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16–20 March 2009

Rostock, Germany

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

WGIAB was setup in 2007 as a forum for developing and combining ecosystem-based management efforts for the Baltic Sea. WGIAB has given itself 3 main tasks:

1) to conduct holistic ecosystem assessments based on large multivariate datasets;
2) to consider the use of ecosystem modelling in the assessment framework;
3) to develop adaptive management strategies for the different Baltic Sea ecosystems.

During the meetings in 2007 and 2008 WGIAB concentrated on collection and analyses of large multivariate datasets. This effort resulted in ecosystem assessment for 7 subsystems of the Baltic Sea (ICES 2008b). These ecosystem assessments demonstrated dramatic changes (i.e. regime shifts) during the last 3 decades on all trophic levels of the ecosystems related to climate variability and human exploitation.

While the development of adaptive management strategies is planned for 2010, WGIAB during the 2009 meeting concentrated on developing and conducting ecosystem modelling. In an “ensemble approach” the responses of cod and sprat SSB to five scenarios of fishing of cod (continued high fishing mortality, implemented cod management plan, cod fishing moratorium) and sprat (increased fishing) were investigated. To this end, four single species cod models, four multispecies models and one foodweb model have been used. In addition, these fishing scenarios were tested assuming either no climate change, or a future warmer and less saline Baltic Sea. The responses of cod and sprat to the fishing and climate scenarios tested differed between the nine models, both quantitatively and qualitatively. However, the ensemble modelling approach used herein allowed a straightforward comparison of the range of possible outcomes projected by the diverse models used. Thus, the ensemble modelling approach provided a means to (1) assess whether these differences in predictions also resulted in different conclusions on management, and (2) draw general conclusions valid across all single species and foodweb models used.

Three general conclusions were made across models and climate scenarios: (i) business as usual fishing of cod will hinder a recovery of the Eastern Baltic cod stock, (ii) a reduction in fishing pressure on cod is predicted to have a smaller positive effect on the cod stock in a future changing climate than if climate change is not accounted for, and (iii) the effects of increased sprat fishing on the cod and sprat stocks are highly uncertain, ranging from no effect to extinction depending on model and climate scenario. The results produced are preliminary as several of the models are still in a developing phase, and as climate effects were evaluated on very few runs. However, based on the experience of the “ensemble modelling” WGIAB started to develop a strategy on the use of ecosystem modelling in the future assessment framework, which will be continued in 2010.

The participation in WGIAB increased considerably during its lifetime (12 participants in 2007, 23 in 2008) to 28 participants from 8 countries during this year meeting. Due to this enlarged participation in 2009, WGIAB was able to update and analyze datasets for the holistic ecosystem assessments. During the 2009 meeting, WGIAB managed to update and analyse the data series of four subsystems, i.e. CBS, GoR, GoF and COAST (for info on subsystems see ICES, 2008). The datasets of the 3 remaining subsystems will be updated intersessionally. Additionally, a data mining exercise has been conducted for Western Baltic ecosystems. Intersessionally these

data series will be screened for use in an IEA for the area with the goal to perform the analyses on next year meeting.

Further activities of the 2009 WGIAB meeting included i) planning for a contribution to the Baltic Sea Action Plan and HELCOM BIO, ii) reviewing the research on ecosystem analysis and modelling in the Baltic Sea region, iii) contributing to answer a EC request through WKMAMPEL, and iv) input to other ICES EGs and a back-to-back meeting with TGBALT developing a new structure to ensure that scientific advances of Baltic Sea specific expert groups can support and further the Baltic Sea advice produced by regular assessment working groups, and how this can be represented under the ICES structure.

1 Opening of the meeting

The Co-Chairs Christian Möllmann (CM), Anna Gårdmark and Juha Flinkman welcomed the participants (Annex 1) of the meeting. CM introduced the goals of WGIAB, the state of the different tasks to be conducted by the group and the purpose of this meeting (see introduction). CM further expressed the gratitude of the group to the hosting "Institute of Baltic Sea Fisheries" and the local organizers.

The meeting has been given the following Terms of References:

The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea [WGIAB] (Co-Chairs: Christian Möllmann, Germany; Anna Gårdmark, Sweden; Juha Flinkman, Finland) will meet in Rostock, Germany from 16–20 March 2009 to:

a) review and update recent changes in the ecosystem and the need to update the Integrated Ecosystem Assessments for the different Baltic Sea subareas;

b) evaluate target levels in the Baltic Sea Action Plan and the HELCOM BIO set of indicators and assessment system in relation to the knowledge derived from the WGIAB data analyses;

c) review and coordinate the research on ecosystem analysis and modelling between different projects and activities in the Baltic Sea (e.g. BONUS projects);

d) use available ecosystem models for the different subareas in retrospective and scenario runs as a basis for ecosystem-based advice;

e) outline a strategy of the use of ecosystem models within the future ecosystem-based advice.

WGIAB will report by 15 April 2009 for the attention of SCICOM.

2 Adoption of the agenda

CM introduced the agenda which was shortly discussed, adjusted and finally adopted by the participants.

3 Introduction

WGIAB was set up in 2007 as a forum for developing and combining ecosystem-based management efforts for the Baltic Sea. The general approach of WGIAB is to assess the state and development of the different Baltic Sea subecosystems considering all trophic levels and the impact of climate, fisheries and eutrophication. WGIAB therefore is intended to serve as a counterpart and support for the ICES Baltic Fisheries Assessment Working Group (WGBFAS), but also to support related HELCOM assessment efforts such as HELCOM BIO and HELCOM FISH.

WGIAB has given itself 3 main tasks:

1) to conduct holistic ecosystem assessments based on large multivariate datasets;
2) to consider the use of ecosystem modelling in the assessment framework; and
3) to develop adaptive management strategies for the different Baltic Sea ecosystems.

During the meetings in 2007 and 2008 WGIAB concentrated on collection and analyses of large multivariate datasets. This effort resulted in ecosystem assessment for 7 subsystems, i.e. Öresound, Central Baltic Sea, Gulf of Riga, Gulf of Finland, Bothnian Sea, Bothnian Bay and a coastal ecosystem (ICES 2008b). These ecosystem assessments demonstrated dramatic changes (i.e. regime shifts) during the last 3 decades on all trophic levels of the ecosystems related to climate variability and human exploitation (Möllmann *et al*., 2006, Möllmann *et al*., 2009, Blenckner *et al*. in prep.). Additional to the new knowledge on ecosystem structure and function of Baltic ecosystems, a major product of WGIAB for future ecosystem-based management approaches are the impressive regional data sets on abiotic and biotic indicators (ICES 2008). These have a large potential for future ecosystem analyses and are started to be used in other contexts. One example is the provision of data and expertise to the Baltic Salmon and Trout Working Group (ICES 2008d, WGBAST; see Chapter 10) and the evaluation of the ecosystem effects (including the size of the cod stock) of a potential reduction of the size of the sprat stock through an increased fishing mortality for sprat (see Chapter 9). This evaluation has been conducted in support of the ICES Workshop on Multiannual management of Pelagic Fish Stocks in the Baltic (ICES 2009) for a request of the EU Commission. As a preliminary product of the work conducted by WGIAB, the analyses and the resulting Ecosystem Overview Documents of the different subsystems will be published in an *ICES Cooperative Research Report*, which was finalized during the present meeting.

During the 2009 meeting WGIAB concentrated as planned in 2008 on developing and conducting ecosystem modelling and based on this developing a strategy for the use of ecosystem modelling in the Baltic Sea assessment framework. Toward this goal WGIAB performed comparative analyses of a set of cod population dynamics, multispecies and foodweb models using an approach that is known as “ensemble modelling” in climate research. In this approach the different models are forced with the same scenarios (e.g. of future climate development) and their projections are collected in an ensemble. By this WGIAB evaluated alternative fisheries management scenarios for cod and sprat under alternative scenarios of future climate change (see Chapter 7). Based on the experience of the “ensemble modelling” WGIAB started to develop a strategy on the use of ecosystem modelling in the future assessment framework, which will be continued in 2010 (see Chapter 8).

The participation in WGIAB increased considerably during its lifetime (12 participants in 2007, 23 in 2008) to 28 participants from 8 countries during this year meeting. Due to this enlarged participation in 2009, WGIAB was able to conduct 2 major exercises, i.e. (i) to conduct the planned ensemble modelling study, and (ii) also to update and analyse datasets for the holistic ecosystem assessments (see Chapter 4). During the 2009 meeting, WGIAB managed to update and analyse the data series of four subsystems, i.e. Central Baltic Sea, Gulf of Riga, Gulf of Finland, and a coastal ecosystem (for info on subsystems see ICES 2008). The datasets of the 3 remaining subsystems will be updated intersessionally. Additionally, a data mining exercise has been conducted for Western Baltic ecosystems. Intersessionally these data series will be screened for use in an IEA for the area with the goal to perform the analyses on next year meeting.

In 2010 WGIAB intends to bring together the results and experiences from the IEAs and the “ensemble modelling” in order to develop adaptive management strategies for the Baltic Sea ecosystems.

4 Recent changes in the Baltic ecosystem – update of the Integrated Ecosystem Assessments (ToR a)

4.1 Introduction

As the focus of the present meeting of WGIAB was on modelling (see Chapter 3), it was planned for this meeting to only discuss the need to update the Integrated Ecosystem Assessments (IEA) in case of observed severe changes in the abiotic environment. However, due to the large number of participants the group had the capacity to update the databases and to perform the standard analyses outlined in last year report (ICES 2008b).

During the WGIAB meeting in 2008, Integrated Ecosystem Assessments (IEA) were conducted for 7 subregions of the Baltic Sea (ICES 2008):

1) The Central Baltic Sea (CBS), encompassing the 3 deep basins, Bornholm Basin, Gdansk Deep and Gotland Basin;
2) the Sound (ÖS);
3) the Gulf of Riga (GoR);
4) the Bothnian Sea (BoS);
5) the Bothnian Bay (BOB);
6) a coastal site in Sweden (COAST);
7) the Gulf of Finland (GoF).

For each area a multitude of time-series were collected providing information about climate, hydrography, nutrients, phytoplankton, zooplankton, fish and fisheries, plus, where available, data for benthos and top predators like seals. The type and number of variables available for each system differ, but were balanced according to drivers and response variables and included to the best knowledge of the group all available key components describing each foodweb. A description of the time series and data sources is given in the Appendix of ICES (2008).

During the 2009 meeting, WGIAB managed to update and analyse the data series of four subsystems, i.e. CBS, GoR, GoF and COAST (for info on subsystems see ICES 2008). The results of the updated IEAs, their interpretation and a general comparison with the outcome of previous analyses are presented in Chapter 4.2. The datasets of the 3 remaining subsystems will be updated intersessionally. Additionally, a data mining exercise has been conducted for Western Baltic ecosystems. Intersessionally these data series will be screened for use in an IEA for the area with the goal to perform the analyses on next year meeting.

A further task to be completed during the present meeting in relation to the IEA has been to complete a draft for an ICES Cooperative Research Report (CRR) containing the system-specific IEA in form of Ecosystem Overview Documents (a recommendation from the 2008 meeting; ICES 2008b) and to revised the HELCOM indicator fact sheet.

4.2 Results of updated Integrated Ecosystem Assessments

IEAs were performed by following the same strategy as in recent years:

- Performing Principal Component Analysis (PCA) based on the correlation matrix of all variables and taking the PC-scores of the first and second axis to visualise the time-trajectory of the system
- Creating a traffic light plot (Link *et al.*, 2002) to visualize the status and temporal development of the system and its variables. Quintiles of metrics were colour coded and variables were sorted according to their subsequently derived PC1 loadings;
- Performing the Sequential Regime Shift Analysis (STARS) following Rodionov (2004) for each single time series, after correcting for autocorrelation. The resulting Regime Shift Indices (RSI) were summed up for each year, with the proportion of explanatory and response variables indicated by different colours in a bar plot.

Two different time-series analyses were applied to detect sudden changes on the integrated ecosystem level. First, STARS was performed on the first two principal axis of the PCA. Second, Chronological Clustering (Legendre *et al.*, 1985) was used on the normalised data, based on the Euclidean distance measure, applying a connectedness level of 0.5, and different α values.

4.2.1 Central Baltic Sea

The CBS comprises the three deep basins, the Bornholm Basin (BB), the Gdansk Deep (GD), and the Gotland Basin (GB) (ICES Subdivisions 25, 26, 27 and 28) with a maximum water depth in the western Gotland Deep of 459 m. Due to the topography characterised by several ridges high saline and oxygen rich North Sea water penetrates into the deeper basins only during periods of strong westerly winds. These episodic inflow events strongly affect the hydrography and by this the environmental conditions and ecosystem structure in this area (Hänninnen *et al.*, 2000).

Time series of 59 variables (12 fish (incl. fisheries mortality for cod, herring, and sprat), 6 zooplankton, 16 phytoplankton, 8 nutrient, and 17 physical datasets) were updated and quality controlled. In contrast to last year's assessment "cod reproductive volume" was no longer included as it is highly cross-correlated to deepwater oxygen content. All data series were compiled to one estimate per year and covered in maximum the period from 1974 to 2007.

An overview of the temporal changes of all time series is presented in Figure 4.2.1.1. Variables are sorted according to their PC1 loadings of the subsequently performed PCA generating a pattern with variables at the top showing an increasing trend over time (green-red) with highest values in the recent 15 years, to variables at the bottom showing the opposite trend (red-green) with highest values in the late 1970s to early 1980s. The first group of variables comprises e.g. *Acartia* spp. and *T. longicornis* biomass, sprat SSB, cod weight-at-age 3, dinoflagellates and temperature metrics. Decreasing values were found e.g. for cod and herring SSB and recruitment, *P. acuspes* biomass, salinity metrics and the maximum ice extend. Variables with less clear temporal trends are found in the centre of the plot, some of them showing relatively high values in the 1970s–1980s, high values between 1988 and 1993, and again low values afterwards. This group consists mainly of indicator time series related to nutrients and phytoplankton variables.

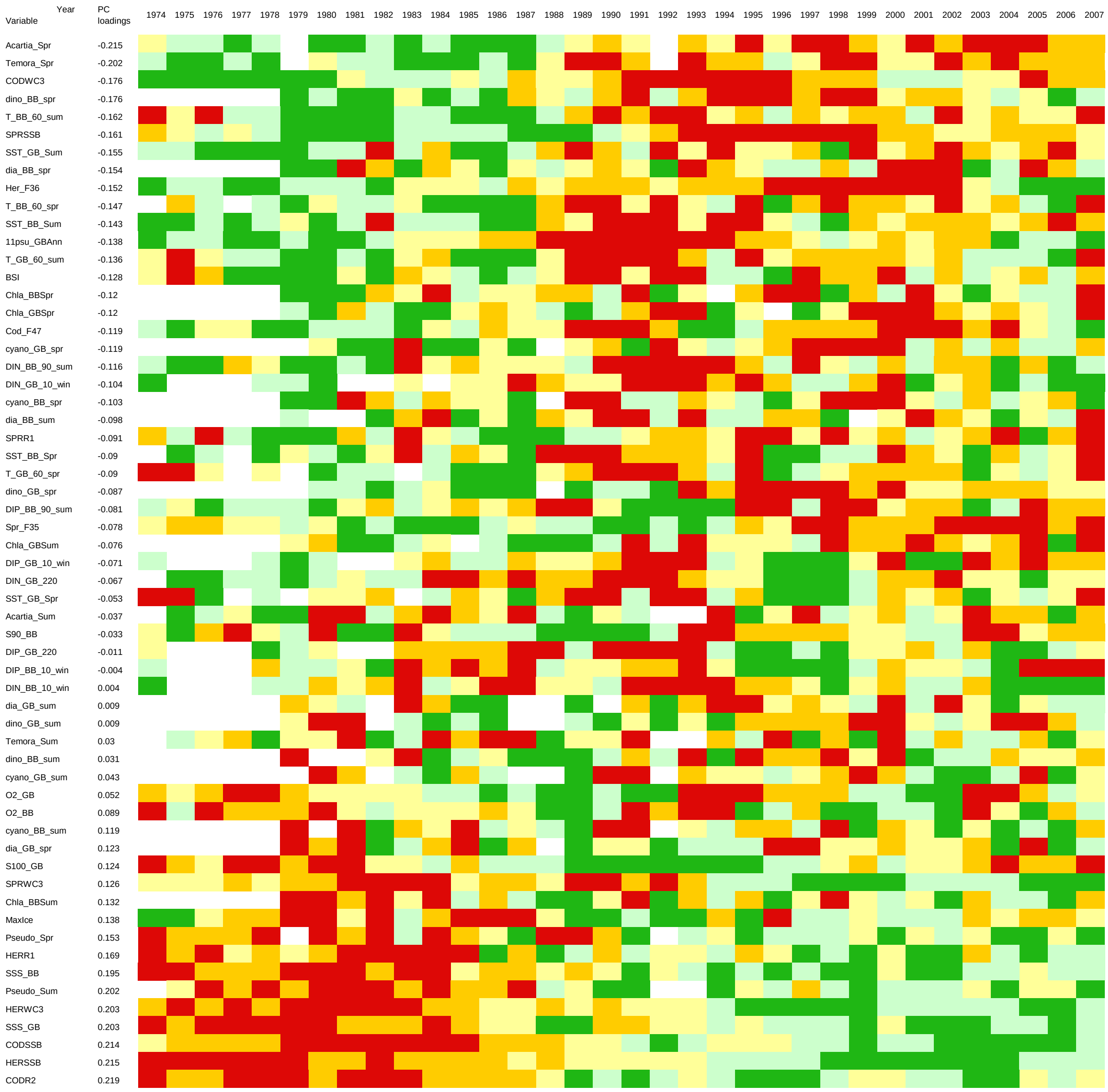


Figure 4.2.1.1. Traffic light plot of the temporal development of CBS time series covering the years 1974–2007. Variables are transformed to quintiles, colour coded (green = low values; red = high values, white = missing values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names as in ICES (2008).

The Sum of Regime Shift Indices (RSI) calculated for each of the 59 single variables resulted in highest cumulative values for the years from 1985 to1990, for 1994, and 2002 (Figure 4.2.1.2). Until 2000 shifts were mainly identified for response variables, whereas in more recent years shifts were found predominantly for explanatory variables with so far no immediate response. However, the method detects extremely high values for the last year of the time-series with equal proportions of RSI values between explanatory and response variables. Highest RSI values were found for SST, Chlorophyll *a* and diatom biomass, all measured in the Bornholm Basin. If this shift will be confirmed in the following years and if there is a future response of other functional groups remains to be open. Nevertheless, the prewhitening procedure obviously affects the outcome of the analysis as less pronounced changes are found in case of leaving autocorrelation unconsidered.

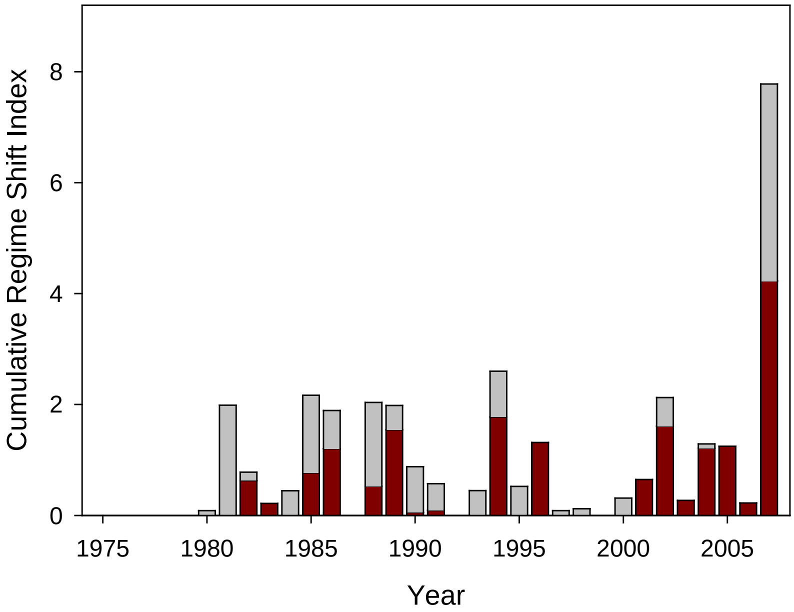


Figure 4.2.1.2. Sum of Regime Shift Indices (RSI) of 59 variables (28 driver (in red) and 31 response variables (in grey)) derived from STARS (□=0,05;cut-off length= 8; Huber parameter = 2, prewhitening with IP4).

The PCA of the full data series resulted in 27.0 and 14.1 % of explained variance on the first and second axis, respectively (Figure 4.2.1.3). The most pronounced shift could be detected in the late 1980s where PC1 scores changed from positive to negative values where they remain since then. On the second axis biggest differences between consecutive years were observed in 1980/1981 and in the period from 1992–1995. STARS applied on PC1- and PC2-scores located shifts in 1983, 1988 and 1993, whereas the latter shift was least pronounced, i.e. RSI values were comparatively low. In contrast to this, only two shifts were identified by Chronological Clustering for α=0.01, one between 1984/1985 and one between 1987/1988.

The relative changes of the variables over time and in relation to the observed ecosystem shifts can be derived from the factor loadings on the first two principal components (not graphically displayed). PC1 mainly reflects temperature (high negative loadings on PC1, meaning an increasing trend over time) and salinity (high positive loadings on PC1, meaning a decreasing trend over time). Highest negative PC1 loadings of biotic time-series were found for species known to have profited from the recent warming, e.g. sprat (Köster *et al.*, 2003), *Acartia* spp. and *T. longicornis* (Möllmann *et al.*, 2003) as well as Bornholm Basin dinoflagellates (Wasmund *et al.*, 1998). In contrast, species which have suffered from the decrease in salinity, e.g. cod (Köster *et al.*, 2005), *P. acuspes* (Möllmann *et al.*, 2003) and herring (Möllmann *et al.*, 2005) are negatively correlated to the previous group. Another factor that has obviously contributed to the decline of the cod and herring stocks is a high fishing pressure (represented as the fishing mortality coefficient F). F-values for both species load negatively on PC1, while the biomass development of both stocks are negatively correlated to the fishing pressure and load positively on PC1. PC2 mainly reflects changes which have occurred in the deep water, i.e. during the long stagnation period until 1993, which has decreased deepwater salinity and oxygen saturation (high positive loadings on PC2). In contrast deepwater nutrients increased in this period (high negative loadings on

PC2). After the reversal of the conditions after the 1993 inflow, the same deepwater trends were observed until the recent inflow in 2003.

Generally, the pronounced change in the late 1980s seems to be driven by an increase in temperature as a result of the change in atmospheric forcing reflected by positive values in the BSI time-series. Since the mid-1990s the system seems to have reached a new stable state that despite of differences in the abiotic conditions didn't move back to its originally observed structure. Although high RSI values were observed for single variables in 2007, no indications of a new ecosystem change in recent years could be detected in the composite PCA.

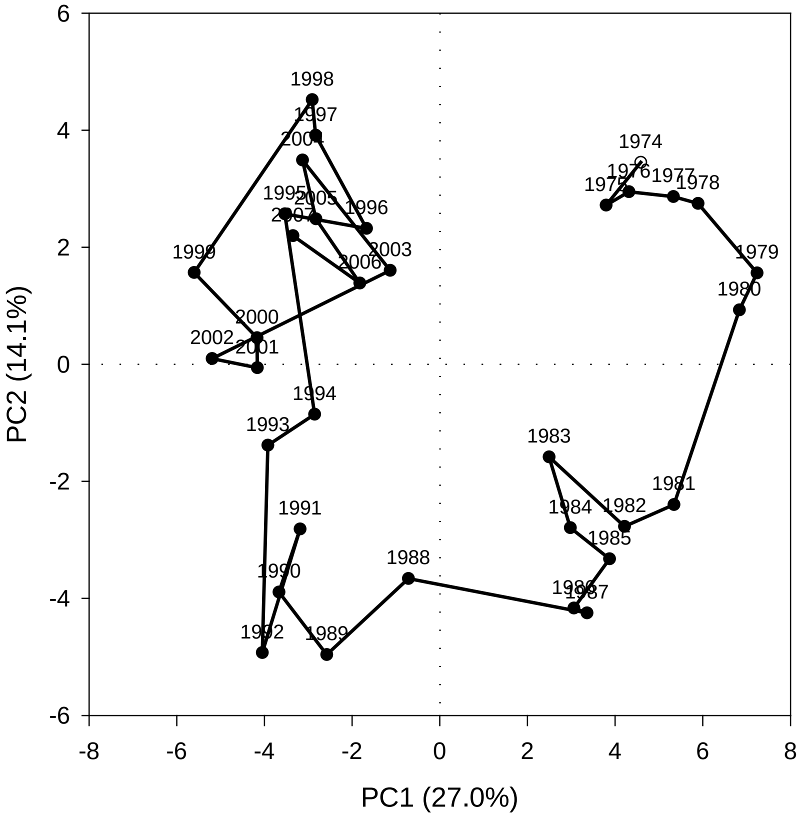


Figure 4.2.1.3. Time trajectory of principal components (PC) 1 and 2 of the full dataset (59 variables), based on the correlation matrix.

4.2.2 Gulf of Riga

The GoR is a shallow subsystem of the Baltic Sea with restricted water exchange. It is considered to be one of the most eutrophic regions of the Baltic Sea and its hydrographical and biological characteristics differ distinctly from the Baltic Proper.

