SD 26 and 28

T: pursuit success during and after peak spawning time

P_p : prey availability of Pseudocalanus nauplii

a, b, c: estimated parameters

Fig. 7.1.1 contains predicted vs. observed recruitment values for model 2. The model explains 77% of the variability in recruitment and although autocorrelation of residuals is indicated for SD 28, the combined model did not exhibit similar indications.

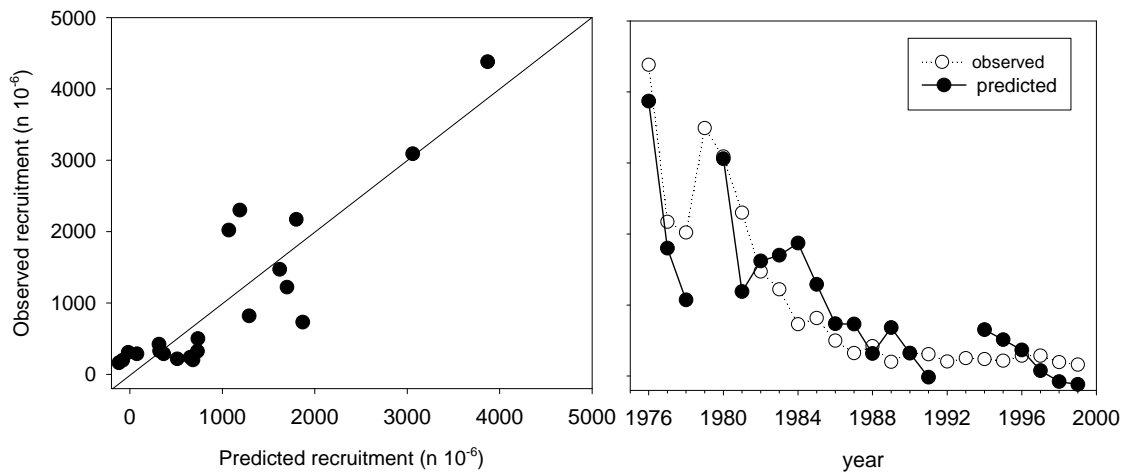


Fig. 7.1.1 Cod recruitment at age 0 determined by MSVPA versus predicted by model 2.

A corresponding ln-transformed model explained a similar portion of the variance in recruitment (76%), with as well all variables being significant, but with indications of autocorrelation of residuals in all SDs and the area combined model. Utilising P_n as prey availability instead of P_p resulted in a similar fit in the combined model, but removal of the autocorrelation, a tendency which is obvious also for SD 25 and 26. The explained variance can be enhanced somewhat by excluding OES in SD 28, a variable not contributing in explaining recruitment in the exploratory analysis. This leads to model 3 with a similar set-up as model 2 above, with

$$\ln \sum R_i = a + b * \ln \sum (PEP_i * OES_i * PES_i) + c * \ln (T * P_n)$$

with: OES_i : Oxygen related egg survival fraction in SD i , with $OES = 1$ in SD 28

PES_i : Predation related egg survival fraction in SD i , with $PES = 1$ in SD 26 and 28

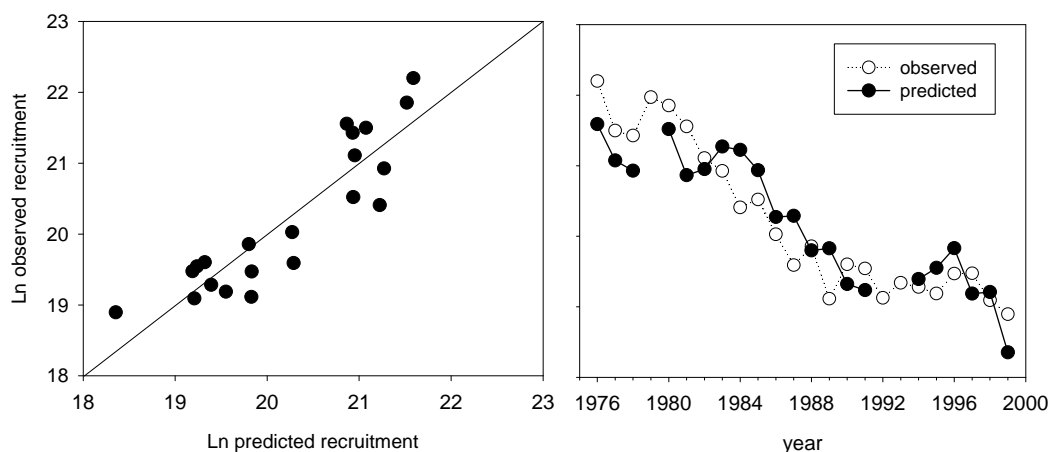


Fig. 7.1.2 Cod recruitment at age 0 determined by MSVPA versus predicted by model 3.

To test the stability of the models to adding/removing new data the model 2 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 (Fig. 7.1.3). 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.

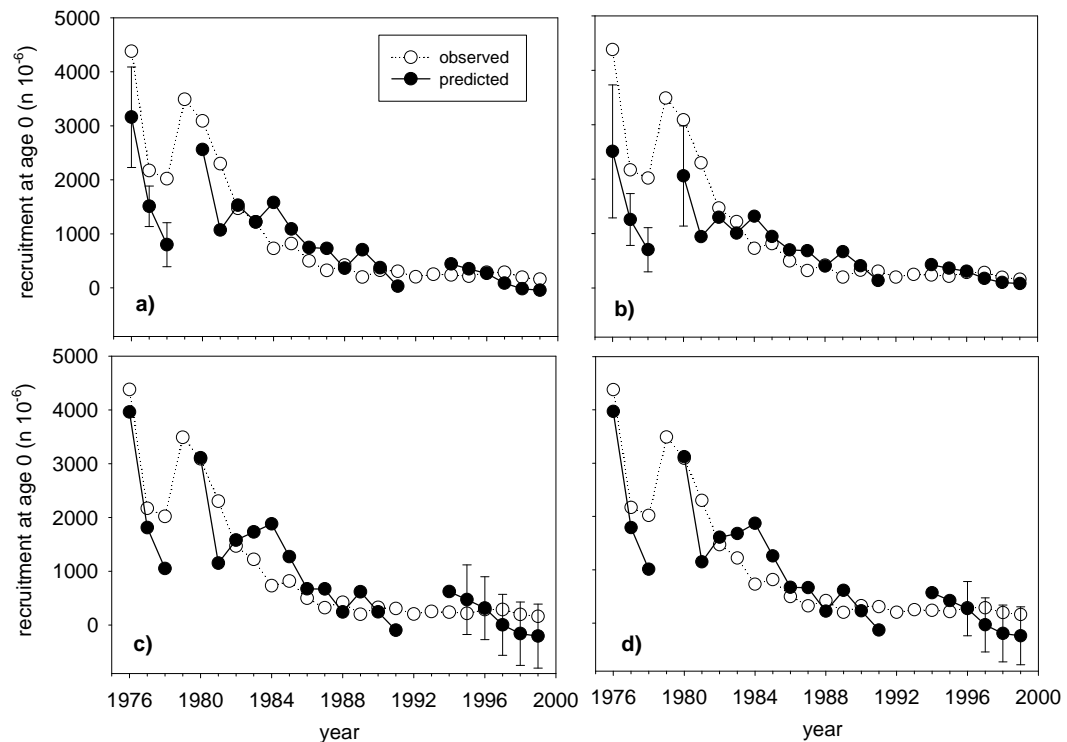


Fig. 7.1.3 Cod recruitment at age 0 determined by MSVPA versus predicted by model 2; parameter estimated from data series 1980-1999 (a), 1981-1999 (b), 1976-1994 (c) and 1976-1995 (d) with 95% confidence limits of the predicted means.

A similar test with model 3 revealed similar features as the test with model 2 (Fig. 7.1.4), but more important it substantially underestimates the recruitment at the beginning of the time series, i.e. at high recruitment success, even when including high recruitment periods in the parameter estimation.

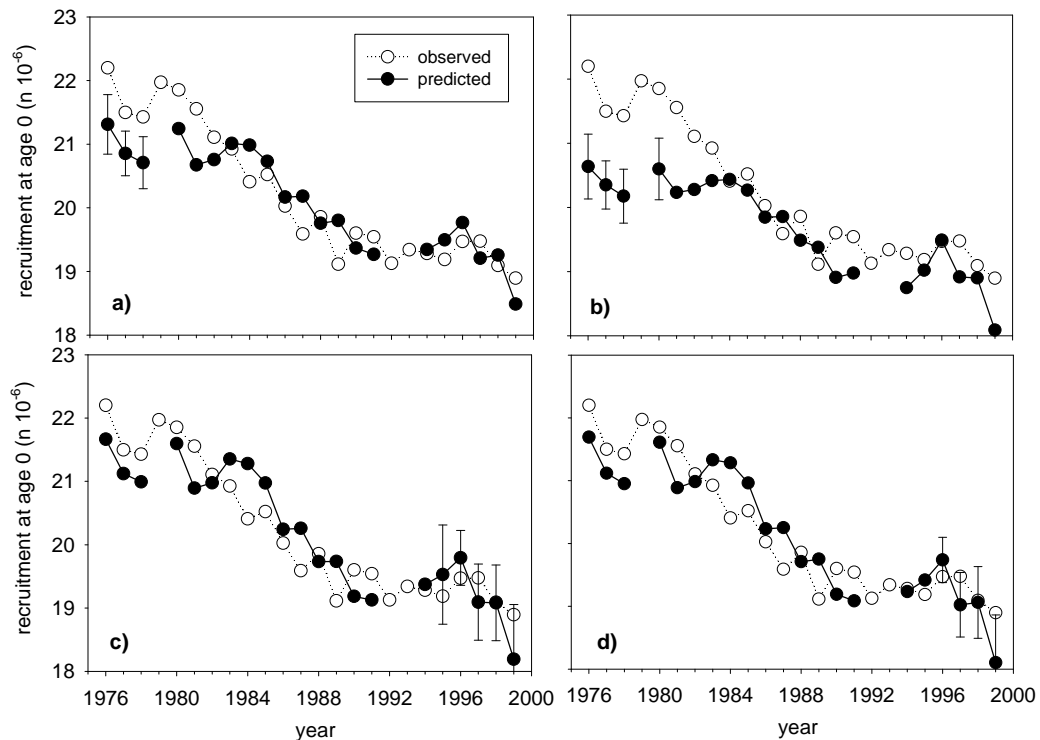


Fig. 7.1.4 Cod recruitment at age 0 determined by MSVPA versus predicted by model 3 (ln-transformed); parameter estimated from data series 1980-1999 (a), 1981-1999 (b), 1976-1994 (c) and 1976-1995 (d) with 95% confidence limits of the predicted means.

8 Consequences of heterogeneous distribution of predator and prey on species interactions in the Central Baltic

8.1 Background

The Baltic Sea environment is heterogeneous. Features such as fronts or clines in temperature, salinity and oxygen saturation structure predator and prey populations in space (Neuenfeldt 2002, Neuenfeldt and Beyer 2004, 2006). Such spatial structuring can be essential for the partial stabilization and persistence of species interactions (Gause 1936, Huffaker 1958); accounting for spatial structure is hence a prerequisite for understanding population dynamics.

The reduced frequency of major Baltic inflows observed since 1976 was accompanied by a change in the diet composition of adult cod. The mass ratio of herring to sprat in the stomachs of adult cod in the central Baltic Sea was halved from ca. 1 in 1970-1975 to ca. 0.5 in 1986-1990 (Uzars 1994). However, this decrease was considerably less than the decrease in the sea, where the herring-sprat ratio decreased at least 3-fold (Parmanne *et al.* 1994, Köster *et al.* 2001a). Thus, the observed changes in the cod diet are not simply a function of changes in the relative prey biomasses, and higher order mechanisms in the predator-prey relationship may be responsible. One mechanism which could explain this conservatism or stability of the cod diet composition is a change observed in the spatial distributions of the predator and prey species.

The effect of prey densities on the abundance of a prey species in the diet of an individual predator is expressed by the functional response (Holling 1959, Murdoch 1973). In heterogeneous environments such as the Baltic Sea it is likely that prey habitats do not overlap fully with the predator habitat, and that hence the prey-specific densities encountered by an individual predator depend on the location of the predator. Therefore, the aggregate diet of the

entire predator population may not be predicted solely from the functional response of the individuals making up the population (Chesson 1984).

8.2 Predator-prey overlap

The aggregate functional response f_i^* with respect to prey species i ($i = 1, 2$) is calculated as the weighted mean of the individual functional responses f_i in the different strata of the predator habitat with the relative predator abundances n_j / n in the strata as weighting factors. Here, $\rho_{i,j}$ denotes the stratum-specific prey densities, n the total predator abundance, and n_j the predator abundance in stratum j :

$$f_i^* = \sum_{j=0}^2 \frac{n_j}{n} f_i(\rho_{1,j}, \rho_{2,j}), \quad \text{with} \quad n = \sum_{j=0}^2 n_j$$

The relative predator abundance n_j / n in each stratum can be represented by habitat overlaps. With the term PEV_i indicating the potential encounter volume, i.e. the water volume where prey i and the predator co-occur (Neuenfeldt 2002), there are two ways to formulate habitat overlap, either from the predator or from the prey perspective:

$$O_i = \frac{PEV_i}{H_{pred}} \quad ; \quad Q_i = \frac{PEV_i}{H_i}$$

The predator-prey overlap O_i defines the fraction of the predator habitat, where prey i occurs, whereas the prey-predator overlap Q_i (henceforth termed occupation) defines the fraction of the prey habitat, where prey individuals run the risk of encountering a predator. Due to the homogeneity assumption, the fraction which a given stratum has of the total predator habitat equals the fraction of the predator population in that particular stratum. The fraction of the predator population in each stratum is thus represented by predator-prey overlaps as follows:

$$\frac{n_j}{n} = \begin{cases} 1 - O_1 & ; j = 0 \\ O_1 - O_2 & ; j = 1 \\ O_2 & ; j = 2 \end{cases}$$

8.3 Functional responses

We considered two well-known and generic functional response models both representing the simplest possible extensions from the linear (or type 1) response (Holling 1959). Our first model, the Holling type 2 functional response, expanded to two species (Murdoch 1973), accounts for prey-specific handling-times h_i , i.e. the generalized Holling's disk equation:

$$f_i(\rho_1, \rho_2) = \frac{\delta \alpha_i \rho_i}{1 + \delta(\alpha_1 h_1 \rho_1 + \alpha_2 h_2 \rho_2)}$$

The parameter δ is an overall searching rate and α_i is a preference measure (Chesson, 1978). Alternatively, we can express this and, in general, any form of functional response as the total prey consumption $f_T = f_1 + f_2$ multiplied by the proportion of the diet made up by species i . Since this diet proportion is defined by the preferences α_1 and $\alpha_2 (= 1 - \alpha_1)$ we obtained:

$$f_i(\rho_1, \rho_2) = f_T \frac{\alpha_i \rho_i}{\alpha_1 \rho_1 + \alpha_2 \rho_2}$$

where f_T in general will depend on α_1 and α_2 (Chesson 1984). The second functional response model is simply specified by considering f_T constant. This is an active response model very close to the formulation used in the MSVPA, because the predator keeps the rate of food consumption constant by actively modifying the searching rate δ , so search rate becomes a function of prey densities (Chesson 1984). In a case with considerable difference in average prey mass ($w_2 > w_1$), f_i is replaced with $f_i w_i$ to model a constant rate of average food consumption $f_T = \sum f_i w_i$ by mass rather than numbers. The aggregate functional response ratio is then quantified directly as the prey-specific mass-ratio of stomach content.

8.4 Population consequences

The aggregate functional response ratio f_2^*/f_1^* is a convenient starting point for analyzing the population consequences of overlap dynamics, because the denominator, that in reality contains not only two but a number of prey species which density is hardly to estimate, cancels out. Empirical data from the Bornholm basin during March overlap situations showed that the ratio of consumed herring to sprat increases *faster* than proportionally to the ratio of cod-herring to cod-sprat overlaps (Neuenfeldt and Beyer 2006).

Focusing on the effect of changes in the prey abundance ratio N_2/N_1 , the aggregated functional response ratio can be written as:

$$\frac{f_2^*}{f_1^*} = \frac{\frac{O_2}{O_1} \frac{f_2(\rho_1, \rho_2)}{f_1(\rho_1, \rho_2)}}{\frac{O_2}{O_1} + \left(1 - \frac{O_2}{O_1}\right) \frac{f_1(\rho_1, 0)}{f_1(\rho_1, \rho_2)}}$$

In the numerator, the consumption rate of prey 2 as compared to prey 1 (in stratum 2) can be expressed by:

$$\frac{f_2(\rho_1, \rho_2)}{f_1(\rho_1, \rho_2)} = A \frac{H_1}{H_2} \frac{N_2}{N_1}$$

Similarly, $f_1(\rho_1, 0)/f_1(\rho_1, \rho_2)$, the consumption rate of prey 1 (in stratum 1) as compared to the consumption rate of prey 1 (in stratum 2) is expressed by:

$$\frac{f_1(\rho_1, 0)}{f_1(\rho_1, \rho_2)} = 1 + B \frac{H_1}{H_2} \frac{N_2}{N_1}$$

The aggregated functional response ratio can hence be re-written as:

$$\frac{f_2^*}{f_1^*} = \frac{A \frac{H_1}{H_2} \frac{O_2}{O_1} \frac{N_2}{N_1}}{1 + B \frac{H_1}{H_2} \left(1 - \frac{O_2}{O_1}\right) \frac{N_2}{N_1}}$$

In the type 2 functional response model, A becomes prey density independent, $A = \alpha_2/\alpha_1$, whereas $B = \delta h_2 \alpha_2 \rho_1 / (1 + \delta h_1 \alpha_1 \rho_1)$ depends on the density of prey 1, $\rho_1 = N_1/H_1$. In the active response model, both coefficients are density independent, $A = B = \alpha_2/\alpha_1$. Note that A is a

factor of w_1/w_2 smaller than B in case of the active response model with constant mass-rate of food consumption.

In the active response model, Figure 8.4.1 shows the effect of prey abundance ratio on the ratio of prey in the diet of cod, at different overlap ratios. The ratio of herring to sprat in the cod diet will increase at rate $A(H_{\text{spr}}/H_{\text{her}})(O_{\text{spr}}/O_{\text{her}})$, if the abundance ratio increases in situations of low herring abundance compared to sprat. At the other extreme, when $N_{\text{her}}/N_{\text{spr}}$ is large, the maximum ratio of herring to sprat in the aggregate cod diet becomes $(A/B)[O_{\text{her}}/O_{\text{spr}}(1-O_{\text{her}}/O_{\text{spr}})]$. Both increase rate and maximum ratio of herring to sprat decrease when overlap ratios decline during stagnation periods.

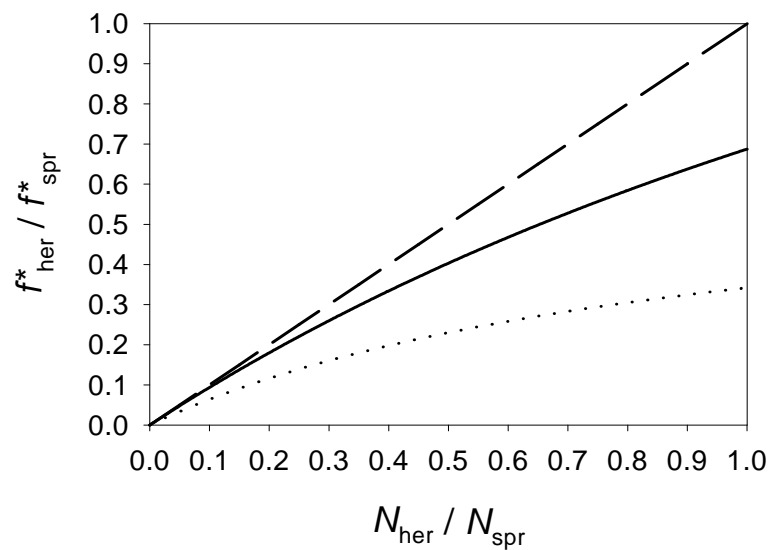


Figure 8.4.1. Aggregated (i.e. averaged to population level) per capita consumption rate by cod of herring relative to sprat in relation to the relative abundance of the two prey types, as predicted by the active response model. The curves represent the relationship at different ratios of cod-herring to cod-sprat overlaps ($O_{\text{her}}/O_{\text{spr}} = 1$ (dashed), 0.7 (solid), 0.4 (dotted)).

Considering for simplicity only the average overlap ratio of 0.7, cod consumption of sprat was generally on a higher level than would be expected, if herring and sprat had been sharing the same (potential encounter) volume. The predation on sprat decreased with the reduced cod stock in the 1980s and consequently lowered the abundance ratio of herring to sprat, since the herring stock can be considered constant in this context. At decreasing abundance ratio of herring to sprat, the consumption ratio will decrease slower than the decreasing abundance ratio. This means that the percentage of the sprat stock consumed by cod actually decreased compared to that of herring. Thus, the environmentally driven overlap will amplify the emergence of an increase in the sprat stock, in particular when major inflows do not occur.

If predator-prey overlaps are disregarded, then observed diet-stability can be misinterpreted as a situation of increasing preference by the individual predator for a prey that decreases in abundance. Such a situation is referred to as negative switching (Chesson 1984), which usually is quantified by an empirical power relationship (Elton & Greenwood 1976). Instead, using conceptual modeling, we derived from first principles the somewhat less accelerating Monod-type of functional form for the ratio in the diet versus the ratio in the environment (Figure 8.4.1). Thereby we showed that, if one part of the predator habitat contains both prey types and another region contains only one of them, then ‘apparent’ negative switching can be observed. ‘Apparent’ means that negative switching will emerge at the population level although it does not occur at the individual level.

Focus is now put upon the number of prey 1 individuals eaten on population level per capita and unit time relative to N_1 . Asking to what extent an increase or decrease in N_1 results in a greater than proportionate increase or decrease in the *per capita* number of prey 1 individuals eaten, it becomes possible to describe how population overlap and individual functional response together affect the stability of prey population 1.

Using the Type 2 functional response in this context, different handling time concepts, such as relating handling time either to capture only or to capture plus digestion, can be investigated for their implications on stability in different overlap scenarios. Disregarding handling time but considering total consumption constant, based on the ARM the effect on prey 1 stability of compensatory feeding on prey 1 in the absence of prey 2 can be investigated.

The model:

FR TYPE	TYPE 2	ARM
f1	$\alpha_1 N_1 (1 + \alpha_1 N_1 h_1 + \alpha_2 N_2 h_2)^{-1}$	$f_T \alpha_1 N_1 (\alpha_1 N_1 + \alpha_2 N_2)^{-1}$
f10	$\alpha_1 N_1 (1 + \alpha_1 N_1 h_1)^{-1}$	f_T , or 0 in O1-O2 if $\rho_1=0$
f1*	$(O_1 - O_2)f_{10} + O_2 f_1$	
f2*	$O_2 \alpha_2 N_2 (1 + \alpha_1 N_1 h_1 + \alpha_2 N_2 h_2)^{-1}$	$O_2 f_T \alpha_2 N_2 (\alpha_1 N_1 + \alpha_2 N_2)^{-1}$
per capita predation rate	f_i^* / N_i	

Note that O_1 equals 1, because prey population 1 overlaps completely with the predator population in this simplified overlap scenario. Unless explicitly mentioned, $\alpha_1=\alpha_2=0.5$ and $h_1=h_2=1$. Furthermore, f_T was set to 1. N_2 was set to 1 in the following simulations.

