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ICES International Council for the Exploration of the Sea

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Executive summary

The aim of WGIAB is to conduct and further develop Integrated Assessments for the different subsystems of the Baltic Sea, as a step towards implementing the ecosystem approach in the area. 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 parts of the environment. The work of this newly established working group involves (i) a further development of overview assessments, and assessments for other subsystems of the Baltic, (ii) contributions to the HELCOM assessment system, (iii) develop new monitoring strategies, (iv) develop adaptive management strategies, and (v) consider the use of ecosystem modelling in the assessment framework. WGIAB decided on 3 major goals to be accomplished within the 3 next years, which are (i) to regularly conduct RIEAs (Regional Integrated Ecosystem Assessments), (ii) develop adaptive management strategies and (iii) incorporate modelling into the assessment work.

The regular task of updating the RIEAs for different subsystems of the Baltic Sea was the focus of this years meeting. RIEAs have been performed for new subareas (Gulf of Finland and Bothnian Sea), while for the Central Baltic Sea and the Gulf of Riga the RIEAs were refined.

For all systems multivariate analyses have been conducted using matrices of time-series representing the ecosystems and their environments. Time-series were analysed by Principal Component Analysis (PCA). To illustrate systematic patterns in the time-series the traffic light framework applied in stock assessments was used. Additionally, to identify the years in which largest shifts occurred a clustering technique that is able to group sequential years has been applied. Finally, for selected systems variables of each dataset were separated into explanatory (mainly environmental measurements, fisheries data) and response variables (biological datasets) and were compared to each other by a canonical analysis using Redundancy Analysis (RDA). All 4 investigated subsystems displayed pronounced changes in the last 2–3 decades with a series of Reg*ime Shifts* (RS) identified in all multivariate datasets. Climate-related hydrographic change in the Baltic, i.e. decreases in salinity and oxygen and increase in temperature, have been identified as the main drivers of the ecosystem changes. Eutrophication and fisheries have been found to have system-specific impacts on the observed changes. The conducted IEAs proved to be an effective method for displaying ecosystem changes in the investigated subareas of the Baltic Sea and provide a sound basis for future ecosystem-based assessment approaches in the Baltic Sea. In addition, the compiled data sets are valuable sources of information for studies on ecosystem functioning and on natural and man-made effects on the ecosystems.

While the RIEAs will be a regular task of WGIAB, the focus of the work during the next 2 years will be on incorporating modelling into the assessment work (in 2008) and developing adaptive management strategies (in 2009). WGIAB started a review on available modelling approaches for the Baltic and outlined a short strategy for the use of modelling within the IA framework to be refined on the meeting in 2008. Management strategies will be developed in close cooperation between ICES and HELCOM. The group faced a series of communication problems, especially with the developing HELCOM assessment system. These need to be resolved for a future successful work of WGIAB.

Secondary aims discussed during the meeting were (i) the development of and a strategy of regularly updating the databases for the RIEAs, and (ii) surveying the presently conducted monitoring activities in the different areas and based on this suggesting a monitoring strategy suitable for future RIEAs.

1 Opening of the meeting and adoption of agenda

The Co-Chairs Christian Möllmann, Bärbel Müller-Karulis and Juha Flinkman welcomed the participants (Annex 1) and introduced the agenda (Annex 2) for the workshop. 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 (ICES), Bärbel Müller-Karulis*, Latvia (BSRP), and Juha Flinkman*, Finland (HELCOM)) will meet in Hamburg, Germany from 12–16 March 2007 to:

a) update and further develop the Integrated Assessments (IA) for the Central Baltic Sea and the Gulf of Riga and starting IAs for other subsystems of the Baltic Sea, e.g. the Gulf of Finland;

b) cooperate with the HELCOM Biodiversity Assessments (BA), especially by integrating fish and fishing pressure in the HELCOM work;

c) develop an adaptive management framework (DPSIR) to support the HELCOM Baltic Sea Action Plan;

d) develop a common indicator database jointly with the HELCOM and ICES Secretariats and link the data to the HELCOM indicator fact sheets;

e) prepare ecosystem overview and assessment documents as the basis for ecosystem-based management, coordinating the work with HELCOM MONAS and HELCOM Projects (e.g. BIO and EUTRO-PRO) and ICES (e.g. WGRED) activities;

f) provide an inventory on survey and monitoring activities by the different countries for a sound planning of future IAs, taking into account the inventories developed by HELCOM EUTRO-PRO and HELCOM BIO;

g) review the various ecosystem modelling approaches available for the area, and their importance and utility towards future IAs.

2 Introduction to WGIAB and its future strategy

The aim of WGIAB is 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 Sea. 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. An initial step towards the implementation of IAs for the Baltic Sea has been made in 2006 through the ICES/BSRP/HELCOM "Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB)". The workshop was successful in bringing together expertise from the different science organisations in the area and produced first ecosystem overview assessments for the Central Baltic Sea and Gulf of Riga. These overview assessments demonstrated dramatic changes during the last 3 decades on all trophic levels of the ecosystems related to climate variability and human exploitation. Further, these first analyses of extensive datasets contributed to the understanding of the functioning of both ecosystems.

The work of the newly established working group will base on the achievements of WKIAB and further develop the IA framework. This involves (i) a further development of overview assessments, and assessments for other subsystems of the Baltic, (ii) contributions to the

HELCOM assessment system, (iii) develop new monitoring strategies, (iv) develop adaptive management strategies, and (v) consider the use of ecosystem modelling in the assessment framework. The working group will serve as a counterpart to the fish stock assessment working groups and provide these with information on the biotic and abiotic compartments of the ecosystems. A key task of the working group will be 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 BSRP, BALTEX, as well as EU-projects and networks of excellence such as EUR-OCEANS. Especially conserving and integrating the achievements of BSRP into the assessment process will be a major task. The working group will thus be key to implementing the ecosystem approach to the Baltic Sea.

WGIAB decided on 3 major goals to be accomplished within the 3 next years, which are (i) to regulary conduct RIEAs (Regional Integrated Ecosystem Assessments), (ii) develop adaptive management strategies and (iii) incorporate modelling into the assessment work. The regular task of updating the RIEAs for different subsystems of the Baltic Sea will be the focus of this years meeting. RIEAs will be performed for new subareas (Gulf of Finland and Bothnian Sea), while for the Central Baltic Sea and the Gulf of Riga the RIEAs will be refined.

While the RIEAs will be regular task of WGIAB, the focus of the work during the next 2 years will be on incorporating modelling into the assessment work (in 2008) and developing adaptive management strategies (in 2009).

Secondary aims to be discussed during this and potentially also during future meetings will be (i) the development of and a strategy of regularly updating the databases for the RIEAs, and (ii) surveying the presently conducted monitoring activities in the different areas and based on this suggesting a monitoring strategy suitable for future RIEAs.

3 Integrated Ecosystem Assessments (TORs a & e)

Integrated Ecosystem Assessments (IEA) have been conducted for 4 subregions of the Baltic Sea: i) the Central Baltic Sea (CBS), encompassing the 3 deep basins, Bornholm Basin, Gdansk Deep and Gotland Basin; ii) the Gulf of Riga (GoR), iii) the Gulf of Finland (GoF), and iv) the Bothnian Sea (BoS).

In a first working step last years IEAs for the CBS and GoR (ICES 2006) have been updated and where necessary recompiled. For the 2 new subsystems, GoF and BoS, an inventory of available time-series has been conducted. Afterwards time-series have been selected for the IEAs based on a number of criteria: i) length of the covered period, ii) number of missing data points, iii) repesentativeness for a specific ecosystem component, iv) low cross-correlation with other variables. The finally selected time-series together with meta-data information are given in Annex 7.

Multivariate analyses

For all systems multivariate analyses have been conducted using the finally selected matrices of time-series. All data-series had a frequency or were compiled to one value per year and covered in maximum the period 1974 to 2005. Initially, time-series were analysed by Principal Component Analysis (PCA). Missing values in the datasets were replaced by variable averages. To improve linearity between variables and to reduce the relationship between the mean and the variance the biological time-series as well as nutrient values were ln(x+1) transformed. Subsequently a standardized PCA based on the correlation matrix was performed on the transformed values. Variable loadings and eigenvectors/ scores (years) were displayed on the first factorial plane and the years were connected in chronological order. Year scores along PC1 and PC2 were additionally plotted against time to detect possible regime shifts.

To illustrate systematic patterns in the time-series the traffic light framework applied in stock assessments (Link *et al.,* 2002; Choi *et al*., 2005) was used. Raw values of each variable were categorised into quintiles and each quintile was given a specific colour. Afterwards the variables were sorted according to their loadings along the first PC.

Additionally, to identify the years in which the largest shifts occurred a clustering technique that is able to group sequential years has been applied (chronological clustering; Legendre *et al.*, 1985; Legendre and Legendre, 1998). To show the most important breakpoints in the dataset the significance level alpha, which can be considered as clustering-intensity parameter, was set to 0.01, the connectedness level to 50%. According to the use of the correlation coefficient in the PCA analysis, data were first standardised and then the Euclidean distance function was calculated to determine the similarity between years.

Finally, for selected systems variables of each dataset were separated into explanatory (mainly environmental measurements, fisheries data) and response variables (biological datasets) and were compared to each other by a canonical analysis using Redundancy Analysis (RDA). RDA is a linear eigenvector ordination technique related to PCA, which constrains the axes to be linear combinations of explanatory variables. The significance of the relationship was investigated at two levels by Monte Carlo permutation tests: First a general test was applied concerning the null hypothesis of independence between response and explanatory data using the sum of all canonical eigenvalues. Second, a forward selection process was performed, which is an analogous procedure to the selection process in stepwise multiple regression, to identify the most important explanatory variables. Each variable was first treated as a single predictor and the variance explained represented, hence, ‘marginal effects’. Thereafter, the best explanatory variable was selected and all other environmental variables were ranked according to the additional explained variance that was given in conjunction with the already selected variable (-s). This process was repeated until all variables were included, with the explained variance representing “conditional effects”. At each step the significance of the added variables was tested by permuting randomly the rows of the species matrices (999 unrestricted permutations of raw data) and recomputing the RDA.

Summary of IEAs

Detailed description of the state and development of the investigated ecosystems including the IEAs are given in the respective “Ecosystem Overview documents” in Annexes 3-6.

All 4 investigated subsystems displayed pronounced changes in the last 2-3 decades with *Regime Shifts* (RS) identified in all multivariate datasets (Table 3.1).

Table 3.1. Summary of the Regime Shifts (RS) detected in the 4 ecosystems investigated (CBS – Central Baltic Sea, GoR – Gulf of Riga, GoF – Gulf of Finland, BoS – Bothnian Sea).

System	Period covered	RS 1	RS 2	RS 3	RS 4
CBS	1974–2005.	1980/81	1987/88	1992/93	
GoR	1974–2005		1988/89	1995/96	
GoF	1979–2005.			1995/1996	2002/2003
BoS	1979–2005		1989/90		

A first RS was identified only in the CBS in the beginning of the 1980s, which seemed to be related to changing deep-water conditions. This RS could not be detected in the other systems, which is additionally due to the shorter period of available data for the GoF and the BoS. The most pronounced RS occurred at the end of the 1980s, detected in all systems but the GoF. The shift in this period corresponds to the change in atmospheric forcing also demonstrated for other regions of the world ocean e.g. the Canadian Eastern Scotian Shelf (Choi *et al*., 2005), the U.S. Continental Shelf (Link *et al*., 2002), the North Pacific (Hare and Mantua

2000) and the North Sea (Beaugrand, 2004; Weijermann *et al*., 2005). For northern Europe this period is characterized by suddenly increasing temperatures as a result of a change in NAO (Alheit *et al*., 2005). For the Baltic Sea region, and especially the CBS-ecosystem, this period was additionally characterized by very low salinities, especially in the deepwater along with oxygen deficiency. Hence, contrary to other areas, other hydrographic trends in addition to temperature may have caused the observed RS. The short lag in timing between the Baltic systems might be due to variable lags in the response of the different populations to the hydrographic change. No RS in the end of the 1980s has been detected for the GoF. This might have been a result of the greater importance of eutrophication for this area. It might however be a result of the variable selection for the multivariate analyses, an issue that has to be resolved in future analyses. The same applies to the RS in the early 2000s, only detected in the GoF.

Another consistent period of RS is the early 1990s obviously initiated by the change in the deepwater conditions after the major inflow in early 1993 (Matthäus and Lass, 1995). Again a time lag is visible between the CBS and the GoR/GoF, which might due to the later arrival of the deepwater in the more eastern areas, but again due to a differential response time of the populations. Even though the BoS is generally not much affected by the deepwater conditions, it shows a regime shift in the early 1990s. A potential RS after the inflow in 2003 (Feistel *et al*., 2006) is only indicated for the GoF, but might become visible in other areas when data for recent years can be included in the analyses.

Overfishing may have contributed to the changes in the ecosystem. The decrease of the Eastern cod stock is partly due to an unsustainable fishing pressure after the environmentally-induced recruitment decline in the early 1980s. This had consequences also for other areas where cod disappeared from the systems reducing the predation pressure on planktivorous fish. In the CBS, decreased cod contributed to increased sprat abundance (Köster *et al*., 2005), cascading down to *P. acuspes* (Möllmann and Köster 2002). Herring in the CBS (and the GoF) has suffered from the ecosystem change due to increased competition with sprat and changed food composition (Casini *et al*., 2006; Möllmann *et al*., 2005; Rönkkonen *et al*., 2004). In other areas, e.g. GoR and BoS, herring has increased due to reduced cod predation and improved feeding conditions.

In summary, the conducted IEAs proved to be an effective method for displaying ecosystem changes in the investigated subareas of the Baltic Sea. Hence, the analyses provide a sound basis for future ecosystem-based assessment approaches in the Baltic Sea, especially related to fisheries and eutrophication. In addition, the compiled data sets are valuable sources of information for studies on ecosystem functioning and on natural and man-made effects on the ecosystems.

In the future, WGIAB will try to improve the datasets and refine the analyses. The group intends to incorporate parts of the Western Baltic into its work, which certainly depends on data availability and the interest of data-holding institutions to contribute to the process. The group further to initiate a separate trial assessment investigating differences between coastal and deep basin ecosystems of the CBS.

4 Cooperation and management (TORs b and c)

One of the future goals of WGIAB is to contribute to the HELCOM assessment work, specifically by (i) cooperating with the HELCOM Biodiversity Assessment (BA), and (ii) by developing an adaptive management framework to support the HELCOM Baltic Sea Action Plan (BSAP).

Concerning the BA, the group felt uninformed on the latest developments. WGIAB attributed the lack of communication to the presently ongoing process of developing the BA, which at the time of the meeting did not have a nominated project manager. Further cooperation between WGIAB and the HELCOM Eutrophication and Biodiversity assessments should be discussed during the back-to-back meeting of HELCOM EUTRO-PRO and HELCOM BIO in Copenhagen (3–7 Septt). In general, the group requests from HELCOM to (i) be more closely informed on the newest developments, and (ii) as a means towards a better communication/cooperation to enable the participation of a newly elected chair of the BA to the next WGIAB-meeting in 2008.

The future efforts of WGIAB towards developing an adaptive management framework in support of the BSAP were another point of discussion during the WGIAB-meeting. Georg Martin (Estonia) reported on the recent developments and the future road to the development of the BSAP. Due to the unresolved stage of the BSAP, WGIAB felt at this stage unable to plan in detailed its contribution to it. Similar as for the BA, the group felt uninformed by HELCOM about the newest developments and hopes for an improvement of the communication in the future.

As a starting point for the future work, WGIAB reviewed the existing "HELCOM system of Vision, *Goals* and *Objectives*" and defined its potential future contribution. WGIAB will in the future contribute to the goals of

1) a favourable status of the Baltic Sea biodiversity, and
2) Baltic Sea unaffected by eutrophication.

WGIAB can contribute to the development of *indicators* as well as targets and/or limits attached to these indicators for all *Objectives* of the above mentioned goals,

i.e. for *Goal 1*:

- Natural landscapes and seascapes,
- Thriving and balanced communities of plants and animals,
- Viable populations of species;

and for *Goal 2*:

- Concentrations of nutrients close to natural levels,
- Clear water,
- Natural level of algal blooms,
- Natural distribution and occurence of of plant and animals,
- Natural oxygen levels.

The main contributions of WGIAB to this system are the remarkable databases on biotic and abiotic time-series, already collected for four subsystems of the Baltic Sea. These databases allow explicitly to:

i) identify key indicators for the state and development of the ecosystem; these can be aggregative indicators (e.g. the PC components of the multivariate analyses conducted by WGIAB (see chapter 3 and Annexs 3-6) or single indicators (e.g. abundance time-series) for different compartments (e.g. trophic levels) of the ecosystems;

ii) test the performance of the key indicators using different methods, e.g. power analysis (Jennings 2005) or Signal Detection Theory (Rice

2003); further the use of ecosystem models for indicator testing will be explored;

iii) select/develop limits and /or targets for selected indicators as a basis for management actions.

WGIAB was confident of its potential to contribute to the future development of the HELCOM assessment work. In general the group felt uninformed and uninvolved of ongoing developments. In the future the role of WGIAB within this system has to be clarified which requires leading HELCOM scientist to be involved in WGIAB.

Similarly as with HELCOM, WGIAB felt in doubt about its future role within the ICES assessment system, an issue that has to be resolved during next years' WGIAB meetings.

5 Development of a common ICES/HELCOM indicator database facilitating the future work of WGIAB (TOR d)

The work of WGIAB relies on timely deliverable of the best available data on a wide variety of biotic and abiotic variables. Presently the group uses data from various sources, including both ICES, HELCOM as well as from national and university institutes. The data are presently held by the WGIAB-chairs and members in a non-consistent way. Different ways to overcome this non-ideal situation have been discussed.

B. Müller-Karulis introduced a concept on an indicator database and a suggest dataflow between ICES, HELCOM and other data sources to be used in WGIAB (Annex 7). J. Flinkman reported a FIMR-activities to construct a HELCOM-database.

In the discussion the question arose on how the plans of the new HELCOM-database is related to the present system where the data are usually reported to the ICES datacentre. The group felt uninformed about the recent developments and unable to see its role in these and hence to suggest a realizable data handling strategy. Thus 2 decisions were made concerning the database issue:

1. a formal request will be made to both ICES and HELCOM to clarify the database situation (especially with respect to biological data), and to clarify the view of both organisations towards the data policy supporting the type of activities WGIAB conducts;
2. until there is an official data base policy, the group decided to use the ICES-sharepoint server to manage their data (see further explanations below).

WGIAB will store compiled indicator time-series on the ICES sharepoint server, in the form of one MS EXCEL-file per subsystem. These will be updated by the participants before or during the annual meeting of WGIAB. Along with the datafiles, detailed descriptions on the time-series (e.g. sources, sampling methods, data compilation routines) will be provided on the server. The group felt however unable to accomplish this ambitious task during this years meeting, hence it was decided to include this work as a TOR for next years meeting (see TOR f in Annex 8).

WGIAB further discussed if the compiled data should be made public to be used by other groups and scientists for their work. Concern was raised if these aggregated data should be given to other scientist without providing the specific expert knowledge. On the other hand it was acknowledged that according to recent data policies all data should be freely available. It was thus decided that the data are only available to the members of the group (and others appointed by the Co-Chairs) on the sharepoint server. However, there will be a remark in the report, that the data are freely available through a request to the Co-Chairs which will pass it to the respective expert.

6 Monitoring (TOR f)

The different monitoring programs in the Baltic Sea area were already reviewed and discussed during the 2006 ICES/BSRP/HELCOM Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea (ICES CM 2006/BCC:09) and the different monitoring programs are briefly described below. No major new developments occurred until the 2007 WGIAB meeting. However, data for the lower trophic levels required for integrated assessment is mainly provided by the HELCOM COMBINE monitoring program, which is currently reorganized. To ensure the continuity of time-series essential for integrated assessment, WGIAB will review the different time-series used as input data during its 2008 meeting, and notify data providers and the relevant ICES and HELCOM working groups of the importance of the identified key time-series for integrated assessment.

In general, the Baltic Sea is a well monitored marine ecosystem. However, data are collected under a variety of programmes (HELCOM COMBINE, fishery management under EC regulation 1543/200). There is often little data exchange between different monitoring programmes and institutions involved, but integrated assessment demands collection of data on all ecosystem components and their driving factors. Attention should especially be paid to parameters important to integrated assessment that are currently not well covered by existing monitoring programs. These are primarily mesozooplankton, macrozooplankton, fish stomach content, and to a lesser degree macrozoobenthos.

Major gaps in observations identified during WKIAB and the 2007 WGIAB meetings were:

- lack and shortness of phytoplankton/chlorophyll a time-series, especially in the Baltic Proper.
- lack of zooplankton data in the Bornholm basin.

Existing Baltic Sea monitoring programmes

Currently, in the open sea Baltic monitoring programmes are focused on the effects of eutrophication and hazardous substances (HELCOM COMBINE) as well as on fishery management (European Council regulation 1543/2000). Major Baltic Sea status assessments are the annual fish stock assessments conducted by ICES working groups, and the ongoing HELCOM assessments of eutrophication (HELCOM EUTRO-PRO) and biodiversity (HELCOM BIO) Additional monitoring requirements are created by the EU Habitats and Birds directives and in the future also by the upcoming EU Marine Strategy. Further, in coastal and transitional waters, the EU Water Framework Directive (WFD) demands extensive data collection on biological and chemical parameters and regular assessment of ecological status.

Data requirements for integrated assessment

While the HELCOM monitoring programme describes the lower trophic level of the ecosystem (hydrography, nutrients, phytoplankton, zoobenthos), the upper trophic level (fish, fishery) is mainly described by the EU fisheries data collection programme.

Mesozooplankton links fish to the lower parts of the foodweb, both as the food source for planktivorous fish (herring, sprat), but also as the food supply of larvae for other fish species. Currently, long-term data in the open Baltic exist primarily from the Latvian Fish Resources Agency, while within HELCOM COMBINE, mesozooplankton is only a voluntary parameter.

Data is not compatible between different sources, as different gears (WP2, Juday net) and mesh sizes are used.

Other parameters that are currently not well covered by Baltic Sea monitoring are macrozooplankton and fish stomach contents.

7 Modelling (TOR g)

Modelling is an important component of an Integrated Assessment framework. Hence one of the major tasks of WGIAB will be to (i) review the available modelling tools in the Baltic, and (ii) to develop a strategy for their use within ecosystem-based management. As described above (see Chapter 2), WGIAB will concentrate on the modelling issue on its 2008 meeting in Öregrund, Sweden. Consequently this years meeting was used to start reviewing modelling activities in the countries bordering the Baltic Sea.

In order to review the various ecosystem modelling approaches available for the area, and their importance and utility towards future IAs, the co-chairs made an effort to invite scientists involved in ecosystem modelling of the Baltic Sea. However, due to financial and time-constraints this effort was of limited success. However, 4 presentations have been given during the meeting:

1) Coupling of Individual-Based Models of fish early life-history to biogeochemical NPZD-models (Myron Peck; University of Hamburg);
2) An biogechemical NPZD-model with extensions for stage-structured zooplankton and interacting fish species (Thomas Neumann; Institute of Baltic Sea Research, Warnemuende);
3) Multispecies Assessment Models – Potentials and Limitations (Alex Kempf; University of Hamburg);
4) A statistical interaction model for the Central Baltic Sea (Martin Lindegren; Danish Institute for Fisheries Research, Charlottenlund).

These presentations covered already a broad range of biogeochemical, population, fish stock assessment and statistical models, thus as a start for the future work of the group has been made. However, important modelling groups, as for e.g. the MARE-group (www.mare.su.se) could not participate, although they have signalled their interest in contributing to WGIAB. The group further noticed the inventory on modelling activities conducted within EUR-OCEANS (www.eur-oceans.eu) and agreed to consider the work of the EUR-OCEANS Baltic Sea System Study (Leaders: F. Köster, Denmark and D. Turner, Sweden) in the future work and especially on the next meeting

On the next meeting in 2008 WGIAB will (i) outline the use of ecosystem modelling approaches available for different Baltic subsystems, and (ii) develop a strategy for their use within the future Integrated Assessment framework. This will include a number of working steps:

1) an inventory of existing models and a review of their operationability for the use in future IAs;
2) a decision on models to be used in the future work in WGIAB, based on specified criteria (e.g. involvement of model developer in WGIAB, operationability, predictive capability etc.);
3) development of enviromental and anthropogenic scenarios for potential model predictions;
4) preparation of a modelling workshop back-to-back to the WGIAB-meeting in 2009.

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Annex 2: Agenda

Monday, 12/03/07

1000 – 1045 Practical information, Introduction to the Workshop and Discussion of the Agenda (Christian Möllmann & Bärbel Müller-Karulis)

1045 – 1100 Coffee & Tea

1100 – 1300 Integrated Assessment Session (TORs a & e)

1. Presentation of SGPROD (Bärbel Müller-Karulis)
2. Presentations on data availability (CBS – Christian Möllmann, GOR – Bärbel Müller-Karulis, GOB – Anna Gårdmark, GOF – Juha Flinkman)
3. Planning of work and reporting

1300 – 1400 Lunch

1400 – 1530 Integrated Assessment Session cont.

- Split in area subgroups; start data compilation

1530 – 1600 Coffee & Tea

1600 – 1800 Discussion on database issues (Tor d)

- Ideas on developing a future database (Bärbel Müller-Karulis)

Tuesday, 13/03/07

0900 – 1045 Integrated Assessment Session cont.

- work in area subgroups; continue data compilation; start preparation of Ecosystem overview documents

1045 – 1100 Coffee & Tea

1100 – 1300 Integrated Assessment Session cont.

- work in area subgroups; continue data compilation; start preparation of Ecosystem overview documents

1300 – 1400 Lunch

1400 – 1530 Integrated Assessment Session cont.

- 1st review of the results

1530 – 1600 Coffee & Tea

1600 – 1800 Inventory on survey and monitoring activities (Tor f)

- update monitoring review by WKIAB
- additional topic: develop ideas for a potential BONUS-IA-Project

1900 - Common Dinner

Wednesday 14/03/07

0900 – 1045 Integrated Assessment Session cont.

- Start with Multivariate statistical analyses

1045 – 1100 Coffee & Tea

1100 – 1300 Integrated Assessment Session cont.

- Cont. of Multivariate statistical analyses

1300 – 1400 Lunch

1400 – 1530 Cooperation & Management Session (TORs b & c)

- Ideas on potential work of WGIAB towards an adaptive management strategy (Christian Möllmann)
- Multivariate Statistical analyses cont. in parallel

1530 – 1600 Coffee & Tea

1600 – 1800 Integrated Assessment Session cont.

- Review of results

Thursday 15/03/07

0900 – 1045 Integrated Assessment Session cont.