Compared to the previous IEAs the analysis was extended to a period from 1973–2007 including 24 quality-controlled variables (7 fish, 7 zooplankton, 4 phytoplankton, 2 nutrient, and 4 physical datasets).

An overview of the temporal changes of all time series is presented in Figure 4.2.2.1. Variables are sorted according to their PC1 loadings of the subsequently performed PCA generating a pattern with variables at the top showing an increasing trend over time (green-red) with highest values in the recent 15 years, to variables at the bottom showing the opposite trend (red-green) with highest values in the late 1970s to early

1980s. The first group of variables include Herring SSB, *Eurytemora affinis* and *Acartia* spp. biomass in spring, winter phosphate concentrations and the recently invaded cladoceran *Cercopagis pengoi*. A clearly decreasing trend over time could be observed for landings of cod, which occurs in the Gulf only at high cod abundance in the CBS, Secchi depth, salinity and herring weight.

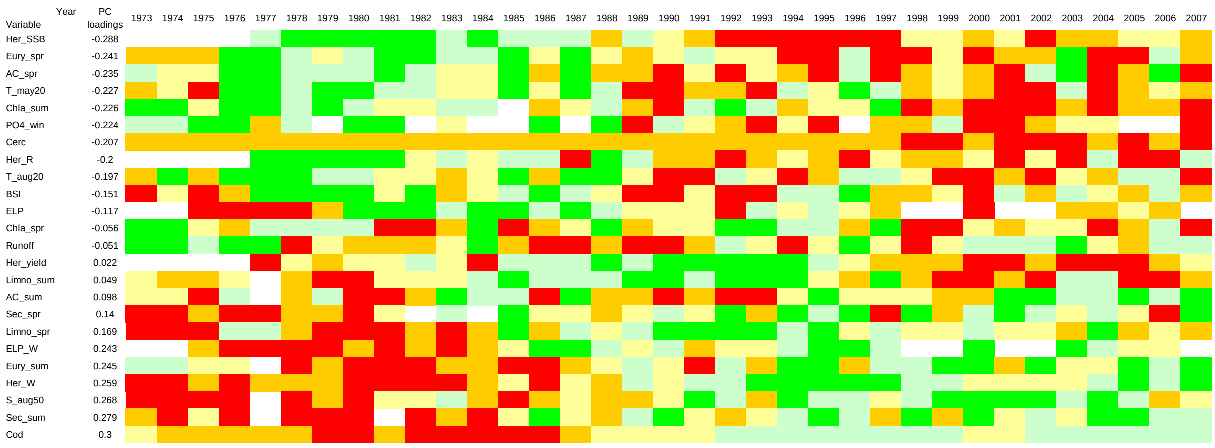


Figure 4.2.2.1. Traffic light plot of the temporal development of the GoR time-series covering the years 1973–2007. Variables are transformed to quintiles, colour coded (green = low values; red = high values; white = missing values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names as in ICES (2008).

The Sum of Regime Shift Indices (RSI) calculated for each of the 24 single variables resulted in highest cumulative values in the years 1985, 1988, 1995 as well as in the last year of the time series, in 2007 (Figure 4.2.2.2). Due to the low number of explanatory variables shifts were mainly found for response variables. Between 1985 and 1988 highest RSI values were found for Herring (yield/SSB, SSB, weight-at-age 3). In 2007 an extremely high cumulative RSI value was calculated. However, this effect was almost exclusively caused by *Cercopagis pengoi* (RSI = 12.5), which had very high abundance in the 2007 summer samples.

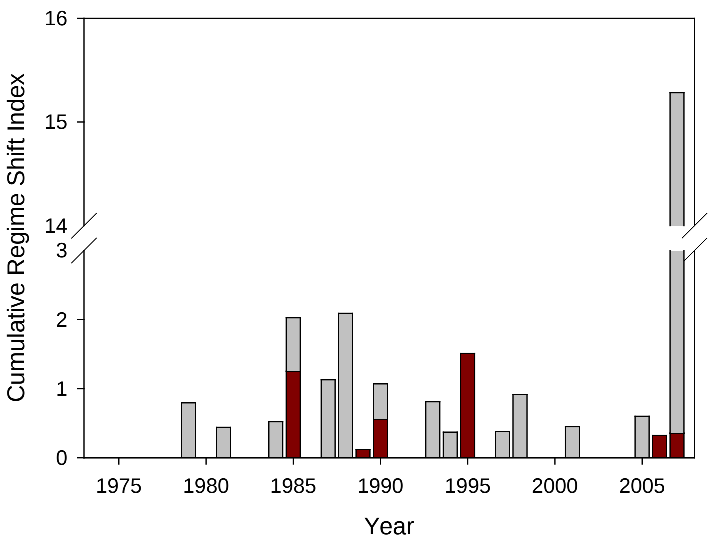


Figure 4.2.2.2. Sum of Regime Shift Indices (RSI) of 24 variables (7 driver (in red) and 17 response variables (in grey)) derived from STARS (α=0,05; cut-off length= 8; Huber parameter = 2, prewhitening with IP4).

The PCA of the full data series resulted in 36.0 and 13.8 % of explained variance on the first and second axis, respectively (Figure 4.2.2.3). The most pronounced shift could be detected in the second half of the 1980s where PC1 scores changed from 1988 to 1989 from positive to negative values. Since then there was no change back to positive PC1-scores, i.e. the ecosystem is currently in a different state than it was in the period from 1970s to 1980s. In contrast to the STARS results, the last year of the analysis in the multivariate sense did not differ much from previous years, i.e. it is currently not a change in the system but in one single variable, the dispersal of an invading species (*C. pengoi*). On the second axis biggest differences between consecutive years were observed in the period from 1994–1996. STARS applied on PC1- and PC2-scores located shifts in 1985–1986, and 1994/1995. In contrast to this, Chronological Clustering, taking all variables into account, locates the shifts slightly later, namely in 1988/1989 and 1997/1998 (α=0.01). The relative changes of the variables over time and in relation to the observed ecosystem shifts can be derived from the factor loadings on the first two principal components (not graphically displayed). Generally, these three time periods are characterised by:

- cold, saline conditions (1973–1988),
- extremely high runoff and nutrient loads, as well as low fishing pressure on herring in the intermediate period (1989–1997),
- by low salinity, high temperature, high summer phytoplankton production, and high herring SSB, resulting in a temperature driven increase in spring zooplankton biomass and a decline in summer due to the high herring predation pressure (1998–2007).

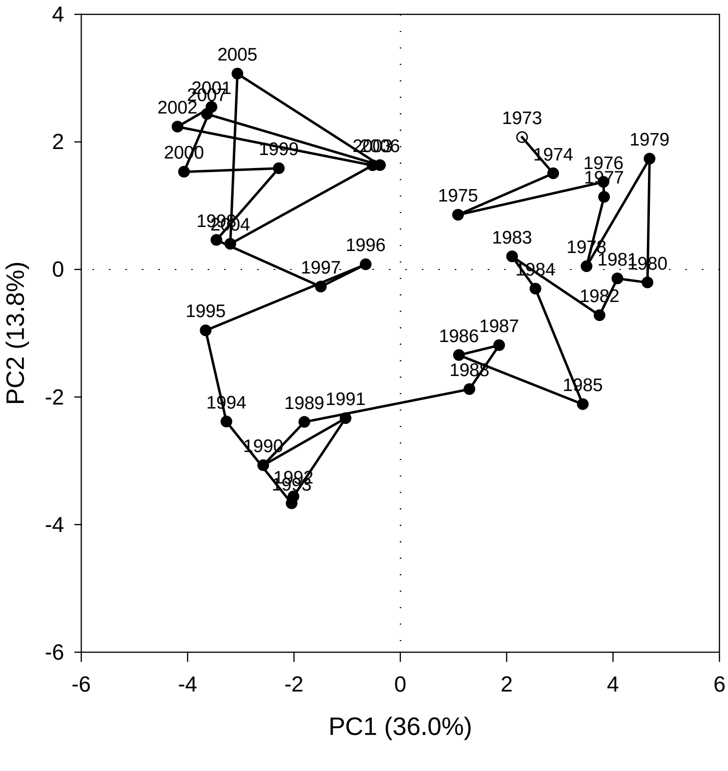


Figure 4.2.2.3. Time trajectory of principal components (PC) 1 and 2 of the full dataset (24 variables), based on the correlation matrix.

4.2.3 Gulf of Finland

The GoF is directly connected to the Baltic Proper, without any sill. Therefore, any fluctuations in deep water of the Baltic Proper are immediately detectable at the GoF. Deep, stagnated water easily enters the Gulf, with consequences on salinity and oxygen conditions. Hence, considerable fluctuations in deep layer oxygen content and the internal loading of phosphate are common.

IEAs were performed for a time-period from 1979–2008. Altogether, 30 variables from several fish-, phyto- and zooplankton-, nutrient-, and physical-related datasets were considered. An overview of the temporal changes of all time series is presented in Figure 4.2.3.1. Variables are sorted according to their PC1 loadings of the subsequently performed PCA generating a pattern with variables at the top showing an increasing trend over time (green-red) and variables at the bottom showing the opposite trend (red-green). In contrast to the other systems no clear break is visible, i.e. only few variables show synchronous shifts. The most pronounced increasing trend was observed for sprat catch and phosphate loadings in spring and summer, whereas the opposite decreasing trend was found for Herring SSB and catch, sprat weight-at-age 3, and upper layer salinity in August.

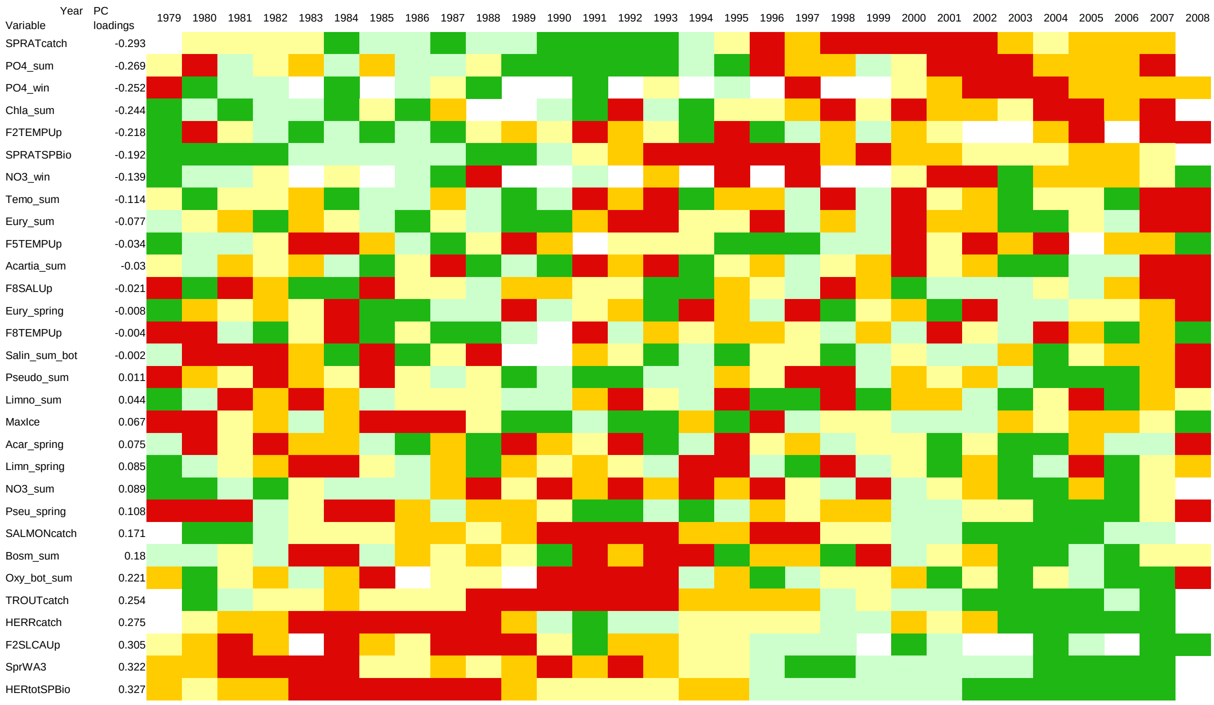


Figure 4.2.3.1. Traffic light plot of the temporal development of GoF time series covering the years 1979–2008. Variables are transformed to quintiles, colour coded (green = low values; red = high values, white = missing values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names as in ICES (2008).

The Sum of Regime Shift Indices (RSI) calculated for each of the 30 single variables resulted in highest cumulative values in the late 1980s, the mid-1990s and especially in the last two years of the dataset, in 2007 and 2008 (Figure 4.2.3.2). Most variables showing a significant RSI were explanatory and not response variables with the exception of the more recent years: In 2007 extremely high RSI values were found for *Temora longicornis*, *Acartia* spp. and *Eurytemora affinis* biomass in summer. In that year biomass estimates were 8 to 13 times higher as the average of previous years.

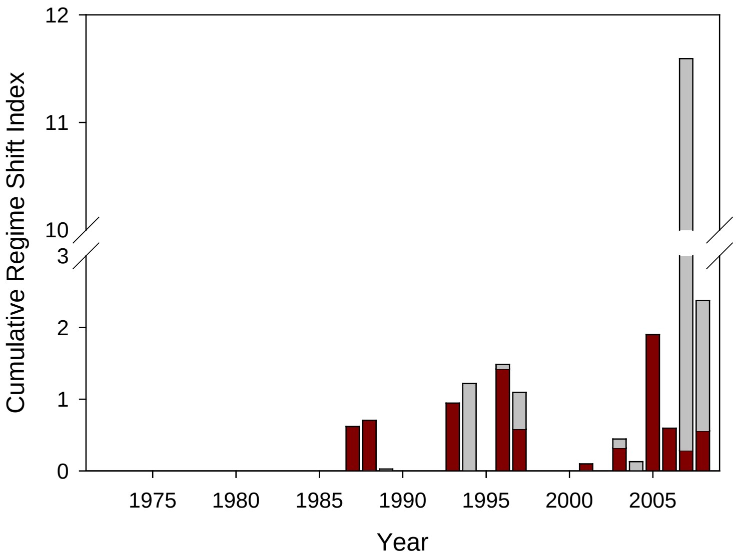


Figure 4.2.3.2. Sum of Regime Shift Indices (RSI) of 30 variables (12 driver (in red) and 18 response variables (in grey)) derived from STARS (α=0,05; cut-off length= 8; Huber parameter = 2, prewhitening with IP4).

The PCA of the full data series resulted in 26.7 and 17.2 % of explained variance on the first and second axis, respectively (Figure 4.2.3.3). The most pronounced shift on the first axis was detected during 1994–1996 when PC1 scores changed from positive to negative values where they have remained since then. On the second axis biggest differences between consecutive years were observed in the early 1980s and after 2002 when the system became very variable. STARS applied on PC1- and PC2-scores located three shifts in 1991, 1995, and 2007. In contrast to this, the time of the shift was different when applying Chronological Clustering: For α=0.01 shifts were identified in 1988/1989, 1995/1996, and 2002/2003.

The relative changes of the variables over time and in relation to the observed ecosystem shifts can be derived from the factor loadings on the first two principal components (not graphically displayed). Variables highly correlated to PC1 are the same as the ones placed at the top (negatively correlated) or the bottom (positively correlated) of the traffic light plot. This means that the years before 1995 were generally characterised by high Herring SSB and catch, sprat weight-at-age 3 and upper layer salinity in August, whereas the more recent period is characterised by high sprat catches and high phosphate loadings in summer and winter. The second axis shows a high positive correlation to temperature metrics, biomass of various zooplankton species and nitrate loadings. In contrast to this *Pseudocalanus* spp. biomass and the extent of maximum ice coverage are negatively correlated to PC2 and were thus characteristic of the early 1980s and the years 2003 and 2006.

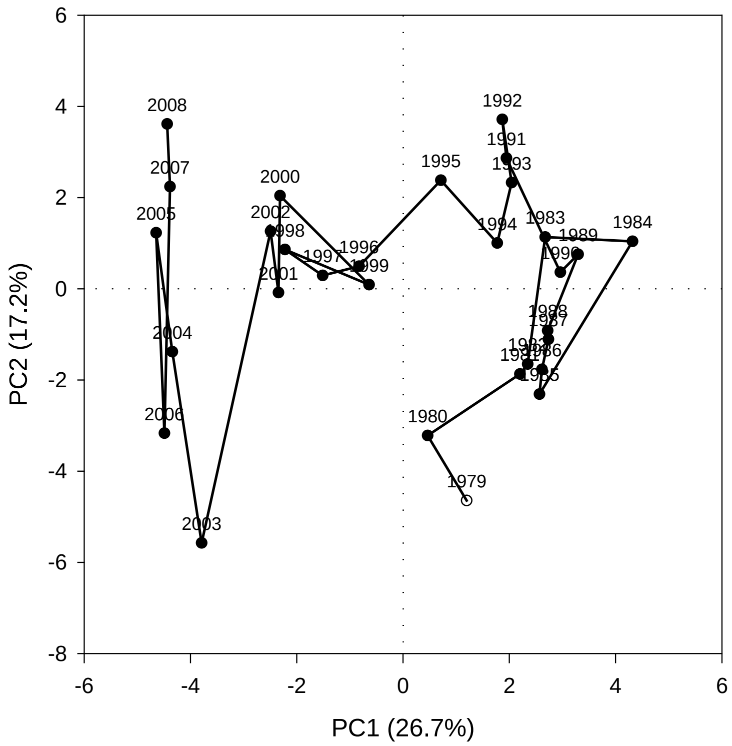


Figure 4.2.3.3. Time trajectory of principal components (PC) 1 and 2 of the full dataset (30 variables), based on the correlation matrix.

In conclusion, the GoF follows the CBS rather closely in terms of salinity and deep-water oxygen deficiency. However, during extended periods of stagnation, when saline water intrusions into the Baltic do not occur, stratification in the Gulf dissolves. During such periods, as in 1979–1993, deep areas become well oxygenated, which could be observed as thriving benthic communities (Laine *et al.*, 2007). This was beneficial for the entire GoF foodweb. The strong inflow event in 1993 possibly caused one of the shifts observed in 1995, as CBS deep water again entered the GoF, recreating deep-water stratification. Indeed, intensity of saline water inflows seems to be a distinct driver of the system. However, the effects of nutrient loading from drainage basin, as well as internal loading seem to be similarly important.

4.2.4 Coastal site off Sweden

The coastal area of Kvädöfjärden in the northern Baltic Proper is an archipelago area generally considered to be of good environmental quality, without major local anthropogenic influences. The surrounding land area is not densely populated and the level of local fishing pressure is assumed to be low. However, water clarity has decreased in the past decades, indicating that the area is affected by large-scale eutrophication. Data for some biological variables are available since the early 1960s and all currently monitored variables are represented since 1989.

The updated IEA was carried out on the longer data set dating from 1971 until 2008 taking 18 variables into account (5 fish, 5 benthic variables, seals, secchi depth, nutrient loads and 4 physical metrics).

An overview of the temporal changes of all time series is presented in Figure 4.2.4.1. Variables are sorted according to their PC1 loadings of the subsequently performed PCA generating a pattern with variables at the top showing a decreasing trend over time (red-green, e.g. salinity metrics, cod abundance and secchi depth) and variables at the bottom showing the opposite trend (green-red, e.g. perch, *Macoma baltica*, *Marenzelleria viridis* and seals). The change from high to low or vice versa is most pronounced in the late 1980s.

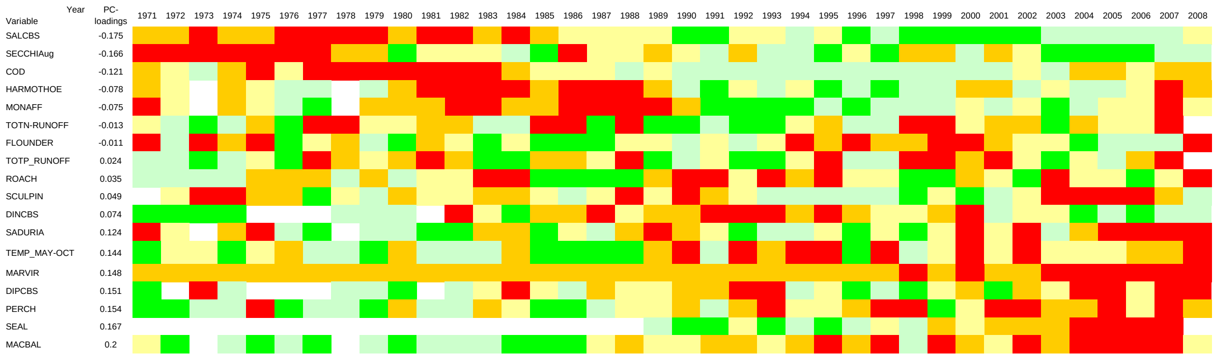


Figure 4.2.4.1. Traffic light plot of the temporal development of "Coastal" time series covering the years 1971–2008. Variables were transformed to quintiles, colour coded (green = low values; red = high values, white = missing values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names as in ICES (2008).

The Sum of Regime Shift Indices (RSI) calculated for each of the 18 single variables resulted in highest cumulative values throughout the 1980s, and in the most recent period from 2002 until 2008 (Figure 4.2.4.2). Strongest changes for abiotic drivers were found in 1986 and 2008 (open water salinity), and in 1981 and 2004 (nutrient loadings). Other variables showing a significant RSI were predominantly response variables. In recent years the RSI values were strongly influenced by the new invading species *Marenzelleria viridis* and the strong increase of the seal population.

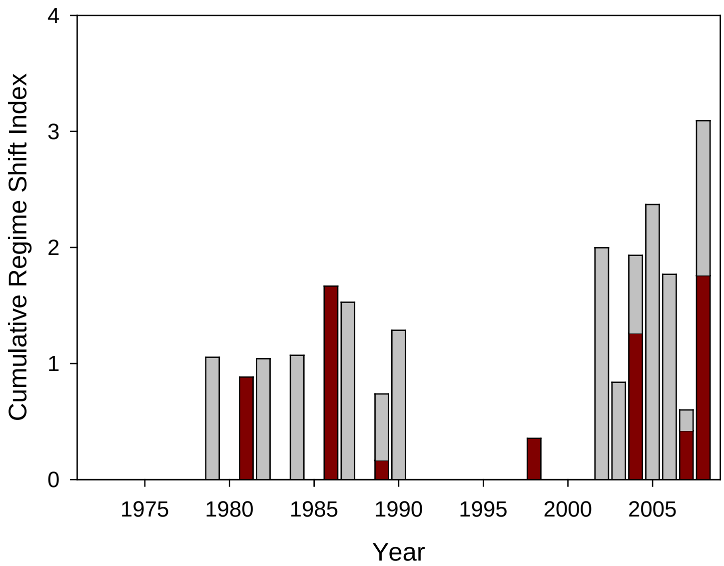


Figure 4.2.4.2. Sum of Regime Shift Indices (RSI) of 18 variables (6 driver (in red) and 12 response variables (in grey)) derived from STARS (α=0,05; cut-off length= 8; Huber parameter = 2, prewhitening with IP4).

The PCA of the full data series resulted in 26.7 and 16.7 % of explained variance on the first and second axis, respectively (Figure 4.2.4.3). Although the first year of the time series seems to be different in its ecosystem structure the following period until 1988 was rather stable and no major year-to-year changes could be observed. Then, strong changes occurred in the following years until 1991 when another comparatively stable state was reached. Since 2000 the systems turned out to be rather variable with strong changes along the second PC-axis.

STARS applied on PC1- and PC2-scores located three shifts in 1987, 1991, and 2002. This result is largely comparable to the outcome of Chronological Clustering: For α=0.01 shifts were identified in 1988/1989, 1997/1998, and 2002/2003.

The relative changes of the variables over time and in relation to the observed ecosystem shifts can be derived from the factor loadings on the first two principal components (not graphically displayed). The initial period was characterised by comparatively high salinities and secchi depths and low temperatures and low abundance of *Macoma baltica*. Then the system developed a state with increased nitrate loadings in open waters and consequently decreasing water transparency. The pronounced changes since the turn of the millennium is mainly driven by the increase in seal population, and in the invading species *Marenzelleria viridis.* Also, the soft-bottom benthic species *Saduria entomon*, has increased in abundance especially in the last two years. All variables showed high positive loadings on both, PC1 and PC2.

In summary, the most significant regime shift was observed in 1988 and was clearly associated with a decrease in salinity and an increase in temperature. The shift was also associated with changes in the soft bottom evertebrate community, by a reduced abundance of *Monoporeia affinis* and *Harmothoe sarsi* and an increased abundance of *Macoma baltica*. Furthermore, cod was virtually absent from the system in the 1990s. Overall, eutrophication has increased over the whole investigated period, as evident from a decreasing secchi depth, a decreasing *Fucus* depth distribution (not included in the IEA of longer time series data) and increases in nutrient levels. In recent years, mainly the strong increase of the grey seal population and the introduced species *Marenzelleria viridis* indicate a new shift in the first half of the 2000s.

