ICES WGIAB REPORT 2012

SCICOM Steering Group on Regional Sea Programmes

ICES CM 2012/SSGRSP:02

Ref. SCICOM

Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB)

26–30 March 2012

Stockholm, Sweden

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CIEM Conseil International pour l'Exploration de la Mer

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Recommended format for purposes of citation:

ICES. 2012. Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB), 26–30 March 2012, Stockholm, Sweden. ICES CM 2012/SSGRSP:02. 178 pp. https://doi.org/10.17895/ices.pub.9018

Contents

Executive summary

The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) was set up as a forum for developing and combining ecosystem-based management efforts for the Baltic Sea. The group is intended to serve as a counterpart and support for the ICES Baltic Fisheries Assessment Working Group (WGBFAS) as well as for related HELCOM assessment efforts and projects. The group was established in 2007.

The work of the group during previous years has been focused on conducting holistic ecosystem analyses based on large multivariate datasets, in order to increase understanding of biological patterns and processes affecting ecosystem level changes in the region, and on considering ecosystem modelling in an integrated assessment and management framework.

In 2012, WGIAB continued this path by synthesising the current state of data and models in relation to the applied integrated assessment and management cycle, and summarising the current state of integrated status and trends assessments in open sea and coastal sub-systems of the Baltic Sea, also continuing the task from previous years to increasingly include coastal areas in the analyses.

Integrated trend analyses were performed for 12 coastal sub-systems and two pelagic systems. The longest data set covered as an extended time-period as from 1960, but the majority of time-series typically dated back to the late 1980s or early 1990s. For the open sea areas, updated analyses were performed for the Bothnian Sea and the Baltic Proper. The assessment focused on identifying key ecosystem components by identifying main trends, main drivers of change over time, temporal discontinuities and common patterns among sub-systems.

The group continued towards closing the integrated ecosystem assessment cycle by relating the achievements and ambitions of the group to the different steps in the cycle with a focus on; i) current state of data and models in relation to prevailing marine management strategies (CFP, MSFD), ii) selection and evaluation of management indicators, iii) methods for risk assessment and iv) management strategy evaluation. In order to provide example of how a quantitative integrated ecosystem assessment process could proceed, WGIAB 2012 also applied some available information, indicators and models for the Central Baltic Sea food-web in the relevant steps of the IEA loop, simulating the effect of fishing and nutrient load reductions in the presence of further climate change, using four models (from single-species to food-web models), providing example outputs of different management scenarios on indicator development

The meeting was held 26–30 March 2012 at the Baltic NEST Institute, Stockholm University, Stockholm, Sweden, with 30 participants from 8 countries. The meeting was held back-to-back with the Working Group in Integrated Assessment of the North Sea, WGINOSE.

1 Opening of the meeting

Words of welcome to the participants of the meeting were given by Maciej Tomczak, co-chair of WGIAB, followed by a presentation of the Baltic NEST Institute (BNI) by Christoph Humborg, head of the Baltic NEST Institute. The participants of the meeting were represented by 30 participants from 8 countries (Annex 1). The meeting was held back-to-back with the Working Group in Integrated Assessment of the North Sea, WGINOISE (2012a).

Introductions to WGIAB and WGINOISE and their terms of references for the meeting were given by Lena Bergström, co-chair of WGIAB, and Christian Möllmann, co-chair of WGINOISE, respectively. Points of common relevance for the two groups were identified, the main task being to develop scientific tools for an integrated ecosystem-based assessment.

As an introduction to the week, plenary talks were given on the following topics:

- The U.S. Approach to Integrated Ecosystem Assessment (Phillip Levin, NOAA Fisheries)
- Introduction to Stockholm Resilience Centre research– concept of resilience (Carl Folke, Stockholm Resilience centre)
- The HELCOM Coreset project (Samuli Korpinen, HELCOM)
- ICES Ecosystem overviews (Han Lindeboom, ICES).

1.1 Adoption of the agenda

Maciej Tomczak introduced the agenda which was shortly discussed, adjusted and finally adopted (Annex 2) by the participants.

1.2 Terms of reference for WGIAB 2012 meeting

The Terms of References (ToRs) given to the WGIAB meeting were as follows below. The meeting participants discussed the terms of references and agreed to fulfil them by two thematic groups; terms of reference *a* and *d* being addressed together under the heading Integrated Trend Analyses (ITA), and terms of reference *b*, *c* and *e* under the heading Integrated Ecosystem Assessment (IEA).

2011/2/SSGRSP02 The **ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea** (WGIAB), chaired by Martin Lindegren, Denmark; Maciej Tomczak*, Sweden; and Lena Bergström*, Sweden, will meet in Stockholm, Sweden, 26–30 March 2012 to:

a) Continue the Integrated Status and Trends Assessments for the different Baltic Sea subsystems, including biodiversity aspects, and applying early-warning methods on key indicators of these subsystems;

b) Further develop the “Biological Ensemble Modelling Approach (BEMA)” as a basis for analysing anthropogenic and natural impacts on ecosystem structure and function, by applying it on available multispecies and food-web models;

c) Further develop and promote ecosystem-based advice for Baltic Sea fish stocks based on the Integrated Status and Trends Assessments and indicators of recruitment environments and functions of Baltic Sea fish stocks, and provide these to the WGBFAS;

d) Enhance understanding of ecosystem processes in the Baltic Sea subsystems by analysing temporal and spatial functional relationships in foodwebs;

e) Further develop an Integrated Ecosystem Assessment cycle for the Baltic Sea and in close cooperation with other integrated assessment activities within ICES (e.g. WGNARS, WGEAWESS, WGINOSE) and HELCOM, as well as accounting for results from ongoing research projects.

WGIAB will report by 15 May 2012 (via SSGRSP) for the attention of SCICOM.

Supporting Information

Priority	WGIAB aims to conduct and further develop Integrated Ecosystem Assessments cycles for the different subsystems of the Baltic Sea, as a step towards implementing the ecosystem approach in the Baltic Sea.
Scientific justification	Key to the implementation of an ecosystem approach to the management of marine resources and environmental quality is the development of an Integrated Ecosystem Assessment (IEA). An IEA considers the physical, chemical and biological environment, including all trophic levels and biological diversity as well as socio-economic factors and treats fish and fisheries as an integral part of the environment. The work of the group includes (i) a further development of analyses of ecosystem structure and function for the different subsystems of the Baltic, (ii) contributions to the HELCOM assessment system, (iii) implementing the use of environmental information and ecosystem modelling in the assessment framework and (iv) developing adaptive management strategies. The working group serves as a counterpart to the fish stock assessment working groups and provides these with information on the biotic and abiotic compartments of the ecosystems. A key task of the working group is to serve as a communication and organisation platform between the different science organisations/groups involved in the area. Primarily this applies to the cooperation between ICES and HELCOM, but will also include cooperation with EU and BONUS projects. The working group is thus key to implementing the ecosystem approach to the Baltic Sea. Further a close cooperation with IEA activities in other areas (e.g. WGNARS, WGEAWESS, WGINOSE) is envisaged to coordinate the ICES IEA activities within SSGRSP.
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 20-30 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	Relevant to the work of ACOM and SCICOM.
Linkages to other committees or groups	SSGSRP, all SG/WGs related to Baltic Sea issues, WGINOSE, WGNARS, WGEAWESS, SGIMM, SGEH
Linkages to other organizations	HELCOM, BONUS, EU DGs.

2 Introduction

2.1 The WGIAB scope and organisation within ICES

The ICES/HELCOM group WGIAB is a forum for developing and combining ecosystem-based management efforts for the Baltic Sea. It is intended to provide scientific support for related management and assessment working groups, such as the ICES Baltic Fisheries Assessment Working Group (WGBFAS; ICES 2012b) and relevant HELCOM assessment efforts. The group was established in 2007 (ICES 2007a-2011a).

WGIAB is organized under the ICES SCICOM Science group on Regional Seas and has recently obtained counterparts in the other regional seas, including the Working Group on Integrated Assessments of the North Sea (WGINOSE, ICES 2011b), Working Group on the Northwest Atlantic Regional Sea (WGNARS, ICES 2010b, 2011c) and the Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS, ICES 2011d; Figures 2.1).

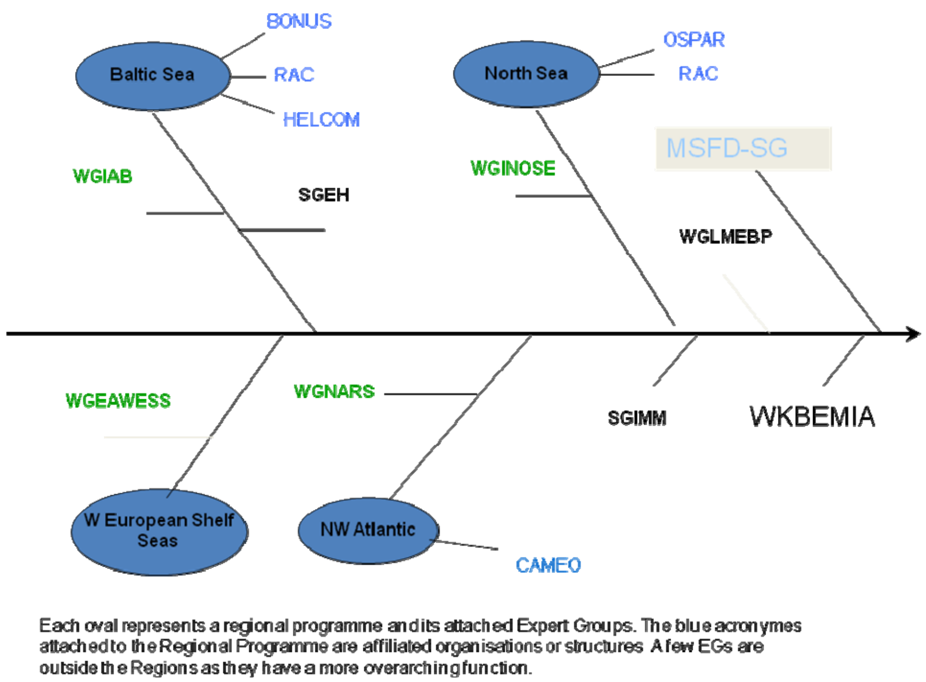

Figure 2.1. SSGRSP overview. Each oval represents a regional programme and its attached Expert Groups. The blue acronyms attached to Regional Programme are affiliated organisations or structures. A few EGs are outside the Region as they have a more overarching function (Figure by Yvonne Walther).

2.2 The WGIAB focal areas

The overall goal of the WGIAB is to promote and develop advice for adaptive, ecosystem-based management strategies for the Baltic Sea. The group has decided to build this development on the broader understanding of Integrated Ecosystem Assessment (IEAs) as a full assessment- and management cycle (Levin *et al*. 2009; Tallis *et al*. 2010).

One fundamental function of the group is to connect experts from various fields of science, environmental monitoring and assessment to collate and analyse long-term data sets representative of different parts of the marine ecosystems of the Baltic Sea. Two WGIAB core activities, in this respect, are the multivariate analyses of ecosystem status and trends (ITA; integrated trend and status assessments; Möllmann *et al.*, 2009, Dieckmann & Möllmann 2010, Lindegren *et al.* 2010), and the development and common evaluation of ecosystem and food-web models (Gårdmark *et al.*, submitted).

2.2.1 Main activities and results

The long-term data sets used in the ITA represent trends over time at various levels of the food-web, including biotic, abiotic and fisheries-related variables. The data is analysed in order to assess the current state of the ecosystem, identify main temporal changes, and identify the key variables affecting these changes. The data is also used in comparative analyses across ecosystems. One important output of the cross-system comparisons was the demonstration of major shifts in ecosystem composition occurring simultaneously in different sub-basins of the Baltic Sea. The main shift was identified in the end of the 1980s, signalling in the central Baltic Sea a shift from a decrease in cod stocks and *Pseudocalanus acuspes,* and an increase in sprat stocks, as related to climate variability and human exploitation (Möllmann *et al.* 2005, Möllmann *et al.* 2008, Möllmann *et al.* 2009, Casini *et al.* 2009, Lindegren *et al.* 2010, Casini *et al.* 2012).

In addition to activities related to ITA, WGIAB performs comparative analyses and evaluation of single species population models, as well as multispecies and food-web models through a Biological Ensemble Approach (BEMA, ICES 2009a, Gårdmark *et al.*, submitted). In this approach a set of different models are forced with the same scenarios (e.g. of future climate development) and their projections are collected in an ensemble. In particular, we have evaluated alternative fisheries management scenarios for cod and sprat under alternative scenarios of future climate change (ICES 2009a). The long-term aim of this work is to evaluate the potential use of different ecological models in fish stock assessment and management within the frame work of the Ecosystem Approach to Management of marine resources, and in particular act as a set of tools available within the standardized IEA management cycle (Levin *et al.* 2009, Tallis *et al.* 2010) intended for the Baltic Sea.

The previous efforts of the group has focused on: (i) assessing the uncertainty of projected responses of Eastern Baltic cod and the food-web to differences in the modelling approach and model structure, as well as (ii) providing first general conclusions on the potential response of the cod stock and the ecosystem (incl. uncertainty ranges) to a set of fisheries management scenarios and a selected future climate change scenarios. Currently, a diverse set of models with different assumptions, data basis and processes modelled are developed and available for use and comparative evaluation within the WGIAB. It is our ambition to invite and incorporate new initiatives within model development for the Baltic Sea and further our work on comparative analyses and model evaluation within the Biological Ensemble Approach.

In 2011, the meeting took a more process-based approach to development of ecosystem indicator systems. In the IEA cycle, the purpose of indicators is to signal when management objectives regarding ecosystem attributes are not met (Levin *et al.* 2009; Tallis *et al.* 2010). To develop such indicators, a thorough understanding of ecosystem processes and responses to human pressures is needed. A major goal was therefore to start analyses towards a better understanding of processes leading to the shifts in ecosystem structure, with the aim to use this for future developments of indicators for an IEA cycle. The questions addressed were (i) Are there any discontinuous food-web interactions in the Central Baltic Sea pelagic?, (ii) How does climate affect different trophic levels and does it differ across basins?, and (iii) How does trophic control (bottom-up vs. top-down) regulate different trophic levels and does it differ across basins? In parallel, the group has also assessed the potential to derive indicators to forewarn of large ecosystem restructurings, by evaluating a set of proposed "early-warning indicator" methods on the real monitoring data assembled by WGIAB (Lindegren *et al.*, in press). Also, coastal and small scale Baltic ecosystems were for the first time analysed, to initiate cooperation, collect data, and unify a statistical framework. The questions addressed were (i) are there discontinuous food-web interactions within coastal ecosystems and if so, how can they be identified (ii) are there synergistic effects between open sea and coastal systems as well as between coastal systems.

To follow up on these achievements, the group found it timely in 2012 to make a more structured synthesis of the current state of data and models in relation to the integrated assessment and management cycle, and to summarise for which open sea and coastal Baltic Sea sub-systems integrated trend analyses have been performed by the group. At the same time, this would define a basis for future work and priorities of the group, also accounting for the recently emerged potential for coordination and cooperation with other integrated assessment working groups within ICES and the increasing demand for environmental status assessment as well as ecosystem-based advice to fisheries management, as motivated by the implementation of the Marin Strategy Framework Directive in 2012 and the reform of the Common Fisheries Policy.

2.3 Structure of the report

Below, we present the results of the work and discussions during WGIAB 2012, with respect to the integrated trend analyses (ITA; Section 3), and the development of the assessment and management cycle (IEA; section 4). The report also includes reflections from the group on the request from ICES concerning Ecosystem overviews (Section 5), and on the long term visions of WGIAB and its potential contributions to future demands within marine management (Section 6).

3 Integrated Trend and status assessments (ToRs a, d)

3.1 Aims of the assessment

In 2012, WGIAB advanced further the integrated status and trend analyses of coastal ecosystems across the Baltic Sea, which were initiated in the previous year (ICES 2011a) and updated the trend and status assessment of the open sea pelagic food-web of the Central Baltic Sea, the Gulf of Riga, and the Bothnian Sea. The analyses and results for each of the systems are presented in Annex 4, and key findings are summarised below. The studies were combined in order to assess the presence of common and distinct patterns and trends over time.

3.2 Data included and methods applied

Integrated analyses of ecosystem status and trends had until 2011 been performed for 7 open sea sub-systems and 7 coastal systems. During the 2012 meeting, additionally 5 areas were added to the ITA metadata table (Table 3.2).

The analyses applied were composed of the following parts (ICES 2011d):

1) Assessment of trends in individual variables, as visualised by anomaly plots and a traffic light plot;
2) Assessment of multivariate trends for the complete data sets and separately for abiotic and biotic variables, based on PCA;

3) Assessment of temporal discontinuities, based on Chronological clustering or Coniss Broken stick.

Table 3.2. Baltic Sea ecosystem and sub-systems for which ecosystem data have been complied within WGIAB, and assessed in a common multivariate framework. The number of variables included in each assessment is shown as total (Tot), and separately for biotic (Biot), abiotic (Abiot), as well as Fisheries related variables (Fr). A detailed account of the data included for each subsystem assessed during the meeting is included in Annex 4.

		ITA		**Number of variables**				
		Start year	End year	Tot	Biot	Abiot	Fr	ITA year
OPEN SEA								
Bothnian Bay	BoB	1979	2006	26	13	11	2	2008
Bothnian Sea	BoS	1979	2010	25	16	8	1	2012
Baltic Proper	CBS	1975	2010	61	34	27	0	2012
Gulf of Riga	GoR	1973	2008	26	10	15	1	2012
Gulf of Finland	GoF	1979	2008	30	12	14	4	2009
The Sound	TS	1979	2005	40	27	13	x	2008
Kattegat	K	1982	2008	63	45	15	3	2010
COAST								
Holmön	HO	1994	2010	30	16	12	2	2012
Forsmark	FM	1987	2010	20	10	9	1	2012
Archipelago Sea	AS	1991	2009	26	16	10	0	2011
Gulf of Riga west coast	GoRc	1986	2011	23	15	8	0	2012
Narva Bay	NB	1993	2010	46	15	31	0	2012
Pärnu Bay (NE Gulf of Riga)	PB	1960	2010	22	13	7	2	2012
		1969	2010	26	13	7	6	
		1993	2010	34	15	13	6	
Kvädöfjärden	KF	1989	2010	20	11	8	1	2012
Curonian lagoon	CL	1992	2011	46	32	10	4	2012
Vistula lagoon	VL	1992	2011	45	23	19	3	2012
Gulf of Gdansk	GoG	1994	2010	35	15	15	5	2012
Vendelsö	VO	1981	2010	30	15	14	1	2012
Limfjord	LF	1984	2008	44	19	21	4	2012

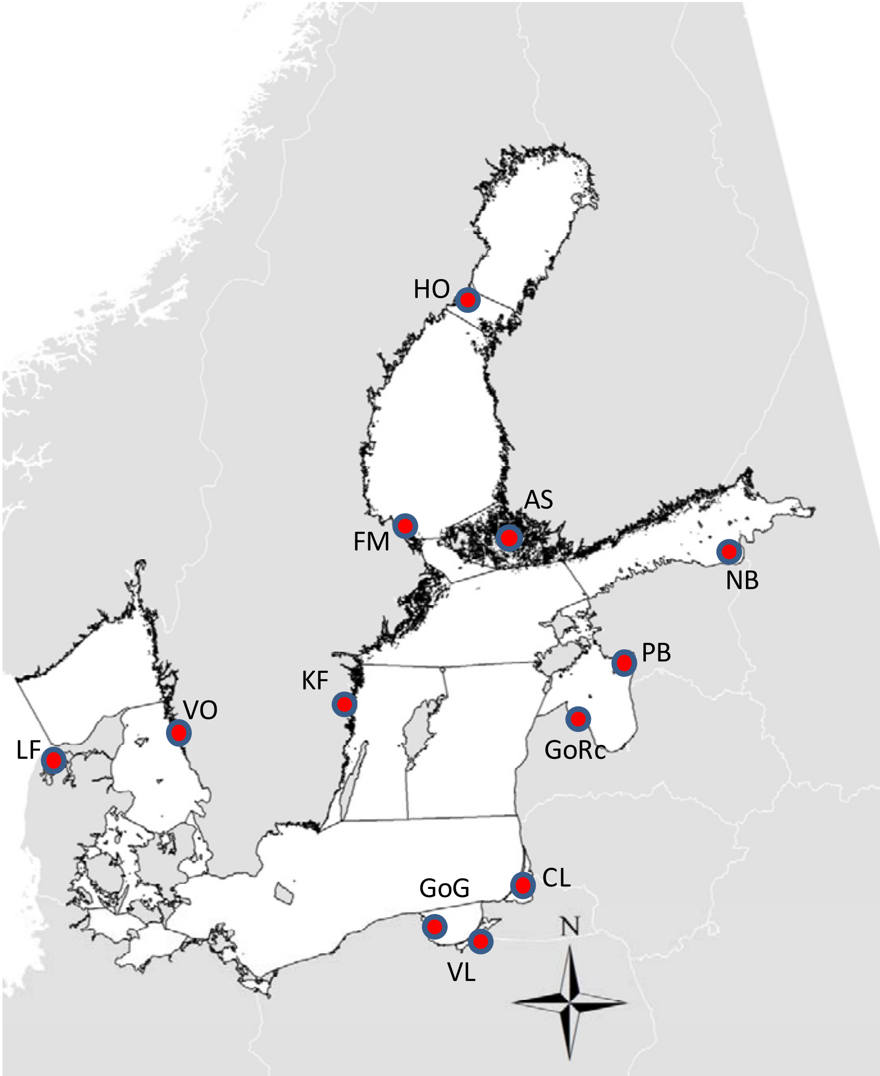

Figure 3.2. Location of Baltic Sea coastal areas for which ecosystem data have been complied within WGIAB, and assessed in a common multivariate framework. For abbreviations, see Table 3.2.

3.3 Summary of results

3.3.1 Coastal and small-scale Baltic Sea sub-systems

12 sub-systems were included in the analyses. The data sets compiled were very diverse, varying in their coverage of trophic levels, of environmental and human pressures, as well as in time-series length and quality. Generally, the number of trophic levels included varied between two to four, including phytoplankton, zooplankton, macro zoobenthos, fish and seals. With the exception of the Narva Bay, data on fish was included in all data sets. Environmental data typically represented temperature, salinity, oxygen and nutrient conditions/loads. Some of the data sets also included data on fishing pressure. The longest data set covered as an extended time-period as from 1960, but the majority of time-series typically dates back to the late 1980s or early 1990s. In the Pärnu Bay area, the data were divided to cover three different time-periods (1960–2010, 1969–2010 and 1993–2010 respectively).

As expected, given the difference in coverage of trophic levels and ecosystem structure in the different data sets, some unique development trajectories on the data set level did occur. It is, however, rather striking that changes in ecosystem structure occurred during the mid and late 1990s in nine of the twelve areas assessed. Significant changes also took place in four areas between 2003 and 2005. Since many of the discontinuity analyses was performed on all variables (abiotic and biotic variables together) these results is rather preliminary.

The development of the abiotic conditions during the time periods assessed do to some extent differs between areas. In the two western areas (Limfjord and Vendelsö) there has been an increase in water temperatures and decrease in nutrient loads, whereas there has been a general trend of decreasing salinity levels and increasing temperatures in the coastal areas in other Baltic Sea basins. Here the development of nutrient status differs remarkably between areas, likely as a result of land use practises and differences in data set length. For the biotic data there are some area-specific development trajectories, but generally a good coherence with the change in environmental variables in the area. In many areas, species and groups that are favoured by more eutrophic states has increased in abundance concurrent with increasing nutrient loads. Similarly, species of fish favoured by lower water temperatures has generally decreased in abundance in data sets with increasing water temperatures. The increase in abundance of seals and alien species (*Cercopages sp.* and *Marenzelleria sp.*) has increased in those data sets where they have been included, but this response is likely not linked to the abiotic state of the area.

Table 3.3.1. Summary of main results from the assessment of coastal areas. Number of variables and trophic levels included, changes in ecosystem structure according to the discontinuity analyses (*Shifts*), amount of variation explained by the first two PCA axes (*Explained variation*) and the biotic variables with highest positive and negative loading on the first PC (*Contributing variables to PC1*). * Denotes that the analysis was performed on both abiotic and biotic variables together, (+) an increasing trend and (-) a decreasing trend during the time-period assessed.

Area	Time period	# of variables	# trophic levels	Shifts (bio)	Explained variation (bio)	Contributing variables to PC1 (bio)
Limfjord	1984-2008	44	3	1992/1993* 1997/1998*	36 %	Larger cursteaceans (+), Eelpout (-)
Vendelsö	1981-2010	30	2	1996/1997	49.2 %	Amphiuridae (+), Montacutidae (-)
Gulf of Gdansk	1994-2010	36	2	2004/2005*	43 %*	Plaice (+), Eelpout (-)
Vistula Lagoon	1992-2011	44	4	1997/1998*	38 %*	Sabrefish SSB (+), Polychaetes (-)
Curonian Lagoon	1992-2011	44	4	1995/1996*	32.6 %*	Oligochaetes (+), Pikeperch weight (-)
Kvädöfjärden	1989-2010	20	3	1994/1995 2004/2005	39,7 %	Cod (+), Perch (-)
Gulf of Riga (West coast)	1986-2011	23	2	1996/1997*	44.2 %	Cercopages (+), Sticklebacks (-)
Pärnu Bay	1960-2010	22	2	1990/1991*	37.9 %*	Cercopages (+), Pikeperch weight (-)
	1969-2010	26	2	1983/1984* 1991/1992* 1998/1999*	41.1 %*	Cercopages (+), Whitefish landings (-)
	1993-2010	34	3	1998/1999*	36.3 %*	Smelt landings (+), Bosmina (-) ?
Forsmark	1987-2010	20	3	2003/2004	49. 4 %	Marenzelleria (+), Roach (-)
Narva Bay	1993-2010	46	3	1996/1997*	19 %*	Phytoplantkon spring (+), Limnoclalnus spring (-)
Archipelago Sea	1991-2009	26	2	2004/2005*	40 %*	Perch recruitment (-), Chrysophycae (+)
Holmön	1994-2010	30	4	1999/2000	51.5 %	Whitefish (-), Grey seal (+)

3.3.2 Pelagic (open sea) food-web

In all, 7 pelagic (open sea) sub-systems have been assessed over time (Table 3.2). Of these, data for the Central Baltic Sea, the Gulf of Riga and the Bothnian Sea were updated and analysed in 2012.