- Cont. preparing Ecosystem overview documents

1045 – 1100 Coffee & Tea

1100 – 1300 Modelling Session

Potential Presentations:

1. ERGOM (Thomas Neumann)
2. Multispecies models (Alex Kempf)
3. A statistical model for the Central Baltic (Martin Lindegren)
4. ISIS-Fish (Gerd Kraus)
5. Coupling Fish/Zooplankton with NPZD-model

1300 – 1400 Lunch

1400 – 1530 Plenary

- Reviewing state-of-the-art
- Defining necessary sub-groups for reporting
- Define TOR´s/Venue for next years meeting
- Collect recommendations
- Contributions to ICES ASC 2007

1530 – 1600	Coffee & Tea
1600 – 1800	Reporting in sub-groups

Friday 16/03/07

0900 – 1045	Reporting in sub-groups
1045 – 1100	Coffee & Tea
1100 – 1300	Wash-up and further reporting in sub-groups
1300 -	Closure of the meeting

Annex 3: Ecosystem overview document for the Central Baltic Sea

This document summarizes the state and development the Central Baltic Sea (CBS; incl. the Bornholm Basin, the Gdansk Deep, and the Gotland Deep – ICES Subdivisions 25, 26, 27 and 28) during 1974 to 2005. It is an output of the ICES "ICES/HELCOM Working Group on Integrated Assessments for the Baltic Sea [WGIAB]" and provides background environmental information for the ICES fish stock assessment (i.e. WGBFAS), but also information on the effects of fishing on the Baltic ecosystem for HELCOM.

This status report comprises information on the development of (i) the climate over the Baltic Sea area with resulting changes in the hydrography, (ii) nutrients, (iii) phyto- and zooplankton populations, and (iv) the major fish stocks and their fisheries. Finally, multivariate analyses of all time-series are presented, providing an integrated view on changes in ecosystem structure and functioning.

Of the time-series which were available to WGIAB, only those with a sufficient temporal coverage were used in this status report as well as in multivariate analyses (see below). Although potentially important components of the ecosystem are not represented (e.g. macrozooplankton, benthos), the report is believed to give a sufficiently broad overview of the ecosystem. In the future, lacking ecosystem components will be included, if data are made available. A description of the time-series used and their sources is given in Annex -Table 7.1.

Climate and hydrography

The development of the climate over the Baltic Sea area in the last 3 decades is displayed by the Baltic Sea Index (BSI), which is well correlated with the Index of the North Atlantic Oscillation (NAO) (Lehmann *et al*., 2002). While during the 1970s and 1980s the index was mainly in a negative state, it was mainly positive afterwards (Figure CBS-1). This change in sign of the index was associated with more frequent westerly winds, warmer winter and eventually a warmer climate over the area. This is very well demonstrated by the convincing correlation for the BSI with the maximum ice extend in the Baltic (r=0.84). Beside the influence on the thermal conditions, climate also influences the salinity in the CBS. During the high BSI-period since the late 1980s only 2 major Baltic inflows were recorded. The absence of major inflow events to the Baltic since the 1980s, although unpredictable to date, has been hypothesized to be related to the high NAO (BSI) period (Hänninen *et al*. 2000). Increasing runoff leading to sea level variations may have hindered major inflow events (Matthäus and Schinke, 1999). Deep water salinity has clearly decreased during the low inflow frequency until 1993, demonstrated by the depth of the 11psu isocline in the GB.

Time-series of water temperatures and salinity from the Bornholm (BB) and Gotland Basins (GB) in spring clearly reflect the change in the atmospheric forcing (Figure CBS-2). Temperatures were on average higher since the 1990s, while surface salinity decreased significantly since the mid-1980s. Deepwater is strongly dependent on the occurrence of inflow events and shows the stagnation period until the early 1990s and the effect of the recent inflows in 1993 and 2003.

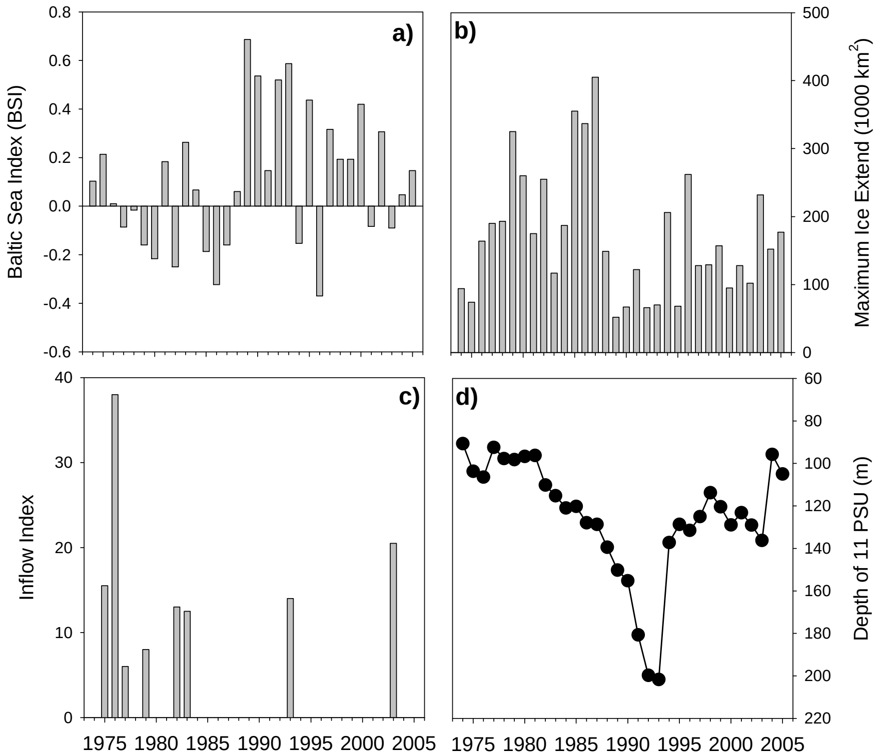

Figure CBS-1. Climate effects on the CBS-ecosystem: a) the Baltic Sea Index (BSI), b) Maximum Ice Extend, c) Inflow index, and d) depth of the 11psu isoline in the Gotland Basin.

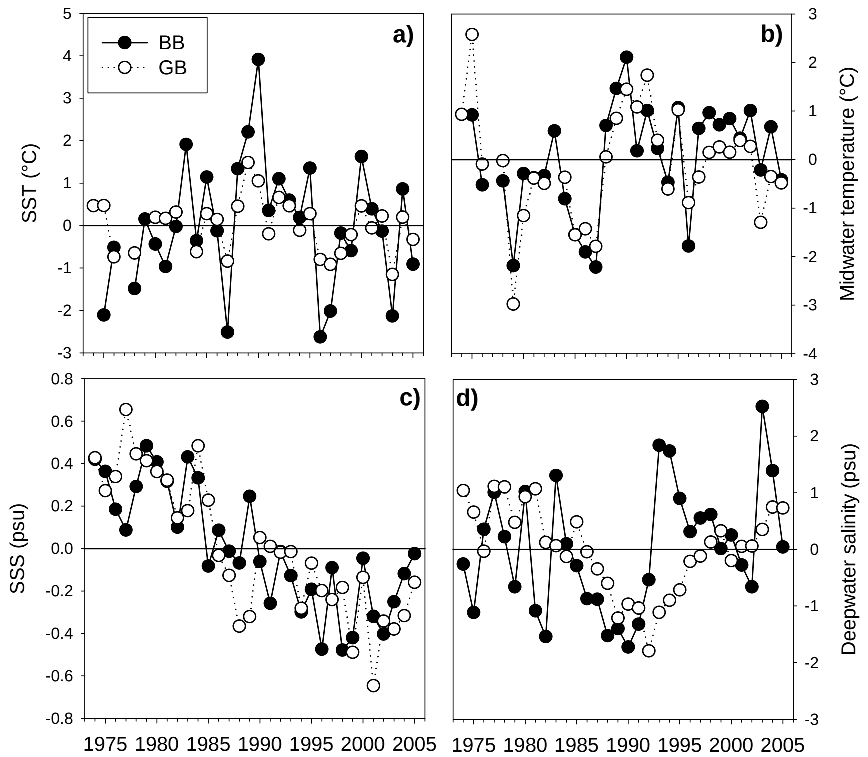

Figure CBS-2. Hydrographic changes in the Bornholm (BB) and Gotland Basins (GB): Anomalies of a) Sea surface temperature (SST), b) Midwater temperature (40–60m), c) Sea surface salinity (SSS), and d) Deepwater salinity (BB – 70–90m, GB – 80–100 m).

Nutrients

Surface winter DIN and DIP values displayed a step-wise increase between 1990 and 1991 decreasing afterwards (Figure CBS-3). Summer deep water DIN and DIP time-series showed increasing values during the stagnation period from the mid 1970s and sharp decreases following the inflows in 1993 and 2003.

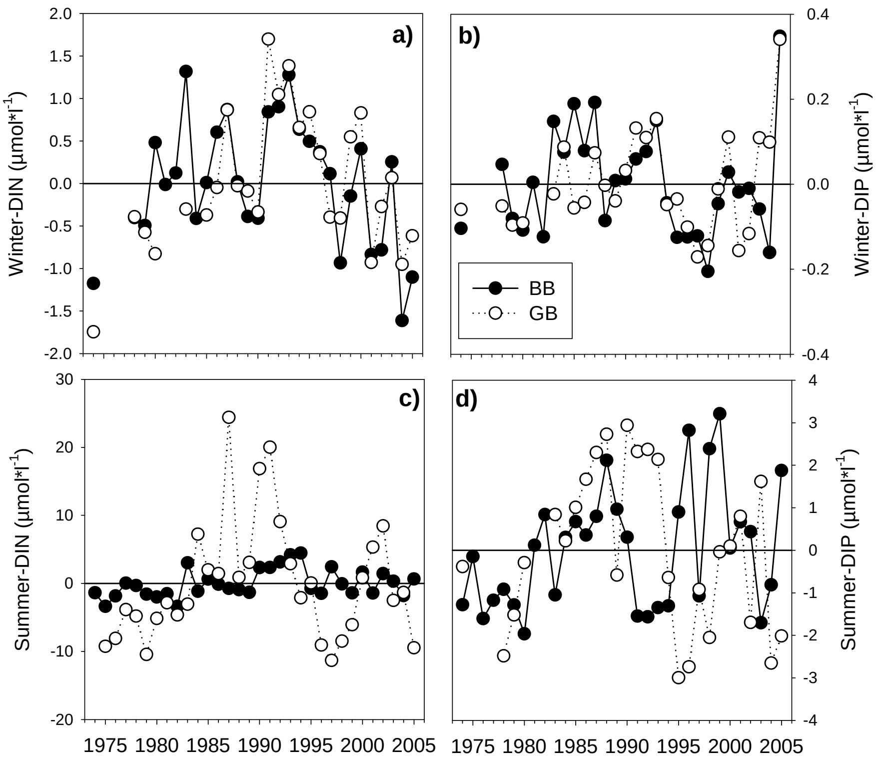

Figure CBS-3. Changes in nutrient concentrations in the Bornholm (BB) and Gotland Basins (GB): Anomalies of a) winter DIN, b) winter DIP, c) summer DIN), and d) summer DIP; winter values are from the surface, summer values are from 70–90m (BB) and 200–220m (GB).

Phytoplankton

The development of the phytoplankton biomass in the CBS is demonstrated using both either Chl a and measurements and total biomass measurements based on abundance counts from net sampling (Figure CBS-4). Variability in the phytoplankton time-series is very high and temporal trends are difficult to detect. Both in the Eastern Gotland Basin as well as in the Bornholm Basin, during the 1990s the phytoplankton spring bloom was more pronounced. This pattern is mainly due to the increase in dinoflagellates (Figure CBS-5). This trend is discussed to be a result of enhanced water column stability due to higher winter and spring temperatures (Wasmund *et al.*, 1998). In contrast diatom times-series display a slight decrease in biomass, although not visible in the BB in spring. Summer phytoplankton biomass in the Bornholm Basin has decreased slightly during recent years, while it remained on a constant level in the Eastern Gotland Basin.

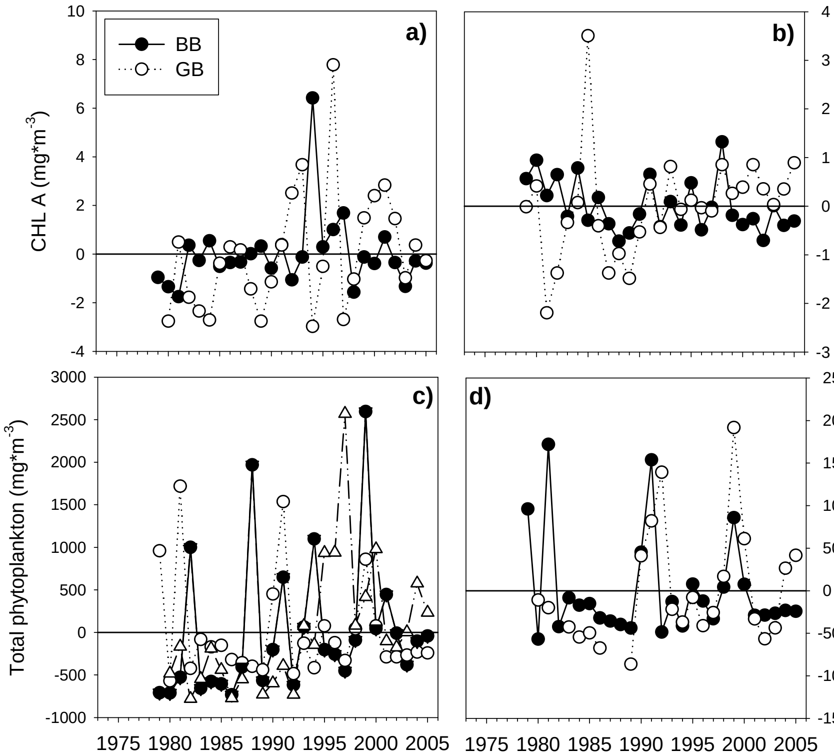

Figure CBS-4. Changes in phytoplankton biomass in the Bornholm (BB) and Gotland Basins (GB): Anomalies of chlorophyll a in a) spring and b) summer, as well as total phytoplankton biomass in c) spring and d) summer.

Zooplankton

The dominating zooplankton species in the CBS are the copepods *Acartia* spp., *Temora longicornis* and *Pseudocalanus acuspes* (Figure CBS-6). During spring a clear shift has occurred from a dominance of *P. acuspes* until the end of the 1980s to *Acartia* spp. and *T. longicornis* afterwards. This shift has been explained by decreased salinity and high sprat predation pressure (*P. acuspes*) and increased temperature (*Acartia* spp., *T. longicornis*) (Möllmann and Köster, 2002; Möllmann *et al*., 2003). During summer this shift is still visible, despite a higher variability.

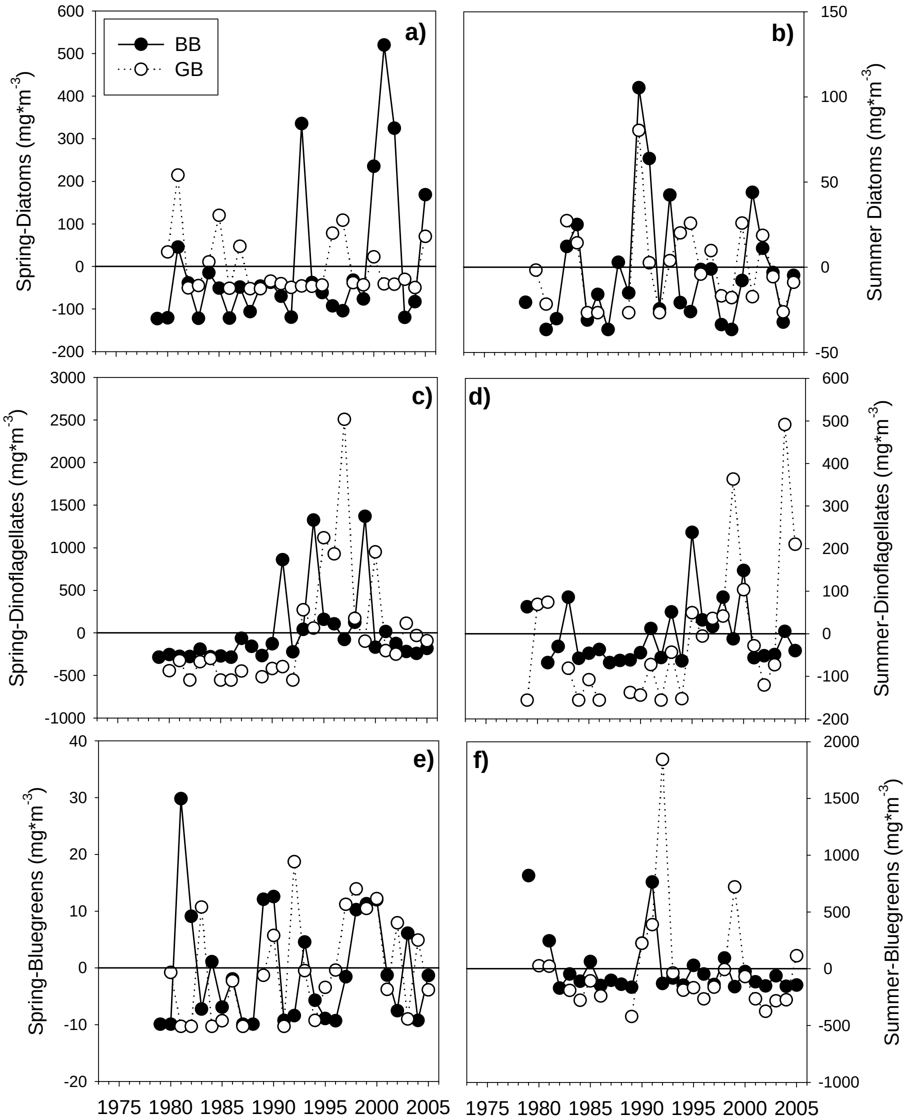

Figure CBS-5. Changes in phytoplankton species composition in the Bornholm (BB) and Gotland Basins (GB): Anomalies of diatom biomass in a) spring and b) summer, dinoflagellate biomass in c) spring and d) summer, as well as bluegreen biomass in e) spring and f) summer.

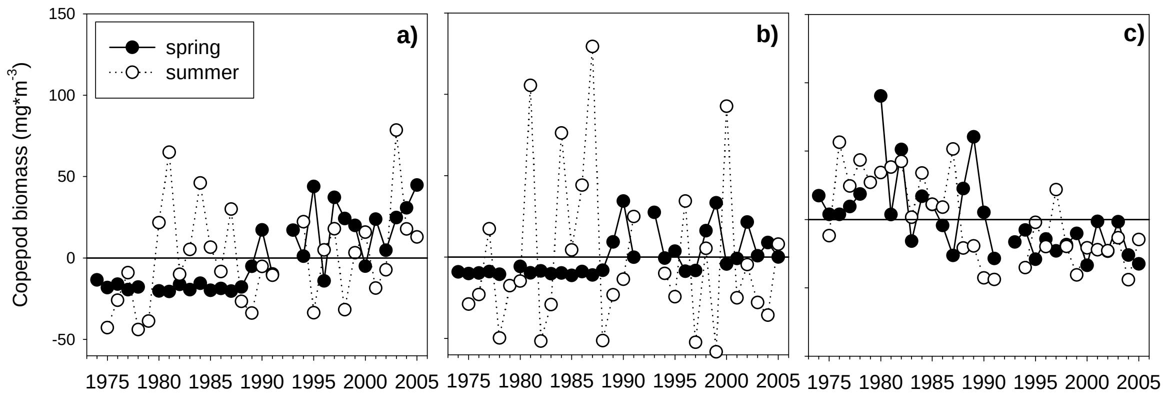

Figure CBS-6. Changes in zooplankton species composition in the CBS: Anomalies of a) *Acartia* spp., b) *T. longicornis*, and c) *P.acuspes* in spring and summer.

Fish and fisheries

The commercial fish community changed from cod – to sprat-dominated during the recent decades (Figure CBS-7). The cod stock collapsed due to climate-induced recruitment failure and a continuously high fishing pressure (Köster *et al.*, 2005). The sprat stock increased meanwhile to record levels during the 1990s being a result of climate-induced recruitment success and lower predation pressure by cod (Köster *et al.*, 2003; MacKenzie and Köster, 2004). Herring biomasss decreased mainly due to reduced growth (Möllmann *et al.*, 2005), but also lower recruitment (Figure CBS-7).

Sprat exhibited clear density-dependent responses in individual weight, while for cod this relationship broke down in the 1990s (Figure CBS-7). Individual herring weight declined with stock size stabilizing since the mid 1990s, which is partly a result of the varying proportion of local populations with variable growth patterns (ACFM 2005). Further a real growth reduction since the late 1980s was observed and discussed to be a result of competition with the large sprat stock (Casini *et al.*, 2006; Möllmann *et al.*, 2005). Further, for both pelagic fish species, but especially for herring, the decreased population size of the copepod *P. acuspes*, their main food source in spring, is an important factor for reduced individual growth (Möllmann *et al.*, 2003, 2005; Rönkkonen *et al.,* 2004).

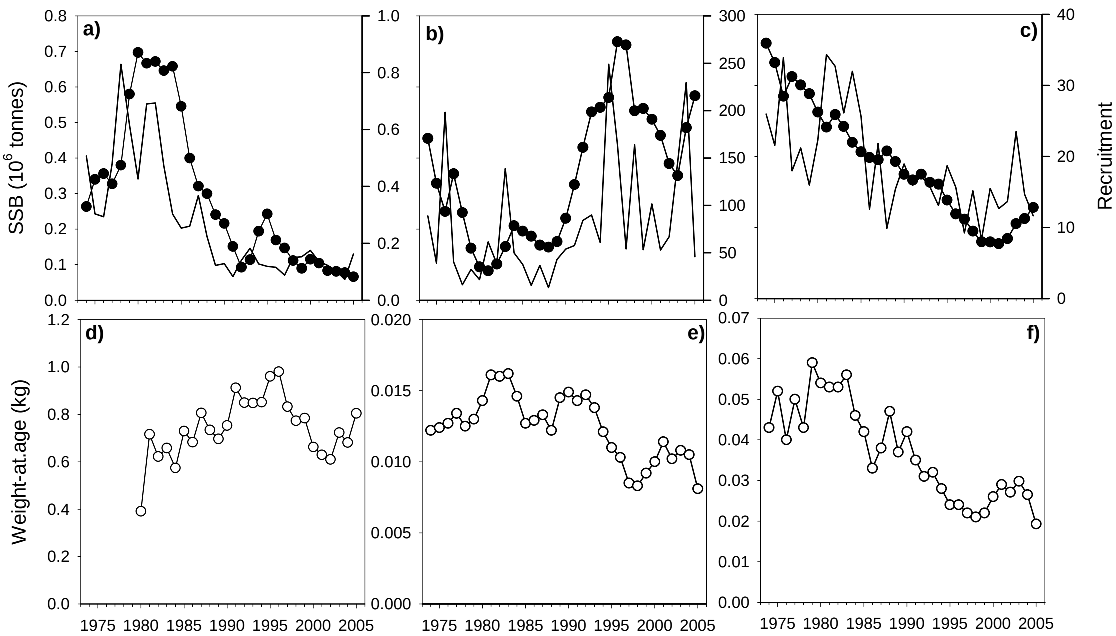

Figure CBS-7. Spawning stock biomass (SSB – dots and lines), recruitment (age 2 for cod, age 1 for sprat and herring - lines) for a) cod, b sprat and c) herring; weight at age 3 in the catch of d) cod, e) sprat and f) herring.

Integrated analysis

Multivariate analyses were conducted to provide an integrated view on the state and development of the ecosystem. Altogether, 65 variables were considered: 12 fish, 6 zooplankton, 20 phytoplankton, 8 nutrient, and 19 physical datasets. All data-series were compiled to one assessment per year and covered in maximum the period 1974 to 2005 (see Annex-Table 7.1). Time-series were analysed by Principal Component Analysis (PCA), followed by a Redundancy Analysis (RDA) with forward selection of explanatory variables.

An empirical overview of the temporal change of all CBS time-series is presented in Figure CBS-8. Generally there is a trend from variables placed at the bottom left of the plot having high values during the 1970s and early 1980s, to variables at the upper right displaying high values in the recent 15 years. The first group consists e.g. of variables related to cod, herring, *P. acuspes*, salinity and maximum ice extend, while the second group consists e.g. of sprat, *Acartia* spp., *T. longicornis*, dinoflagellates and temperature. An intermediate group is further visible with 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.

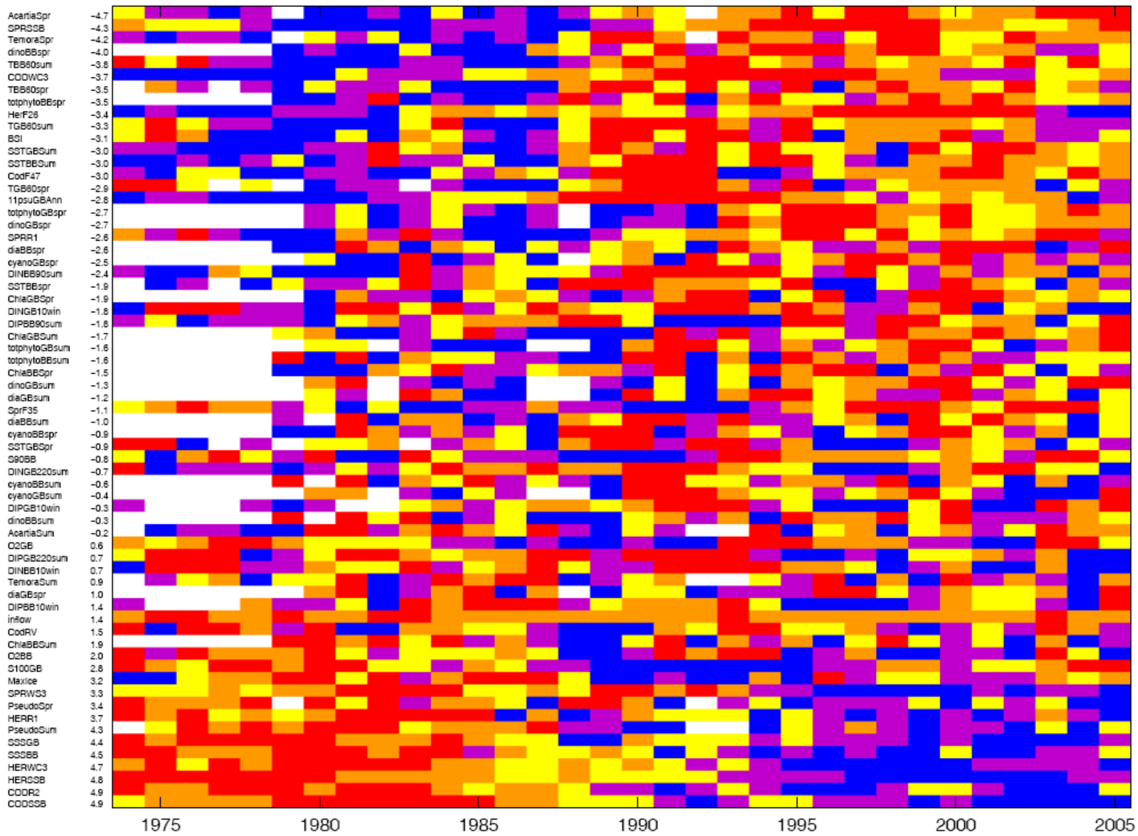

Figure CBS-9. Traffic-light plot of the development of the CBS ecosystem.t Time-series are transformed to quintiles, colour coded (blue –low values; red – high values, white – missing values), and sorted according to their loading for the first principal component. Variable names are explained in Annex-Table 7.1.