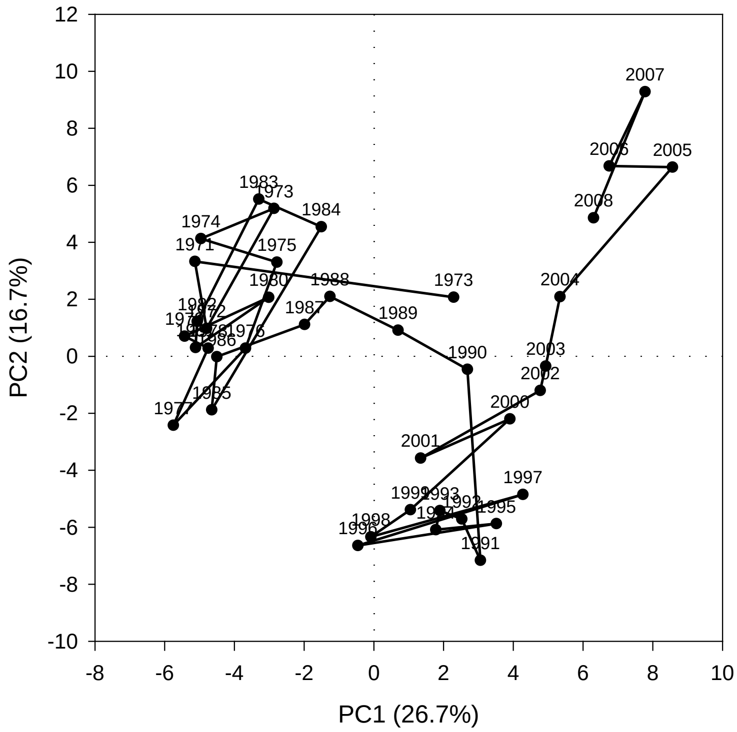


Figure 4.2.4.3. Time trajectory of principal components (PC) 1 and 2 of the full dataset (18 variables), based on the correlation matrix.

4.2.5 Regime shift identification – a comparison between systems

Regime shifts were identified with different methods each giving slightly different results and therefore require special interpretation. To compare the time of regime shifts between systems as well as between last year IEAs and the updated assessments, we used the result of Chronological Clustering (Legendre 1985). For this all data series were standardised and the Euclidean Distance function was calculated to determine similarity between years. The significance level α (=clustering intensity parameter) was set to 0.01 for all systems and the connectedness level to 50%.

Recapitulating last year results (time series ending in 2006), all seven subsystems displayed pronounced structural changes in the last two to three decades, related to climate, fisheries and eutrophication (Table 4.2.5.1). Regime shifts were identified in all multivariate datasets. The major period of reorganisation in all Baltic systems was at the end of the 1980s (between 1987 and 1989), when the strongest and most persistent changes were observed. Although the main drivers of this change were different between subsystems, sudden increases in temperature and decreases in salinity were observed throughout. Both these variables are influenced by large-scale atmospheric processes illustrated by the Baltic Sea Index (BSI), a regional homologue to the North Atlantic Oscillation index (NAO) (Lehmann *et al.*, 2002). The change from a generally negative to a positive BSI in the late 1980s was associated with more frequent westerly winds, warmer winter and eventually a warmer climate over the area. Further, the absence of major inflow events has been hypothesized to be related to the high NAO period (Hänninen *et al.*, 2000). An indication of this is that only two major inflows to the Baltic Sea have been recorded during the high BSI-period since the late 1980s.

Several regions underwent a structural change also during the middle of 1990s, probably related to the major inflow in 1993. Further, indications exist that a recent shift in ecosystem organisation occurred in the Gulf of Finland and at the Swedish coast. These results called for a revision as soon as more recent data become available and therefore was resumed during this year's meeting.

Table 4.2.5.1. Summary of regime shifts detected in the seven ecosystems investigated during the WGIAB meeting in 2008. Regime shifts were identified from the whole data set for each ecosystem using chronological clustering (with α=0.01).

Time-period	**The Sound** 1979–2005	**Central Baltic Sea** 1974-2006*	**Swedish Coast** 1971-2006	**Gulf of Riga** 1973-2006	**Bothnian Sea** 1979–2006	**Bothnian Bay** 1979–2006	**Gulf of Finland** 1979-2007
A			1976/77		1982/83		
B	1987/88	1987/88	1987/88	1988/89	1988/89	1987/88	1988/89
C	1995/96	1994/95		1997/98		1993/94	1995/96
D			2004/05				2002/03

*incl. Cod RV

At the current meeting, data series of four systems (i.e. CBS, GoR, GOF and COAST) were updated until 2007 or 2008. The same set of variables was included in the analyses, with the exception of the "reproductive volume for cod" that was no longer considered for the analysis of the Central Baltic Sea, as it was highly cross correlated to deep-water oxygen content. Furthermore, data extracted from fisheries assessment naturally deviate slightly for the more recent years from the estimations made in previous assessments.

The major shift identified at the end of the 1980s was unaffected by the new analytical runs. The same holds for all other shifts identified for the Gulf of Riga and the Gulf of Finland. However, the analysis of the Central Baltic Sea and the Swedish coast datasets gave slightly different results. In the Central Baltic Sea the shift in the mid-1990s is no longer detectable, whereas a reorganisation of the system is already indicated in the first half of the 1980s. This earlier shift does not persist if the dataset is shortened, i.e. the time-series do not start in 1974 but in 1979. Because of missing phytoplankton data from 1974–1978 and the necessary exchange of missing values with the averages of the four nearest data points, the outcome of the first analysis is definitely influenced, and this can indirectly cause a shift in the multivariate dataset. Surprisingly the shift in the mid-1990s becomes again identifiably in this additional run, indicating that there was a change in the ecosystem, although it was rather weak compared to the synchronous shifts in 1987–1989.

The results of the previous and updated analysis of the Swedish coast dataset did also differ: The first shift in 1976–1977 is no longer detectable. Furthermore, an additional shift is identified in the late 1990s.

The most important outcome of the updated analyses is that no new recent shifts were identified for the Central Baltic Sea and the Gulf of Riga, whereas the sudden changes in 2002–2003 were confirmed for the Gulf of Finland and the Swedish coast. However for the latter system the time of the shift is dated slightly earlier for the updated analysis than it was done before (2004/2005).

Table 4.2.5.2. Summary of regime shifts detected in four ecosystems, for which data series were updated during the WGIAB meeting in 2009. Regime shifts were identified from the whole data set for each ecosystem using chronological clustering (with α=0.01). Differences in the time of regime shifts in comparison to last year's results are indicated by italics, no longer existing shifts are indicated by a slash.

Time-period	Central Baltic Sea		Swedish Coast	Gulf of Riga	Gulf of Finland
	1974-2007	1979-2007	1971-2008	1973-2007	1979-2008
A	*1984/85*		-		
B	1987/88	1987/88	1988/89	1988/89	1988/89
C	-	1993/94	*1997/98*	1997/98	1995/96
D			*2002/03*		2002/03

5 Contribution to Baltic Sea Action Plan and HELCOM BIO (ToR b)

In the Baltic Sea Action Plan (BSAP) the environmental ministers of all countries surrounding the Baltic Sea have committed to target levels of reductions in input of nitrogen and phosphorus to the Baltic Sea. The basis for these reductions is the overarching goal of achieving an environmental status of the Baltic Sea characterised by a water transparency (secchi depth) of the 1950ies. The Baltic Nest Model has been used to derive the maximum allowable nutrient input that corresponds to this secchi depth, and the reductions in nutrient input from the average levels in 1997–2003 necessary to achieve this maximum allowable input will be calculated. However, these target reductions in nutrients presented in the BSAP were only preliminary. They are to be revised during 2009, following updated calculations by the Baltic Nest Institute. The WGIAB therefore decided to postpone the evaluation of target nutrient levels of the BSAP until revised target levels have been adopted.

The HELCOM project HELCOM-BIO has during 2006–2008 performed a biodiversity assessment of the Baltic Sea. To this end an indicator system, known as BEAT, has been developed, and a number of examples of its application have been compiled within the project. The final report of the project had not been approved by HELCOM in time for this meeting, but is expected during 2009. However, according to the draft HELCOM-BIO report "the overall aim…is mainly to initiate a discussion on the role and functions of assessments based on marine biodiversity indicators in HELCOM work. The aim is not to conclude on a matured method and definite assessment." This also becomes evident in the only basin-wide assessment made, of the Baltic roper subbasin. This involves two indicators at the landscape level (anoxic seabed area, wild salmon rivers), six community indicators out of which five are number of zoobenthos taxa and one is number of threatened biotopes, and five species indicators (number of white tailed eagles, number of established alien species after 1950, Eastern Baltic cod SSB, number of threatened and declining species according to the HELCOM red list, rate of increase in common seal). Thus, there is a striking lack of zooplankton and fish indicators. Because of its premature state, WGIAB decided to not evaluate BEAT at the level of each indicator. However, for the future development of BEAT and other indicator based biodiversity assessments some general remarks can be made:

- The set of indicators used need to well represent trophic levels as well as functions in the assessed ecosystems

- Reference levels and acceptable deviations must be clearly defined, based on the goals of management
- Indicators of biodiversity need to account both for species richness (number of species) and evenness (relative abundance of species), as well as the richness and evenness of ecosystem functions (e.g. ecological guilds).

6 Review and coordinate the research on ecosystem analysis and modelling between different projects and activities in the Baltic Sea (ToR c)

As described in Chapter 3, WGIAB is intended as a forum for developing and combining ecosystem-based management efforts for the Baltic Sea. Hence, the group tries to link as much as possible between existing projects and activities on ecosystem analysis and modelling in the Baltic region. During the 2009 meeting the focus of this coordination and information effort was on newly started BONUS+ projects (i.e. ECOSUPPORT & AMBER; see below). Furthermore bioeconomic modelling was discussed which may augment the activities of WGIAB in the future. Finally, a presently evaluated network proposal to the European Science Foundation, developed by members of WGIAB, is presented.

6.1 Economic-ecological modelling for sustainable fisheries management in the Baltic (Rudi Voss)

Integrated assessment might benefit from including social and/or economic viewpoints. Especially sustainable fisheries management, as a subarea of integrated assessment, will have to account for economic aspects, if it is supposed to be successful in the long run. Including general economic aspects like e.g. costs of fishing or discounting, might change management goals considerably.

In 2008 a multidisciplinary working group was established at the University of Kiel, Germany dealing with environmental, resource and ecological economics. The group has a special focus on sustainable fisheries management in the Baltic. It is comprised of educated economists, landscape ecologists and fisheries biologists. Out of this group, Jörn Schmidt and Rüdiger Voss attended the WGIAB meeting, among others to present recent, potentially relevant, ongoing bioeconomic modelling activities and to stimulate future collaboration.

Themes addressed in the presentation: Consumer preference for diversity and economic multispecies interaction can have profound consequences for management strategies, even in absence of biological interactions: (a) Under open access depletion of one stock may result in a cascading collapse of other stocks, (b) the need for regulation is the higher the stronger the consumer preferences for diversity and (c) regulation of one species ignoring the economic feedbacks on other species may induce overregulation of that species and depletion of other stocks not being depleted under full open access. In another example, it could be shown that optimal (economic) management changes, if there is a value for biodiversity considered. An alternative viewpoint towards fisheries management can be obtained by a modelling approach towards socially sustainable fishery, as defined by e.g. a steady increase in fisherman's capital of a prespecified rate. Stock recovery paths will change accordingly and time needed to reach a certain target biomass can be calculated. A highly idealized economic-ecological modelling study revealed the possibility of multiple steady states, each having a basin of attraction (i.e. resilience) without necessarily leaving the sustainability criteria. These have, however, to be agreed by society.

Two further projects aim at improving realism of bioeconomic models. (a) Uncertainty in the biological production function (i.e. stock–recruitment relationship) shall be estimated and explicitly incorporated in the economic modelling component. As a case study, the eastern Baltic cod stock is envisaged. (b) for realistic, management oriented work, age-structured models will be used. These allow for more biological realism and are rather easy coupled to standard assessment model (e.g. VPA, SMS). However, such models are hard to solve analytically, and hinder full interpretation of results. A reduced model with 3 age classes is presently developed for Baltic cod, a full model (8 age classes) shall be run in collaboration with Olli Tahvonen (Finland), who developed and analyzed general model behaviour with encouraging results.

Future work on multispecies optimization in the Baltic is planned under the EU project FACTS (under review), as well as spatially resolved modelling within the frame of ISIS fish.

6.2 EU BONUS Project ECOSUPPORT "Advanced modelling tool for scenarios of the Baltic Sea ECOsystem to SUPPORT decision making"

Coordinator: Markus Meier (SMHI)

6.2.1 Concept, objectives and expected outcome of the project

The main aim is to provide a multimodel system tool to support decision makers. The tool is based upon scenarios from an existing state-of-the-art coupled atmosphere-ice-ocean-land surface model for the BS catchment area, marine physical-biogeochemical models of differing complexity, a foodweb model, statistical fish population models, economic calculations, and new data detailing climate effects on marine biota.

Our concept to achieve the above aim is built on the confidence of the models' capacity to simulate changing climate and includes several steps: (i) assessing the predictive skills of the models by comparing observed and simulated past climate variability (i.e. quantification of model uncertainties) and analyzing causes of observed variations; (ii) performing multimodel ensemble simulations of the marine ecosystem for 1850–2100 forced by reconstructions of past climate and by various future greenhouse gas emission and air- and river borne nutrient load scenarios (ranging from a pessimistic business-as-usual to the most optimistic case); (iii) analyzing projections of the future BS ecosystem using a probabilistic approach accounting for uncertainties caused by biases of regional and global climate models (RCMs and GCMs), lack of process description in state-of-the-art ecosystem models, unknown greenhouse gas emissions and nutrient loadings, and natural variability; (iv) assessing impacts of climate change on the marine biota (e.g. effects of ocean acidification), biodiversity and fish populations (with focus on cod, sprat and herring); (v) calculating the costs of climate change; (vi) generating a free access data base of scenario model results and tools to access the database; and (vii) disseminating the project results to stakeholders, decision makers (e.g. via the Helsinki Commission - HELCOM) and the public (webpage, newsletters, seminars, conferences, etc.).

The objectives are to:

- calculate the combined effects of changing climate and changing human activity (nutrient load reductions [runoff and airborne], coastal management, fisheries) on the BS ecosystem,
- assess the resulting socioeconomic impacts,
- perform time-dependent scenario simulations from present climate until 2100, and quantify the uncertainties around these future projections,

- support decision makers and stakeholders with a tool providing them with relevant and readily accessible information that will help to raise wider public awareness,
- conduct focused assessments of local scale impacts of changing climate on coastal areas (with focus on the Gulf of Finland, Vistula Lagoon, and the Polish coastal waters).

The expected outcome is an advanced modelling tool for scenario simulations of the whole marine ecosystem that can underpin and inform management strategies to ensure water quality standards, biodiversity and fish stocks.

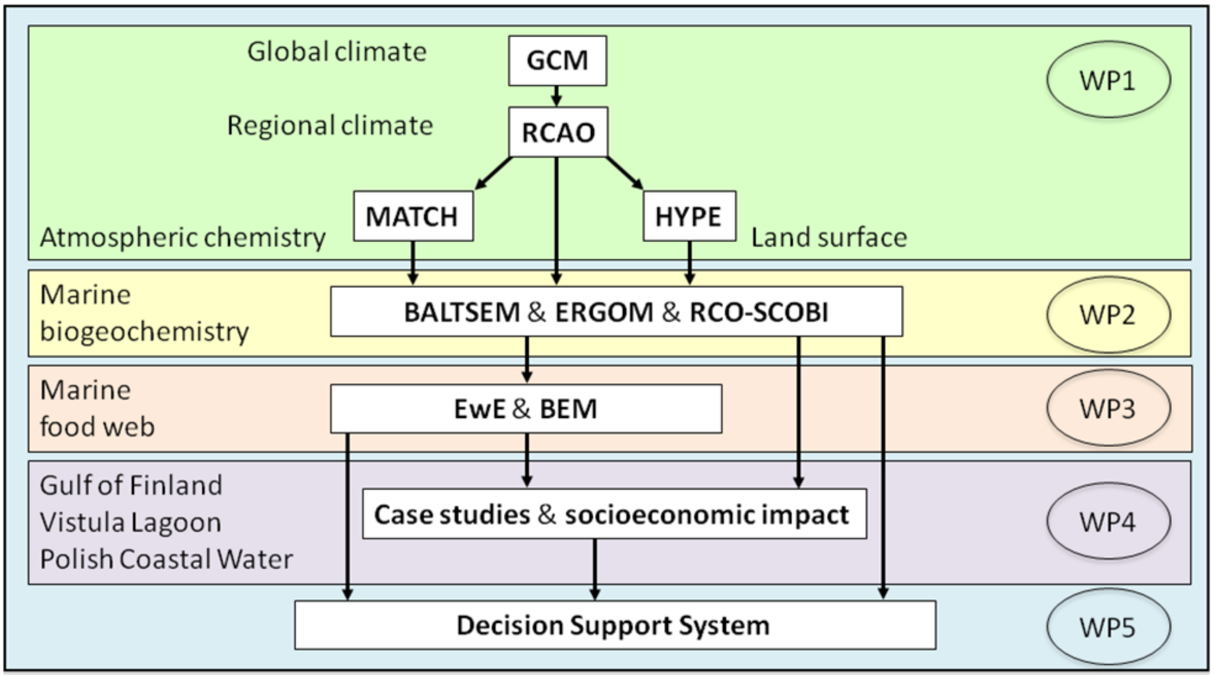


Figure 6.2.1: Model hierarchy in ECOSUPPORT and work package structure (see Section 11). The schematic is highly simplified neglecting complex interactions (e.g. fish predation pressure on zooplankton, changing society/policy affects climate and nutrient load scenarios).

6.2.2 ECOSUPPORT partner institutes and associated members:

Partner number	Principal Scientist	Institute	Acronym	Country
1	Markus Meier	Swedish Meteorological and Hydrological Institute	SMHI	Sweden
2	Thorsten Blenckner	Baltic Nest Institute, Resilience Centre, Stockholm University	BNI	Sweden
3	Boris Chubarenko	Atlantic Branch of P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences	ABIORAS	Russia
4	Jonathan Havenhand	Tjärnö Marine Biological Laboratory, Göteborg University	TMBL	Sweden

5	Brian MacKenzie	Technical University of Denmark, National Institute for Aquatic Resources	DTU-Aqua	Denmark
6	Thomas Neumann	Baltic Sea Research Institute Warnemünde	IOW	Germany
7	Jan-Marcin Weslawski	Institute of Oceanology Polish Academy of Sciences	IOPAS	Poland
8	Urmas Raudsepp	Marine Systems Institute at Tallinn University of Technology	MSI	Estonia
9	Tuija Ruoho-Airola	Finnish Meteorological Institute	FMI	Finland
10	Eduardo Zorita	GKSS-Research Centre Geesthacht GmbH	GKSS	Germany
11	Björn-Ola Linnér	Center for Climate Science and Policy Research, Linköping University	CSPR	Sweden
"Associated" partner	Anna Gårdmark	Swedish Board of Fisheries, Øregund	SBF	Sweden

6.3 EU BONUS Project AMBER "Assessment and Modelling Baltic Ecosystem Response"

Coordinator: Joachim Dippner (IOW)

6.3.1 Concept, Objectives and expected outcome of the project

The general aim of AMBER is the implementation and application of the Ecosystem Approach to Management (EAM) to the Baltic Sea in the face of two closely intertwined environmental threats, eutrophication and climate change. Focus is on the coastal ecosystem (CE) because it supports most of the 85 mi inhabitants of nine nations around the Baltic Sea catchment. The CE receives most human derived nutrient loads from rivers, submarine ground water discharge (SGD), atmospheric deposition, and point sources and links the land with the open Baltic Sea. The CE controls the biogeochemical transformations of P-, N- compounds (phosphate, nitrate, DON, etc.) through the close coupling between water and sediments. Furthermore, it is crucial for fish as reproduction area, nursery and grazing ground and tightly connected to the open Baltic Sea. For an optimal integrated management and for the implementation and application of EAM concepts on the CE is it necessary to study in a holistic approach the link between the catchment (including groundwater) and the open Baltic Sea and how climate change will affect the river water constituents and the biogeochemistry of the coastal waters and sediments. Unfortunately it is difficult to separate the signals of climate change from the direct impact of human activity. To understand and manage the future development of CE, the separation of these signals is necessary. Hence, one of the first steps of AMBER is the separation of climate from anthropogenic signals by means of a combinatorial variation in model's boundary conditions using the output of existing regional climate change scenarios and the output of a watershed model simulating changes in land use.

To implement the EAM concept successfully requires the best available scientific information as a basis for integrated management. Therefore, retrospective analyses on long-term data sets, intensive modelling with different types of models and selected measurements of biogeochemical transformation processes in the coastal water and the groundwater will be applied and integrated on the "Research Level"

(Figure 6.3.1.1). In a second step AMBER will apply models for future projections. To reduce the problem of model uncertainties, the ensemble method will be applied. The resulting projections are milestones for the development of EAM tools in the policy and advisory level.

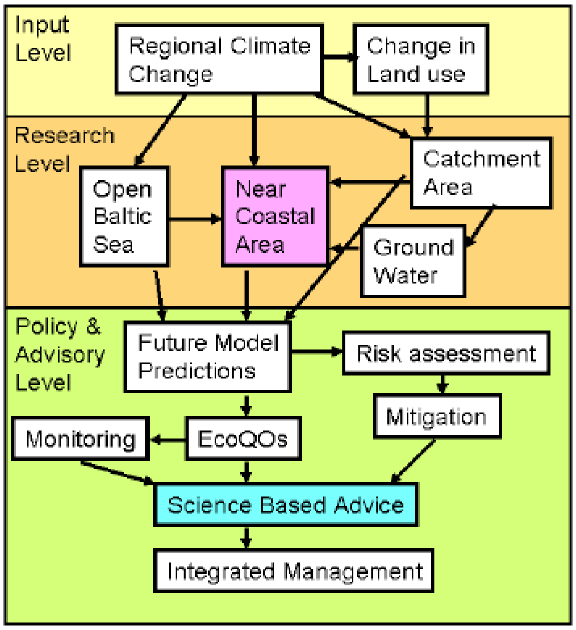


Figure 6.3.1.1. Flowchart of AMBER

The most important goals of AMBER are: a) Qualitative risk assessments for various climate change scenarios/ land uses/ life style change scenarios. From the risk assessment b) mitigation strategies will be derived which are necessary tools for integrated management. AMBER will derive c) Ecological Quality Objectives (EcoQOs) for the application of EAM following the guidance of ICES (2005). EcoQOs are a basis for d) the development of indicators, limits and targets. These quantitatively describe ecosystem state, ecosystem properties or impacts. Finally, cost effective indicators will be developed to improve monitoring strategies and to guide environmental management in decision making. EAM with its tools risk assessment, mitigation strategies, derivation of EcoQOs and improvement of monitoring strategies will be the core of science based advice for integrated management.

6.3.2 AMBER List of Principal Scientists:

1) Dr. Horst Behrendt, Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Berlin, Germany;
2) Prof. Dr. Michael E. Böttcher, Leibniz Institute for Baltic Sea Research Warnemünde (IOW), Germany;
3) Dr. Susanna Hietanen, Department of Biological and Environmental Sciences, University of Helsinki (UH), Finland;
4) Dr. Christoph Humborg, Department of Applied Environmental Science, University Stockholm (ITM), Sweden;
5) Dr. Markus Meier, Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden;

6) Prof. Dr. Christian Möllmann, Institute for Hydrobiology and Fisheries Research (IHF), University Hamburg, Germany;

7) Dr. Arturas Razinkovas, Coastal Research and Planning Institute, University of Kleipeda (CORPI), Lithuania;

8) PD Dr. Gerald Schernewski, Leibniz Institute for Baltic Sea Research Warnemünde (IOW), Germany;

9) PD Dr. Maren Voss, Leibniz Institute for Baltic Sea Research Warnemünde (IOW), Germany;

10) Dr. Ilppo Vuorinen, Archipelago Research Institute, University Turku (ARI), Finland;

11) Prof. Dr. Jan-Marcin Weslawski, Institute of Oceanography Polish Academy of Science (IOPAS), Sopot, Poland.

6.4 ESF Network Proposal ECOSHIFT "Regime shifts in marine ecosystems – a large-scale comparative approach to develop the basis for an ecosystem-based management of marine resources"

6.4.1 Summary of the proposal

Regime shifts are commonly defined as abrupt changes between contrasting persisting states of any complex system. In ecology these events which involve large-scale reorganizations in the structure and function of the biological components have been detected in terrestrial, freshwater and marine environments. Regime shifts can cause large-scale losses of ecosystem services with severe consequences for human well-being. Recently regime shifts were documented for various marine ecosystems, and many of those occurred quasi-simultaneously raising the question about global scale environmental forcing. However, these events are probably the result of a multitude of factors operating in various ways, including climatic and anthropogenic forces as well as internal dynamics. So far the analysis of ecosystem changes and their major drivers and mechanisms often remained inconclusive due to the fragmentary data basis and the lack of interdisciplinary knowledge. Thus, there is a strong need for comparative studies of ecosystem dynamics, contrasting systems experiencing similar external forcing and/or having a comparable ecosystem structure with each other. By per-forming an in-depth analysis of synchronies between major ecological changes in European and worldwide marine ecosystems, direct and indirect effects of climatic and anthropogenic drivers as well as mediator mechanisms can be identified and disentangled. The proposed network provides the unique opportunity to assemble institutes and research groups that provide the necessary expertise and comprehensive long-term data series to successfully conduct this large-scale comparative approach. The consortium will (1) test and suggest common and standardized methods to regime shift detection, (2) identify large-scale synchronies and regional expressions in regime shift patterns and their underlying causative agents and mechanisms, (3) develop commonly applicable early warning indicators of regime shifts, and (4) build the basis for an ecosystem based approach to management in order to prevent or reverse regime shifts or mitigate the effects of unfavourable changes.