3.3.2.1 Bothnian Sea

During the last three decades the Bothnian Sea has become warmer and less saline, and there are correlated significant changes in the composition of the food-web. These changes in species abundances reflect the overall warming and desalinization; marine and cold-water mesozooplankton and zoobenthic species have decreased, whereas limnic copepods and cladocerans have increased. Since these limnic zooplankton are key prey for herring, and as fishing mortality is low, the herring stock has more than tripled since the 1980s. In addition to warmer and less saline waters, phosphorous concentrations continue to increase. The results also showed that whereas the environmental changes has been more gradual, the food-web shifted to distinctly (and significantly) different species composition in early 1980s, late 1980s, and again in early 2000s. For more detailed results, see Annex 4.

3.3.2.2 Central Baltic Sea

Analyses of the Central Baltic Sea showed that this ecosystem continues to be affected by anoxia and high phosphorus availability and only during inflow years, as in 2003, the initial state of the abiotic system is shortly attained. The most pronounced changes in the Central Baltic ecosystem were alterations in fish stocks (decline of cod and herring and parallel increase in sprat biomass), and zooplankton abundance (increase of *Acartia* and *Temora* biomass in spring, decrease of *Pseudocalanus*). These were paralleled by freshening surface waters, warmer winter waters below the thermocline and warmer surface waters.

A pronounced regime shift was observed in 1987/1988, according to STARS analyses on all variables. This regime shift was also detectable in the abiotic variables alone and marked the warming of the Baltic. When prewhitening was applied, STARS did not identify regime shifts in the PC1 of the biotic system, but picked up two small shifts in PC2 instead (1983/1984, 1994/1995). 1993 marked the onset of strong summer phytoplankton blooms in the Gotland Basin, whereas the 1983/1984 shift was probably too close to the start of the phytoplankton time-series (1979/1980) to be interpreted reliably. If gradual ecosystem changes were not removed by prewhitening, STARS identified two pronounced shifts in PC1 of the biotic variables in 1985/1986 and 1992/1993. These were related to zooplankton and fish stocks, with zooplankton changes occurring slightly earlier than the decline in cod and herring and the increase in sprat stocks. For more detailed results, see Annex 4.

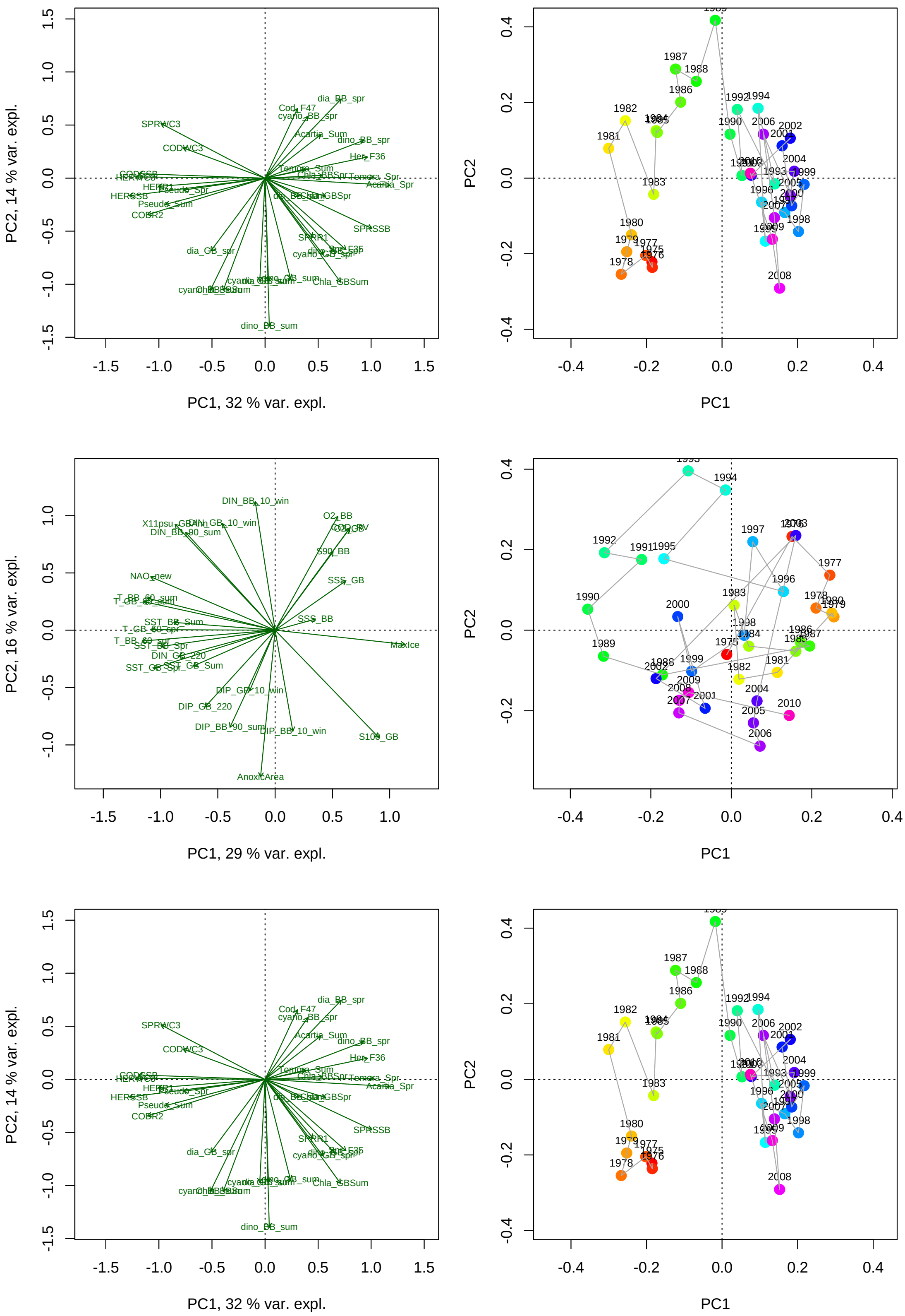

Figure 3.3.2. Biplots of variable loadings (left) and time-trajectories of year scores (right) in the in the PC1-PC2 plane for the Central Baltic Sea time-series. Rows show changes in all variables (top), abiotic (middle) and biotic (bottom) variables. Year scores are color-coded into red (1970s), orange-green (1980s), light blue (1990s) and blue-purple (2000s).

3.3.2.3 Gulf of Riga

The main changes over time in the Gulf of Riga were observed in herring stock, zooplankton biomass, temperature and salinity, as well as winter phosphate concentrations and summer phytoplankton biomass. The increase in herring biomass observed was paralleled by a decline in summer biomass of Eurytemora and a decline of individual herring weight. This indicated strong competition for zooplankton prey in the Gulf. In contrast to summer, spring copepod biomass had increased, driven by higher water temperatures. Winter nutrient concentrations showed differing trends for phosphate and nitrate. While winter nitrate concentrations correlated well to nitrogen loads and river runoff, winter phosphate dynamics were decoupled from their inputs and belong, according to the principal component analysis, to the structuring factors of the Gulf of Riga ecosystem. The rise in winter phosphate concentrations had, together with low summer zooplankton biomass, triggered an increase in summer phytoplankton biomass, potentially also due to an increase in cyanobacteria. For more detailed results, see Annex 4.

3.4 Method development

In the process of the analyses, the meeting provides a forum for discussing and evaluating input data from the perspective of ecological relevance, as well as statistical and data quality issues. One commonly data quality issue is the occurrence of missing observations, solutions for which were further developed by members of the group, for further considerations in upcoming meetings.

3.4.1 Presentation of the method developed at AtlantNIRO for application in the integrated ecosystem research

Pavel Gasyukov

The data used in the integrated ecosystem analysis describe the objects and processes in the ecosystem including information on fishes and fisheries, as well as various biotic information and indices of the environment conditions. The above mentioned data, as a rule, are presented in the form of large-size tables.

The availability of gaps appeared in the cases, when observations were of low quality or absent, is one of these data characteristics. The practice of integrated assessments in different areas of the Baltic Sea indicated that the percent proportion of the missing observations may be considerable. For example, the data for the Central Baltic area contain 1960 values, while the number of missing data is 50. The information for the Gulf of Riga contains 736 values, including 13 gaps, while the ecosystem data for the Kattegat contains 1836 values, including 124 gaps.

The availability of missing observations complicates the ecosystem research, distorts the resulting estimates and in some cases prevents the assessment totally (the principal-component method cannot be used with missing data).

In such situations WGIAB replaces the missing data with a mean value of the nearest four observations. However, this approach is not always justified.

Other methods applying minimization of objective functions and accounting for missing observations availability seem more justified. Two methods have been proposed:

1) Imputation method (Ilin & Raiko, 2008). At the initial stage of calculations all missing observations are replaced with the mean values of respective columns of the data matrix. As a result any missing observation are absent in the matrix and the standard

PCA method can be applied. Then, new values of the missing observations are calculated for the given number of components in PCA, and the standard PCA is repeated. This iterative process is continued until the convergence is achieved.

The number of components of PCA is determined, for example, using the double check method with the known data. This number of components should provide the prescribed accuracy.

Figure 3.4.1.1 shows time-series of individual indices based on the sample data from the Central Baltic area, which were used in calculations with the double check method (in each figure one time-series corresponds to the observed index values, while the other one represents recovered values, when the observed index has been excluded from the sample in the process of the double check method application). In the example considered, the recovery of missing observations may be assumed satisfactory, though in some cases deviations of the observed and recovered indices are significant.

2) Variational bayesian PCA (Ilin & Raiko 2008). This method belongs to the group of probabilistic PCA methods, including: probabilistic PCA, maximum a posteriory estimation и Variational Bayesian PCA. These methods have several advantages as compared to the imputation method: 1) incorporation of the noise component into the model, 2) the algorithm has the normalization property, 3) the algorithm reduces overfitting, and 4) provides statistical characteristics of estimates and confidential intervals.

Therefore, the considered methods allow to recover missing observations in the ecosystem data with subsequent assessment of statistical characteristics of different indices and their confidential intervals, as well as to fulfil filtration of information.

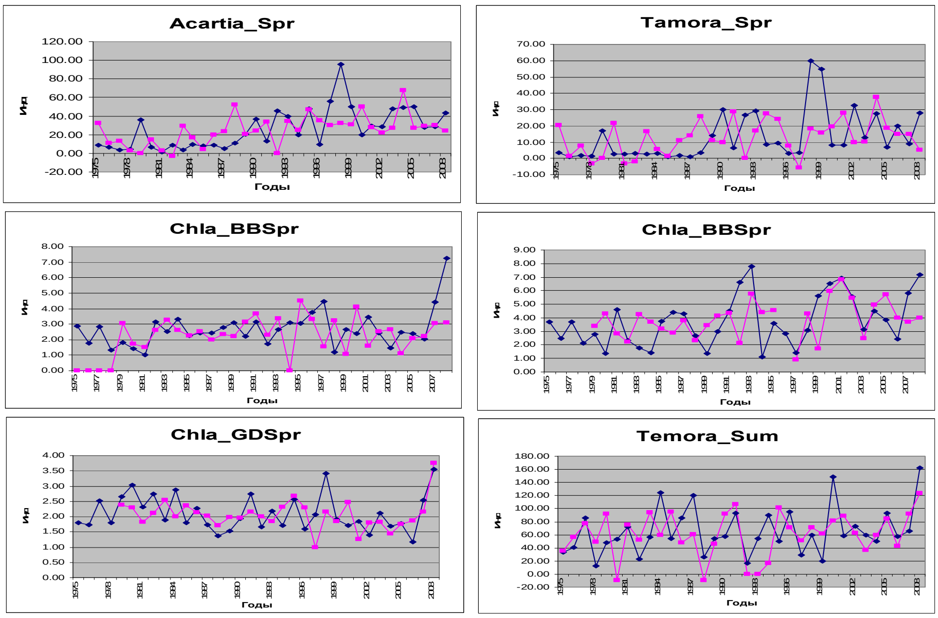

Figure 3.4.1.1. Time-series (sample) of observed and recovered indices for the entire Central Baltic area. The recovery has been fulfilled using the Imputation method.

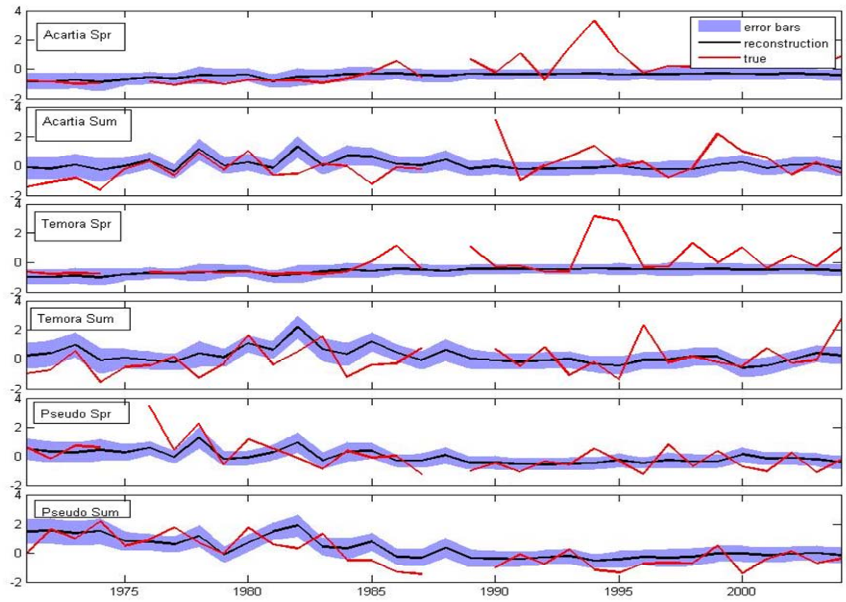

Figure 3.4.1.2. Time-series of normalized (sample) observed and recovered indices for the entire Central Baltic area. The recovery has been fulfilled using the Variational bayesian PCA method.

4 Integrated Ecosystem Assessment (ToRs b, c, e)

4.1 Background

The concept of ecosystem-based management can be defined in many ways, depending on context and on the priorities/needs or the user. In its work, WGIAB has decided to follow the broader understanding of integrated ecosystem assessments as a formal synthesis and quantitative analysis of information on relevant natural and socio-economic factors, in relation to specified ecosystem management objectives (Levin *et al.* 2009, Tallis *et al.* 2010). In this sense, an integrated ecosystem assessment is a process and a product for organising science in order to inform management decisions. Important features of the process are that it is place-based, based on modelling and data, and includes interactions among systems. The human component is recognised as a strong part.

The IEA process generally contains five steps (ICES 2011b, as modified from Koslow *et al.* 2009):

1) An initial scoping will identify management objectives, ecosystem attributes of concern, and relevant ecosystem stressors.

2) Indicators that reflect ecosystem attributes and stressors specified in the scoping process will be developed and tested. These must be linked objectively to decision criteria.

3) A hierarchical risk analysis will explore the susceptibility of an indicator to natural or human threats, as well as its resilience (the ability of the indicator to return to its previous state after being perturbed).

4) Results from the risk analysis for each ecosystem indicator are integrated in an ecosystem assessment, which quantifies the overall status of the ecosystem relative to historical status and prescribed targets.

5) The final phase of the IEA is an evaluation of the potential of different management options to influence ecosystem status, using ecosystem models and a formal Management Strategy Evaluation (MSE)

The process further recognises that available science is not the bottleneck for implementation and moving forward, the main issues to solve being related to policy and governance (Levin *et al.* 2009). Adaptivity is ensured by feedback loops in which the indicators are monitored and management effectiveness is evaluated (Figure 4.1).

Several of the activities undertaken by WGIAB cover aspects of this process. For example, the multivariate analyses on ecosystem status and trends contribute data and knowledge to steps 1, 2 and 4, while the Biological Ensemble Modelling is a prerequisite for steps 2, 3 and 5.

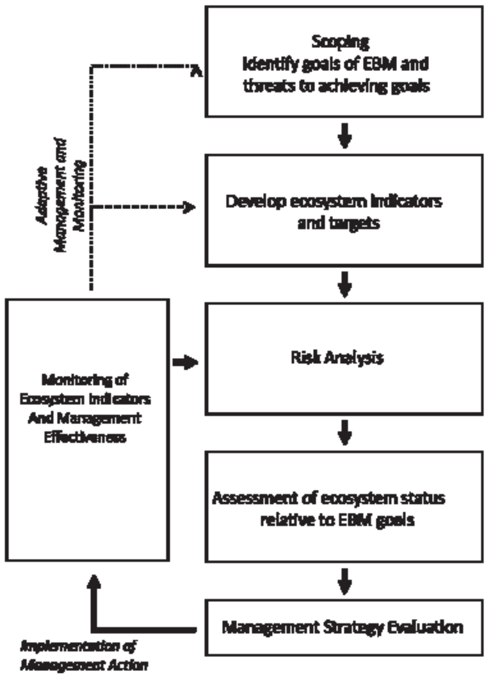

Figure 4.1. The five-step process of Integrated Ecosystem Assessment. The cycle is repeated in an adaptive manner (From Levin *et al.* 2009).

4.2 Evaluation of the assessment and management approach

Different approaches for integrated ecosystem assessments were evaluated by their strengths and weaknesses by WGECO (ICES 2010c). At the meeting, an account of the evaluation was presented for the participants of WGIAB and WGINOSE by Dave Reid. The evaluation included the OSPAR approach (Robinson *et al.* 2008, 2009), the REGNS approach (Kenny *et al.* 2009), the United States approach (Levin *et al.* 2009) and the Canadian approach (as described by ICES 2010c). The outcome of the evaluation was discussed by the participants and it was concluded that a further comparison of the approaches from different aspects was warranted, as they differ in scope and are not easily compared on a general basis. Also, some of the points picked up by the evaluation are no longer relevant, as the different approaches are continuously being developed. The evaluation of the US IEA Approach (ICES 2010c), was revisited in order to provide a more updated version, also accounting for its links to the MSFD.

"Forming, storming, norming, performing" (Bruce Tuckman)

4.2.1 Strengths and Weakness of the United States approach to integrated ecosystem assessment by ICES (2010c), as modified by Phillip Levin

In the United States context, an integrated ecosystem assessment (IEA) is defined as a formal synthesis and quantitative analysis of information on relevant natural and socio-economic factors, in relation to specified ecosystem management objectives (Levin *et al.* 2009). IEAs do not supplant single-sector management; instead, they inform the management of diverse, potentially conflicting ocean-use sectors. The development of an IEA can be described as a five-stop process with a sixth step that provides monitoring feedback. These six steps are briefly described below and are linked, to the extent possible, with the steps of the MSFD.

1) **Scoping process to identify key management objectives and constraints**. Starting from the entire ecosystem perspective the scoping step focuses the assessment on a sub-system of ecosystem components that are linked to the issues of management importance. The scoping process involves stakeholders with differing objectives, which cross ecological, social and political boundaries and who have unclear or open-access property rights on ecosystem services. The scoping process corresponds to elements of the MSFD initial assessment (Step 1).

2) **Identify appropriate indicators and management thresholds**. Indicators may track the abundance of single species, may integrate the abundance of multiple species, or serve as proxies for ecosystem attributes of interest that are less readily measured. Management thresholds can be derived from historical baseline data and/or models fit to the ecological data. Useful indicators should be directly observable and based on well-defined theory, be understandable to the general public, cost-effective to measure, supported by historical time-series, sensitive and responsive to changes in ecosystem state, and responsive to the properties they are intended to measure (Rice and Rochet, 2005). The step corresponds with establishing a series of environmental targets and associated indicators in the MSFD (Step 2).

3) **Determine the risk that indicators will fall below management targets**. The goal of the risk analysis is to qualitatively or quantitatively determine the probability that an ecosystem indicator will reach or remain in an undesirable state as specified by thresholds in Step 2. Risk analysis is used to characterize the scale, intensity, and consequences of particular pressures on the state indicators, either by qualitative ranking by expert opinion or with quantitative analyses. The MSFD does not include explicitly a risk-analysis step, but a risk-based approach has recently been suggested as an appropriate aspect of prioritising management within the MSFD assessment (Cardoso *et al.*, 2010).

4) **Combine risk assessments of individual indicators into a determination of overall ecosystem status**. The risk analysis quantifies the status of individual ecosystem indicators, whereas the full IEA considers the state of all indicators simultaneously. The MSFD does not require this integrative step, or provide guidance on how to integrate multiple indicators into fewer.

5) **Evaluate the ability of different management strategies to alter ecosystem status**. Ecosystem modelling frameworks and statistical analysis are used to evaluate the ability of different management strategies to influence the status of natural and human system indicators. Management strategy

evaluation can be used as a filter to identify which measures are capable of meeting the stated management objectives. This step corresponds to an important aspect of the process of developing a programme of measures in the MSFD (Step 4).

6) **Monitoring of ecosystem indicators and management effectiveness**. Continued (and possibly enhanced) monitoring of ecosystem indicators is required to determine the extent to which management objectives are being met. A separate evaluation of management effectiveness is required to determine if management measures are having the desired effect on the pressure indicators. This step can be considered adaptive management in an ecosystem context. It corresponds to the establishment of a monitoring programme in the MSFD (Step 5).

Strengths

- The IEA process and its objectives have been defined in published articles.
- Provides an explicit vehicle to focus assessment and management actions across government agencies and state and federal jurisdictions.
- Flexibility to make the management objectives and constraints specific to the region.
- Management objectives can be determined as part of the scoping process, which allows for opportunity for increased stakeholder input.
- IEAs can be performed at different spatial scales, ranging from Puget Sound (e.g. 100 km) to the California Current (e.g. 1000 km).
- Includes risk assessment as an explicit step.
- Combines risk assessments of individual indicators into a determination of overall ecosystem status.
- Monitors ecosystem indicators and management effectiveness, allowing for adaptive learning.
- Explicit central guidance on the scope and core elements of an IEA.
- Explicitly links human and natural components of the ecosystems.

Weaknesses

- Lacks uniform candidate lists of state indicators and pressure indicators.
- Reliance on thorough scoping process to identify management questions can lengthen the time it takes to conduct IEAs. Because of this, the indicators and modelling frameworks initially selected may need to be modified for answering the management questions that emerge from scoping.
- Reliance on complex ecosystem models (Ecopath, Ecosim, Atlantis) can decrease transparency of results.
- The IEA process does not require consistency among regions in reference points for ecosystem attributes. Thus different US regions may have different reference points for the same ecosystem attributes. However, in the US, reference points for water quality, fish stocks, marine mammals and endangered species are set by law in the corresponding acts.
- The IEA process can help to justify existing monitoring programs but has no mandate to initiate additional monitoring to fill data gaps.

4.3 Current state of data and models in relation to the integrated ecosystem assessment cycle

4.3.1 Scoping process to identify key management objectives and constraints (Step 1)

A scoping discussion was undertaken, focusing on data availability in relation to prevailing management strategies, and potential constraints to pursuing these further.

Tallis *et al.* (2010) outlined how data at various levels of quality can be included in the integrated ecosystem assessment framework. When data availability is poor, evaluated can be based on qualitative conceptual models of the ecosystem or statistical analyses, whereas quantitative modelling may be preferred in abundant data situations, to clarify the relationships between management targets and major ecosystem features. On a general basis, data was considered sufficient for following quantitative approaches for most Baltic open sea areas, although several data gaps could also be identified, and may serve as a basis for future priorities within monitoring. For the Baltic Sea coastal areas, data quality and availability is under evaluation for most areas (see section 3).

Although two overarching management strategies of importance for the Baltic Sea area, and the scientific scope of WGIAB, were easily identified at a high structural level of organisation, the Marine Strategy Framework Directive (MSFD) and the Common Fisheries Policy (CFP), both these were under development/reforming at the time of the meeting, giving no detailed guidance on their operational aspects. As concerns the MSFD, however, a lot of activity was identified at the level of national management, as discussed during the meeting. An update on activities at the level of regional coordination by the HELCOM Coreset project was provided by Samuli Korpinen on day 1, and a general discussion on ICES and MSFD related issued were undertaken together with WGINOSE on day 4 of the meeting, under the lead of Gerd Kraus and Yvonne Walther.

One important scientific challenge for the successful implementation of the MSFD and the CFP was identified as the evaluation of how different management goals are interdependent on each other, for example the recognition of potential trade-offs between and among indicators within Descriptor 1, 3 and 4 of the MSFD. A structural challenge was identified by a poor level of interaction among sectorial pillars, for example among the environment pillar and the fisheries pillar.

4.3.2 Identifying indicators and management thresholds (Step 2)

Participants discussed how WGIAB can contribute to and forward the identification and development of indicators in relation to management objectives. The group decided to use the 11 descriptors as defined in the EU MSFD, with a focus on Descriptors 1 (Biodiversity), 3 (Commercial fish and shellfish) and 4 (Foodwebs).

Based on the current suggestions for indicators made by the HELCOM Coreset project in relation to the Baltic Sea Action Plan (BSAP) and ICES (2012b), WGIAB identified as a first step those for D1, D3 and D4 indicators from indicators that are related to its work, by structuring them according to data availability, in relation to the existing ITA multivariate datasets (see section 3.2), and model availability, in relation to the EwW, SMS and BALMAR models (Table 4.3.2.1, and 4.3.2.2; see also section 4.4).

Table 4.3.2.1. Core indicators for assessing environmental status suggested by HELCOM Coreset and their relationship to work of WGIAB. Data availability in relation to the work of WGIAB was ranked by: 0 = No data; 1= Data potentially available; 2=Data available; and model availability by: 0 = Not included; 1= Can potentially be included; 2=Included. (EwE, an Ecopath with Ecosim model of the Central Baltic Sea, Tomczak, *et al.* 2012; SMS, a stochastic multi-species model of cod-sprat-herring in the Central Baltic Sea, ICES 2012d; BALMAR, Lindegren *et al.* 2009)

HELCOM PROPOSED CORE INDICATOR	Data	EwE	SMS	BALMAR
Populations (D1.2)				
Effects of hazardous substances on marine mammals	0			
Abundance of waterbirds in the breeding season	1	1	0	0
Abundance of key fish species	2	2	2	2
By-catch of mammals and waterbirds	1	1	0	0
Proportion of waterbirds being oiled annually	0			
Abundance of salmon spawners and smolt	0			
Abundance of sea trout spawners and parr	0			
Communities and habitats (D1.4)				
Distribution and extent of benthic biotopes	0			
State of macrozoobenthic communities (BQI, etc.)	1			
Population structure of long-lived macrozoobenthic species	1			
Lower depth distribution of macrophyte species	0			
Phytoplankton diversity	1	0	0	0
Proportion of large fish in a community	2	2	2	2
Food webs (D4)				
Abundance and mean size of zooplankton	1	2	0	0
Productivity of white-tailed eagle	1	0	0	0
Abundance of key functional groups of fish	2	2	2	2
Abundance of waterbirds in the winter season	1	1	0	0
Population growth rate of marine mammals	1	1	0	0

Table 4.3.2.2. D3 indicators and their relationship to work of WGIAB, assessed as explained in the table caption 4.3.2.1.