These first two composite variables (PC1 and PC2) explain 23.9 and 12.9 % of the total variance, respectively (Figure CBS-10 a). PC1 displays a rapid change from positive to negative scores in the early 1990s. The development of PC2 is characterized by a steady increase until the early 1990s and a sharp drop afterwards. A plot of the time-trajectories of PC1 vs. PC2 demonstrates changes in ecosystem states in 1980/81, 1987/88 as well as 1992-94. (Figure CBS-10 b). While the shifts in 1980/81 and 1992–1994 are mainly visible on PC2, the shift in 1987/88 occurred mainly on PC1.

The relative influence of the various time-series on the observed changes can be derived from the factor loadings (Annex-Table 7.1) of the first 2 principal components PC1 and PC2. PC1 reflects mainly the opposition of the increase in temperature (high negative loadings on PC1) and the decrease in salinity due to climatic processes (high positive loadings on PC1). Highest positive PC1 loadings for the biotic time-series were derived 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 found on the opposite site of the PC2-range.

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 have highly negative loadings on PC1, while the biomass development of both stocks are opposite to the fishing pressure and display highly positive PC1-loadings.

PC2 reflects mainly changes which have occurred in the deep water, i.e. the long stagnation period until 1993, which has decreased deepwater salinity and oxygen (high negative loadings on PC2). In contrast deepwater nutrients increased in this period (high positive 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.

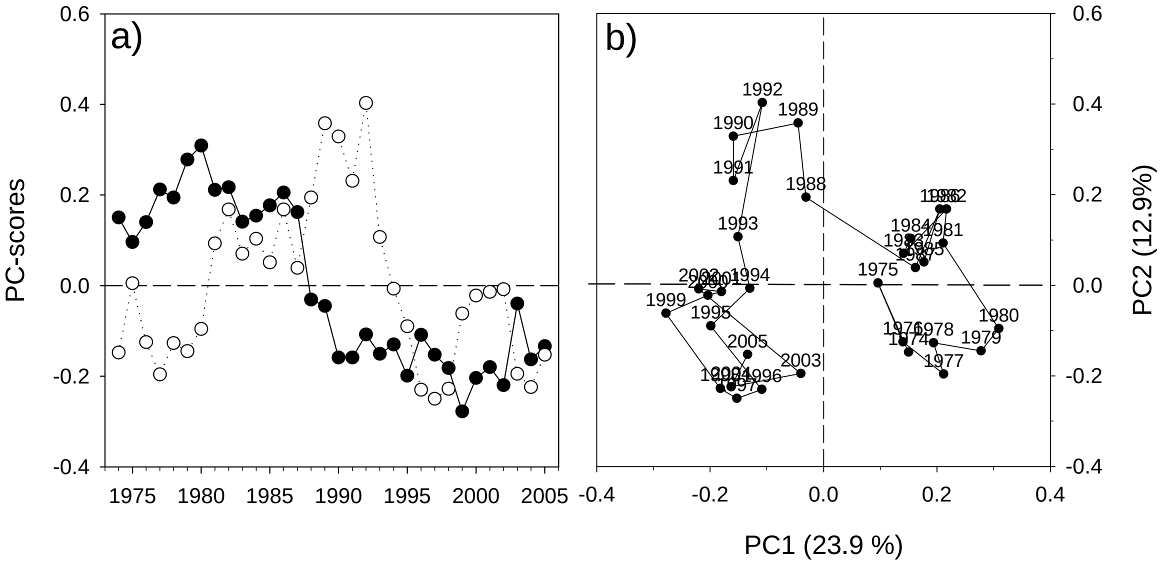

Figure CBS- 10. Scores of principal components 1 (black circles) and 2 (white circles); Time scores of principal components 1 and 2 (PC1 and PC2); variance explained by PCs in brackets.

The observed regime shifts in the CBS ecosystem can be explained by major changes in the ecosystem reflected by both PC1 and PC2. The shifts in 1980/81 and 1992–1994 were mainly due to deepwater related processes, changes in nutrients (increase in 1980/81; decrease in 1993) and increase in salinity and oxygen after the 1993 inflow. The most pronounced change occurred on PC1 in 1987/88 which is due to the increase in temperature as a result of the change in atmospheric forcing reflected in a change to positive values in the BSI time-series.

The dominant importance of hydrographic conditions for the ecosystem is supported by results of the forward-selection routine performed in connection with an RDA. The method exclusively selected salinity and temperature time-series as the most imprtant driving factors.

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Annex 4: Ecosystem overview document for the Gulf of Riga

The Gulf of Riga is a shallow sub-system (maximum and mean depth 62 and 20 m, respectively) of the Baltic Sea experiencing only a restricted water exchange with the surface water of the Baltic Proper. The Gulf is highly influenced by riverine runoff, with 18 – 56 km3 of freshwater discharging annually into the 424 km3 large Gulf. Consequently, the Gulf of Riga is considered to be one of the most eutrophic regions of the Baltic Sea (Wassmann and Andrushaitis 1993, Wasmund *et al.,* 2001). Due to the shallow sills separating the Gulf of Riga from the Baltic Proper, which prevent the inflow of high saline water from below the Baltic Proper halocline, and because of its shallowness the hydrography of the Gulf differs significantly from the Baltic Proper. While surface salinity is only by approximately 1.5 PSU lower than in the adjacent Eastern Gotland Sea, the Gulf lacks a permanent halocline and the water column is completely mixed during autumn and winter. From April to September/October, a seasonal thermocline separates the upper 20 m of the water column from the bottom waters. Phytoplankton development in the Gulf follows the characteristic temperate latitude pattern, with a pronounced spring bloom comprised of diatoms and dinoflagellates after the onset of thermal stratification in April/May, followed by a short low-biomass phase in June and a stable summer community in July – August/September. Depending on the onset and dynamics of autumn storms, a diatom dominated autumn bloom can develop in September/October. After the decline of the glacial relict species *Limnocalanus grimaldii* in the 1980ies, the zooplankton community currently consists mainly of the copepods *Acartia* spp. and *Eurytemora affinis*, consistent with the relatively low salinity in the Gulf of Riga.

The main commercial fish species – also the dominant planktivore in the Gulf – is herring, while cod is present only during high cod stocks in the Baltic Proper. Sprat is permanently found in the Gulf of Riga, but its abundance in the gulf is comparatively small and fluctuates depending on the stock abundance in the Central Baltic. Demersal marine species present are flounder, eelpout and fourhorned sculpin (Anon., 1995). The ichthyofauna of the Gulf of Riga also includes anadromous species from which most abundant are smelt, salmon and sea trout, as well as a large number freshwater species. Freshwater species are usually widely distributed in the costal zone and near river mouth areas. Sprat, marine demersal species as well as anadromus and freshwater species were not considered in the analyses due to lack of necessary time-series.

Hydrography

The most conspicuous change in the hydrographic conditions in the Gulf of Riga (Figure 1) is the decrease in salinity since the 1970s, interrupted by an inflow of saline water from the surface layer of the Baltic Proper in 2006, which increased the water column salinity by 0.4 PSU (see Figure 1, top right). The inflowing water spread along the seafloor and restricted the water exchange between bottom and surface, leading to low oxygen conditions in the near-bottom water in autumn 2006 (Latvian Fisheries Resource Agency, unpublished data).

Long-term temperature trends are characterized by a significant warming, especially since the 1990ies, which is a result of the change in atmospheric forcing indicated by the pronounced positive state of the Baltic Sea Index. The winter 2005/2006 was severe, with extensive ice cover in the Gulf of Riga, which is reflected by the low February temperatures. The cold winter was followed by rapid warming of the upper part of the water column and quick formation of the seasonal thermocline. Temperatures in the 0–20 m water layer in May reached the long-term average (4.4 °C). Summer temperatures in the Gulf of Riga were again low, caused by a cold late spring and early summer period.

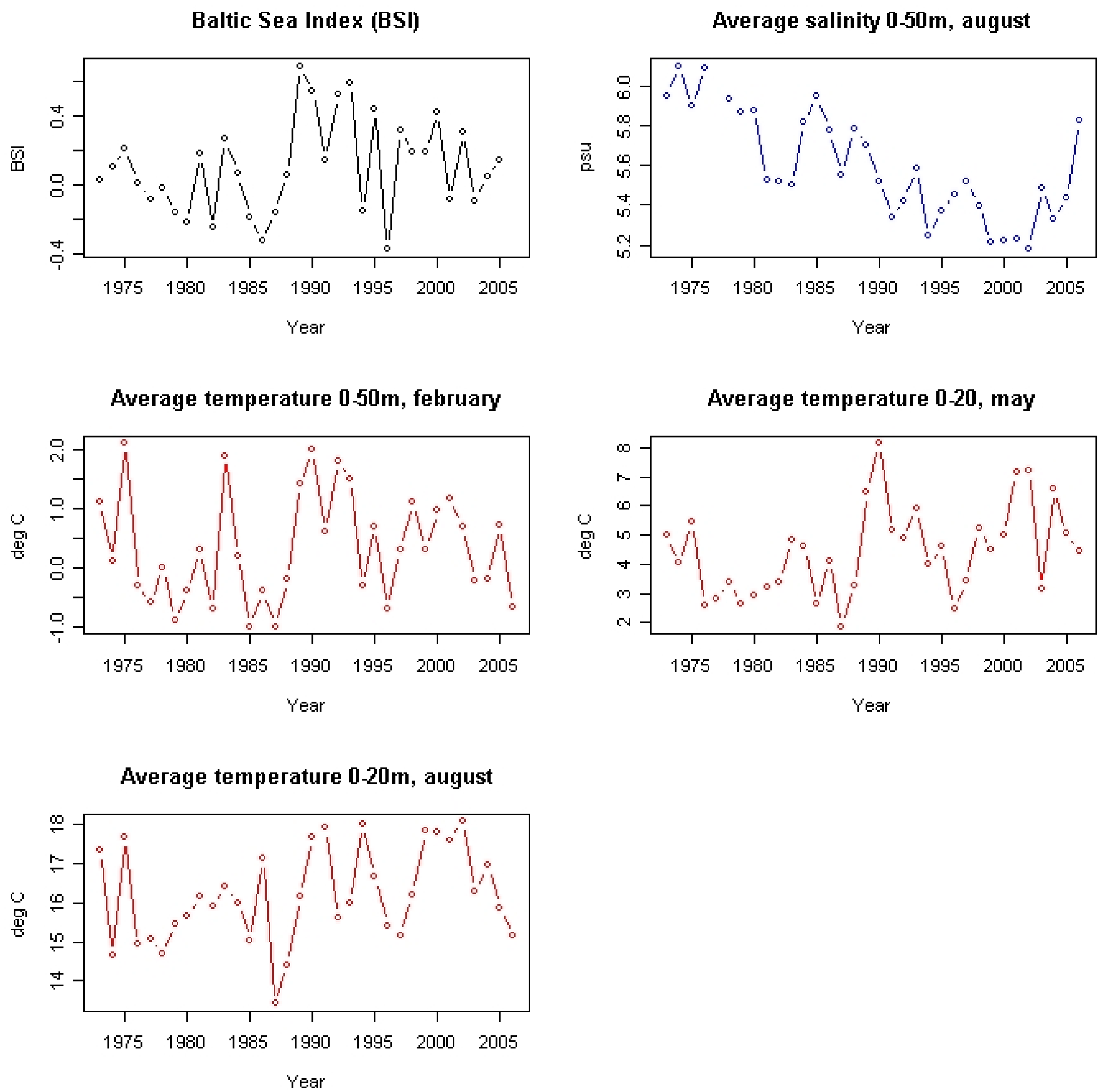

Figure GoR-1. Hydrographic conditions in the Gulf of Riga.

Nutrients

Nutrient load and runoff data for the Gulf of Riga were available until 2003, winter nutrient concentrations until 2004 (Figure 2). Winter nutrient data for 2005 and 2006 are missing because the ice cover in the Gulf of Riga precluded sampling. DIN and DIP inputs to the Gulf peaked around 1990, followed by a decline for both nutrients, mainly related to the lower runoff. The decreasing nutrient load is well reflected in the drop in winter DIN concentrations in the Gulf, whereas winter DIP due to the longer phosphorus residence time in the system and continuous internal loading from the bottom sediments remained on a high level.

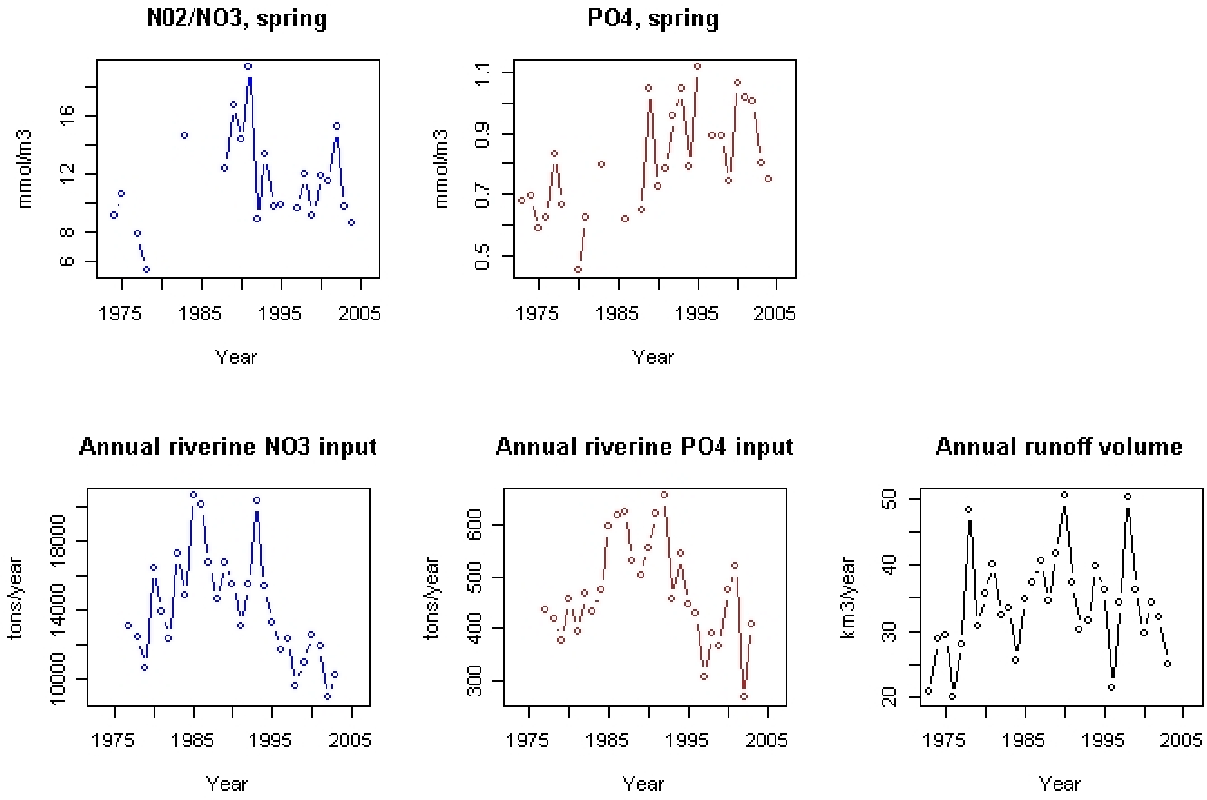

Figure GoR-2. Winter nutrient concentrations, river runoff and DIN and DIP loads to the Gulf of Riga.

Phytoplankton

An assessment of the phytoplankton spring bloom dynamics based on the available monitoring survey data is difficult because of the high temporal and spatial variability of the bloom. In addition, chlorophyll a and Secchi depth observations contradict each other - while chlorophyll a data suggest a relatively high spring bloom in 2006, transparency was high, suggesting low bloom intensity (Figure 3, left panel).

Temporal trends are clearer during the relatively stable summer period (Figure 3, right panel). Consistent with the long-term increase in summer chlorophyll a in the Gulf of Riga, chlorophyll a concentrations in 2006 were on a high level, reflected also in low transparency, and the summer phytoplankton productivity therefore seems to remain on a high level.

The share of cyanobacteria in the summer phytoplankton biomass fluctuated between 25 % and 50 % in the time period 1996 – 2006, for which detailed species composition data are available. Non-toxic Aphanizomenon dominated the cyanobacteria composition. Also during summer 2006 no exceptional summer blooms of cyanobacteria or high biomasses of potentially toxic phytoplankton were noticed (Latvian Institute of Aquatic Ecology, unpublished data).

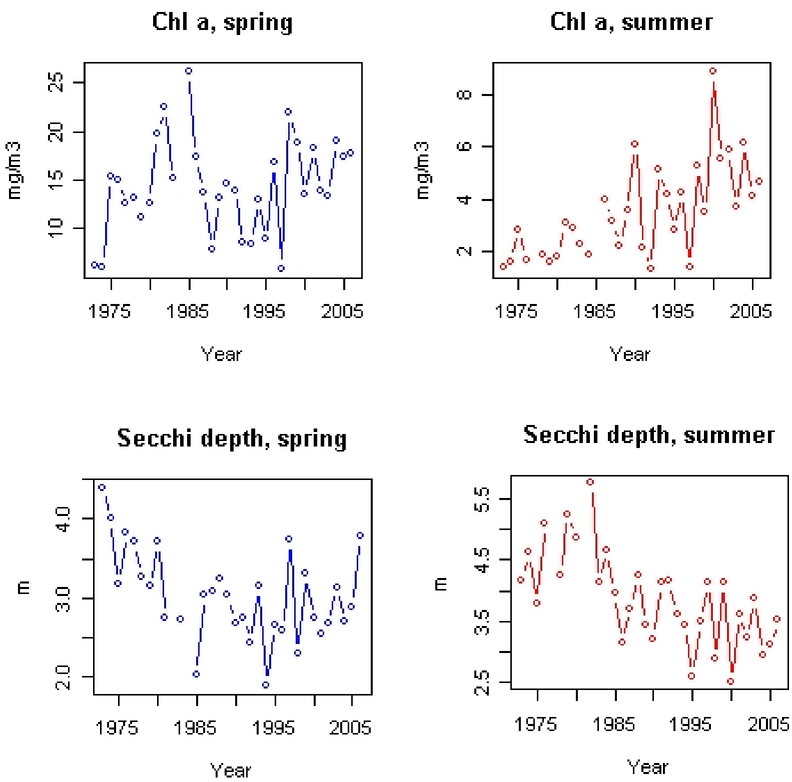

Figure GoR-3. Chlorophyll *a* and Secchi depth.

Zooplankton

Characteristic for the long-term trends in the Gulf of Riga zooplankton (Figure 4) are increasing biomasses of the dominating copepods, *Acartia* spp. and *Eurytemora affinis*, in spring, while their biomass decreases in summer. In spring 2006, low biomasses were recorded for both *Acartia* and *Eurytrmora*, potentially related to the cold winter conditions. Summer biomasses in 2006 were larger than the record-low levels in 2005, but still on a rather low level. The introduced predatory cladoceran *Cercopagis pengoi* remained a significant component of the zooplankton community in the Gulf, but its biomass was low in 2006 compared to the previous years. Biomass of the largest zooplankton species in the Gulf, the glacial relict *Limnocalanus grimaldii*, remained on a low level; the sharp increase in biomass in 2005 was not preserved in 2006. Despite its low biomass, the decline in *Acartia* and *Eurytemora* left *Limnocalanus grimaldii* – according to biomass – to be the most abundant copepod in the Gulf in summer 2006 (data not shown in Figure 4).

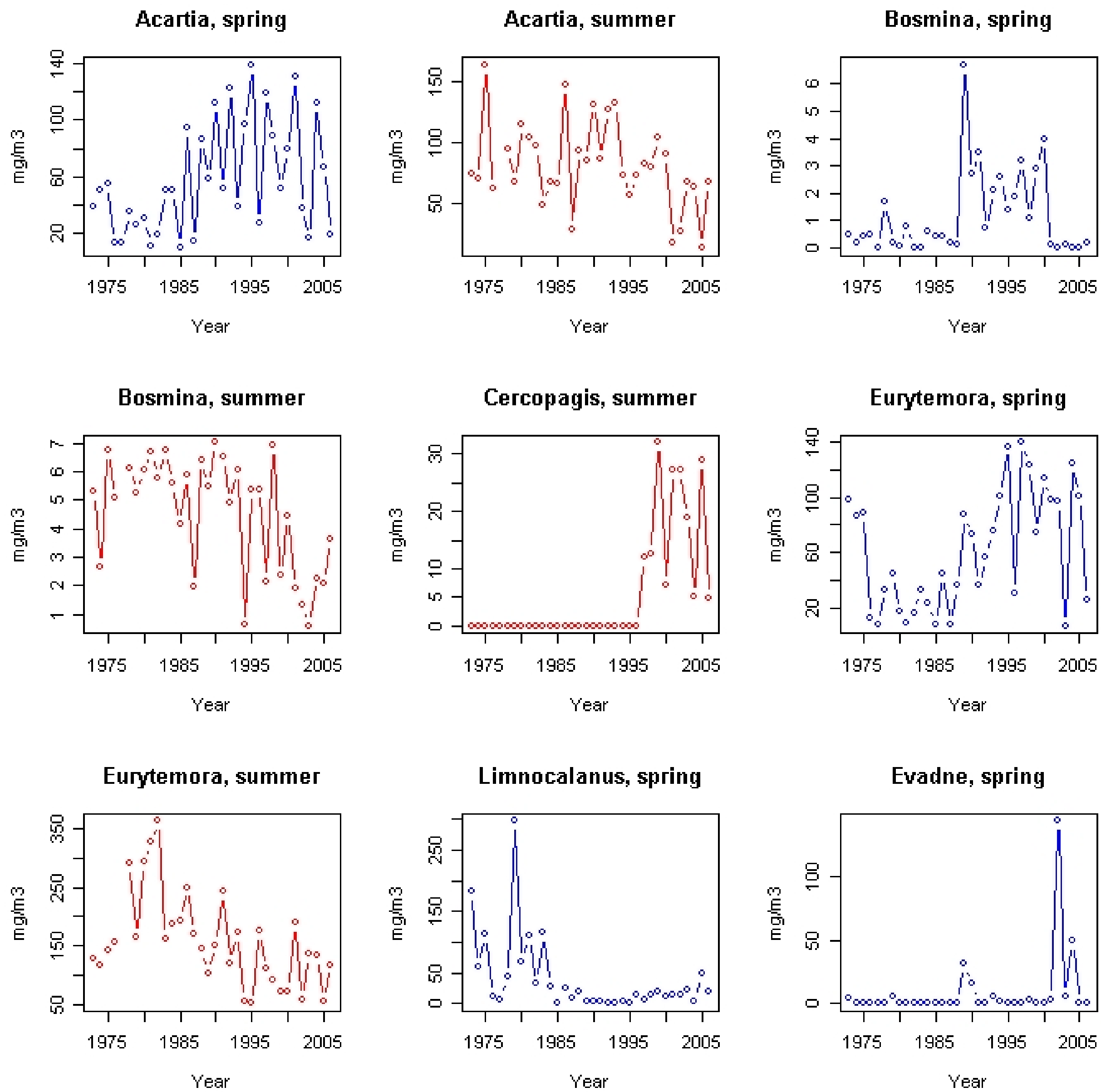

Figure GoR-4. Zooplankton dynamics in the Gulf of Riga.

Fish

Herring is the dominating commercial fish species in the Gulf of Riga and the main zooplankton consumer. The Gulf of Riga herring is a separate population of Baltic herring, with low growth rates and only very limited migration into the Baltic Proper (ICES, 2006 a). Cod was only present in the Gulf of Riga in the beginning of the 1980s (Figure 5, top left), when the Baltic cod stock was on its highest stock level. The Gulf of Riga herring stock has tripled between the mid 1980s and mid 1990s, and afterwards stabilized on a high level (Figure 5, top right). Recruitment (number of individuals at age 1) roughly paralleled the development of the spawning stock, with pronounced interannual variations. Strong year classes entered the fisheries for example in 2003 and 2001. Recruitment to the stock in 2006 – 3.21 billion individuals – was slightly below the average (3.67 billion individuals) observed during the stock increase in 1990–2006. Condition, as expressed by herring weight at age 3, had dropped in parallel to the stock increase. After an improvement observed in 1999–2003, herring weight had dropped again to very low levels in 2004 and 2005, suggesting strong intraspecific competition for limited food resources. Most likely, the drop in herring weight follows with a time-lag of approximately one year, after growth conditions had worsened, so that herring growth had probably slowed already in 2002, and had reached its minimum in 2003 and 2004 (Georg Kornilovs, personal information). Fishing pressure – expressed by the yield/SSB ratio, was low during the mid-1980s to mid-1990s, but has recovered and now slightly exceeds the level in the beginning of the 1980s.