6.4.2 Name and full coordinates of principal applicant(s) (up to three including the contact person):

1) Prof. Christian Möllmann, University of Hamburg, Institute for Hydrobiology and Fisheries Science (IHF), Grosse Elbstrasse 133, D-22767 Hamburg, Germany, Phone: +49 40 42838 6621, christian.moellmann@uni-hamburg.de

2) Prof. Nils Chr. Stenseth, Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biology, University of Oslo, P.O. Box 1066 Blindern, N-0316 Oslo, Norway, Phone: +47 22 85 45 84/44 00, n.c.stenseth@bio.uio.no
3) Prof. Philippe M. Cury, CRH - Centre de Recherche Halieutique Méditerranéenne et Tropicale, IRD - IFREMER & Université Montpellier II, Avenue Jean Monnet, BP 171, 34203 Sète Cedex, France; Phone +33 - 0- 4 99 57 32 34; pcury@ifremer.fr

In total circa 60 institutes from 25 countries are involved in the initiative.

7 Modelling (ToR d)

7.1 Introduction

WGIAB performed comparative analyses of a set of cod population dynamics and foodweb models using an approach that is known as "ensemble modelling" in climate research. In this approach the different models are forced with the same scenarios (e.g. of future climate development) and their projections are collected in an ensemble. Here we evaluated alternative fisheries management scenarios for cod and sprat under alternative scenarios of future climate change. The long-term aim of this work is to evaluate the potential use of different ecological models in fish stock assessment and management within the frame work of the Ecosystem Approach to Management of marine resources for the Baltic Sea. As a kickoff for future work WGIAB during the 2009 meeting agreed on the aims to (i) assess the uncertainty of projected responses of Eastern Baltic cod and the foodweb to differences in the modelling approach and model structure, as well as (ii) provide first general conclusions on the potential response of the cod stock and the ecosystem (incl. uncertainty ranges) to a set of fisheries management scenarios and a selected future climate change scenarios.

At this meeting, nine different models, four single species cod models, four multispecies models and one foodweb model were used to run five scenarios on fishing mortality of cod and sprat under two climate scenarios. Below follows a description of the scenarios and a brief overview of the models used and the results of this extensive modelling study. More detailed descriptions of the individual models can be found in Annex 7

NOTE OF CAUTION

The results presented here are preliminary and primarily intended for evaluating the "ensemble modelling approach". Hence, WGIAB does not consider these as final assessments of the future development of Baltic cod or the foodweb, nor as a final evaluation of fisheries management actions. Although WGIAB believes in the strength and potential of the modelling approach, the presented results and the models themselves require further investigation and specification before exploitable for management advice.

7.2 Fishing scenarios and climate forcing

The baseline data for the fisheries management scenarios were historical fishing mortalities for cod, herring, and sprat, as estimated by the ICES Study Group on Multispecies Assessment in the Baltic in their final Multispecies Virtual Population Analysis (MSVPA) run for the Baltic Proper excluding the Gulf of Riga (ICES 2006). The following fisheries management scenarios were considered in the modelling study:

1. "Business as usual" (BAU) – mean fishing mortalities of the last ten years (1996–2005) from above given MSVPA run (ICES 2006 (F_{cod}=1.08, F_{sprat}=0.36, and F_{herr}=0.34);
2. "Cod management plan target" (F_{cod}=0.3);
3. "Cod fishing ban" (F_{cod}=0);
4. "moderately intensified sprat fishing (F_{sprat}=0.6);
5. "strongly intensified sprat fishing (F_{sprat}=0.8).

The five fishing scenarios were combined with two climate scenarios, assuming 1) no change in climate, or 2) changes in temperature and salinity. The climate change scenario is based on International Panel on Climate Change (IPCC) emission scenario A2 and predicted using coupled regional atmospheric and hydrodynamic circulation models (BACC 2008, Meier 2006). These runs resulted in an increase in SST of 3.5 °C, which is an average projection, as well as a decrease in salinity of 0.8 psu until the period 2071–2100, which is the smallest change in salinity predicted by a number of scenarios and model setups (BACC 2008, Meier 2006).

The above described coupled atmospheric-hydrodynamic model runs represent so-called "time-slice experiments" which provide temperature and salinity changes between a reference and a future period (Meier 2006). Hence, no full time-trajectories of hydrodygraphic variables were available for model forcing. To overcome this, a time-series technique exploiting the autocorrelation pattern of the observed time-series was applied (Ripa & Lundberg 1996). Hence, time series of future temperature and salinity have been generated using the mean, variance and autocorrelation structure (AR1) of the historical time series, and in the case of the climate change scenario, a linear trend has been added to achieve the temperature and salinity values until 2100 (Figure 7.1). Finally, to account for uncertainty in the predictions, a random noise component, based on the variation observed in the period 1973–2005, has been added and five future time-series have been generated for each hydrographic variable of which the average has been used for model forcing. Note, that given the complexity and vast computational effort in running multiple replications for all model and scenarios, our future climate scenarios represent only a relatively narrow range of possible future SST and salinity time-series for the Baltic Sea. Assessing the full confidence envelope of future climate impact and management actions on the Baltic Sea foodweb was beyond the scope of this preliminary ensemble modelling exercise.

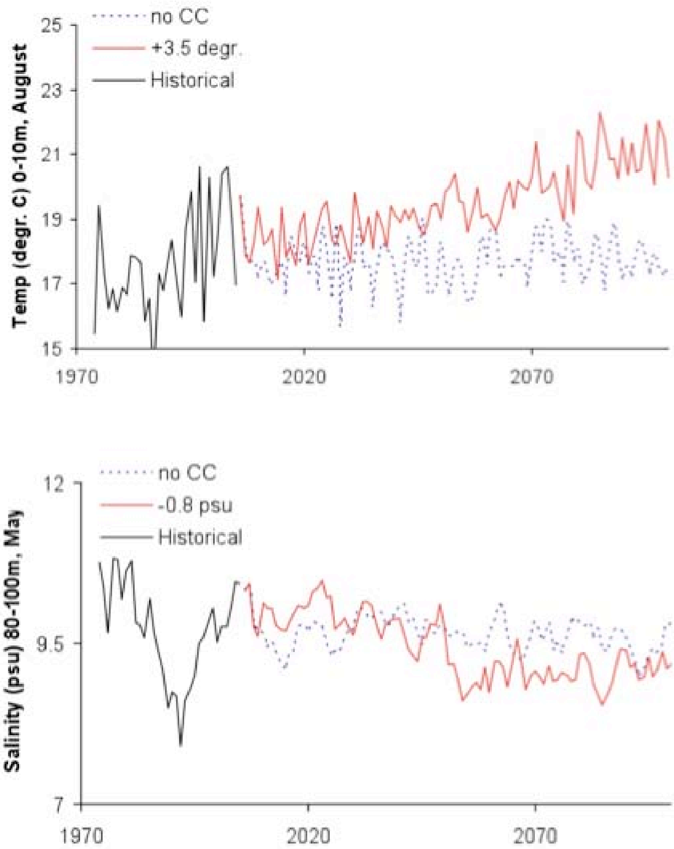


Figure 7.1. Climate forcing time series used in the modelling scenarios, (upper panel) mean temperature at 0–10m in August and (lower panel) salinity at 80–100m in the Gotland Deep in May.

Temperature and salinity have different effects on the species in the foodweb, and because of the different model setups, the climate forcing factors were differently implemented in the different models. In general, the August surface temperature was used as the forcing factor for sprat (following Baumann *et al*., 2006), and spring salinity in the Gotland basin (80–100m) for cod (c.f. Heikinheimo 2008; S. Neuenfeldt, DTU-Aqua, unpublished data), whereas no climate effects on herring were incorporated. Climate effects were included as an environmentally sensitive stock–recruitment (SSB-R) relationship for cod (see below) and a pure temperature-recruitment relationship for sprat (Baumann *et al*., 2006) (Table 7.1). In models lacking these recruitment relationships, salinity and temperature were directly used as forcing on biomass levels. Note that the projected temperature values in the climate change scenario, in contrast to the projected salinity values, go beyond the values observed in the "historical" time series, 1973–2005 (Figure 7.1). The impact of temperature forcing on the modelled species is therefore highly uncertain.

The basic model for the cod SSB-R relationship is given in Heikinheimo (2008), but has been modified according to the salinity data used for the climate change scenarios. The stock–recruitment relationship fits an exponential relationship to SSB and salinity data, accounting for approximately 80% in the observed variance in cod recruitment. However, the fitted relationship cannot account for a negative effect of cod SSB on recruitment at high levels of spawning stock biomass (S. Neuenfeldt, DTU-Aqua, unpublished data). In order to avoid potential unrealistically high numbers of cod at high salinities and SSB, a ceiling of 5*109 recruits has been implemented. Future values of cod reproductive volume (RV) (MacKenzie *et al*., 2000), used as forcing of cod in model 9 (see Table 7.3), were generated from the future salinity series (Figure 7.1) by using a salinity-RV relationship derived from observed data of the period 1974–2006 (RV=exp(0.4077*Salinity-1.2827; R^2=0.39).

Table 7.1. Climate forcing factors and environmentally dependent stock–recruitment relationships used for the majority of models in the ensemble modelling (for deviations see Results and Annex 7).

Species	Forcing factor, E	Model
Cod	Salinity, 80–100 m depth, May, Gotland basin (compiled by WGIAB 2008)	R=exp(-2.42285* SSB+0.29133*SSB*E+12.18724), where R is 1000 age 0 cod, SSB is 100000 tonnes spawning stock biomass. R=max($5*10^9$) R=exp(-1.8336*SSB+0.19867*SSB*E+11.850525), where R is 1000 age 2 cod, SSB is 100000 tonnes spawning stock biomass. R=max($5*10^9$)
Sprat	Temperature, 0–10 m depth, August, in the area 53°–60°N & 13°–23°E (compiled from BED[1])	R=5.84*10^9*E^2-1.74*10^11*E+1.33*10^12 where R is age 0 sprat
Temora longicornis and *Acartia* spp.	Spring surface temperature (0–50m) in the area 53°–60°N & 13°–23°E (compiled from BED[1])	Was used for forcing the biomass in model 9

[1] Baltic Environmental Database at the Baltic Nest Institute.

Table 7.2. Fishing and climate scenarios used in the ensemble modelling.

No.	Scenario	Fcod	Fsprat	Fherring	Climate
1	Business as usual, BAU	1.08	0.36	0.34	Mean of 1974–2005
2	Cod plan target met	0.3	0.36	0.34	Mean of 1974–2005
3	Cod fishing ban	0	0.36	0.34	Mean of 1974–2005
4	Sprat fishing increased	1.08	0.6	0.34	Mean of 1974–2005
5	Intense sprat fishing	1.08	0.8	0.34	Mean of 1974–2005
6	Business as usual, BAU	1.08	0.36	0.34	+3.5 degrees, -0.8 psu in 2100
7	Cod plan target met	0.3	0.36	0.34	+3.5 degrees, -0.8 psu in 2100
8	Cod fishing ban	0	0.36	0.34	+3.5 degrees, -0.8 psu in 2100
9	Sprat fishing increased	1.08	0.6	0.34	+3.5 degrees, -0.8 psu in 2100
10	Intense sprat fishing	1.08	0.8	0.34	+3.5 degrees, -0.8 psu in 2100

7.3 Model descriptions

Four single species cod models, four multispecies models and an extensive foodweb model were used in the ensemble modelling (Table 7.3). An overview of their assumptions, data basis and processes modelled are given in Table 7.4.

Table 7.3. Models used in the ensemble modelling approach.

No.	Model	Reference	Person	Institute
1	"Stochastic Cod Model"	In prep.	Anders Wikström	Lund University, Sweden Swedish Board of Fisheries
2	"CodFLR", Spatially explicit cod model in FLR	Bastardi *et al.* submitted	Francois Bastardi	DTU-Aqua, Denmark
3	MCMC cod long-term projections	ICES 2008a	Eero Aro,	FGFRI, Finland
4	"Cod mini model" incl. long-term projections	In prep.	Bärbel Müller-Karulis	Latvian Institute of Aquatic Ecology, Latvia
5	"Dynamic cod-herring-sprat model"	Heikinheimo submitted	Outi Heikinheimo	FGFRI, Finland
6	"SMS", Stochastic Multispecies Model	Lewy & Vinther 2004. ICES CM 2004/FF:20	Stefan Neuenfeldt	DTU-Aqua, Denmark
7	Stage-structured multispecies biomass model	van Leeuwen *et al.*, 2008. J. Sea Research	Anieke van Leeuwen	University of Amsterdam, The Netherlands

				Swedish Board of Fisheries
8	"BALMAR", Multivariate Autoregressive foodweb model	Lindegren *et al.* submitted	Martin Lindegren	DTU-Aqua, Denmark ,University of Hamburg, Germany
9	"BNI foodweb model" using Ecopath with Ecosim l	In prep.	Maciej Tomczak Susa Niiranen Thorsten Blenckner	DTU-Aqua, Denm., Baltic Nest Institute, Sweden, Baltic Nest Institute, Sweden

Table 7.4. Overview of the data basis and processes included in the models. For model numbers, see Table 7.3

Model no. Structure	1	2	3	4	5	6	7	8	9
Fitted to data	X	X	X	X	X	X		X	X
- catches (landings)	X		X			X			
- survey catches	X		X			X			
- weight at age			X			X			
- stomach contents						X			X
- XSA estimates	X								X
- MSVPA estimates					X			X	
Processes modelled									
- age-dependent predation									X
- size-dependent predation						X	X		
- resource-dependent body growth							X		
- size-dependent egg production							X		
- population level recruitment (SSB-R)		X	X	X		X			
Species interactions modelled					X	X	X	X[1]	X
- cod predation on clupeids					X	X	X		X
- cod cannibalism						X	X		X
- interspecific food competition									X
- cod predation on zooplankton							X		X
- clupeid predation on zooplankton							X		X
- cod predation on zoobenthos							X		X

[1] Species interactions are represented in this model by estimations of empirical correlation of species biomasses. Pair-wise interactions of cod, herring, and sprat stock biomasses are modelled, as well as an effect of zooplankton on herring biomass.

The models applied during the meeting can be divided into different groups. **Models 1 and 8** are the most data driven models. Model 1 is a univariate nonlinear autoregressive model describing cod biomass (driven by catch data). Model 8 is a first order multivariate autoregressive model and it can be viewed as a linear approximation to a non-linear first order stochastic process and essentially functions as a set of lagged multiple linear regression equations (one each for cod, herring and sprat) solved simultaneously to derive the most parsimonious model. These structurally simple empirical models fit well to historical data. Individual processes or population level phenomena such as recruitment are however not explicitly modelled. Hence these models have difficulties to address future variability stemming from changes in species interactions in the foodweb.

All other models include deterministic equations to describe species or ecosystem dynamics. Some models (2, 3, 4, 5, 6, 9) derive parameters for these equations by fitting model predictions to e.g. catch data and/or stock biomass estimates, whereas model 7 is parameterised based on published experimental results on e.g. metabolism without fitting the model output values. **Models 2, 3, 4, 5 and 6** are based on extensions of the Virtual Population Analysis (VPA), i.e. Extended Survivor Analysis (XSA), commonly used in the ICES Baltic fish stock assessment (ICES 2008a). Models 2, 3, and 4 are single species models of cod, whereas models 5 and 6 also include herring and sprat. Models 2, 3, and 6 contain Monte Carlo Markov chain (MCMC) projections in order to assess the confidence limits of projections. Model 4, in contrast, uses deterministic predictions. The common feature of these models is that they describe mainly top down effects. Models 2, 3, and 4 include the effect of fisheries and the multispecies models 5 and 6 additionally the effect of cod predation on herring and sprat, and in model 6 also cod cannibalism. These models hence do address bottom up effects (e.g. changes in the physical environment and zooplankton availability to larvae) only implicitly through the environmentally sensitive spawning stock biomass recruitment relationship. Changes in cod growth due to changes in herring and sprat conditions observed in the Baltic (e.g. Casini *et al*., 2006, Möllmann *et al*., 2005) are not modelled.

Model 7 differs from the other models in that it explicitly includes the individual energetic processes of an average cod or sprat of a certain size (in a homogeneous environment), such as food consumption, growth, maturation and reproduction. Zooplankton and benthos are included but modelled in less detail. All dynamics at the population and community level hence result from processes at the individual level. Growth, development and reproduction, of cod and sprat are modelled based on the energy budget of an average-sized individual per stage. Food consumption, either from zooplankton or benthic resources or through predation on fish prey, is a function of the availability of these different food types in the homogeneous environment as well as of the size of the predator and the prey. Hence, model 7 accounts for the effect of food availability on cod biomass, as mediated by individual growth and resource-dependent reproduction. Since size-dependent consumption and resource-dependent somatic growth are accounted for, as well as both certain top down and bottom up processes, the model can potentially be used to analyse changes in future population dynamics of cod and sprat also under conditions of e.g. productivity that have not been experienced historically. However, direct effects of climate change cannot be addressed yet, as environmental variation forcing on cod or sprat recruitment is not yet accounted for. Furthermore, similar to how the data driven models depend on the calibration time series of e.g. fish biomasses, the output from this model highly depends on the parameterization of the average individuals' food consumption and energy allocation. Major assumptions in this context were that juvenile cod (0.4–104 g, with a mean of 18.2) forage on small sprat, and that both cod and sprat growth and survival are resource dependent (and hence density dependent).

Model 9 is a mass balance foodweb model that describes trophic interactions among functional groups of the ecosystem by a set of linear equations addressing fisheries and species interactions on all trophic levels. The dynamical mode of model 9 (Ecosim) uses a system of differential equations that express biomass flux rates among functional groups, as a function of time varying biomass and fishing mortalities. Ecosim incorporates the foraging arena assumption through a parameter called vulnerability (v), which describes how much the predation mortality for a given prey can increase if the predator abundance is increased. When the predator is at its carrying capacity with regard to the given prey, the predation mortality cannot be increased any further (v=1), and an increase in predator abundance, (e.g., due to good recruitment) will be compensated for by a decrease in predator consumption rates. This in turn will result in lower predator production, and the predator abundance will move back toward its carrying capacity. The model is fitted to long-term (1974–2006) time series of macrozoobenthos, three phytoplankton groups, four zooplankton groups, and a number of age classes of cod, sprat and herring. In addition, climatic forcing on zooplankton groups described in Table 7.1 is incorporated in the model. Sprat egg production was directly forced with August temperature, and cod egg production was directly forced with the cod reproductive volume, as no direct stock–recruitment relationships can be included in the model. Because of the fitting of the model to historical time series of all species included, this model has, similar to the most data driven models 1 and 8, difficulties to address future variability stemming from changes in species interactions in the foodweb.

All models, except models 1, 7, 8, and 9 use an empirical environmentally dependent SSB-R relationship for cod and sprat (described in *Fishing scenarios and climate forcing*, above). Models 1 and 8 do not account for reproduction separately, but rather model the changes in total SSB between years. In these two models, environmental forcing acts directly on SSB levels. Instead of forcing recruitment via a stock–recruitment relationship, in model 9, cod egg production was forced with cod reproductive volume and sprat egg production with temperature. Model 5 included only forcing of the cod SSB-R relationship, whereas clupeid recruitment were modelled using a Ricker function independent of environmental variables. As model 7 simulates individual processes from which population dynamics (including resource-dependent reproduction) follow, it does not simulate recruitment based on a population level SSB-R relationship. Egg production instead results from individual spawning effort, based on the energy budget of an individual. Reproduction in this model thus depends both on individual size and the energy available to an individual. Environmental effects on reproduction, however, are not included in model 7.

The models that involve fitting to historical catch or stock biomass estimates (models 1, 2, 4, 5, 6, 8, 9) represent well the historical estimates of cod SSB as derived by SGMAB (ICES 2006). All models capture the development of cod SSB (Figure 7.2, left part of the upper left graph) during the last three decades, i.e. the cod boom period in the 1980s, and all (but model 5) also capture the smaller peak at the mid-1990s, with a subsequent decline to current levels. The biomass levels, however, differ between the models. For example, in model 9 cod SSB during peak years is only half of the SSB estimated by SGMAB (“data” in Figure 7.2, upper left panel). Thus, any comparisons of model predictions between time periods, of e.g. future SSB values to current levels, are always done within each model. Model 3 is only a projection model, and does not produce historical estimates. Model 7 has not been fitted to data and its quantitative output is thus not directly comparable to those generated by the other models. However, the model does capture the declining cod stock in response to the current high fishing mortality of cod (Figure 7.2, lower left panel).

7.4 Results

7.4.1 Modelled effects of cod fisheries management scenarios assuming no climate change

Despite the generally similar projections of future cod SSB there are differences in the projected responses of the cod stock to continued intense fishing of cod (BAU) between the models, even when climate change is not accounted for (Figure 7.2a). One model (number 7) predicts that the cod stock will go extinct, three models (number 1, 3 and 9) that cod SSB will remain at approximately the same level as currently, whereas four models predict a slight increase in cod SSB (number 2, 4, 6 and 8) and model 5 even predicts a 4-fold increase in cod SSB (data not shown). It is worth noting, however, that no model predicts a recovery of the cod stock to the high levels in the 1980s, nor comparable to the medium levels observed in the mid 1990s (the latter comparison is not made for model 5 as it does not capture this peak). The common conclusion from all the models is thus that business as usual fishing of cod (and of sprat and herring) would hinder a recovery of the cod stock.

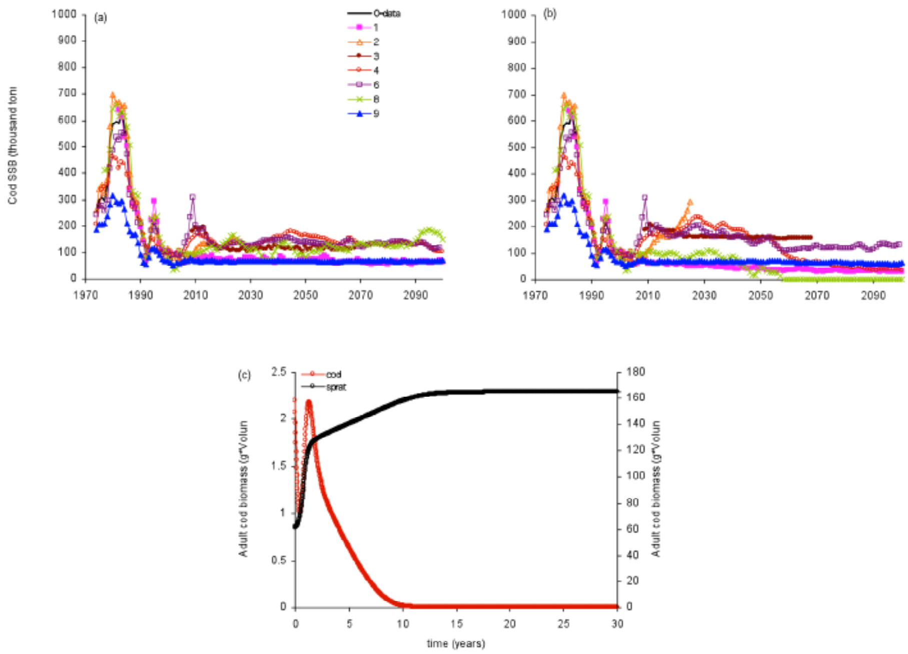


Figure 7.2. Projections of cod spawning stock biomass in the business as usual scenario, where fishing mortalities for cod, herring and sprat are set at mean levels of 1996–2005, assuming (a, c) no climate change or (b) increasing temperature and decreasing salinity. Panel c) shows the predictions on cod and sprat adult biomass from model 7 in response to mortality levels equivalent to the mean fishing mortalities during 1996–2005.

The slight increase in cod SSB projected by some models may result from the salinity-dependent recruitment function. With this SSB-R relationship, also low SSB can result in relatively high recruitment if salinity (and oxygen) is high, which is a reasonable assumption for Eastern Baltic cod (Köster *et al.*, 2005). In the projected salinity series used (Figure 7.1), the mean salinity in the future scenarios are always above the all-time-low salinities observed in the early 1990s. Thus, the projected salinity driven cod recruitment carries through and maintains SSB or even slightly increases it. However, none of these slight increases results in a recovery of the stock, not even to the levels in the mid 1990s. The uniform result across all models is that the cod SSB will stay at very low levels (or even go extinct) if fishing continues as presently.