Both the Type 2 and the ARM functional responses are *a priori* destabilizing independent of predator-prey overlap, because per capita predation rates decrease at increasing prey densities, even if $O_2=1$:

$$\text{ARM:} \quad \frac{d}{dN_1} \left(\frac{f_1^*}{N_1} \right) = -\frac{1}{N_1^2} (1 - O_2) f_T + O_2 f_T \alpha_1 \frac{-\alpha_1}{\{\alpha_1 N_1 + (1 - \alpha_1) N_2\}}$$

$$\text{TYPE 2:} \quad \frac{d}{dN_1} \left(\frac{f_1^*}{N_1} \right) = (1 - O_2) \alpha_1 \frac{-\alpha_1 h_1}{(1 + \alpha_1 N_1 h_1)^2} + O_2 \alpha_1 \frac{-\alpha_1 h_1}{(1 + \alpha_1 N_1 h_1 + (1 - \alpha_1) N_2 h_2)^2}$$

However, in the ARM at $O_2 < 1$ the decrease is more pronounced than at $O_2 = 1$ (Figure 8.4.2). If $O_2 < 1$ in the ARM, then the predators have exclusively prey 1 to obtain a constant amount f_T of consumed fish in a $(1 - O_2)$ -fraction of their dispersion volume. The *per capita* predation rate decreases at increasing prey 1 density at a rate that is inversely proportionate to N_1^2 . Therefore, the effect is especially pronounced at $N_1 < 1$.

In consequence, increases of N_1 are amplified in the ARM at $O_2 < 1$, especially when N_1 is initially small. Here it becomes important to distinguish between the traditional functional response experiments with simultaneous encounters and the sequential encounters in the field. Especially if N_1 is measured in number of schools per unit volume then a situation where the individual predator has less than 1 encounter per unit time is realistic. Also the density of prey individuals can well be less than 1.

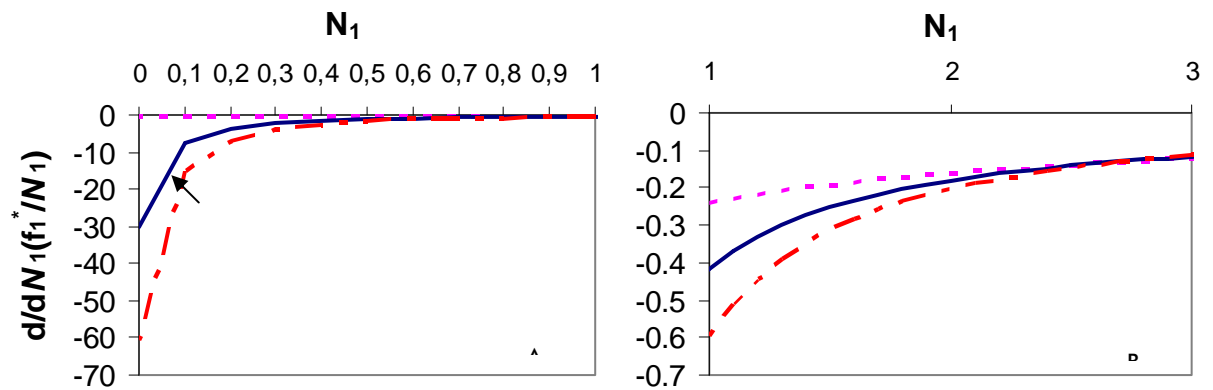


Figure 8.4.2. ARM - Rate of decrease in per capita predation rate at increasing N_1 for different overlaps O_2 , i.e. the predators have exclusively prey 1 to obtain a constant amount f_1 of consumed fish in a $(1-O_2)$ -fraction of their dispersion volume. The curves are displayed separately for N_1 between 0 and 1 (A) and between 1 and 3 (B). N_2 was kept constant at 1.

Also in the type 2 functional response model the *per capita* predation rate decreases faster at increasing N_1 if $O_2 < 1$ (Figure 8.4.3.), however, not at such a great rate as in the ARM (because of the $1 + \dots$ in the denominator).

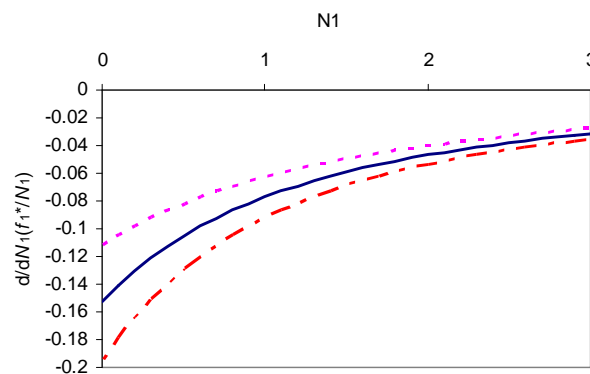


Figure 8.4.3. Type 2 - Rate of decrease in predation at increasing N_1 for different overlaps O_2 . The dashed lines show the functional response and predation intensity at $O_2=1$. The solid lines display response and predation intensity $O_2=0.7$. The dash-point lines reflect $O_2=0.4$.

Yet, a greater decrease rate of *per capita* predation at low but increasing N_1 can be observed, if h_1 in the type 2 model is high, corresponding to a (long) handling time (for example during digesting a meal consisting of several prey specimen after school encounter) during which the predator individual cannot search for new prey.

In order to allow for a direct comparison with the reference graphs in many textbooks, I plotted a type 2 functional response at constant predator and prey abundances, but differing predator-prey overlaps (Figure 8.4.4A). The aim with these panels is to illustrate that overlap influences the per capita predation rate (Figure 8.4.4C), thereby decoupling predation mortality from predator and prey abundances. These effects are more pronounced in the ARM (Figure 8.4.4B and 8.4.4D). However, when handling time is considered to include stomach evacuation, then the type 2 response shows a similar behavior (Figure 8.4.5A and 8.4.5B).

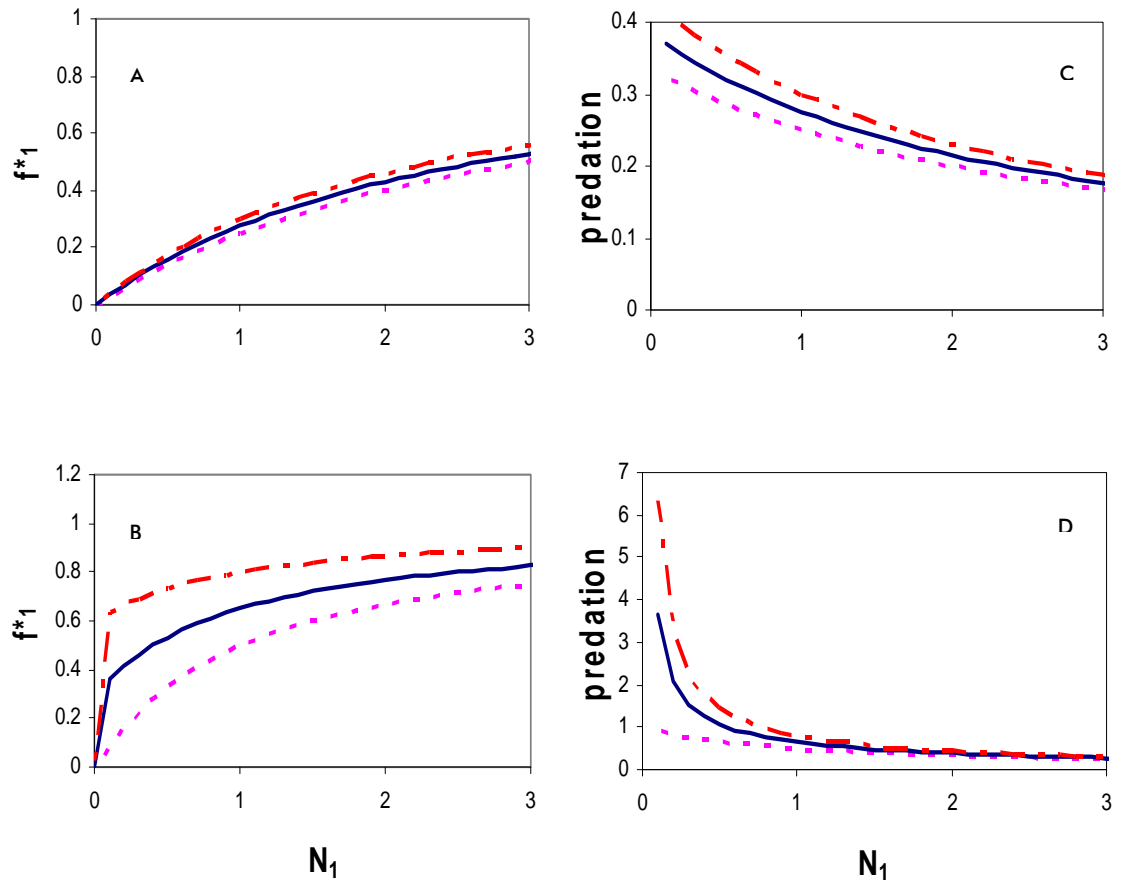


Figure 8.4.4: Aggregated per capita functional responses type 2 (A) and ARM (B) and related per *capita* predation rates for Type 2 (C) and ARM (D). The dashed lines show the functional response and predation intensity at $O_1=O_2=1$. The solid lines, in contrast, reflect response and predation at $O_1=1$, and $O_2=0.7$, i.e. in a situation where 30 % of the predator habitat contain prey 1 only. The dash-point lines reflect $O_1=1$ and $O_2=0.4$.

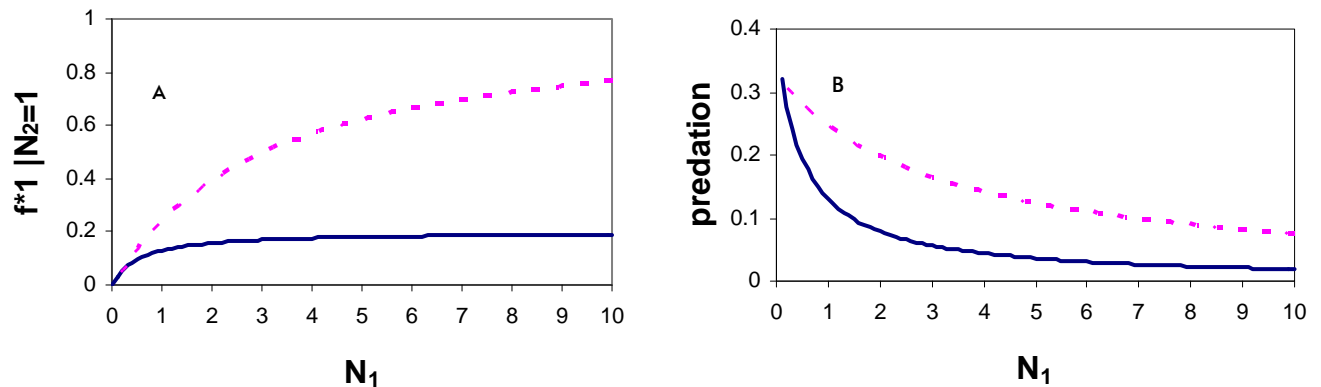


Figure 8.4.5. Type 2 response with $O_2=0.7$ and $h_1=5$. As well as in the ARM, the *per capita* predation rate at low N_1 decreases faster here as compared to the reference situation.

Only few events with for example favorable conditions for recruitment are sufficient to prevent prey population 1 from extinction and to sustain population growth, due to the rapid decrease in instantaneous predation mortality at low but increasing abundance. Prey refuges might conserve the minimum prey abundance necessary to initiate rapid population growth at favorable environmental conditions. Furthermore, there are no mutual effects between prey 1 and prey 2 as in 'real' negative switching. However, other food (which is not accounted for in this exercise) becomes important for the stability of prey 1 when it co-occurs with prey 1 in the $(1-O_2)$ stratum.

This exercise indicates that environmentally driven overlaps may play an important role in Baltic regime shifts. However, it only represents the first investigation of how the clupeid diet of adult cod depends on the hydrographic conditions in the Bornholm basin during March. A thorough examination of the environmental impact on the sprat increase requires an understanding of migration and feeding behaviour of cod, herring and sprat together with a quantification of their spatial overlap dynamics in all seasons. Furthermore, any future stomach sampling should representatively sample the different regions of the cod habitat.

Implementation

In the above exercise on population consequences a very simple overlap scenario has been considered, assuming that the cod population habitat was divided in a section with herring and sprat, and a section with sprat only. A more generic setup would include sections with herring only and with other food only. However, in order to exemplify the implementation of overlap in the MSVPA/SMS model world, the present simplified scenario is used only. The overlap considered here is schematized in Figure 8.4.6.

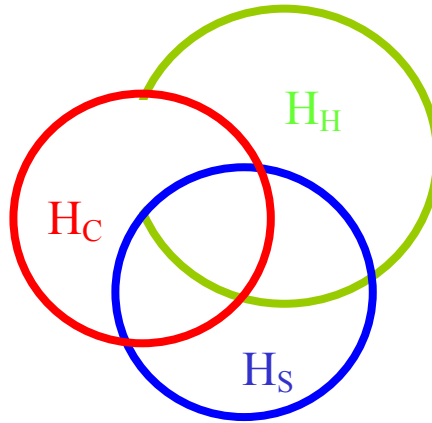


Figure 8.4.6. Overlap scheme for the Baltic Sea cod clupeid overlap. H_C indicates the cod habitat, H_H the herring habitat and H_S the sprat habitat. In the C+S part of the cod habitat where cod co-occurs with sprat, and C+H+S is the part of the cod habitat where cod co-occurs with both herring and sprat. Inside each species' habitat the individuals are considered to be homogenously distributed, so that e.g. the fraction C+S has from the total cod habitat equals the proportion of the total cod population residing inside this fraction.

The predation mortality $M2$ of prey species i is represented by $M2_i = D_i \bar{B}_i^{-1}$. \bar{B} is the average biomass $\bar{N}_i w_i$ during a given quarter. Devoured prey D_i is calculated as $D_i = \bar{N}_j f_i$, where \bar{N}_j is the average number of predators (during a quarter of the year). The individual functional response f_i of a predator for prey species i behind the calculation of MSVPA abundances is:

$$f_i = C_j \frac{G_i \bar{B}_i}{\left[\sum_i G_i \bar{B}_i \right] + G_o OTH}$$

This is an active response model as characterised above. C_j is the individual predator-specific quarterly ration, considered independent of \bar{B}_i and $\sum \bar{B}_i$, given as external input. G is an individual based preference index which is also called suitability. $G_o OTH$ is a constant biomass of other food with its own suitability. Note that \bar{B}_i in the nominator cancels out when formulating $M2_i$ as in Gislason and Sparre (1987):

$$M2_i = \bar{N}_j C_j \frac{G_i}{\left[\sum_i G_i \bar{B}_i \right] + G_o OTH}$$

The G_i are assumed constant and without accounting for variable predator-prey overlap defined by:

$$G_i = \frac{S_i \bar{B}_i^{-1}}{\sum_i (S_i \bar{B}_i^{-1})}$$

S_i is the mass in the stomach, which is in the Baltic not back-calculated to mass at ingestion.

Accounting for predator-prey overlap, the general solution for known *PEV*-specific average stomach content of prey *i*, $S_{PEV}(i)$ and unknown *total* population level average stomach content $S^*(i)$ is described in Gislason and Sparre (1987). For the Baltic, only the total population level is known, not the *PEV*-specific ones. Hence:

$$S_{PEV}(i) = \frac{S^*(i)}{O(i)}$$

The average prey-specific biomass cannot be used to determine the *PEV*-specific average stomach contents. Instead, the prey biomasses in each section of the predator biomass have to be used. These section specific biomasses can be formulated using Overlap, Occupation and *PEV* as outlined in table 1.

Table 1: Weighting factors for total prey-specific which have to be applied in order to derive *PEV*-specific prey biomasses:

PEV-SECTION	HERRING FRACTION	SPRAT FRACTION
C+H+S	$Q_{(H)} = PEV_{(H)} H_{(H)}^{-1}$	$PEV_{(H)} H_{(S)}^{-1}$
C+S	0	$(PEV_{(S)} - PEV_{(H)}) H_{(S)}^{-1}$

Applying these weighting factors yields:

$$S_{PEV,(H)} = \frac{G_{(H)} N_{(H)} w_{(H)} Q_{(H)}}{G_{(H)} N_{(H)} w_{(H)} Q_{(H)} + G_{(S)} PEV_{(H)} H_{(S)}^{-1} N_{(S)} w_{(S)} + G_{(O)} B_{(O)}}$$

and:

$$S_{PEV,(S)} = \frac{G_{(S)} N_{(S)} w_{(S)} PEV_{(H)} H_{(S)}^{-1}}{G_{(H)} N_{(H)} w_{(H)} Q_{(H)} + G_{(S)} PEV_{(H)} H_{(S)}^{-1} N_{(S)} w_{(S)} + G_{(O)} B_{(O)}} +$$

$$\frac{G_{(S)} N_{(S)} w_{(S)} [PEV_{(S)} - PEV_{(H)}]^{-1}}{G_{(S)} N_{(S)} w_{(S)} [PEV_{(S)} - PEV_{(H)}]^{-1} + G_{(O)} B_{(O)}}$$

The solutions to these equations cannot be arrived analytically; instead a numerical method has to be used. Age and quarter indices have been left out in order to simplify the notation.

The total average prey-specific stomach content may then be estimated as $S^*(i) = S_{PEV}(i) * O(i)$, and the total average food composition can be derived from the prey-specific stomach contents. Predation mortality is then given by:

$$M2_i = \bar{N}_j C_j \frac{S_i}{\sum_i S_i}$$

Here, the average predator abundance \bar{N}_j does not have to be weighted by the prey specific overlap, because overlap has been accounted for in the calculation of stomach content. The new suitability coefficients $G(i)$ are prey specific and express the combined effect of prey vulnerability and predator preference. However, as compared to the old suitability, the effect of prey availability and accessibility has been accounted for by using overlap. This overlap is given as external input and hence facilitating to account for environmentally driven changes in predator and prey distributions.

9 MSVPA key run for 1974–2005 in the eastern Baltic

The 4M software package (Vinther *et al.*, 2002) was applied to make a MSVPA “key-run” for cod, sprat and herring in the Central Baltic for the period 1974–2005. This run estimates the natural mortalities for use in the single species assessment WG.

9.1 Input data

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). Catch at age and weight at age in the catch and in the stock for 2001–2005 from the report of the single species working group (ICES 2006/ACFM: 24).
- quarterly cod stomach content data (1977–93) by Sub-division as revised by 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 Sub-divisions 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 2005 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, for sprat maturity ogives were used as given in ICES (2002/ACFM:17)
- suitability sub-model as introduced in ICES (1992/Assess:7)
- quarterly consumption rates for cod as revised in ICES (2001/H:04), quarterly consumption rates for 2001–2004 according to the same method, quarterly consumption for 2005 as in 2004.
- 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 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 2006/ACFM:24). 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.

9.2 Results of the key run for 1974–2005

The main results of the MSVPA key-run for the Central Baltic are given in Figures 9.2.1–9.2.3 and summarized in Tables 9.2.1.–9.2.6

Cod

The spawning stock biomass of Eastern Baltic cod derived by the MSVPA run showed a pronounced increase from 1977 to 1980, remained 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. An exceptional high fishing mortality in the MSVPA output in 1991 is probably caused by missing records in the catch data set for age-group 7 in the 3rd and 4th quarter of 1992, although in the same cohort in previous and following years catches were recorded. Natural mortalities of 0-, 1- and 2-group

cod are in the same order of magnitude as derived by earlier MSVPA runs. Annual predation mortalities are listed in Table 9.2.4.

Comparing the old MSVPA key-run (ICES 2005/H:06) with the present one revealed minor deviations between cod biomass and recruitment during the 1990s which are due to the tuning procedure. Deviations are higher early in the time series, i.e. 1974-1976, where the correction of input data resulted in a downward correction of the SSB and recruitment as well as for 1980-1982 where the present MSVPA estimates higher SSB being closer to the single-species assessment (ICES 2006/ACFM:24) than before (Figure 9.2.4). In comparison to the output of the single species assessment, stock biomass and spawning stock biomass are slightly lower in the MSVPA output. The difference is to the largest extent driven by the usage of quarter 1 weight-at-age in the MSVPA as compared to yearly average weights in the single species assessment.

Sprat

The estimated spawning stock biomass of sprat shows a pronounced decline from the mid 1970s to the early 1980s followed by an increase peaking in the end 1990s, declining again afterwards (Figure 9.2.2). Predation mortalities of sprat showed a continuous decline from the mid 1970s to early 1990s and remained rather constant afterwards (Figure 3.5 and Table 3.8). Generally the SSB values of sprat from the new MSVPA run show no discrepancies when compared to the earlier analysis (ICES 2005/H:06).

Herring

Spawning stock biomass estimates of Central Baltic herring derived by the MSVPA key-run show a continuous decline (Figure 9.2.3), which is to a large extent caused by reduction in weight-at-age. Recruitment at age 1 derived by the MSVPA shows a high level in the early 1980s and a declining trend afterwards (Figure 9.2.3). 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. Major differences between old and new multispecies assessments for herring were only visible for recruitment and fishing mortality in the latest years, which is a result of the tuning procedure. The MSVPA results do not entirely match the single-species assessment values, as with the latter does not include the Gulf of Riga included.

Natural mortalities

Natural mortalities estimated by MSVPA are routinely used in the single assessment (ICES 2006/ACFM:24). The values estimated by the last iteration of the multispecies tuning are presented in Tables 9.2.1–9.2.3.