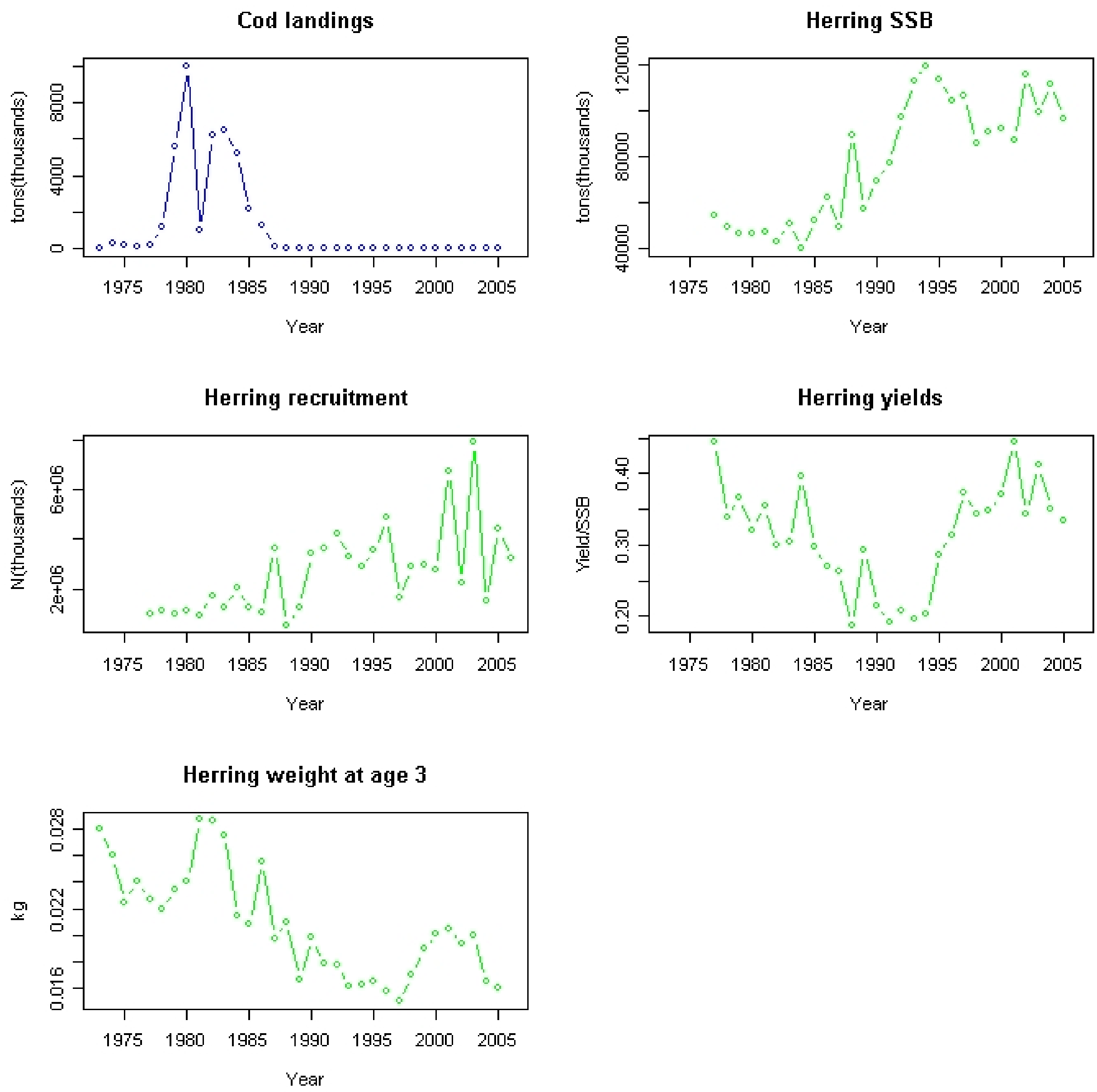

Figure GoR-5. Fish stocks, recruitment, condition and yield in the Gulf of Riga.

Integrated analysis

Compared to the previous PCA run (ICES 2006 b, Möllmann *et al.*, 2006), the current analysis was extended by the years 2004 and 2005. The loading pattern of the principal components (see Figure 6) showed similar trends as previously. PC1, which explains 30.8 % of the data variance, is related to the increase in herring stock and spring zooplankton biomass, the warming observed in all temperature time-series, as well as to the increase in winter DIP concentrations and summer chlorophyll a (time-series on the left side of the traffic-light plot in Figure 6). Part of the same pattern and represented by high positive loadings on PC1, is the decline of summer transparency, the decrease in herring weight and summer zooplankton biomass, as well as the gradual decrease of salinity in the gulf. PC2 carries 15.9 % of the data variance, and is related to the nutrient (N and P) loading to the Gulf, the dynamics of *Acartia* and *Bosmina* in summer, the trend in *Limnocalanus* and *Cercopages* abundances, as well as to the fishing pressure (yield/SSB) on herring.

Similar as in the previous analysis, the PCA run confirms that both climatic and eutrophication-related signals are important drivers for the ecosystem dynamics of the Gulf of Riga, together with the development of the herring stock. These driving factors are all represented by the first principal component. Winter DIP dynamics – related to PC1 - are again decoupled from the nutrient loads represented by PC2, which is consistent with the long residence time of phosphorus in the Gulf (Savchuk, 2002), leading to prolonged internal loading from the bottom sediments. Productivity – as reflected by summer chlorophyll levels – is again linked to the DIP pool as the ultimately limiting nutrient, while the spring zooplankton dynamics are most likely related to the warming of the Gulf. Summer zooplankton trends are opposite to spring, suggesting top down control by the increasing herring stock.

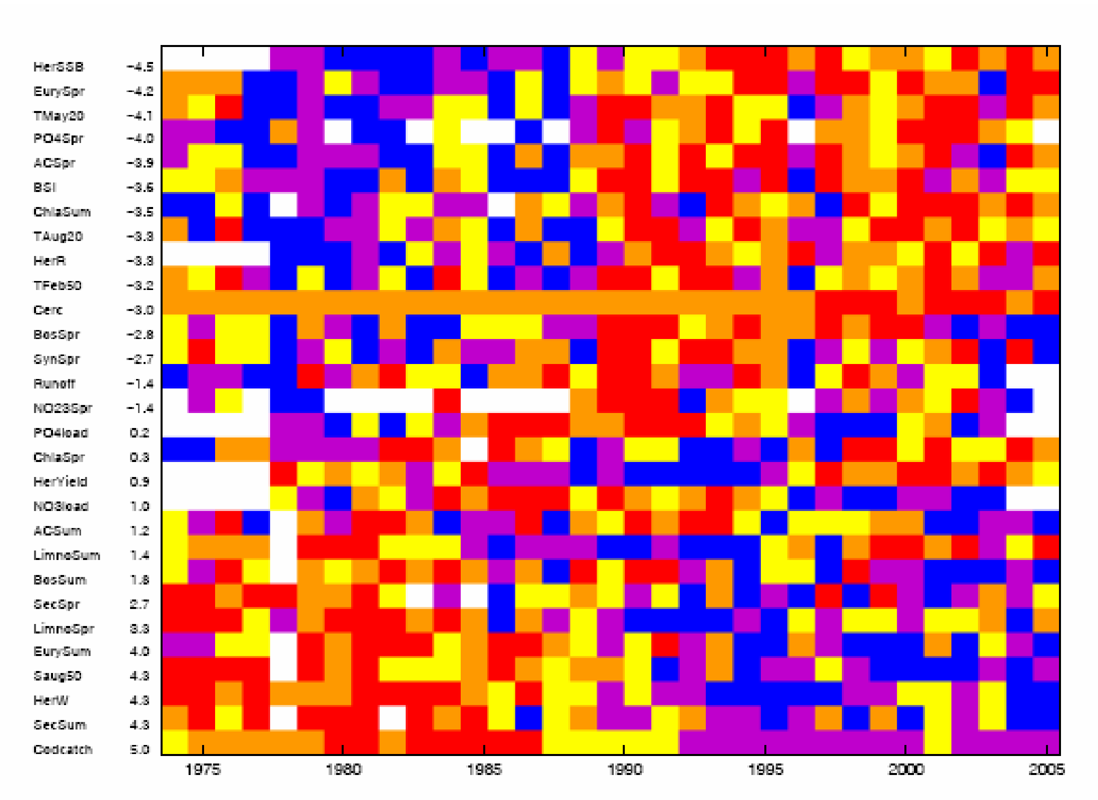

Figure GoR-6. Traffic-light plot of the development of the GoR ecosystem. Time-series are transformed to quintiles, colour coded (blue – low values; red – high values, white – missing values), and sorted according to their loading for the first principal component. Variable names are explained in Annex-Table 7.2.

The pattern indicated in the PCA loadings was also confirmed by redundancy analysis, where winter nutrient concentrations, runoff and nutrient load, temperature and salinity time-series as well as fishing pressure were considered as explanatory variables. Their first two linear combinations explained 47.7% and 19.0% of the data variance, respectively. Single explanatory variables with the highest influence were salinity (August, 0–50 m), winter DIP concentration and temperature (May, 0–20 m), while the most important combination of explanatory variables was salinity (August, 0–50 m), Baltic Sea Index and fishing pressure (Herring yield/SSB).

Chronological clustering of the time scores in the principal component analysis again identified three distinct groups of years (Figure 7). The first cluster, 1974–1988, characterizes cold and saline conditions in the Gulf, with low spring zooplankton biomass, low herring stock, low summer chlorophyll and predominantly low winter DIP. The third cluster, 1996 – 2005, is described by opposite conditions: low salinity, high temperatures, increase in spring zooplankton but decline in summer, high herring stock, as well as high winter DIP and summer phytoplankton production. The intermediate period 1989–1995 is marked by similar scores on PC1 as during phase III, indicating that the PC1-related ecosystem components already had undergone fundamental change. Instead, low scores for PC2 characterize the intermediate period, which are related to extremely high runoff and nutrient loads, as well as to low fishing pressure on herring. As the major ecosystem changes – temperature/salinity shifts, increase in herring stock and winter DIP, changes in zooplankton biomass, had already taken place at the transition phase I/phase II, the peak nutrient load paralleled by low fishing pressure characterizing phase II seems not to have triggered the shift between ecosystem states I and III in the Gulf of Riga. Rather, the intermediate period represents an exceptional series of years which is, except for runoff, nutrient load and fishing pressure, similar to the 1996–2005 cluster of years.

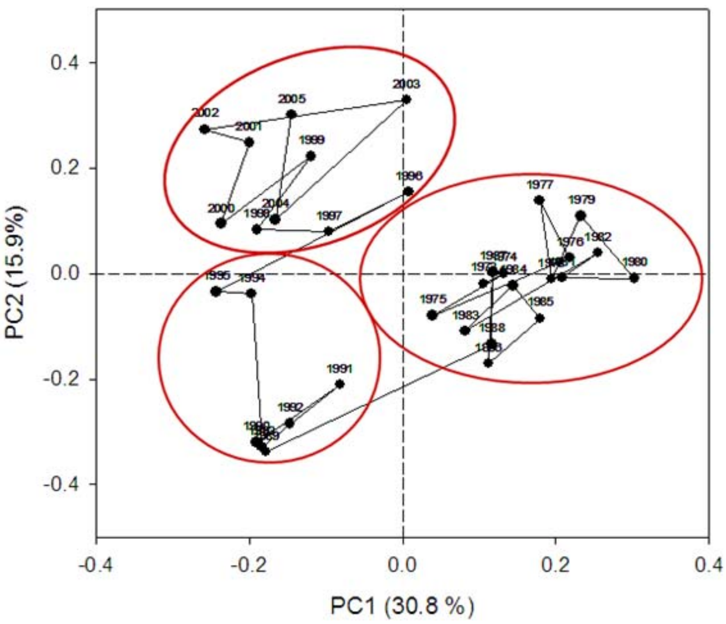

Figure GoR-7. Phase plot of time-scores for PC1 and PC2 (variance explained by PCs in brackets) in the Gulf of Riga, groups identified by chronological clustering.

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Annex 5: Ecosystem overview document for the Gulf of Finland

Hydrography

The basic flow pattern consists of inflowing water along the southern coast of the gulf, then traverses at the eastern end, and flows out along the northern coast (Figure GoF-1). The Neva river, which is the largest river in the Baltic Sea drainage area, discharges into the gulf, and the Finnish coast contributes significantly to riverine fresh water input as well. The Gulf of Finland is directly connected to the Baltic Proper, without any sill, that could prevent deep water from entering the gulf. Therefore the hydrography is similar to Baltic Proper, with deep water from below the halocline entering occasionally, with consequences on salinity and oxygen conditions in the gulf.

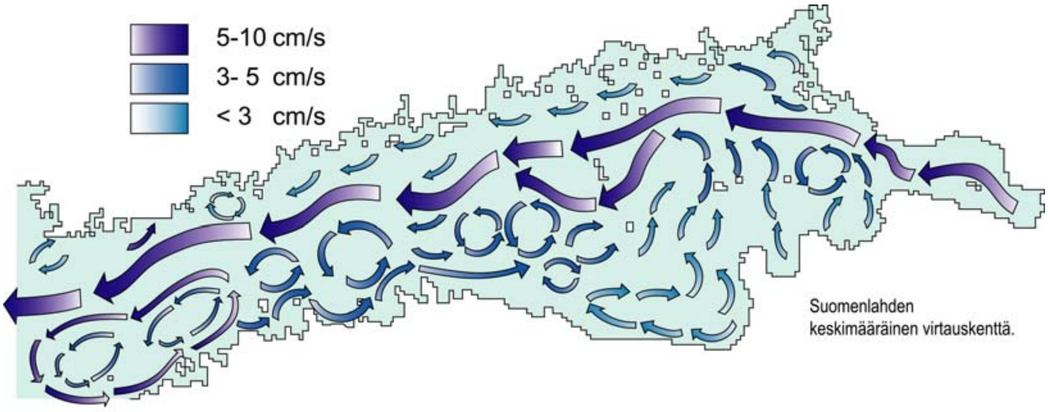
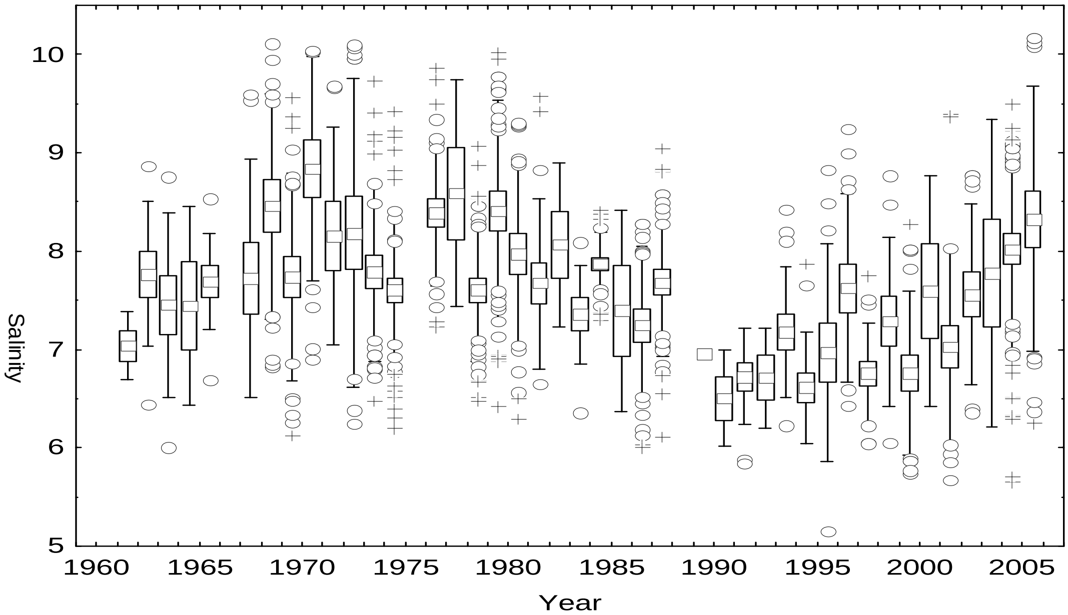
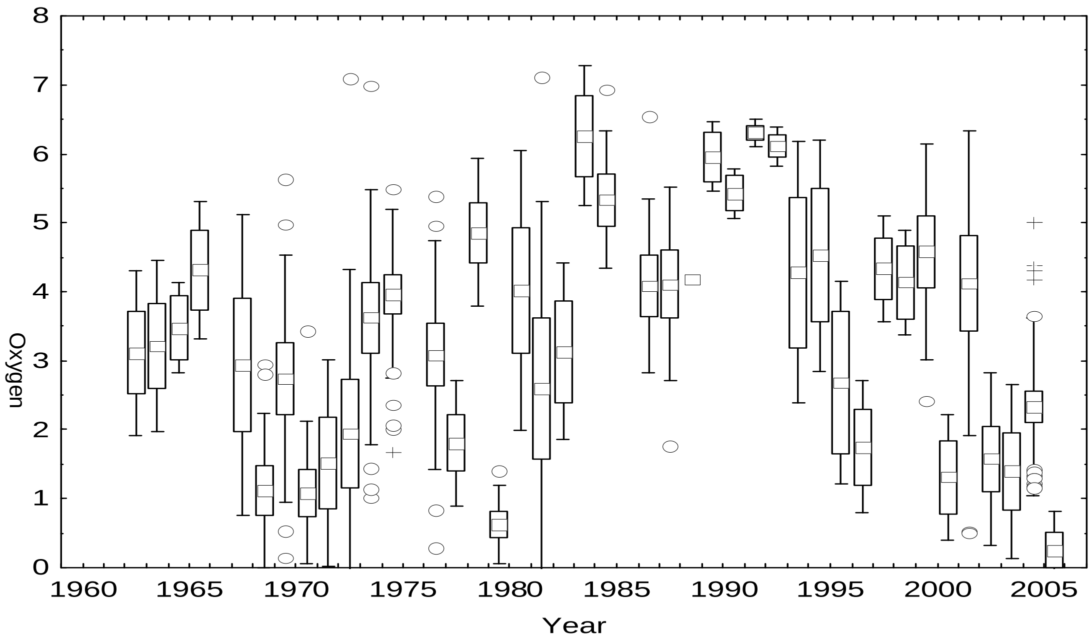


Figure 1. Average current field in Gulf of Finland (Andrejev *et al.*, 2004)

Fluctuations in salinity can be observed during the last 40 years, with a marked decline in salinity between late 1970s to mid-1990s, and an increase thereafter (Figure GoF-2). The oxygen content of the deep water has generally declined since mid-1980s (Figure GoF-3). The conditions in the bottom layer of GoF may be disrupted by wind mixing due to shallowness of the gulf. However, due to anoxic Baltic deep water entering the gulf, and severe eutrophication, anoxic conditions often develop rapidly even after well-mixed conditions. When they occur, they significantly contribute to eutrophication through release of phosphorus from anoxic sediments, a process known as internal loading. There is also an upward trend in seasonal deep water temperature (Figure GoF-4).





Figures GoF-2 and 3. Salinity and oxygen time-series in the Gulf of Finland. The bottom salinity (30-bottom) shows decreasing overall trend (Mann-Kendall Z=-2.15; p<0.05). Bottom oxygen shows decreasing tendency since the early 1990s, but no significant overall trend. Recent increase in bottom salinity is likely caused by inflow of oxygen depleted water from the Baltic Proper, which has resulted a significant decrease in bottom oxygen in the Gulf of Finland.

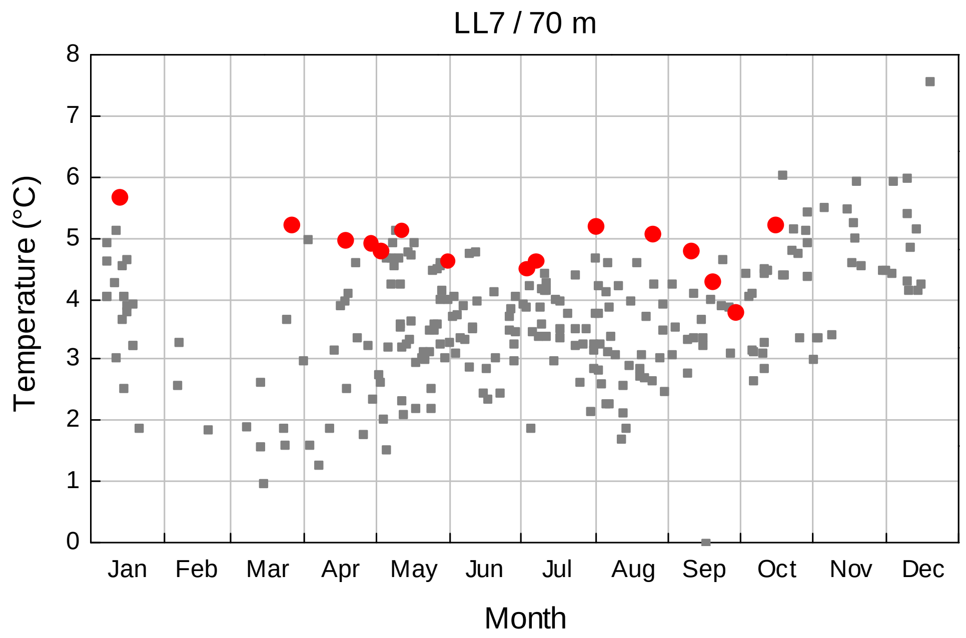


Figure 4. Seasonal variation of deep water temperature in the central Gulf of Finland (LL7 / 70m). Red dots in the figure indicate the observations in 2006, grey dots 1962–2005.

Nutrients

Nutrient concentrations in the Gulf of Finland differ between phosphate-phosphorus and nitrate-nitrite. A marked increase in phosphorus since the mid-1990s depicts prolonged anoxic conditions. Anoxic bottom water facilitates phosphorus release from sediments and enhances internal loading (Figure GoF-5). As for nitrate-nitrite, there has been a slight decrease since early 1990s, after a period of steady increase (Figure GoF-6).

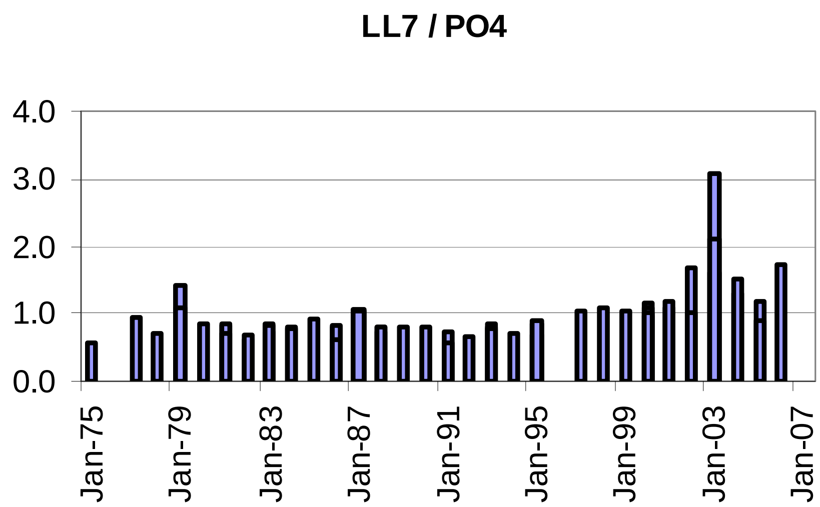


Figure GoF-5. Winter-time average phosphate concentration (µmol/l) in the central Gulf of Finland (LL7, Alenius *et al.* 2006).

Both nutrients, however, show one similar trend: concentrations increase towards east. This is often explained by the effect of rivers Neva, which discharges into the easternmost end of GoF, and Kymijoki, which discharges into the GoF at approximately 27º East. Other rivers naturally add to this, as well as airborne and other non-point source nutrient loading.

However, a recent study by Eremina *et al*. (2006) shows that the effects of point sources such as St. Petersburg are much less significant than nutrient pools already circulating in the system, or input from the Baltic Proper.

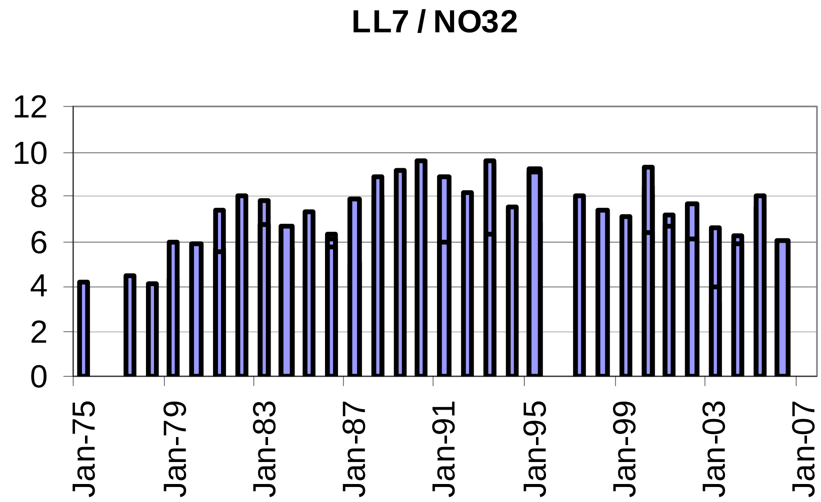


Figure GoF-6. Winter-time average nitrate+nitrite concentration (µmol/l) in the central Gulf of Finland (LL7, Alenius *et al.* 2006).

Nutrient concentrations in Figures GoF-5 and -6 are given as winter average values, as they represent the situation after mixing by winter storms. Nutrients at late winter-early spring are available for phytoplankton spring bloom, which is nitrogen restricted. High concentrations of phosphorus at this time mean a phosphorus surplus after spring bloom, which in turn facilitates blue-green algal blooms.

Phytoplankton

The general positive trend in phytoplankton biomass within the Baltic Sea, expressed as chlorophyll-a concentration, is most significant in Gulf of Finland (Kaitala *et al*., 2006; Suikkanen *et al*. 2007, Figure GoF-7).