D3 INDICATORS (COMMERCIAL FISH AND SHELLFISH)	Data	EwE	SMS	BALMAR
Level of pressure of the fishing activity (D3.1)				
Primary indicator: Fishing mortality (F)	2	2	2	2
Secondary indicator: Ratio between catch and biomass index	2	2	2	2
Reproductive capacity of the stock (D3.2)				
Primary indicator: Spawning Stock Biomass (SSB)	2	2	2	2
Secondary indicator: Biomass indices	2	2	2	0
Population age and size distribution (D3.3)				
Proportion of fish larger than the mean size of first sexual maturation	2	0	0	0
Mean maximum length across all species found in research vessel surveys	2	0	0	0
95% percentile of the fish length distribution observed in research vessel surveys	2	0	0	0
Size at first sexual maturation (secondary indicator)	2	0	0	0

Based on these tables and the following considerations, WGIAB will proceed with the identification and assessment of indicators on its next meeting in 2013. These indicators could be of either immediate use or potential long term use. One example for the later uses could be studies on the effects on other parts of the food web, if the targets of Descriptor 3, all stocks are fished at sustainable levels are achieved. As another example, ecosystem health could be characterized with respect to food webs in relation to ambient (natural) environmental factors, both qualitatively and quantitatively, including any set boundaries. It was also been suggested as one of WGIAB's next potential activities, to investigate the relationship between the abundance of certain (key) species and ecosystem attributes ecosystem attributes like ecosystem structure and function.

When carrying out all work mentioned above, care will be taken to take into account the recommendations made by several authors as well as ICES expert groups to achieve scientific sound indicators. Some of these recommendations are summarized in the following text.

In its report from 2011, WGIAB concluded that the following issues should be accounted for when developing indicators, based on earlier work done by WGIAB (ICES 2011a)[1]:

1) **Indicator species/groups are linked**, as demonstrated by e.g. trophic cascades (Casini *et al.* 2008, Möllmann *et al.* 2008) and subject to changes in trophic regulation (Casini *et al.* 2009). Therefore, (a) indicators at different trophic groups must be developed jointly, (b) targets within one food-web must be set jointly to account for the presence of tradeoffs among management objectives affecting different parts of the food-web.

[1] These issues were presented to HELCOM CORESET during one of its biodiversity workshops in 2011.

2) **Reference states change over time**; shifts in ecosystem composition has have been demonstrated in all Baltic Sea sub-basins (Diekmann and Möllmann 2010). As ecosystem structure and function differs between regimes (e.g. Casini *et al.* 2009), targets need to be adaptive. Monitoring of several functional groups is necessary to enable detection of ecosystem regime shifts.

3) **Multiple natural and anthropogenic drivers are related to shifts in ecosystem composition**, and these drivers differ between Baltic Sea sub-basins (Möllmann *et al.* 2009, Lindegren *et al.* 2010). Therefore, indicators and targets need to be defined at a scale smaller than the whole Baltic Sea (e.g. sub-basins).

During the 2010 meeting, WGIAB did considerable work on developing indicator systems for an ecosystem-based management. This included (i) reviewing the indicator systems of the HELCOM Baltic Sea Action Plan (BSAP) and the EU MSFD, and relating them to WGIAB work, (ii) developing indicators systems to support ecosystem-based assessment of the Baltic fish stocks and the ecosystem, and (iii) projecting foodweb indicators using an EwE foodweb model (ICES 2010a).

At its meeting in 2011, WGIAB noted that several of the analyses performed by WGIAB provide a basis for selecting relevant pressure indicators. In particular the analyses of processes leading to observed ecosystem changes, conducted by WGIAB both in this meeting and previously (Möllmann *et al.* 2009, Lindegren *et al.* 2010), are important for selecting appropriate indicators of pressures on biodiversity.

While selecting indicators, each indicator should be evaluated on its merits, with a watchful eye for redundancies, potential synergies, and gaps among promising metrics, as ICES (2005) recommends. Rice and Rochet (2005) stated in their useful framework for selecting a set of indicators, that the chosen indicators should be directly observable and based on well-defined theory, while also being understandable to the general public, cost-effective to measure, supported by historical time-series, sensitive and responsive to changes in ecosystem state (and management efforts), and responsive to properties they are intended to measure.

4.3.2.1 Early warning indicators

Alterations in structure and functioning of marine ecosystems have been increasingly reported through the world in relation to overfishing, climate and eutrophication. These pronounced and abrupt multi-trophic level reorganizations of large-scale ecosystems are usually termed ecosystem regime shifts and happen when the ecosystem resilience is low. In the past several regime shifts have been detected in the Baltic Sea.

Obtaining early warning of potential regime shifts from monitoring is direly needed for resource management and conservation efforts to maintain key ecological functioning and important goods and services (Scheffer *et al.* 2009). During last year's meeting, WGIAB initiated efforts to provide and evaluate potential early-warning signals of approaching ecosystem regime shifts. The primary aim of this effort relates to its potential management usage within the IEA step 2, i.e. as a tool to detect ecological threshold and targets in relevant ecosystem indictors. In 2011, we tested and evaluated a set of temporal and spatial early-warning indicators, proposed in theoretical and experimental studies, on real monitoring data on a key ecosystem component in the central Baltic Sea, the important copepod species *Pseudocalanus acuspes*. We applied six different types of early-warning indicators to spatio-temporally resolved data (covering the Bornholm basin, Gdansk deep, and Gotland basin), and assessed their predictive ability to forewarn the major regime shift in 1988. The preliminary results (Lindegren *et al.*, accepted) and evaluations of underlying assumptions of the different methods show that there is no single indicator or method that is particularly suitable. In contrast, application of the combination of multiple methods, combined with sensitivity analyses, outperforms any single early warning indicator.

As a compliment to identifying potential early-warning signals, a state-of-the-art statistical analysis was performed allowing the detection of non-linearities and thresholds in food-web interactions and their relationship to drivers such as overfishing and climate. The analysis was applied to the large dataset of hydro-climatic, phyto- and zooplankton as well as fisheries variables collected in the Central Baltic Sea during the period 1979–2006. This approach, by linking the different species-specific models to a food-web model, enabled us to test for the cause of the observed regime shifts. A combination of fishery and environmental scenarios has been applied to the food-web model to test for the presence of thresholds, assess its resilience and detect hysteresis in this particular system. Our simulation results show that under the current environmental regime the Baltic Sea system presents hysteresis as fishing should be reduced further below the pre-shift conditions to return to the previous state. Such interactions give new insights into early warning indicators.

These preliminary analyses provide a first methodological comparison, which will be further evaluated, developed and applied in upcoming work related to IEA step 2.

4.3.2.2 An approach for integrating the indicator based assessment of commercially exploited fish species of the North Sea

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Descriptor 3 of the Marine Strategy Framework Directive demands the assessment of the environmental status of commercially exploited fish stocks considering their abundance, fishing pressure and stock size- or age structure. In the here presented approach, the 22 most important demersal species (by catch volume) of the North Sea (including the Eastern Channel and Skagerrak, ICES Areas VIId & IIIa) were assessed on the basis of the D3-indicators suggested by the EC-Commission decision 477/2010 (EU-COM, 2010).

The assessment of stock structure focused on the length structure, because this data was available from the IBTS-Q1 survey for all considered species, whereas age data is only obtained for the commercial species of major importance such as cod or plaice. For the assessment of stock size either the spawning stock biomass (SSB) from analytical stock assessments or the mean number of caught individuals per hour was used. Fishing pressure was assessed by fishing mortality (F) or harvest ratio (HR), which is the ratio of commercial landing biomass and the survey CPUE (by biomass). The length structure was assessed by the 95%-percentile of the length frequency distribution (L_{95}). Because the L_{95} has been demonstrated to be highly sensitive to the proportion of small individuals and hence recruitment processes (Probst *et al.*, 2012), the assessment of length structure was complemented by an additional size-based indicator, the mean size of the largest ten observed individuals (L_{max10}).

The assessment of good environmental status (GES) was performed for each indicator and each species. Except for the cases, where absolute reference values from analytical stock assessments were available, the trend of each indicator metric was assess with a traffic-light approach in which the last three-year's mean of the indicator metric should fall either above the 75%-quantile of the total available time-series to achieve a 'green' status or between the 75%- and 50%-quantile to achieve a yellow'. Any last—three-year's mean below the 50%-quantile was considered as 'red'. For harvest rate the GES borders were set at <25%: 'green', 25%–50% 'yellow and > 50%: 'red'.

To determine the GES of each species, the indicators were aggregated following two rationales: either GES was achieved, if no further deterioration occurs (GES I) or if an improvement is evident (GES II). Because most of the assessment is trend based and limits/and targets for most of the indicator metrics are currently unknown, GES II is more precautionary, but also harder to achieve. Accordingly, GES I was achieved, if none of the four indicator metrics of a species achieved 'red', whereas GES II was achieved, if all indicator metrics achieved 'green' (except for L_{95} which is a relative indicator and hence should at least achieve 'yellow'). This is because the number of large individuals may increase in synchrony with recruitment, hence in a growing stock L_{95} could remain stable while the stock is still improving).

At last an overall aggregation of GES of all species was performed by applying probabilities of a binomial distribution. It was assumed that for each species the random chance of achieving GES I and II was 0.5. According to the binomial distribution the number of species which would achieve GES with a random probability of less than 5% was therefore 15.

Results

Depending on the method of how to assess GES, only six or three species achieved GES i and II, respectively. Accordingly, the aggregated D3-GES was not achieved in either case. In fact, GES was only achieved for three species (megrim, brill and tub gurnard) under both scenarios. This result implies that the status of commercially exploited demersal fish species in the North Sea is still critical, but also that the indicator based assessment of a stock under the MSFD can be stricter than the ICES analytical stock assessment. E.g. plaice did not achieve GES because its size-structure, namely the L_{max10}, did not score 'yellow', whereas the ICES stock assessment indicates a long-time high of spawning stock biomass and sustainable levels of exploitation. On the other hand, the assessment of exploitation is less precise using harvest ratio instead of analytical F.: for cod, the HR performed green, whereas the ICES stock assessment indicates, that F is still above FMSY. Under the absence of absolute reference points, the trend-based assessment is associated with higher uncertainty and should be used with caution.

Borja, Á., Elliott, M., Carstensen, J., Heiskanen, A.-S., and van de Bund, W. 2010. Marine management – Towards an integrated implementation of the European Marine Strategy Framework and sthe Water Framework Directives. Marine Pollution Bulletin, 60: 2175-2186.

EU-COM. 2008. Directive 2008/56/EC of the European parliament and of the council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF

EU-COM. 2010. Commission decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters.

Probst, W. N., Stelzenmüller, V., and Fock, H. O. 2012. Using cross-correlations to assess the relationship between time-lagged pressure and state indicators – an exemplary analysis of North Sea fish population indicators ICES Journal of Marine Science, 69: 670-681.

4.3.3 Risk assessment (Step 3)

The Driver Pressure State Impact Response (DPSIR) framework application considers the different levels of ecosystem interactions that have to be dealt with during an IEA framework. In the work of Levin *et al.* (2008) drivers are defined as potential pressures on the ecosystem that are of natural (e.g. physical forcing, predator prey relationships) or human (e.g. fishing, pollution, economy) origin and disturb the system at different levels and amplitudes and can change the (ideally already measured) state of an ecosystem (Levin *et al.*, 2009). If the state of an ecosystem is sufficiently assessed, a risk analysis of the selected indicators provides the information needed for implementing a management strategy. The measured changes in the ecosystem (e.g. declines in biodiversity) are defined as impacts and the management evaluation provide the management responses to predicted or measured impacts that are needed to modify the drivers (Figure 4.3.3).

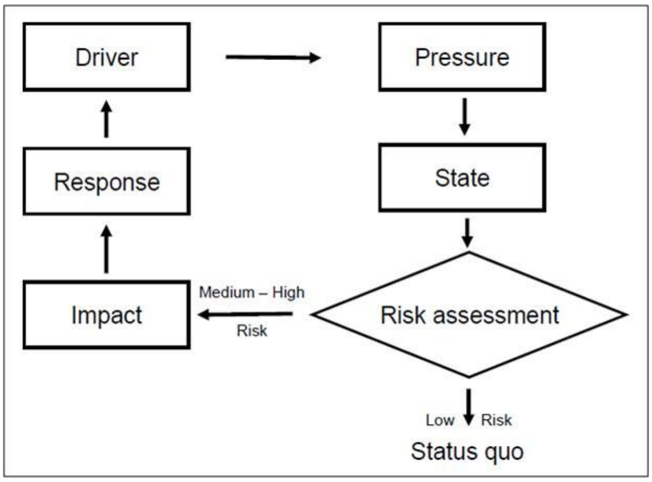

Figure 4.3.3. The DPSIR framework for environmental indicators used by NOAA (from Levin *et al.* (2008)

The resilience of each indicator has to be evaluated in order to gain insight into the interactions between different components within the system, and define suitable indicators for the set management goal.

Within the risk analysis step, the level of sensitivity and exposure of the indicators to all stressors have to be assessed for the system of interest in order to conduct the appropriate management action. The evaluation of exposure and sensitivity can lead to incorrect conclusions and therefore has to be handled with care, since the sensitivity of an indicator can highly depend on geographic areas or individual habitat structure (Fairman *et al.* 1999). If long data series on risk occurrence are available, the likelihood of each risk can be evaluated, followed by a derivation of an overall risk score (productivity-susceptibility analysis PSA). In ecosystem-based fisheries management, PSA has been used successfully, i.e. in the hierarchical approach of Smith *et al.* (2007) in recent years. In intermediate data situations, literature values for resilience for appropriate indicators and local knowledge can be used in a PSA as well as population or ecosystem viability analysis from count-based time-series data (Holmes and Fragan 2002; Ebenman and Jonsson 2005) to evaluate the potential risks on indicators.

In data poor situations, informal stakeholder processes can be applied to develop maps of pressure intensity and frequency along with the system resilience (Tallis *et al.* 2010). An often overlooked but essential part of the risk analysis is the stakeholder participation and the governance of the framework. If time is limited, a combination of maps and conceptual models can be an appropriate way to determine threats, as developed by Halpern *et al.* (2008). Identified risks can be ranked according to their impact on the indicators or the management goal. Different evaluation and statistical methods are developed depending on the IEA approach (Fletcher *et al.* 2002; Fletcher 2005; Milton 2001; Stobutzki *et al.* 2001; Griffiths *et al.* 2006; Hobday *et al.* 2006). Supporting tools for the decision process can be Fuzzy Logic or Bayesian Belief Networks (e.g. Stelzemüller *et al.* 2010). Several of the models used by WGIAB in the ensemble modelling are stochastic models, which can be used to perform risk analyses in a probabilistic sense.

4.3.4 Determine overall ecosystem status and evaluate the ability of different management strategies to alter ecosystem status (Step 4 and 5)

In 2009, WGIAB performed an example of a management strategy evaluation (MSE) for one indicator, using the biological ensemble modelling approach developed during that meeting (ICES 2009a, Gårdmark *et al.* submitted). Whereas the management "strategies" evaluated where quite simplistic (constant fishing mortalities reflecting either no directed cod fishery, exploitation at target fishing levels, or business as usual exploitation), the MSE accounted for ongoing climate change, and demonstrated how management decisions can be made drawing upon information from multiple ecological models with varying complexity (Gårdmark *et al.* submitted). By aggregating information from models ranging from single species to full food-web models, the approach informs on robust management strategies. That is, it shows which management strategies that are modelled to achieve a specific target, independent of the ecological modelled used and independent of the climate scenario tested.

For simple single-species indicators it is possible to construct large model ensembles ranging from single species to food-web models to use for MSE, but for e.g. food-web indicators it is not as there are only few multi-species and food-web models available for the Baltic Sea. Applications of the IEA elsewhere often rely on a single ecosystem model, such as Atlantis models (Fulton *et al.* 2004), which couple physical transport-biogeochemical process models with food-web models. There are several spatially explicit biogeochemical models, driven by regionally downscaled coupled atmospheric and ocean circulation models, developed for the Baltic (Eilola *et al.* 2011). Scenarios simulated in these have been used as input in a recently developed Ecosim/Ecopath model of the Baltic Sea food-web (Tomczak *et al.* 2012), but there is no full coupling between the food-web model and the biogeochemical models as there is no feed-back from the trophic processes down to the primary production simulated in the biogeochemical models. The plans on developing an Atlantis model for the Baltic Sea, by DTU-Aqua within the EU FP7 project VECTORS (see marine-vectors.eu), were presented to the WGIAB 2012 meeting. Inclusion of such a highly complex model in model ensembles used for MSE can inform both further model developments, and on the potential effect of management strategies in the Baltic Sea.

4.4 Example of the Integrated Ecosystem Assessment process

As an example of how the integrated ecosystem assessment process could be applied to the Baltic Sea ecosystems, WGIAB 2012 used some available information, indicators and models for the Central Baltic Sea food-web in the relevant steps of the IEA loop.

Step 1 – Scoping: As WGIAB has not undertaken any formal scoping process involving stakeholders the goals of the Baltic Sea Action Plan (BSAP) and the Marine Strategy Framework Directive (MSFD), resulting from political processes, were used for the exercise.

Step 2 – Indicator development: Among the indicators proposed to support the MSFD we identified the ones possible to address in the ecological models available to the meeting for management strategy evaluation (MSE) simulations. These were found within the MSFD descriptors on biodiversity (D1), commercial fish (D3) and food-webs (D4). The indicators identified were (using MSFD numbering): 1.2.1 Population biomasses of cod, sprat, herring, zooplankton biomass, phytoplankton biomass and mysid biomass; 3.2.1 Reproductive capacity of commercial stocks as spawning stock biomasses of cod, sprat, and herring; 4.2.1 Abundance of large fish (cod); 4.3.1 Trends (in biomass) of important groups, like clupeids and *Pseudocalanus*. In addition, we identified relevant ratios of functional groups as potential food-web indicators for D4 of the MSFD (cod:clupeids, clupeids:zooplankton, zooplankton:phytoplankton). However, as of yet, no specific targets of any of these indicators have been identified to relate to the overall goal of the MSFD, and we therefore focused on relative changes in the selected indicators.

Step 3 – Risk analysis: While the focus of the exercise was on management strategy evaluation (step 5) through model simulations, the results could also be used for a simplified risk analyses by e.g. comparing impacts on the different indicators, to identify highly sensitive ecosystem components.

Step 4 – Assessment of ecosystem status: The current status and historical development of the Central Baltic Sea system was assessed in the integrated trend analysis (see section 3).

Step 5 – Management strategy evaluation: We simulated the effect of fishing and nutrient load reductions, in the presence of further climate change, on the Central Baltic Sea food-web using four models (Wikström *et al.* submitted, Müller-Karulis & Pliksh unpublished, Lindegren *et al.* 2009, Tomczak *et al.* 2012), ranging from single-species to food-web models, and evaluated the effects of the different management scenarios on the indicators identified in Step 2. As this exercise is not a full MSE within an IEA, but merely intended as an example, we present only some management scenarios on a few ecosystem indicators, from a subset of the models, below.

4.4.1 Management Strategy Evaluation example

One aim with the exercise was to evaluate the combined effect of fisheries management and eutrophication mitigation actions. We tested three fishing scenarios: 1) Target fishing: constant fishing mortality reflecting the target of the current management plan for Eastern Baltic cod, and the proposed targets for a corresponding clupeid plan (0.3 cod, 0.4 sprat, 0.2 herring); 2) High fishing: constant fishing mortality at the 75^{th} percentile of the observed fishing mortalities during 1974–2010 (1.1 cod, 0.4 sprat, 0.3 herring); 3) Optimised fishing: time-varying fishing mortality, where the annual fishing mortality for each species is the economically optimal fishing mortality, as derived in an ecological-economic optimization model including cod, sprat, and herring (see section 4.6.5). In the Ecopath/Ecosim model (Tomczak *et al.* 2012) we also tested two different nutrient reduction scenarios: 1) BSAP: reflecting nutrient loads at target levels in the BSAP, and 2) Business as usual: reflecting continued high nutrient loading. All these scenarios were applied assuming continued climate change, reflected as the emission scenario A1B1. The nutrient reduction scenarios and the climate scenario were applied to the biogeochemical model BALTSEM, to simulate nutrient concentrations, oxygen concentrations and temperatures, which thereafter were used as forcing of the ecological models.

The MSE simulations in the Ecopath/Ecosim food-web model showed how the combined influence of fishing and nutrient loading is detrimental for the top piscivore cod (proposed as an MSFD indicator of both biodiversity, commercial fish stocks and foodweb structure; Figure 4.4.1.1). Only if fishing is kept at target levels and the nutrient loads are reduced to target levels of the BSAP will cod in the long run remain at, or above, the stock biomass observed in the most recent three decades (Figure 4.4.4.1). Simulations of the response of the other ecosystem indicators (i.e. species/groups) identified in Step 2 were also made and presented to the group.

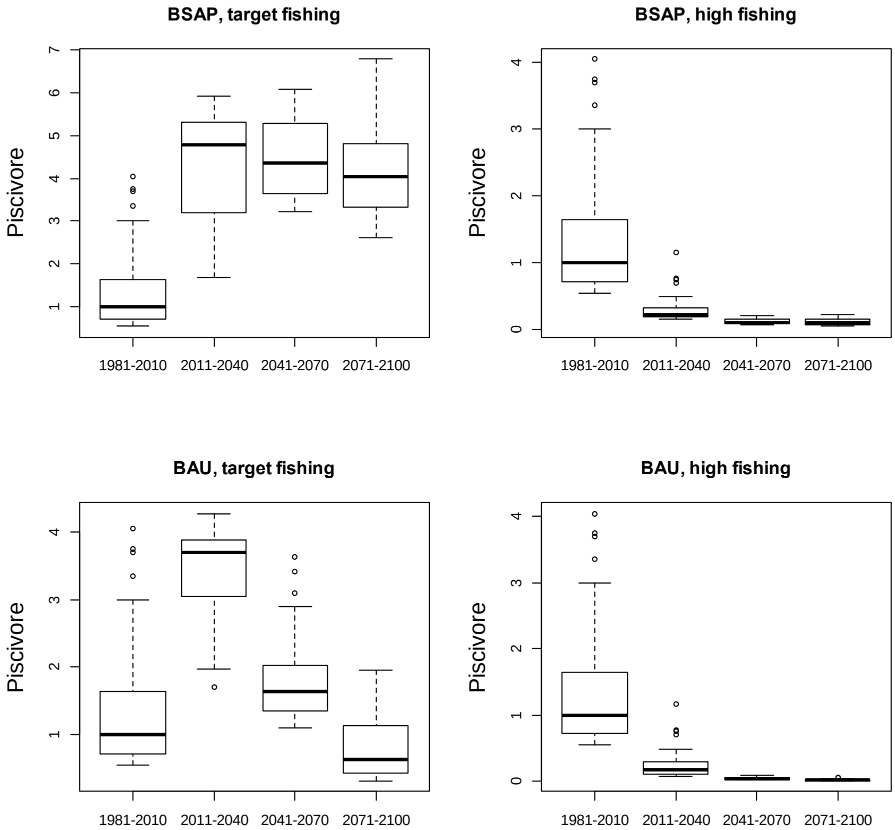

Figure 4.4.1.1. Simulated response of the Eastern Baltic cod to fishing and nutrient reduction scenarios from the Ecosim/Ecopath model of the Central Baltic Sea. The response is presented as median (and SDs) cod SSB over each 30-yr period from current to 2100, relative to the median of cod SSB 1981–2010.

In addition, we studied the response of groups of species providing certain ecosystem functions. The ecosystem functions and services provided by each of the 15 species/groups included in the Ecosim/Ecopath model were identified, based on the work presented by Andrea Rau (see section 4.6.2). The Ecosim/Ecopath model far from accounts for all species providing a certain service, and we can therefore not simulate the response of the service itself. However, it is possible to study how the species that provide the service (and are included in the model) respond to the different fishing and nutrient reduction scenarios. For example, the modelled species providing water purification will increase during this century, especially if nutrient loads remain high (Figure 4.4.1.2). This results from that the groups providing water purification in the model are mysids, *Pseudocalanus*, *Acartia* and mesozooplankton, which all increase in the model due to the increased phytoplankton biomass found under high nutrient loads.

Finally, for a marine MSE the effects of management scenarios on ecosystem indicators are not only relevant, but also the effect on fisheries yield, which is illustrated in Figure 4.4.1.3. Comparing the effects on piscivore (i.e. cod) catches with those on the cod stocks, shows that with target fishing (at F_{cod}=0.3) and target nutrient reductions, it is possible to maintain current catch levels while the Eastern Baltic cod stock rebuilds to levels well above those observed during the last 30 years (Figure 4.4.1.3). In contrast, if either nutrient loads or exploitation levels exceed targets, there will be no cod catches at the end of this century.

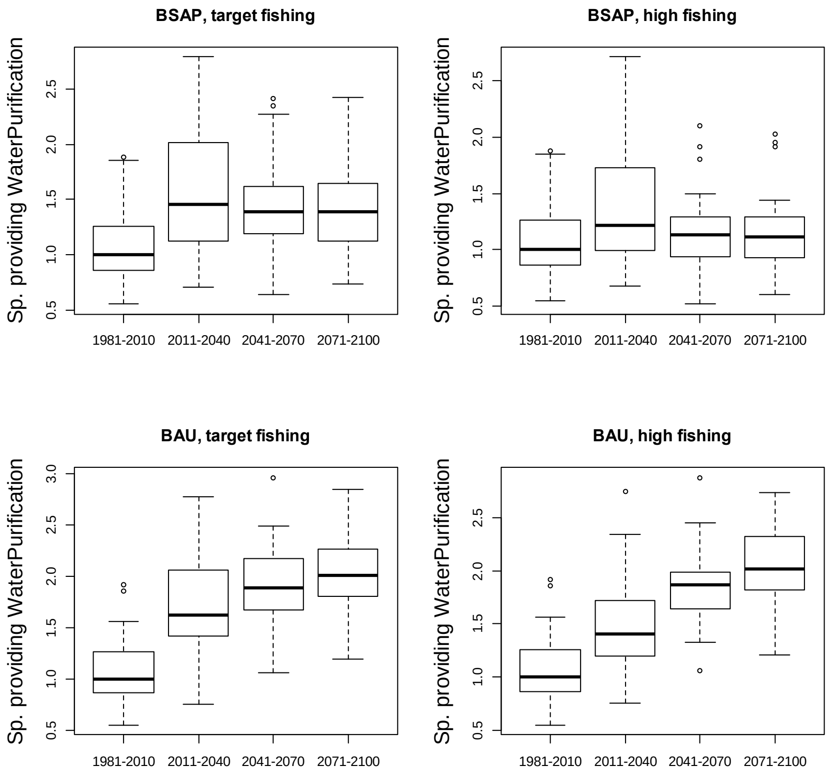

Figure 4.4.1.2. Simulated response of species providing the ecosystem function Water Purification to fishing and nutrient reduction scenarios from the Ecosim/Ecopath model of the Central Baltic Sea. The response is presented as median (and SDs) biomass of all species providing Water Purification over each 30-yr period from current to 2100, relative to the median biomass 1981–2010.