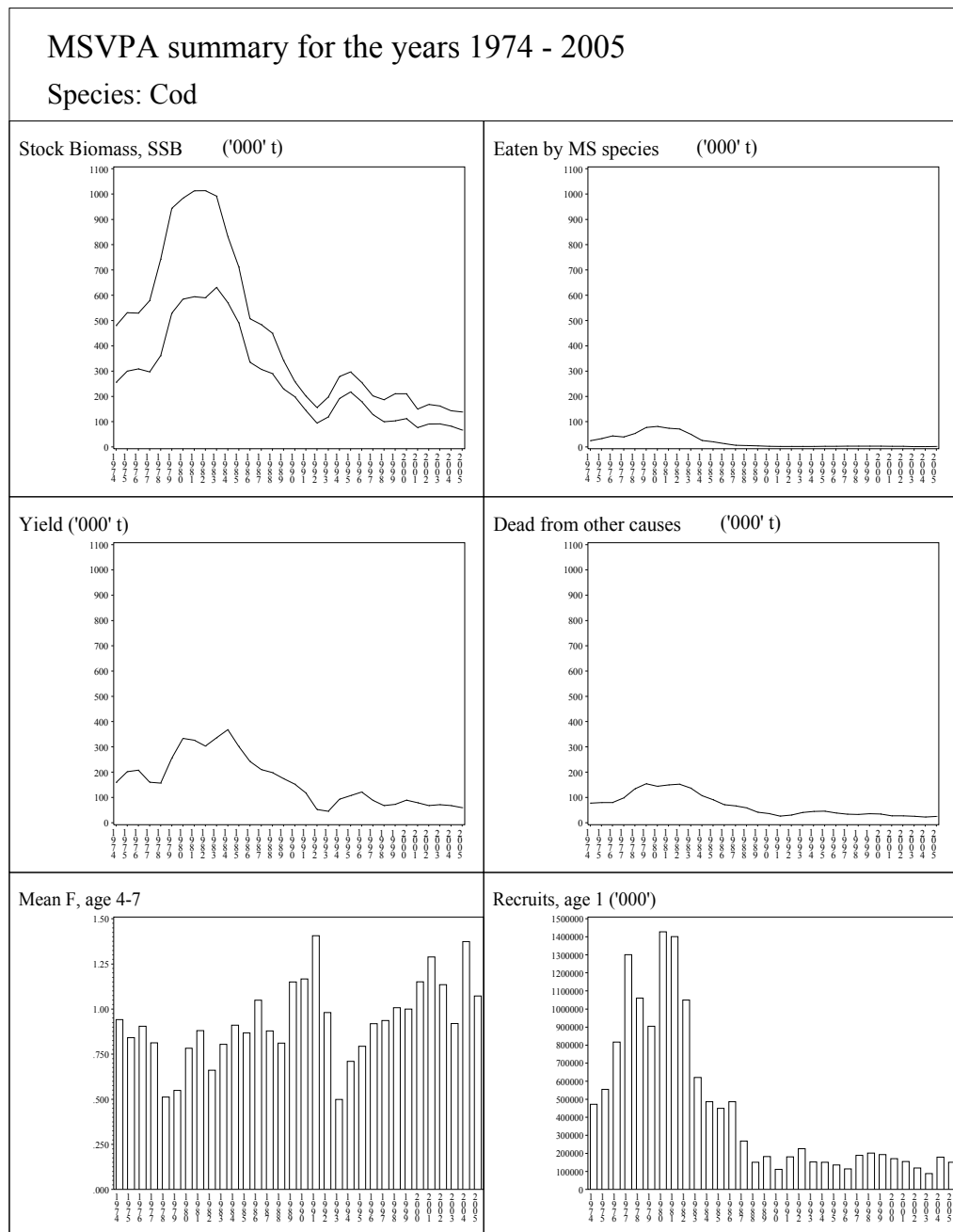


Figure 9.2.1: MSVPA key-run summary for cod 1974-2005

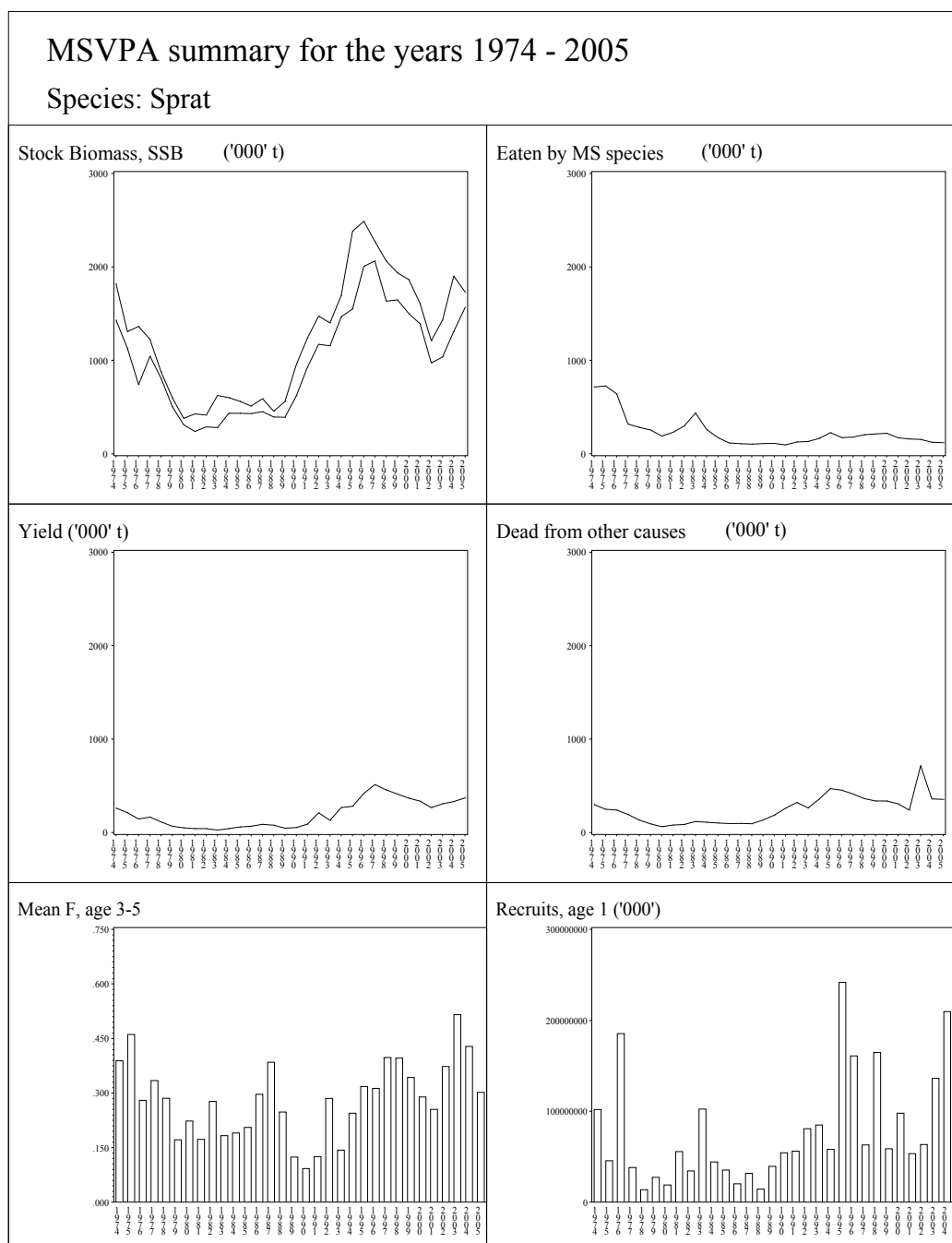


Figure 9.2.2: MSVPA key-run summary for sprat 1974-2005

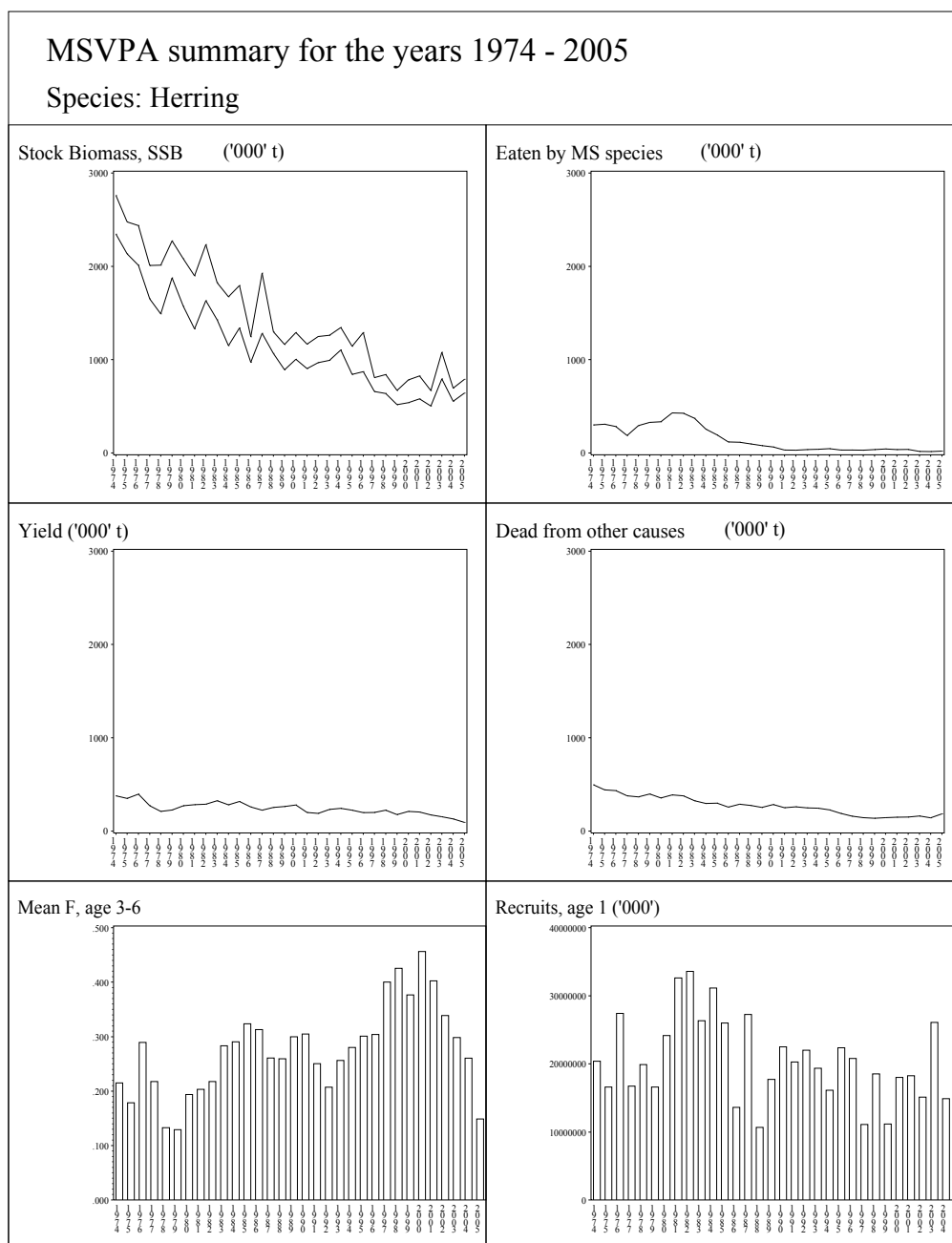


Figure 9.2.3: MSVPA key-run summary for herring 1974-2005

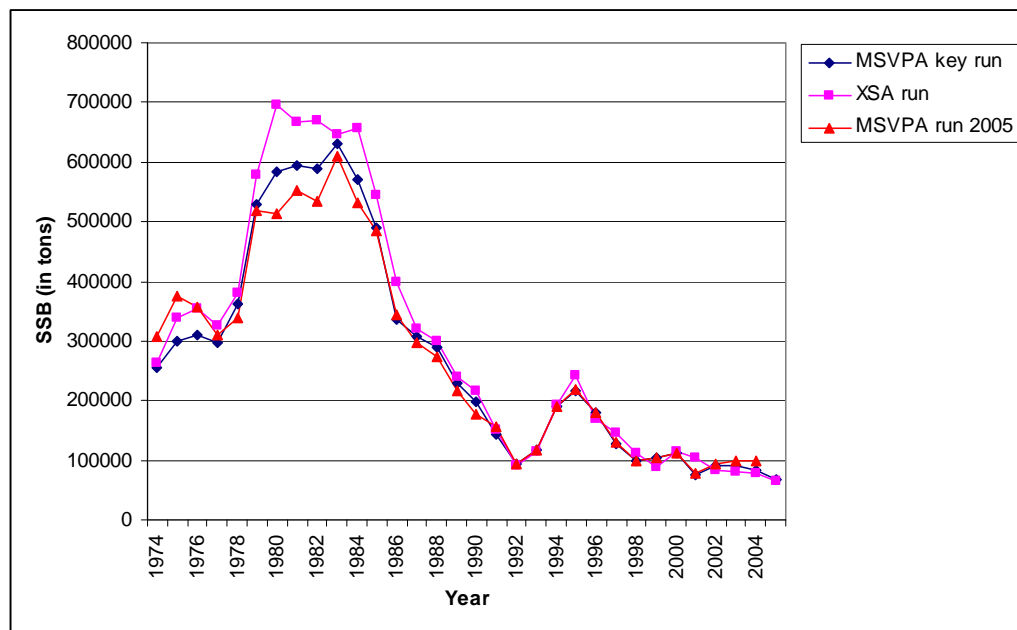


Figure 9.2.4: Eastern cod spawning stock biomass from MSVPA key-run in comparison with singlespecies assessment output (ICES 2006/ACFM:24) and previous MSVPA run output (ICES 2005/H:06).

Table 9.2.1 Predation mortality (M2) Species Cod

Age	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
0	0.9578	1.0001	0.9470	0.6278	0.9482	1.1586	0.9337	0.9506	1.2132	1.2867	0.7308	0.6071	0.4980	0.4423	0.4100
1	0.2588	0.3807	0.2694	0.2465	0.3474	0.4806	0.5056	0.4772	0.5838	0.5776	0.4374	0.3504	0.2316	0.1784	0.2149
2	0.0380	0.0585	0.0503	0.0415	0.0492	0.0732	0.0926	0.0813	0.0943	0.1036	0.0828	0.0698	0.0390	0.0284	0.0367
3	0.0046	0.0063	0.0062	0.0053	0.0058	0.0092	0.0118	0.0119	0.0126	0.0143	0.0125	0.0105	0.0048	0.0041	0.0053
4	0.0009	0.0010	0.0011	0.0010	0.0010	0.0017	0.0020	0.0023	0.0025	0.0028	0.0025	0.0021	0.0008	0.0009	0.0011
5	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Age	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
0	0.3016	0.2205	0.1183	0.1271	0.2094	0.2127	0.2604	0.2293	0.2435	0.2354	0.2559	0.2601	0.1996	0.2390	0.0959
1	0.1656	0.1138	0.0612	0.0442	0.0679	0.0779	0.0945	0.0848	0.1059	0.1017	0.0940	0.1061	0.0875	0.1048	0.0534
2	0.0323	0.0213	0.0129	0.0064	0.0076	0.0103	0.0149	0.0149	0.0215	0.0174	0.0154	0.0164	0.0148	0.0173	0.0080
3	0.0048	0.0033	0.0023	0.0007	0.0008	0.0012	0.0020	0.0019	0.0030	0.0024	0.0017	0.0019	0.0017	0.0021	0.0010
4	0.0010	0.0007	0.0005	0.0001	0.0001	0.0002	0.0004	0.0004	0.0006	0.0005	0.0003	0.0004	0.0003	0.0004	0.0002
5	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Age	2004	2005
0	0.1253	0.1196
1	0.0517	0.0502
2	0.0088	0.0075
3	0.0012	0.0009
4	0.0002	0.0002
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000
8	0.0000	0.0000

Table 9.2.2 Predation mortality (M2) Species Herring

Age	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
0	0.3382	0.2490	0.3117	0.1751	0.2672	0.2879	0.2213	0.2276	0.2839	0.2840	0.1553	0.1336	0.1174	0.1151	0.0912
1	0.3728	0.5335	0.3499	0.2932	0.4464	0.5737	0.6003	0.4974	0.6120	0.5794	0.4472	0.3491	0.2499	0.1966	0.2335
2	0.1111	0.1334	0.1068	0.0878	0.1315	0.1726	0.1652	0.1486	0.1842	0.1866	0.1326	0.1053	0.0741	0.0617	0.0664
3	0.0724	0.0882	0.0742	0.0654	0.0938	0.1307	0.1268	0.1169	0.1447	0.1444	0.1078	0.0854	0.0574	0.0463	0.0503
4	0.0461	0.0579	0.0488	0.0443	0.0621	0.0875	0.0857	0.0817	0.1006	0.1004	0.0756	0.0601	0.0397	0.0316	0.0349
5	0.0452	0.0568	0.0468	0.0430	0.0610	0.0838	0.0805	0.0790	0.0974	0.0981	0.0715	0.0572	0.0385	0.0309	0.0337
6	0.0306	0.0374	0.0316	0.0300	0.0422	0.0585	0.0558	0.0539	0.0686	0.0678	0.0494	0.0398	0.0270	0.0214	0.0228
7	0.0255	0.0316	0.0262	0.0239	0.0341	0.0462	0.0439	0.0423	0.0536	0.0545	0.0379	0.0308	0.0214	0.0171	0.0181
8	0.0077	0.0096	0.0079	0.0072	0.0103	0.0137	0.0129	0.0126	0.0160	0.0163	0.0111	0.0091	0.0064	0.0051	0.0054

Age	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
0	0.0669	0.0478	0.0325	0.0425	0.0508	0.0501	0.0606	0.0588	0.0639	0.0638	0.0779	0.0680	0.0564	0.0623	0.0178
1	0.1682	0.1106	0.0661	0.0638	0.0848	0.0870	0.0868	0.0787	0.0973	0.1086	0.1198	0.1238	0.1080	0.1217	0.0591
2	0.0507	0.0335	0.0188	0.0177	0.0252	0.0271	0.0319	0.0294	0.0337	0.0329	0.0357	0.0359	0.0301	0.0349	0.0149
3	0.0409	0.0265	0.0142	0.0124	0.0172	0.0200	0.0254	0.0237	0.0272	0.0246	0.0252	0.0254	0.0209	0.0249	0.0105
4	0.0286	0.0188	0.0099	0.0080	0.0115	0.0136	0.0179	0.0164	0.0191	0.0171	0.0164	0.0171	0.0139	0.0169	0.0074
5	0.0273	0.0183	0.0094	0.0076	0.0119	0.0135	0.0177	0.0160	0.0183	0.0167	0.0157	0.0168	0.0133	0.0164	0.0075
6	0.0191	0.0127	0.0065	0.0053	0.0078	0.0091	0.0122	0.0114	0.0134	0.0116	0.0110	0.0113	0.0090	0.0111	0.0048
7	0.0148	0.0101	0.0051	0.0043	0.0067	0.0075	0.0100	0.0091	0.0105	0.0093	0.0089	0.0094	0.0074	0.0092	0.0040
8	0.0044	0.0030	0.0015	0.0013	0.0021	0.0023	0.0030	0.0027	0.0031	0.0028	0.0027	0.0028	0.0022	0.0028	0.0012

Age	2004	2005
0	0.0321	0.0347
1	0.0565	0.0659
2	0.0170	0.0174
3	0.0125	0.0119
4	0.0086	0.0079
5	0.0084	0.0078
6	0.0056	0.0052
7	0.0046	0.0043
8	0.0014	0.0013

Table 9.2.3 Predation mortality (M2) Species Sprat

Age	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
0	0.4579	0.2854	0.4334	0.1969	0.2946	0.2763	0.2135	0.2351	0.2654	0.2637	0.1383	0.1209	0.1157	0.1213	0.0878
1	0.7617	1.1945	0.6763	0.5719	0.8456	0.9731	1.0648	0.8167	1.0014	0.8604	0.6499	0.5375	0.4422	0.3305	0.3748
2	0.3730	0.5616	0.3495	0.3007	0.4707	0.5988	0.6429	0.5050	0.6310	0.5769	0.4547	0.3465	0.2512	0.1982	0.2418
3	0.2495	0.3694	0.2278	0.2140	0.3429	0.4535	0.4818	0.3775	0.4772	0.4297	0.3473	0.2620	0.1855	0.1474	0.1796
4	0.2488	0.3515	0.2219	0.1963	0.3107	0.3933	0.3981	0.3325	0.4136	0.3948	0.2984	0.2265	0.1651	0.1363	0.1593
5	0.3016	0.4340	0.2837	0.2354	0.3680	0.4684	0.4807	0.3963	0.4916	0.4904	0.3590	0.2754	0.1985	0.1627	0.1937
6	0.2628	0.3928	0.2622	0.2289	0.3494	0.4757	0.5263	0.4117	0.5071	0.4886	0.3938	0.3022	0.2011	0.1563	0.1961
7	0.3602	0.5279	0.3626	0.3248	0.4814	0.6562	0.7221	0.5766	0.7077	0.6813	0.5446	0.4232	0.2833	0.2188	0.2654

Age	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
0	0.0603	0.0448	0.0373	0.0517	0.0567	0.0512	0.0589	0.0561	0.0638	0.0712	0.0870	0.0756	0.0637	0.0680	0.0183
1	0.2665	0.1838	0.1209	0.1356	0.1591	0.1502	0.1261	0.1145	0.1482	0.1870	0.2140	0.2112	0.1874	0.2043	0.1029
2	0.1733	0.1104	0.0675	0.0640	0.0938	0.0889	0.0786	0.0678	0.0847	0.1051	0.1156	0.1218	0.1054	0.1195	0.0633
3	0.1310	0.0820	0.0482	0.0461	0.0668	0.0660	0.0594	0.0524	0.0625	0.0744	0.0832	0.0859	0.0743	0.0850	0.0441
4	0.1122	0.0740	0.0438	0.0404	0.0637	0.0604	0.0559	0.0479	0.0579	0.0705	0.0770	0.0823	0.0697	0.0800	0.0417
5	0.1361	0.0895	0.0531	0.0473	0.0765	0.0729	0.0695	0.0595	0.0729	0.0863	0.0944	0.1021	0.0869	0.0992	0.0510
6	0.1474	0.0919	0.0547	0.0475	0.0647	0.0679	0.0679	0.0621	0.0786	0.0845	0.0932	0.0963	0.0854	0.0965	0.0472
7	0.2066	0.1294	0.0754	0.0648	0.0887	0.0941	0.0980	0.0906	0.1117	0.1157	0.1254	0.1284	0.1129	0.1288	0.0622

Age	2004	2005
0	0.0357	0.0420
1	0.0956	0.1317
2	0.0550	0.0673
3	0.0384	0.0465
4	0.0366	0.0441
5	0.0462	0.0524
6	0.0448	0.0493
7	0.0605	0.0664

Table 9.2.4 VPA summary: Species Cod

Year	Mean F	Yield	Stock	Spawning stock	Recruits	Age 1
Ages	4 to 7	('000' t)	('000' t)	Biomass	('000' t)	('000')
1974	0.941	159	480	255	472101	
1975	0.841	201	531	300	554705	
1976	0.904	207	528	309	816618	
1977	0.812	160	578	296	1301587	
1978	0.512	155	741	361	1060288	
1979	0.549	255	944	528	905324	
1980	0.782	333	984	584	1427981	
1981	0.881	326	1013	594	1401655	
1982	0.660	303	1013	589	1049545	
1983	0.805	335	991	631	621020	
1984	0.910	367	831	571	486028	
1985	0.868	301	711	490	448962	
1986	1.049	242	507	334	486105	
1987	0.879	210	483	306	268630	
1988	0.812	198	450	289	150280	
1989	1.150	174	342	229	182075	
1990	1.167	152	258	198	111158	
1991	1.407	118	201	144	181493	
1992	0.981	52	156	94	226301	
1993	0.498	44	196	118	152091	
1994	0.710	93	278	191	150538	
1995	0.793	107	296	217	135327	
1996	0.919	121	254	179	113666	
1997	0.936	88	202	127	189122	
1998	1.007	67	186	99	200926	
1999	0.999	72	210	103	193460	
2000	1.151	89	210	111	170477	
2001	1.289	78	149	76	154451	
2002	1.136	67	167	90	118457	
2003	0.919	71	162	91	88669	
2004	1.375	67	142	82	178596	
2005	1.072	59	138	67	150014	