An important part of the differences between the model predictions stem from the differences in processes (and their parameterisation) included in the models. The most extreme prediction, i.e., extinction of cod (model 7), is a result from the interplay of size-dependent predation by cod on sprat, and the resource-dependent body growth of both cod and sprat in this model. These results indicate that the Central Baltic Sea foodweb may exist in either of two potential "foodweb states" exhibiting different cod-sprat-zooplankton interactions and feedbacks in the same environment (i.e., zooplankton productivity): either (1) one where the cod population has a high biomass and there is a strong predation pressure on sprat, causing the sprat population to be dominated by the largest and smallest size-class and (2) where cod is virtually absent from the system and the sprat population is abundant but stunted in size. In this state there is insufficient prey - of the right size - for cod to recover from low densities, even though the actual numbers and biomass in the sprat population are higher (not shown, see van Leeuwen *et al.*, 2008 for an analysis of these mechanisms). Thus, model 7 predicts that once the cod stock has been fished down to below a threshold density, it will approach an alternative stable state where the cod stock has low biomass. It should however be noted that the model builds on the strong assumption of size-dependent predation effects and an investigation of their validity for the Baltic case is underway. Furthermore, the model in its present form does not include environmental forcing, the latter being an important characteristic of cod and sprat populations in the Baltic Sea. Nevertheless, because of the fundamentally different approach compared to the other models, WGIAB considers the model an important component of the model ensemble. Further developed versions of model 7 will potentially lead to insights which will not be derived by the other models, as these all build on perceived history and will not be able to predict unexpected, fundamentally different future foodweb configurations.

Because of the different model approaches and structures, the predicted future trajectories of cod SSB under the scenarios of cod fishing at the target fishing mortality in the cod management plan (Fcod=0.3) or of a cod fishing ban (Fcod=0) differ between the models. The difference, however, is mainly between the predictions of model 7 to those of the other models. Between all other models, the predicted future trajectories of cod SSB show strikingly similar dynamics. Several single species and multispecies models predict that a cod fishing mortality of 0.3 will result in a recovery of the cod SSB to levels equivalent to or above the peak cod years in the 1980s by tripling or even a 6-fold increase in SSB from current levels (1, 2, 3, 4, 6, 8, 9) (Figure 7.3a), and model 5 even predicts a 10-fold increase in cod SSB (data not shown). In contrast, model 7 predicts that, as the depleted cod level is a stable state (alternative to the abundant cod state), none of the cod fisheries management scenarios will lead to a recovery of the stock (data not shown). This, again, is because of the assumed size specific predation by cod on sprat (which is in both model 6 and 7) and its assumed interplay with their resource-dependent body growth (which is only accounted for in model 7).

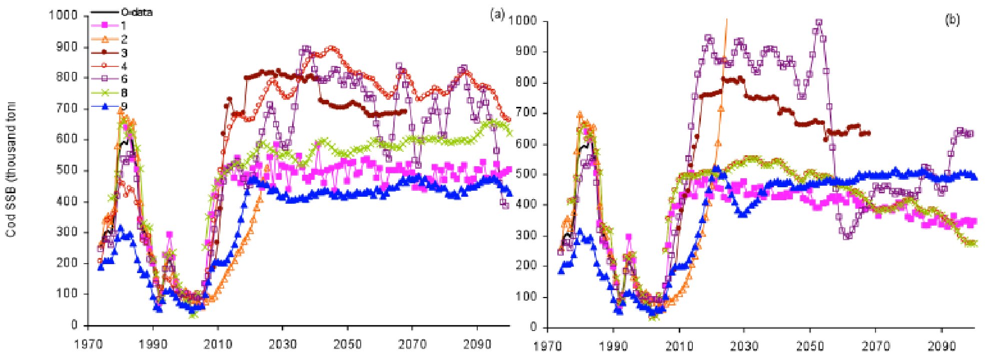


Figure 7.3. Projections of cod spawning stock biomass in the scenario where fishing mortality for cod is reduced to the target level (F_{cod}=0.3), in the cod management plan, assuming (a) no climate change or (b) an increasing temperature and a decreasing salinity.

The multispecies and foodweb models (models 5 to 9) predict quite different responses of sprat SSB to continued fishing at current levels in the BAU scenario. Whereas models 6 and 9 predict that sprat SSB will remain at approximately at its current level, models 8 and 5 predict that the current levels of fishing will reduce the sprat stock to about half its current level until 2100 (Figure 7.6a; data not shown for Model 5). If cod fishing is reduced to F=0.3 the sprat SSB will decrease because of the higher predation by cod. Whereas model 8 even predicts that sprat goes extinct before the next century, models 6 and 9 predict that the sprat stock will be reduced to about half its current level (Figure 7.6c) and model 5 to about a tenth of its current level (data not shown). This is because model 6, in contrast to 5, 7, and 8, explicitly includes the sprat temperature recruitment relationship (Table 7.4). As the sprat recruitment, according to the recruitment model (Table 7.1), is independent of sprat SSB, there will always be input of sprat even if the stock is minimal. Because of this, sprat cannot be reduced further in model 6. Similarly, for model 9, although the temperature recruitment relationship in Table 7.4 is not explicitly incorporated, sprat egg production in this model is also temperature driven and thus, sprat cannot be driven to extinction.

7.4.2 Modelled effects of sprat fisheries management scenarios assuming no climate change

The different ways of accounting for the interactions between sprat and cod also make the predicted responses of these stocks to changes in sprat fishing differ between the multispecies models. Intense fishing of sprat (combined with business as usual fishing of cod) is predicted to have a negative effect on cod SSB in model 9, such that cod SSB in this scenario (Figure 7.4 a) is even lower than in the base line scenario with less sprat fishing (BAU, Figure 7.2 a). This is because this model is fitted to estimates of cod, herring, and sprat (ICES 2005) where the only interaction between cod and sprat is the predation of cod on sprat. Thus, in this model the only effect of sprat fishing is to reduce the amount of food (sprat) for cod compared to in the BAU scenario. In contrast, model 6 predicts almost no effect on the cod SSB (Figure 7.4 a) compared to the business as usual scenario. This is because in this model, sprat does neither affect cod growth nor cod recruitment. Slight differences between the scenarios result from changes in cod cannibalism due to the changed total food biomass.

Similarly, model 7 predicts that increased sprat fishing alone is not sufficient to shift the foodweb from the current cod depleted state (data not shown). This is because the high fishing mortality on cod still prevents its recovery. So, in model 7, only if the increased sprat fishing is combined with a reduced fishing mortality on cod, the cod stock can recover (Figure 7.5).

In contrast to these three models, model 8 predicts a gradual increase in cod SSB if sprat fishing alone increases; showing an almost 80% increase in cod SSB after 25 years (Figure 7.4 a) compared to the BAU scenario (Figure 7.2 a). The model thus predicts that cod SSB returns to levels equivalent of the mid 1990s, but not a recovery to the 1980s levels (Figure 7.4 a). This increase in cod SSB results from the increase in its prey, herring, which in response to lower interspecific competition with sprat increase substantially over the period (not shown).

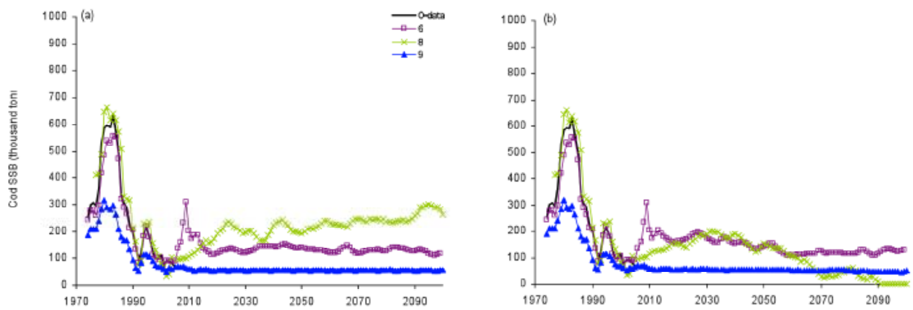


Figure 7.4. Projections of cod spawning stock biomass in the scenario where sprat fishing mortality is 0.6, assuming (a) no climate change or (b) increasing temperature and decreasing salinity.

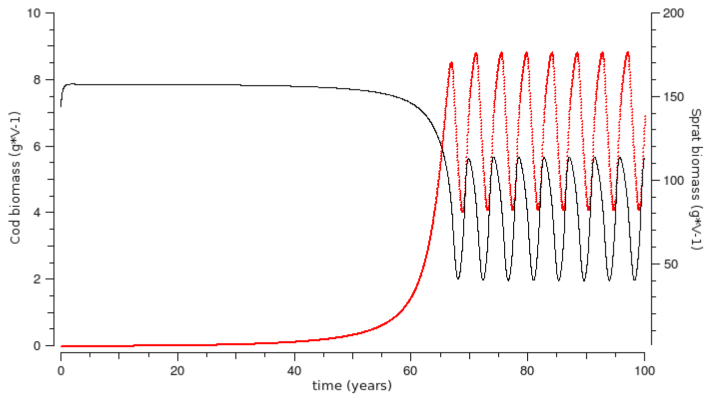


Figure 7.5. Projection of adult biomass of cod and sprat in model 7 when increased sprat fishing (equivalent to F_{sprat}=0.8 scenario) is combined with a cod fishing mortality reduced to the target (F_{cod}=0.3) in the cod management plan. Red indicates adult cod biomass and black adult sprat biomass.

The predictions of sprat SSB in response to increased sprat fishing mortality (0.6) also differ qualitatively between the models; model 8 predicts that sprat SSB steadily decreases in the long term, whereas models 6 and 9 predict that sprat SSB will fluctuate around half or two thirds of its current level (Figure 7.6 e). A general prediction from all three models, however, is that reducing cod fishing mortality to 0.3 has a stronger negative impact on the sprat SSB than increasing the fishing mortality on sprat to 0.6 (Figure 7.6 c,e). These results, however, must be taken with some caution, as in model 6 it depends on the way sprat recruitment was modelled: as a function of only temperature, and not sprat SSB. Although sprat recruitment is closely correlated with temperature, long-term projections of recruitment decoupled from SSB are highly unlikely, especially at low stock sizes.

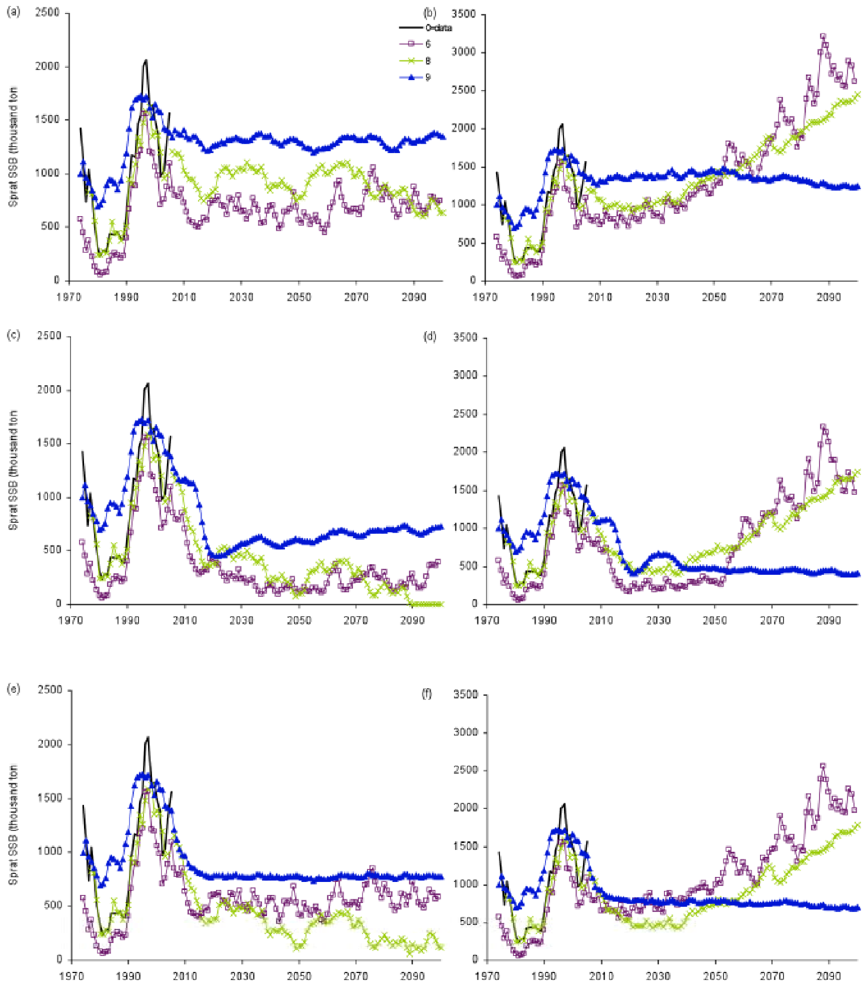


Figure 7.6. Projections of sprat spawning stock biomass assuming (a, c, e) no climate change or (b, d, f) an increasing temperature and decreasing salinity, when (a, b) fishing continues as business as usual, (c, d) cod management plan target fishing mortality for cod (F_{cod}=0.3) is implemented, or (e, f) sprat fishing is intensified (F_{sprat}=0.6). Notice the difference in y-axes between panels with (b, d, f) and without (a, c, e) climate change.

7.4.3 Modelled effects of cod and sprat fisheries management scenarios assuming climate change

The predicted effect of a linear but stochastic increase of temperature of 3.5 degrees C and a decrease in salinity of 0.8 psu until 2100 on the cod SSB varies quite substantially between the models (Figure 7.2 b). Models 5 and 8, for example, predict that cod will go biologically extinct due to the decreased salinity and high mortality if fishing continues as currently (Figure 7.2 b; data for model 5 not shown). Similarly, model 1 predicts that the risk of extinction of cod is 35% in this scenario. Salinity has a very strong effect on cod in model 8 because it acts directly on cod biomass (as the model does not assume or include a SSB-R relationship). The synergetic effects of fishing and low salinity may be particularly strong in model 8 as it does not account for the age structure of the modelled fish populations. Thus, the negative effect of salinity, that in reality acts on cod egg and larvae, in model 8 affects total population biomass directly, instead of progressively acting on population biomass through poor recruitment of a sequence of year classes (as in model 6 or 9). One extreme among the predictions is by model 3 that seems to predict a positive effect of the changing climate (Figure 7.2 b), when compared to the effect of continued fishing without accounting for climate change (Figure 7.2 a). However, it must be noted that this is because different stock–recruitment functions were used in model 3 in the scenarios without vs. with climate change. In the former case, a fitted Beverton-Holt relationship without any forcing was used, whereas in the latter, the salinity-dependent SSB-R relationship was used. Any comparison of climate effects can thus not be made in this model.

In general, all the results related to salinity forced cod recruitment must be taken with caution, as the salinity projections in the climate change scenario until 2030 are actually higher than in the scenario without climate change (Figure 7.1 b). This long period of higher salinity results in several years of good recruitment which maintains a large cod stock for several years following 2030, when salinity is decreasing, despite intense fishing. This points to the importance of drawing conclusions on climate change requires a large number of simulations of future climate, and not, as in this explorative analyses, a mean of five runs. Furthermore, a scenario where future salinity is reduced more severely (Meier 2006) should be used for comparison.

Predictions of cod SSB from the multispecies models are again different: model 9 shows no major effect of climate change on cod SSB if fishing continues as currently (Figure 7.2 a,b). Model 6 shows that cod SSB will slowly decline with a changing climate, but, that compared to without climate change there is still a slight net positive effect on cod SSB (Figure 7.2b). Although this could be interpreted to be an effect of the positive effect of the strong temperature increase on the sprat stock (Figure 7.6 b), which in model 6 acts as a food source for cod, this is likely to be an effect of the salinity driven cod recruitment. Models 5 and 8, in contrast, predict that cod will go extinct (Figure 7.2 b) due to the combination of high fishing pressure and low recruitment (i.e. due to reduced SSB and decreased salinity conditions).

Similarly, the predicted effects of increased temperature on sprat SSB are quite different; whereas models 6 and 8 predict a strong increase in sprat SSB, models 5 and 9 predict that the stock will remain approximately at its current level (Figure 7.6 b; model 5 not shown). This is likely the effect of how temperature forcing of sprat was included in the models. In model 5, sprat was not forced by temperature, and climate therefore affects sprat only indirectly, via the salinity forcing of cod. In model 9, temperature affects sprat egg production, rather than directly on recruitment of age 0 sprat (as in model 6) or total sprat biomass (as in model 8), which likely explains the weaker effect of temperature on sprat predicted by this model.

The effect of increased sprat fishing on cod SSB do not change with a warmer and less saline climate in models 6 and 9. The positive effect of increased sprat fishing on cod SSB, predicted by model 8, however, does not last if future climate will change (Figure 7.4). The cod SSB is predicted to increase for about 20 years following increased sprat fishing, but is thereafter predicted to decline to less than current levels in about 60 years from now (Figure 7.4 b).

Despite these differences between model predictions, the overall effect of the alternative fishing scenarios are not altered much by climate change. Most importantly, the model results show that fishing mortality rather than climate has the main impact on cod recovery. The effect of climate change can be seen on the impact of a cod fishing moratorium on the cod SSB: whereas a cod fishing ban is predicted by all models to lead to a cod recovery if there is no climate change, a fishing moratorium is predicted to be less effective in a future changing climate (Figure 7.7). Comparisons of the scenarios with and without climate change show that three general conclusions from the overall model predictions hold also under climate change. First, implementing a cod fishing mortality of 0.3 still results in a stock recovery to at least the levels of mid 1990s, or in some models, even to levels equivalent to the cod peak years in the 1980s (Figure 7.3). Second, a situation of no climate change (potentially favourable for cod) is not enough for the cod stock to recovery. Third, continued cod fishing at current levels will prevent a cod recovery.

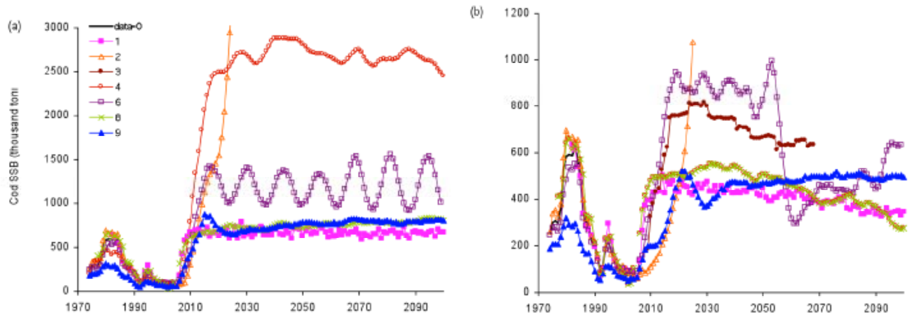


Figure 7.7. Projected cod SSB under a cod fishing ban, (a) without climate change, and (b) with increasing temperature and decreasing salinity. Notice the difference in y-axes between the panels.

7.5 Conclusions

In an "ensemble approach" the responses of cod and sprat SSB to five scenarios of fishing of cod (continued high fishing mortality, implemented cod management plan, cod fishing moratorium) and sprat (increased fishing) were investigated. To this end, four single species cod models, four multispecies models and one foodweb model have been used. In addition, these fishing scenarios were tested assuming either no climate change, or a future warmer and less saline Baltic Sea (Meier 2006, BACC 2008).

The responses of cod and sprat to the fishing and climate scenarios tested differed between the nine models, both quantitatively and qualitatively. However, the ensemble modelling approach used herein allowed a straightforward comparison of the range of possible outcomes projected by the diverse models used. Thus, the ensemble modelling approach provided a means to (1) assess whether these differences in predictions also resulted in different conclusions on management, and (2) draw general conclusions valid across all single species, multispecies and foodweb models used.

An overview of the development of cod and sprat SSB in response to cod and sprat fishing scenarios as well as increasing temperature and decreasing salinity predicted by the nine models is given in Table 7.5. Notice, however, that the results produced are preliminary as several of the models are still in a developing phase, and as climate effects were evaluated on very few runs. **The results must therefore not be taken as final assessments of the future Baltic cod or foodweb, nor as final evaluation of fisheries management actions.**

Table 7.5. Overview of simulated future cod and sprat SSB predicted by cod and foodweb models under alternative fishing and climate scenarios (CC indicates climate change, see Figure 7.1). Decrease or increase refer to predicted SSB in 2100 relative to predicted SSB in the beginning of future simulations (2006), for each model. Extinction before year 2100 is indicated by †. "None" indicates that the scenario was tested, but that no model predicted the result of that column. Numbers refer to model numbers (see Table 7.3). For an overview of model structure and data basis, see Table 7.4

Fishing	Climate	Cod			Sprat	
		Decrease	Return to medium levels[1]	Recover to peak levels[2]	Decrease	Increase
Business as usual	current	7†	None[4]	None	5,8	5
	CC	5†,8†	None[4]	None		4,6
Cod plan target met	current	None (7[5])	None	1,2,3,4,5,6,8, 9	5,6,8†,9	5[5]
	CC	None	1,2,4,8	3,5,6,9	5	4,6
Cod fishing moratorium	current	None (7[5])	None	1,2,3,4,6,8,9		5[5]
	CC	None	1,2,3,4,6,8	9		4,6
Sprat fishing increased[3]	current	7[5],9	8	None	6,8†,9	5[5]
	CC	8†,9	None	None	None	4,6

[1] Medium levels of Cod SSB defined as model specific levels of cod SSB equivalent to those predicted for mid 1990s by each model (cf. Figure 7.2a)

[2] Peak levels of Cod SSB defined as model specific levels of cod SSB equivalent to those predicted for mid 1980s by each model (cf. Figure 7.2a)

[3] Only includes results for fishing mortality on sprat set to 0.6.

[4] Comparison for model 5 omitted as this model does not represent the medium levels (small peak) observed in mid 1990s (cf. Figure 7.2a)

[5] Model 7 predicts that once the cod stock is depleted by current fishing levels it will remain depleted, also if cod fishing mortality is reduced or sprat fishing mortality is increased. Similarly, the sprat stock will remain at its high level. The only measures predicted by this model to lead to a cod recovery under current climate conditions is a combination of reducing cod fishing mortality to F=0.3 *and* increasing sprat fishing mortality.

Although there were some qualitative differences in predicted trajectories of future cod and sprat SSB, many models show strikingly similar predictions for cod (Table 7.5), despite the differences in which and how species, species interactions and climate forcing were incorporated in the models (Table 7.4). Table 7.5 shows that two general conclusions can be drawn from the ensemble of models, both with and without climate change:

- None of the models predict a return of cod SSB to the medium levels observed in the mid 1990s if fishing continues at current levels. The common conclusion from all the models is thus that business as usual fishing of cod will hinder a recovery of the Eastern Baltic Sea cod stock.
- A reduction in fishing pressure on cod is predicted to have a smaller positive effect on the cod stock in a future changing climate than if climate change is not accounted for.
- The effects of increased sprat fishing on the cod and sprat stocks are highly uncertain, ranging from no effect to extinction depending on model and climate scenario.

WGIAB considers this first attempt of a "biological ensemble modelling", although preliminary, as very successful. However, a number of improvements are necessary until the results of such an exercise can be operationally used in fish stock assessment and management routines. Among these are:

- a further development of the individual models, including assessments of the sensitivity of their predictions to parametrisation and stock–recruitment relationship used
- inclusion of other modelling approaches (e.g. NPZD ecosystem models, Individual-based early-life stage fish models)
- simultaneous model runs with a large number of potential future salinity and temperature time-series (at least 100 simulations for each climate scenario)
- use of a more than one climate change scenario, i.e. alternative scenarios of the IPCC predictions, and preferably based on down-scaled predictions for the full time series rather than as predicted by the time-slicing method.

8 Outline for a strategy of the use of ecosystem models within the future ecosystem-based advice (ToR f)

8.1 Lessons learnt and conclusions from the 2009 WGIAB meeting

A major aim of WGIAB is to implement its work into regular ecosystem-based assessment and management routines (see above for IEAs- Chapter 4). In addition to Integrated Ecosystem Assessments (IEAs), modelling of the Baltic ecosystem(s) in support of the ecosystem-based advice is a further important goal of WGIAB. On the 2009 meeting WGIAB started this work for the Central Baltic ecosystem using an "Biological Ensemble Modelling Approach (BEMA)" adapted from climate modelling (e.g. Hill *et al*., 2007; BACC 2008). To this end 9 different biological models were used in long-term runs evaluating different cod and sprat management scenarios under two different climate scenarios (see Chapter 7). WGIAB considers this first attempt of a BEMA, although preliminary, as very successful and promising. The approach explicitly addresses uncertainty due to differences in model structure and hence has the potential to extract general conclusions on the status and future of several components in the Baltic ecosystem including commercially important fish stocks. The ensemble modelling approach also provides a means for continuous model improvement. Furthermore, the synthesis across a diverse range of models that the BEMA allows may also increase the credibility of model forecasts of the Baltic ecosystem and fish stocks.

WGIABs efforts towards this approach of ecological modelling is supported by a number of recently started BONUS projects such as ECOSUPPORT and AMBER (see Chapter 6). The close cooperation of WGIAB members will assure the further development of the BEMA, and especially of various ecological models but most importantly the coupling of these to atmospheric and hydrodynamic models. The coupling of the various models will in the future allow more reliable forecasts of ecosystem development under the expected climate change.

A number of improvements/developments are necessary until results of a BEMA can be operationally used in management advice. This concerns the further development and choice of ecological models. WGIAB used an approach collecting models which were easily available and operationally usable during a 5 day meeting. These models are still partly under development, delivering preliminary results (see Chapter 7).