This exercise is not to be viewed as an actual MSE for the Central Baltic Sea, but as an example of its application within an IEA loop. In contrast to in many models used for MSE for fisheries, the models used here do not include any models on actual actions in response to decided management strategies (such as fleet dynamics), nor any management models including e.g. models of the assessment process itself. As such, this example can only give suggestions on the response of ecosystem indicators to fishing and nutrient reduction strategies should they be perfectly implemented (in a world without stochasticity).

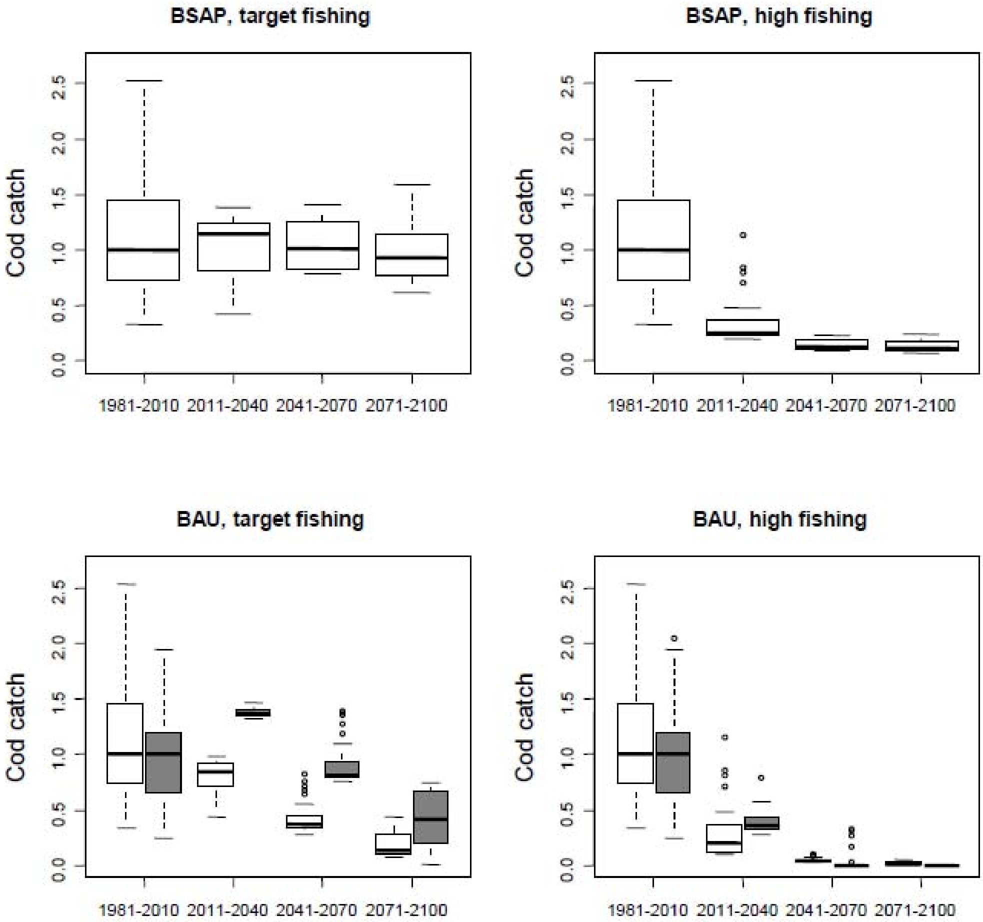

Figure 4.4.1.3. Simulated effects of fishing and nutrient reduction scenarios on catches of Eastern Baltic cod, from the Ecosim/Ecopath model (white bars; Tomczak *et al.* 2012) and the BALMAR model (grey bars; Lindegren *et al.* 2009) of the Central Baltic Sea. The response is presented as median (and SDs) catch biomass over each 30-yr period from current to 2100, relative to the median of 1981–2010.

4.5 Input to WGBFAS: Indicators of the recruitment environment for Eastern Baltic cod (ToR c)

Following discussions during the 2010 back-to-back meeting of WGIAB and the Baltic Sea Fisheries Assessment Working Group (WGBFAS; ICES 2010e), WGIAB has provided WGBFAS with information on environmental conditions relevant for recruitment of Eastern Baltic cod, to supplement the regular assessment of this stock (ICES 2011a). Potential indicators of the recruitment environment were identified by WGIAB (ICES 2011a) by fitting indicators proposed by Gårdmark *et al.* (2011) to the residuals of a stock-recruitment relationship (for details see ICES 2011a). The residuals were used for the indicator selection in order for these to only reflect the environmental effect on recruitment. Positive recruitment residuals from the SSB-R relationship correspond to greater recruitment than expected from SSB, and thus suggest beneficial environmental conditions for recruitment, and vice versa for negative recruitment residuals. The indicators of recruitment environment identified by fitting (individually) to the recruitment residuals were the reproductive volume (across all three basins) and the depth of the 11 psu isosaline in the Gotland basin (ICES 2011a). The values of these indicators corresponding to zero recruitment relationship (no environmental effect on recruitment) were derived from the fitted relationships (for year-classes 1966–2007), and used in the assessment of the environmental conditions for recruitment during 2008–2011. Although not found to be a significant indicator of recruitment conditions as measured on 2-year-olds, *Pseudocalanus* biomass was also been used, as it has shown to be preferred food for cod larvae (Möllmann *et al.* 2003).

The reproductive volume, the depth of the 11 psu isosaline and the *Pseudocalanus* biomass time-series updated during WGIAB 2012 were used to assess the environmental conditions for Eastern Baltic cod recruitment of year-classes 2008-2011. The 11 psu depth indicator from Gotland basin suggests that salinity conditions were favorable for year-classes 2008–2011, but the reproductive volume integrated across all three basins (Bornholm, Gdansk and Gotland) indicates poor abiotic conditions for recruitment, in terms of oxygenated saline water (Figure 4.5a). *Pseudocalanus* biomasses in the Gotland basin also suggest poor food conditions for larval cod of year-classes 2008–2011 (Figure 4.5c), although the poor relationship between this variable and cod recruitment measured as 2-year-olds should be noted (ICES 2011). As these indicators were derived by fitting them separately to the time-series on cod recruitment (ICES 2011a) they cannot be used to predict actual recruitment levels, but should be used to indicate different aspects of the environmental conditions for Eastern Baltic cod recruitment.

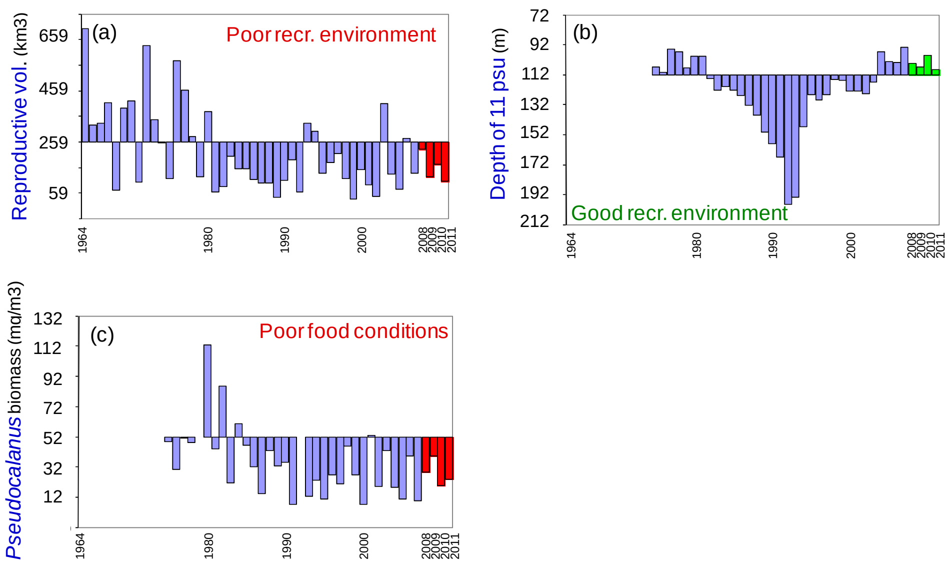

Figure 4.5. Time-series of two indicators of the abiotic recruitment environment for Eastern Baltic cod, (a) reproductive volume and (b) depth of the 11 psu isosaline, as well as of (c) biomass of *Pseudocalanus* acuspes, a key food resource for larval cod, all assembled by WGIAB 2012. Relationships between each variable and residuals from cod recruitment (backshifted) vs. cod SSB were derived by WGIAB (ICES 2011), using linear models of first or second-order polynomials for year-classes 1966–2007. Bars indicate the values relative to the reference value of each variable (derived from the fitted relationships on cod recruitment residuals, as the point where there is no environmental effect on recruitment). For the assessed year-classes 2008–2011 (corresponding to recruitment in 2010–2013), green bars indicate favorable environmental conditions, and red bars indicate poor conditions for cod recruitment.

In addition, a new method of presenting environmental data related to the development and recruitment of Baltic fish stocks proposed by Eero *et al.* (2012) was demonstrated to WGIAB 2012. The meeting supported the suggestion of using this during the stock assessments, and thereto suggested to use the following environmental variables in relation to recruitment: deepwater salinity in the Bornholm basin, reproductive volume and *Pseudocalanus* biomass for cod; spring temperature in mid-water layers and summer sea surface temperature in the Bornholm basin, and cladoceran biomass for sprat, summer sea surface temperature in the Bornholm basins and *Pseudocalanus* biomass for herring. The updated environmental and zooplankton data were provided to WGBFAS to support the stock assessments (ICES 2012c).

4.6 Abstracts of talks relating to the topic

4.6.1 A complex Baltic Food Web How to define functional roles – Who matters most?

Ute Jacob*, Maja Walther, Muriel Kroll, Andrea Rau, Christian Möllmann

Human induced habitat destruction, overexploitation and introduction of alien species cause marine species to go extinct at unprecedented rates from local to global scales. Effects of global change, such as rising air and sea temperature, an increase of extreme weather events, glacier/ice shield melting and sea level rise will add even more pressure on existing ecosystems and their species. Key parameters, (e.g. functional diversity, species composition, and presence/absence of sensitive species) are believed to reflect an ecological network's ability to resist alteration in response to pressures and disturbances such as species loss.

If the food web structure is relatively simple, we can analyse the roles of different species interactions in determining how environmental impacts translate into species loss. However, when ecosystems harbour species rich communities, which most ecosystems do, then the complex network of ecological interactions makes it a challenging task to see how species functional roles influence the consequences of environmental change and other disturbances. Here we use a preliminary food web of the Baltic Sea, the Baltic Propper food web to illustrate the role of species traits in marine food webs. Future work will address questions regarding species and species trait distribution as well as the role of species traits regarding network robustness

4.6.2 Ecosystem service provision in the Central Baltic food web

Andrea Rau

Ecosystem services are the benefits human societies obtain from natural ecosystems. According to the Millennium Ecosystem Assessment 2005 the following 4 categories can be distinguished (examples here with regard to marine systems):

- Provisioning services ensure the provision of basic material for human survival and a good life (food, genetic resources, pharmaceuticals, ornamental resources),
- Regulating services secure a stable environment to live in (erosion control, water purification and waste treatment, natural hazard regulation),
- Cultural services support cultural identity and development (employment, recreation and ecotourism, educational values, inspiration, aesthetic values, social relations, sense of place),
- Supporting services maintain all the other services (primary production, nutrient cycling, soil formation, provision of habitat, keystone species).

The latter has just an indirect beneficial value to humanity.

Recently nature is suffering from dramatic declines in biodiversity; in marine systems a reduction by 90% of large predatory species was discovered. Referring to the Central Baltic Sea the presented study examines if a loss of such large high trophic level species could automatically lead to a loss or degradation of certain ecosystem services, too. This could have relevant consequences for human well-being. In order to answer this question the contribution of single species to ecosystem service provision was analyzed by assigning services to each species of the community individually. Furthermore it was calculated which services are most susceptible to biodiversity loss and thus most likely to become degraded in near future. Ranking types are ranging from A to C with increasing sensibility to ecosystem changes.

It was discovered that especially large sized and high trophic level species, thus the most threatened species in marine systems, are very important in service provision: They provide highest numbers of services or extremely brittle ones, respectively. Services identified to be highly vulnerable to biodiversity loss (type C) are the provision of food, education, recreation and ecotourism as well as the provision of biochemicals, natural medicine and pharmaceuticals. But with ongoing nature degradation humanity will face simultaneous declines of further economically and socially valued ecosystem services as for instance the provision of genetic resources and employment opportunities. These are admittedly not assumed to be very sensitive because they depend on a variety of different species, thus should be relatively resilient to diversity loss; nevertheless each species has to be understood as important unique contributory factor, which loss could never be completely compensated (type B).

The results show how vulnerable and threatened some of the most esteemed ecosystem services are and should for that reason alone alert society and economy. But on top of that it is important to understand that every service is important and valuable to humanity, though most people are not aware of this fact. All biodiversity contributes to human well-being. Ecosystem services are just often common property not traded in markets and accordingly used unsustainably. A sustainable ecosystem-based management is needed to protect biodiversity in our natural ecosystems in order to ensure human welfare now and for future generations.

4.6.3 Climate change effects on the Baltic Sea food web under different nutrient load and fishery conditions

Susa Niiranen, Johanna Yletyinen, Martin Lindegren, Maciej Tomczak and Thorsten Blenckner

The Baltic Sea ecosystem in Northern Europe is expected to face some of the largest changes in regional climate to be seen this century. In the ECOSUPPORT-project, we for the first time in the Baltic Sea studied the ecosystem-wide effects of future climate change (-2100) using data from regionalized global General Circulation Models. Changes in the Baltic Sea food web were studied with an Ecopath with Ecosim food web model for the Baltic proper (BaltProWeb), driven by fishery, and environmental forcing from an ensemble of three biogeochemical models. The BaltProWeb model was run for two cod fishing, three nutrient load and two regional climate change (downscaled from the global IPCC scenarios A1B and A2) scenarios, in all combinations. Across the scenarios, the Baltic cod (*Gadus morhua*) stock was negatively affected by the combination of decreasing water salinity and deep-water oxygen concentration. When fishery was not adjusted to accommodate for the deteriorated reproduction conditions, a cod stock collapse was projected. Cod prey sprat (*Sprattus sprattus*), on the other hand, was in most scenarios favored by the increasing temperatures and decreasing predation pressure. The intermediate trophic level groups, such as zooplankton and clupeids, were largely affected by the interactions of multiple drivers, highlighting the importance of holistic ecosystem approaches when the possible climate change effects on marine ecosystems are evaluated. This study provides a valuable example on how information from global climate models can be used to project food web futures at regional scale. In addition, we address the potential usefulness of ensembles of higher trophic level models by comparing results between BaltProWeb and a multi-species model BALMAR.

4.6.4 LIMOD – Integrating fish into a biogeochemical model of the Gulf of Riga

Bärbel Müller-Karulis

LIMOD - development of a mechanistic model of the Gulf of Riga ecosystem in support of efficient national policy to ensure the protection of the Baltic Sea and to promote the sustainable use of its ecosystem – is an ERAF funded project on modelling the Gulf of Riga ecosystem that is currently implemented in Latvia. LIMOD is a four-year project initiated in 2010 that combines improving an existing biogeochemical model (Muller-Karulis and Aigars, 2011) with extensive field and laboratory work on processes crucial for the Gulf of Riga ecosystem. With respect to modelling, LIMOD couples a bioenergetics model of herring growth (Megrey *et al.* 2007) to the NPZD component of its biogeochemical model. Further, the existing biogeochemical box model is expanded to a one-dimensional model of nutrient, phytoplankton and zooplankton dynamics. Parallel fieldwork focuses on measuring primary production and nitrogen fixation as well as herring food composition in the Gulf of Riga. Special attention is given to transformations in the sediments, with measurements of denitrification and laboratory experiments on the response of sediment phosphorus fluxes to bottom water oxygen concentrations.

4.6.5 Ecological-economic optimization model

Ruediger Voss

A new approach in defining management objectives, taking into account the multiple ecological, economic or social needs has to be taken in order to achieve environmentally-compliant, sustainable fisheries, especially under anticipated climate change. However, convincing strategies for a transition to more sustainable fisheries also require an economic approach. There are two complementary reasons: First, economic incentives determine how resources are used in a market economy. Second, unlike ecology, economics provides sound methods to operationalize normative societal objectives such as welfare and sustainability. Accordingly, in recent time the scientific community, as well as advice-giving organizations have broadened their scope and explore the potential for coupling ecologic and economic considerations for integrated advice (e.g. Kellner *et al.*, 2010; ICES, 2009).

We examine the effects of multi-species advice, which is incorporating known species interactions as well as prognostic climate change scenarios. Including species interaction in an age-structured, ecological-economic optimization model results in trade-offs between the three fisheries involved (cod, herring and sprat): E.g. fluctuations in the size of the cod stock translate to considerable changes in natural mortality rates of sprat and juvenile herring. Therefore, management measures taken for one species will inevitably affect the other species and its related fisheries. Climate change will further effect stock productivity, e.g. via changes in the stock-recruitment relationship. These uncertainties and trade-offs should be communicated to stakeholders.

Using an ecological-economic multi-species model, we compute economically optimal harvesting scenarios for the combined fishery under climate change. The resulting F-vectors are recorded, to be later on used as input in ecosystem models and to be compared to alternative harvest control rules.

Ecological-economic modelling. We developed and applied a coupled three-species, age-structured ecological-economic model. The aim was to derive trajectories of (age-structured) fishing mortality under economically optimal management of the three species system, when accounting for species interaction and climate change. Our model is an extension of the single-species age-structured fishery model of Tahvonen (2009). We use the subscript $i \in \{C, S, H\}$ for the cod (subscript C), sprat (subscript S), or herring (subscript H) fishery. The present value of utility from fishing profits for the cod fishery is

$$V_C = \sum_{t=0}^{T} \rho^t \left\{ \left(\frac{1}{1-\eta} \sum_{s=1}^{8} p_C(s)\, w_C(s) \left(1-\exp(-F_C(t))\right) q_C(s)\, x_C(s,t) - c_C\, F_C(t) \right)^{1-\eta} \right\} \quad (1)$$

where ρ is the discount factor, T is the time horizon, and η is elasticity of intertemporal substitution of income for a representative fisherman. We use $x_C(s,t)$ to denote stock numbers of age s in year t, $p_C(s)$ for age-specific prices, $w_C(s)$ for age-specific weights, and $q_C(s)$ for age-specific relative catchabilities. Instantaneous fishing mortality is $F_C(t)$, and the cost function is of the Spence (1974)-type, where c_C is a cost parameter.

Sprat and herring $i = S, H$ are modelled as schooling fisheries (Tahvonen *et al.* 2012), with value functions

$$V_i = \sum_{t=0}^{T} \rho^t \left\{ \left(\frac{p_i - c_i}{1-\eta} \sum_{s=1}^{8} w_i(s) \left(1-\exp(-F_i(t))\right) q_i(s)\, x_i(s,t) \right)^{1-\eta} \right\} \quad (2)$$

The fishery manager's objective is to maximize a weighted sum of the present values of all three fisheries,

$$\max_{E_C(t), E_S(t), E_H(t)} \left\{ \lambda_C V_C + \lambda_S V_S + \lambda_H V_H \right\} \quad (3)$$

where we change the weights $\lambda_i > 0$ to model different distributional objectives.

The constraints to the optimization are $F_i(t) \geq 0$, the given initial stock numbers $x_i(s,0)$ for all three species in all age groups $s = 1, \ldots, 8$, and the age-structured multi-species population dynamics, which we describe in the following.

Spawning stock biomasses of species i in year t are given by

$$\mathrm{ssb}_i(t) = \sum_{s=1}^{8} w_i(s)\, \gamma_i(s)\, x_i(s,t) \quad (4)$$

where $\gamma_i(s)$ are used to denote age-specific maturities. Population dynamics of the stock of species i are given by

$$\begin{aligned} x_i(1,t+1) &= \varphi_i\, \mathrm{ssb}_i(t) \exp\left(-\beta_i\, \mathrm{ssb}_i(t)\right) \\ x_i(s,t+1) &= \alpha_i(s-1)\left(1-q_i(s)\left(1-\exp(-F_i(t))\right)\right) x_i(s-1,t) \qquad \text{for } s = 2,\ldots,7 \\ x_i(8,t+1) &= \alpha_i(7)\left(1-q_i(s)\left(1-\exp(-F_i(t))\right)\right) x_i(7,t) + \alpha_i(8)\left(1-q_i(8)\left(1-\exp(-F_i(t))\right)\right) x_i(8,t) \end{aligned} \quad (5)$$

For all three species we assume environmentally-sensitive stock-recruitment functions of the Ricker (1954) type. Recruitment success is modulated for sprat by surface temperature in May (Voss *et al.*, 2011), for herring by surface temperature in August (ICES, 2010) and for cod by size of the reproduction volume (RV). We use a linear trend in environmental variables derived from the climate scenario Echam A1B1.

Age-specific survival rates are:

$$\begin{aligned} \alpha_C(s) &= \exp(-M_C(s)) \\ \alpha_S(s,t) &= \exp\left(-M_{S1}(s) - M_{S2}(s)\,\mathrm{ssb}_C\right) \\ \alpha_H(s,t) &= \exp\left(-M_{H1}(s) - M_{H2}(s)\,\mathrm{ssb}_C\right) \end{aligned} \quad (6)$$

which are constant for cod. For sprat and herring, the age-specific survival rates depend on the cod's spawning stock biomass, capturing the effect of cod predation.

<u>Data and estimation of model parameters</u>. Age-specific weights $w_i(s)$ and maturities $\gamma_i(s)$ are the values for 2010 taken from the ICES (2011) assessment reports for the three stocks. Age-specific catchabilities were estimated based on mean age-specific fishing mortalities for the years 2008–2010 ($F_{BAR\ 08\text{-}10}$) as reported in ICES (2011) with φ_A=1 for the age class with highest mortality by normalization. In case φ_A=1 was reached for an age-class <8, it was kept constant for the older age-classes, as it is meant to mirror mesh-size selection. Parameters used in the economic-ecologic model are given in table 4.6.5.

In the multi-species context, natural mortalities for the herring and sprat age-classes are calculated in dependency of the size of the cod stock. Estimates are based on a stochastic multi-species model (SMS: Lewy and Vinther, 2004).

For age-specific prices, we use the European reference prices, which are the lowest prices at which imports of cod of specific weight classes, sprat or herring into the European Union are allowed (EC 1999, 2009). The cost parameter for cod is $c_C = 92.3$ million Euros (Froese and Quaas 2011). To estimate prices and cost parameters for sprat, we use price data and data on variable fishing cost for the Swedish (years 2002–2008) and Polish (years 2005–2008) pelagic trawler and seiner fleets from STECF (2011), which leads to $p_S = 0.144$ euros/kg for the price and $c_S = 0.106$ euros/kg for the cost parameter. Similarly, for herring, we use STECF (2011) data for the Danish, Estonian, Finnish, Polish and Swedish trawl and seiner fleets (years 2002–2008), which gives estimates $p_H = 0.251$ euros/kg for the price and $c_H = 0.151$ euros/kg for the cost parameter. For the elasticity of intertemporal substitution of income for a representative fisherman we assume $\eta = 0.25$.

Table 4.6.5. Parameters used in the economic-ecologic model. Values for maturity, weight, catchability, survival rate as well as numbers at age are taken from ICES standard assessment in 2011 for the latest year, i.e. 2010 (ICES, 2011).

	Maturity			Weight			Catchability		
Age-class	C	H	S	C	H	S	C	H	S
1	0	0	0.17	0.08	0.012	0.0052	0	0.17	0.25
2	0.13	0.7	0.93	0.587	0.018	0.008	0.08	0.33	0.59
3	0.36	0.9	1	0.698	0.026	0.0099	0.43	0.56	0.75
4	0.83	1	1	0.85	0.032	0.0107	0.83	0.74	0.81
5	0.94	1	1	1.022	0.033	0.011	1	0.81	0.83
6	0.96	1	1	1.258	0.039	0.0112	1	0.95	1
7	0.96	1	1	2.218	0.045	0.0108	1	1	1
8	0.98	1	1	3.792	0.045	0.0114	1	1	1

Numerical optimization. In order to determine the optimal management, we numerically solved the optimization problem. For this, the dynamic optimization was performed using the interior-point algorithm of the Knitro (version 6.0) optimization software with Matlab (R2009b) and AMPL (A Modeling Language for Mathematical Programming, AMPL Optimization LLC, Albuquerque, USA).

Optimal time path. Results of the coupled three species model under climate change are illustrated in figure 4.6.5. In the first years of the simulation period, the cod stock is rebuilt to SSB levels of approximately 700 000 tons. This is achieved by low but increasing F values in the transition period. After the stock was rebuilt, F values of ca. 0.32 are calculated for the oldest age-class. Over time, optimal F values are slightly decreasing due to the negative effect of anticipated climate change (decreasing RV) on cod recruitment. However, as the effect of changes in RV is not very pronounced in the S/R model used here, the overall decrease in F is only marginal. Profits from the cod fishery are most important and stay rather stable until the end of the simulation. The herring stock is continuously built up over time. Accordingly, increasing F values over time are calculated accompanied by rising profits. For the sprat fishery, extremely high optimal F values are calculated. The combination of a heavy fishery and an increasing cod stock, diminish the stock to SSB values of <300 000 tons in a few years. Stock size, fishing mortality as well as profits stay in a quasi stable state for ca. 30 years. However, after that period, our economic optimization model predicts a economically-optimal extinction of the stock.