Table 9.2.5 VPA summary: Species Herring

Year	Mean F	Yield	Stock	Spawning stock	Recruits	Age 1
Ages	3 to 6	(('000' t)	(('000' t)	(('000' t)	(('000' t)	(('000' t)
1974	0.215	377	2761	2344	20393630	
1975	0.179	350	2476	2133	16597080	
1976	0.289	394	2438	2011	27402320	
1977	0.217	270	2010	1650	16732370	
1978	0.133	210	2013	1490	19884340	
1979	0.129	226	2273	1877	16617050	
1980	0.194	269	2081	1570	24159720	
1981	0.203	282	1899	1329	32637480	
1982	0.218	287	2234	1632	33590470	
1983	0.283	326	1825	1424	26342890	
1984	0.290	281	1674	1148	31129670	
1985	0.324	317	1794	1339	26015590	
1986	0.313	257	1245	972	13621140	
1987	0.261	222	1926	1282	27271310	
1988	0.259	252	1299	1065	10652140	
1989	0.300	262	1163	892	17729060	
1990	0.305	279	1290	1003	22490960	
1991	0.250	197	1165	904	20290220	
1992	0.207	188	1247	967	22006270	
1993	0.256	231	1261	991	19354480	
1994	0.280	242	1344	1104	16138810	
1995	0.301	222	1142	841	22350350	
1996	0.304	195	1291	870	20787580	
1997	0.400	198	806	657	11106430	
1998	0.426	222	840	638	18526380	
1999	0.377	175	670	517	11174920	
2000	0.456	210	782	539	18000920	
2001	0.403	204	826	579	18263630	
2002	0.339	172	668	502	15110320	
2003	0.299	154	1079	794	26086210	
2004	0.261	130	694	552	14899250	
2005	0.149	91	789	642	11209320	

Table 9.2.6 VPA summary: Species Sprat

Year	Mean F	Yield	Stock	Spawning stock	Recruits	Age 1
Ages						
3 to 5		('000' t)	('000' t)	('000' t)	('000' t)	('000' t)
1974	0.389	263	1819	1429	101901700	
1975	0.461	212	1307	1130	45527210	
1976	0.280	144	1361	739	185463800	
1977	0.335	179	1222	1044	38122790	
1978	0.286	115	876	808	13717450	
1979	0.172	68	599	505	27417940	
1980	0.223	52	378	310	18910120	
1981	0.173	44	426	237	55504670	
1982	0.277	43	413	287	34351250	
1983	0.183	29	625	279	102438700	
1984	0.191	44	600	433	44092930	
1985	0.206	59	561	433	35269690	
1986	0.297	67	510	431	20245330	
1987	0.385	88	591	451	31690280	
1988	0.248	78	454	394	14385080	
1989	0.124	47	558	389	39373150	
1990	0.093	56	954	618	54189080	
1991	0.125	93	1238	926	56139820	
1992	0.285	214	1473	1172	80790990	
1993	0.143	134	1402	1156	84861990	
1994	0.244	268	1693	1464	58084840	
1995	0.318	285	2382	1550	241766700	
1996	0.313	423	2488	2006	160943400	
1997	0.397	517	2272	2062	62848490	
1998	0.396	456	2063	1633	164451800	
1999	0.343	412	1934	1646	58753410	
2000	0.289	366	1863	1498	97780560	
2001	0.255	342	1607	1390	53288670	
2002	0.373	278	1209	970	63367120	
2003	0.516	322	1429	1034	136054400	
2004	0.428	347	1901	1308	209576700	
2005	0.302	381	1733	1565	40296820	

10 Area dis-aggregated MSVPA runs up to 2005 for eastern Baltic

In the Baltic Sea the spatial and temporal suitability of the spawning habitats of cod (*Gadus morhua*) vary dramatically with the oxygen conditions at the depth of incubation of the eggs (e.g., Wieland *et al.*, 1994). As a consequence, the population dynamics of cod exhibit distinct trends in different areas of the Central Baltic (Sparholt and Tomkiewicz 2000), with a corresponding variation in predation pressure on its major prey species, sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) (Sparholt 1994). In turn the population development of these planktivores determines the predation intensity on early life stages of cod (Köster and Möllmann 2000). Hence in order to develop sustainable management strategies for the Central Baltic stocks, assessments and stock projections should resolve and incorporate the effects of environmental variability and species interactions on reproductive success, in particular the potential for different spawning localities to contribute to recruitment success. At present MSVPAs runs are available for two areas in the Baltic, a Western and Central Baltic component to match the stock units used in the regular stock assessments, with the Central Baltic component dominating in terms of biomass and abundance (ICES 1998/ACFM:16). Within these two regions, the abundance and biological characteristics of the three species are heterogeneous both spatially (between subdivisions) and temporally (inter and intra annually). For example, population sizes of Central Baltic cod, as resolved by international bottom trawl (Sparholt and Tomkiewicz 2000) and ichthyoplankton surveys (Köster *et al.*, 2001a), have revealed distinct distributional trends. Furthermore, for cod substantial differences in weight-at-age and maturity ogives have been reported for different subdivisions (ICES 1997/Assess:12, Tomkiewicz *et al.*, 1997). The abundance and characteristics of herring and sprat have also been observed to vary spatially and temporally in the different subdivisions of the Central Baltic (e.g., Ojaveer 1989). The herring stock in the Central Baltic is comprised of a number of different spawning components exhibiting variations in spawning period and growth rates as well as meristic, morphometric and otolith characteristics (e.g., Parmanne *et al.*, 1994). For sprat the existence of distinct populations is controversial as deviations in growth rates observed between subareas have been explained by immigration from the western Baltic and by migration between different basins (Parmanne *et al.*, 1994). However, other authors state that sprat in the eastern Central Baltic form local populations (Ojaveer 1989), which can be separated, primarily by otolith characteristics (Aps 1981).

10.1 The disaggregated MSVPA stock units and age structure

Disaggregated MSVPAs were conducted in Subdivisions 25, 26 and 28; here all species were assumed to be unit stock components. Cod composed of age-groups 0-8 with oldest age-group handled as plus group, preying on herring and sprat. Last-mentioned species were defined as prey in the age-groups 0-8 (oldest age-group handled as plus group) for herring and age-groups 0-7 for sprat. Exhibiting cannibalistic behaviour, cod was also considered as prey in the MSVPA of the Baltic.

10.2 Input Data for the disaggregated MSVPA

Weight at age and catch in numbers

Quarterly catch-at-age in numbers and weight-at-age in the catch according to Subdivisions were revised and updated for years 1976–2003 following the compilation scheme presented in ICES (1997/J:2). Input for 2004 and 2005 was based on national data reported to WGBFAS (ICES 2004 and 2005). Missing data on weight-in-the-catch of cod for age-classes 0 and 1 were substituted in the 3rd quarter by a value of 0.028 in Subdivision 25 and 0.005 in Subdivision 26 and 28. In the 4th quarter a value of 0.028 was used for all Subdivisions.

Any other missing values on weight-in-the-catch were substituted by a mean of neighbouring years for herring and sprat and by a weighted mean of the sub-divisions for cod. Weight-at-

age in the catch was assumed to be equal to weight-at-age in the sea, exceptions being weight-at-age for cod age-groups 0-2.

Here, due to size selection by commercial gear, mean values for two time periods (1977-1989 and 1990-2005) were used. For the time period 1990 to 1997 a multiplicative regression ($Y = a \cdot X^b$) of weight over age was performed and this analysis yielded an estimation of mean weights at age-groups 0-2 in the stock for all quarters (ICES 1999/H:05) in the considered time period. For the years from 1998 up to 2005 the same values were used (Table 10.2.1)

Table. 10.2.1. Values for cod weight – at – age in the stock used in all SDs

ALL SDs	TIME PERIOD 1977 – 1989			TIME PERIOD 1990 – 2005		
	Age 0	Age 1	Age 2	Age 0	Age 1	Age 2
1 st Quarter		0.065	0.206		0.052	0.226
2 nd Quarter		0.073	0.242		0.090	0.339
3 rd Quarter	0.005	0.089	0.310	0.005	0.138	0.425
4 th Quarter	0.028	0.125	0.460	0.024	0.195	0.520

Maturity ogives

Maturity ogives for cod in different Subdivisions represent averages over 5 years periods available from 1980 (applied also before 1980) onwards for combined sexes as presented in ICES (1998/ACFM:16), updated with data for 1998 and 1999 presented in ICES (1999/H:05) and ICES (2000/ACFM:14) and 2000 to 2003 as presented in the last SGMAB-Report (ICES 2005/H:06). For the years 2004 and 2005 the values of the last year were used. According to procedure adopted by WGBFAS the maturity ogives for herring and sprat stocks were assumed to be constant over time.

Stomach content data

Quarterly cod stomach content data according to Subdivision as revised in ICES (1997/J:2) were utilized as input. Intra-cohort cannibalism in cod was excluded by changing prey age to predator age minus 1 and omitting 0-group cod in 0-group cod stomachs.

Quarterly food intake by cod

Quarterly, age-specific consumption rates of cod were estimated as described in Temming (1996) and ICES (1997/J:2) for each sub-division (see chapter 5). Also alternative (consumption rates with effect of oxygen on evacuation) quarterly, age-specific consumption rates of Baltic cod were used (see chapter 5).

Other input data

The residual natural mortality (M_1) was assumed to be 0.2 year^{-1} equally distributed over quarters corresponding to standard MSVPA runs in the Baltic (Sparholt, 1991). The Suitability coefficients were estimated according to standard suitability submodel implemented in the Baltic MSVPA (ICES 1997/J:2). The constant biomass of “other food” assumed to be 1 million tons, similar to ICES (1996/Assess:2).

10.3 Tuning

The tuning of the MSVPA was performed for each Subdivision utilizing the procedure developed by Vinther (2001), iteratively running MSVPAs and XSAs with automatic recursive data exchange. Abundance indices utilized for tuning originated from the Baltic International trawl survey (BITS) directed to cod and the International hydroacoustic survey (BIAS) directed to sprat and herring.

The XSA settings were as follows:

Cod:

- Including age-groups 2–8 abundance indices from international bottom trawl surveys 1994–2005,
- catchability was set to be dependent of stock size for ages < 3 and independent of age > 5 ,
- shrinkage of the terminal population towards a mean F over last 5 years and 3 oldest ages was applied with a standard error of 0.5–0.8,
- otherwise default settings of the Lowestoft assessment programme package were used.

Sprat:

- Using international hydroacoustic survey results as tuning fleets; depending on the performance covering 1987 or 1992 to 2005 with year 1993 excluded, as insufficient area coverage and problems in the intercalibration of the equipment occurred (ICES 1997/Assess:12),
- catchability was set to be dependent of stock size for ages < 3 and independent of age > 4 ,
- shrinkage of the terminal population towards a mean F over last 3–5 years and 3–5 oldest ages was applied with a standard error of 0.5–0.8,
- otherwise default settings of the Lowestoft assessment programme package were used.

Herring:

- Using international hydroacoustic survey results as tuning fleets; depending on the performance covering 1982 or 1986 to 2005 with 1992/1993 excluded in Subdivision 25, 1993 in Subdivision 26, 1993 and 1997 in Subdivision 28 as insufficient area coverage and problems in the intercalibration of the equipment occurred (ICES 1997/Assess:2; ICES 2000/ACFM:14),
- catchability was set to be dependent of stock size for ages < 3 and independent of age > 5 ,
- shrinkage of the terminal population towards a mean F over the last 5–6 years and 6–7 oldest ages was applied with a standard error of 0.8–1.0,
- otherwise default settings of the Lowestoft assessment programme package were used.

10.4 Results of dis-aggregated MSVPA run and discussion of the results

10.4.1 Population biomass

The time trend in stock biomass for cod, herring and sprat in the different Sub-divisions (SD) as determined by the three MSVPA runs are displayed in Figure 10.4.1. For cod a substantial decrease in the biomass is obvious in all three areas from 1983 onwards (Figure 10.4.1; upper panel). In SD 28 the stock biomass declined from nearly 200.000 t in the early time period to less than 10.000 t from 1990 onward, with no subsequent sign of recovery. In both other areas stock biomass was in general higher, i.e. for Subdivision 25 the biomass declined from values of about 375.000–383.000 t in the early 1980s to low values of about 89.000 t in 1992. For SD 26 highest values of 362.000 – 371.000 t were determined for 1982/83, while lowest biomass values were estimated for 1991/92 with values around 47000 - 70000 t. After a slightly enhanced reproductive success and a reduction in fishing mortality in the early 1990s, the biomass increased again in both area to maximum levels of about 175000 t in SD 25 and 107000 t in SD 26 in the 1994/95. After these years the biomass declined continuously to values of about 30.000 t in SD 26 and 70.000 t in SD 25 in the end of the investigated period.

The corresponding developments of the herring biomass estimates are presented in Figure 10.4.1, middle panel. For SD 25 a more or less continuous decline from the beginning of the time series of about 800.000 t to approximately 142.000 t in 1999 is indicated, with a slight increase afterwards. In SD 26 the herring biomass shows an obvious decrease from values over 500.000 t at the beginning of the time period to values of about 193.000 t in the year 1981/82. Since 1988, biomass values were significantly lower, i.e. around 175.000 t, with a slight declining trend. Contrary to the other SD, the herring biomass in SD 28 showed a slight positive development up to the year 1993, i.e. an increase in biomass from 243.000 to 434.000 t, afterwards a continuous decrease in biomass was apparent to values below 80.000 t in the last two years of the time period.

In the beginning of the time period the sprat biomass in SD 25 decreased from 195.000 to 50.000 t in the year 1980 (Figure 10.4.1; below). Afterwards a strong increase in biomass is obvious to maximum values of about 960.000 t in 1995. This increase is followed by a substantial decrease, i.e. to values of about 340.000 t. The biomass of sprat in SDs 26 and 28 showed a rather similar time trend, but not in the same order of magnitude. In the beginning of the investigated time period both biomasses showed a slight decrease. Afterwards both biomass estimates increased in the beginning of the 1980s to 275.000 and 127.000 t, respectively. In the beginning of the 1990s a further increase to 487.000 and 363.000 t was calculated. To the end of the covered time period the biomass in both SDs decreased slightly to values of about 350.000 and 330.000 t respectively in the year 2003. Only in SD 28 a strong increase in biomass from 2003 onwards to values higher than 800.000 t in 2004 and 2005 was obvious.

10.4.2 Predation mortality rates

Estimates of predation mortality rates of juvenile cod as well as herring and sprat are presented in Figs. 10.4.2-10.4.4. For cod in the period 1978-1985 a substantial difference in the cannibalism level between the areas is apparent (Figure 10.4.2), with lowest predation mortalities in Sub-division 25. However, even when being comparatively low, the cannibalism rates in Sub-division 25 are estimated to be still in the order of 0.49-0.89 for 0-group fish (second half of the year) and 0.22-0.40 for 1-group cod (yearly values), compared to corresponding values of 0.51-1.72 (0-group) and 0.32-0.79 (1-group) in both other areas. On the contrary, predation mortalities of 2-group cod were in general low, i.e. less than 0.15 per year, independent of the area. Since the mid 1980s predation mortalities were rather similar in Sub-division 25 and 26 (0.11-0.38 and 0.07-0.16 for age-group 0 and 1, respectively). The area-specific deviation in cannibalism rates is coupled to a lower suitability of juvenile cod as prey of adult cod in Sub-division 25. In Sub-division 28, the predation mortality declined from high levels in 1983 to be virtually absent in the 1990s. This is related to the steady decline in the predatory adult cod stock throughout the last decade (see above).

Predation mortalities of herring (Figure 10.4.3) were highest in Sub-division 26 in the beginning of the time series up to 1983, independent of the prey age considered, with peak values of 0.57 for 0-group (second half of the year), 1.27 for 1-group and 0.23 for age-groups 2-7 in the period 1976-1983. In all areas predation mortalities declined throughout the 1980s to lowest levels in 1991/92 being less than 0.2 for all age-groups. A very slight increase in herring predation mortalities was obvious for Sub-divisions 25 and 26 in the mid 90s, however, reaching only values of in maximum 0.26 (age 1, SD 26, 1995). Predation pressure on herring in Sub-division 28 remained since the beginning of the 1990s on a rather low level, which is related to the low predator population size in this area (see above).

Contrary to herring, the determined predation mortalities of sprat were rather similar in all three areas up to 1987 (Figure 10.4.4). Maximum predation pressure on 0-group occurred in the first year of the analysis (1976) and afterwards in 1983 and on older age-groups in 1980. Independent of the prey age-group, a general decrease in predation until 1992 is obvious in all

areas staying on a constant level afterwards. Predation mortalities were ranging in the beginning of the time series (since 1977) in the order of 0.18-0.31 for 0-group sprat (second half of year) as well as 0.72-1.14 and 0.24-0.65 for 1- and 2-5-group sprat respectively. For juvenile fish this is in the order of magnitude of the predation rates estimated for herring, however, considerably higher for adult fish. Lowest predation mortalities in 1991 in Sub-division 25 and 26 were ranging from 0.04-0.06 for 0-groups and 0.07-0.12 for older fish. Corresponding values in Sub-division 28 were close to zero throughout the 1990s.

10.4.3 Fishing mortality rates

Determined fishing mortality rates (for simplicity summed over quarters) of cod and herring (average over age-groups 3-6) as well as sprat (average over age-group 3-5) are displayed in Figure 10.4.5. Fishing mortalities of cod in Sub-division 25 were in general higher than in SDs 26 and 210.5. They were fluctuating between 0.4-1.66 without any clear time trend (Figure 10.4.5), with the exception that since 1997 the F-values were always at approx. 1.2, i.e. above the long-term average. For both other Sub-divisions, fishing mortality was most of the time lower but again no clear time-trend was obvious. Within the 1990s, even at low biomass values, no substantial decrease in mortality rates is obvious.

For herring, an increase in fishing mortalities from the beginning of the time series until the mid 1980s is estimated for all Sub-divisions (Figure 10.4.5). In Sub-divisions 25 and 26, this level (approx. 0.2) was kept throughout the remaining time period covered, while for Sub-division 28 this was followed by an increase to relatively high levels in most recent years.

The fishing mortalities determined for sprat were much more variable, than those determined for both other species (Figure 10.4.5), with maximum changes from 0.94 to 0.11 in successive years. Although the variability makes it difficult to detect any consistent time trends, an increase in fishing mortality since 1992 from 0.04-0.13 in 1993 to 0.34-0.58 in 1997 is obvious for all areas.

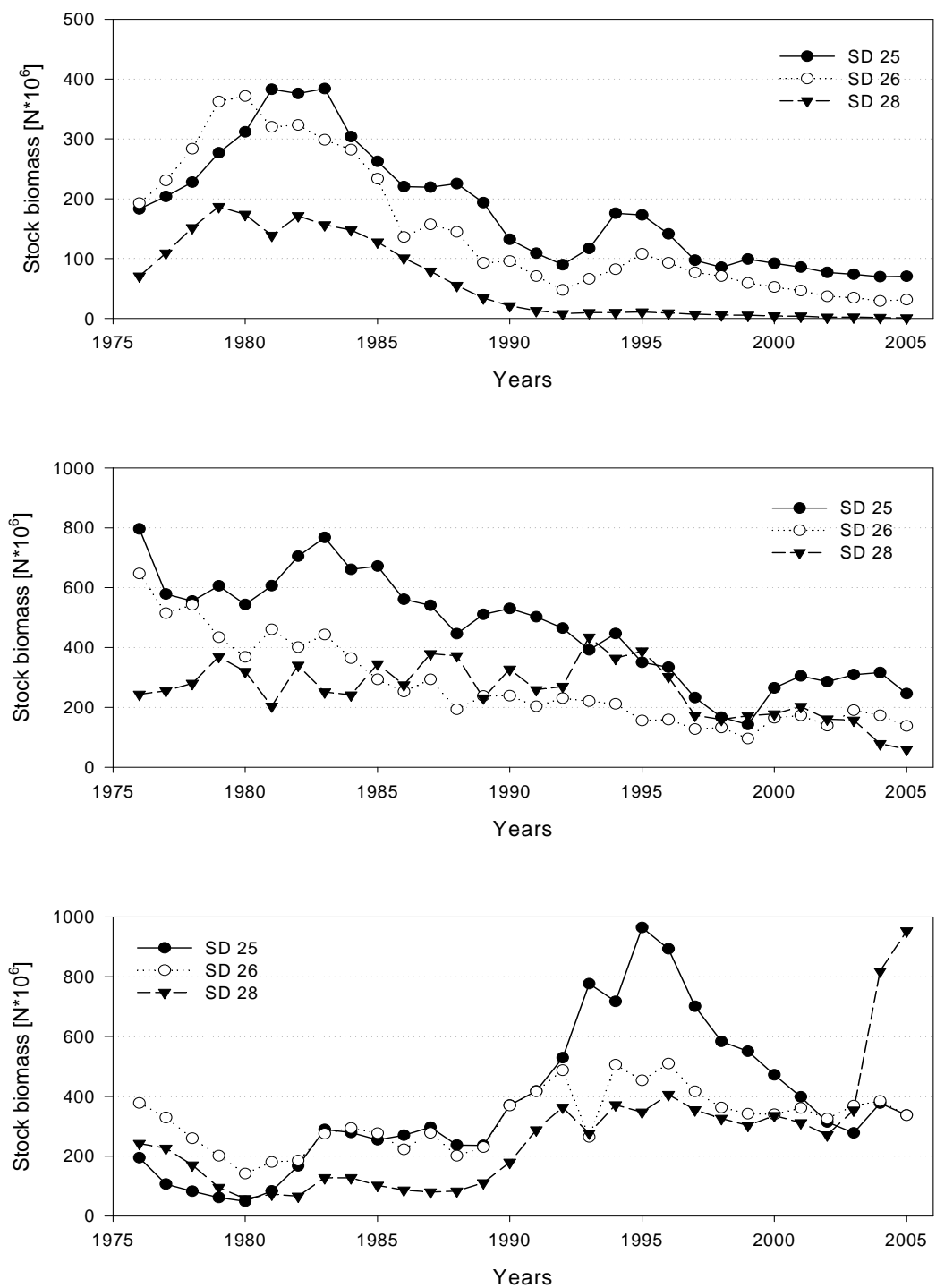


Figure 10.4.1: Stock biomass for cod (above), herring (middle) and sprat (below) in the 1st quarter of each year as sum over age-group 1-8 for cod and herring and age-group 1-7 for sprat.