Hence, a further development of these models as well as the inclusion of other modelling approaches (e.g. biogeochemical NPZD ecosystem models, Individually based early life stage fish models; etc.) is crucial. For regular use of BEMA in management advice a large enough number of models included need to be ascertained, covering a range of modelling approaches and philosophies, i.e. from single species and multispecies to full foodweb and biogeochemical models. An important prerequisite is here the regular "maintenance" of the models, so that manpower and knowledge is constantly available to consistently conduct updates of the BEMA in regular intervals. Moreover, the BEMA enables (and we encourage) the inclusion of new, additional models, such that the advice produced is always based on best available scientific practices.

In the light of the expected climate change an important prerequisite for BEMA is the availability of future hydrographic time-series based on the actual climate model projections. Only the timely provision of these data can assure the evaluation of management strategies based on scenarios of future climate change. Additionally, in the future also the effect of different eutrophication scenarios should be included in the BEMA, e.g. to contribute to the HELCOM Baltic Sea Action Plan. Therefore the prediction of oxygen concentrations based on coupled atmospheric-hydrodynamics NPZD models is required, which is planned to be conducted in above described BONUS research projects. All these exchanges of data and models will in the future need a tight network of institutions providing and exchanging these data. This kind of network is hence crucial for developing a holistic ecosystem-based management of the Baltic Sea ecosystems.

It should be noted that BEMA is mainly directed towards the evaluation of the long-term development of the Baltic fish stocks and the ecosystems under future climate change and various fisheries management scenarios. Other modelling activities serving more short-term advice needs including bioeconomic questions should be implemented into the work of the ICES Baltic community (see below). To this end a workshop has been proposed (see Annex 5) and a suggestion for the organisation of the future Baltic work under the ICES structure has been developed together with TGBALT (see Annex 6).

8.2 A preliminary strategy

Based on the experience of the 2009 modelling and discussions during the WGIAB meeting first ideas on how to incl. ecosystem modelling within the future ecosystem-based advice have been developed and will be further developed on the 2010 meeting (see Annex 3).

Figure 8.1 summarizes a potential future work distribution between Baltic EGs, which is developed together with the discussions with TGBALT on a new ICES regional seas steering committee (see Annex 6). It is envisioned that WGBFAS will in the future deal with the conventional single species assessments, if feasible complemented by a multispecies extension. Integrated Ecosystem Assessments (IEAs) would be conducted in to be specified intervals by WGIAB. Model based evaluations of the future developments would be conducted for short to medium term and economic questions by a newly established Working Group (see Annex 5) which conducts Management Strategy (MSE) and economic valuations. In addition, WGIAB would provided the long-term perspective by using and developing "Biological Ensemble Modelling" (BEMA).

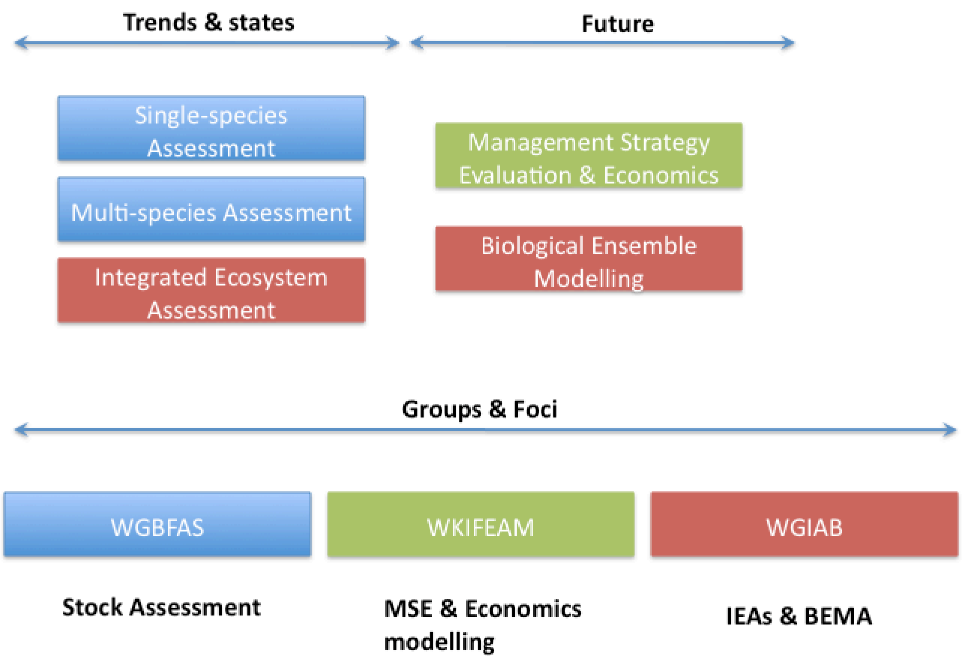


Figure 8.1. Schematic of a suggested work distribution between main Baltic EGs (of both SCICOM and ACOM).

This preliminary view of the future Baltic work will be further discussed in various related groups.

9 Answer to request by WKMAMPEL

ICES received a request from the EC to consider a Baltic pelagic stocks multiannual management plan – ICES WKREFBAS (ICES CM 2008/ACOM:28) provided preliminary insights into the original request and subsequently, the EC revised their request to ICES.

The latest revised request forms the ToRs of a workshop (WKMAMPEL) meeting that took place from midday on 23rd February 2009 until midday on 27th February 2009 at ICES HQ, Copenhagen. It was originally considered that this workshop was to take on all issues of the request, however, after further discussion among the ACOM leadership and during the annual meeting of the expert group chairs (WGCHAIRS) it has been decided to split the items among different groups. It is no longer considered possible to handle all issues within one meeting of the WKMAMPEL group. However, WKMAMPEL does provide a focus to address, and coordinate, the ICES' response.

WGIAB was asked to address ToR d: Evaluate the ecosystem effects (including the size of the cod stock) of a reduction of the size of the sprat stock through an increased fishing mortality for sprat.

A first evaluation has already been done in model terms (ICES 2008c). However, it was not clear whether these model calculations can be used as the basis for scientific sound advice, as only one model was used and the extrapolations involved are large, perhaps beyond the validity of the model. WGIAB formed a subgroup consisting of Anna Gårdmark (Sweden), Michele Casini (Sweden), Martin Lindegren (Denmark) and Christian Möllmann (Germany) reviewing the existing knowledge and the strategy of the group to address this issue on the WGIAB meeting. Christian Möllmann presented the document on the WKMAMPEL meeting.

A final response of WGIAB to WKMAMPEL ToR d will be prepared on the basis of the ensemble modelling conducted during the WGIAB meeting (see Chapter 7). This document will be delivered to ICES to answer the EC request latest by 29 May 2009.

10 Input and relation to other ICES Expert Groups

An important goal of WGIAB is to support other ICES Baltic expert groups with input especially with respect to environmental information, i.e. with the state as well as the historic and future development of the different Baltic sub-ecosystems. The networking of WGIAB between the different Baltic groups is developing and will change in the future to THE major goal (meaning the operational interaction between the different Baltic EGs). Inputs have been already delivered to the Baltic Salmon and Trout Assessment Working Group (ICES 2008d, WGBAST; see below). A closer cooperation with the Baltic Fisheries Assessment Working Group (ICES 2008a,000,WGBFAS; see below) is presently discussed and developed within the efforts of the Transition Group of Integration Activities in the Baltic (TGBALT; see below) to coordinate the Baltic Science in ICES. WGIAB considers the latter of crucial importance as to the opinion of the group the present restructuring efforts of ICES bear the risk that the integration activities developed by the dissolved Baltic Committee and WGIAB are halted. Hence, TGBALT met back-to-back with WGIAB and developed a strategy for a potential future organisation of the Baltic scientific work within ICES. Members of WGIAB will attend a back-to-back meeting of TGBALT with WGBFAS in April to discuss the strategy as well as a further closer cooperation between WGIAB and WGBFAS.

A further goal is to input the approach, experience and expertise of WGIAB into other areas represented by ICES. Specifically these are the Transition Group on Holistic Ecosystem Assessments and Diagnostics (TGHEAD; co chaired by C. Möllmann, WGIAB Co-Chair) and the Working Group on Holistic Assessments of Regional Marine Ecosystems (WGHAME). Coordination of the ICES activities between the three groups will be conducted during the TGHEAD meeting at the ICES ASC in Berlin, September 2009.

10.1 TGBALT and WGBFAS

The ToRs of the back-to-back meeting of TGBALT and WGIAB in Rostock 16 March 2009 were as follows:

a) coordinate the integration and cooperation between current EG working with Baltic Science.

b) establishing an operational links between WGIAB and WGBFAS and other related Expert Groups under ACOM and SCICOM.

c) advance activities in support of Integrated Ecosystem Assessments.

d) map the organisations outside ICES with which the Baltic Science can cooperate. Evaluate possible new interactions and strengthen existing cooperation with organisations, e.g. HELCOM, BONUS 169, BALTIC RAC and the EU COMMISSION.

e) create a questionnaire with accompanying introduction letter for mapping important expertise and affiliating the experts to Baltic Science within

ICES. Start introducing the questionnaire to experts and evaluate the response.

f) investigate ways to integrate socio-economic research in the Baltic Science.

Below the discussions are summarized:

a) the general opinion was from participating ex Baltic Committee (BCC) members that the EG groups formerly under BCC should have a future common platform within the new ICES structure. It was strongly felt, that otherwise the work achieved so far would be jeopardised. A few suggestions where discussed during the meeting but the conclusion was that a Steering Committee focusing on regional issues would be the favoured option as this would be very necessary to further develop the implementation of the Ecosystem Approach to Management in the Baltic Sea. During a meeting a scheme how a new regional seas steering group could be organized (see Annex 6)

b) WGIAB presently develops connections to ICES EGs both within and outside the Baltic community to use the results of its work in other frameworks and in the future especially in the advisory framework. The group has within the Baltic already developed a cooperation with WGBAST and provides this group with environmental data for their assessment activities. As WGIAB was originally planned as a counterpart to the regular fish stock assessment, the group expressed an interest in a general strengthening of the connection with WGBFAS and the possibility to exchange data and information on ecosystem processes. In order to facilitate such cooperation it was suggested that the meetings of the groups could be back-to-back in 2010 overlapping for 1 or 2 days. Considering that 2010 is not a year for benchmark assessment this will would be an opportunity to exchange information and discuss a future closer cooperation.

c) Integrated Assessment activities were discussed including (i) issues of data provision within the Baltic community, and (ii) extending the Baltic experiences to other areas as planned within TGHEAD and WGHAME. This problem will further be pursued intersessionally.

d) was not discussed during the meeting and will be done as an interim exercise.

e) The questionnaire was created but not tested yet on any possible affiliated experts. Inquires have been made to experts in the personal networks of members and of course there is different views in how ICES work is perceived. But several scientists have reacted to the fact that their research would have a direct impact on society and expressed that it would be a satisfaction hitherto lacking from their work to channel ideas through ICES.

f) TGBALT has received a request to investigate possibilities to form a WG based on ongoing projects dealing with management tools including socio economics and risk assessments. Additionally a proposal for a workshop on bioeconomic modelling of the Baltic Sea fish stocks has been developed out of WGIAB (see Annex 6). The meeting decided that these initiatives should be merged and started as workshop in 2009. Afterwards it could be decided if this initiative will be continued as a working group.

10.2 WGBAST (Johan Dannewitz)

Salmon in the Baltic Sea: development in post-smolt survival and factors affecting it.

Background

The Baltic Salmon and Trout Assessment Working Group (WGBAST) initiated preliminary analyses during their meeting 2008 to evaluate the possible reasons for the low at-sea survival of salmon stocks in the Baltic Sea. The post-smolt survival is believed to have decreased in recent years, both for wild and hatchery produced smolt. According to post-smolt survival estimates generated from the assessment model, this decline started in the mid 90s and has continued since then.

The reasons behind the observed decline are unclear, but at least two main hypotheses have been discussed. The "ecosystem hypothesis" states that changes in the Baltic Sea ecosystem have affected salmon post-smolt survival rates negatively, for example due to changes in prey species abundances and increased competition or predation from other species. The "smolt quality hypothesis" states that the increased mortality among hatchery produced smolts is due to changed practices in hatcheries. Hatchery practices have continually been improved. Higher fat and energy contents of the feed, in combination with favourable river temperatures especially in autumn, have resulted in improved growth rates in hatcheries and continually larger smolts. There is a general concern that the large size of reared smolts may have negative fitness consequences in the wild environment.

The work is still in an initial stage, which means that results generated during the WGBAST meeting in 2008 should be viewed as very preliminary. The work will continue during the WGBAST meeting in end of Mars 2009.

Preliminary analyses

Data on potential explanatory variables characterising the Baltic Sea ecosystem and the smolt releasing hatcheries was collected from different data sources, including other ICES working groups which kindly have agreed to let WGBAST get access to their data. Most of the data on predictor variables originated from the Working Group on Integrated Assessments of the Baltic Sea (WGIAB). The usefulness of these data for analyses of variation in salmon survival carried out by WGBAST clearly shows that time series on multiple variables characterising whole ecosystems are extremely valuable. In total, data on 102 predictor variables was obtained, including abundance data on predator and prey fish species, seal, and plankton. Environmental information and nutrient data were also included in analyses.

As response variables, different estimates of salmon survival were used in analyses, including post-smolt survival rates derived from the WGBAST assessment model, Carlin-tag recapture rates for Swedish hatchery stocks, and a more direct estimate of survival for two Swedish wild populations that was based on the relation between river production (parr densities) and subsequent number of returning spawners.

Preliminary analyses indicated that survival of post-smolts in the Baltic Sea may be density dependent as a negative association between salmon survival and total smolt production in the Baltic Sea (including both wild and hatchery smolts) was observed. These results were further supported by the findings that survival index for two large Swedish populations correlated negatively with parr densities in these rivers, which may indicate density dependence in the river and/or the sea. Salmon survival also correlated positively with herring abundance and recruitment. Together, these results highlight the possible influences of ecosystem changes in the Baltic Sea, because following the logic of the competition/food availability hypotheses, changes in the ecosystem could potentially affect the sea carrying capacity for salmon, which may vary between years. Preliminary analyses also indicate that seals may affect survival of salmon. However, the available information on grey seal food preferences is limited, and much more information on seal ecology is necessary to evaluate these relationships.

According to multivariate analyses using a Bayesian approach and which included a few presumably important predictor variables, a model which includes only the seal counts as a predictor gets assigned the highest probability. However, models including smolt abundance and recruitment of prey species must be evaluated further.

Considering the effects of rearing conditions in hatcheries on post-smolt survival rates of hatchery produced salmon, the available data is very limited, making it difficult to draw any general conclusions. There was no direct evidence for a negative association between length of reared smolts and their survival at sea. However, more detailed studies of these relationships are necessary, including possible non-linear associations between these variables.

Finally, the working group did not have time to explore more complex relationships including data on lower levels in the food chain. The work in 2009 may partly address such questions. Also, the working group will prioritise the development of more precise survival estimates and also try to look at changes over time in salmon life histories (e.g. growth and body condition) which may be valuable when formulating hypotheses and evaluating causal relationships.

11 Other themes presented and discussed during the meeting

11.1 Multidecadal scale variability in the eastern Baltic cod fishery 1550–1860: evidence and causes.

MacKenzie, B. R., Bager, M., Ojaveer, H., Awebro, K., Heino, U., Holm, P., Must, A., 2007. Fish. Res. 87, 106–119 (doi:10.1016/j.fishres.2007.07.003)

Identification of periods of high and low cod production, and the reasons for these periods, can increase understanding of variability in populations and ecosystems. In this study we investigate the multidecadal and multicentury scale variations in the cod population in the eastern Baltic Sea (ICES Subdivisions 25–32). Analytically derived estimates of biomass are available since 1966. These estimates show that biomass increased in the late 1970s–early 1980s, but decreased nearly 10-fold until the early 1990s and is still well below the long-term average. Prior to 1966 the biomass of cod is unknown, as is the relative role of fishing, climate variability/regimes, eutrophication and reduction of marine mammal predator populations. We have begun to investigate whether historical fisheries information (landings, effort, distribution) from before the 1880s is available in Baltic archives and museums, and to what extent this information can be used to interpret variations in this population. We have located fisheries data for different parts of the Baltic for different time periods since the 1550s and have interpreted the findings using current process knowledge of oceanographic mechanisms affecting cod reproduction and ecology in the Baltic Sea. The recovered data show that the Baltic ecosystem was able to support modest-large cod populations even though it was oligotrophic and contained large populations of cod predators (e. g., marine mammals). Current ecosystem management policy in the Baltic as developed and implemented by organisations such as the International

Council for the Exploration of the Sea (ICES), the Baltic Marine Environment Protection Commission (HELCOM), the nine coastal countries and the European Union includes recovery of the cod population, a reduction in nutrient loading and measures to promote recovery of seal and harbour porpoise populations. If these policies are successful, the role of predatory fish in the future Baltic could again be substantial and comparable to that which we show existed 450 years ago. However such a scenario will also require a major reduction in cod fishing mortality and suitable hydrographic conditions which promote successful cod reproduction. Historical ecology investigations in the Baltic can contribute to scientifically-based fishery and ecosystem management and recovery plans.

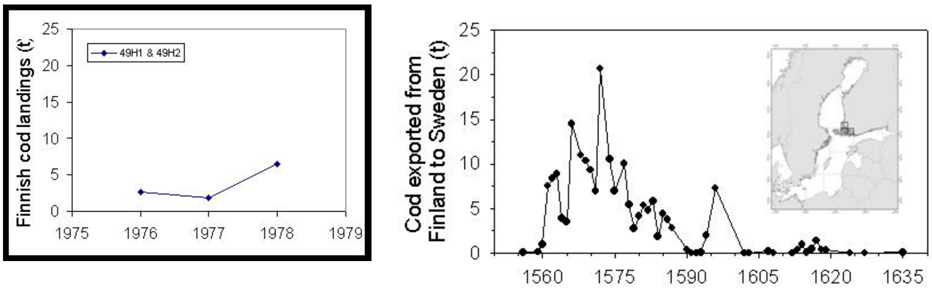


Figure 11.1.1. Left panel: Finnish commercial cod landings in two coastal areas of southwest Finland (ICES squares 49H1 and 49H2, Subdivision 29; Aro and Sjöblom 1984), corresponding to the area where cod fishing occurred during 1556–1635. Note that landings in the late 1500s–early 1600s (ca. 10 t per year) were higher than during 1976–1978. Right panel: Exports of processed cod from southwest Finland to Stockholm, Sweden during 1556–1635. Note that the landings of whole, fresh cod would have been higher if the exported cod were gutted and/or salted. Source: MacKenzie *et al.*, 2007. Fish. Res. 87: 106–119.

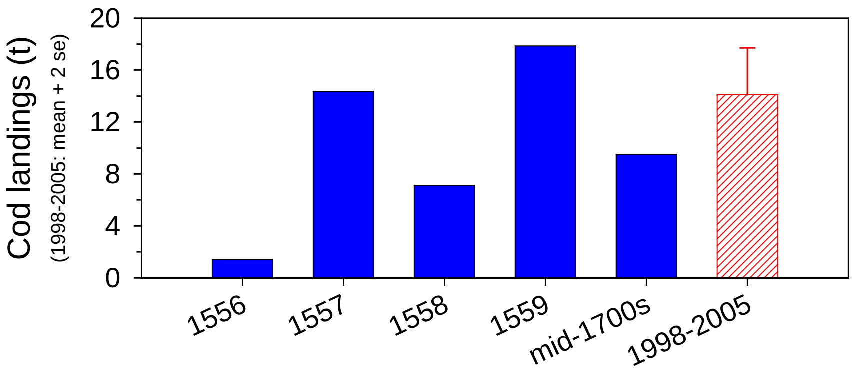


Figure 11.1.2. Landings of cod in fishing villages near Södermanland and the Stockholm archipelago as recovered from Swedish National Archives (Strödda kamerala handlingar) for the years 1556–1559. These landings are most likely underestimates of the total landings (see MacKenzie *et al.*, 2007 for explanation). Nevertheless they were comparable to the Swedish cod landings for the years 1998–2005 for ICES squares in Swedish coastal waters for an area similar to that where cod fishing occurred during 1556–1559 (46G6, 46G7, 46G8, 47G8, 48G8, 48G9, 49G8, 50G7, 50G8, 51G7, 52G7, 53G7). Swedish data for 1998–2005 (hatched bar) kindly provided by Anne-Sofie Gren, Swedish National Board of Fisheries. Source: MacKenzie *et al.*, 2007, Fish. Res. 87: 106–119.

11.2 Switches in ecosystem functioning triggered by trophic cascades in the central Baltic Sea

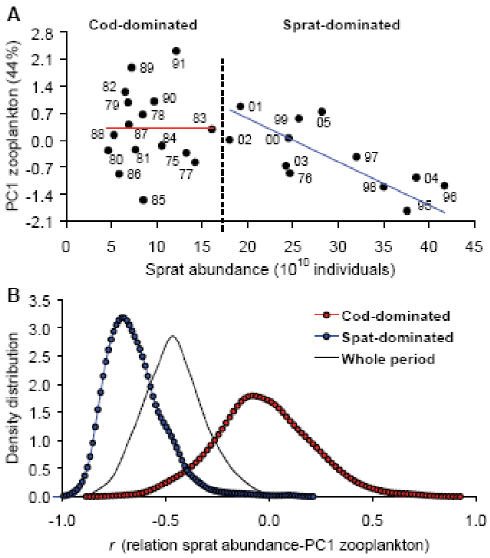
Casini, M., Hjelm, J., Molinero, J.-C., Lövgren, J., Cardinale, M., Bartolino, V., Belgrano, A. and Kornilovs, G. (2009). Trophic cascades promote thresholdlike shifts in pelagic marine ecosystems. Proceedings of the National Academy of Sciences of the USA, 106: 197–202 (doi_10.1073_pnas.0806649105)

The decrease of cod stock during the 1980s has favoured, together with higher temperature, a drastic increase in sprat population starting from the early 1990s.

The increase in sprat has altered the functioning of the central Baltic Sea ecosystem during the last three decades. In fact, foodweb links appear sensitive to an ecological threshold, identified through piecewise regression and threshold generalised additive model (TGAM) analyses, which corresponds to a total sprat abundance of 17×10^{10} individuals. This threshold separates two alternative ecosystem scenarios (cod dominance scenario and sprat dominance scenario) in which the ecological interactions change drastically.

Below such ecological threshold (i.e. in the cod dominance scenario), zooplankton is driven by hydrological conditions. This scenario is favoured and maintained by cod predation on sprat. In contrast, when the cod drop and sprat abundance exceeds the threshold (i.e. in the sprat-dominance scenario), sprat predation starts to control zooplankton dynamics. In this scenario, the direct link between zooplankton and hydrological conditions disappears. Therefore, it seems that sprat abundances above the threshold decouple zooplankton dynamics from hydrology and become the main forcing of zooplankton variations (Figs. 1 and 2). Specifically, the copepod *Pseudocalanus* spp. was positively related to salinity conditions in the 1970s and 1980s, whereas after the sprat outburst this relation disappeared, likely an effect of strong top down regulation by sprat on this plankter. The dual mechanism of zooplankton regulation is also evident in herring growth, shifted from being salinity driven in the 1970s–1980s to being driven by food competition with sprat after the early 1990s. Cod therefore seems to act as a regulator of the Baltic ecosystem, being able to control sprat abundance and buffer stochastically high sprat recruitment events and their severe consequences on other levels of the foodweb.

In recent years, hydrological conditions for cod recruitment have improved not only in terms of favourable conditions for egg and larval survival, but also potentially favouring the development of *Pseudocalanus* spp., which is one of the key zooplankton preys for cod larvae. Cod recruitment success, however, has not increased as expected. The feedback mechanisms potentially delaying cod recovery can be found in the top down control by sprat on the food resources for larval cod, but also in the changed size structure of sprat population and predation by sprat on cod eggs. Moreover, the fishing related changes in age structure of cod spawning individuals cannot be discounted.



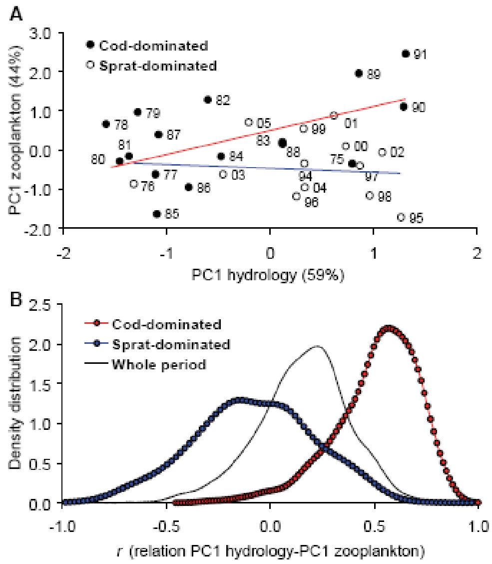


Figure 11.2.1.left Alternative dynamics of the central Baltic Sea ecosystem related to the dominance and subsequent collapse of the cod population. When cod dominate the system, the low sprat population is not able to affect significantly zooplankton. This situation drastically changes in situations of low cod biomass, when the resulting high sprat population heavily controls zooplankton. A) The alternative dynamics are illustrated by the changes in the relationship between sprat abundance and PC1 of zooplankton parameters (i.e. total biomass, species composition, stage composition and vertical distribution) in the scenarios of cod and sprat dominance, respectively. The vertical dashed line represents the ecological threshold separating the two scenarios. B) The alternative dynamics are illustrated by the density distribution of the correlation coefficients between sprat abundance and PC1 of zooplankton parameters, obtained by bootstrap resampling (10,000 times), in the whole study period and in the two alternative scenarios. Source: Casini *et al.*, 2009, PNAS 106: 197–202.