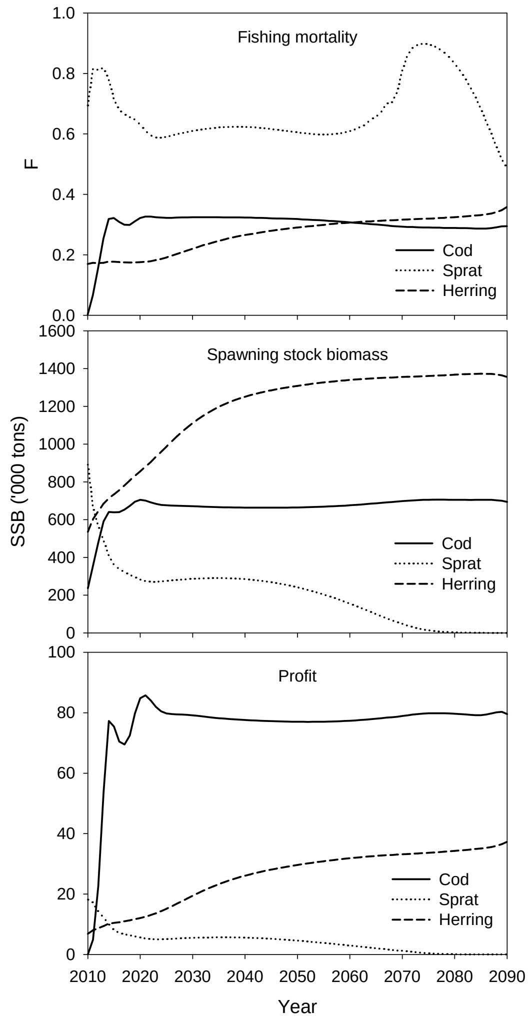

Figure 4.6.5. Model output from a three species, coupled economic optimization: fishing mortality (F, oldest age-class), SSB as well as yearly profits for the cod, sprat and herring fishery.

5 The ecosystem overview

The inclusion of ecosystem overviews as part of the regular reporting of WGIAB, as requested by ICES, was discussed during the meeting. Some preliminary ideas, as introduced by Han Lindeboom, suggested that the overview could include a graphical display of the main components of the ecosystem, with additional graphics and text explaining ongoing main trends in the ecosystem, including drivers and response variables. The graphics could potentially reflect trends in variables corresponding to indicators within each of the relevant MSFD descriptors, or in variables of importance for fisheries advice.

On a general term, the group was positive to providing condensed information on the state of the Baltic Sea ecosystem, as this would potentially benefit interactions among ICES groups and the development of integrated advice. However, a number of questions were identified as central to clarify before finally shaping the overviews.

Given the complexity of most marine food-webs, and specifically the geographical differences among Baltic Sea sub-regions, the group identified a clear risk that aiming for a short and generalised representation of ecosystem state would miss purpose; by being neither detailed enough to be scientifically useful nor popular enough to be understandable by the general audience.

This issue was suggested to be overcome by focusing the ecosystem overviews on specific management questions, which could be agreed on in cooperation with potential users on a continuous basis (for an example of trends in environmental conditions relevant for recruitment of Eastern Baltic cod - see section 4.5, or other assessed stocks for use within WGBFAS). As far as MSFD indicators are concerned, the ecosystem overviews should be shaped in coordination with HELCOM, who is producing regional reports, fact sheets, for selected MSFD-related indicators in the Baltic Sea.

On the other hand, if the target reader is the general audience, aiming for an "all-purpose product", this should preferably be finalised by an expert on public communication, not by the expert group members in order to successfully meet its purpose (see www.psp.wa.gov for an example of a clickable web-page showing the ecosystem state of the U.S. Puget Sound). However, a lot of ecosystem information of relevance for such overviews has been provided by WGIAB over the years. Conceptual as well as quantitative ecosystem models are central for the work of the group (see for example ICES WGIAB 2008, se figure 5.1 for one example), and advancing integrated ecosystem assessment and management is a core task of the group (See also section 3.2 for the most recent update on data collation activities, and section 4 for an update on activities related to integrated ecosystem assessments).

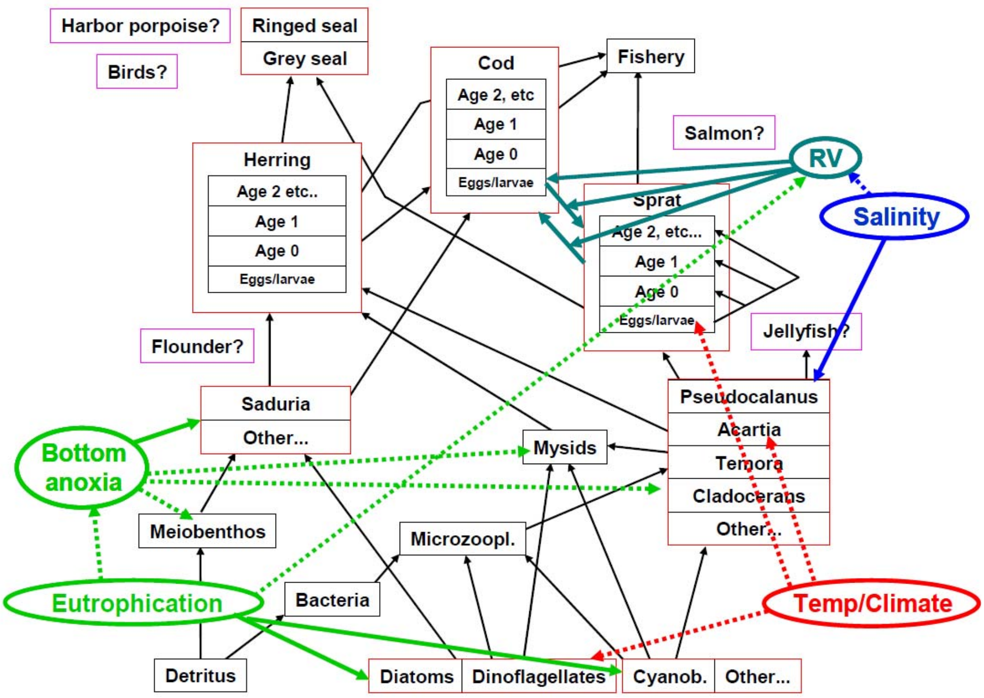

Figure 5.1. Conceptual model based on the EwW NEST food web model for the central Baltic Sea (ICES SD 25–29; 32, excl Gulf of Riga), [Olle Hjerne, Stokholm university]; (ICES 2008a).

6 Future work of the group

6.1 General scope

The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) was set up as a forum to promote and develop advice for adaptive, ecosystem-based management efforts for the Baltic Sea. In the coming years, WGIAB will maintain and increase this cross-sectorial aim, with a focus on increasing ecosystem understanding and providing a scientific basis for informed ecosystem-based management decisions. The results of the group should be useful for developing management advice processes and facilitate interaction among different management sectors.

6.2 Multi-annual terms of reference

At its meeting in 2012, WGIAB decided to adopt implement multiannual terms of references, starting in 2013. Status reports will be provided in the intermediate years, with more comprehensive results reported by the end of the multiannual cycle.

For the years 2013–2015, the group assigned itself the following tasks:

a) **Increase understanding of Baltic Sea ecosystem structure and functioning**, with a focus on species interactions and trends over different temporal and spatial scales, and the identification of key species and processes for maintaining functioning ecosystems and sustainable use of these;

b) **Provide scientific support to develop integrated advice for fisheries management** by data and models;

c) **Develop scientific tools for integrated ecosystem assessments**, and apply these within case studies investigating trade-offs between different management goals.

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Annex 2: Agenda

ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea [WGIAB]; Stockholm, Sweden, 26-30 March 2012

AGENDA

Monday 26/03/12

	Welcome session (WGIAB & WGINOSE)
1300-1310	Words of welcome and practical information (Maciej Tomczak)
1310-1330	Presentation of Stockholm Resilience Centre and Baltic Nest Institute (Carl Folke, Christoph Humborg)
1330 – 1340	Primary objectives and ToRs of WGIAB, presentation of participants (Maciej Tomczak, Lena Bergström & Martin Lindegren)
1340 – 1350	Primary objectives and ToRs of WGINOSE, presentation of participants (Christian Möllmann & Gerd Kraus)
1400 – 1500	The U.S. Approach to Integrated Ecosystem Assessment (Phil Levin)
1530 – 1600	The HELCOM Coreset project (Samuli Korpinen)
1600 – 1630	Ecosystem overviews (Han Lindeboom)
1630 – 1700	*Coffee & Tea*
	WGIAB Introductory session (Seminar room, Starlet)
1700 - 1730	Introduction to subgroups (Assigned subgroup reporters). The group activities will be together with corresponding WGINOSE groups where considered relevant by members of the group.

Suggested teams:

Group 1 Integrated Trend Analyses

- Continued Integrated Status and Trend assessments: Coastal ecosystem analyses and offshore updates [ToR a]
- Application of early-warning methods on key indicators of selected subsystems [ToR a]
- Temporal and spatial functional relationships in food webs [ToR d]

Group 2 Promoting Integrated Ecosystem Advice

- Promotion of ecosystem-based advice for Baltic Fish stocks and Further developing of the Biological Ensemble Modelling Approach [ToR b, c]
- Further developing of the Integrated Ecosystem Assessment cycle [ToR e]

1730 – 1830	Parallel planning in subgroups (Seminar room, Starlet; Seminar room SRC)
1830 – 1900	**WGIAB Plenary: Summary of the day and revision (if needed) of agenda (Seminar room, Starlet)**

Tuesday 27/03/12

0900 – 1030	Parallel work in subgroups (Seminar room, Starlet; Seminar room SRC)
1030 – 1100	*Coffee & Tea*

1100 – 1300 **WGIAB plenary: A complex Baltic foodweb and its ecosystem services**

(Ute Jacob & Andrea Rau) **(Seminar room, Starlet)**

Parallel work in subgroups (Seminar room, Starlet; Seminar room SRC)

1300 – 1400 *Lunch*

1400 – 1530 **Plenary: Modelling approaches supporting the Integrated Ecosystem Assessment Framework (WGIAB & WGINOSE) (Seminar room, Starlet)**

- North Sea ATLANTIS model progress (Myron Peck)
- ECOSUPPORT progress (Susa Niiranen)
- ECOSCENARIOS (Thorsten Blenckner)
- How to use ensemble modeling for Integrated Ecosystem Advice? (Anna Gårdmark)

1530 – 1600 *Coffee & Tea*

1600 – 1700 Parallel work in subgroups (Seminar room, Starlet; Seminar room SRC)

1700 – 1800 **Modelling approaches to be continued incl. discussion in relation to IEA**

- LIMOD - Integrating fish into a biogeochemical model of the Gulf of Riga (Bärbel Müller-Karulis, Ivars Putnis). **(Seminar room, Starlet)**

Wednesday 28/03/12

0900 – 1040 **Plenary: Decision support tools (WGIAB & WGINOSE)**

Presentations by WGINOSE participants

- Evaluation of IEA approaches by strengths and weaknesses, as reported by WGECO (Dave Reid)

- The Health of ecosystems: biodiversity and ecosystem monitoring, the role of the survey programme (Dave Reid)

- An approach for integrating the indicator based assessment of commercially exploited fish species (Nikolaus Probst)

- Use of Bayesian networks in environmental modelling (Vanessa Stelzen-müller)

- Some ideas about how to aggregate long-term model simulations (Ulrich Callies)

1040 – 1100 *Coffee & Tea*

1100 – 1300 Parallel work in subgroups (Seminar room, Starlet; Seminar room SRC)

1300 – 1400 *Lunch*

1400 – 1530	Parallel work in subgroups (Seminar room, Starlet; Seminar room SRC)
1530 – 1600	*Coffee & Tea*
1600 – 1800	**Plenary: Presentation and discussion of results from the ITA Group (WGIAB & WGINOSE) (Seminar room, Starlet)**

Thursday 29/03/12

0900– 1045	**Plenary:** **IEA, integrated advice, and MSFD-related issues (WGIAB & WGINOSE) (Seminar room, Starlet)** Update on ICES and MSFD related issues (Yvonne Walther) Plenary discussion of future IEA work on MSFD-related issues and implications for multi-annual TORs (All)
1045 – 1100	*Coffee & Tea*
1100 – 1300	Parallel work in subgroups (Seminar room, Starlet; Seminar room SRC)
1300 – 1400	*Lunch*
1400 – 1545	**Plenary: Presentation and discussion of results from the IEA Group (WGIAB) (Seminar room, Starlet)**
1545 – 1600	*Coffee & Tea*
1600 – 1800	Parallel work in subgroups (Seminar room, Starlet; Seminar room SRC)

Friday 30/03/12

0900 – 1045	**Final Session (WGIAB) (Seminar room, Starlet)** • Wrap-up of subgroup work (All) • Data contribution to WGBFAS (Anna Gårdmark) • State of the report • Discussion on next meeting (multi-annual ToRs, venue, focus) • Discussion on long-term strategy of WGIAB and WGINOSE
1045 – 1100	Coffee & Tea
1100 – 1300	Continued discussion on long-term strategy **Report writing**
1300	Closure of the meeting

Annex 3: WGIAB draft resolution for 2013–2015

The **ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea** (WGIAB), chaired by Maciej Tomczak, Sweden; Lena Bergström, Sweden, and Martin Lindegren, Denmark, will meet in Padova, Italy, 8–12 April 2013 to:

a) Continue analyses of Baltic Sea food-webs, in order to increase understanding of ecosystem structure and functioning, with a focus on species interactions and trends over different temporal and spatial scales, and the identification of key species and processes for maintaining sustainable ecosystems.

b) Support development of a framework for integrated advice for fisheries management, by data exchange, model evaluation and scientific interaction with the Baltic Sea assessment working groups.

c) Further develop the integrated ecosystem assessment cycle, and apply case studies to investigate trade-offs between different management objectives, including effects on ecosystem services and effects at different spatial and temporal scales.

WGIAB will report on the activities of 2013 (the first year) by 20 May 2013 (via SSGRSP) for the attention of SCICOM.

Supporting Information

Priority	WGIAB aims to conduct and further develop Integrated Ecosystem Assessments cycles for the different subsystems of the Baltic Sea, as a step towards implementing the ecosystem approach in the Baltic Sea.
Scientific justification	Key to the implementation of an ecosystem approach to the management of marine resources and environmental quality is the development of an Integrated Ecosystem Assessment (IEA). An IEA considers the physical, chemical and biological environment, including all trophic levels and biological diversity as well as socio-economic factors and treats fish and fisheries as an integral part of the environment. The work of the group includes (i) a further development of analyses of ecosystem structure and function for the different subsystems of the Baltic, (ii) contributions to the HELCOM assessment system, (iii) implementing the use of environmental information and ecosystem modelling in the assessment framework and (iv) developing adaptive management strategies. The working group serves as a counterpart to the fish stock assessment working groups and provides these with information on the biotic and abiotic compartments of the ecosystems. A key task of the working group is to serve as a communication and organisation platform between the different science organisations/groups involved in the area. Primarily this applies to the cooperation between ICES and HELCOM, but will also include cooperation with EU and BONUS projects. The working group is thus key to implementing the ecosystem approach to the Baltic Sea. Further a close cooperation with IEA activities in other areas (e.g. WGNARS, WGEAWESS, WGINOSE) is envisaged to coordinate the ICES IEA activities within SSGRSP.
Justification of 2013 venue (in a non-ICES Member Country)	The meeting in 2013 will be hosted by dr Alberto Barausse at LASA - Environmental Systems Analysis Lab, Dept. Ind. Eng. (DII), University of Padova, Italy. The Venue is expected to benefit the EG by strengthening existing scientific cooperation between LASA and EG members in the further development of methods and models for an Integrated Ecosystem Assessment framework, also enabling evaluation of the developing ICES IEA framework on a Mediterranean data set, as well as cross-comparisons between the Baltic Sea and Adriatic Sea ecosystems.
Resource	Assistance of the Secretariat in maintaining and exchanging information and

requirements	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 20-30 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	Relevant to the work of ACOM and SCICOM.
Linkages to other committees or groups	SSGSRP, all SG/WGs related to Baltic Sea issues, WGINOSE, WGNARS, WGEAWESS, SGIMM.
Linkages to other organizations	HELCOM, BONUS, EU DGs.

Annex 4: Integrated Trend and Status Assessments

1. Bothnian Sea (BoS)

1.1. Area description

The Bothnian Sea is a relative shallow basin of ca. 70 000 km^2 separated by sills from the Baltic Proper in the south and the Bothnian Bay in the north. Salinity, ranging from ca. 3–5 psu at the surface to 7 psu in bottom waters, is kept low by large amounts of freshwater outflow from rivers, but inflows of saline water across the southern sill allow persistence of marine zooplankton (e.g. *Pseudocalanus acuspes*) and marine fish like herring (*Clupea harengus*).

1.2. Variable descriptions

Time-series of 25 key biotic and abiotic variables were assembled from the offshore Bothnian Sea for the period 1979–2010. The 16 biotic variables include fish, macro-zoobenthos, mesozooplankton, and phytoplankton species/groups. The 9 abiotic and fishery related variables include temperature, salinity, oxygen concentration, nutrient concentration and nutrient loads, as well as estimated fishing mortality on herring, which is the major fishery. Variables are either assembled as annual averages, or averages within particular seasons. Missing values (indicated by white colouring in Figure BoS-1) were replaced by 4-yr running averages for the PCAs, and all biotic variables were ln(x+1)-transformed prior to ordination and cluster analyses.

During the three decades studied, water temperature has shown a long-term increase and salinity has decreased (Figure BoS-2). These changes have affected the composition of e.g. the zooplankton community, in which marine zooplankton such as *Pseudocalanus* decreased whereas limnic cladocerans (such as *Bosmina*) and copepods (*Limnocalanus*) are increasing (Figure BoS-3). Since these limnic mesozooplankton are major prey species of herring in the Bothnian Sea, the herring stock has more than tripled in response (Figure BoS-4) as the stock is not heavily exploited (Figure BoS-5). There are no clear long-term trends in nitrogen concentration or load, whereas the offshore phosphorous concentration has been increasing despite a long-term decrease in the total phosphorous loads from (Swedish) rivers (Figure BoS-6). However, there are no clear eutrophication impacts seen in e.g. phytoplankton data (Figure BoS-7).

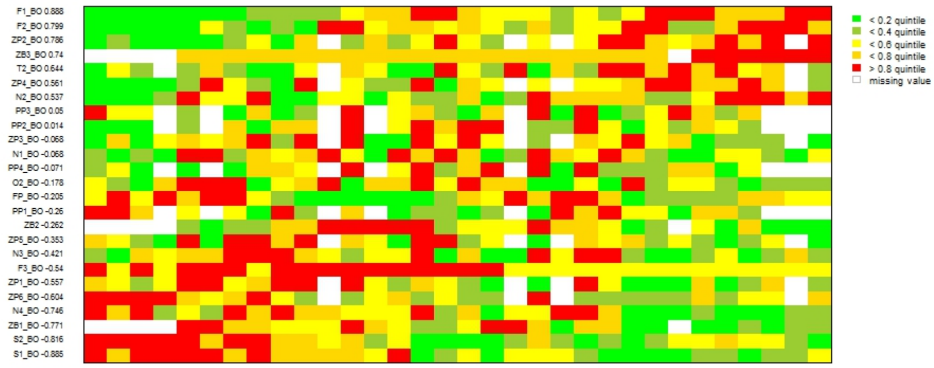

Figure BoS-1. Traffic-light plot of the temporal development of Bothnian Sea time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (values given after variable code). Variable codes refer to trophic level or type of abiotic variable: F-fish, ZB-zoobenthos, ZP-zooplankton, PP-phytoplankton, T-temperature, S-salinity, O2-oxygen, N-nutrients and FP-fishing.

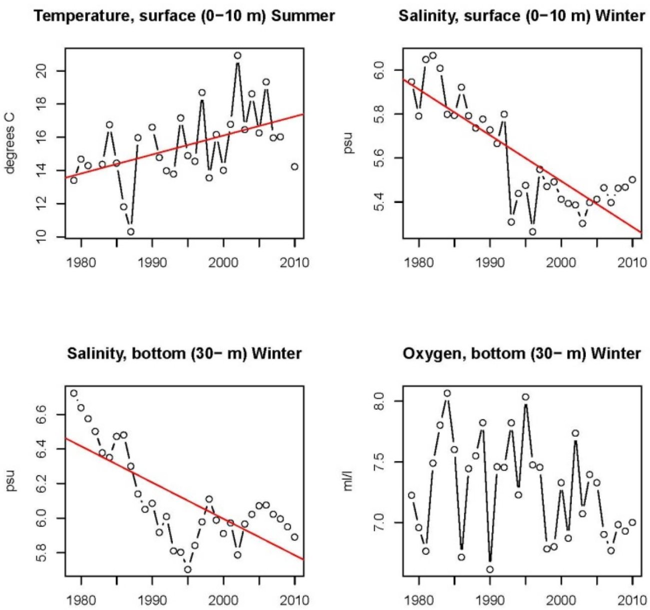

Figure BoS-2. Time-series of hydrological variables assembled for the Bothnian Sea. Full lines indicate significant trend during 1979–2010.

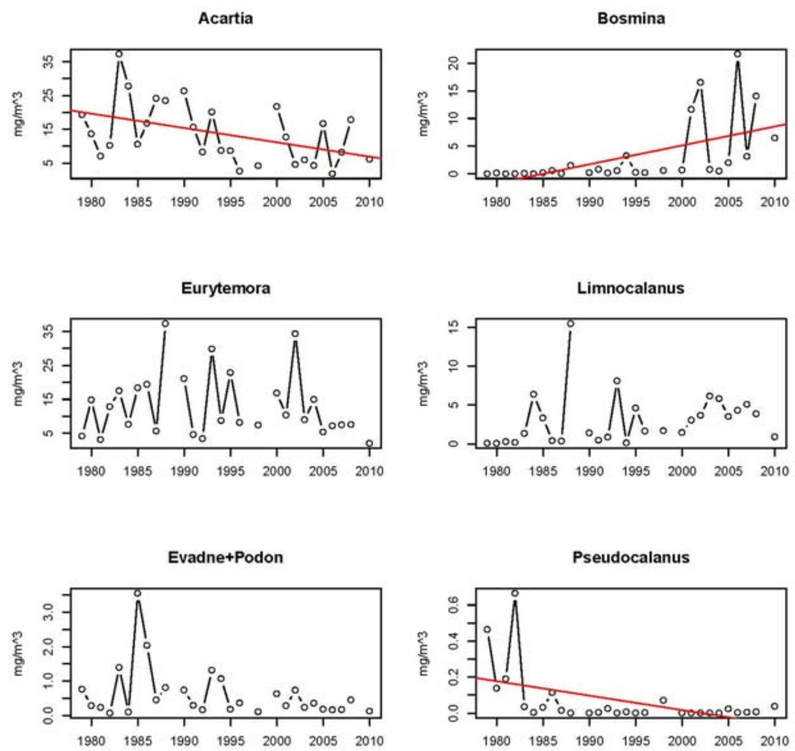

Figure BoS-3. Time-series of zooplankton variables in the Bothnian Sea. Full lines indicate significant trend during 1979–2010.

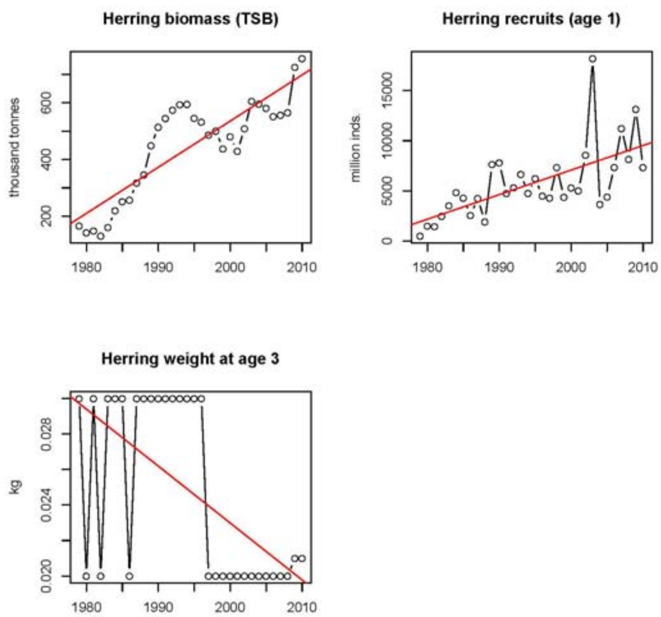

Figure BoS-4. Time-series of fish variables in the Bothnian Sea. Full lines indicate significant trend during 1979–2010.

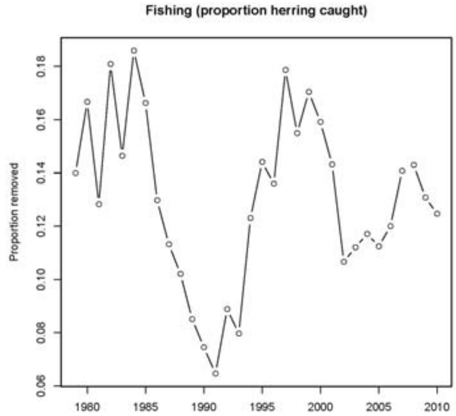

Figure BoS-5. Time-series of fishing mortality (in terms of proportion of individuals ages 3–7 removed) in herring in the Bothnian Sea.

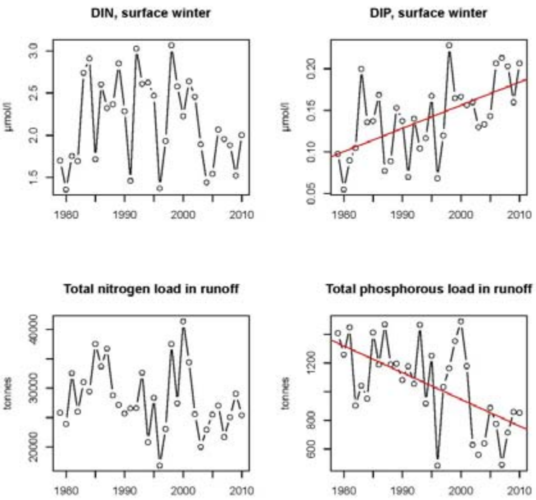

Figure BoS-6. Time-series of nutrient variables assembled for the Bothnian Sea. Full lines indicate significant trend during 1979–2010.