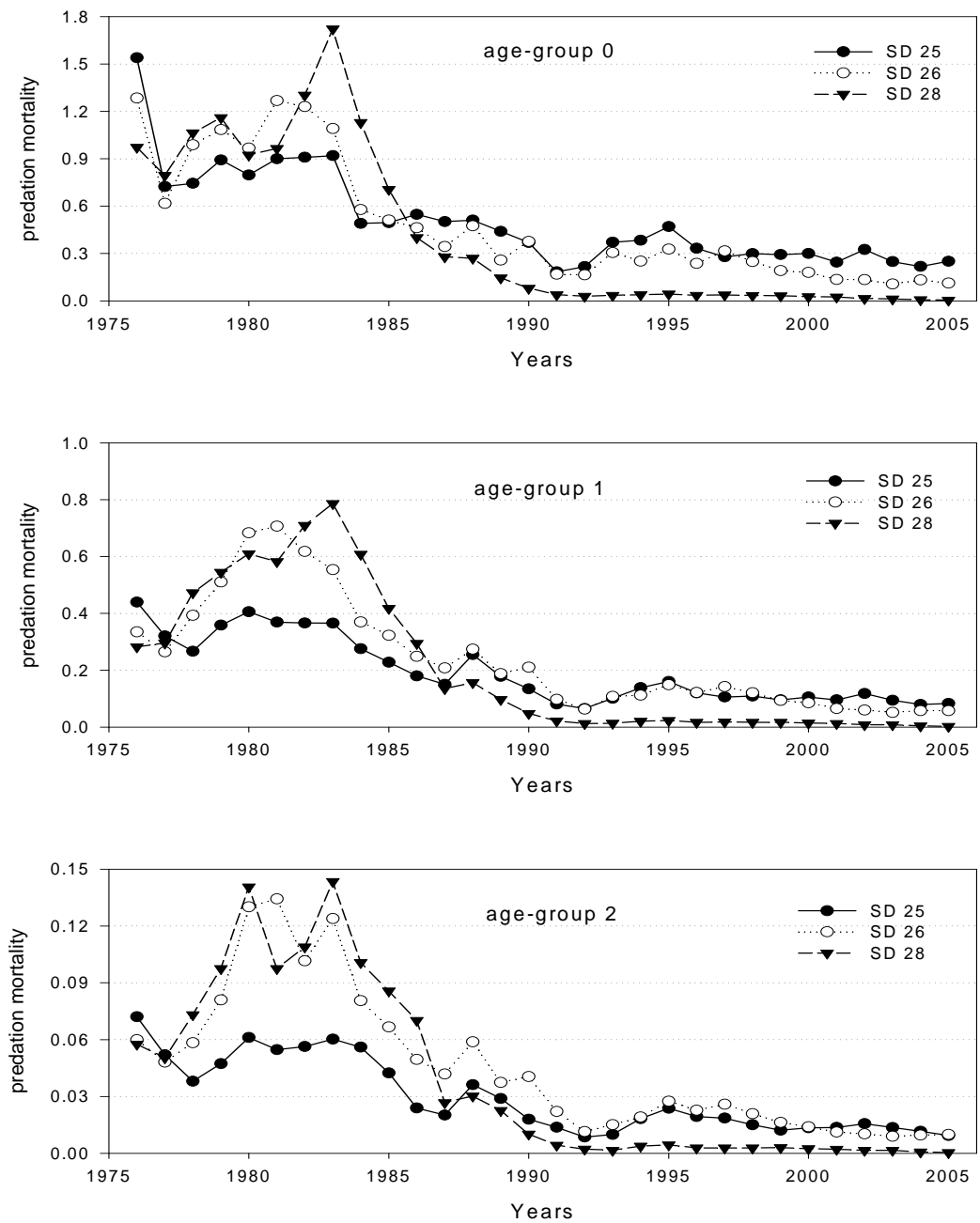


Figure 10.4.2: Predation mortality rates of cod age-group 0 (3rd and 4th quarter; above), age group 1 (per year; middle) and age group 2 (per year; below) in different Subdivisions (SD) of the Central Baltic

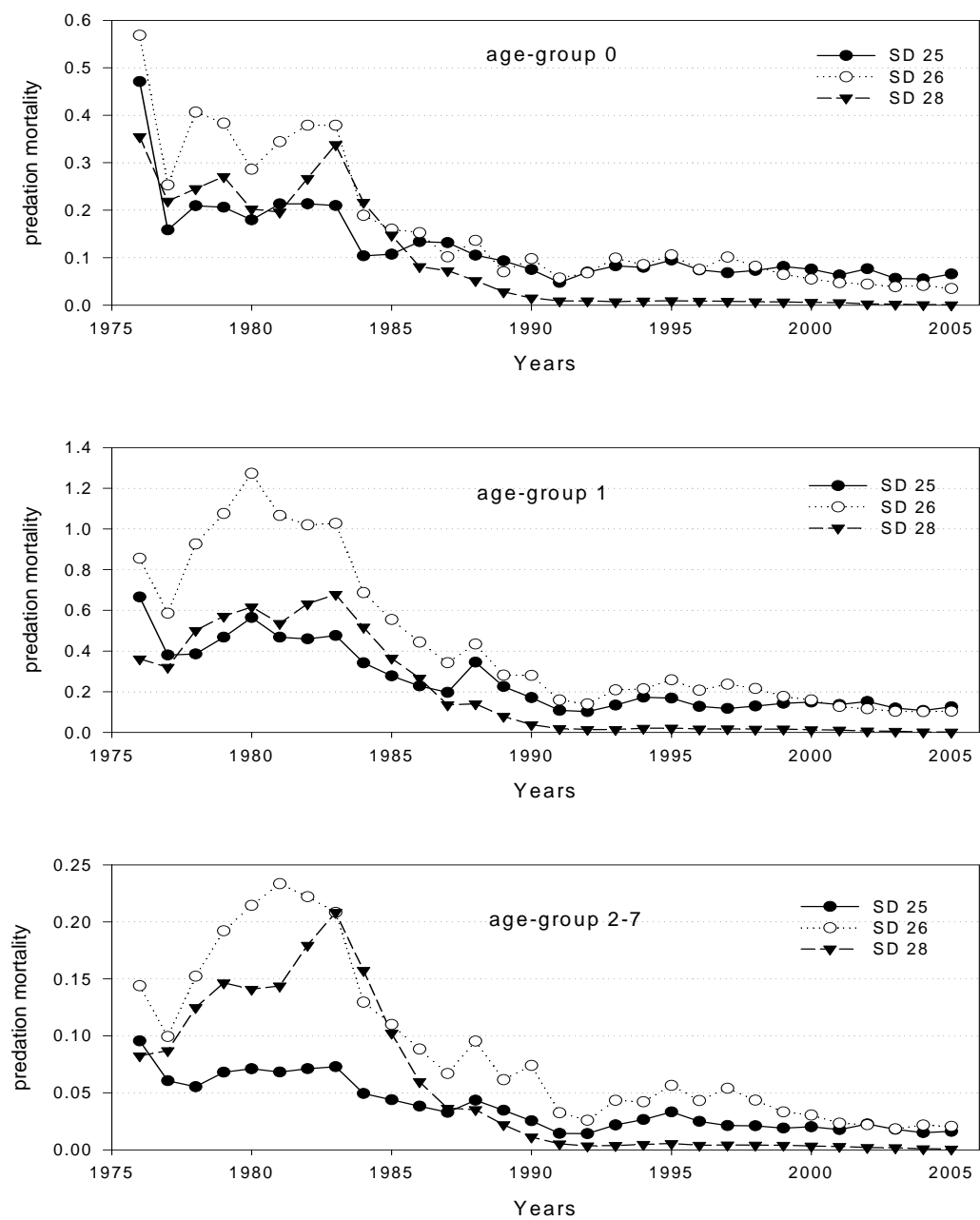


Figure 10.4.3: Predation mortality rates of herring age-group 0 (3rd and 4th quarter; above), age group 1 (per year; middle) and age group 2-7 (as arithmetic averages per year; below) in different Subdivisions (SD) of the Central Baltic

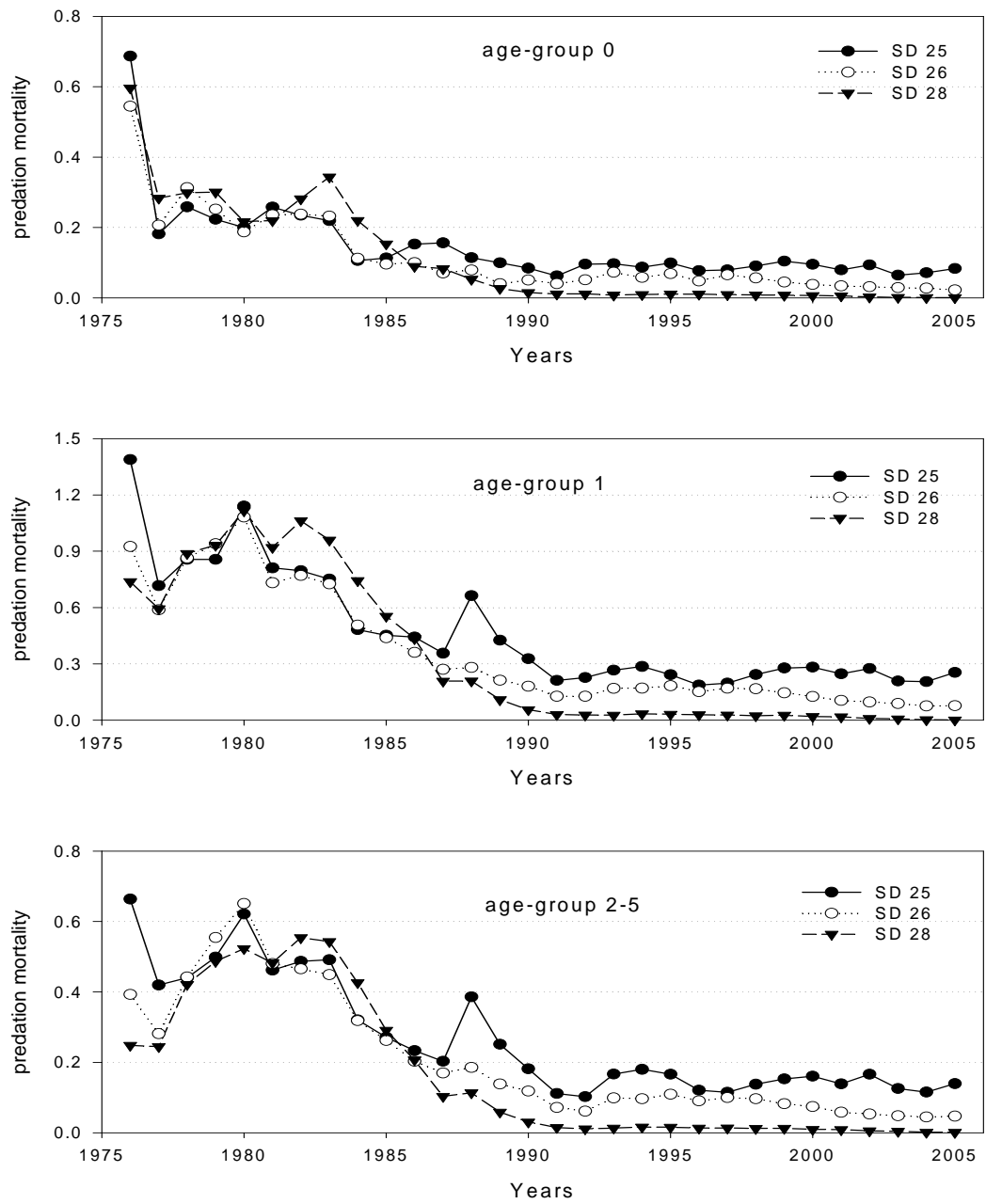


Figure 10.4.4: Predation mortality rates of sprat age-group 0 (3rd and 4th quarter; above), age group 1 (per year; middle) and age group 2-5 (as arithmetic averages per year; below) in different Subdivisions (SD) of the Central Baltic

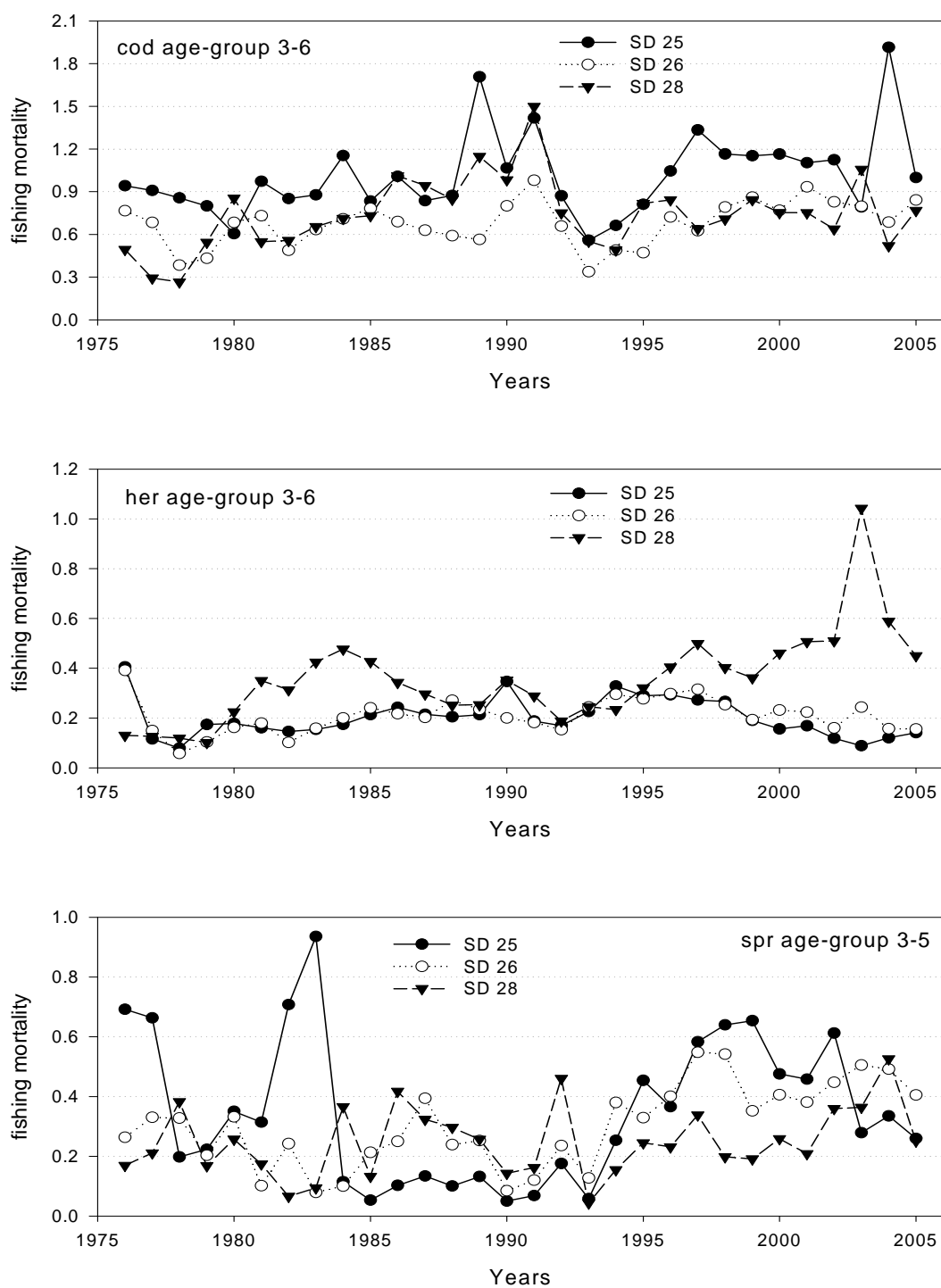


Figure 10.4.5: Fishing mortality rates per year of cod age-groups 3-6 (as arithmetic averages; above), of herring age-groups 3-6 (as arithmetic averages; middle) and of sprat age-groups 3-5 (as arithmetic averages; below) in different Subdivisions (SD) of the Central Baltic Sea

10.5 Results and discussion of disaggregated MSVPA results with reduced consumption rates

10.5.1 Population biomass

Differences between the two estimated biomasses (MSVPA and MSVPA computed with oxygen reduced consumption rates) of cod, herring and sprat as estimated in the 1st quarter for the different SD are displayed in Figure 10.5.1.

For cod only in the first decade of the investigated time period differences in the estimated biomasses were obvious (Figure 10.5.1; above). The standard MSVPA resulted in higher estimated biomasses than the alternative MSVPA. In SD 25 the differences decline from values of about 28000 t in the late 1970s to less than 300 t from 1990 to the end of the regarded time period. In SD 26 the standard MSVPA estimates biomasses which were maximal 3500 t higher than the alternative biomasses. A substantial lower difference could be calculated in the first decade for SD 28, reaching only values of in maximum 490 t.

The differences in stock biomass for herring were much higher than for cod (Figure 10.5.1; middle). In SD 25 high differences in biomasses are obvious in the end of the 1970s (app. 111000 t), declining to relatively low values of about 18000 t in the end of the 1980s. The differences in biomasses strongly increased to the end of the time period again (146000 t in 2004). The difference in biomasses in SD 26 declined continuously over the entire time period from values of about 30000 t to 100 t. A maximum peak in differences of about 24000 t occurred in SD 28 in 1995, followed by a decrease to low differences (app. 100 t) in most recent years.

Contrary to the other species, the differences in sprat biomass between the two calculations show no clear time trend (Figure 10.5.1; below). Additionally for sprat we found positive and negative values in nearly the same order of magnitude (app. + 130 000 t to -150000 t).

10.5.2 Predation mortality rates

For cod the decrease of predation mortality was more pronounced in quarters 3 and 4 than in the first half of the year. In SDs 25 and 26 mainly the years before 1984 were influenced (Figure 10.5.2 and 10.5.3). While the changes were in the same order of magnitude in SD 25 and SD 26, the difference was much less pronounced in SD 28 (Figure 10.5.4).

For herring changes in predation mortalities were most pronounced in the younger age classes (Figs. 10.5.5-10.5.7). In SD 25 mostly years before 1983 were influenced. In quarters 1, 2 and 4 the absolute change was in the order of 0.1, while it was substantially lower in quarter 3 (0.02). In SDs 26 and 28 maximum deviations of 0.05 were reached in quarter 1 (Figs. 10.5.6 and 10.5.7). In all other quarters the deviations were 0.02 in maximum. While there was no clear time-trend in SD 26, in SD 28 the year 1985 showed highest deviations.

The differences in sprat predation mortality are characterised by positive as well as negative values, i.e. for some situations the predation mortality calculated by the new model set-up were higher compared to the standard model formulation (Figs. 10.5.8-10.5.10). In SD 25 the sign of change in predation mortality was mainly dependant on the age-class, at least in quarters 1 and 2. In quarters 3 and 4 only positive deviations were calculated. In SD 26 the situation in quarters 1 and 2 is in agreement with SD 25, in quarters 3 and 4, however, only negative values appeared (Figure 10.5.9). Highest absolute changes were recorded for SD 28 (up to 0.25). These major changes appeared in the age-classes 6-7 in the early 1980s. From the end of the 1980s onwards almost no differences showed up, due to the very low predator stock size (Figure 10.5.10).

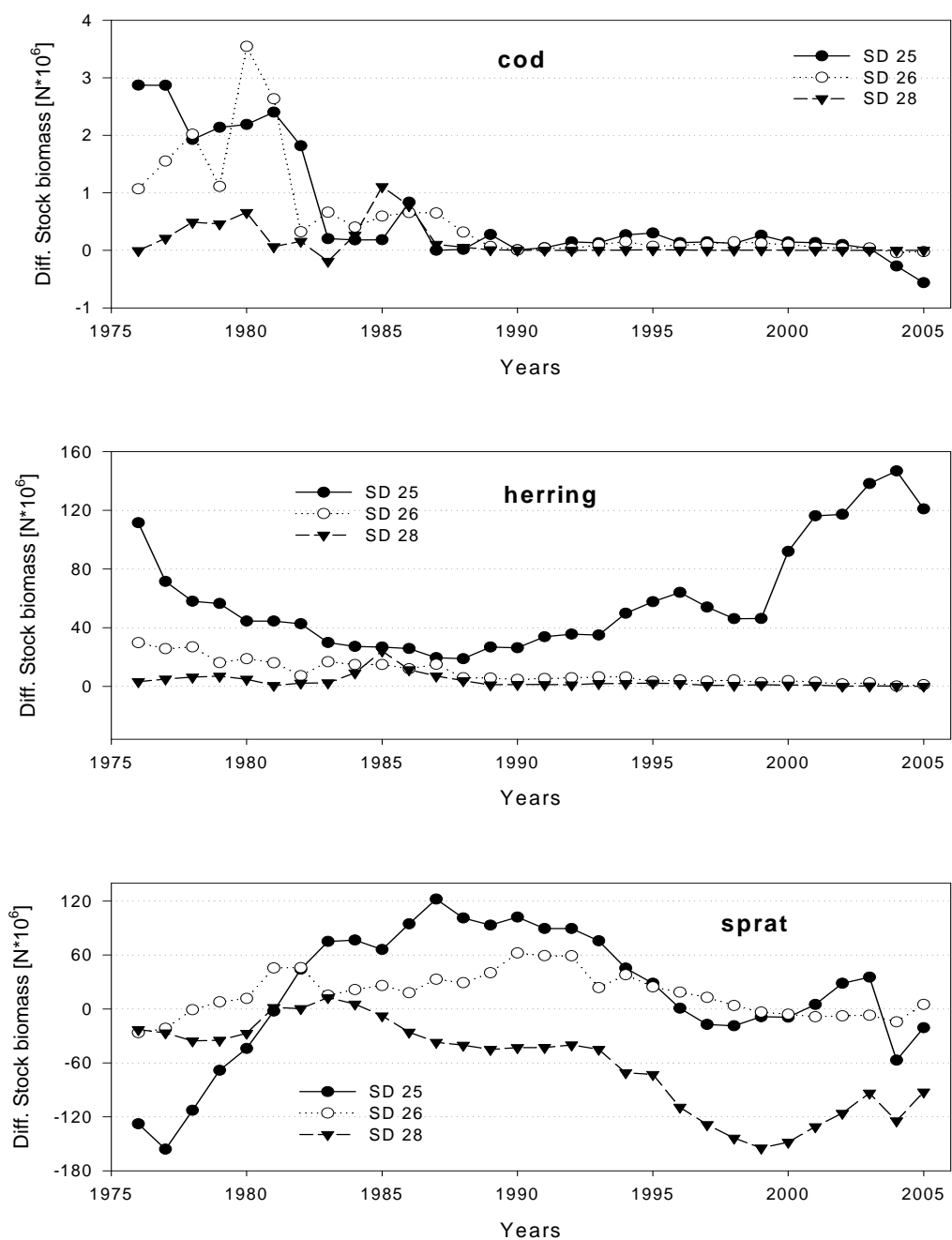


Figure 10.5.1: Differences between computed stock biomass from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for cod (above), herring (middle) and sprat (below) in the 1st quarter of each year summarized over age-group 1-8 for cod and herring and age-group 1-7 for sprat.