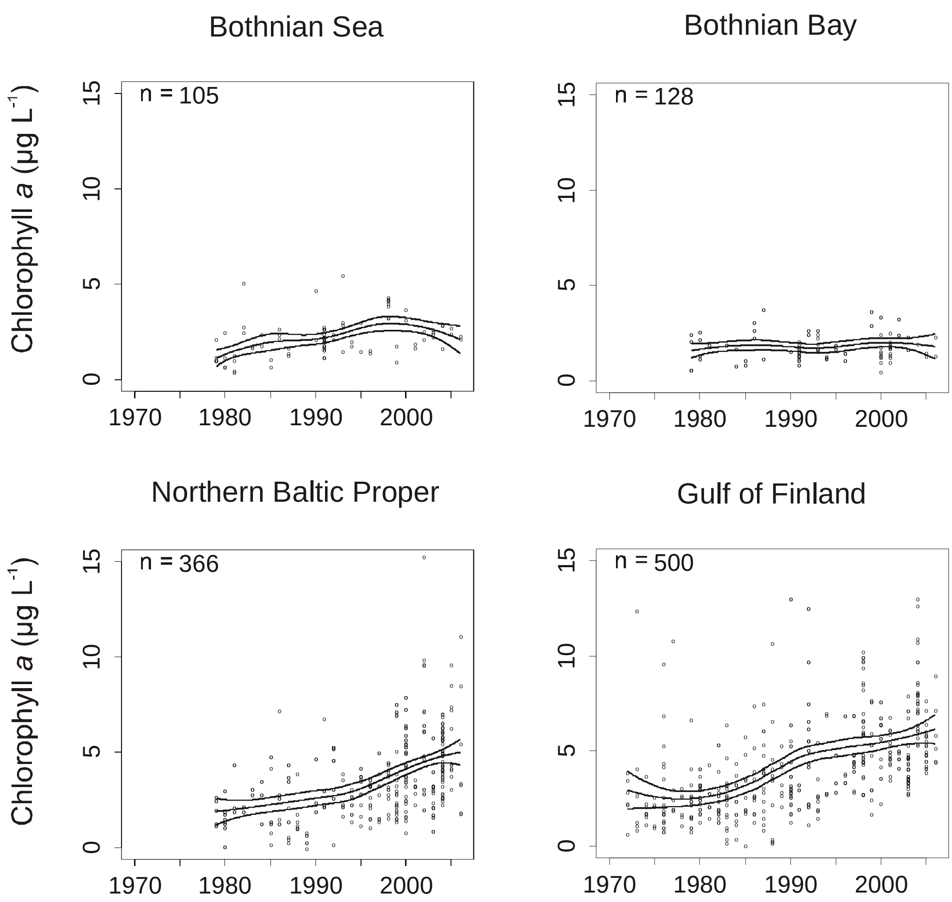


Figure GoF-7. Concentration of chlorophyll-a (µg L^{-1}) in the Bothnian Sea, the Bothnian Bay, the Northern Baltic Proper and the Gulf of Finland. A Loess curve with 95-percent confidence intervals (solid black lines) is fitted to describe the long-term variation. The number of observations for the sub-areas (n) is given in the upper left corner of each plot. (Kaitala *et al.* 2006)

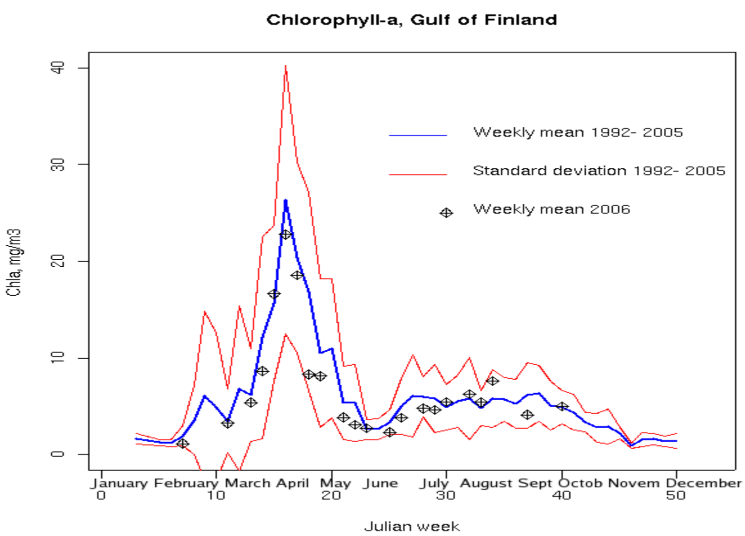


Figure GoF-8.a Annual variation of chlorophyll a (mg m^{-3}) in the Western Gulf of Finland. The blue curve represents the average for the years 1992–2005 and red lines mark standard deviations, the black stars the measurements made in 2006. (Kaitala *et al.* 2006)

The seasonal distribution of chlorophyll-a is strongly spring bloom orientated, with a second peak in late summer-early fall. A significant contributor to this latter peak are the blue-green algae, or cyanobacteria, which represent 40–80% of total phytoplankton biomass in GoF (Figure GoF-8).

Zooplankton

Zooplankton communities in the Gulf of Finland show similar trends to those of the Baltic Proper, albeit not as clearly. In general, there is no significant trend in overall zooplankton or copepod biomass. Only cladocerans show a significant negative development ($p<0.05$). However, when investigating the trends on the species level, the copepod *Pseudocalanus acuspes* displays a significantly decreasing trend ($p<0.05$), while *Centropages hamatus* a significantly increasing trend ($p<0.01$). Cladocerans *Bosmina* and *Evadne* have decreased significantly ($p<0.05$).

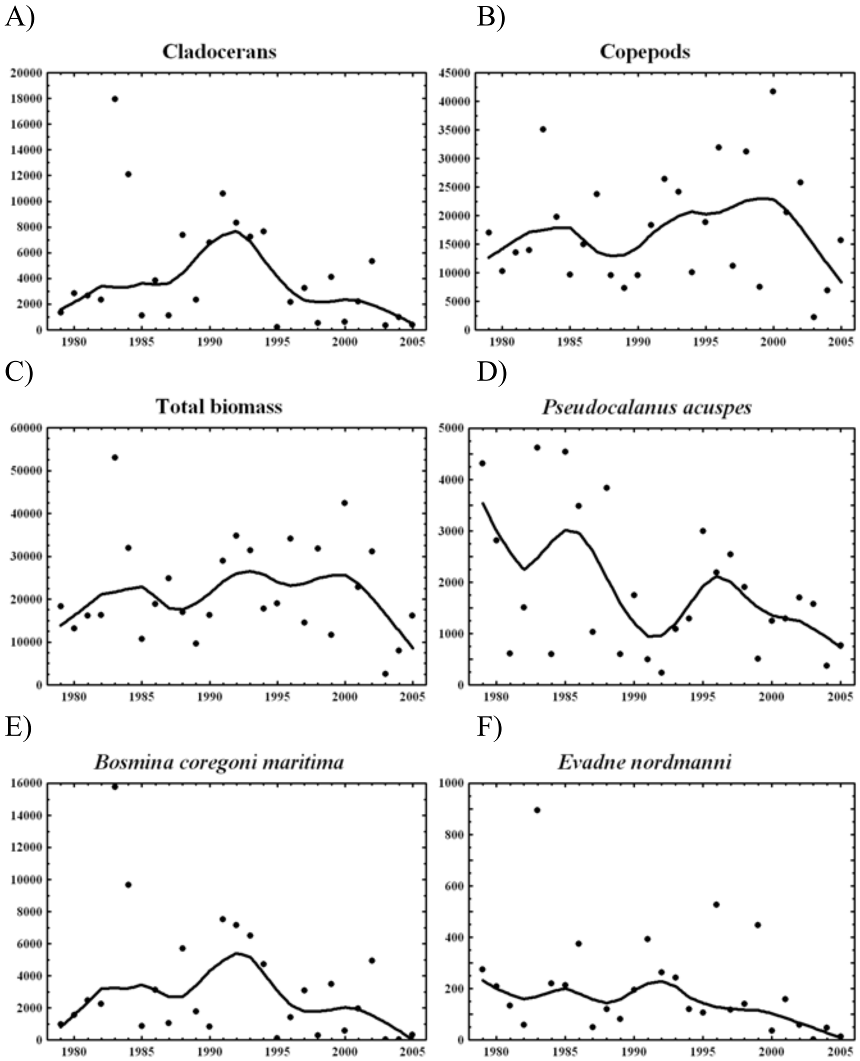


Figure 9. Zooplankton biomass (mg m^{-2})in the Gulf of Finland.. LOWESS smoothing value = 0.30. Panels: A) Cladocerans, B) Copepods, C) Total zooplankton biomass, D) *Pseudocalanus acuspes*, E) *Bosmina coregoni maritima*, F) *Evadne nordmanni*. (Flinkman *et al.* 2006).

Zoobenthos

Benthic communities in the Gulf of Finland experienced a brief period of high abundances during 1977–1993, when the absence of saline water intrusions led to the disruption of the salinity stratification. The halocline was reconstructed by salt water inflows of 1993 and 2003. Re-establishment of the salinity stratification led to a collapse in the benthic abundance, which has not recovered since (Figure GoF-10). This loss of zoobenthic, as well as nectobenthic, i.e. mysid, abundance may have had an effect on the availability of prey for the fish stocks.

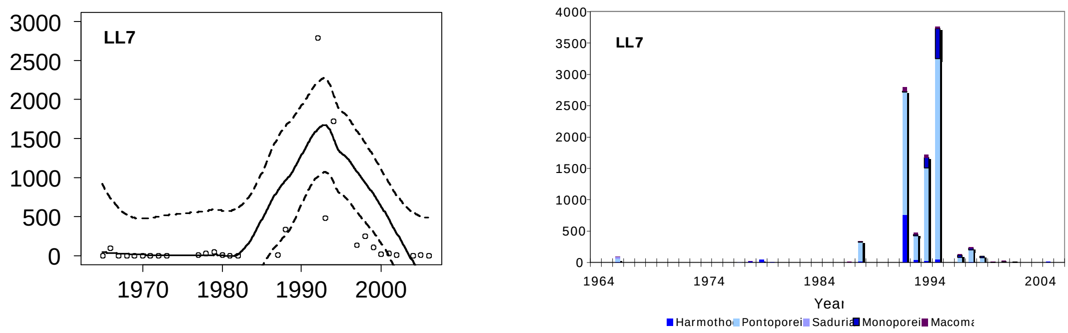


Figure GoF-10. Trends in macrozoobenthic community abundance (LOESS smoothing) and composition in the Gulf of Finland. The x-axes depict years and the y-axes number of individuals per m^2. Note differences in scale on y-axes (Norkko *et al.* 2006).

Fish

Assessing the fish stocks in the Gulf of Finland is problematic due to the fact that GoF has been treated as a part of Northern Baltic Proper in ICES statistics and stock analysis since the early 1990s (ICES, 2006). However, using catch statistics and stock estimates from Estonian and Finnish sources, a general picture of the development of fish stocks can be obtained.

The development of commercially valuable offshore fish catch reveals distinct fluctuations in the stocks. Perhaps the most important trend is the general decrease in herring catch since the late 1980s, and a downward trend in salmon and trout catches after a peak in the early 1990s (Figure GoF-11).

However, a marked increase in sprat catch can be observed since the mid-1990s, followed by a decrease again in the beginning of the 2000s. Estonian data spans further into the past, and reveals a fluctuation pattern, as well as a further increase in the present sprat catch (Figure GoF-12).

The general downward trend of fish stocks other than sprat can be attributed to the salinity decrease and the more frequent occurrence of anoxic conditions. These changes are mediated to fish through plankton and benthic communities, which suffer from the deteriorating environment.

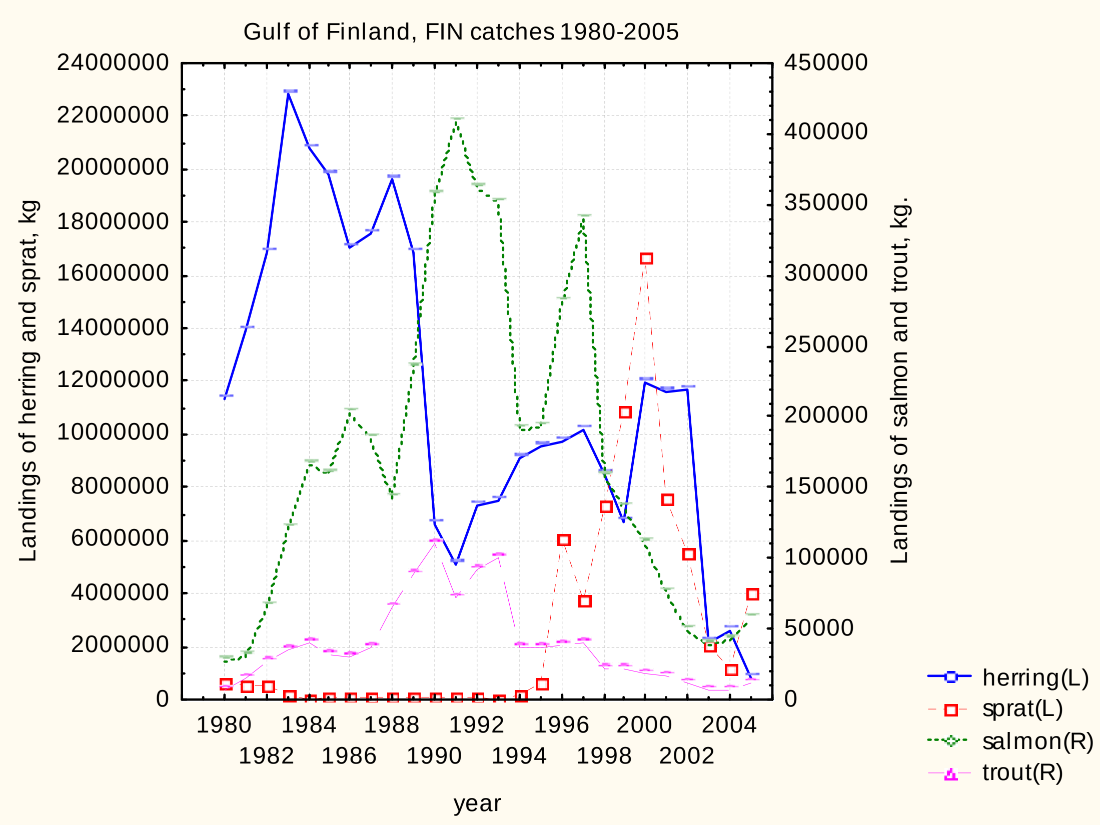


Figure GoF-11. Finnish landings of herring, sprat, salmon and sea-trout in Gulf of Finland.

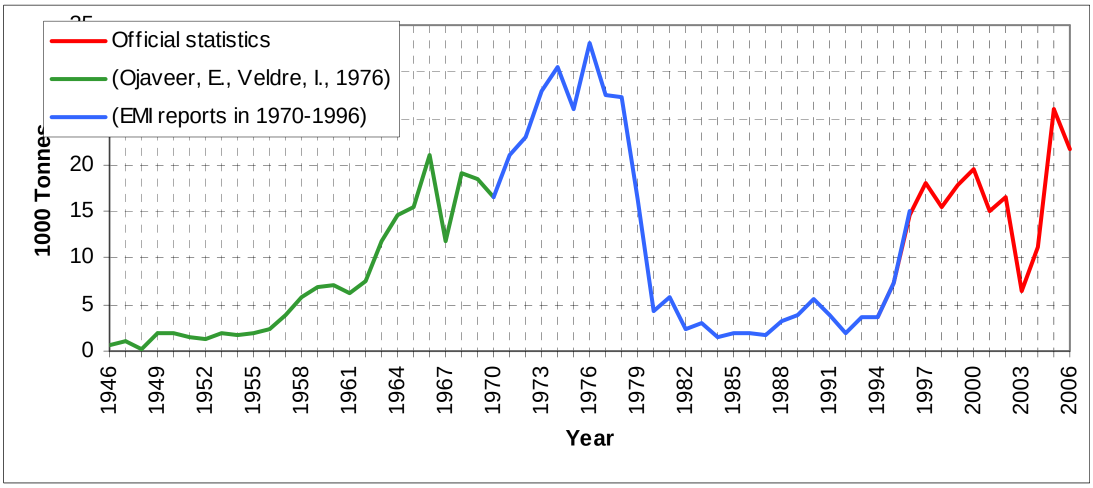


Figure GoF-12. Estonian sprat catch 1946–2006.

Integrated analysis

Multivariate analyses were conducted on a selection of the available time-series to provide an integrated view on the state and development of the ecosystem. Altogether, 35 variables were considered: 8 fish-, 11 zooplankton-, 3 phytoplankton-, 5 nutrient-, and 8 physical-related datasets. All data-series available had a frequency of, or were compiled to, one assessment per year and covered in maximum the period 1979 to 2005. Variable vectors and scores (years) from the PCA were displayed on the first factorial plane and the years were connected in chronological order. The presence of any regime shifts (i.e. large shifts in ecosystem composition) was analysed by chronological cluster analysis. Year scores along PC1 and PC2 were additionally plotted against time to illustrate any regime shifts. Finally the raw values of each variable were categorized into quintiles and each quintile was given a specific colour from blue (first quintile, i.e. low data raw values) to red (fifth quintile, i.e. high raw data values), following the traffic light framework used in stock assessments (Link *et al*., 2002).

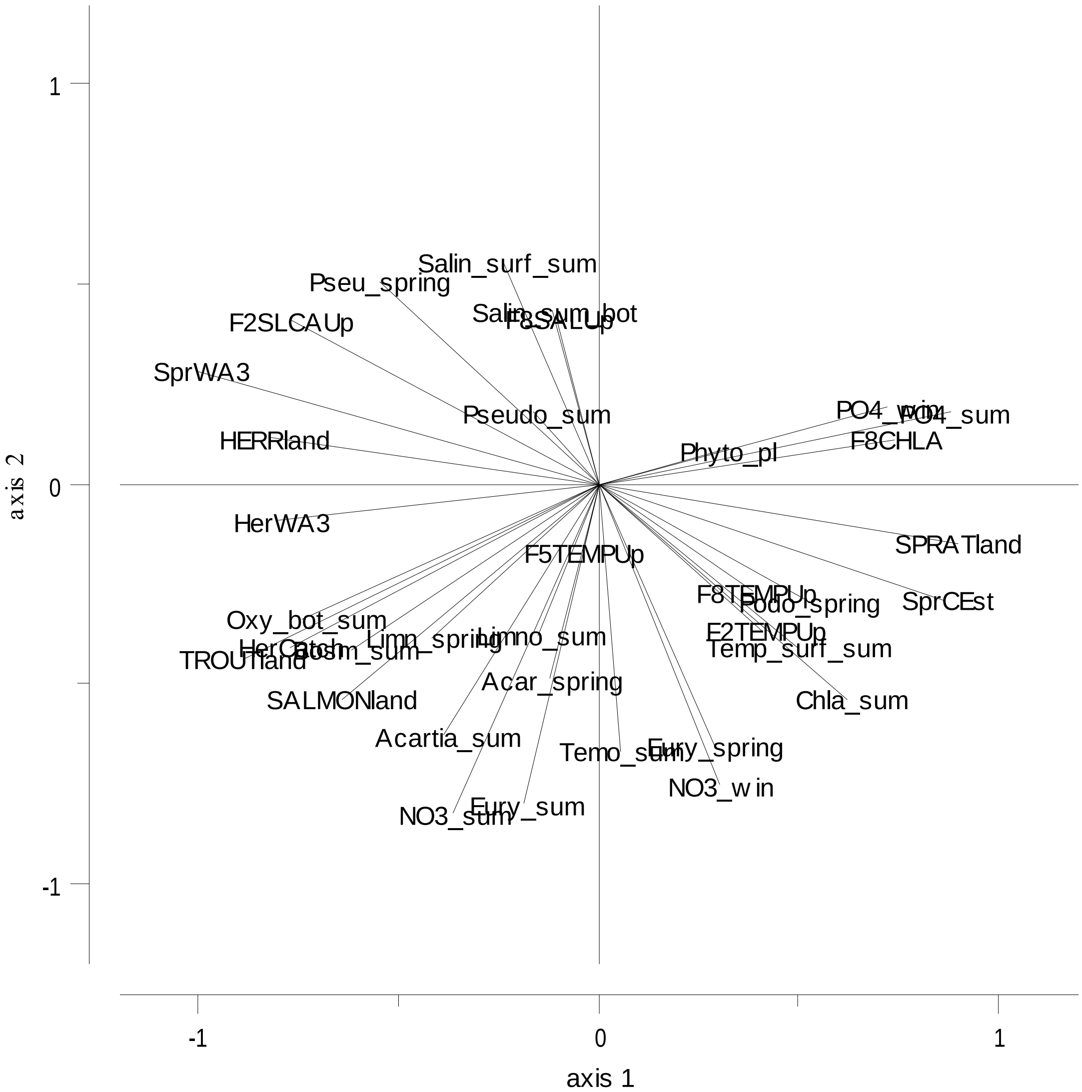


Figure GoF-13. Vectors in the first factorial plane from a PCA on 35 time-series from 1979 and four series from 1983. Variable names are explained in Annex-Table 7.3.

The first two principal components explain 24.1% and 14.4%, respectively. The fist component (PC1) is primarily driven by salinity and herring data as well temperature, PO_4 and Oxygen. The second (PC2) is driven by zooplankton groups (*Acartia* spp. and *P. acuspes*) as well as salinity and NO_3 (Figure GoF-13). A chronological plot of the scores in the first factorial plane illustrates 3 groups of scores, 1979–1995, 1996–2002 and 2003–2005 (Figure GoF-14), separated by chronological clustering.

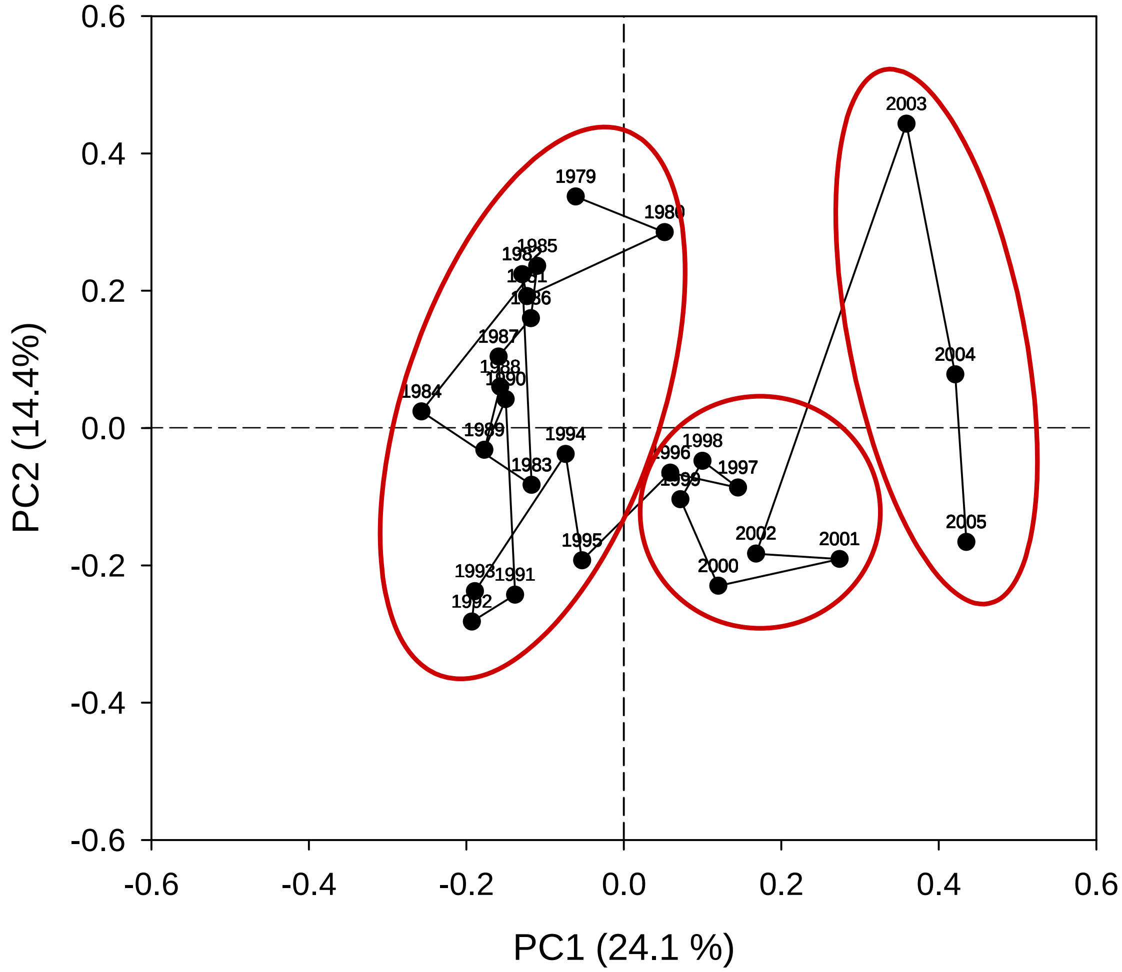


Figure GoF-14. Scores of principal components plotted in chronological order in (a) the first factorial plane. Circles correspond to the results of the cluster analysis using a=0.01.

The traffic light plot illustrates the nature of this compositional change (Figure GoF-15). The Gulf of Finland has changed from a saline, oxgenated and cold ecosystem with abundant marine zooplankton such as *Pseudocalanus* and herring,, to a warmer, less saline ecosystem with oxygen deficiency. In the zooplankton now *Eurytemora* and cladocerans dominate and sprat abundance is high. Further on phytoplankton and PO_4 levels have increased.

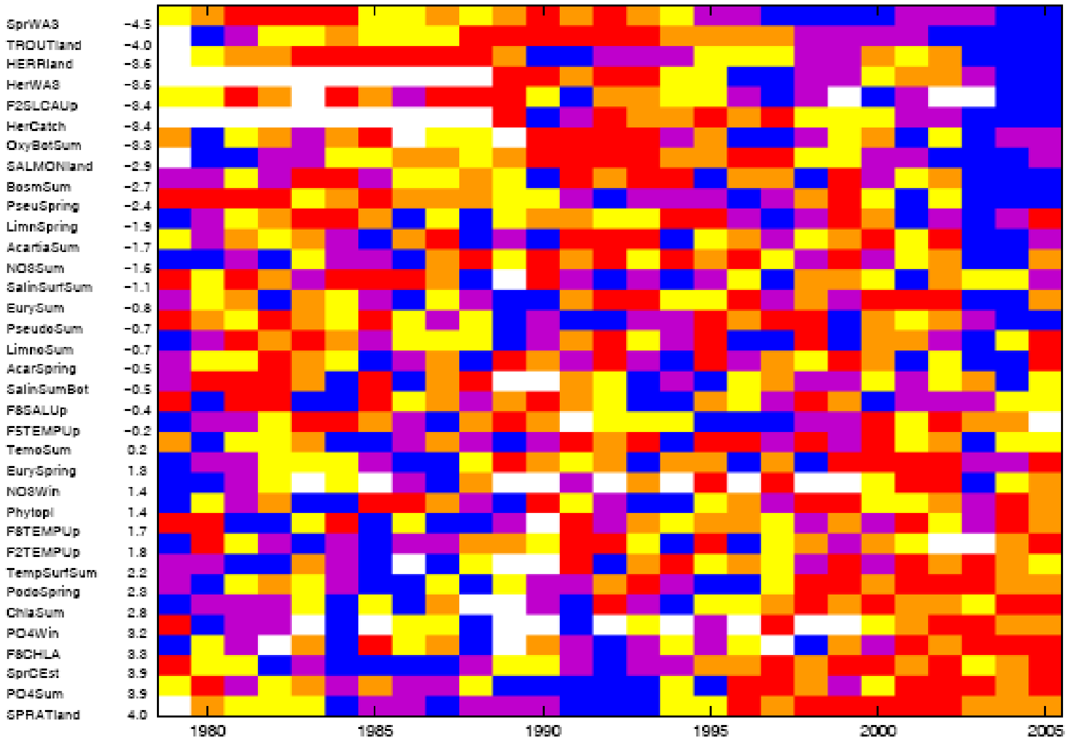


Figure GoF-15. Traffic light plot all variables included in the PCA. Blue indicates low values (in the first quantile), red high values (in the fifth quantile), and white missing values. Variables have been sorted according to their PC1value (given after the variable name) with high PC1 loadings at the top of the graph, and low at the bottom. Variable names are explained in Annex-Table 7.3.