Figure 11.2.1.right. Dual relationships between zooplankton and hydrological conditions in the two scenarios. When cod dominates the system, and consequently the sprat population is low, zooplankton is driven by hydrological conditions. In situations of low cod biomass, on the other hand, zooplankton is decoupled from hydrological conditions because of the much stronger effect of sprat predation. A) The alternative dynamics are illustrated by the dual relationship between hydrological conditions (PC1 of salinity and temperature in spring and summer) and PC1 of zooplankton parameters in the scenarios of cod and sprat dominance, respectively. B) The alternative dynamics are illustrated by the density distribution of the correlation coefficients between PC1 of hydrological conditions and PC1 of zooplankton parameters, obtained by bootstrap resampling (10,000 times), in the whole study period and in the two scenarios. Source: Casini *et al.*, 2009, PNAS 106: 197–202.

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Annex 2: Agenda

Monday 16/03/09

0900 – 1200	Back-to-Back Meeting with the ICES Transition Group of Integration Activities in the Baltic - TGBALT (chaired by Yvonne Walther & Christian Möllmann; for those interested)
1200 – 1300	Lunch
1300 – 1400	Start of WGIAB: Practical information, discussion of the agenda, planning of the work and the reporting, (Christian Möllmann, Anna Gårdmark & Christian v. Dorrien)
1400 – 1530	Discussion and planning of the work

ToRs a and b

- Recent changes in the Baltic ecosystem – update of the Integrated Assessments and potential analyses (Christian Möllmann)Target levels in the Baltic Sea Action Plan (BSAP) and the HELCOM BIO indicator and assessment system (Anna Gårdmark)
- Work of the Baltic Nest Institute with regard to the BSAP (Thorsten Blenckner)

ToRs c, d and e

- Introduction into the planned modelling work (Anna Gårdmark)
- Request by WKMAMPEL (Christian Möllmann)

1530 – 1600	Coffee and Tea
1600 – 1800	Discussion and planning of forthcoming publications in relation to WGIAB

- ICES Cooperative Research Report (Rabea Diekmann)
- HELCOM Indicator Fact Sheet, WGIAB Flyer & more PR (Christian Möllmann)
- Presentation of scientific publications in prep. (Thorsten Blenckner & Rabea Diekmann)

Tuesday 17/03/08

0900 – 1045 Modelling presentations (ToRs c, d & e):

- Strategy of the modelling work (Anna Gårdmark)

Presentations on models to be used (10 min + 5 min questions)

- o XSA and long-term projections (Eero Aro)
- o Stochastic cod model (Anders Wikström)
- o ISIS cod model (Francois Bastardie)
- o SMS (Stefan Neuenfeldt)
- o Physiologically structured foodweb model (Anieke ván Leeuwen)
- o BALMAR foodweb model (Martin Lindegren)
- o ECOPATH/ECOSIM (Maciej Tomczak, Susa Niiranen)

- Presentation on common model forcing, i.e. future salinity and temperature time-series as well as management scenarios (Anna Gårdmark)

1045 – 1100 Coffee and Tea

1100 – 1300 Modelling presentations cont. & discussion on modelling strategy

1300 – 1400 Lunch

1400 – 1530 Parallel work in subgroups

- Modelling
- Integrated Assessment update, ICES CRR and HELCOM Indicator Fact Sheet
- WKMAMPEL request

1530 – 1600 Coffee and Tea

1600 – 1800 Parallel work in subgroups

Wednesday 18/03/08

0900 – 1045 Parallel work in subgroups

1045 – 1100 Coffee and Tea

1100 – 1200 Parallel work in subgroups

1200 – 1300 Short presentations on work progress (10+5 min.)

1300 – 1400 Lunch

1400 – 1530 Presentations on new projects and proposals, modelling approaches and other ideas

- "Economic-ecological modelling for sustainable fisheries management in the Baltic" (Rudi Voss) (30 + 15 min.)
- Project Reviews "ECOSUPPORT" (Brian MacKenzie), "AMBER" (Christian Möllmann), "PLAN FISH" (Anna Gårdmark) (10+5 min. each)
- "Switches in ecosystem functioning triggered by trophic cascades in the Central Baltic Sea" (Michele Casini)
- ESF Network Proposal ECOSHIFT (Christian Möllmann) (5+5 min.)

1530 – 1600 Coffee and Tea

1600 – 1700 Presentations cont.

Thursday 19/03/08

0900 – 1045 Parallel work in subgroups

1045 – 1100 Coffee and Tea

1100 – 1300 Parallel work in subgroups

1300 – 1400 Lunch

1400 – 1530 Summary of the subgroup work, incl.

- discussion of state of the group work

- planning of future activities
- discussion on ToR e)
- decision on writing subgroups

1530 – 1600 Coffee and Tea

1600 – 1800 Parallel work in subgroups

1900 – Common Dinner

Friday 20/03/08

0900 – 1045 Final Session

- Wrap up of subgroup work
- State of the report
- Discussion on next meeting (ToRs, venue, focus)
- Input to WKMAMPEL, TGBALT, WGBFAS, TGHEAD, WGHAME, WGBAST and HELCOM Bio

1045 – 1100 Coffee and Tea

1100 – 1300 Report writing

1300 - Closure of the meeting

Annex 3: WGIAB terms of reference for the next meeting

The **Working Group on Integrated Assessments of the Baltic Sea** [WGIAB] (Chair: Christian Möllmann, Germany, A. Gårdmark, Sweden and Thorsten Blenckner, Sweden) will meet in the ICES Headquarters, Copenhagen, Denmark from XX to XX April 2010 to:

a) update the Integrated Ecosystem Assessments (IEA) for the different Baltic Sea subsystems, conducting an IEA for the Western Baltic, as well as a spatially disaggregated IEA for the Central Baltic to investigate the effects of spatial variability in the relative distribution of the cod and clupeid stocks;

b) develop and coordinate IEAs for other ICES areas with other related ICES expert groups such as TGHEAD and WGHAME;

c) analyse subsystem specific candidate indicators for early warning of regime shifts and design necessary monitoring activities;

d) evaluate target levels of the HELCOM Baltic Sea Action Plan and the HELCOM BIO set of indicators and assessment system in relation to the WGIAB data analyses;

e) review the state of the "ensemble modelling" and finalize a proposal for a strategy of the use of ecosystem modelling within the Baltic Sea assessment and ecosystem-based advice;

f) analyse Baltic Sea fish stock dynamics corresponding to precautionary and limit reference points used for single species advice in relation to different climate and foodweb regimes using the WGIAB ensemble modelling approach

g) recommend and prepare information on ecosystem function and development as well as environment fish relationships for use in WGBFAS;

WGIAB will report by XX April 2010 to the attention of the XXXXX Committee.

Supporting Information

Priority:	This Working Group aims to conduct and further develop Integrated Assessments for the different subsystems of the Baltic, as a step towards implementing the ecosystem approach in the Baltic
Scientific justification and relation to action plan:	The Working Group contributes to Actions 1.1, 1.2, 1.5, 1.6, 1.7, 1.11, 1.12, 2.1, 2.2, 2.8, 2.9, 3.1, 3.2, 3.3, 3.6, 3.12, 3.15, 4.1, 4.2, 4.3, 4.6, 4.11, 5.2, 5.3, 5.4, 5.5, 5.6, 5.9, 5.17, 7.3, 8.1, 8.4 of the ICES Action Plan. Key to the implementation of an ecosystem approach to the management of marine resources and environmental quality is the development of an Integrated Assessment (IA) of the ecosystem. An IA considers the physical, chemical and biological environment, including all trophic levels and biological diversity as well as socio-economic factors and treats fish and fisheries as an integral part of the environment. The work of the group includes (i) a further development of overview assessments, and assessments for the different subsystems of the Baltic, (ii) contributions to the HELCOM assessment system, (iii) implementing ecosystem modelling in the assessment framework and (iv) developing adaptive management strategies. The working group serves as a counterpart to the fish stock assessment working groups and provides these with information on the biotic and abiotic compartments of the ecosystems. A key task of the working group is to serve as a communication and organisation platform between the different science organisations/groups involved in the area. Primarily this applies to the cooperation between ICES and HELCOM, but will also include cooperation with BALTEX, as well as EU projects and BONUS projects. The working group is thus key to implementing the ecosystem approach to the Baltic Sea. Further a close cooperation with IA activities in other areas (e.g. TGHEAD, WGHAME) is envisaged to coordinate the ICES IA activities.
Resource requirements:	Assistance of the Secretariat in maintaining and exchanging information and data to potential participants. Assistance of especially the ICES DATA CENTER to collect and store relevant data series
Participants:	The Group is normally attended by 20–30 members and guests.
Secretariat facilities:	None.
Financial:	No financial implications.
Linkages to advisory committees:	Relevant to the work of ACOM and SCICOM
Linkages to other committees or groups:	BCC, all SG/WGs related to Baltic Sea issues, TGHEAD, WGHAME
Linkages to other organizations:	HELCOM, BOUNS, BALTEX

Annex 4: Recommendations

Recommendation	For follow up by:
1. Discuss and organize a back-to-back meeting of WGIAB and WGBFAS in 2010	ACOM, WGBFAS
2. Discuss proposal for a "Workshop on Ingegration of economics, stock assesment and fisheries management (WKFIEAM) in 2010	ACOM, SCICOM, WGBFAS

Annex 5: Proposal for a Workshop on Integration of economics, stock assessment and fisheries management (WKIEFAM)

A Workshop on integration of economics, stock assessment and fisheries management [WKIEFAM], is planned to take place in Kiel, Germany for 3 days on DATE (Co-Chairs: to be decided) to:

a) review the state-of-the-art in integrating economic (modelling), stock assessment and fisheries management plans

b) identify the data and information required for integrated economic modelling of fisheries

c) identify ways to develop and use ecological-economic modelling tools to be used in fish stock assessment

d) identify ways to evaluate risk assessment scenarios which may affect access to fisheries

Supporting information

Priority	There is an increasing demand for coupled ecological and economical models in advice giving bodies. However, the possibilities to coordinate the expertise of economists and ecologists have not fully been used yet. The goal will be to couple economic expertise directly with the ecological understanding within ICES to enhance the quality of fisheries assessment and the value of the advice.
Scientific Justification and relation to Action Plan:	The incorporation of economics in fisheries assessment might lead to a better result and an enhanced communication with fisheries industry and fishermen as the advice could be made on the basis of a deepened understanding of: the economic incentives of fishermen and industry the economic interaction between different fisheries and transaction costs of different policies coupled with the existing sound biological knowledge within ICES. The workshop will directly feed goals 3and 5 of the action plan: "Evaluate options for sustainable marine related industries, particularly fishing and mariculture" and "Enhance collaboration with organisations, scientific programmes, and stakeholders (including the fishing industry) that are relevant to the ICES goals".
Relation to Strategic Plan:	The possibilty to incorporate economics directly into the scientific advice would enhance the acceptance of the advice on stakeholder level and to "…deliver the advice that decisionmakers need…" (goal 3 of the strategic plan)
Resource Requirements:	No specific ressource requirements beyond the need for members to prepare for and participate in the meeting
Participants	Interested scientist, economic modellers, ACOM members, Assessment group members, stock assessment experts
Secretariat Facilities	Sharepoint, secretariat support for reporting
Financial:	Travel cost support
Linkages to Advisory Committees:	The incorporation of economy in fisheries advice should be of basic interest to ACOM

Linkages to other Committees or Groups:	Assessment groups (ACOM)
Linkages to other Organisations:	None
Cost Share:	

Annex 6: Proposal for a structure of a new Regional Seas Steering Committee within the new ICES Structure

The 2009 meeting of WGIAB was started with a joint meeting with TGBALT (see Chapter 10). During this meeting general issues on the future of the "Baltic Science Community" within the new ICES structure have been discussed. A major outcome was a potential structure on how the different EGs interact/interface in the future. This structure is outlined in the figure below.

Generally the idea of a "Regional Sea Steering Committee - RSSC" was supported by the group. The RSSC should be the forum which coordinates the different Baltic EGs under SCICOM ("green groups"). In parallel the interaction with similar groups from other regions should be coordinated ("blue groups").

A major concern in the discussion was the lacking interface between SCICOM and ACOM groups. This should be assured for the Baltic by WGIAB, while for the general level TGHEAD should be the coordinating forum. These groups should provide input on ecological/environmental information into ACOM groups ("grey groups").

A new initiative is WKIFEAM (see Annex 5) which has the aim to advance Bio-economic and management strategy modelling for the Baltic Sea. For further ideas on how the different groups might interact in the future, see Chapter 8.2.

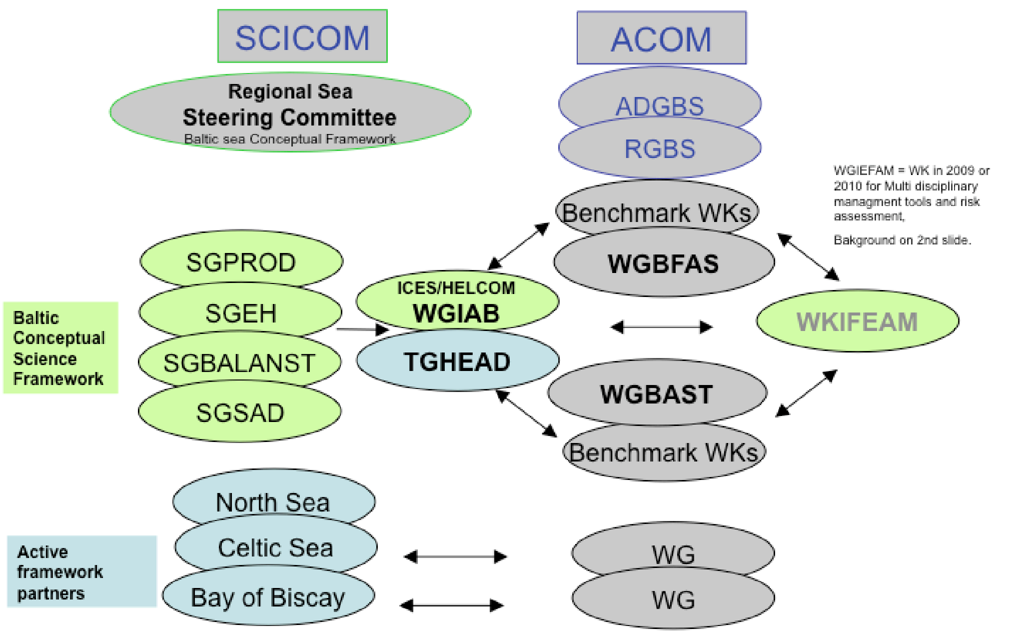

Figure A6.1. Scheme of a potential structure for the Baltic Sea Science Community within the new ICES structure.

SGPROD – Study Group on Baltic Sea Productivity Issues
SGEH – Study Group for the Development of Integrated Monitoring and Assessment of Ecosystem Health in the Baltic Sea
SGBALANST – Study Group on data requirements and assessment needs for Baltic Sea trout
SGSAD – Study Group on Salmon Age Determination

WGIAB – ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea
TGHEAD – Transition Group on Holistic Ecosystem Assessments and Diagnostics
ADGBS – Advisory Draft Group for the Baltic Sea
RGBS – Review Group for the Baltic Sea
WGBFAS – Baltic Fisheries Assessment Working Group
WGBAST – Working Group on Baltic Salmon and Trout

Annex 7: Models description

Model 1: Stochastic autoregressive cod model

Wikström, A., Knape, J. & Jonzén, N.

Model fitting to data traditionally assumes either that population size or any index thereof are measured with perfect accuracy (there is no 'observation error') or that the population evolves deterministically over time (there is no 'process error'). Undoubtedly both sources of error are present in practice and the aim with the model presented here, is to make it possible to estimate parameters of interest when both types of errors are present simultaneously.

The model consists of an unobserved (hidden) state, stock biomass (B), which is measured by an observable state: Catch per unit effort (CPUE).

The stock biomass is described by a Ricker model with temperature (T) and harvesting (H) as covariates. The process error ($\exp(\varepsilon)$) is lognormally distributed. Other variables (e.g. spawing volume and salinity) could also be introduced in the model as additional covariates.

The relation between CPUE and B is described by an observation equation. The parameter q is catchability and the exponent variable (α) allows for a nonlinear relation between CPUE and B ($\alpha = 1$ means a linear relation). The observation error ($\exp(\omega)$) is lognormally distributed. We did not find it possible to estimate the parameters α_2 and q simultaneously. The two parameters (q and α) in the observation equation was for that reason externally estimated with data from XSA stock estimations.

$$B_{t+1} = B_t \exp(\alpha_1 + \alpha_2 B_t + \alpha_3 T_t - H_t + \varepsilon_t)$$

$$H_t = -\ln(1 - C_t/N_t)$$

$$CPUE_t = qB_t^{\alpha}\exp(\omega_t)$$

B_t is stock biomass.

C_t is reported landings (catch) multiplied with 1.35 to account for discarding and unreported catches (cf. ICES 2008a)

$CPUE_t$ is catch per unit effort.

T_t is temperature.

H_t is instant harvest mortality (fishing mortality).

α_1 is a location parameter

α_2 is the strength of density dependence.

α_3 is a proportionality constant for temperature.

ε_t is an environmental random variable (process error) drawn from a normal distribution with mean value zero and standard deviation: σ_p.

q and α defines the relation between CPUE and B. The parameter values used in the simulations are estimated from XSA data from the time period 1982–2005 (WGBFAS 2007).

ω_t which describes measurement error is drawn from a normal distribution with mean value zero and standard deviation: σ_m.

For application during this meeting, it was decided that only the variable: Spawing biomass (SSB) should be used in the model comparison. The stochastic model only calculates total biomass (SB) and no SSB. The models output has therefore been transformed from SB to SSB by multiplication with a constant (0.604) which is estimated from historical XSA data (WGBFAS 2007).

The stochastic model calculates fishing mortality (F) from calculated total biomass and reported catch (F=-ln(1-C/SB). The values obtained from the model are lower than the values from the XSA analyze (F_{mod}=0.67and F_{VPA}=1.08, calculated as mean values for the last 10 years). To make a fair comparison with the other models, especially in the "business as usual" cases, the catch values have been increased with 35%. This gives a Fishing mortality from the model (F_{mod}=1.03) which is approximately the same as the XSA value. The catch values used in the model is without misreports and according to WGIAB (2008) "…(recent misreporting estimates imply that true catches are at minimum 30–40% greater than reported catches)." The here proposed increase of the catch values, with 35%, seems in that perspective quite reasonable.

As model 1 is a stochastic model it is possible to calculate the probability of cod extinction for the different scenarios (see Table A7.1).

Table A7.1. Probability of cod extinction for the stochastic model (model 1)

Scenario	No climate change	Climate change
1	0.128	
2	0	
3	0	
6		0.346
7		0
8		0

Model 2: Cod model in FLR

Bastardie, F.

A Management Strategy Evaluation framework (MSE) has been recently developed (Bastardie *et al*. in prep) to test the performance of the recovery plan for the Baltic cod stocks introduced in 2008. The evaluation frame is built in the R programming language (R 2007) from basic blocks provided by the Fishery Library in R (FLR / FLCore 2.0 www.flr-project.org). FLR is an R package providing fishery related classes for storing stock and fishery data, and stock assessment methods. A MSE is a tool aiming at comparing the relative performance of various management decisions for reaching the management objectives. One key aspect is the testing of the robustness of the management procedures against various sources of uncertainties to get an indication of the sensitivity of the management being tested. A MSE stochastic simulation framework comprises two elements: the Operating Model (OM) and the Management Procedure (MP). The OM represents standard plausible alternative population status and evolution, e.g. different SSB-R relationships, from which the departure is measured from. The MP or management strategy is the combination of the available simulated data, the stock assessment ('perceived' stock status) and the management model or Harvest Control Rule (HCR). These generate the management options, such as a targeted F and the TAC. An important aspect of MSE is that the management decisions from the HCR are cycled back into the OM so that their impact is reflected in the simulated stock evolution. This present evaluation includes the sensitivity testing of the management system in driving the stocks against a range of errors in the management procedure (process, observation and implementation error).

This model framework is reused and conditioned on the forcing time series and variables that the Working Group chose as a standard platform to compare outcome of the different models. The model projects forward the cod stocks indicators under future environmental scenarios of salinity and with or without the management plan.

The FLR MSE framework is coupled with the BALMAR statistical foodweb model predicting cod, sprat and herring Spawning Stock Biomass (SSB) from biological interactions, salinity and temperature under different environmental scenarios. The time series forcing are not those suggested by the WG but rather those which have been used to fit the BALMAR model. BALMAR model output is currently SSB while the FLR model projects number-at-age forward. The cod stock number at age needed then to be calculated back to feed the FLR model from the predicted BALMAR cod SSB. This has been done using the maturity ogive, the weight-at-age and a selectivity pattern as allocation key for age disaggregation.

Table A7.2. Cod model in FLR

	1. Single cod stock evaluation (Model 2)	2. cod stock evaluation under multi-species interactions and climate forcing (Model 2b)
General settings	Time span for projection: 2006-2025 *[one hundred years forward was not realistic because too time consuming for a low relevance for the present model (i.e. single stock management model)]* Number of iterations (for stochastic management error) 50 Start year of the projection 2006 Start year of the management plan 2007	
cod stock biological parameters	Age-structured population (2 to 8+) Historical population from the last WG assessment (WGROUND09) Weight-at-age mean over 2005-2007 (WGROUND09) Maturity-at-age mean over 2005-2007 (WGROUND09) Number-at-age pop 2006 from initial run from XSA 2008 M-at-age 0.2 across ages SSB-R age 2 depending on salinity: R= exp(-1.83360*SSB/1e5+0.19867*SSB/1e5*SALINITY+11.85025) decided by WGIAB with the salinity in psu and SSB in ktons	
sprat and herring stocks biological parameters	None	SSB sprat 2006 958 ktons *not the same as BALMAR because BALMAR start in 2004* SSB herring 2006 688,231 ktons *not the same as BALMAR because BALMAR start in 2004* F sprat 2006 0.30214 *as BALMAR* F herring 2006 0.14864 *as BALMAR*
Exploitation parameters	exploitation pattern constant Implementation error on TAC at y+1 lognormal error with CV= 0.1 TAC constraints +/- 15%	
Operating Model	Exponential decay $N_{y+1,a+1} = \begin{cases} N_{y,1} & , a=1 \\ N_{y,a}e^{-F'_{y,a}-M'_{y,a}} & , 1<a<A- \\ N_{y,A-1}e^{-F'_{y,A-1}-M'_{y,A-1}} + N_{y,A}e^{-F'_{y,A}-M'_{y,A}} & , a=A-1 \end{cases}$	BALMAR model predicting cod, sprat and herring SSB Conversion of the SSB to number-at-age using: $N_{a,y} = \lfloor SSB_y \times (\sum_a Sel_a \times Mat_a) \times Sel_a \rfloor / Wt_a$ With Sel a, an allocation key for age disaggregation: $Sel_a = \left[N_{a,y-1} \times Wt_{a,y-1}\right] / \sum_a \left[N_{a,y-1} \times Wt_{a,y-1}\right]$
Assessment model & parameters	Model eXtended Survivor Analysis (XSA) assessing past stock numbers and fishing mortalities from catch-at age data and CPUE indices (i.e. the true population with observation error). Model settings XSA settings from WGROUND09 except for shrinkage on F with standard error set to 2 recruitment in the 2 years Short-Term Forecast (STF) constant at 130494 thousands from geometric mean over past 17 years as in WGROUND09 Observation error * lognormal error with CV of 30% on CPUE indices at y-1 * lognormal error with CV of 15% on catch at age matrix at y-1	
Environmental forcing	Salinity time series from WGIAB 2009 with/without climate change psu= -0.5y-1	Time series of • salinity • temperature as used in BALMAR with/without climate change psu= -0.5y-1, T x
Harvest Control Rule interpreted from the EU multi-annual recovery plan	$F_y = F_{y-1} \times Effort_y / Effort_{y-1}$ $F_{y+1} = \begin{cases} F_y \times 0.9 & if \quad F_y \geq F_{target} \times 1.1 \\ F_y \times 1.1 & if \quad F_y < F_{target} \times 0.9 \\ F_{target} & Otherwise \end{cases}$ $Effort_{y+1} = \begin{cases} Effort_y \times 0.9 & if \quad F_y \geq F_{target} \times 1.1 \\ Effort_y \times F_{target} / F_{y+1} & if \quad F_{target} \times 0.9 < F_{y-1} < F_{target} \times 1.1 \\ Effort_y & Otherwise \end{cases}$ Assumption: Start Effort = 1	
Remark	No density-dependence (e.g. cannibalism); No predation	

Model 3: Monte-Carlo-Markov-Chain stochastic prediction model for cod

Aro, E.