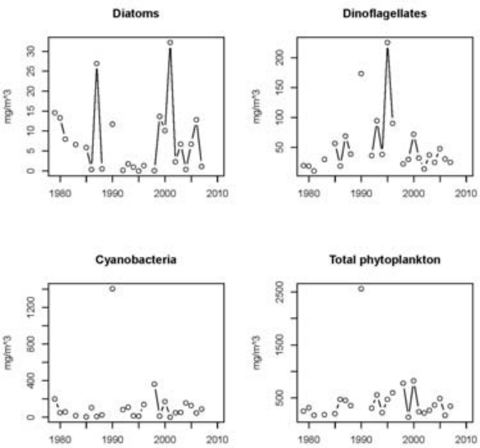

Figure BoS-7. Time-series of phytoplankton variables in the Bothnian Sea.

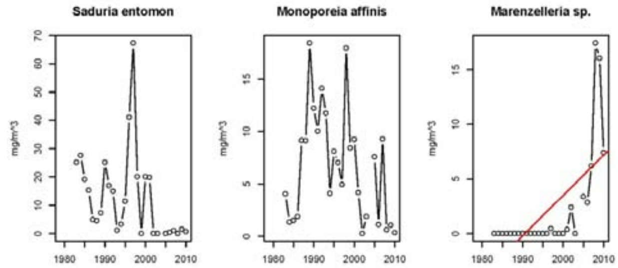

Figure BoS-8. Time-series of zoobenthic variables in the Bothnian Sea. Full lines indicate significant trend during 1979–2010.

1.3. Results of integrated trend analyses

The PCA on key biotic and abiotic variables 1979–2010 shows a great change in the composition of the Bothnian Sea ecosystem, although the first two axes of the PCA on all variables explain only 46% of the variation (Figure BoS-9). In the beginning of the period Bothnian Sea was more saline, with lower phosphorous concentration, more marine zooplankton and less herring, whereas it is currently warmer, less saline, with higher concentrations of phosphorous, and more abundant limnic mesozooplankton and many, but small, herring (Figure BoS-10). Chronological clustering on all variables shows that there was a shift in the late 1980s, and again early 2000s, to a significantly different composition (Figure BoS-9).

Separate ordinations of the biotic variables and the potential drivers (abiotic and fishing variables) show that the food-web has shifted to a significantly different composition (Figure BoS-11; non-overlapping chronological clusters) whereas the combined environmental conditions are not distinctly different now compared to 30 years ago (Figure BoS-13; overlapping clusters found), despite the warming and desalinating trends observed in the univariate analysis, as found also as the main trends explaining the first axis in the abiotic PCA, Figure BoS-14). The overall changes in the food-web composition is mainly explained by declines in marine and cold-water zooplankton and zoobenthic species being replaced by limnic zooplankton, leading to increases in herring biomass (Figure BoS-12). In the beginning of the period, biomasses of the marine copepod *Pseudocalanus* (ZP6) and of diatoms (PP1) were high, together with high abundance of another marine copepod, *Acartia* (ZP1), and the ice age-relict isopod *Saduria* (ZB1). In contrast, the most recent decade is characterised by high biomasses of herring and their prey, the limnic zooplankton *Bosmina* (ZP2) and *Limnocalanus* (ZP4), as well as the invasive polychaete *Marenzelleria* (ZP3) (Figure BoS-12). The ordination of biotic variables and potential drivers combined shows how this compositional change of the food web is correlated with the warming and the decrease in salinity (Figure BoS-10).

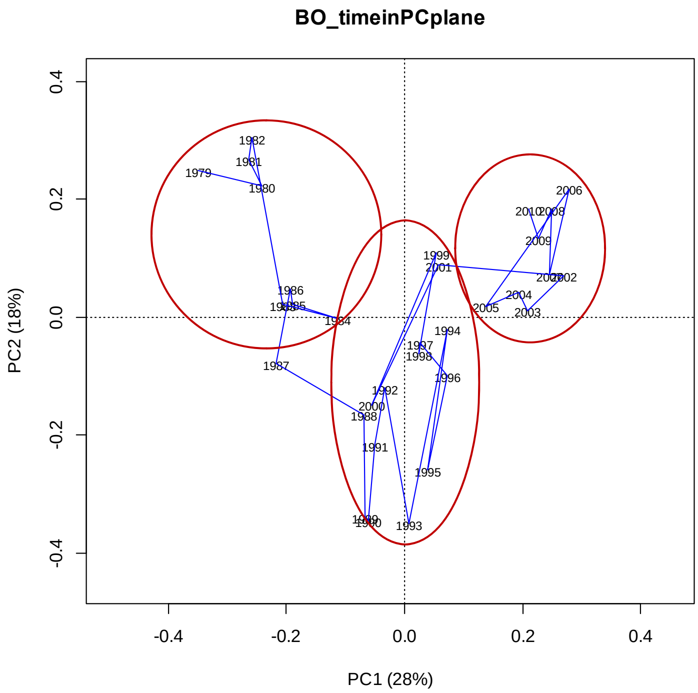

Figure BoS-9. Results of the standardized principal component analysis using all 25 biotic and abiotic variables assembled for the Bothnian Sea showing the time trajectory on the first factorial plane (explained variance given in brackets). Circles indicate significantly (alpha=0.01) different clusters identified in a chronological cluster analysis.

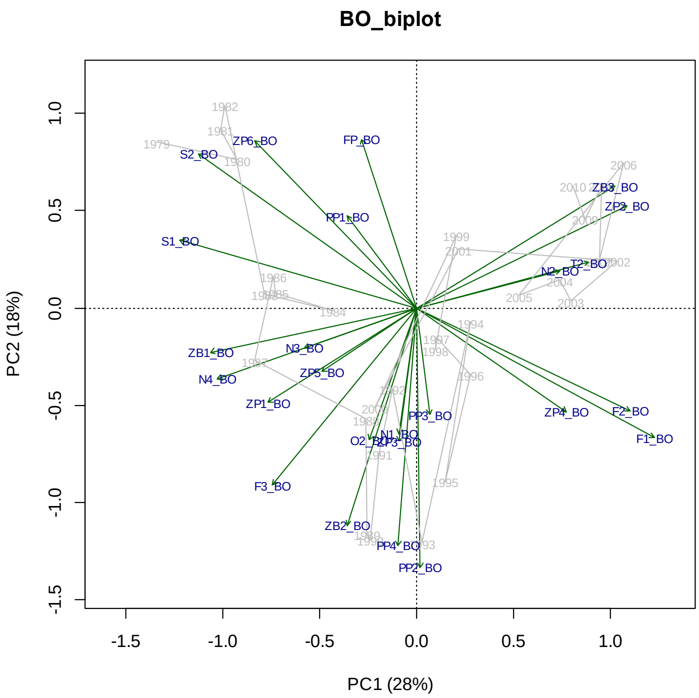

Figure BoS-10. Results of the standardized principal component analysis using all 25 biotic and abiotic variables assembled for the Bothnian Sea showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey), with explained variance in brackets.

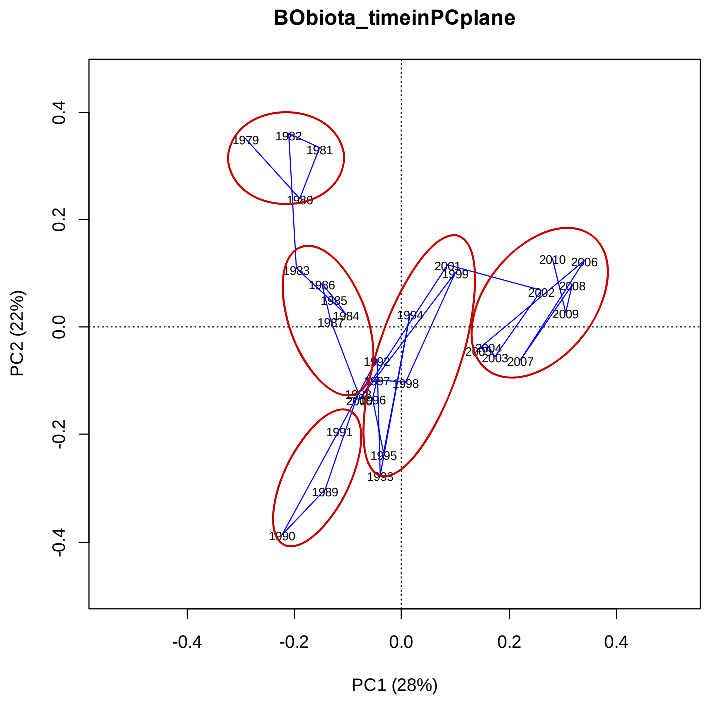

Figure BoS-11. Results of the standardized principal component analysis using all 16 biotic variables assembled for the Bothnian Sea showing the time trajectory on the first factorial plane (explained variance given in brackets). Circles indicate significantly (alpha=0.05) different clusters identified in a chronological cluster analysis.

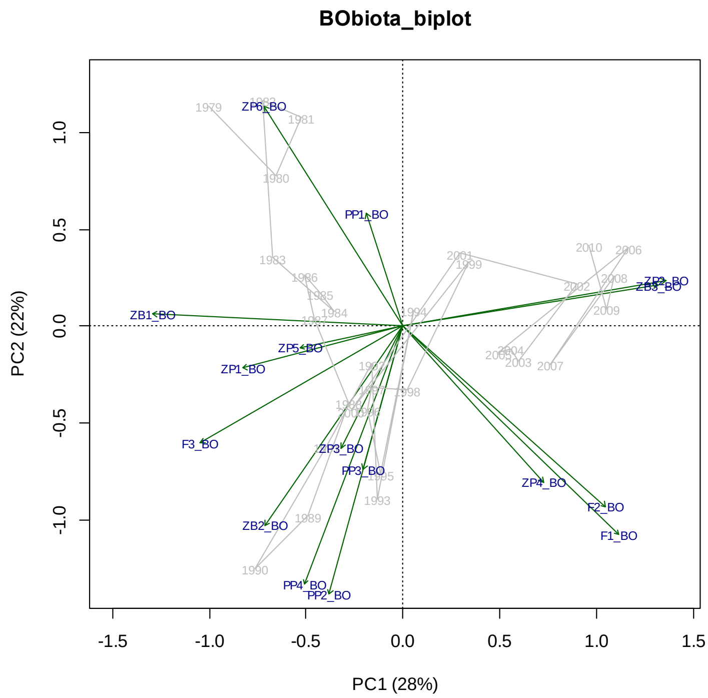

Figure BoS-12 PCAbiota2. Results of the standardized principal component analysis using all 16 biotic variables assembled for the Bothnian Sea showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey), with explained variance given in brackets.

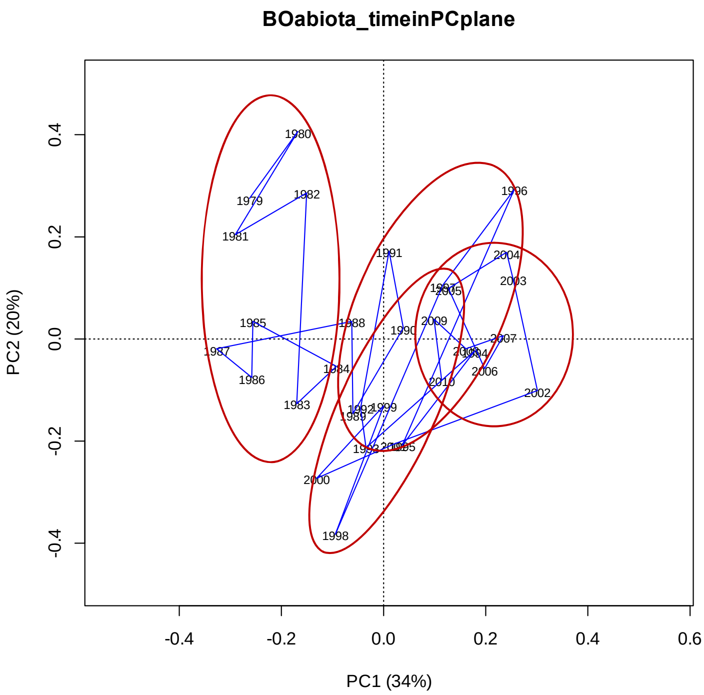

Figure BoS-13. Results of the standardized principal component analysis using the 8 abiotic variables and 1 fishery related variable assembled for the Bothnian Sea showing the time trajectory on the first factorial plane (explained variance given in brackets). Circles indicate significantly (alpha=0.01) different clusters identified in a chronological cluster analysis.

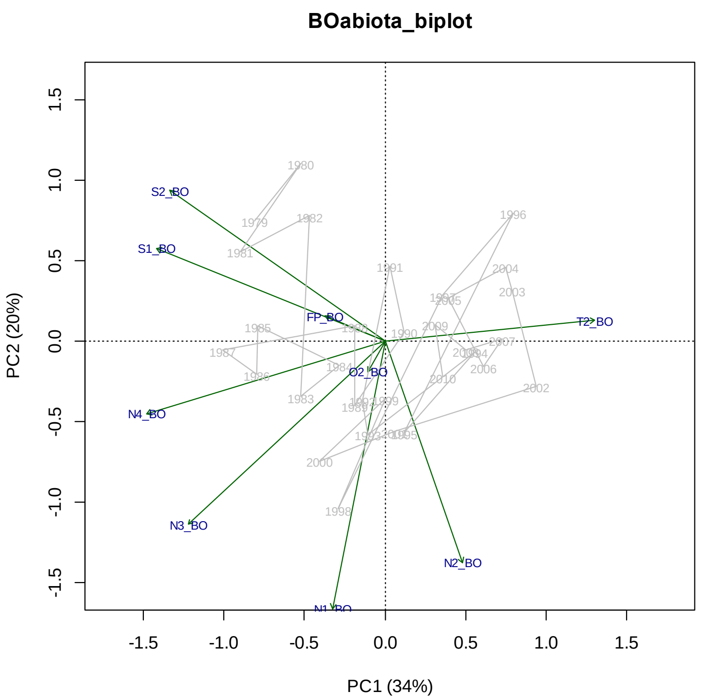

Figure BoS-14. Results of the standardized principal component analysis using the 8 abiotic variables and 1 fishery related variable assembled for Bothnian Sea showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey), with explained variance given in brackets.

2. The Central Baltic Sea (CBS)

To detect major ecosystem changes we performed a principal component analysis on time-series characterizing climate, hydrography, nutrients, phytoplankton, zooplankton, fish and fisheries. We then use a traffic light plot to illustrate major ecosystem changes. In a traffic light plot variables are colour-coded according to quintiles and plotted in the order of their loadings along the first principal component axis. Further, biplots show the relationships between individual variables with the first two principal component axis and time-trajectories of ecosystem change are illustrated by plotting year scores within the PC1-PC2 plane. Finally, regime shifts in the principal components were identified by sequential regime shift analysis (STARS, Rodionov, 2004, Rodionov, 2006). For a detailed description of data treatment and statistical methods, see Diekmann & Möllmann (2010).

2.1. Trend analysis

2.1.1. Hydrography

The 2009 and 2010 winters were relatively harsh. Despite the cold winters, May sea surface temperatures have been close to average or even slightly above average in the Bornholm and Gotland Basin (Figure CBS-1, top). Below the thermocline however a cold winter water layer remained throughout summer (Figure CBS-1, middle). Surface salinities in the Central Baltic have been increasing since the beginning of the 2000s and in the Gotland Basins, surface salinities in 2011 were close to the 1975–2011 average (Figure CBS-1, bottom left). In the halocline region (80–100 m depth) salinities have recovered close to the data series maximum (Figure CBS-1, bottom right).

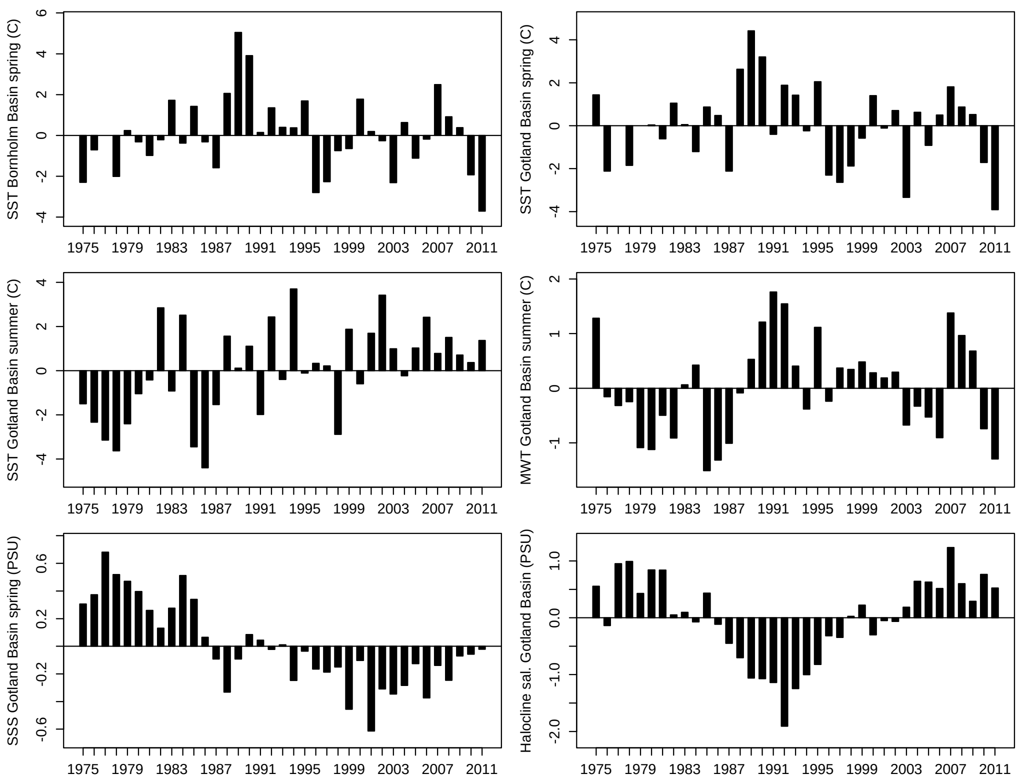

Figure CBS-1. Temperature and salinity in the Central Baltic. Anomaly plots show surface water temperatures in May in the Bornholm Basin (top left, mean = 5.87 C) and the Gotland Basin (top right, mean = 5.27 C) as well as surface (middle left, mean = 15.16 C) and midwater temperatures (40–60 m, middle right, mean = 3.38 C) in summer in the Gotland Basin. Bottom row depicts surface salinity in May in the Gotland Basin (bottom left, mean = 7.13 PSU) and salinity at 80–100 m depth in the Gotland Basin in summer (bottom right, mean = 9.81 PSU).

While saltwater inflows have almost restored the salinity conditions in the Central Baltic after the stagnation period at the end of the 1980s, bottom water oxygen conditions have continued to deteriorate (Figure CBS-2, top left). Major Baltic inflows occurred in 1993, 1996 and 2003 (Hansson *et al.*, 2011) and brought short time improvements in bottom water oxygen conditions. Since 2003 only warm baroclinic inflows have occurred that were not dense enough to reach deep water layers and contained comparatively little oxygen (Hansson *et al.*, 2011).

However, these inflows were sufficient maintain salinity in the halocline region and to ventilate the Bornholm Basin (HELCOM indicator fact sheets, http://www.helcom.fi/BSAP_assessment/ifs/ifs2011/). As a consequence of the higher amount of salt in the Baltic, stratification has increased and the halocline depth has recovered from its record low at the end of the 1980s (Figure CBS-2, bottom left). However, combined with a low supply of oxygen to bottom waters and most likely high sediment oxygen consumption (see e.g. Meier *et al.*, 2011), this has caused anoxic bottom waters to expand quickly between 1993 and 2001 and to remain on a record high level until present (Hansson *et al.* 2011, Figure CBS-2 top right). Due to the low oxygen concentrations, also cod reproductive volume is presently low. While in 2008–2010 at least a part of the Gotland Basin was suitable for cod reproduction, oxygen conditions indicate that in 2011 cod reproduction was successful only in the Bornholm Basin.

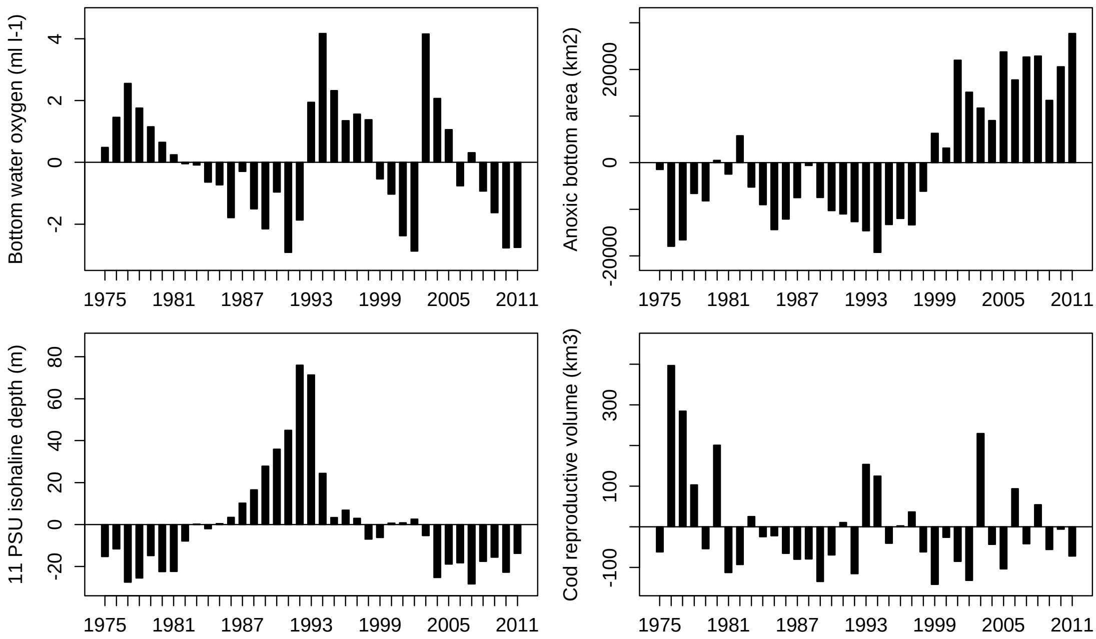

Figure CBS-2. Oxygen conditions in the central Baltic Sea. Anomaly plots show oxygen concentrations at 200–220 m depth in the Gotland deep (top left, mean = -1.25 ml l^{-1}, anoxic bottom area in the Baltic Proper, Gulf of Finland and Gulf of Riga (top right, mean = 22 018 km^2), depth of the 11 PSU isohaline (bottom left, mean = 122 m) and cod reproductive volume (bottom right, mean = 177 km^3).

2.1.2. Nutrients

Winter surface water nutrient concentrations show similar trends in the Bornholm and Gotland Basins (Figure CBS-3 top and middle). The recent trend of declining winter nitrate concentrations and high phosphate values seems to be interrupted since 2006, when DIN pools have started to increase again. Still, winter DIN values remain below their long-term average, while DIP concentrations are relatively large. N/P ratios have therefore increased slightly, but remain still at low levels (4.9 mol/mol in 2001–2011 compared to 8.2 mol/mol in 1994–2000). Deep water nutrient concentrations in the Gotland Basin reflect the water renewal pattern in the basin (Figure CBS-3, bottom) and presently deep water DIN and DIP concentrations are above their long-term average.

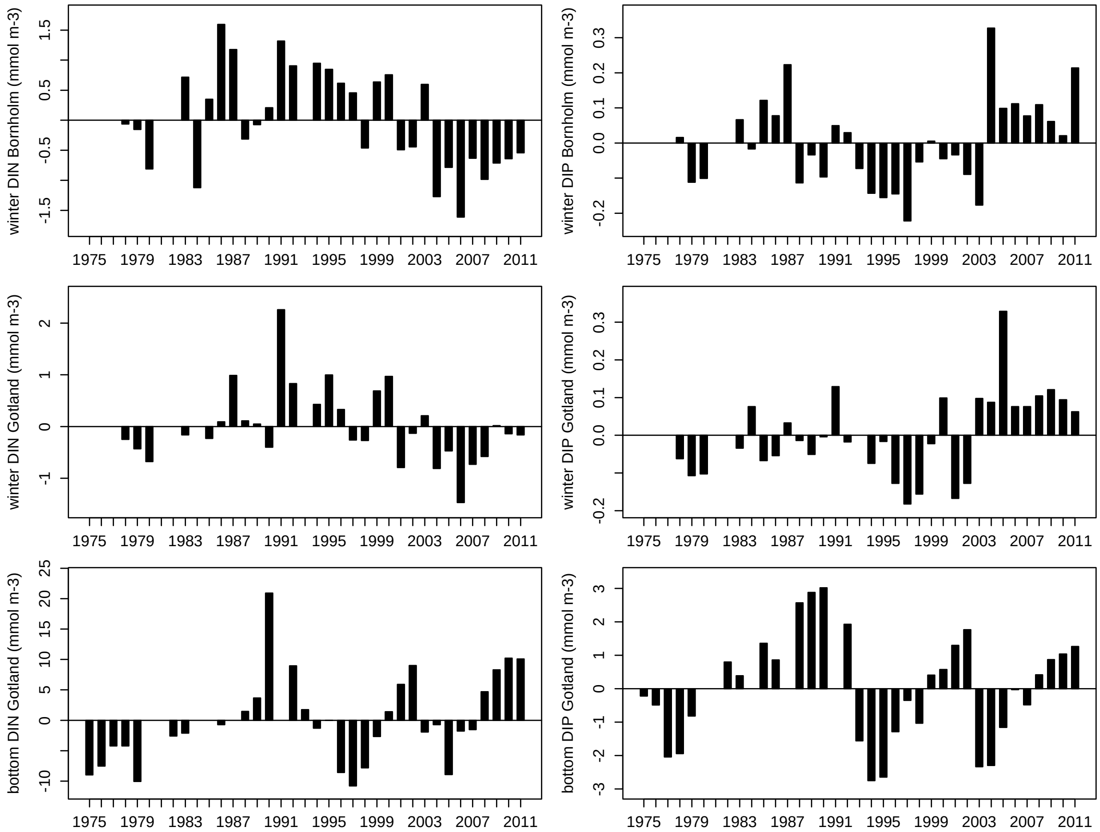

Figure CBS-3. Nutrient conditions in the central Baltic Sea. Anomaly plots show surface winter DIN and DIP concentrations in the Bornholm Basin (top row, means 3.57 mmol m^{-3} DIN and 0.64 mmol m^{-3} DIP) and the Gotland Basin (middle, means 3.67 mmol m^{-3} DIN and 0.55 mmol m^{-3} DIP). Bottom row shows deep water (200–220 m) nutrient concentrations in the Gotland Basin (means 11.14 mmol m^{-3} DIN and 4.36 mmol m^{-3} DIP).