In summary, the integrated analysis showed regime shifts in the ecosystem composition in the mid 1990s and recently. Compared to the other subsystems (Central Baltic, Gulf of Riga, Bothnia Sea) nutrient increase seems to be more important, which might explain the different timing of the shift. The primary drivers of the shifts in the Gulf of Finland are the decrease in salinity, increasing temperature and increasing nutrient levels. These trends are a result of the combination of the changed atmospheric forcing and eutrophication. For the Baltic Sea region, the changes in atmospheric forcing decreased the frequency of inflow events of saline and oxygen-rich water from the North Sea and increasing run-off due to precipitation, which both contribute to the decreasing salinity in the Gulf of Finland, and to the corresponding changes in the ecosystem.

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Annex 6: Ecosystem overview document for the Bothnian Sea

The Bothnian Sea is a basin of about 79 000 square kilometer surface area, separated from the Baltic Proper by a sill. Because of its separation, its hydrography and biota is distinct from that in the Baltic Proper. The salinity is low, ranging from three psu at the surface to about seven psu in the bottom waters. There is not always a permanent halocline and the water below the thermocline is often well-mixed (Voipio, 1981), why oxygen deficiencies has not been observed in the offshore bottom areas. Occasionally, strong inflows of saline water into the Baltic Sea reach the Bothnian Sea, enabling the persistence of marine species like the zooplankton *Pseudocalanus* or *Temora* in the southernmost Bothnian Sea.

The phytoplankton community is phosphorous limited in the northernmost Bothnian Sea, and nitrogen limitation increases southwards (Granéli *et al.*, 1990, Andersson *et al.*, 1996). The zooplankton community is dominated by brackish water species such as dinoflagellates, *Eurytemora affinis* and *Bosmina longispina maritima*. The Bothnian benthic communities are dominated by glacial relicts: the isopod *Saduria entomon* and the amphipod *Monoporeia affinis*, and by the mussel *Macoma baltica* (Kautsky and Kautsky, 2000; Laine, 2003).

Many marine fish species, such as cod and flounder, have their northernmost distribution limit in the Bothnian Sea. In the southern Bothnian Sea herring and sprat are the most important species in the open sea. Common coastal-dwelling species are sticklebacks (*Gasterosteus aculaetus* and *Pungitius pungitius*), perch (*Perca fluviatus*), pike (*Esox lucius*), roach (*Rutilus rutilus*), bleak (*Alburnus alburnus*), pikeperch (*Sander lucioperca*) and burbot (*Lota lota*). Salmon (*Salmo salar*) and the benthic feeding European whitefish (*Coregonus lavaraetus*) are together with herring the most important species for coastal fisheries. Grey seal (*Halichoerus grypus*) is the dominating top predator, and the population is increasing rapidly, during the period 1990–2004 with about 7.5% annually (Karlsson and Helander 2004).

Recent and more long-term trends in hydrography, nutrients, phyto- and zooplankton, zoobenthos, fish and fisheries, as assessed during this meeting, are presented below. These are followed by an integrated assessment of overall trends in the ecosystem composition.

Climate and hydrography

Climatic and hydrographic data for 1973–2005 collected by the Swedish Meterological and Hydrological Institute (SMHI) and the Finnish Institute of Marine Research (FIMR) was compiled and averaged across stations in the whole Bothnian Sea. Summer sea surface (July-Sept., <10 m depth) temperature shows an increasing tendency since the 1970s, whereas the bottom (30–300m depth) temperature in summer has decreased (Figure BoS-1). The latter is likely an effect of the decreased inflow of water from the Baltic Proper, which also has resulted in a significant decrease in salinity in the bottom waters (Figure BoS-2). There is no trend in winter (November–March) temperatures.

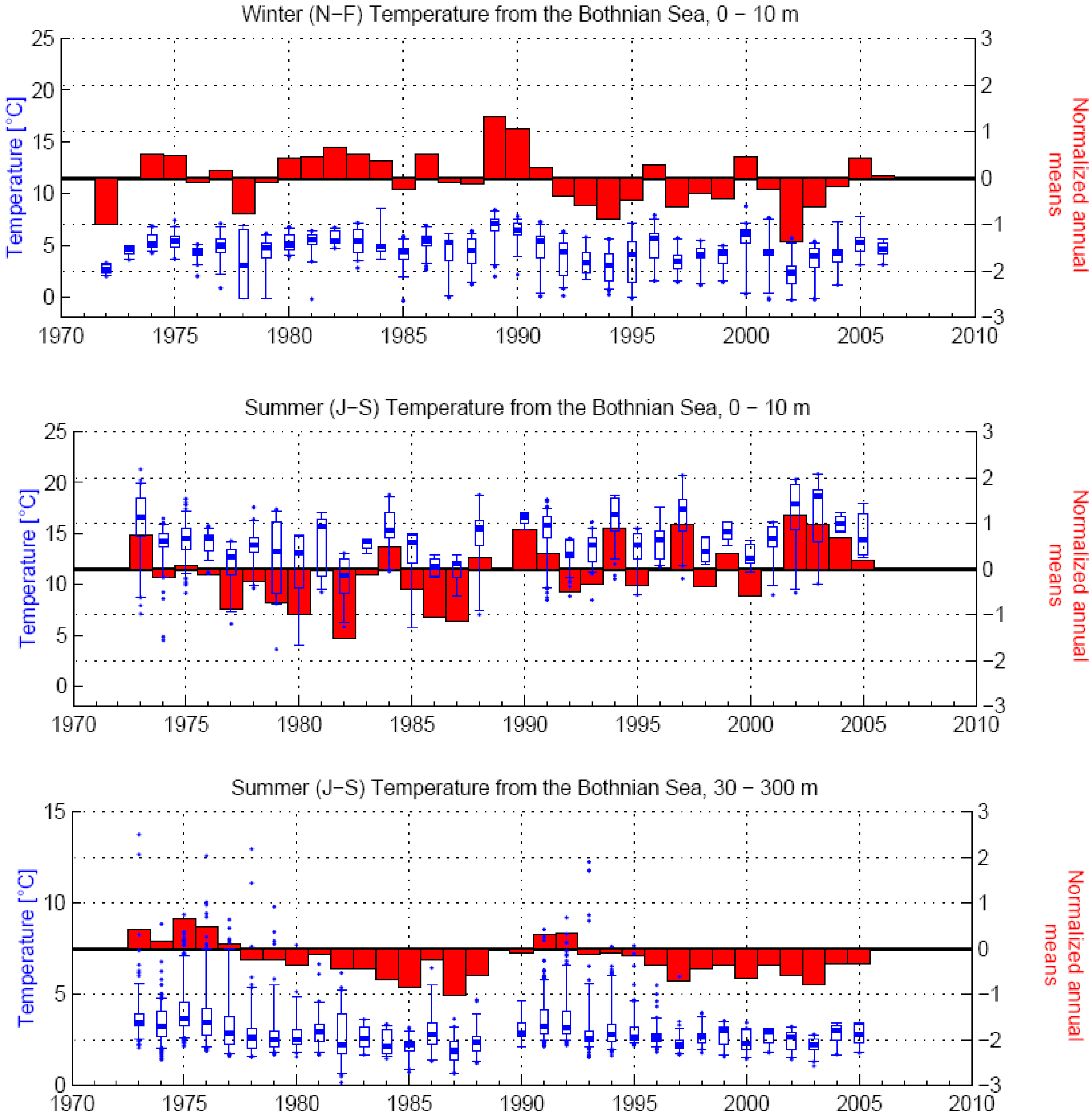

Figure BoS-1. Time-series on temperature anomalies in the Bothnian Sea.

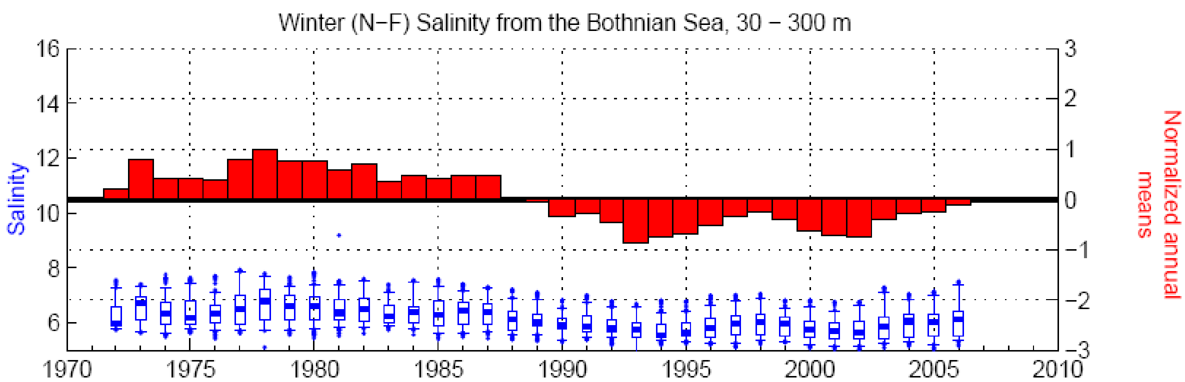

Figure BoS-2. Time-series on salinity and temperature anomalies in the Bothnian Sea.

Nutrients

Winter nutrient data in the open sea for 1973–2005 collected by SMHI and FIMR was compiled and averaged across stations in the whole Bothnian Sea. The amount of dissolved inorganic nitrogen (DIN) increased until 2000, whereafter it has decreased again (Figure BoS-3). Dissolved inorganic phosphorous (DIP), in contrast, has had a tendency to increase since 1980, but the trend is not statistically significant (Figure BoS-3). In parallel to the increase in nutrients, the secchi depth has decreased since 1980 until the end of the time-series 1998 in a Bothnian Sea wide data set (extracted from the Aarup Secchi Database hosted by ICES), and until 2001 at a coastal site (collected by the Swedish Board of Fisheries, SBF), whereafter it has increased (Figure BoS-4).

Winter nutrient data in the open sea for 1973-2005 collected by SMHI and FIMR was compiled and averaged across stations in the whole Bothnian Sea. The amount of dissolved inorganic nitrogen (DIN) increased until 2000, whereafter it has decreased again (Figure BoS-3). Dissolved inorganic phosphorous (DIP), in contrast, has had a tendency to increase since 1980, but the trend is not statistically significant (Figure BoS-3). In parallel to the increase in nutrients, the secchi depth has decreased since 1980 until the end of the time-series 1998 in a Bothnian Sea wide data set (extracted from the Aarup Secchi Database hosted by ICES), and until 2001 at a coastal site (collected by the Swedish Board of Fisheries, SBF), whereafter it has increased (Figure BoS-4).

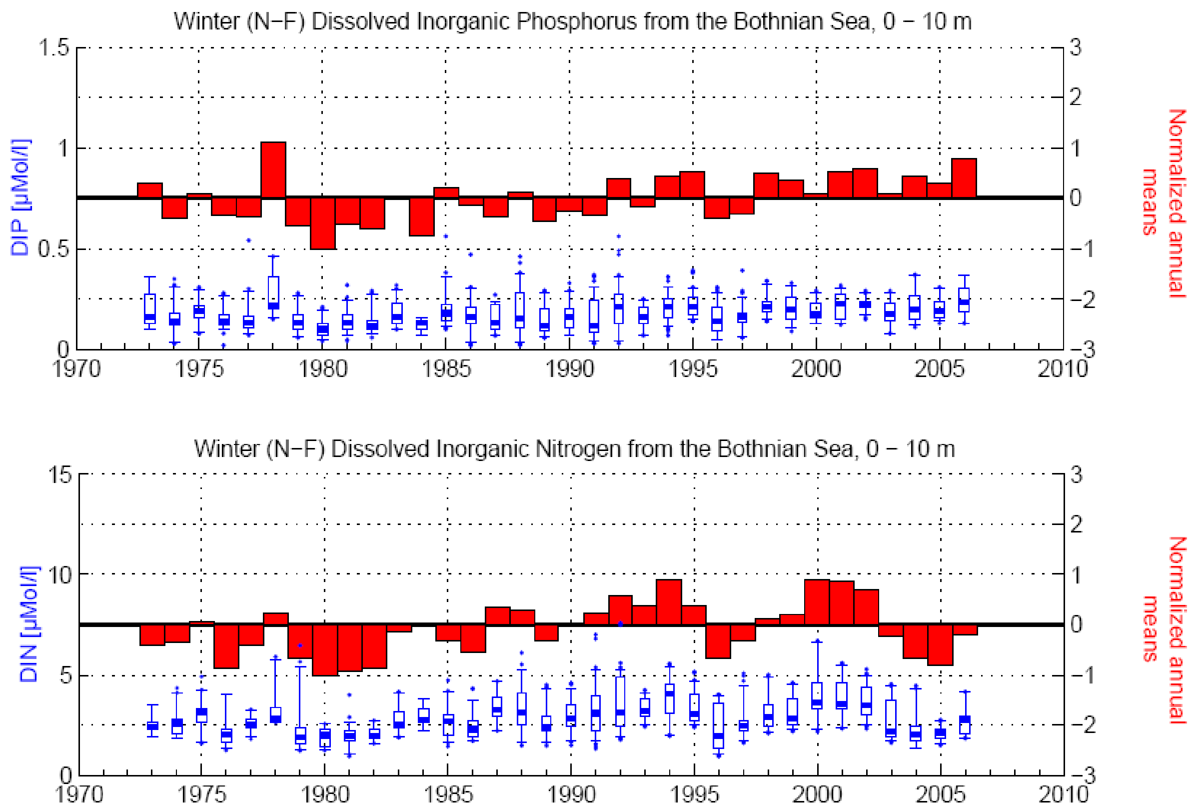

Figure BoS-3. Time-series on nutrient levels in the Bothnian Sea.

The nutrient load (DIN, DIP) from river run-off from Swedish rivers collected by the Swedish Agricultural University as part of a national monitoring programme was compiled by river basin and summarised across all areas. There are no directed trends in run-off nutrient loads overall or in particular regions.

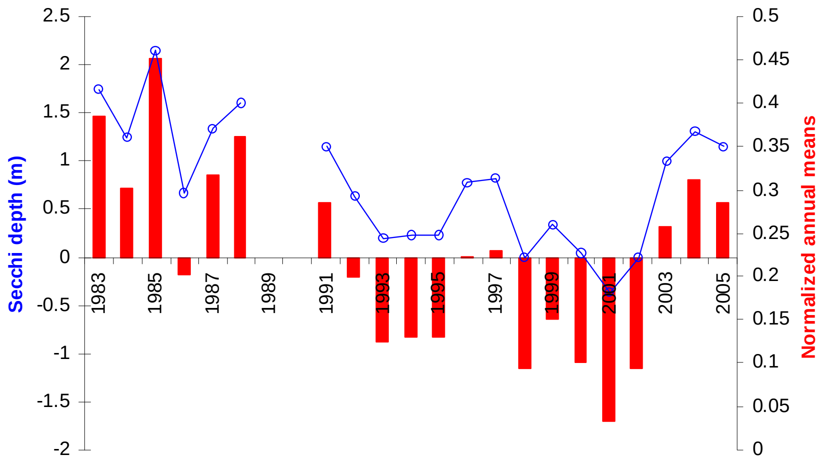

Figure BoS-4. Time-series on secchi depth (m) in the Bothnian Sea east coast (correlated with total average secchi depth available 1983-1998; rho=0.78).

Phytoplankton

Summer data on phytoplankton biovolume (mg m^{-3}) from 0-10m-layer collected by FIMR covers the 1979–2005 period. Samples are taken at three stations (F64, SR5, and US5B), which show no contradiction in long-term trends. Data from all stations were therefore averaged and clustered into three taxonomic groups (diatoms *Diatomophyceae*, dinoflagellates *Dinophyceae*, and cyanobacteria *Nostocophyceae*), which together with total phytoplankton biovolume were included in the integrated assessment below. The biovolume of cyanobacteria have increased in the southernmost station (F64), but there were no other statistically significant trends in phytoplankton at individual stations or in the average across stations (Figure BoS-5). In contrast, the concentration of chlorophyll a, which is an indicator of the standing stock of phytoplankton biomass, has at the same stations almost doubled since 1979 (Figure BoS-6).

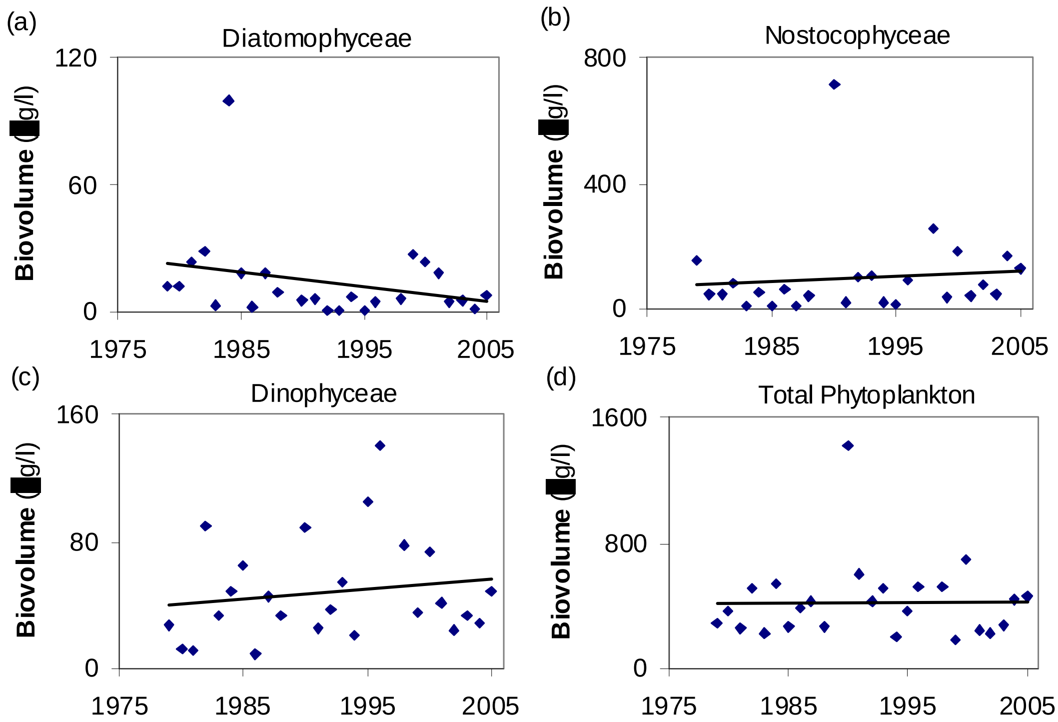

Figure BoS-5. Time-series on phytoplankton in the Bothnian Sea. Biovolume (mg/l) of (a) diatoms, (b) cyanobacteria, (c) dinoflagellates, and (d) total phytoplankton.

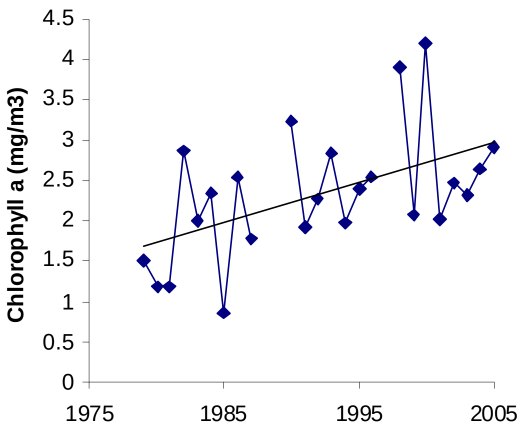

Figure BoS-6. Time-series on chlorophyll *a* (an indicator of total phytoplankton biomass) in the Bothnian Sea.

Zooplankton

Summer (July-September) data on zooplankton biomass (mg m-3) collected by FIMR covers the years 1979–2006. Data from 5 stations (SR5, SR5B, US5, US5B, and F64) were merged as these show similar trends in zooplankton. The data was grouped in seven taxonomic groups, five copepod groups (*Acartia*, *Eurytemora*, *Limnocalanus*, *Pseudocalanus* and *Temora*) and two cladoceran groups (*Evadne*, *Podon* and *Bosmina*).

The brackish-water cladoceran *Bosmina* has increased (Figure BoS-7) in parallel with the decline in salinity (Figure BoS-2). Correspondingly the marine copepods *Pseudocalanus* and *Temora* have decreased by more than 80–90% (the extreme values in 2003 for these two groups was observed only in the southernmost station, and resulted from the salt water inflow in that year). The marine copepod *Limnocalanus*, in contrast, shows an increase, but only in the early 1980s whereafter there has been no trend. There are no other statistically significant trends in zooplankton.

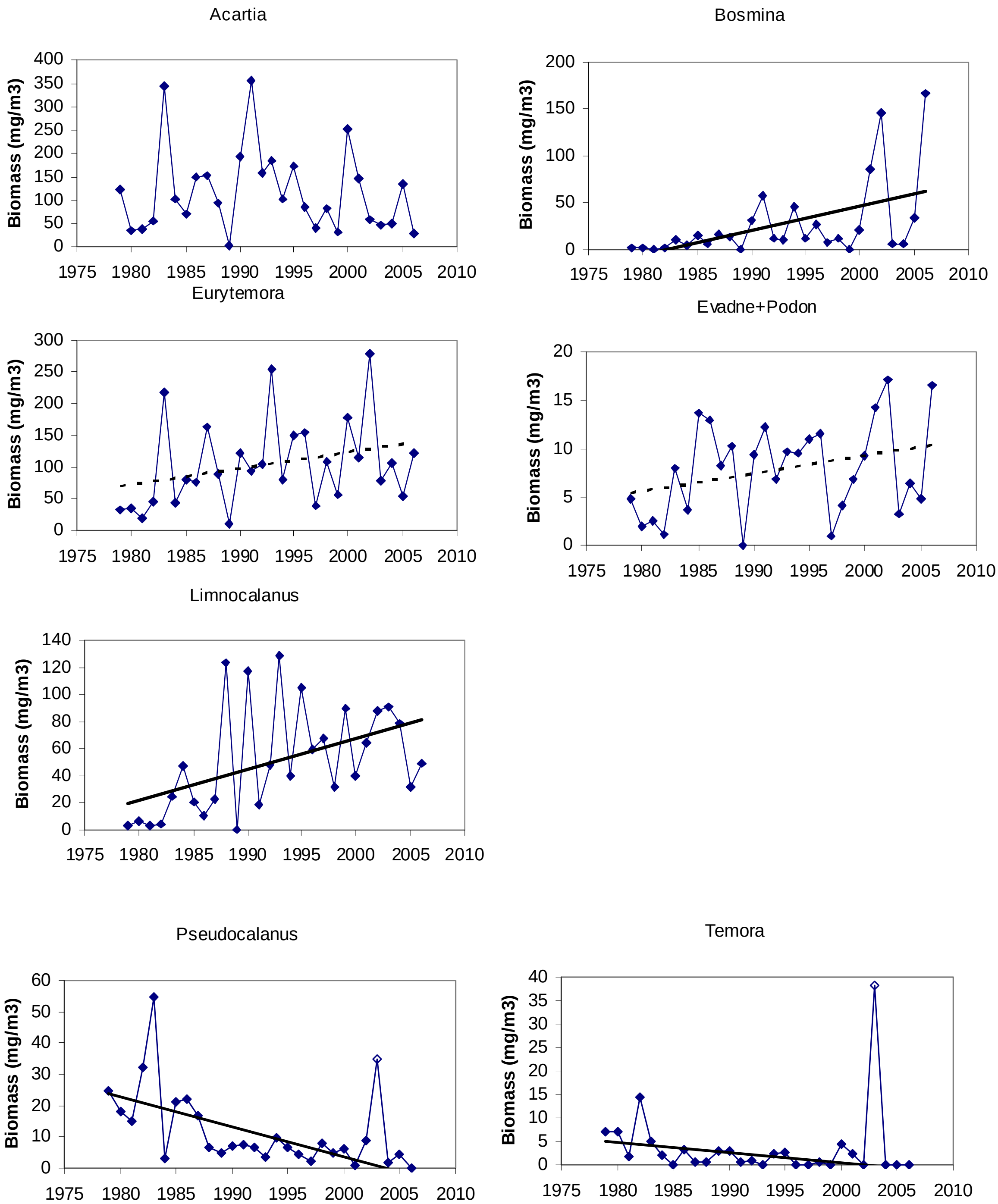

Figure BoS-7. Time-series on selected zooplankton groups in the Bothnian Sea. Open symbols indicate outliers not included in analyses. Full lines indicate statistically significant trends (p<0.05), hatched lines tendencies (p<0.10).

Zoobenthos

Zoobenthos biomass data for 1983–2005 was compiled for three selected species in two coastal areas (southern area collected by SBF, northern station N1 by Umeå Marine Sciences

Centre, UMF, within a national monitoring programme).The coastal zoobenthic community show opposite trends in the southern and northern Bothnian Sea. In the south, *Macoma balthica* and *Saduria entomon* have increased ($p<0.001$ and $p<0.05$,-respectively, Figure BoS-8a), whereas in the north they have decreased by two thirds (*M. balthica* $p<0.001$, *S. entomon* $p<0.01$ after removing outlier years 1995 and 1998; Figure BoS-8b). *Monoporeia affinis*, however, has decreased in both areas, in the south until 1998 ($p<0.01$), whereas in the north the decrease is continuing ($p<0.001$). The sampled zoobenthic community in the open sea (averaged across stations N20, N21 and N25 sampled by UMF) is very poor, consisting of *M. affinis* and *S. entomon*, which both showed an increase until mid 1990s, whereafter they have both declined (Figure BoS-8c).