Projections for cod in SD 25–32 were calculated for a 60 year period by Monte Carlo Markov Chain simulation. The model used is an extension of ICES standard medium-term simulation model, where uncertainty in survivor estimates as well as stock-recruitment model (in this case a classical Beverton-Holt SSB-R model) and environmental model (salinity driven SSB/R) were taken into account. The model is formulated and fitted to observations of catch in numbers by age groups, exploitation pattern, mean weight at age in the stock and the catch, maturity ogive, all from ICES standard single species assessment of cod (ICES 2008a) and a selected stock-recruitment relationship. Output variables (SSB, yield, recruitment) are estimated as mean values from 200 simulations per year for years 2009–2068.

Different stock-recruitment relationships were used in the scenarios without and with climate change. In the projections assuming no climate change a Beverton-Holt stock-recruitment relationship was fitted to historical estimates of SSB and recruitment for all the years 1974–2007 (ICES 2008a) assuming recruitment normally distributed random variable. This SSB-R relationship was then used for the projections. Other inputs for projection was the same as used for the short-term forecast by WGBFAS 2008: ages 2–8+ were used, mean weight at age was assumed to equal 2005–2007 average and represent the present growth rate for the whole simulation period. Density-dependent growth changes have thus not been taking into account in these simulations. In the projections assuming climate change, the salinity-dependent SSB-R relationship was used, with recruitment measured in number of two year old (Table 7.1).

Model 4: Cod mini model

Müller-Karulis, B.

The Minimodel is an age-structured model of the Baltic cod stock, driven by fishing mortality and a salinity-dependent stock-recruitment function. The model is similar to the type of models used e.g. for medium-term prediction of herring stocks in the Baltic (a).

Number of fish in age class i at the beginning of year j, N_i^j, is calculated as $N_i^j = N_{i-1}^{j-1} \exp\left(-M_{i-1}^{j-1} - S_{i-1}^{j-1} F_{i-1}\right)$, where M_{i-1}^{j-1} denotes the natural mortality age group j experienced during the previous year, while the term $S_{i-1}^{j-1} F_{i-1}$ describes the fishing mortality incurred by a fishery operating at selectivity S_{i-1}^{j-1} and average fishing mortality F_{i-1}. Ages 3 to 8 were included in the model. Age class 8 survivors were returned to age class 8 to close the model. Recruits, i.e. the number of cod at age 2 at the beginning of each year, were modelled by a salinity-dependent Ricker type stock–recruitment function as

$$N_2^j = a \cdot N_{mature}^{j-2} exp\left(b \cdot N_{mature}^{j-2} + c \cdot Sal_{80-100}\right)$$

where N_{mature} is the number of mature fish in the stock, calculated based on average maturity for each age class observed in 2002 – 2004, and Sal_{80-100} is the summer salinity in the in the halocline region of the Eastern Gotland Basin, i.e. at 80 – 100 m depth. Coefficients a, b, and c, were obtained by fitting a linear model to the logarithmic form of the stock–recruitment function, using XSA data for stock size and number of recruits generated for the time period 1974–2005:

$$\log\left(\frac{N_2^j}{N_{mature}^{j-2}}\right) = a \cdot + b \cdot N_{mature}^{j-2} + c \cdot Sal_{80-100}$$

The stock–recruitment relationship represents the XSA based recruitment reasonable well (Figure A7.1 left, $R^2_{adj} = 0.44$, $p < 1e\text{-}4$). At the range of observed cod SSB values, the number of surviving recruits reaches a salinity-dependent maximum with higher recruitment success at larger salinities in the Gotland deep halocline region (Figure A7.1, right).

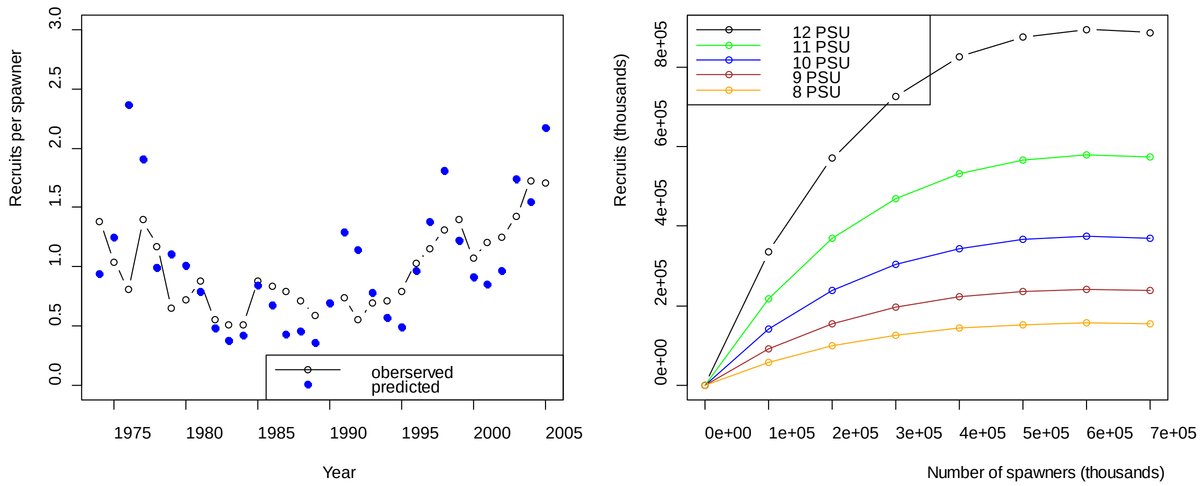

Figure A7.1. Observed (as estimated by ICES 2008a) and predicted cod recruitment during 1974 – 2005 (left) and salinity isopleths (right) of the stock–recruitment relationships for cod stock sizes and Gotland deep halocline salinity ranges observed

Model 5: Dynamic model on the interactions between cod, sprat and herring

Heikinheimo, O.

This model is based on the MSVPA results (SGMAB key run 2005). The age structure is simplified, i.e. adult age groups were combined. The fish stocks are presented as numbers of individuals, with the exception of the spawning stock biomass. The main structural difference compared to MSVPA is the functional response in predation by cod on sprat and herring. In this model the type and form of the functional response can be modified (type III was used in the simulations). In MSVPA the functional response was of type II.

The stock-recruitment relationships for sprat and herring are based on the MSVPA results (2005), with no environmental effects. The S/R equation for cod is according to Heikinheimo (2008), with the annual average deep-water salinity from Landsort Deep (depths >100 m) as environmental index. The salinity was modelled as constant for “good” and “bad” periods for cod reproduction (because of comparability to the

MSVPA results). Random variation was incorporated in the parameters of the S/R equations (*a,b,* and *c* in the equation for cod).

Possible negative effects by sprat on cod, such as predation by sprat on cod eggs, or food competition in the early phases, were not modelled. Cannibalism in cod was taken into account as higher natural mortality in young age groups in periods with abundant cod stock.

The software Powersim Constructor with Euler's integration method was used to compile and run the model.

The submitted manuscript is currently under review. An earlier version of the model was presented in the ICES Annual Science Conference in Helsinki, 2007 (ICES CM 2007/C:11).

Basic equations:

The stock-recruitment equation for cod (Heikinheimo 2008) is

$R = S\exp(a - bS + c(E - \bar{E}))$ (1)

where R is the number of age-0 recruits in thousands, S is the spawning stock biomass (in thousand tonnes), E is the environmental variable (average deepwater salinity) and $\bar{E}$ is the mean value, and c is constant.

For both herring and sprat, recruitment was modelled according to ICES (2005) using Ricker's equation

$R = \alpha S \exp(-\beta S)$ (2)

where R= recruitment (number of age 0 recruits), S= spawning stock biomass (kg) and α and β are constants.

The recruits in each submodel enter the age class 0 at a species-specific recruitment time, and the fish enter the next age class in the beginning of each year. The rate of change in each age class during the year was modelled according to the equation

$dN_a/dt = -ZN_a,$ (3)

where N_a is the number of fish in age class a and Z is the instantaneous rate of total mortality per year.

Modelling the predation by cod on herring and sprat

The clupeids are considered here as one group of prey for cod, because their individual size and behaviour are similar. The total consumption then breaks down in proportion to abundance of the prey species (see below). The value for maximum consumption of clupeids was derived from the number of clupeids taken per cod versus clupeid density, according to the results of SGMAB key run (ICES 2005). The equation for functional response is

$P_i = C_i\,(N_{h+s})^n/[(N_{h+s})^n+(D_{h+s})^n]$ (4)

P = functional response, i.e. number of herring + sprat eaten by one cod in one year

C = maximum consumption by cod of herring + sprat (in numbers), i.e. the number of herring and sprat together eaten by one cod/ year when the abundance of the clupeids was at a maximum level during the study period

i = age classes of cod (age 1, age 2, age ≥3)

N_{h+s} = size of herring + sprat stock in numbers (all age groups)

D_{h+s} = half saturation constant (size of herring + sprat stock when the consumption was half of the maximum)

n = constant that determines the type of the functional response (n = 1 for type II response, n ≥2 for type III response)

According to the SGMAB results, sprat was taken about twice the proportion that the relative abundance compared to herring would suggest (Figure 3). To take this into account, the functional responses by prey species were calculated as follows:

$P(\text{her})_i = N_h P_i / (N_h + sN_s)$; (5)

$P(\text{her})_i$ = number of herring eaten by one cod in one year

i = cod age 1, 2, ≥ 3

N_h = size of the herring stock

N_s = size of the sprat stock

s = 'preference coefficient' for sprat compared to herring;

and respectively;

$P(\text{sprat})_i = sN_s P_i / (N_h + sN_s)$ (6)

$P(\text{sprat})_i$ = number of sprat eaten by one cod in one year

The value given for the preference coefficient in the model was 2, which is a rough estimate based on the results of SGMAB.

Instantaneous mortalities per year caused by one cod of age class i are calculated as $P(\text{her})_i / N_h$ and $P(\text{sprat})_i / N_s$, and the total predation mortality caused by cod ($M2$):

$M2(\text{her}) = \Sigma\ (N(\text{cod})_i\ P(\text{her})_i / N_h)$ (7)

$M2(\text{sprat}) = \Sigma\ (N(\text{cod})_i P(\text{sprat})_i / N_s)$ (8)

Model 6: SMS

Neuenfeldt, S.

SMS (Stochastic Multi Species model) (Lewy and Vinther, 2004) is a stock assessment model including such biological interactions estimated from a parameterised size-dependent food selection function. The model is formulated and fitted to observations of total catches, survey CPUE and stomach contents for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix. Once the parameters have been estimated, the model can be run in projection mode, using recruitments from stock–recruitment relations and fishery mortality derived from an array of Harvest Control Rules.

SMS is, in contrast to MSVPA, a stochastic model where the uncertainties on fishery, survey and stomach contents data are included. The parameters are estimated using maximum likelihood (ML) and the confidence limits of the estimated values are calculated by the inverse Hessian matrix or from the posterior distribution from Markov Chain Monte Carlo simulations. The approach contains submodels for stock recruitment, food selection, predation mortality, fishing mortality and survey catchabilities. Further, in contrast to the fully age-structured MSVPA, SMS is a semi age–length structured model where the stomach content observations and the food selection model are length based. This allows for more realistic food selection models and the use of the originally sampled length based stomach data. Catch data models are kept age structured as length-structured data are not available for the cases considered.

The Baltic multispecies assessment process started about 20 years ago and presently the following data (catch, mean weight, proportion mature and food ration) by age group, quarter and year are available for the Baltic Sea.

Baltic Main Basin combined subdivisions (ICES 2008a):

Years 1974–2007

Cod in Subdivisions 25–29+32

Sprat in Subdivisions 25–32,

Herring in Subdivisions 25–29+32 (i.e. including the Gulf of Riga),

a total of 55000 cod stomachs sampled in the period 1977–1994

Input data to SMS are given by quarter of the year. This time step has also been used by ICES SGMAB (ICES 2005) and input including catch numbers, mean weight at age, proportion mature and food rations were as far as possible copied from this SG. Survey CPUE data were copied from ICES single species assessment data. Stomach content data, 1977–1994 have previously been compiled for use in the age-based MSVPA and are used by SGMAB. SMS uses stomach data by size classes, however, and a recompilation of the "raw" stomach data are now available on the standard ICES format. During the recompilation of data, errors were spotted in the old data compilations and some of the methods previously used were rejected.

SMS can fit the catch at age, survey CPUE and recruitment submodels reasonably well, but the model has limited ability to predict the stomach contents. Further analysis of the residuals from the stomach contents observations showed a distribution of residuals for the named prey species, with an excess of large positive residuals (higher observed than expected stomach contents). The distribution of "other food" residuals has an overrepresentation of negative residuals. The residuals of named prey species seem independent of the predator-prey size ratio, indicating a good fit to the size model. When the residuals are plotted against the size of the prey, there seems however to be an overweight of positive residuals for the smallest prey of all the prey species. This indicates that more small preys are found in the stomachs than expected from the model.

Model 7: Stage-structured biomass model of cod, sprat and their resources

van Leeuwen, A., de Roos, A.M. & Persson, L.

Baltic community / foodweb description

The stage-structured population model is based on a simplified representation of the Baltic foodweb that cod is part of. In this representation we take into account the cod population itself, one clupeid prey population (parameterization based on sprat), one benthic, and two zooplankton resource populations. The fish populations are divided into 3 life history stages: one juvenile, and two adult stages (small and large). We have taken into account only interactions of metamorphosed individuals, ignoring interactions that take place in the egg or larval stage of sprat and cod. In the interaction scheme used here, all sprat forage on a single zooplankton resource, whereas juvenile cod forage on another zooplankton resource, in addition to a small proportion of fish in its diet. So by default, cod and sprat do not compete with each other. For the adult stages, the diet composition of cod changes from a diet dominated by zooplankton to a diet that consists of a benthic resource in combination with fish prey (sprat or cod). (See Van Leeuwen *et al*., 2008 for a more extensive description of the model settings.)

General model formalism

The stage-structured model formulated for the cod-sprat-zooplankton system in the Baltic Sea is a model in terms of ordinary differential equations that was derived as an approximation to a physiologically structured population model (PSPM, Metz and Diekmann, 1986; De Roos, 1997; see De Roos *et al*., 2008 for a detailed description of this derivation). The stage-structured model is based on a detailed description of individual level processes, in particular food-dependent growth in body size and a size-dependent definition of reproduction and interactions, both within and between species. This size dependence is in the stage-structured model formulation implemented through the stage-dependent definition of processes, where the average size in a particular stage is used as representative size for all individuals in this stage. It should be pointed out, however, that in an equilibrium situation, the complete range of sizes throughout the stages is accounted for.

All dynamics at the population and community level result from processes at the individual level entirely. A feedback between the ecosystem, population and individual level arises because changes in the different stages are dependent on their own state and in addition the state of the population, community and environment.

Processes at the individual level

The essential feature of the stage-structured model is that dynamic processes at the individual level, like growth, development and reproduction, are modelled on the basis of a consistent representation of the individual energy budget, which stringently enforces conservation of energy and biomass. Individual growth and reproduction are the processes realizing biomass production. Energy requirements for both these processes are covered from the individual's net energy production, which amounts to the difference between the energy assimilated from consumed food and the maintenance costs. Food consumption, either from zooplankton or benthic resources or through predation on fish prey, is a function of the availability of these different food types in the environment. This explicit link between food availability, consumption and individual biomass production is one of the key characteristics of the stage-structured population model (of size-structured models in general) that differentiates it from other modelling formalisms.

Growth can only be accomplished when energy acquisition through feeding is larger than the maintenance costs and net energy production is hence positive. Individuals in the two adult stages invest a part of their acquired energy in gonadal development. When the energy balance yields a negative outcome, the individual is subject to starvation.

Loss of biomass from populations is through energy requirements to cover maintenance costs or through mortality, which is composed of background mortality, stage-dependent predation mortality and stage-dependent fishing mortality. It is relevant to point out here, that predation does not only lead to a decrease of biomass in the prey population, but simultaneously represents acquisition of energy and thus biomass for the predator, leading to biomass production at this level in the foodweb. In other words, the interactions between species that take place at the individual level, render the flow of biomass between populations and therefore give rise to the dynamics of the community as a whole.

Model 8: BALMAR

Lindegren, M., Möllmann, C., Nielsen, A., Brander, K., MackKenzie, B.

Foodweb dynamics of Baltic cod, sprat and herring were simulated using a first order multivariate autoregressive model (MAR(1) (based on an approach developed by Ives *et al*. (2003). A MAR(1) model can be viewed as a linear approximation to a nonlinear first order stochastic process (Ives *et al*., 2003) and essentially functions as a set of lagged multiple linear regression equations (one for each species of the foodweb) solved simultaneously to arrive at the most parsimonious model overall (Hampton and Scheuerell, 2006). Written in state space form, the MAR(1) model we used is given by:

$$\mathbf{X}(t) = \mathbf{B}\mathbf{X}(t-1) + \mathbf{C}\mathbf{U}(t-y) + \mathbf{E}(t) \qquad (1)$$

$$\mathbf{Y}(t) = \mathbf{Z}\mathbf{X}(t) + \mathbf{V}(t) \qquad (2)$$

where X are SSB values of cod, sprat and herring derived from multispecies fish stock assessment for the Baltic Sea (ICES 2006) at time t and t-1 respectively, and B is a 3 x 3 matrix of species interactions, an analogue of the "community matrix" used by May (1972) and Pimm (1982). Encompassing the effects of commercial fishing and climate-driven ecosystem dynamics, the covariate vector U contains values of mean annual fishing mortalities (F) and a number of selected climate variables known to affect recruitment of cod, sprat and herring respectively. Consequently, C is a 3 x 9 matrix whose diagonal elements specify the effect of covariates on each species. The process error E(t) is assumed multivariate normal and temporally uncorrelated. Likewise, the observation error of the covariance matrix of the normal random variable V(t) is assumed independent. Regression parameters were found by maximum likelihood estimation using a Kalman filter (Harvey 1989). The Kalman filter is a recursive estimator that sequentially calculates the unobserved values X(t) from the previous time step (t-1) using the model formula specified in Eq. 1. Predictions from the "hidden" state are then updated using the observed values, Y(t) of the "true" state (Eq. 2). Model fitting was performed on available time series covering the period 1974–2004.

Model 9: The Baltic Nest Institute foodweb model using Ecopath with Ecosim

Tomczak, M., Blenckner, T., Niiranen, S., Hjerne O

Ecopath/Ecosim (Christensen *et al.*, 2005) is a software for building foodweb models (www.ecopath.org), originally proposed by Polovina (1984) and later modified by adding the network analysis (Ulanowicz 1986). Trophic interactions among the functional groups (i) of the ecosystem can be described by a set of linear equations:

$Pi = Yi + Bi + M2i + Ei + Pi * (1\text{-}EEi)$

Where Pi is the total production; Y is the total catch; Bi is the total biomass ; M2i is the predation mortality; Ei is the net migration; and EEi is the ecotrophic efficiency of functional group i,(the fraction of production of i that is consumed within the system, exported or harvested).

EEi could be also expressed as:

$Bi*(P/B)i * EEi – \Sigma Bj * (Q/B)j * DCji – Yi – Ei = 0$

where (P/B)i is the production/biomass ratio of prey (i); (Q/B)j is the consumption/biomass ratio of predator (j); DCji is the fraction of the prey in average diet of predator(Christensen and Pauly, 1992). The dynamic part, Ecosim, allows temporal analysis and to fit the model to time series.

The current version of the NEST Ecopath/Ecosim model covers the area of the Central Baltic Sea (ICES SD 25–29 excl. GoR) and contains 28 functional groups (Figure A7.2). The model has been created based on different databases and literature sources. Fish groups are split into multistanza groups to represent the main ontogenetic changes and shifts in diets. Fisheries are represented by 3 fleets fishing on main fish species (Cod, Sprat and Herring). The mass-balanced model represents the state of the ecosystem in the middle of 1970’s and year 1974 has been chosen as a baseline for the temporal Ecosim simulation. To fit and drive the Ecosim model, time series of biomasses, fishing mortalities and environmental drivers have been used (Table A7.3). Biomasses and fishing mortalities are derived from WGBFAS 2008 report (ICES 2008a), based on XSA single species assessment. Calibration time series represent 33 years (1974–2007).

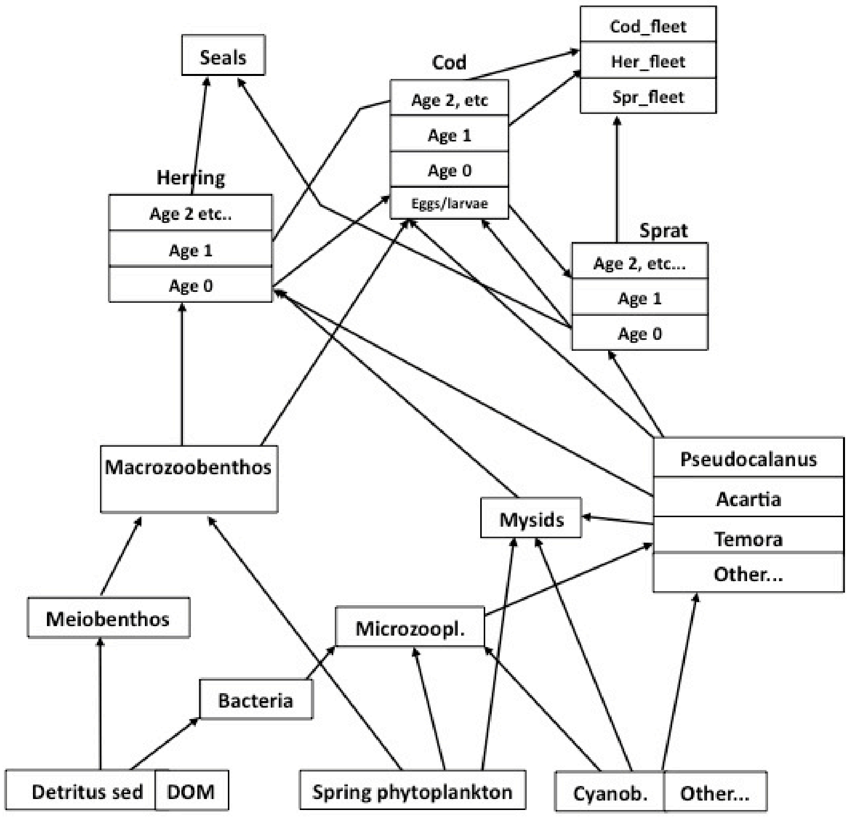

Figure A7.2. The conceptual design of the BNI foodweb model using EwE (model number 7).

Table A7.3. Forcing factors for the model

Forcing Factor	Season	Forced Group	Type of forcing
Temp_O_10_Aug	Summer	Sprat	eggs production
Temp 0_50m_spring	Spring	Acartia sp; Themora sp	impact on biomass
Sal_0_10 annual	Annual	Pseudocalanus sp	impact on biomass
Sal_80_100m GB	Annual	Cod	eggs production or youngest stanza
CodRV	Annual	Cod	eggs production or youngest stanza
macrozoobenthosB	Annual	macrozoobenthos	to fit relative biomass time series
Acartia_Spr	Spring	Acartia sp	
Temora_Spr	Spring	Temora sp	
Pseudo_Ann	Annual	Pseudocalanus sp	
spring phytoplankton	Spring	spring phytoplankton	
other phytoplankton	Everything else than spring	other phytoplankton	
cyanobacteria	Spring	cyanobacteria	
B_Sprat 1	Annual	Sprat Age 1	
B_Ad. Sprat	Annual	Sprat Age 2+	
B_Herring 1	Annual	Herring Age 1	
B_Herring 2	Annual	Herring Age 2	
B_Ad. Herring	Annual	Herring Age 3+	
B_Cod 2	Annual	Cod Age 2	
B_Cod3	Annual	Cod Age 3	
B_Ad. Cod	Annual	Cod Age 3+	
F_Sprat 1	Annual	Sprat Age 1	Fishing pressure on given group
F_Ad. Sprat	Annual	Sprat Age 2+	
F_Herring 1	Annual	Herring Age 1	
F_herring 2	Annual	Herring Age 2	
F_Ad. Herring	Annual	Herring Age 3+	
F_Cod 2	Annual	Cod Age 2	
F_Cod3	Annual	Cod Age 3	
F_Ad. Cod	Annual	Cod Age 3+	

Annex 8: Technical Minutes

Review related to the Report of **ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea** (WGIAB) 2009.

11–15 May 2009

Reviewers: Asgeir Aglen (Chair), Alberto Murta

WG Co-Chairs: Christian Möllmann, Anna Gårdmark and Juha Flinkman

Secretariat: Henrik Sparholt, Michala Ovens, Ellen Johannesen

The Review Group was asked to review the parts of the WGIAB report relevant for the special request: "Evaluate the ecosystem effects (including the size of the [Eastern Baltic] cod stock) of a reduction of the size of the sprat stock through an increased fishing mortality for sprat" (WKMAMPEL ToR d)

Since the RG only had two members and the timing of the review was close to the Advice Drafting Group, the RG gave priority to the review of the RGBFAS stocks where management advice should be given. In relation to the special request above the RG read through sections 7 and 9 in WGIAB, but were not able to dig into the details of the models used.

General

Comprehensive simulations have been done and the results (Section 7) are well described. The conclusions (Section 7.5) are left somewhat open, with warnings that results are preliminary and some of the models are still in a development phase. It is stated that the results should not be taken as final evaluation of fisheries management actions.

Section 9 concludes that a final response from WGIAB regarding this request should be communicated in late May 2009. This will be delivered to ADGBS.