2.1.3. Phytoplankton

The phytoplankton data collected for WGIAB are probably not fully sufficient to capture the variability of the spring bloom or to assess changes in species composition. Recent publications have shown shifts (Klais *et al.* 2011) and alternating oscillations between diatom and dinoflagellate during spring in the Central Baltic, with diatom dominated spring blooms in the 1980s and since 2000, whereas dinoflagellates were most abundant during the 1990s (Wasmund *et al.* 2011).

During summer, phytoplankton biomass is more stable and the WGIAB data show fluctuating phytoplankton concentrations in the Bornholm Basin and a steady increase in summer chlorophyll *a* in the Gotland Sea, with relatively low summer biomass in 2009–2011 (Figure CBS-4). The pronounced chlorophyll *a* maximum in 2008 in the Gotland Sea probably reflects the large cyanobacteria surface accumulations observed, whereas in the year of 2011 only small blooms occurred (http://www.helcom.fi/BSAP_assessment/ifs/ifs2011/en_GB/Cyanobacterialblooms2011/).

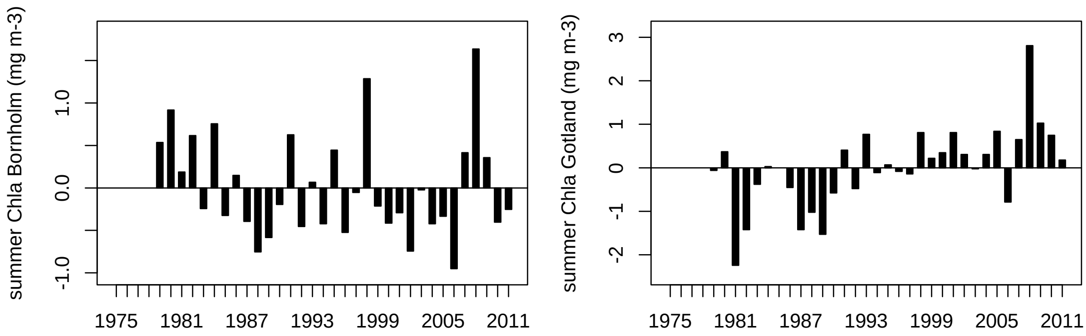

Figure CBS-4. Summer chlorophyll a concentrations in the Central Baltic Sea. Anomaly plots show chlorophyll a concentrations in the Bornholm (left, mean = 2.12 mg m^{-3}) and Gotland (right, mean = 2.44 mg m^{-3}) basin.

2.1.4. Zooplankton

Acartia spp. and *Temora longicornis* (Figure CBS-5, left and middle), the dominating copepods above the Central Baltic halocline, have clearly benefitted from warmer water temperatures in spring. However, the relatively cold winters in 2009 and 2010 are also reflected in low abundances of both species in spring of 2010 and 2011. During summer both species show slightly differing trends. While *Acartia* spp. biomass declines again after a maximum in the mid 1990s, *Temora longicornis* shows strong fluctuations with an increasing trend throughout the entire time-series. In contrast to *Acartia* spp. and *Temora longicornis*, the copepod stage of *Pseudocalanus acuspes* is primarily distributed in the halocline region of the Central Baltic basins. Its biomass has declined until the beginning of the 1990s and has remained low since then (Figure CBS-5, right).

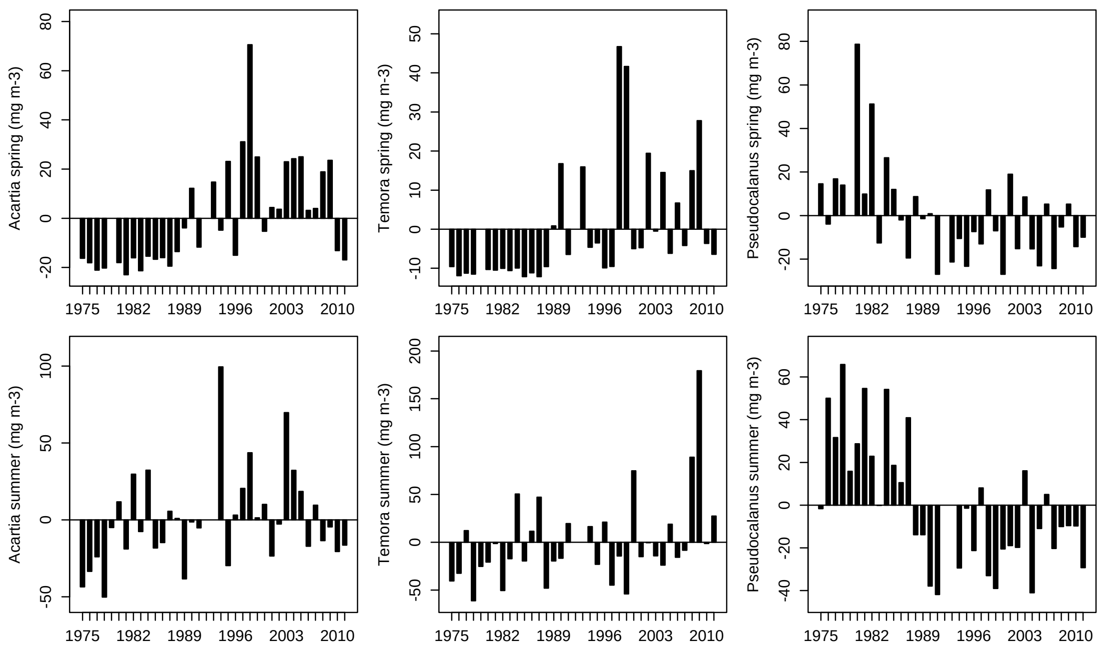

Figure CBS-5. Zooplankton biomass in the Central Baltic Sea. Anomaly plots show biomass in spring (top row) and summer (bottom row) for Acartia spp. (left, means 24.7 mg m^{-3} and 61.2 mg m^{-3}), Temora spp. (left, means 13.0 mg m^{-3} and 73.7 mg m^{-3}) and Pseudocalanus spp. (right, means 34.3 mg m^{-3} and 55.2 mg m^{-3}).

2.1.5. Fish and fisheries

Reducing the fishing mortality of cod has initiated a recovery of the cod stock to average SSB for the time period 1975–2010, despite low recruitment (

Figure CBS-6, left). Also the sprat stock is currently at its time-series average, after record high biomasses in the mid 1990s. Recruitment conditions continue to be favourable for sprat, but fishing mortality for the stock is relatively high (

Figure CBS-6, right). Central Baltic Sea herring has stabilized on a low level. Recruitment has been low since the mid-1980s and despite lowering the fishing mortality after the end of the 1990s, the stock has only recovered slightly (

Figure CBS-6, middle).

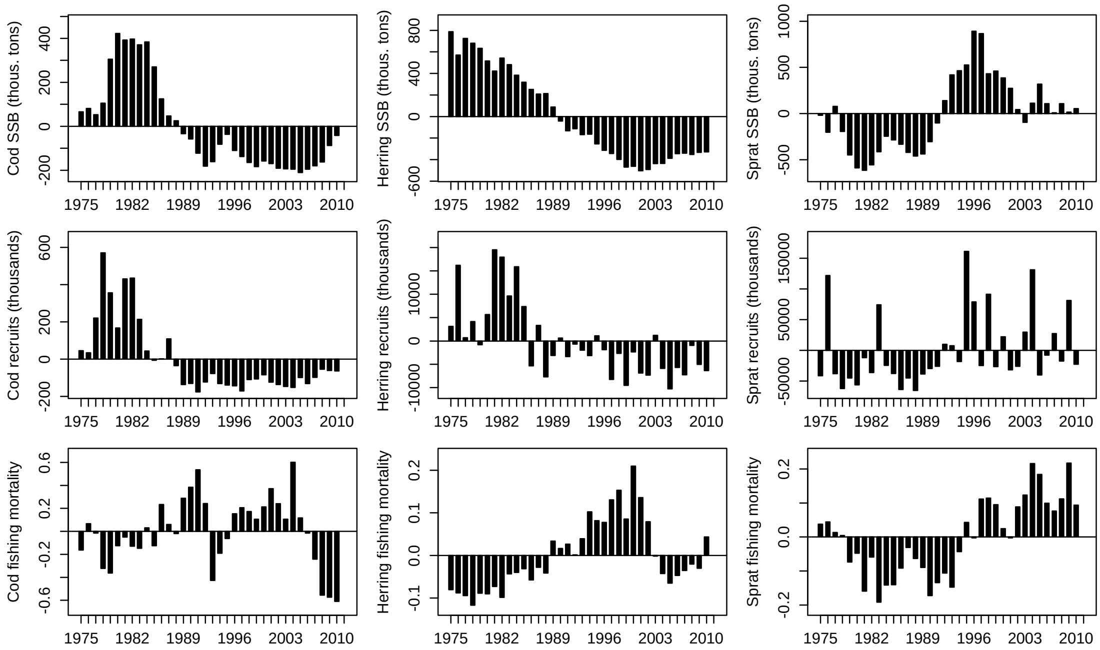

Figure CBS-6. Fish and fishery indicators for the Central Baltic Sea. Anomaly plots show spawning stock biomasses of cod, herring and sprat (top row, means 274 $*10^3$ tons, 864 $*10^3$ tons, 259 $*10^3$ tons), recruitment (middle, means cod recruits at age 2 = 258 $*10^3$, herring recruits at age 1 = 17.3 $*10^6$ tons, sprat recruits at age 1 = 79.0$*10^6$) and fishing mortality F (bottom, means 0.86, 0–27, 0.31).

2.2. Integrated analysis

In total, 61 variables were included in an integrated analysis, 27 characterizing abiotic conditions (climate, hydrography, nutrients, oxygen) and 34 describing biotic conditions (phytoplankton, zooplankton, fish). The traffic light plot (Figure CBS-7) shows alterations in fish stocks (decline of cod and herring and parallel increase in sprat biomass), and zooplankton abundance (increase of *Acartia* and *Temora* biomass in spring, decrease of *Pseudocalanus*) to be the most pronounced changes in the Central Baltic ecosystem. These are paralleled by freshening surface waters, warmer winter waters below the thermocline and warmer surface waters.

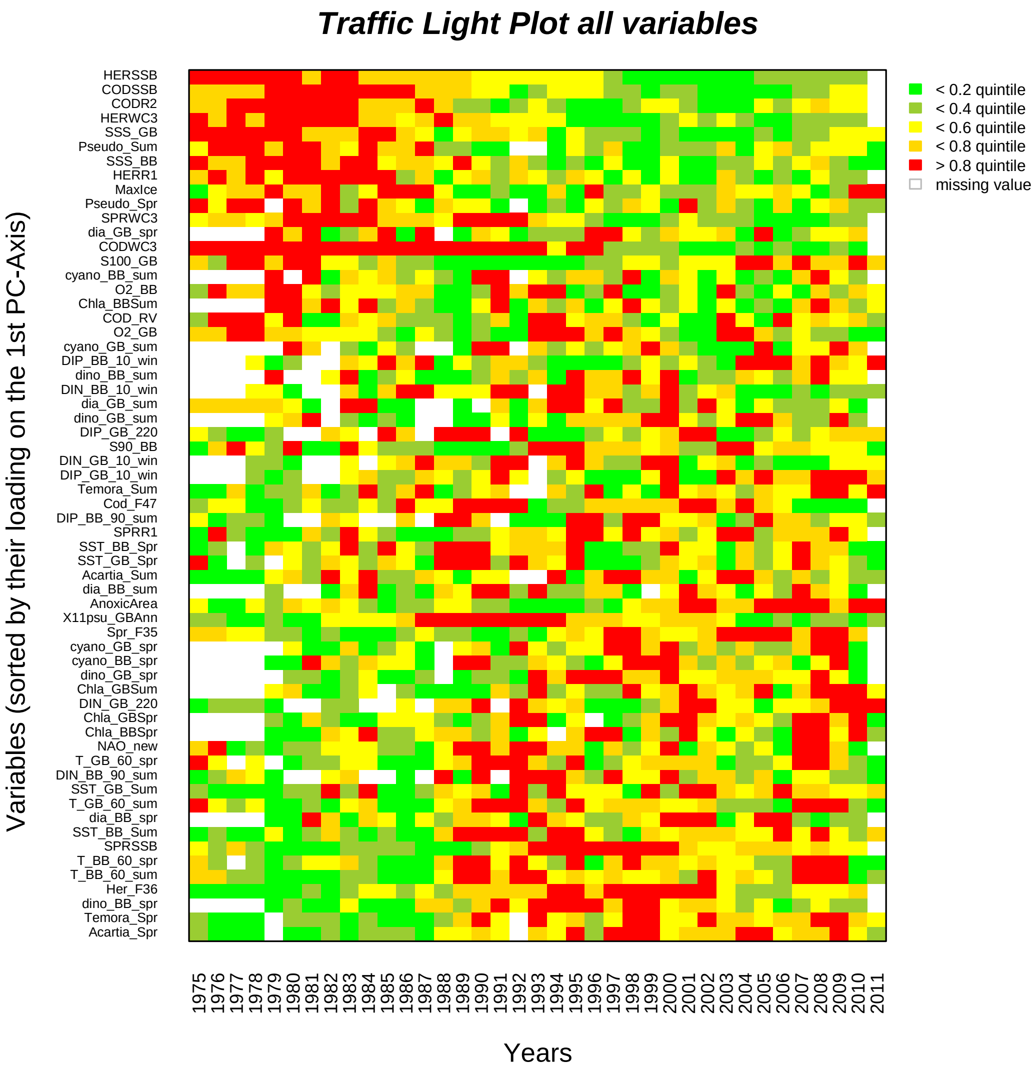

Figure CBS-7. Traffic-light plot of the temporal development of the Central Baltic Sea time- series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1).

The first principal component (Figure CBS-8, left) is mostly associated to changes in fish stocks, zooplankton, salinity and temperature, whereas the second principal component captures bottom water oxygen and nutrient concentrations, halocline depth and salinity, as well as anoxic area and cod reproductive volume. If the principal component analysis is restricted to abiotic variables, temperature which correlates with PC1 is clearly separated from bottom water oxygen conditions, anoxic area, halocline depth and cod reproductive volume, which correlate with PC2. Winter DIN and DIP concentrations follow the PC2 pattern with opposite sign, so that large anoxic bottom areas are associated with high phosphorus mobility, while DIN concentrations are reduced. The relationship between bottom water oxygen conditions and DIP pools has been described already at the end of the 1990s (Conley *et al.* 2002). Restricting the analysis to biotic factors shows the dominant changes in fish stocks and zooplankton, whereas PC2 mainly reflects changes in summer phytoplankton biomass. The principal component analysis also indicates that high summer chlorophyll *a* values are associated with high cyanobacteria biomass.

If all variables are included in the analysis, STARS identifies a pronounced regime shift in 1987/1988. This regime shift is also detectable in the abiotic variables alone and marks the warming of the Baltic. If prewhitening is applied, STARS does not identify regime shifts in the PC1 of the biotic system, but picks up two small shifts in PC2 instead (1983/1984, 1994/1995). 1993 marks the onset of strong summer phytoplankton blooms in the Gotland Basin, whereas the 1983/1984 shift is probably too close to the start of the phytoplankton time-series (1979/1980) to be interpreted reliably. If gradual ecosystem changes are not removed by prewhitening, STARS identifies two pronounced shifts in PC1 of the biotic variables in 1985/1986 and 1992/1993. These are related to zooplankton and fish stocks, with zooplankton changes occurring slightly earlier than the decline in cod and herring and the increase in sprat stocks.

While the ecosystem state in the 1970s is clearly separated from its present state in the time-trajectories for all as well as for biotic variables, the picture is less clear for the abiotic variables alone (Figure CBS-8, right). However, with the exception of 2003 all years past 2000 show lower PC2 scores than the 1970s, 1980s and 1990s. This means that while the PC1 values indicate a break in warming, the PC2 associated variables anoxic area, bottom water oxygen conditions and winter nutrient pools have not returned to their initial state. Therefore the Central Baltic ecosystem continues to be affected by anoxia and high phosphorus availability and only during inflow years, as in 2003, the initial state of the abiotic system is shortly attained.

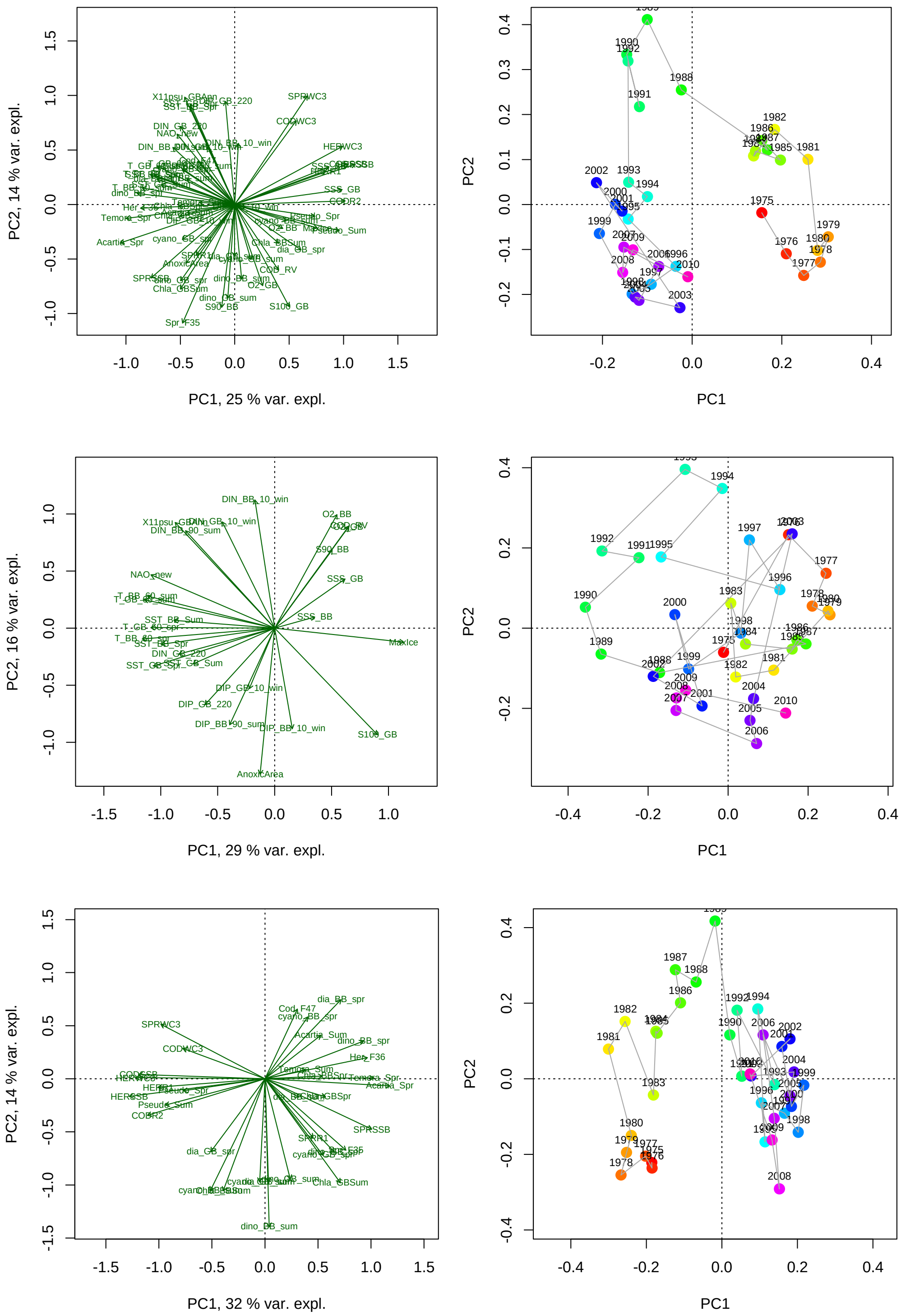

Figure CBS-8. Biplots of variable loadings (left) and time-trajectories of year scores (right) in the in the PC1-PC2 plane for the Central Baltic Sea time-series. Rows show changes in all variables (top), abiotic (middle) and biotic (bottom) variables. Year scores are colour-coded into red (1970s), orange-green (1980s), light blue (1990s) and blue-purple (2000s).

2.3. References

Conley, D. J., Humborg, C., Rahm, L., Savchuk, O. P., & Wulff, F. (2002). Hypoxia in the Baltic Sea and Basin-Scale Changes in Phosphorus Biogeochemistry. *Environmental Science & Technology*, *36*(24), 5315–5320.

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3. Gulf of Riga, open sea (GoR)

For the Gulf of Riga, not all time-series could be updated. Due to cuts in the Latvian marine monitoring programme, no winter nutrient data are available for 2010 and 2011. Also load calculations for the Gulf of Riga were not updated for 2008–2011. However, Daugava River runoff was available as a load proxy.

3.1. Trend analysis

3.1.1. Hydrography

Similar the adjacent Gotland Basin, the cold winters in 2009 and 2010 interrupted the series of warm spring water temperatures in the Gulf of Riga and May water temperatures above the thermocline were slightly below their long-term average in 2010 and 2011 (Figure GoR-1, top left). Despite the slow warming in spring, the euphotic zone was warmer than average in summer. Salinity, which had steadily increased since its minimum in the second half of the 1990s, started to decline again in 2010 and 2011. Runoff from the Daugava River, the largest river draining into the Gulf, has fluctuated around its long-term average since 2004. Runoff was above the long-term average in 2009/2010 and slightly below the long-term average in 2011.

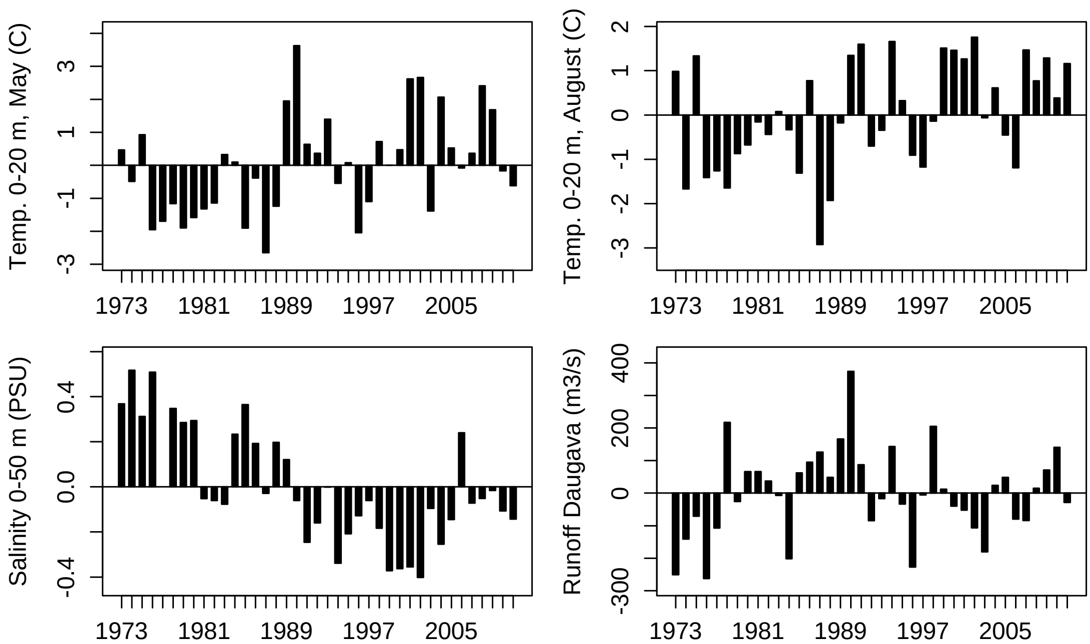
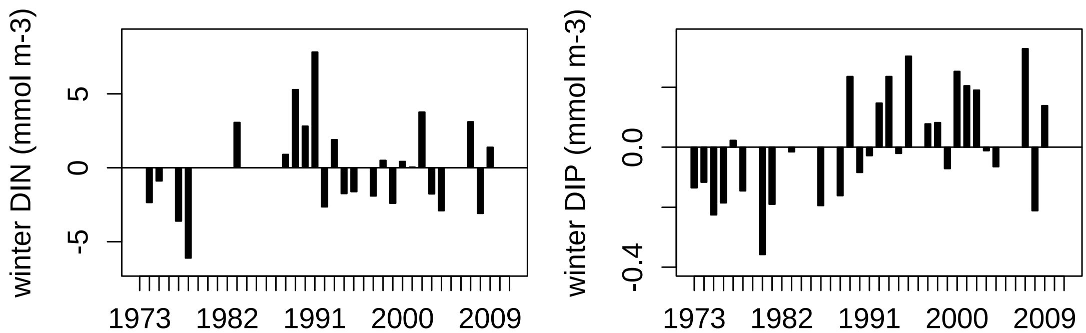


Figure GoR-1. Temperature, salinity and runoff to the Gulf of Riga. Anomaly plots show surface water temperatures in May (top left, mean = 4.51 C) and the August (top right, mean = 16.3 C) as well as water column average salinity in August (bottom left, mean = 5.58 PSU) and freshwater runoff from the Daugava River to the Gulf (mean = 616.3 m³ s-1).

3.1.2. Nutrients

Winter nutrient concentrations show a decrease of DIN values since their maximum in 1991 and mostly high DIP pools since the end of the 1980s (Figure GoR-2). Due to the missing data, it is unknown whether this trend continues beyond 2009.



FigureGoR-2. Nutrient conditions in the Gulf of Riga. Anomaly plots show surface winter DIN (left, mean = 11.54 mmol m^{-3}) and DIP (right, mean = 0.81 mmol m^{-3}).

3.1.3. Phytoplankton

The Gulf of Riga shows very variable spring blooms with an increasing trend (FigureGoR-3, left). Summer phytoplankton biomass is less variable and has strongly increased at the end of the 1990s and declined steadily to below average values in 2011. The high summer phytoplankton biomass in the 2000s has been linked both to weaker top-down control by zooplankton as well to expanding cyanobacteria blooms (Jurgensone *et al.* 2011).