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption rates) for cod in SD 25 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

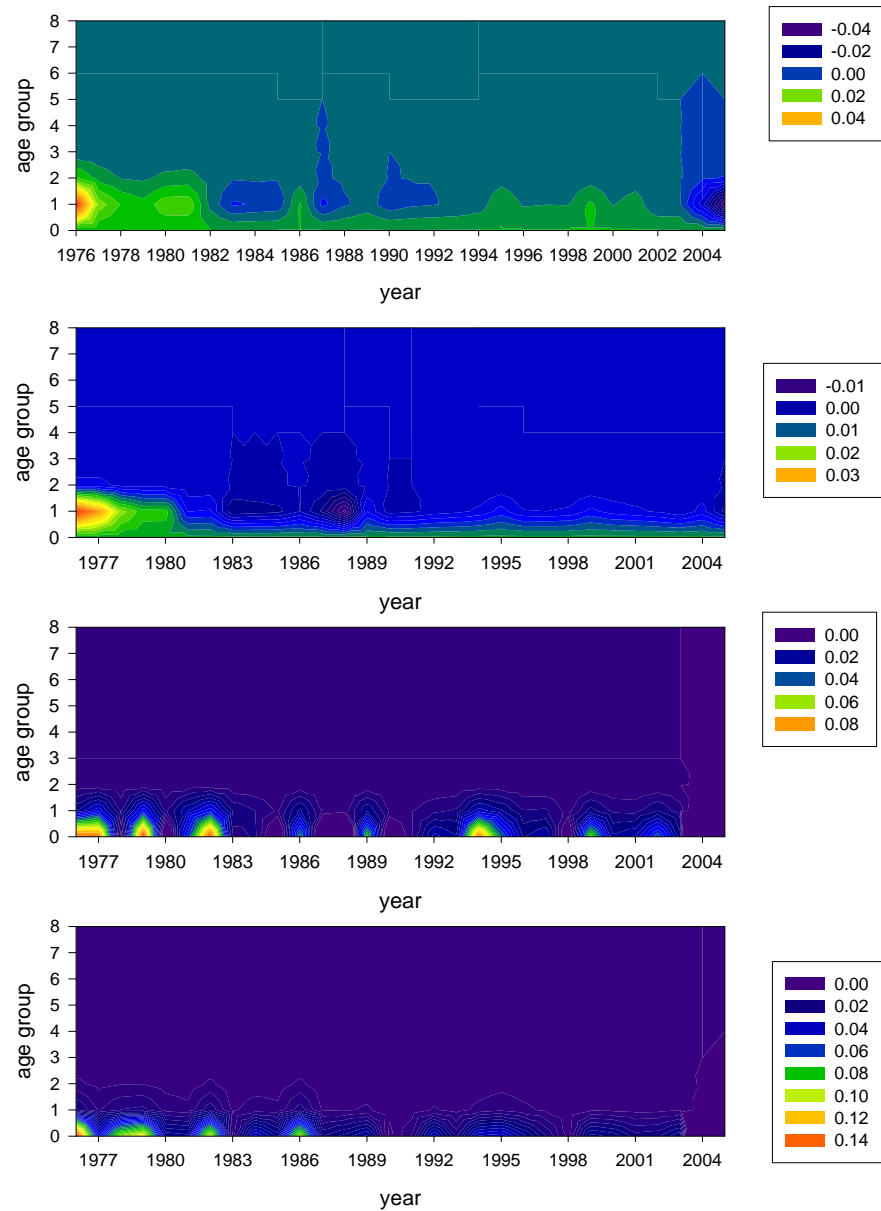


Figure 10.5.2: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for cod in SD 25 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption rates) for cod in SD 25 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

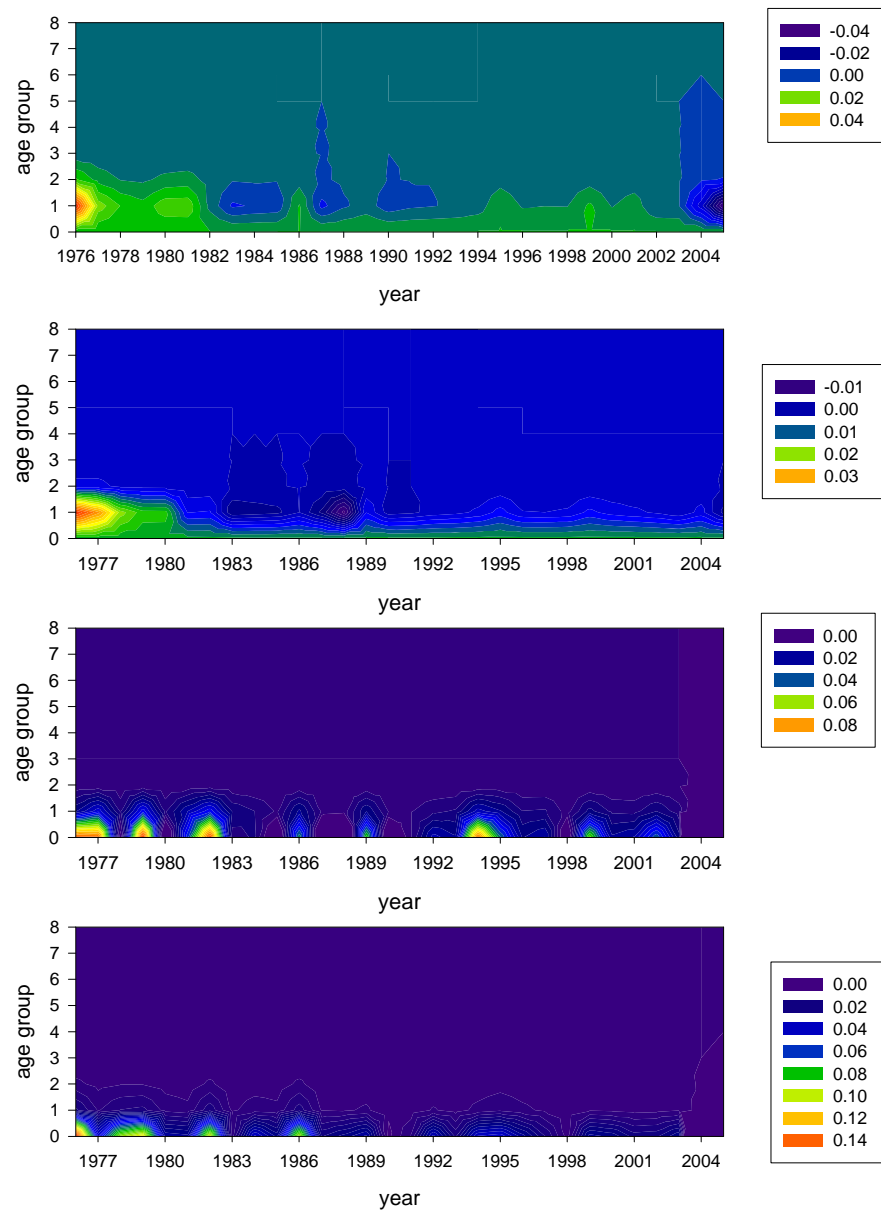


Figure10.5.3: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for herring in SD 25 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption rates) for cod in SD28 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

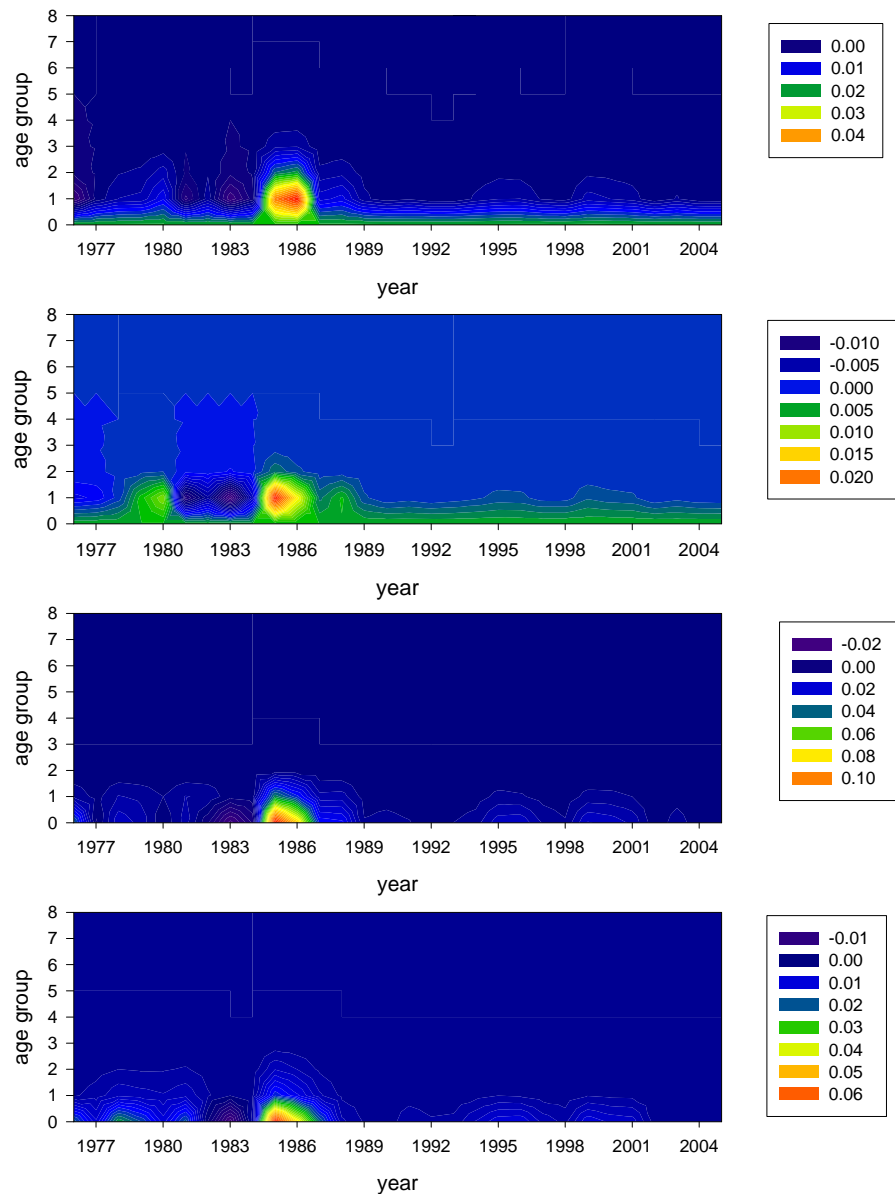


Figure10.5.4: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for sprat in SD 25 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influence)
for herring in SD 25
for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

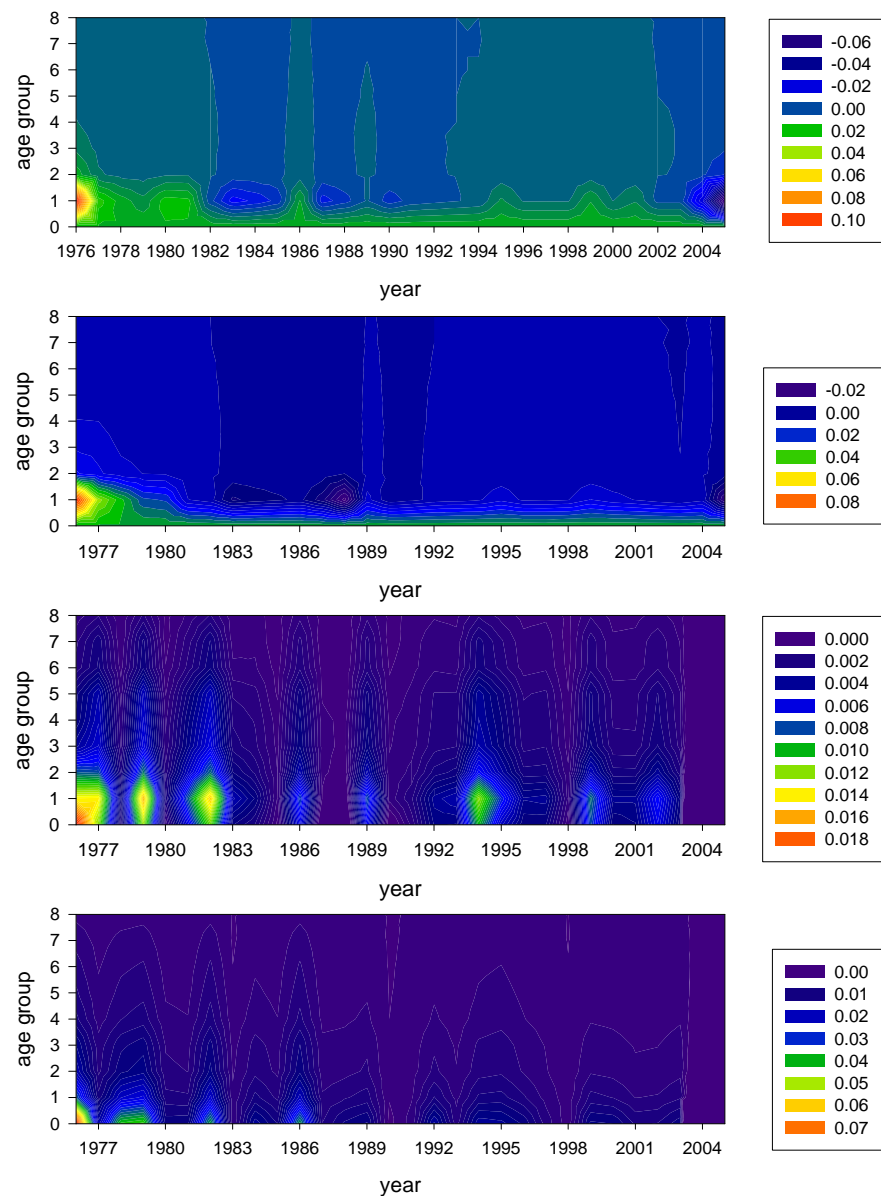


Figure10.5.5: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for cod in SD 26 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption) for herring in SD26 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

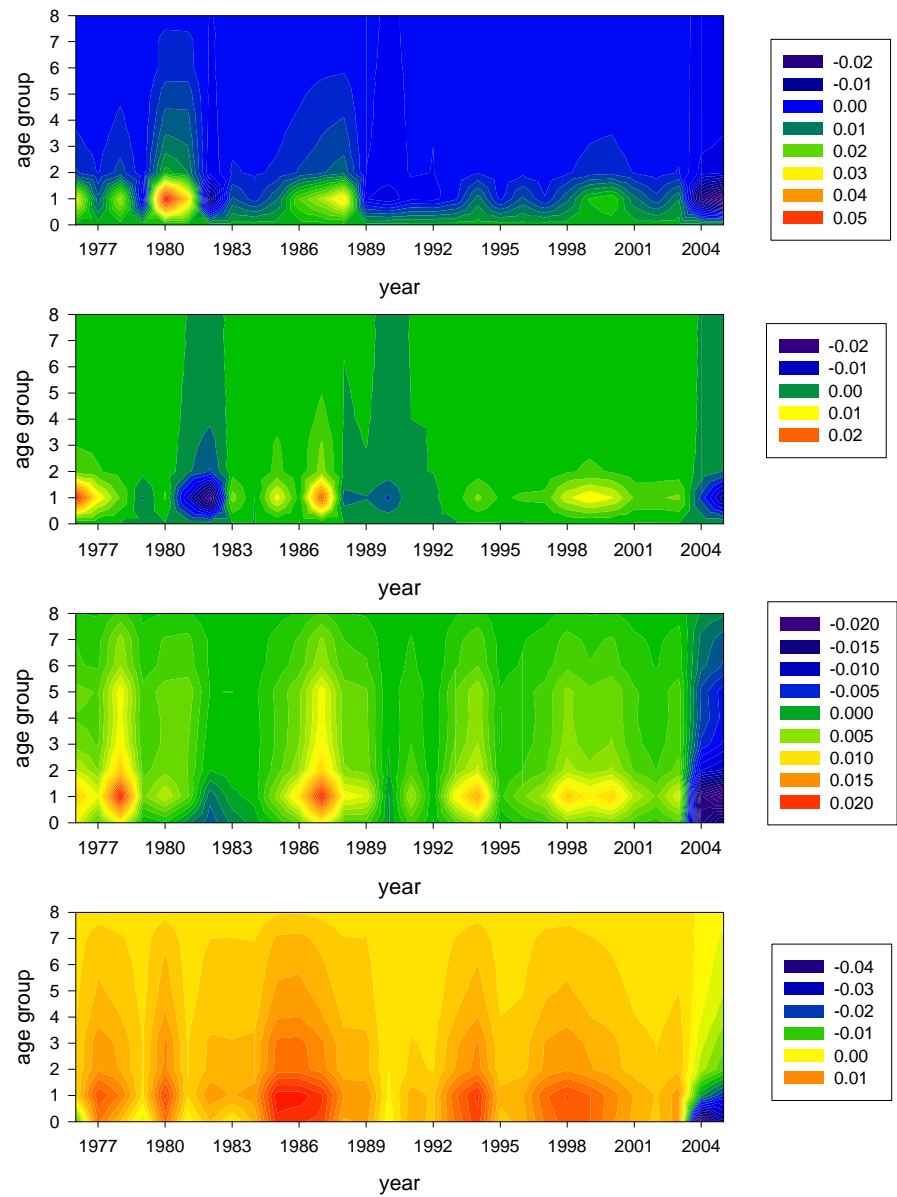


Figure10.5.6: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for herring in SD 26 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption rates) for herring in SD28 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

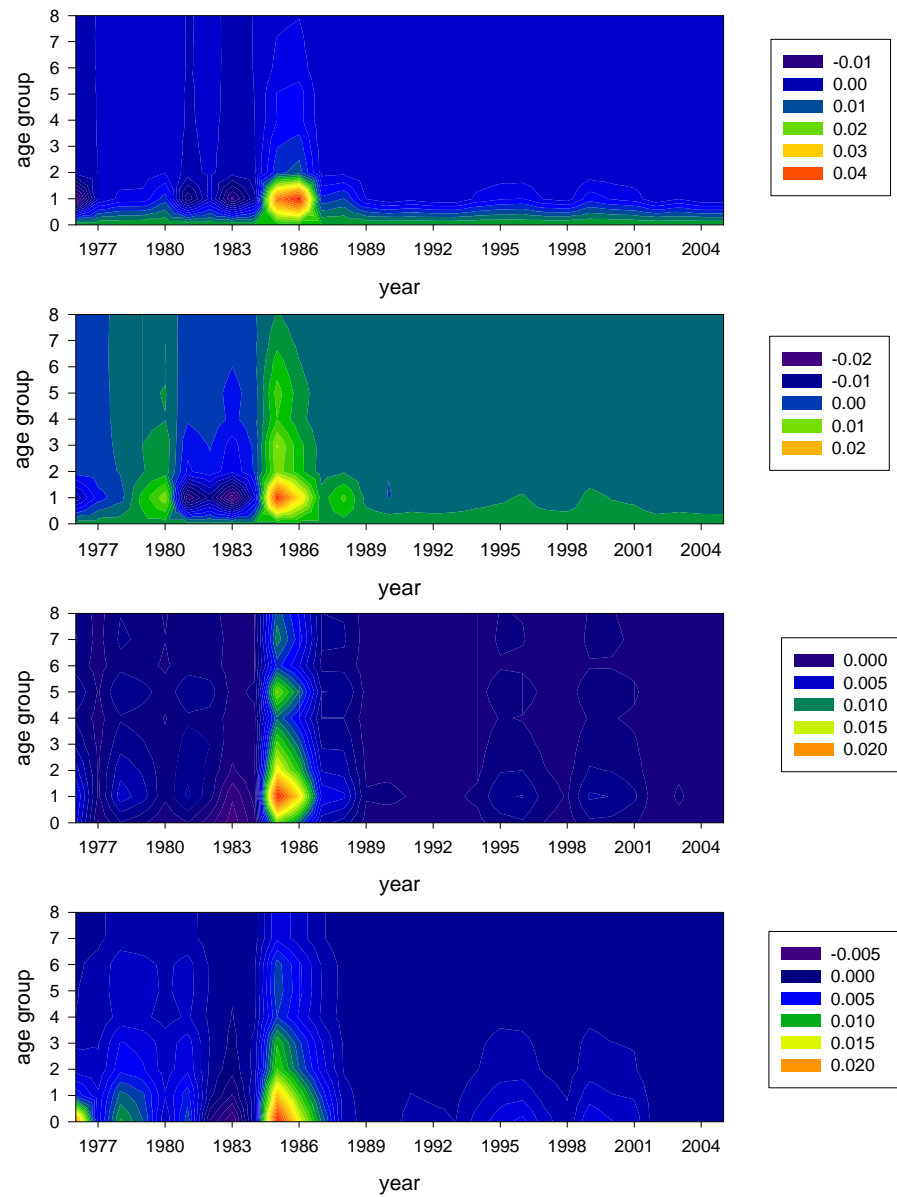


Figure10.5.7: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for sprat in SD 26 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption rates) for sprat in SD 25 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

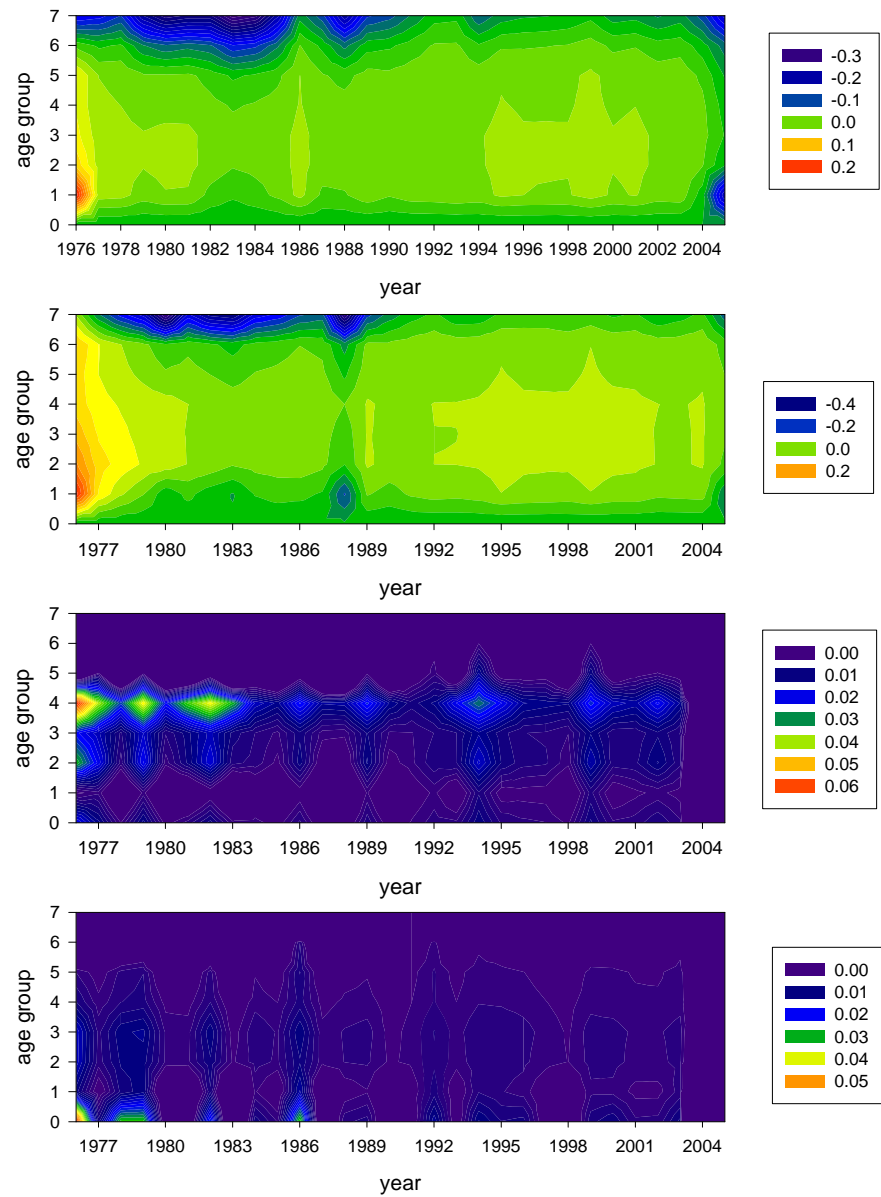


Figure10.5.8: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for cod in SD 28 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption rates) for sprat in SD26 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