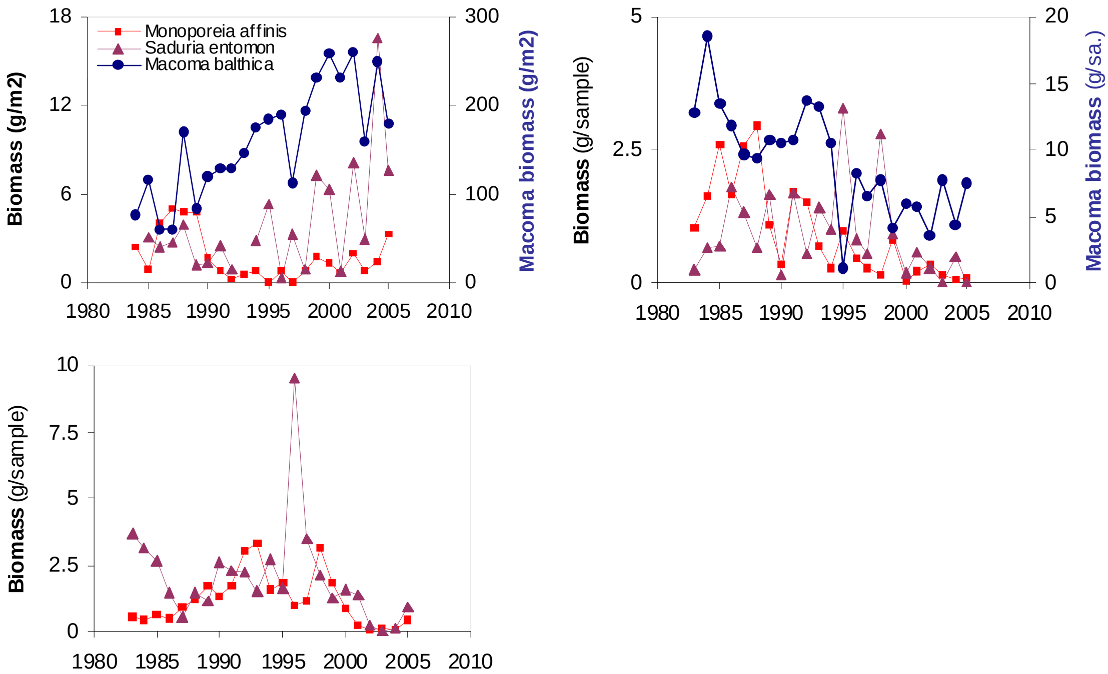

Figure BoS-8. Time-series on selected zoobenthos species (squares: *Monoporeia affinis*, triangles: *Saduria entomon*, circles: *Macoma balthica*) in the Bothnian Sea, (a) southeastern coast, (b) northeastern coast, and (c) a northern offshore area. In coastal areas (a, b) *Monoporeia affinis* biomasses have been scaled (*10) for clarity.

Fish and fisheries

Catch per unit effort data (cpue) on coastal freshwater fishes collected by SBF covers the years 1975-2005. Two species were selected, perch (*Perca fluviatus*) and roach (*Rutilus rutilus*) which both almost doubled in cpue until the mid 1990s ($p<0.001$) but seem to have decreased thereafter.

Herring biomass and recruitment obtained from the ICES Baltic Fisheries Assessment Group (WGBFAS) show an even more drastic increase at the end of the 1980s. For example, the mean recruitment 1990–2005 is almost twice as high as 1973-1989 (Figure BoS-10a). It is noteworthy, however, that these estimates are not independent of effort data (for trawls corrected for efficiency increases, obtained from WGBFAS) which shows large changes with trapnet fishing being replaced by a massive trawl fishing (Figure BoS-11). In parallel to the herring biomass increase, weight at age have decreased by 25–45% (depending on age, $p<0.01$ for all ages; Figure BoS-10b).

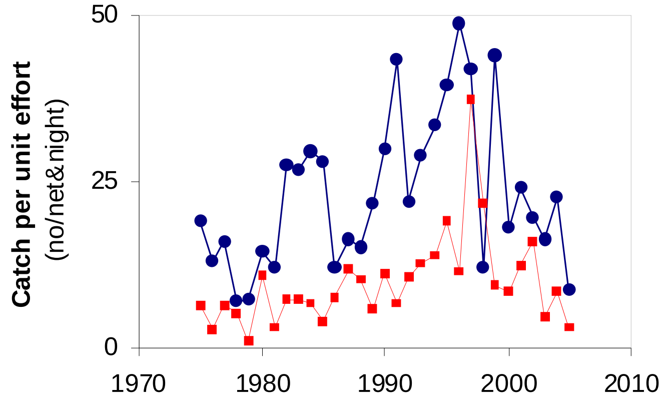

Figure BoS-9. Time-series on catch per unit effort in coastal gill-net monitoring in the Bothnian Sea. Circles indicate perch (*Perca fluviatus*) and squares roach (*Rutilus rutilus*).

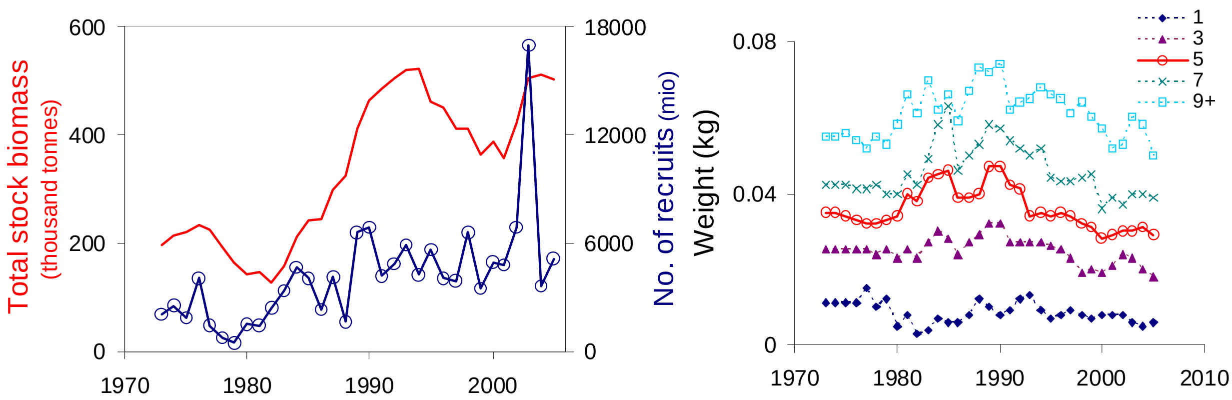

Figure BoS-10. Time-series on (a) herring total biomass (full line), number of recruits (circles) and (b) weight at age in the Bothnian Sea.

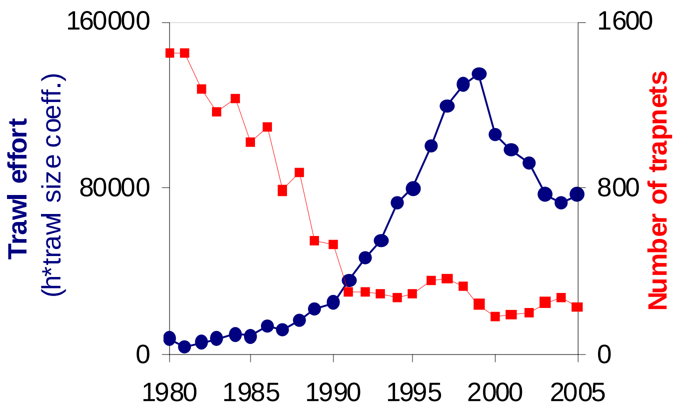

Figure BoS-11. Time-series on effort in Finnish herring fishery in the Bothnian Sea. The data on effort in the pelagic and demersal trawl fisheries has been calibrated for changes in efficiency, and the trawl hours multiplied by gear specific conversion factors.

Integrated analysis

Multivariate analyses were conducted on a selection of the available time-series to provide an integrated view on the state and development of the ecosystem. All data-series available had a frequency of, or were compiled to, one assessment per year and covered in maximum the period 1979 to 2005. Time-series were analysed by Principal Component Analysis (PCA), followed by a Redundancy Analysis (RDA) with forward selection of explanatory variables.

To improve linearity between variables nutrients and biological variables were ln(x+1) transformed. Subsequently a standardized PCA based on the correlation matrix was performed on the transformed values. The RDA was also made on normalised data, and climatic, hydrological, nutrient, and effort data were chosen as explanatory variables.

Variable vectors and scores (years) from the PCA were displayed on the first factorial plane and the years were connected in chronological order. The presence of any regime shifts (i.e. large shifts in ecosystem composition) was analysed by chronological cluster analysis. Year scores along PC1 and PC2 were additionally plotted against time to illustrate any regime shifts. Finally the raw values of each variable were categorised into quintiles and each quintile was given a specific colour from blue (first quintile, i.e. low data raw values) to red (fifth quintile, i.e. high raw data values), following the traffic light framework used in stock assessments (Link *et al.*, 2002).

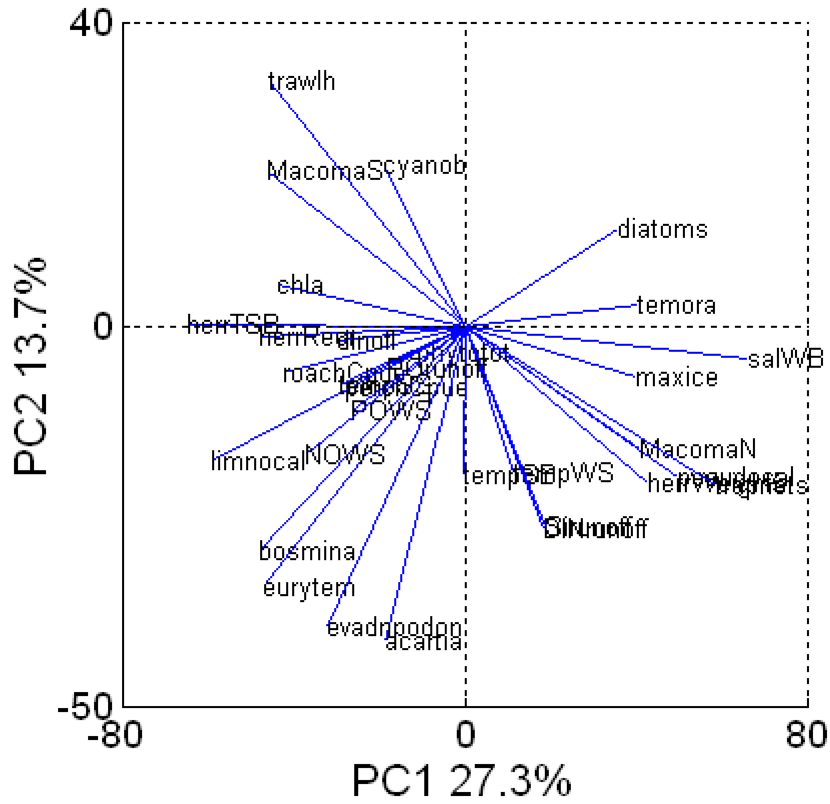

Figure BoS-12. Vectors in the first factorial plane from a PCA on 27 time-series from 1979 and four series from 1983 (M. balthica south and north, trapnet and trawling effort). Variable names are explained in Annex-Table 7.4.

The first principal component explains almost twice as much variation as the second (27.3% and 13.7%, respectively). The fist component (PC1) is primarily driven by salinity and herring data, whereas the second (PC2) is driven by the non-decreasing zooplankton groups, trawling effort and the opposing trends in *M. balthica* (Figure BoS-12). A chronological plot of the scores in the first factorial plane illustrates two groups of scores, 1979-1989 and 1990-2005 (Figure BoS-13a), which also was confirmed as separate groups by chronological clustering (using either a=0.01 or a=0.05). A time plot of the scores further illustrates that most of the change is due to a decrease in PC1 (Figure BoS-13b). Although 1989 in this figure may look like an outlier year, it is not very different from the years 1979-1988 in its score in PC1, which was the component capturing most of the variation in the data (Figure BoS-13b).

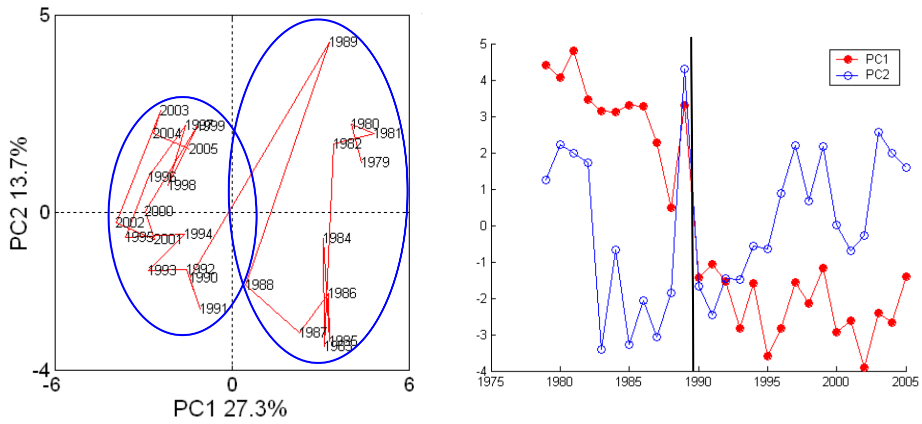

Figure BoS-13. Scores of principal components plotted in chronological order in (a) the first factorial plane, and (b) as a time-series. Circles in (a) and the vertical line in (b) corresponds to the results of the cluster analysis using a=0.01 or 0.05.

The traffic light plot of deviations in raw data from the long-term mean illustrate the nature of this compositional change (Figure BoS-14). The Bothnian Sea has changed from a saline and cold (maximum ice cover is a proxy for temperature) ecosystem with abundant marine zooplankton such as *Pseudocalanus* and *Temora*, and large herrings exploited by trapnets (top left corner of Figure BoS-14), to a warmer and less saline ecosystem with brackish water zooplankton such as Bosmina, and abundant but smaller herrings exploited by trawling (lower right corner of Figure BoS-14). Mean values during the first period (1979-1989) compared to the second (1990-2005) are salinity: 7.3 ± 0.1 psu vs. 6.7 ± 0.1 psu, maximum ice coverage: 202 000 ± 50 100 km^2 vs. 135 000 ± 29 500 km^2, *Pseudocalanus*: 20 ± 9 mg/m^3 vs. 5 ± 1 mg/m^3, *Temora*: 4 ± 3 mg/m^3 vs. 1 ± 1 mg/m^3, *Bosmina*: 6 ± 4 mg/m^3 vs. 32 ± 19 mg/m^3, total herring biomass: 220 000 ± 34 000 ton vs. 445 000 ± 28 000 ton, and herring weight at age five 38 ± 2 g vs. 34 ± 3 g.

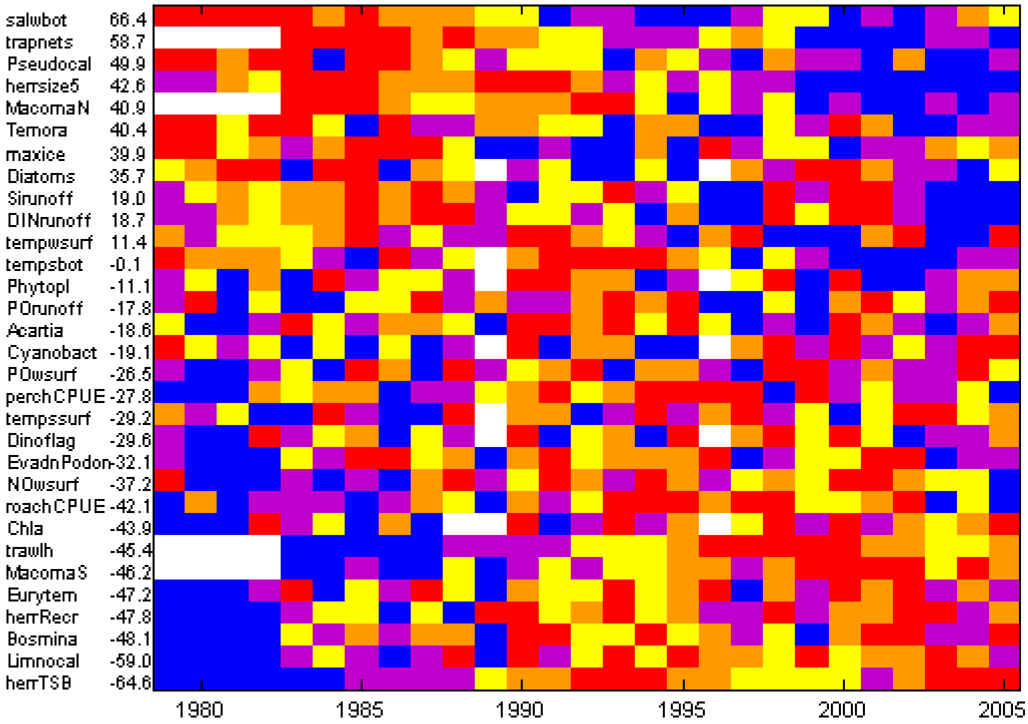

Figure BoS-14. Traffic light plot of deviations from long term mean for all variables included in the PCA. Blue indicates low values (in the first quantile), red high values (in the fifth quantile), and white missing values. Variables have been sorted according to their PC1value (given after the variable name) with high PC1 loadings at the top of the graph, and low at the bottom. Variable names are explained in Annex-Table 7.4.

Among the explanatory variables in the redundancy analysis the first axis was best explained by salinity and fishing effort and the second axis by winter SST (Figure BoS-15).

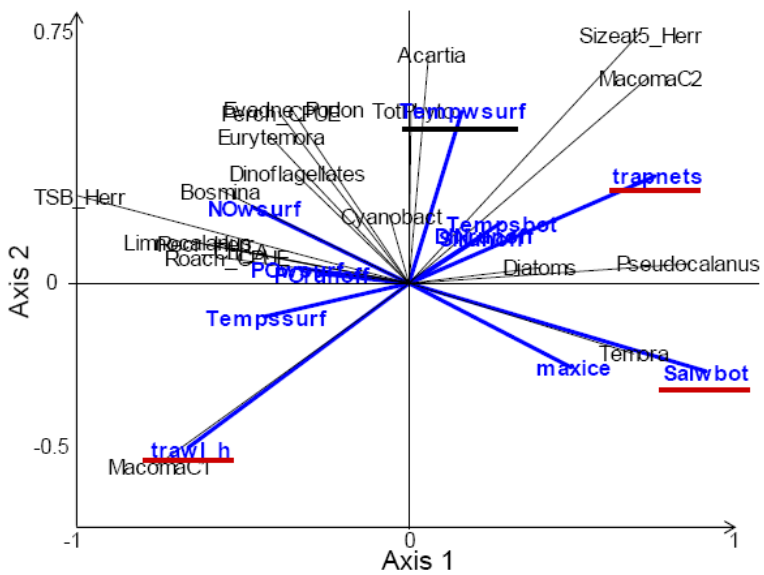

Figure BoS-15. Redundancy analysis made on the same time-series as the PCA. Fat blue text indicates explanatory variables, and black dependent variables. Variables that best explain the

To identify the driving explanatory variables, a forward selection analysis was made. As suggested by the PCA, salinity and fishing effort have the largest marginal effects. Maximum ice coverage, summer SST and nitrogen also had large marginal effects but did not significantly increase the explained variation. It is important to point out, however, that the interpretation of fishing effort as an explanatory variable is not unequivocal. In particular, the herring biomass and recruitment data is not independent of the effort data since the latter is used to estimate the former (ICES, 2006). Hence, the trend in effort can also be interpreted as a response to the ecosystem change, particularly to the changing size of herring.

In summary, the integrated analysis showed a regime shift in the ecosystem composition from the period 1979–1989 to the period 1990-2005. In contrast to the regime shifts observed in more marine ecosystems such as the Baltic Proper or the North Sea (Möllmann *et al.*, 2006; Beaugrand, 2004), the primary driver of the shift in the Bothnian Sea is the decrease in salinity and only secondly by increasing temperature (as indicated by decreasing maximum ice coverage). Both of these trends, however, are consequences of climate change. For the Baltic Sea region, climatic change involves decreased frequency of inflow of saline water from the North Sea and increasing run-off due to precipitation, which both contribute to the decreasing salinity in the Bothnian Sea, and to the corresponding changes in its ecosystem.

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Annex 7: Data used in the Integrated Ecosystem Assessments

Annex-Table 7.1. Time-series used in the Integrated Ecosystem Assessment of the Central Baltic Sea and their loadings on PC1 and PC2.

VARIABLE	ABBREVIATION	UNIT	AREA	SEASON	SOURCE	PC1	PC2
Cod Spawner biomass	CODSSB	Tonnes	SD 25–32	Annual	ICES	4.899	1.01
Cod recruitment	CODR2	No age 2 (10^3)	SD 25–32	Annual	ICES	4.877	−0.074
Cod weight	CODWC3	kg (age 3)	SD 25–32	Annual	ICES	−3.728	1.35
Cod fishing mortality	COD_F47	age 4–7	SD 22–32	Annual	ICES	−2.987	1.154
Sprat Spawner biomass	SPRSSB	Tonnes	SD 22–32	Annual	ICES	−4.281	−2.401
Sprat recruitment	SPRR1	No age 1 (10^3)	SD 22–32	Annual	ICES	−2.595	−1.814
Sprat weight	SPRWC3	kg (age 3)	SD 22–32	Annual	ICES	3.308	3.746
Sprat fishing mortality	SPR_F35	age 3–5	SD 22–32	Annual	ICES	−1.09	4.195
Herring Spawner biomass	HERSSB	Tonnes	SD 25–29+32excl. GOR	Annual	ICES	4.76	1.018
Herring recruitment	HERR1	No age 1 (10^3)	SD 25–29+32excl. GOR	Annual	ICES	3.659	0.532
Herring weight	HERWC3	kg (age 3)	SD 25–29+32excl. GOR	Annual	ICES	4.7	1.422
Herring fishing mortality	HER_F26	age 2–6	SD 25–29+32excl. GOR	Annual	ICES	−3.413	−0.026
Acartia spp.s	Acartia_Spr	$mg*m^{-3}$	Gotland Basin	Spring	LATFRA	−4.666	−1.267
Acartia spp.	Acartia_Sum	$mg*m^{-3}$	Gotland Basin	Summer	LATFRA	−0.249	−0.31
Temora longicornis	Temora_Spr	$mg*m^{-3}$	Gotland Basin	Spring	LATFRA	−4.229	0.442
Temora longicornis	Temora_Sum	$mg*m^{-3}$	Gotland Basin	Summer	LATFRA	0.934	0.594
Pseudocalanus acuspes	Pseudo_Spr	$mg*m^{-3}$	Gotland Basin	Spring	LATFRA	3.356	1.455
Pseudocalanus acuspes	Pseudo_Sum	$mg*m^{-3}$	Gotland Basin	Summer	LATFRA	4.321	−0.828
Chlorophyll *a*	Chla_BBSpr	$mg*m^{-3}$	Bornholm Basin	Spring	ICES	−1.545	−0.004
Chlorophyll *a*	Chla_BBSum	$mg*m^{-3}$	Bornholm Basin	Summer	ICES	1.852	−0.896
Chlorophyll *a*	Chla_GBSpr	$mg*m^{-3}$	Gotland Basin	Spring	ICES	−1.854	−0.422
Chlorophyll *a*	Chla_GBSum	$mg*m^{-3}$	Gotland Basin	Summer	ICES	−1.669	−2.083
Diatoms	dia_BB_spr	$mg*m^{-3}$	Bornholm Basin	Spring	ICES	−2.577	0.156
Dinoflagellates	dino_BB_spr	$mg*m^{-3}$	Bornholm Basin	Spring	ICES	−4	−0.937

VARIABLE	ABBREVIATION	UNIT	AREA	SEASON	SOURCE	PC1	PC2
Bluegreen algae	cyano_BB_spr	$mg*m^{-3}$	Bornholm Basin	Spring	ICES	−0.942	1.402
Diatoms	dia_BB_Sum	$mg*m^{-3}$	Bornholm Basin	Summer	ICES	0.961	−2.252
Dinoflagellates	dino_BB_sum	$mg*m^{-3}$	Bornholm Basin	Summer	ICES	−0.316	−1.731
Bluegreen algae	cyano_BB_sum	$mg*m^{-3}$	Bornholm Basin	Summer	ICES	−0.622	0.134
Diatoms	dia_GB_spr	$mg*m^{-3}$	Gotland Basin	Spring	ICES	0.961	−2.252
Dinoflagellates	dino_GB_spr	$mg*m^{-3}$	Gotland Basin	Spring	ICES	−2.686	−3.278
Bluegreen algae	cyano_GB_spr	$mg*m^{-3}$	Gotland Basin	Spring	ICES	−2.523	−0.864
Diatoms	dia_GB_sum	$mg*m^{-3}$	Gotland Basin	Summer	ICES	−1.177	−1.295
Dinoflagellates	dino_GB_sum	$mg*m^{-3}$	Gotland Basin	Summer	ICES	−0.316	−1.731
Bluegreen algae	cyano_GB_sum	$mg*m^{-3}$	Gotland Basin	Summer	ICES	−0.369	2.124
Total phytoplankton	Totphyto_BB_spr	$mg*m^{-3}$	Bornholm Basin	Spring	ICES	−3.498	−0.295
Total phytoplankton	Totphyto_BB_sum	$mg*m^{-3}$	Bornholm Basin	Summer	ICES	−1.606	−0.055
Total phytoplankton	Totphyto_GB_spr	$mg*m^{-3}$	Gotland Basin	Spring	ICES	−2.688	−3.778
Total phytoplankton	Totphyto_GB_sum	$mg*m^{-3}$	Gotland Basin	Summer	ICES	−1.623	−1.042
Dissolved inorganic nitrogen (surface)	DIN_BB_10_win	$\mu mol*l^{-1}$	Bornholm Basin	Winter	ICES	0.702	2.1
Dissolved inorganic phosphorus (surface)	DIP_BB_10_win	$\mu mol*l^{-1}$	Bornholm Basin	Winter	ICES	1.398	2.338
Dissolved inorganic nitrogen (surface)	DIN_GB_10_win	$\mu mol*l^{-1}$	Gotland Basin	Winter	ICES	−1.811	2.181
Dissolved inorganic phosphorus (surface)	DIP_GB_10_win	$\mu mol*l^{-1}$	Gotland Basin	Winter	ICES	−0.326	1.44
Dissolved inorganic nitrogen (deepwater)	DIN_BB_90_sum	$\mu mol*l^{-1}$	Bornholm Basin	Summer	BED / IOW / SMHI / FIMR / ICES	−2.421	1.164
Dissolved inorganic phosphorus (deepwater)	DIP_BB_90_sum	$\mu mol*l^{-1}$	Bornholm Basin	Summer	BED / IOW / SMHI / FIMR / ICES	−1.769	0.344

VARIABLE	ABBREVIATION	UNIT	AREA	SEASON	SOURCE	PC1	PC2
Dissolved inorganic nitrogen (deepwater)	DIN_GB_220_sum	µmol*l^{-1}	Gotland Basin n	Summer	BED / IOW / SMHI / FIMR / ICES	−0.656	3.701
Dissolved inorganic phosphorus (deepwater)	DIP_GB_220_sum	µmol*l^{-1}	Gotland Basin	Summer	BED / IOW / SMHI / FIMR / ICES	0.69	3.652
Maximum ice cover	MaxIce	Km^2	Baltic	Annual	FIMR	3.244	−1.197
Baltic Sea Index	BSI		Central Baltic	Winter	IFM	−3.072	2.291
Inflow strength	inflow	Km^3	Central Baltic	Annual	IOW	1.434	−0.773
Depth of 11 psu isoline	11psu_GBAnn	m	Gotland Basin	Annual	LATFRA	−2.816	3.572
Cod reproductive volume	REPVOL	Km^3	Central Baltic	Annual	IFM	1.45	−2.298
Sea surface temperature	SST_BB_Spr	°C	Bornholm Basin	Spring	BED / IOW / SMHI / FIMR / ICES	−1.902	3.264
Sea surface temperature	SST_BB_Sum	°C	Bornholm Basin	Summer	BED / IOW / SMHI / FIMR / ICES	−2.998	1.767
Sea surface temperature	SST_GB_Spr	°C	Gotland Basin	Spring	BED / IOW / SMHI / FIMR / ICES	−0.917	3.747
Sea surface temperature	SST_GB_Sum	°C	Gotland Basin	Summer	BED / IOW / SMHI / FIMR / ICES	−3.043	1.839
Midwater temperature (40–60m)	T_BB_60_spr	°C	Bornholm Basin	Spring	BED / IOW / SMHI / FIMR / ICES	−3.53	1.997
Midwater temperature (40–60m)	T_BB_60_sum	°C	Bornholm Basin	Summer	BED / IOW / SMHI / FIMR / ICES	−3.817	0.413
Midwater temperature (40–60m)	T_GB_60_spr	°C	Gotland Basin	Spring	BED / IOW / SMHI / FIMR / ICES	−2.888	2.016