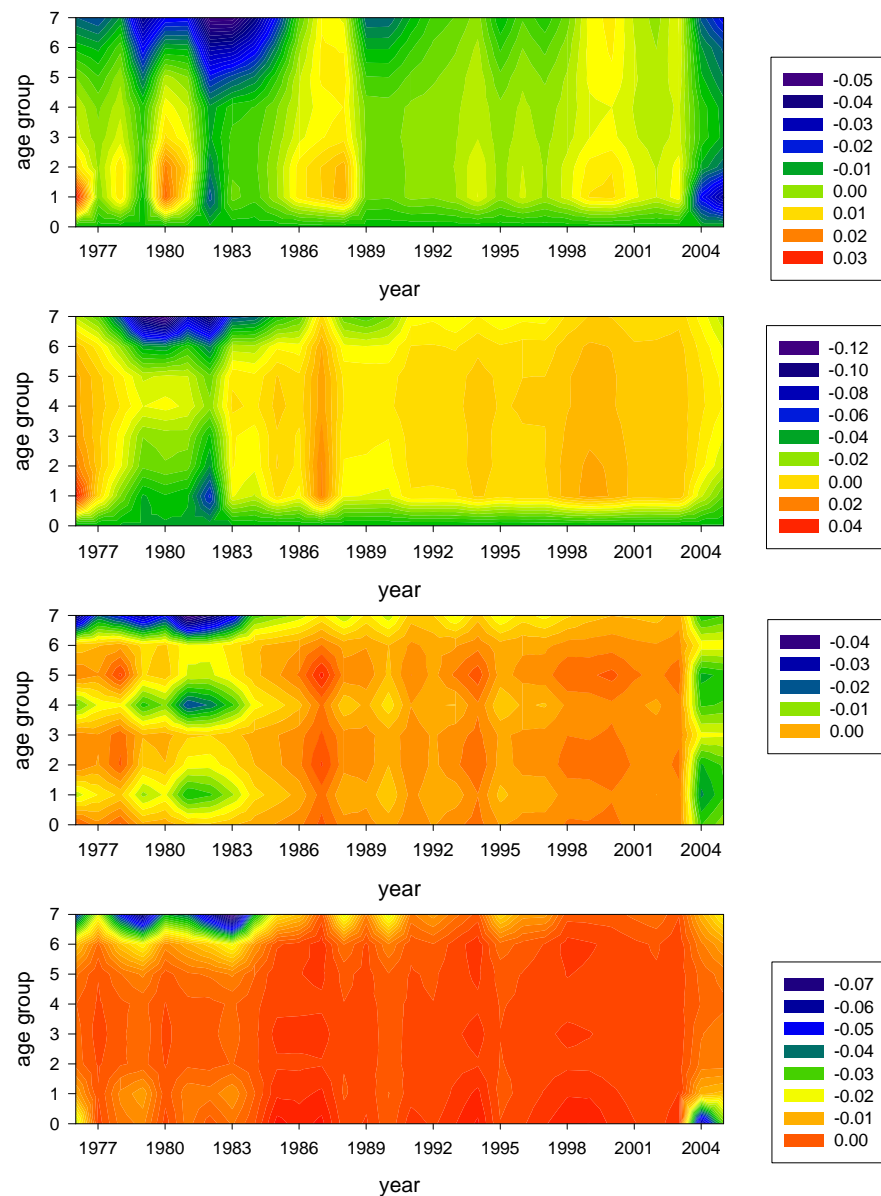


Figure10.5.9: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for herring in SD 28 in 1st quarter (above) to 4th quarter (below).

Difference between estimated M2 (MSVPA with and without oxygen influenced consumption rates) for sprat in SD28 for the 1st Quarter (A), the 2nd Quarter (B), the 3rd Quarter (C) and the 4th Quarter (D)

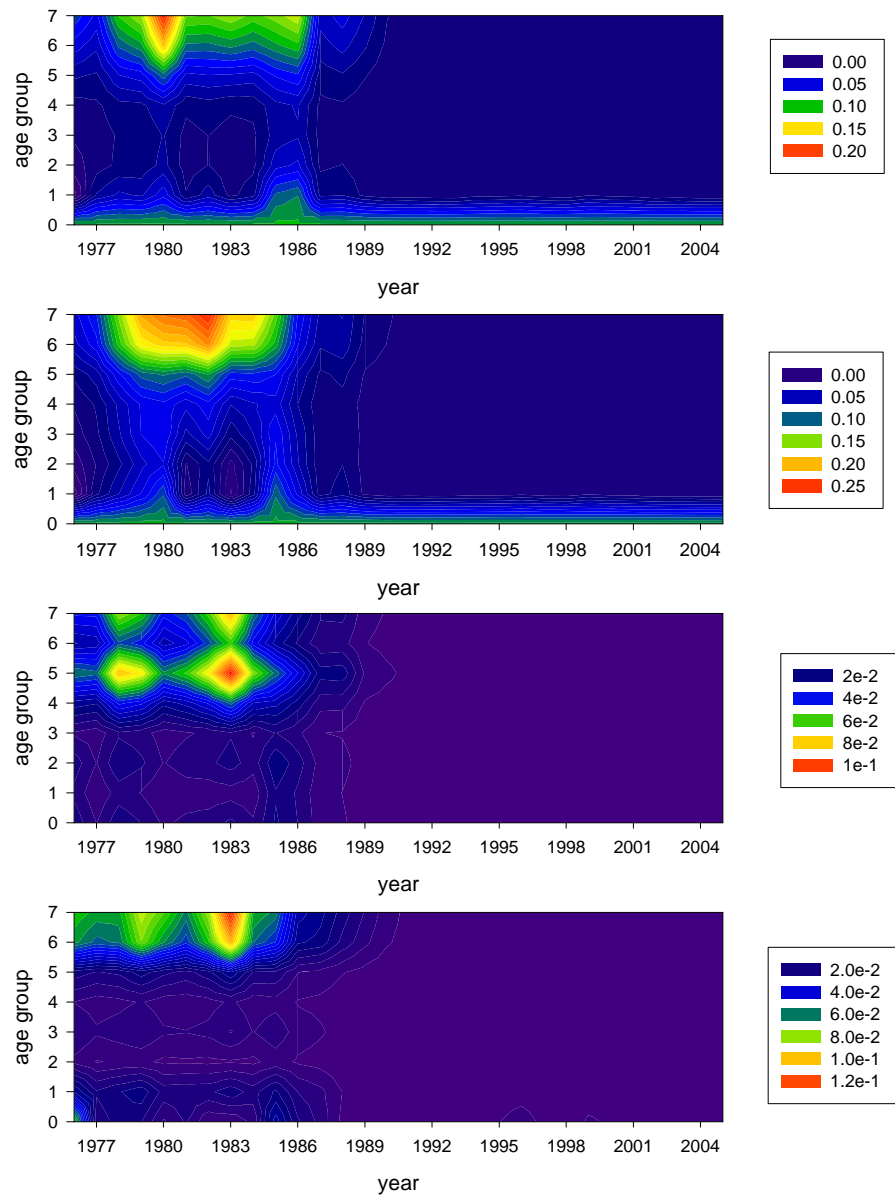


Figure10.5.10: Differences between computed predation mortalities from MSVPA and alternative MSVPA (with oxygen reduced consumption rates) for sprat in SD 28 in 1st quarter (above) to 4th quarter (below).

11 SMS-Application of the Stochastic MultiSpecies model

The stock units utilized in the present SMS analysis for the Central Baltic are: i) cod in Subdivisions 25–29+32, ii) sprat in Subdivisions 25–32, and iii) herring in Subdivisions 25–29, 32 (Gulf of Riga included).

Cod and sprat

As the sprat population in Subdivisions 30 and 31 is rather low (landings are less than 5000 t in most recent years), the stock estimate is basically 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 Subdivision 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 the sprat stock in entire Baltic is treated as a single stock unit in single species assessment.

Herring in Subdivisions 25–29 and 32

SGMAB (ICES 2005/H:06) used the main basin herring stock data that is 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 Central Baltic 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. Tests have been performed (ICES 2005/H:06) using data of the herring stock in SD 28 in- and excluding Gulf of Riga. However, 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 for the entire time series.

11.1 Input data

Input data to SMS are given by quarter of the year and follow as far as possible ICES SGMAB (2005/H:06) 4M runs with respect to:

- a) catch number
- b) catch mean weight
- c) proportion mature,
- d) mean weight in the sea,
- e) food consumption (ration)
- f) M1 (residual natural mortality)

11.1.1 Survey CPUE data

Survey indices at age data were copied from ICES single species assessment (ICES 2006/ACFM:24). These time series includes CUE indices from the commercial fishery, but as the commercial tuning data also are included in the catch data, the two sets are correlated, which might bias the parameter estimate. Thus, the commercial CPUE series were not used by SMS.

11.1.2 Stomach contents data

Stomach content data, 1977-1993 have previously been compiled for use in the age-based MSVPA. The collation of national stomach content data set into one set for multispecies assessment has mainly been done by DIFRES and the result published in ICES papers (e.g. ICES C.M. 1991/J:30) ICES 1989/J:2, ICES 1990/Assess:25 and ICES 1993/J:11). Data and

most of the software are still available at DIFRES. As a first try, the existing software was used to extract stomach data to SMS, which requires stomach content given by predator and prey length group, and not by ages as used in MSVPA. This should be possible as prey data originally were first transformed to international stomach contents by length group (1 cm groups) and afterwards transformed into ages (ICES 1993/J:11).

A closer inspection of this “intermediate” data by length groups showed however an odd length distribution of the preys. The original data from the period 1977-1980 were in most cases given by 5-10 cm classes for the preys. These size classes were transformed to one cm groups assuming a size distribution as in the sea and an estimated size selection function (ICES 1993/J:11). For later years, preys were measured to cm groups when possible. The combination of observed and estimated data resulted in many cases in an unrealistic length distribution, which cannot be used by SMS to fit the prey size selection. Therefore a new the data collation was made using the “raw” stomach data.

11.1.2.1 Errors in “number of stomachs” previously used

A few errors in the previous version of stomach data were spotted in the re-compilation of data. When data are exchanged on “table format” used in the first sampling years, values in the table give number of stomachs investigated (number of stomachs with food= n_{full}) and proportion empty (total number of stomachs, $n_{stom} = n_{full} + n_{empty}$ that is empty).

Example USSR, 1978, Q4, subdivision 26

a) length-group 21-25 cm, number stomach investigated=5, proportion empty=0.29

5 full + 2 empty = 7; proportion empty $2/7 = 0.2857 \sim 0.29$

b) length-group 26-31 cm, number stomach investigated=7, proportion empty=0.50

7 full + 7 empty = 14; proportion empty $7/14 = 0.5$

It cannot be interpreted as total number of stomachs and proportion empty. E.g. a) 29% of 5 stomachs or b) 50% of 7 stomachs do not give integer values.

Data on “table format” are given per stomach (e.g. total stomach content (g) /no of stomachs). It was interpreted as mean stomach content for all stomachs, including the empty stomachs. In the previously compilation of data (ICES 1993/J:11) and later used in MSVPA, it has been assumed that the “number of stomach investigated” includes empty stomachs. More than half of all available stomachs (Poland, USSR, Latvia and GDR) were reported on the “table format” and if the assumption is incorrect, the population mean stomach content might be heavily biased.

When stomach data are given by individual stomachs (Denmark, Sweden and Germany) the previous compilation of data has counted the number of empty and stomachs with food in the correct way.

11.1.2.2 Re-compilation of stomach content data

Due to the mix of observed and estimated, and potentially wrong number of stomachs assigned to each sample, it was decided to abandon most of the originally software for data compilation and redo the task in a more suitable way for SMS.

Data compilation was done in two major steps:

a) Transform observations into a new exchange format similar to the one used in the North Sea (ICES Cop. Res. Rep. No. 219, 1997);

- b) Aggregation of national data (at the common exchange format) into a dataset usable by SMS.

11.1.2.3 Standardisation of cod size classes.

The length classes of the cod size classes has not been standardised between countries in the sampling. Example: 1977, quarter 1 has data by cod length:

26-31 cm,
26-35 cm,
31-35 cm,
36-40 cm,
36-45 cm
41-50 cm,
46-55 cm

Input to SMS is stomach content by distinct size-classes. Therefore, the nationally defined size-classes had to be standardised before they can be aggregated. Where one size class was a true subset of another, they were combined into one. (e.g. 26-31 + 26-35 + 31-35 = 26-35) “Odd” size classes were renamed to the nearest size class (e.g. 36-40 + 36-45 + 41-50 = 36-45). The standardisation was done for each year individually such that the number of size-classes remains high and with a minimum of renaming “odd” size classes.

11.1.2.4 Weighting of stomach data by sub-area

SMS uses stomach contents data by size classes for the whole Baltic Sea area. Stomachs have been sampled and compiled for each sub-area individually. To calculate a mean stomach contents by size-class it is necessary to weight the mean stomach content by sub-area by the proportion of the stock for the particularly sub-area.

Previous work by Sparholt *et al.* (ICES CM 1993/J:11) includes proportion (PRPOP) in the various sub-areas of the total cod stock in the Eastern-Baltic by age and quarter (these data are from research vessel data 1982-1989 and GLM analysis). Sparholt *et al.* (ICES CM 1993/J:11) also includes cod mean length and standard deviation by age and quarter for the cod stock (derived from R/V DANA surveys 1981-1988). These data are used to produce an age to length conversion key (ALK). Output from the 4M model (ICES 2005/H:06) give total stock numbers by age and quarter (N), such that the weighting factors (W) can be calculated.

$$W_{l,q,s} = \sum_a N_{a,q} PROP_{a,q,s} ALK_{a,l,s}$$

11.1.2.5 Treatment of “unidentified clupeids”.

Unidentified clupeids were redistributed on sprat and herring according to their presence in the basic stratum (cod length, subdivision, year, quarter) if data by species were available.

Alternatively by allocation keys based on the stratifications:

- a) cod length, subd, year
- b) cod length, subd,
- c) cod length
- d) all data

When allocation keys include more than one sub-division, the keys were made as a weighted average of the content within the basic strata using the proportion of the stock within the area as weighting factor.

Length information of unidentified clupeids were available in a very few cases, but ignored in the data compilation.

11.1.2.6 Definition of prey size classes for herring and sprat

Prey sizes are mainly given by 5 cm groups for the period 1977-1981. In cases where data are given by smaller length classes they are allocated to the relevant 5 cm group.

Data for the period after 1981 are given by 1 cm class, which are maintained for sprat in the compilation. Herring preys are compiled by 2-cm groups.

11.1.2.7 Estimation of missing prey size for herring and sprat.

Preys without size information are afterwards allocated to size classes according to the observed distribution in the stratum (cod length, prey, subdivision, year and quarter) or if data were unavailable according to the observed data in more widely defined strata:

- a) cod length, prey, subd and quarter
- b) cod length, prey and subd,
- c) cod length and prey

When allocation keys include more the one sub-division, the keys were made as a weighted average of the content within the basic strata using the proportion of the stock within the area as weighting factor. The prey size classes are different for the two periods 1977-1981 and 1982-1995 and data were compiled separately.

11.1.2.8 Prey mean size in the stomach

The size-classes used for preys were first transformed into a mean-length for the size-class. For one cm-groups the mean of the range was used as mean length. It was assumed that the prey mean length of five cm-groups follows the size distribution in the sea, which were estimated from 4M stock numbers and mean length and SD by age (see later section on prey ALK).

Mean weight per prey mean size was calculated from a length weight relation.

11.1.3 Age - length keys (ALK)

ALKs for use in years with stomach contents observations were calculated information on mean length at age (ml) and the standard deviation (SD) of the length distribution at age.

Cod mean length at age are copied from Table 5 in ICES 1993/J:11 (based on R/V DANA surveys in SD 25, 2 and 28 in 1981-1988).

Sprat data are copied from Table 9 in ICES 1993/J:11 (based on Polish data on commercial catches in sub-division 25 and 26 in 1977-1989).

Herring mean length at age data are from the same source where it is presented in 3 tables:

- 1) Table 6: Mean length at age and quarter in sub-division 26 in 1985-1989 from Swedish hydroacoustic surveys and Polish commercial data)
- 2) Table 7: Conversion factors to get length at age for 1977-1980 and 1981-1984 from length at age 1985-1989, based on Polish commercial catches.
- 3) Table 8: Difference in mean length at age of herring between subdivision.

Stock numbers from an area disaggregated 4M run (ICES 2005/H:06) were used to weight the area specific length data calculated from table 6-8 input. Mean length estimated for herring in 1989 were copied to the period up to 1994.

To avoid insignificant and unrealistic length observation, only data from a truncated normal distribution ($ml \pm 3*SD$) were used.

11.2 Configuration of baseline SMS

A hind cast using catch data from the period 1974-2005 and all available stomach data (1977-1994) forms the basis of a baseline prediction. The recruitment for cod is estimated from the geometric mean over the period 1986-2005. A Ricker relation, fitted to the whole time series, is used for herring. Sprat recruitment is estimated as a geometric mean over the years 1990-2005.

11.2.1 Predation parameters

Figure 11.2.1 presents the stomach content observations in a plot using the $\log(\text{predator size})$ on the x-axis and $\log(\text{predator size} / \text{prey size})$ on the y-axis. Body weight was used as the size of both predator and prey. The plot does only present the stomach content observations, which is a function of size selection and the available amount of that particular size. As the available amount is not included in the plot it only gives a rough overview of the size selection.

It can be seen that in the size spread (related to the σ^2 parameter) in general increases with increasing predator size. For sprat, the spread seems however constant for all cod sizes (except for the very small cod), which is simple due to the limited size range of sprat. Prey cod and herring have a wider size range in the sea, which is reflected in the stomach contents. The regression lines have similar parameter values for prey cod and herring while the sprat regression has a higher intercept and slope parameter. This may be an effect of the limited size range of sprat in the sea or prey specific size selection.

Explorative SMS runs were made with different versions of the prey selection model:

$$\exp\left(-\frac{\left(\log \frac{\text{pred size}}{\text{prey size}} - (\eta_{pred} * \tau_{prey} + \nu_{pred} * \log(\text{pred size}))\right)^2}{2\sigma_{pred}^2}\right)$$

- a) Equal size selection (=1) within the observed predator/prey size range and 0 outside the observed size range
- b) Simple size selection, parameter τ fixed to 1.0 and parameter ν fixed to 0.0
- c) Size selection with predator size adjustment, as b but estimation of parameter ν
- d) Size selection with predator size and prey species adjustment; estimation of all parameters.

Configuration a) assumes a fixed size ratio for each predator prey species combination. It seems to be the case for sprat (Figure 11.2.1), while increasing size range with increasing predator size is observed for cod and herring. Very large (relative to the predator size) herring preys are recorded for medium sized cod, which will lead to an overestimation of large herring eaten by large cod, as the same size preference is assumed for all cod sizes by configuration a). A closer inspection of the record of with relatively large herring showed that the record represents a very few fish, and it was decided to ignore observations with $\log(\text{predator size} / \text{prey size})$ of less than 2, equivalent to excluding record where the predator was less than 7.4 times the weight of the prey.

Configuration b) uses a log-normal distributed size preference. The same is used in c), but this configuration does also take the apparent size dependent size preference into account (the

slope value in figure 11.2.1). Configuration d) adds a possible prey specific size selection (the intercept values if figure 11.2.1).

11.3 Results

11.3.1 Comparison of the various size selection sub-models

The performance statistics for the four model configurations are presented in Table 11.3.1.

The four models show similar log-likelihood values for catch, CPUE and Stock recruitment observations.

Configuration a) does not use the size information of the various prey species while configurations b)-d) do. Therefore, the log likelihood values for stomach observations can only be compared for configuration b)-d). Configuration b) and c) can be considered as a reduced configuration d) model, such that a likelihood ratio tests can be applied. The results of such show that the increase of parameters from both model b) to c) and from c) to d) give significant improvement of the model fit (assuming chi-square statistics).

The three configurations using a size selection model give quite similar result with respect to recruitment, mean F, SSB and eaten biomass (Figure 11.3.1a-c), however, when size selection is assumed uniform within the observed range (configuration a) the same metrics become very different. Especially the herring metrics are very different, with a much higher SSB and eaten biomass for the uniform size selection model. The estimated herring SSB is very sensitive to the input value for the maximum relative prey size. If the present value of $1 / 7.4$ (see previous section) are replace by $1 / 10$ the herring biomass becomes quite similar to the results from configuration b)-d), however the amount eaten of herring is still much higher than observed the these configurations. Due to the high sensitivity to input variables the uniform size selection model was abandoned. For the remaining configurations, the likelihood ratio test indicates that configuration d) gives the best fit, and this configuration was chosen as basis for the further scenarios.

Table 11.3.1. Summary statistics for the four models with different size selection sub-models objective function (negative log likelihood) values

configuration a)

Number of parameters = 307

objective function contributions (negative log likelihood):

	Catch	CPUE	S/R	Stom.	Sum
Cod	-243.6	-13.2	-23.5	1052.0	771.7
Herring	-594.8	-81.2	-16.6	0.0	-692.7
Sprat	-244.2	-30.8	-1.7	0.0	-276.6
Sum	-1082.6	-125.2	-41.8	1052.0	-197.6

configuration b)

Number of parameters = 309

objective function contributions (negative log likelihood):

	Catch	CPUE	S/R	Stom.	Sum
Cod	-243.1	-13.2	-23.0	2220.6	1941.2
Herring	-580.4	-86.7	-21.6	0.0	-688.6
Sprat	-242.1	-32.3	-1.2	0.0	-275.6
Sum	-1065.6	-132.1	-45.8	2220.6	977.0

configuration c)

Number of parameters = 310

objective function contributions (negative log likelihood):

	Catch	CPUE	S/R	Stom.	Sum
Cod	-243.3	-13.4	-22.0	2203.0	1924.3
Herring	-580.1	-86.2	-21.3	0.0	-687.6
Sprat	-242.1	-32.1	-1.1	0.0	-275.4
Sum	-1065.5	-131.8	-44.4	2203.0	961.3

configuration d)

Number of parameters = 312

objective function contributions (negative log likelihood):

	Catch	CPUE	S/R	Stom.	Sum
Cod	-243.4	-13.3	-22.1	2188.8	1909.9
Herring	-578.2	-85.8	-20.8	0.0	-684.8
Sprat	-242.1	-32.4	-1.3	0.0	-275.8
Sum	-1063.8	-131.5	-44.2	2188.8	949.4

Table 11.3.2. Estimates and standard deviation of the vulnerability parameter for different size selection models.