Variable	Abbreviation	Unit	Area	Season	Source	PC1	PC2
Midwater temperature (40–60m)	T_GB_60_sum	°C	Gotland Basin	Summer	BED / IOW / SMHI / FIMR / ICES	−3.291	1.964
Sea surface salinity	SSS_BB	psu	Bornholm Basin	Spring	BED / IOW / SMHI / FIMR / ICES	4.487	0.795
Sea surface salinity	SSS_GB	psu	Gotland Basin	Spring	BED / IOW / SMHI / FIMR / ICES	4.397	−0.221
Halocline salinity (70–90m)	S90_BB	psu	Bornholm Basin	Spring	BED / IOW / SMHI / FIMR / ICES	−0.832	−3.376
Halocline salinity (80–100m)	S100_GB	psu	Gotland Basin	Spring	BED / IOW / SMHI / FIMR / ICES	2.788	−3.691
Deepwater oxygen	O2_BB	ml*l^{-1}	Bornholm Basin	Spring	BED / IOW / SMHI / FIMR / ICES	2.01	−0.817
Deepwater oxygen	O2_GB	ml*l^{-1}	Gotland Basin	Spring	BED / IOW / SMHI / FIMR / ICES	0.642	−3.713

Annex-Table 7.2. Time-series used in the Integrated Ecosystem Assessment of the Gulf of Riga

Variable	Abbreviation	Unit	Season	Source
Acartia spp.	AC_spr	mg*m^{-3}	Spring	LHEI
Acartia spp.	AC_sum	mg*m^{-3}	Summerl	LHEI
Bosmina coregoni maritima	Bos_spr	mg*m^{-3}	Spring	LHEI
Bosmina coregoni maritima	Bos_spr	mg*m^{-3}	Spring	LHEI
Cercopagis pengoi	Cerc	mg*m^{-3}		LHEI
Eurytemora affinis	Eury_spr	mg*m^{-3}	Spring	LHEI
Eurytemora affinis	Eury_sum	mg*m^{-3}	Summer	LHEI
Evadne nordmanni	Eva_spr	mg*m^{-3}	Spring	LHEI
Limnocalanus grimaldii	Limn_spr	mg*m^{-3}	Spring	LHEI
Limnocalanus grimaldii	Limn_sum	mg*m^{-3}	Summer	LHEI
Podon sp.	Pod_spr	mg*m^{-3}	Spring	LHEI
Synchaeta sp.	Syn_spr	mg*m^{-3}	Spring	LHEI
Chlorophyll *a*	Chla_spr	mg*m^{-3}	Spring	LHEI

Variable	Abbreviation	Unit	Season	Source
Chlorophyll *a*	Chla_sum	$mg*m^{-3}$	Summer	LHEI
Secchi depth	Sec_spr	m	Spring	LHEI
Secchi depth	Sec_sum	m	Summer	LHEI
Herring yield	Her_yield	tonnes	Annual	ICES
Herring spawner biomass	Her_SSB	tonnes	Annual	ICES
Herring weight	Her_W	kg	Annual	ICES
Herring recrruitment	Her_R	No age 1	Annual	ICES
Cod landings	Cod_catch	tonnes	Annual	ICES
Nitrogen	NO23_spr	$\mu mol*l^{-1}$	Spring	LHEI
Phosphorus	PO4_spr	$\mu mol*l^{-1}$	Spring	LHEI
Nitrogen load	NO3_load	$\mu mol*l^{-1}$	Spring	LHEI
Phosphorus load	PO4_load	$\mu mol*l^{-1}$	Spring	LHEI
Runoff	RunoffJanAug	m^3*s^{-1}	January–August	Laznik *et al.*, 1999, HELCOM
Salinity (0–50m)	S_aug50	psu	August	LATFRA
Temperature (0–20m)	T_aug20	°C	August	LATFRA
Temperature (0–50m)	T_aug50	°C	August	LATFRA
Temperature (0–50m)	T_feb50	°C	Febuary	LATFRA
Temperature (0–20m)	T_may20	°C	May	LATFRA
Temperature (0–50m)	T_may50	°C	May	LATFRA
Baltic Sea Index	BSI	–	Winter	IFM

Annex-Table 7.3. Time-series used in the Integrated Ecosystem Assessment of the Gulf of Finland

Variable	Abbreviation	Unit	Season	Source
Pseudocalanus acuspes	Pseudo_sum	$mg*m^{-3}$	Summer	FIMR
Temora longicornis	Temora_sum	$mg*m^{-3}$	Summer	FIMR
Acartia spp.	Acartia_sum	$mg*m^{-3}$	Summer	FIMR
Eurytemora affinis	Eury_sum	$mg*m^{-3}$	Summer	FIMR
Limnocalanus lacustris	Limno_sum	$mg*m^{-3}$	Summer	FIMR
Bosmina coregoni maritima	Bosm_sum	$mg*m^{-3}$	Summer	FIMR
Phytoplankton biomass	Phyto_pl	$\mu g*l^{-1}$	Summer	FIMR
Temperature (0–10m)	Temp_surf_sum	°C	Summer	FIMR
Salinity (0–10m)	Salin_surf_sum	psu	Summer	FIMR
Salinity (30m–bottom)	Salin_sum_bot	psu	Summer	FIMR
Chlorophyll *a* (0–20m)	Chla_sum	$\mu g*l^{-}$	Summer	FIMR

Variable	Abbreviation	Unit	Season	Source
Phosphates	PO4_sum	$mmol*m^{-3}$	Summer	FIMR
Nitrates	NO3_sum	$mmol*m^{-3}$	Summer	FIMR
Phosphates	PO4_win	$mmol*m^{-3}$	Winter	FIMR
Nitrates	NO3_win	$mmol*m^{-3}$	Winter	FIMR
Oxygen bottom	Oxy_bot_sum	ml^{-}	Summer	FIMR
Herring landing	HERRland	kg	Annual	FGFRI
Sprat landing	SPRATland	kg	Annual	FGFRI
Salmon landing	SALMONland	kg	Annual	FGFRI
Trout landing	TROUTland	kg	Annual	FGFRI
Acartia spp.	Acar_spring	$mg*m^{-3}$	Spring	EMI
Eurytemora affinis	Eury_spring	$mg*m^{-3}$	Spring	EMI
Podon spp.	Podo_spring	$mg*m^{-3}$	Spring	EMI
Limnocalanus lacustris	Limn_spring	$mg*m^{-3}$	Spring	EMI
Pseudocalanus acuspes	Pseu_spring	$mg*m^{-3}$	Spring	EMI
Sprat catch (Estonia)	SprCEst	1000 tonnes	Annual	EMI
Sprat weight at age 3	SprWA3	g	Annual	EMI
Herring catch (Est+Fin+Rus)	HerCatch	1000 tonnes	Annual	EMI
Herring weight at age 3	HerWA3	g	Annual	EMI
Temperature (0–10m)	F2TEMPUp	°C	Winter	EMI
Silica (0–10m)	F2SLCAUp	$mmol*m^{-3}$	Winter	EMI
Temperature (0–10m)	F5TEMPUp	°C	May	EMI
Temperature (0–10m)	F8TEMPUp	°C	August	EMI
Salinity (0–10m)	F8SALUp	psu	August	EMI
Chlorophyll *a* (0–10m)	F8CHLA	$mg*m^{-3}$	August	EMI

Annex-Table 7.4. Time-series used in the Integrated Ecosystem Assessment of the Bothnian Sea

VARIABLE	ABBREVIATION	UNIT	SEASON	AREA	SOURCE
Perch catch per unit effort	perchCPUE	numbers*net^{-1}*night^{-1}	Summer	SW Bothnian Sea coast	SBF
Roach catch per unit effort	roachCPUE	numbers*net^{-1}*night^{-1}	Summer	SW Bothnian Sea coast	SBF
Herring total stock biomass	herrTSB	tonnes	Annual	Bothnian Sea offshore	ICES
Herring recruitment	herrRecr	thousands of 1-yr-olds	Annual	Bothnian Sea offshore	ICES
Herring weight at age 5	herrsize5	kg	Annual	Bothnian Sea offshore	ICES
Macoma balthica biomass	MacomaS	g*m$^{2-1}$	Summer	SW Bothnian Sea coast	SBF
Diatoms	Diatoms	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Dinoflagellates	Dinoflag	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Cyanobacteria	Cyanobact	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Phytoplankton	Phytopl	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Acartia sp.	Acartia	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Bosmina sp.	Bosmina	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Eurytemora sp.	Eurytem	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Limnocalanus sp.	Limnocal	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Evadne sp.and Podon sp.	EvadnPodon	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Pseudocalanus sp.	Pseudocal	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Temora sp.	Temora	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Macoma balthica	MacomaN	g*sample^{-1}	Summer	NW Bothnian Sea coast	Umeå University
Chlorophyll a	Chla	mg*m$^{3-1}$	Summer	Bothnian Sea offshore	FIMR
Surface temperature (0–10 m)	tempwsurf	degrees C	Winter	Bothnian Sea offshore	SMHI, FIMR
Surface temperature (0–10 m)	tempssurf	degrees C	Summer	Bothnian Sea offshore	SMHI, FIMR
Bottom temperature (30-m)	tempsbot	degrees C	Summer	Bothnian Sea offshore	SMHI, FIMR
Salinity bottom (30-m)	salwbot	psu	Winter	Bothnian Sea offshore	SMHI, FIMR
Dissolved inorganic phosphorous (0–10 m)	POwsurf	□mol*l^{-1}	Winter	Bothnian Sea offshore	SMHI, FIMR

VARIABLE	ABBREVIATION	UNIT	SEASON	AREA	SOURCE
Dissolved inorganic nitrogen (0–10 m)	NOwsurf	□mol*l^{-1}	Winter	Bothnian Sea offshore	SMHI, FIMR
Maximum ice coverage	maxice	km^2	Winter	Baltic Sea	FGFIR
Runoff dissolved inorganic nitrogen	DINrunoff	tonnes	Annual	W Bothnian Sea coast	Swedish University of Agricultural Sciences, Environmental Assessment Unit
Runoff dissolved inorganic phosphorous	POrunoff	tonnes	Annual	W Bothnian Sea coast	Swedish University of Agricultural Sciences, Environmental Assessment Unit
Runoff silicate	Sirunoff	tonnes	Annual	W Bothnian Sea coast	Swedish University of Agricultural Sciences, Environmental Assessment Unit
Commercial trawl effort	trawlh	h	Annual	Bothnian Sea	FGFRI
Commercial trapnets	trapnets	number of nets	Annual	E Bothnian Sea coast	FGFRI

Annex 8: Facilitating the use of Baltic Sea indicatorsw

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Data needs for integrated assessment

The experience of the ICES/BSRP/HELCOM Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB) showed, that the analysis of a large dataset describing the Baltic Sea is done most efficiently based on already preprocessed, quality controlled and published indicator time-series of characteristic ecosystem features (ICES 2006). Generating indicators from raw data for integrated assessment is time-consuming and often duplicates effort that has been undertaken already for aggregating raw data for example into HELCOM indicator fact sheets. Therefore, an important step towards increasing the efficiency of expert groups for integrated assessments would be, to make aggregated indicator time-series available in a similar manner as raw data. Also the archiving of indicator time-series and the raw data they are based upon should be assured.

At the same time, much important data characterizing the Baltic Sea ecosystem is collected within research programs. For example, primary productivity measurements have been widely removed from monitoring programs to reduce costs. Primary production is presently mainly measured for research purposes, but assessments would benefit from access to these data. Therefore databases for Baltic Sea integrated assessment should be constructed in a way to attract contributors outside the monitoring community.

A crucial issue for data exchange is the implementation and documentation of quality control (quality flags, easy feedback from data users to originators, methods for data aggregation from raw data clearly documented). To be successful, exchange of both raw data as well as aggregated indicator time-series has to respect intellectual property rights. Finally, the sustainability of databases should be assured.

In summary, databases for integrated assessment of the Baltic Sea therefore should:

- Provide user friendly, timely (web-) access to information
- Implement a high degree of quality control
- Increase the efficiency of assessment and environmental research
- Attract data contributors besides obligatory data submitters (research data)
- Respect intellectual property rights
- Assure database sustainability

Present raw data and indicator archiving

An overview (table 1) of the oceanographic, nutrient and biological indicators currently published in the HELCOM indicator fact sheets (http://www.helcom.fi/environment2/ifs/ifs2006/en_GB/_cover/) and of the indicators used for eutrophication assessment in HELCOM EUTRO shows, that the ICES datacenter archives only part of the raw data used for generating Baltic Sea indicators. According to the data sources given in the indicator fact sheets, the ICES datacenter functions most successful as data archive and data distributor for indicators concerning hydrography (temperature, salinity, oxygen, hydrogen sulfide), nutrient concentrations, and Secchi depth.

Most of the data necessary for generating the indicators used in the HELCOM EUTRO pilot eutrophication assessment are based on HELCOM COBINE hydrochemical and biological monitoring data. Archiving these raw data is within the current scope and responsibility of the ICES data center, while other indicators presented in the indicator fact sheets, e.g. EMEP atmospheric emission and deposition, satellite derived indicators (chlorophyll a, surface algal blooms, SST), buoy data (salinity, temperature), and ship-of-opportunity measurements (Alg@line) are outside the scope of the ICES Data Centre. These data are archived mainly at the generating institutes.

Presently, the exchange of aggregated indicator time-series is entirely based on direct communication between involved scientists.

Options for indicator archiving

An important step to increase the efficiency of Baltic Sea assessment and avoid duplication of work is to make not only raw data, but also indicator time-series available for further use by assessment projects and individual researchers. This can be achieved by constructing either a) a separate database of indicator time-series or b) storing definition queries that generate indicator time-series in the raw data database.

Presently, data to generate Baltic Sea environmental indicators comes from multiple sources and is archived in a variety of databases (see table 1). Also, many indicators are generated by complex data handling procedures, which are beyond the scope of simple database queries. Therefore it seems more feasible to store aggregated indicators separated from the underlying raw data. Storage of indicator time-series can be organized both at a dedicated database or decentralized at contributing institutes. For example, since the volume of many aggregated indicator time-series is rather moderate compared to the underlying raw data, web access to indicator time-series could be easily implemented through download links from the indicator fact sheets.

Database and workflow for integrated assessments

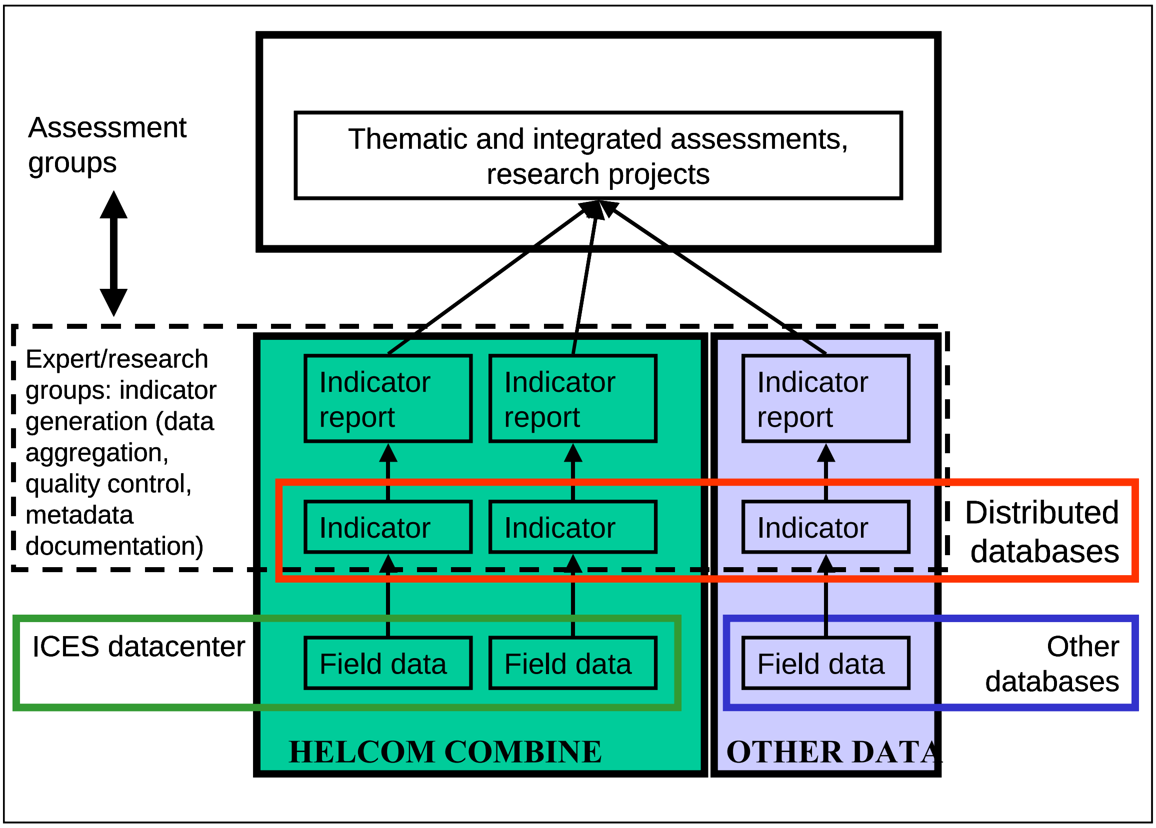

Figure 1. Workflow model for integrated assessment.

Figure 1 outlines a possible model for the workflow and database structure for integrated assessments. **Expert groups** that aggregate raw data into meaningful indicators, i.e. characteristic time-series, play a central role in assuring the quality of the indicators produced. They also serve as additional quality control for the raw data. Feedback between expert groups, other raw data users and the raw data archive should be facilitated, so that potentially faulty data discovered during the indicator generation process would be reported back to the database and recorded in a data quality flag.

Indicators, i.e. aggregated raw data that characterizes an ecosystem state variable or processes, are together with their metadata published in web-accessible format. The metadata comprises what is now implemented as HELCOM indicator reports (information on raw data and ancillary data used, procedure for indicator generation from raw data, information on ecological significance of the indicator). **Assessment groups** or projects base then a large portion of their work on already published, preprocessed indicator time-series.

It is essential that raw data is available in a timely manner for generation of indicators. For example, HELCOM indicator reports using ICES Data Centre information state, that data from the current year had to be exchanged directly between monitoring institutes.

Indicator clearinghouse

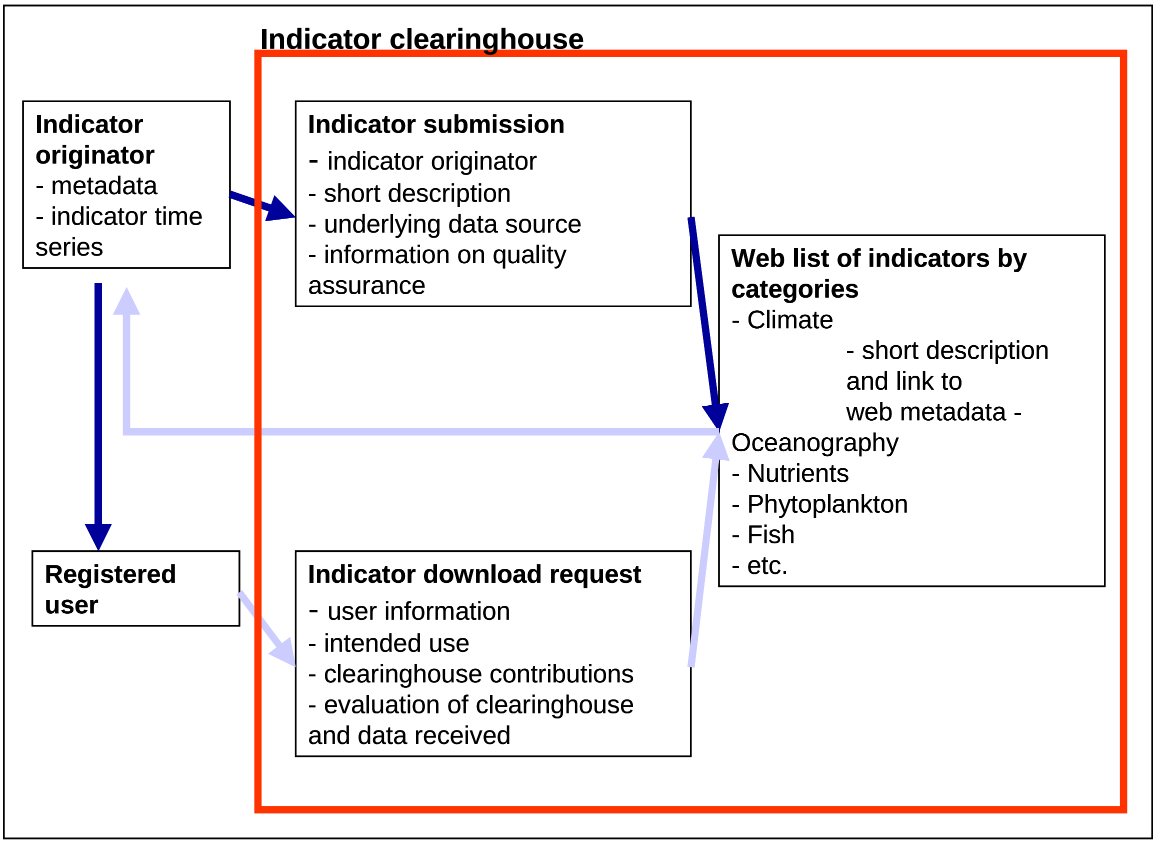

Figure 2. Indicator clearinghouse.

Based on the current structure of Baltic Sea indicator reports, access to indicator time-series would be implemented most easily by a web-link from the indicator report (or other web-based metadata description) to a downloadable table containing the indicator time-series. A web-based indicator clearinghouse (Figure 2), which contains a list of available indicators by categories, would increase the accessibility of information, improve cooperation between different groups and attract research groups to submit data. The clearinghouse is a web service that contains a list of available Baltic Sea indicators by categories, together with a short description and a link to their metadata ("indicator report"). Submission of indicator time-series should be possible for all interested users; however, indicator metadata should contain information on quality assurance (for example, indicator approved by MONAS, responsible research group and project, publication). Download of indicator time-series could for example be handled by a download form in the clearinghouse that queries the user for the purpose of data use, their prior contributions to the indicator clearinghouse, and an evaluation of the clearinghouse and data received. Download forms should be automatically forwarded to the indicator time-series originator, which releases the data for download.

Conclusions

- The current structure of Baltic Sea information management does not facilitate access to already aggregated indicator time-series
- Baltic Sea environmental indicators are produced and archived in a decentralized manner
- Future workflow for integrated assessments should rely on preprocessed indicator time-series
- An indicator clearinghouse would improve the accessibility of indicator time-series, while protecting intellectual property rights

References

ICES. 2006. Report of the ICES/BSRP/HELCOM Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB), 1–4 March 2006, Tvärminne, Finland. ICES CM 2006/BCC:09, 57 pp.

Annex 9: WGIAB terms of reference for the next meeting

The **Working Group on Integrated Assessments of the Baltic Sea** [WGIAB] (Co-Chairs: C. Möllmann, Germany, B. Müller-Karulis, Latvia; Juha Flinkman, Finland) will meet in Öregrund, Sweden from 25–29 March 2008 to:

a) update the Integrated Assessments (IA) for the Central Baltic Sea, the Gulf of Riga, the Gulf of Finland and Bothnian Sea, and starting IAs for other subsystems of the Baltic Sea, e.g. the Western Baltic, as well as coastal-open sea comparisons;

b) prepare ecosystem overview and assessment documents as the basis for ecosystem-based management, coordinating the work with HELCOM MONAS and HELCOM Projects (e.g. BIO and EUTRO-PRO) and ICES (e.g. WGBFAS, WGRED) activities;.

c) outline the use of ecosystem modelling approaches available for the area, and outline a strategy of their use within the future Integrated Assessment framework;

d) continue to develop an adaptive management framework in cooperation with HELCOM BIO and related ICES-groups;

e) propose a data management strategy between ICES and HELCOM,

f) produce detailed descriptions of the data-series produced as background for use by other groups and scientists.

WGIAB will report by 15 April to the attention of the Baltic 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 base 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) developing of new monitoring strategies, and (iv) considering the use of ecosystem modelling in the assessment framework. 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 networks of excellence such as EUR-OCEANS. 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 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 some 15–20 members and guests.

SECRETARIAT FACILITIES:	None.
FINANCIAL:	None.
LINKAGES TO ADVISORY COMMITTEES:	Relevant to the work of the ACE, ACME, and ACFM.
LINKAGES TO OTHER COMMITTEES OR GROUPS:	BCC, all SG/WGs related to Baltic Sea issues
LINKAGES TO OTHER ORGANIZATIONS:	HELCOM, BALTEX
SECRETARIAT MARGINAL COST SHARE:	None.

Annex 10: Recommendations

WGIAB has the following recommendations which are listed in table below. The group has exchanged the ACTION-column with a RECIPIENT-column.

RECOMMENDATION	RECIPIENT
1. Inform WGIAB on the database situation (especially with respect to biological data), and outline the view of both organisations towards the data policy supporting the type of activities WGIAB conducts (see also Chapter 5)	HELCOM (Secretatriat), ICES (Secretariat and Data Centre)
2. Inform WGIAB on the latest developments with regard to the Baltic Sea Action Plan	HELCOM (Secretatriat),
3. Inform WGIAB on latest developments for the HELCOM biodiversity assessment, and assure that HELCOM BIO chair will attend the next WGIAB meeting	HELCOM BIO
4.Provide WGIAB with zooplankton data, poorly covered in the WGIAB-datasets, i.e. the Bornholm Basin and the Western Baltic	HELCOM Zooplankton Expert Network
5. Consider the implementation of Zoo- and Ichthyoplankton as well as Chorophyll a sampling in the regular work of BITS and BIAS (see also Chapter 6)	ICES WGBIFS