	COD		HERRING		SPRAT	
Configurations	estimate	std	estimate	std	estimate	std
a)	5.30	0.98	2.43	0.36	2.51	0.34
b)	5.83	1.29	0.65	0.14	0.73	0.15
c)	14.32	3.65	1.55	0.37	1.45	0.27
d)	25.43	16.59	4.68	2.24	0.68	0.06

Table 11.3.3. Estimates and standard deviation of the size selection parameters for different size selection models.

	PREFERRED SIZE (H)				PREDATOR SIZE ADJUST (Y)		PREY SPECIES ADJUST (T)			
			VARIANCE (Σ^2)				cod		Herring	
Configurations	estimate	std	estimate	std	estimate	std	estimate	std	estimate	std
a)	-	-	-	-	-	-	-	-	-	-
b)	5.61	0.41	3.29	0.95	fixed 0	-	fixed 1	-	fixed 1	-
c)	7.42	0.33	5.0	-	0.72	0.10	fixed 1	-	fixed 1	-
d)	5.16	0.49	5.0	-	0.43	0.10	1.58	0.22	1.69	0.18

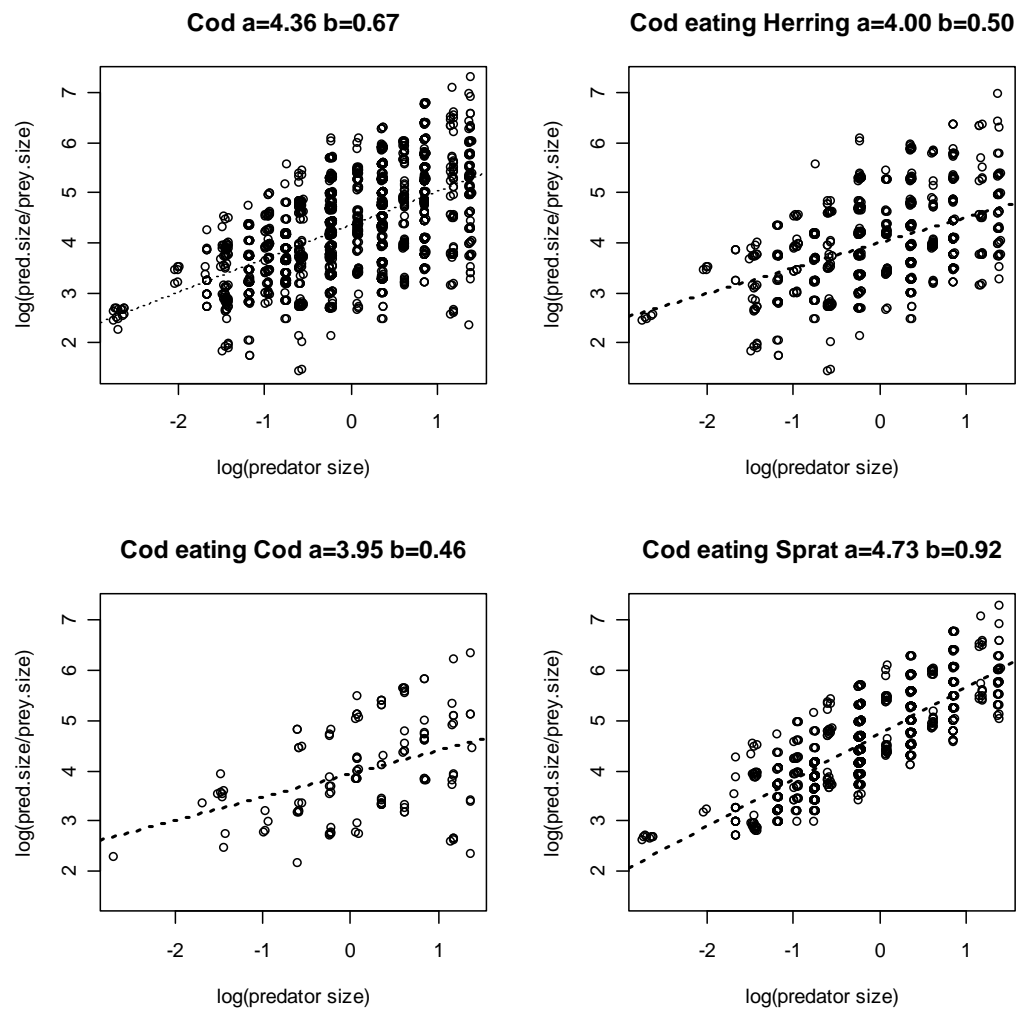


Figure 11.2.1 Stomach contents observations. Each observation has equal weight in calculating the regression line.

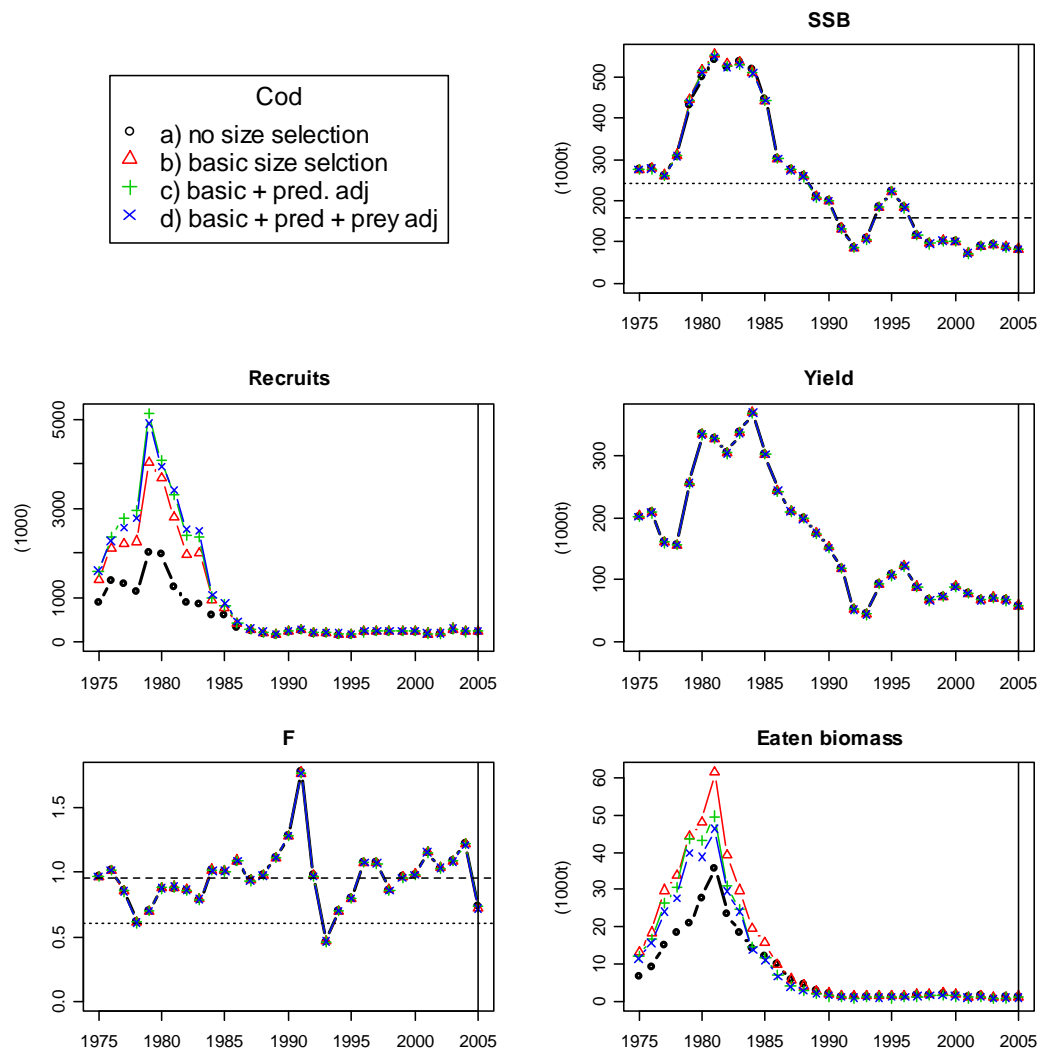


Figure 11.3.1a Output variables for four specifications of prey size selection model.

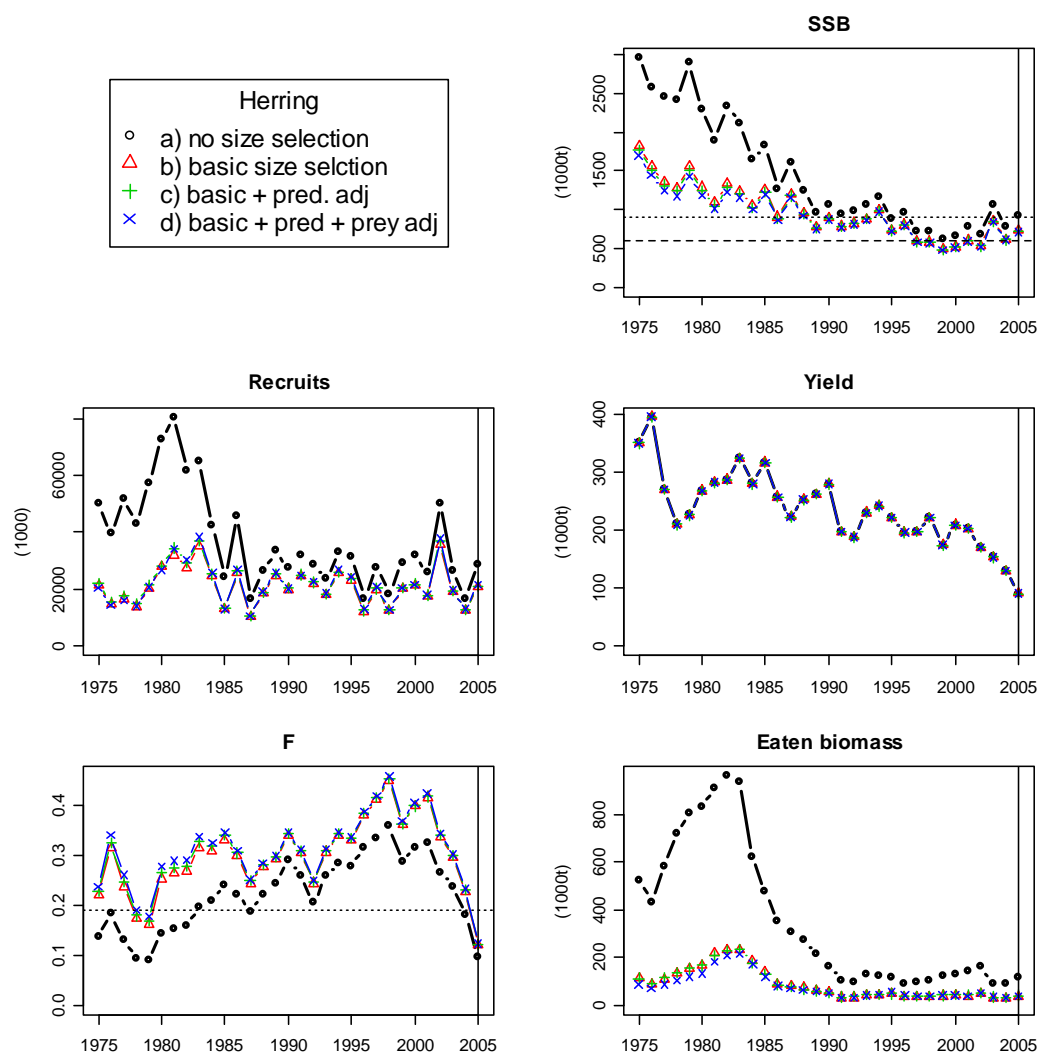


Figure 11.3.1b Output variables for four specifications of prey size selection model.

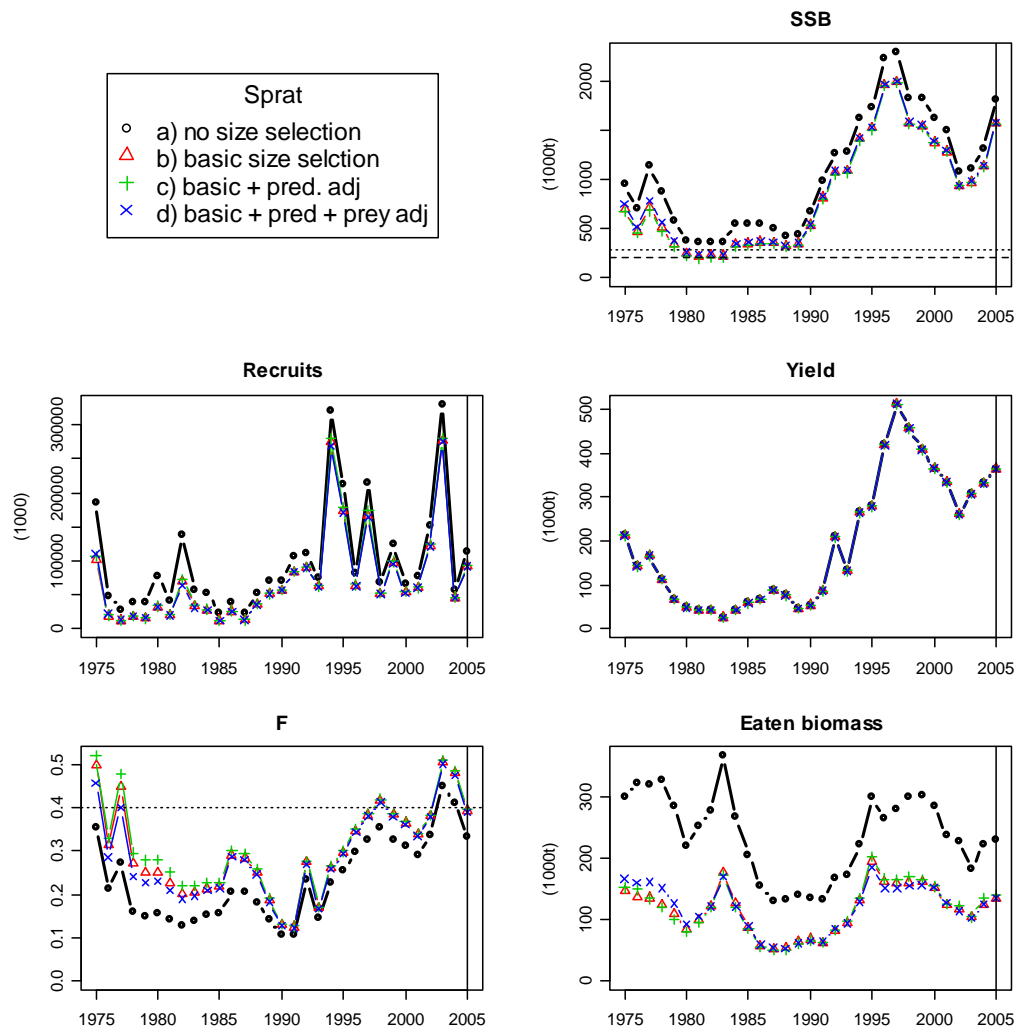


Figure 11.3.1c Output variables for four specifications of prey size selection model.

12 Implementation and evaluation of suitable medium and long-term projection methodology for different fishery scenarios and management objectives

During the SGMAB meeting, a specific EU FP6 project BECAUSE workshop on the implementing of the SMS in the Baltic, to be held in January 2007 in Copenhagen was prepared, by i) reviewing harvest control rules for the species in the Central Baltic, and ii) identifying possible scenarios for future recruitment and species interactions.

12.1 Harvest control rules

Harvest control rule for Eastern Baltic cod were set according to the Proposal for a Council regulation “Establishing a multi-annual plan for the cod stocks in the Baltic Sea and the fisheries exploiting those stocks” COM(2006) 411, specifying:

Article 4

Objective and targets

The plan shall ensure the sustainable exploitation of the cod stocks concerned by gradually reducing and maintaining the fishing mortality rates at levels no lower than:

- 1) 0.6 on ages 3 to 6 years for the cod stock in Subdivisions 22, 23 and 24, and
- 2) 0.3 on ages 4 to 7 years for the cod stock in Subdivisions 25 to 32.

Article 5

Setting of TACs

- 1) Each year, the Council shall decide by a qualified majority on the basis of a proposal from the Commission on the TACs for the following year for the cod stocks concerned.
- 2) The TACs for the cod stocks concerned shall be set in accordance with Articles 6 and 7.

Article 6

Procedure for setting the TACs for the cod stocks concerned

- 1) The Council shall adopt the TAC for the cod stocks concerned that, according to a scientific evaluation carried out by the Scientific, Technical and Economic Committee for Fisheries (STECF), is the higher of:
 - a) the TAC that would result in a 10% reduction in the fishing mortality rate in its year of application compared to the fishing mortality rate estimated for the preceding year.
 - b) the TAC that would result in the level of fishing mortality rate defined in Article 4.
- 2) Where the application of paragraph 1 would result in a TAC that exceeds the TAC for the preceding year by more than 15%, the Council shall adopt a TAC which is 15% greater than the TAC of that year.
- 3) Where the application of paragraph 1 would result in a TAC that is more than 15% below the TAC of the preceding year, the Council shall adopt a TAC which is 15% less the TAC of that year.
- 4) Paragraph 3 shall not apply where a scientific evaluation carried out by the STECF shows that the fishing mortality rate in the year of application of the TAC will exceed a value of 1 per year from the ages 3 to 6 years for the cod stock in Subdivisions 22, 23 and 24 or a value of 0.6 per year for the ages 4 to 7 years for the cod stock in Subdivisions 25 to 32.

Article 7

Derogation from Article 6

By way of derogation from Article 6, the Council may, where it considers this appropriate, adopt a TAC that is below the TAC that follows from applying Article 6.

For eastern Baltic cod this means as Harvest Control Rule:

Reduce F by 10% compared to the year before, until F (4-7) is 0.3. Interannual changes in TAC are restricted to $\pm 15\%$, except if $F > 0.6$ (ages 4-7), then TAC may be reduced by $> 15\%$.

Harvest control rule for central Baltic herring

Herring: fishing at F_{pa} (0.19) for $SSB > 900\,000$ tons, 0.1 for $900\,000 < SSB < 600\,000$ and $F=0.05$ for $SSB < 600\,000$ tons. Interannual changes in TAC are restricted to $\pm 25\%$

Harvest control rule for sprat:

Sprat: Keep F at 0.4 for $SSB > 275\,000$ tons, 0.2 for $275\,000 < SSB < 200\,000$ Blim and $F=0$ for $SSB < 200\,000$ t. Interannual changes in TAC are restricted to $\pm 25\%$, %.

The implementation of the scenarios imitates the present used system where a TAC for year Y , is set based on an assessment with terminal year, $Y-2$ (e.g the TAC for 2007 is set based on an assessment with terminal year 2005). In such calculation it is assumed that the TAC for the intermediate year (year $Y+1$) is taken fully and that recruitment in year Y and $Y-1$ follows the stock recruitment relationship without any noise.

12.2 Recruitment and stomach contents in predictions

For comparison of model performance, four configurations of stomach data and recruitment model were defined, which mimic possible combinations of recruitment regimes. The following forecast settings were used for all four options:

- 1) Mean weight in the sea and food rations as average for 1995 to 2004
- 2) Maturity ogives are kept same as in last year's assessment report
- 3) Exploitation pattern average 2004 to 2005 (after last change in Bacoma window mesh size to 110 mm for cod) with a 20% reduction in exploitation pattern for age 2
- 4) TAC for **cod** is set to 49000 in 2006 and to 45000 t for 2007.
- 5) TAC for **sprat** in 2006 is set 460000 t and 477000 t in 2007
- 6) TAC for **herring** in 2006 is 128000t and 164000t in 2007.

Option 1, Baseline.

The baseline prediction will be based on the result from a hindcast using catch data from the period 1974-2005 and all available stomach data (1977-1994). The recruitment for cod is estimated from the geometric mean over the period 1986-2005. A Ricker relation, fitted to the whole time series, is used for herring. Sprat recruitment is estimated as a geometric mean over the years 1990-2005.

Option 2, long term mean

Recruitment based on the full time series 1974-2005. For herring and sprat a Ricker relation is assumed. Cod recruitment is estimated from a "Hockey stick" relation with inflection point 500000 t.

Option 3, high cod recruitment

Recruitment for all species is estimated from the geometric mean over the period 1974-1986. The predation parameters is estimated for stomach data from the same period (i.e 1977-1986).

Option 4, low cod recruitment

Recruitment for all species is estimated from the geometric mean over the period 1987-2005. The predation parameters are estimated for stomach data from the same period (i.e 1987-1994).

13 Coordination and interlinking multispecies and ecosystem modelling activities in the Baltic

An improved linkage between scientific activities within physical, chemical and biological oceanography, as well as fish stock assessment including multispecies assessment is a pre-requisite for the ICES Strategic Plan and BSRP goals of developing and implementing a holistic approach to ecosystem and fisheries management in the Baltic.

Progress in multispecies modelling oriented work in the Baltic is coupled to various scientific activities within ICES, i.e., to i) multispecies model development ii) Baltic fish stock assessment (WGBFAS, WGBIFS and related Study Groups and Workshops), iii) Baltic ecosystem assessment (BSRP related initiatives), but also activities outside ICES.

A new Study Group on Baltic Fish and Fisheries Dynamics [SGBFFD] would provide an essential interface with the Study Group on Multispecies Model Development (WGMSAM) and it will be responsible for performing multispecies assessments for the Baltic by utilizing the models developed in WGMSAM. The prerequisite for this development is historic data compilations and revisions for Baltic fish stock assessment and prediction purposes. One of the main goals of the new SG is also to develop and implement the environmental information in the fish stock assessment and prediction tools.

14 Dissolving SGMAB and recommendations

The Study Group on Multispecies Assessment in the Baltic (SGMAB) has now come to the end of its life span. Thus SGMAB recommend that the group in its present form is dissolved.

The SGMAB also recommend that a **Study Group on Baltic Fish and Fisheries Dynamics** (SGBFFD) will be established. This group should have a wider geographical and ecological remit than was the case for SGMAB and thus it will form an improved linkage between scientific activities within physical, chemical and biological oceanography, as well as fish stock assessment, which is a pre-requisite for the ICES Strategic Plan and BSRP goals of developing and implementing a holistic approach to ecosystem and fisheries management in the Baltic.

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Annex 2: Agenda

Agenda

SGMAB NOVEMBER 2006

Agenda SGMAB 2006

Study Group on Multispecies Assessment in the Baltic [SGMAB]

Helsinki, Finland 02-07 November 2006

1. Opening
2. Adoption of agenda and timetable
3. Review the progress of the stomach sampling program
4. Update and correct the multispecies database
5. Validate of the consumption rates for Eastern Baltic cod
6. Develop a concept for inclusion of environmental sensitive and spatially explicit stock recruitment relationships into multispecies predictions;
7. Include coupled weight at age, proportion of maturity at age and consumption process models in multispecies prediction models;
8. Coordinate and interlink the SG with multispecies and ecosystem modelling activities in the Baltic
9. Explore the effect of heterogeneous distribution of predator and prey on species interactions in the Central Baltic
10. Develop, apply and validate enhanced multispecies models (SMS)
11. Implement and evaluate the suitable medium- to long-term projection methodology
12. Recommendations of the Study Group on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB)
13. Future work and coordination of future work
14. Our recommendations
15. Dissolving SGMAB
16. Any Other Business
17. Close