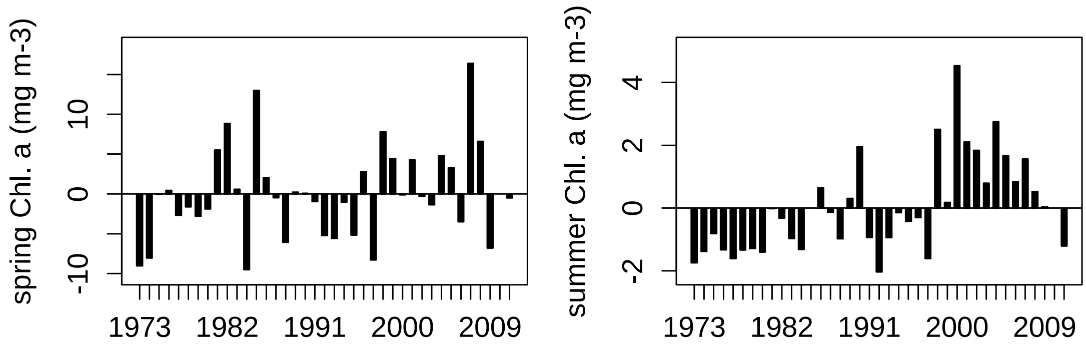


Figure GoR-3. Phytoplankton conditions in the Gulf of Riga. Anomaly plots show spring (left, mean = 14.1 mg m^{-3}) and summer (right, mean = 3.22 mg m^{-3}) chlorophyll *a* concentrations.

3.1.4. Zooplankton

Since the mid 1990s also the increasing trend in spring copepod biomass seems to be broken in the Gulf of Riga. Both spring biomasses of *Eurytemora* and *Acartia* (Figure GoR-4) have started to fluctuate strongly and were below their long-term averages in 2010 and 2011. No recent changes are obvious in summer and the biomass of both species continues to remain on low levels. The glacial relict species *Limnocalanus macrurus* (Figure GoR-4, bottom left) shows strong interannual variations, but the population seems to recover from low biomasses observed during the 1980s and 1990s. *Cercopagis pengoi* (Figure GoR-4, bottom right) is an invasive species to the Gulf of Riga that is present since 1997. Its biomass is fluctuating strongly, especially in warm summers.

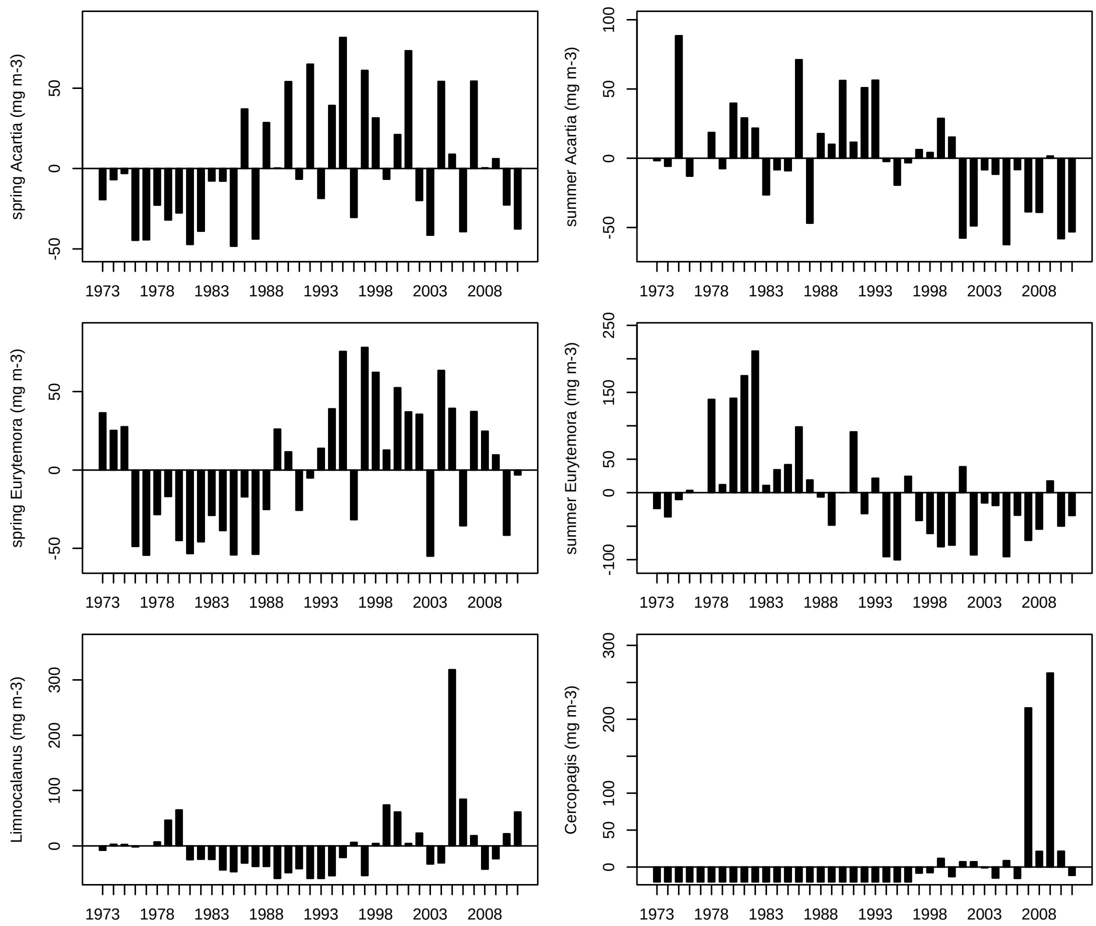


Figure GoR-4. Zooplankton conditions in the Gulf of Riga. Anomaly plots show spring (top left, mean = 57.8 mg m^{-3}) and summer (top right, mean = 75.5 mg m^{-3}) biomasses of *Acartia* spp. and *Eurytemora* spp. (middle, means 61.5 mg m^{-3} and 151.8 mg m^{-3}) as well as summer biomass of *Limnocalanus macrurus* (mean = 58.8 mg m^{-3}) and *Cercopagis pengoi* (mean = 20.2 mg m^{-3}).

7.1.5. Fish and fisheries

Herring is the most important commercial fish species in the Gulf of Riga. Its stock has increased from low values in the 1970s and 1980s to a maximum in the mid 1990s, from which it presently returned again to average values (Figure GoR-5, top left). In parallel, fishing pressure, expressed as yield/SSB, has declined until the mid 1990s and then increased sharply to a peak in the first half of the 2000s. Herring recruitment has been extremely variable since the late 1990s (Figure GoR-5, top right). Cod is present in the Gulf of Riga only during high stock sizes in the Central Baltic. Its biomass is unknown, but cod catches (Figure GoR-5, bottom right) peaked in the beginning of the 1980s and no catches were reported starting in 1992. Since 2009 cod reappeared as by-catch in the Gulf of Riga. However, no data are available on its present abundance.

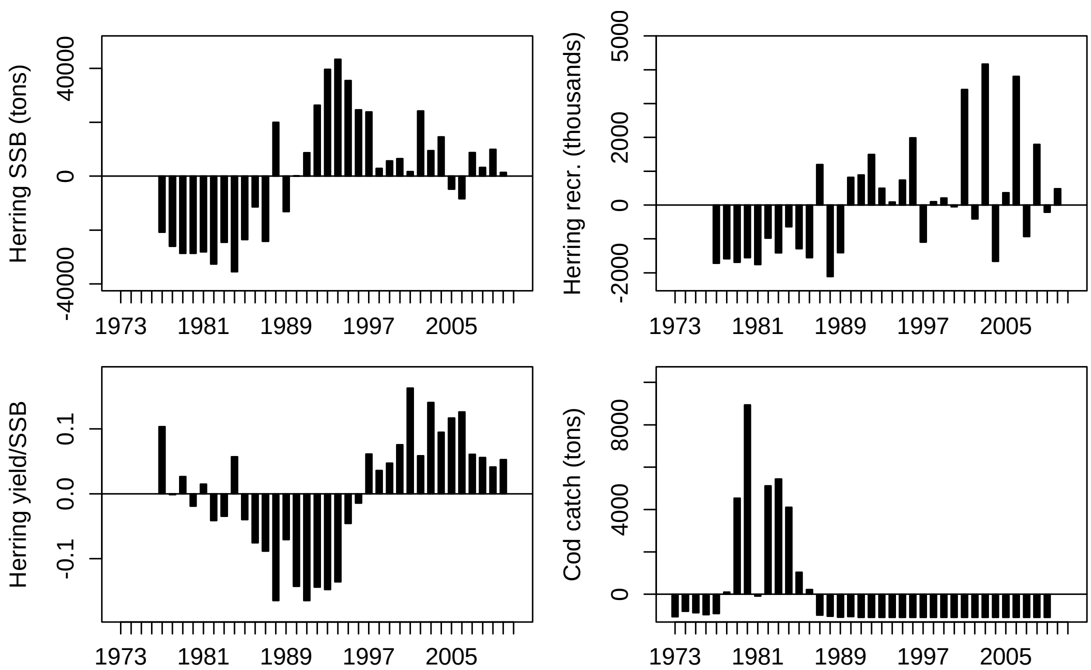


Figure GoR-5. Fish and fishery indicators for the Gulf of Riga. Anomaly plots show herring SSB (top left, mean = 75 377 tons), herring recruitment at age 1 (top right, mean = 2 665 * 10^3), herring yield (catch/SSB, bottom left, mean = 0.34) and reported cod catches (bottom right, mean = 1 088 tons).

3.2. Integrated analysis

In total, 26 variables were included in the analysis. They describe climatic conditions (2 variables), nutrient load and runoff to the Gulf (3 variables), hydrographic conditions (3 variables), nutrient concentrations (2 variables), phytoplankton (4 variables), zooplankton (7 variables), as well as fish and fisheries (5 variables).

The traffic light plot for the Gulf of Riga identifies both trends in herring stock, zooplankton biomass, temperature and salinity as well as winter phosphate concentrations and summer phytoplankton biomass as major changes in the Gulf of Riga. The increase in herring biomass observed is paralleled by a decline in summer biomass of *Eurytemora* and a decline of individual herring weight. This indicates strong competition for zooplankton prey in the Gulf. In contrast to summer, spring copepod biomass has increased, driven by higher water temperatures. Winter nutrient concentrations show differing trends for phosphate and nitrate. While winter nitrate concentrations correlate well to nitrogen loads and river runoff, winter phosphate dynamics are decoupled from their inputs and belong, according to the principal component analysis, to the structuring factors of the Gulf of Riga ecosystem. The rise in winter phosphate concentrations has, together with low summer zooplankton biomass, triggered an increase in summer phytoplankton biomass, potentially also due to an increase in cyanobacteria blooms (see Jurgensone *et al.* 2011).

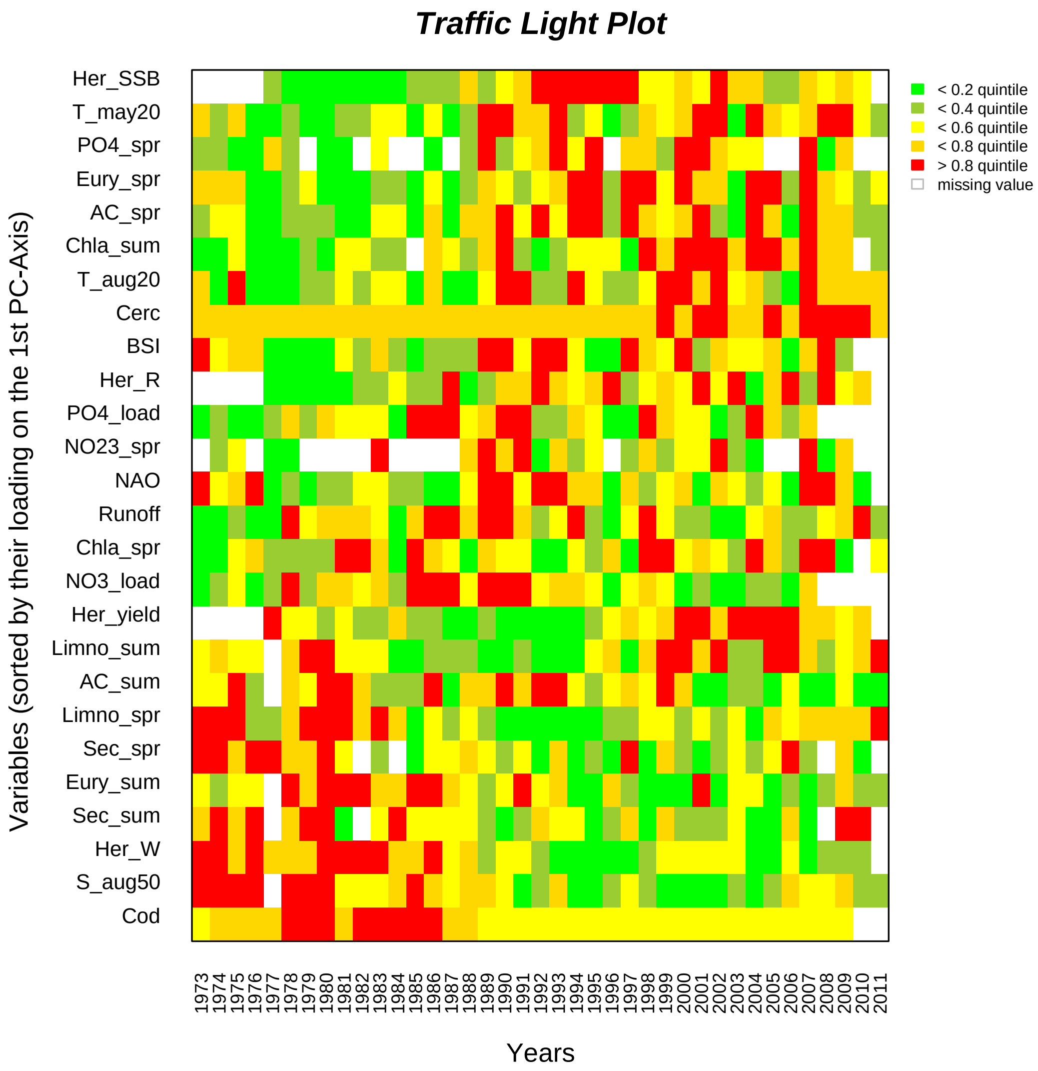


Figure GoR-6. Traffic-light plot of the temporal development of the Gulf of Riga time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1).

The decoupling between winter phosphate concentrations and loads, together with the opposite relationship for nitrogen, is also confirmed by the PCA biplot, as well as the high correlation between winter phosphate and summer chlorophyll *a*. The biplot further indicates, that the herring stock dynamics is more closely related to recruitment than to fishing pressure.

STARS identifies two regime shifts in PC1 for the Gulf of Riga dataset, in 1982/1983 and 1988/1989. The first regime shifts marks a slight summer warming in the Gulf and initial higher summer phytoplankton biomass, whereas 1988/1989 initiated the major restructuring in water temperatures, zooplankton biomass and herring stock size in the Gulf of Riga.

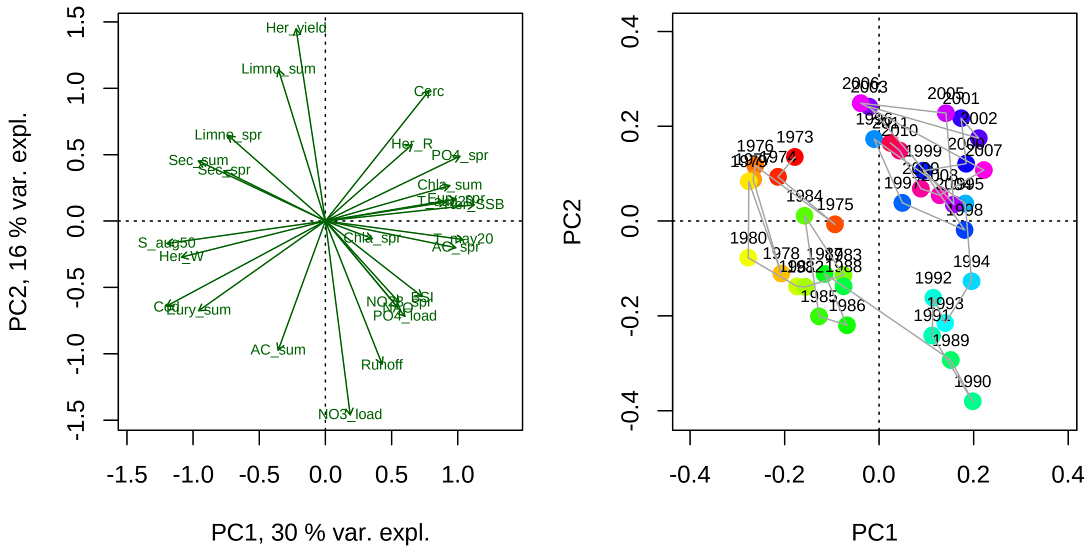


Figure GoR-7. Biplot of variable loadings (left) and time-trajectories of year scores (right) in the in the PC1-PC2 plane for the Gulf of Riga time-series. Year scores are colour-coded into red (1970s), orange-green (1980s), light blue (1990s) and blue-purple (2000s).

3.3. References

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4. Bothnian Bay coast – Holmön (HO)

4.1. Area description

The Holmön area is situated in the southern parts of the Bothnian Bay (Figure HO-1). The area is exposed to the open sea and has an average salinity in the range of 3–4. The sampling sites for biotic parameters are generally rather shallow (maximum depth ~ 20 m), but the surrounding areas are deeper. The Holmön area serves as a national reference area for coastal fish monitoring in Sweden and is only mildly impacted by local anthropogenic pressure. As for many other coastal areas, however, influence from perturbations in the offshore area is likely to affect the coastal system in Holmön (Eriksson *et al.*, 2011; Olsson *et al.*, *in press*).

For the integrated analyses in the Holmön area in total 30 variables were considered: five hydrographical, seven nutrient-related, two related to fishing pressure, five representing zooplankton, five macro-zoobenthos, five fish and one top predator (grey seals). No data on phytoplankton were included. The rationale for this was that reliable local information was not available, and corresponding open sea information was not considered representative enough. For the physical and nutrient variables, both coastal (five) and offshore (nine) time-series were included. All datasets were compiled as one value per year and covered the period 1994–2010.

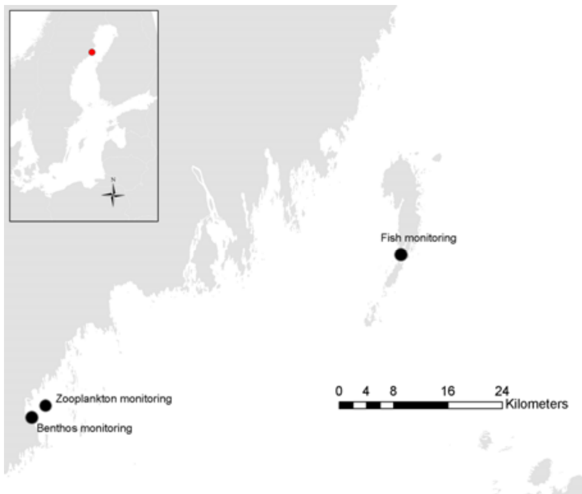

Figure HO-1. Location of the Holmön area in the southern Bothnian Bay.

4.2. Variable descriptions

4.2.1. Hydrography

The variables temperature, salinity and a proxy for large-scale atmospheric conditions, Baltic Sea Index (BSI), were included as the hydrographical variables potentially affecting the coastal system in Holmön. Summer temperature was included both at the local and offshore (basin wide) scale, and the coastal data also included spring temperature. Since no local data was available, offshore values for salinity (annual average) were used. As previous studies have suggested that large-scale climatic conditions influence the structure of offshore (Möllmann *et al.*, 2009, Dieckman and Möllmann 2010) and coastal systems (Olsson *et al.*, *in press*) in the Baltic Sea, we included the Baltic Sea Index in the data set. The index generally reflects the differences in sea level pressure between Szcecin (Poland) and Oslo (Norway), and hence serves as a proxy for the direction and strength of winds over the Baltic (Lehmann *et al.*, 2002).

Over the time-period assessed, the only variable exhibiting a temporal trend was salinity, which decreased over the time-period assessed (Figure HO-2).

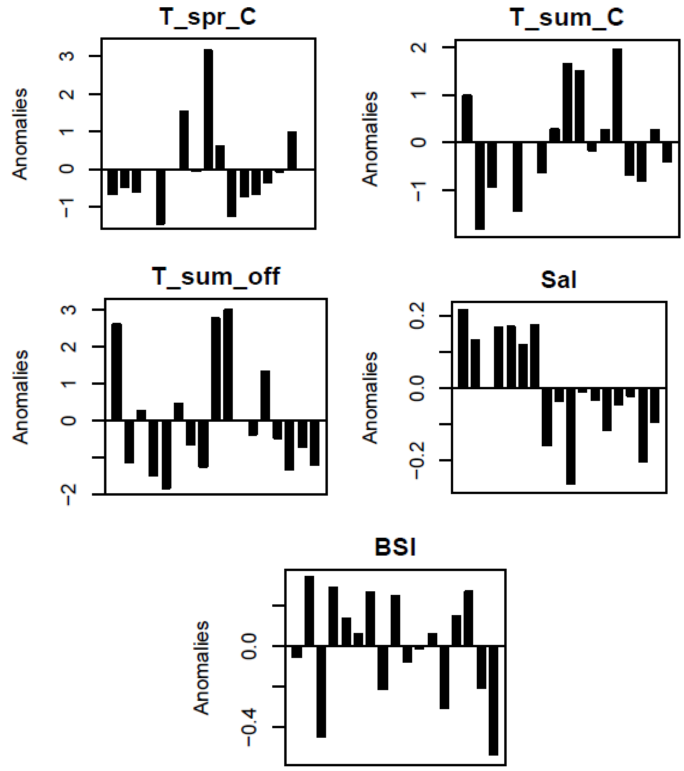

Figure HO-1. Long-term changes in hydrographical variables in the Holmön area: anomalies from the overall mean in coastal spring – (T_spr_C), coastal summer – (T_sum_C) and offshore summer (T_sum_off) temperature (°C), salinity (Sal, psu), and BSI.

4.2.2. Nutrients

The level of nutrient concentrations on the local scale was represented by local water transparency in August and discharge of nitrogen and phosphorous from land within the county of Holmön (Västerbotten, AC). As proxies for nutrient load on the larger scale, offshore concentration of DIN (dissolved inorganic nitrogen), DIP (dissolved inorganic phosphorous), as well as total discharge of nitrogen and phosphorous from land to the Bothnian Bay were used.

There was a decrease in offshore concentrations of DIN, and a tendency (although not statistically significant) to an increase in local water transparency and offshore DIP concentrations between 1994 and2010 (Figure HO-2). The other four variables exhibited no temporal change during the assessed time-period.

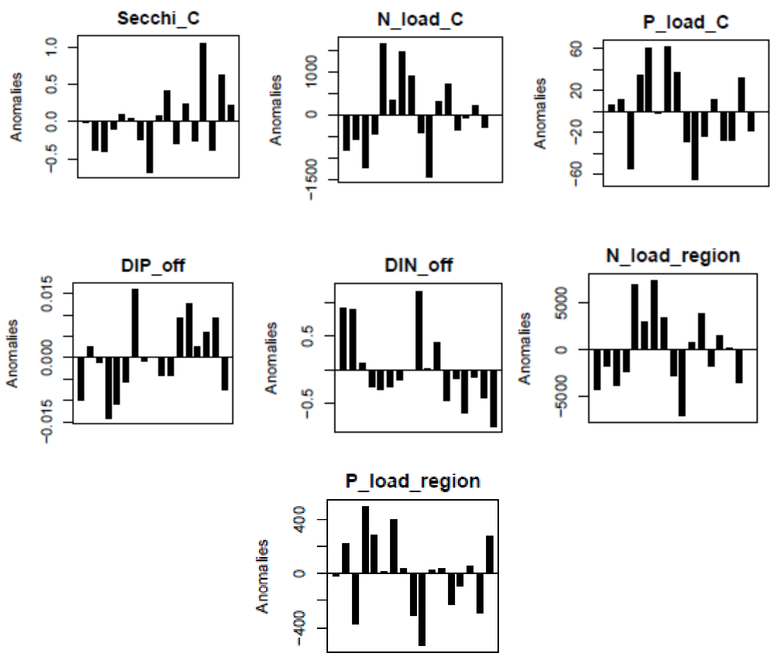

Figure HO-2. Long-term changes in nutrient related variables in the Holmön area: anomalies from the overall mean in local water transparency (Secchi_C), local discharge from land in nitrogen (N_load_C) and phosphorous (P_load_C), offshore concentrations of DIP (DIP_off) and DIN (DIN_off), as well as total discharge of nitrogen (N_load_region) and phosphorous (P_load_region) from land to the Bothnian Bay.

4.2.3. Fishing

As a proxy for local fishing pressure the total landed catch (all species and gears) within ICES rectangle 5665 was used. The F-based estimate of proportion of 3–7 year old herring in the Bothnian Bay was used as a proxy for regional (within basin) fishing pressure.

There have been strong inter-annual fluctuations but no temporal trend in coastal fishing pressure, whereas the fishing mortality of herring decreased during the time-period assessed (Figure HO-3).

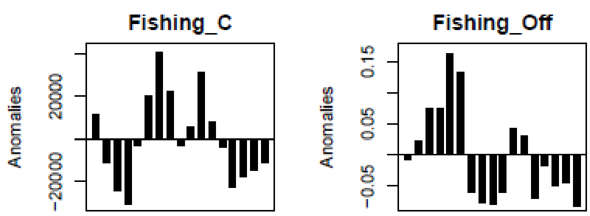

Figure HO-3. Long-term changes in coastal – (Fishing_C) and offshore (Fishing_Off) fishing pressure in the Holmön area and in the Bothnian Bay: anomalies from the overall mean.

4.2.4. Zooplankton

Five data sets were considered to represent the zooplankton community in the area; calanoid copepods (*Acartia sp.*, *Eurytemora sp.* and *Limnocalanus macrurus*), cyclopoid copepods (*Cyclops sp.*), cladocerans (*Bosmina coregoni maritime*, *Evadne nordmanni* and *Podon sp.*), rotifers (*Kellicottia longispina*, *Keratella sp.*, *Polyartha sp.*, *Radiosperma sp.* and

Synchatea sp.) and total zooplankton concentration. Samples represented the concentration of each taxonomic group at 15–20 meters depth during summer (July/August).

Based on this dataset, the zooplankton community has exhibited large inter-annual fluctuations, and the concentration of cladocerans has increased between 1994–2010 (Figure HO-4).

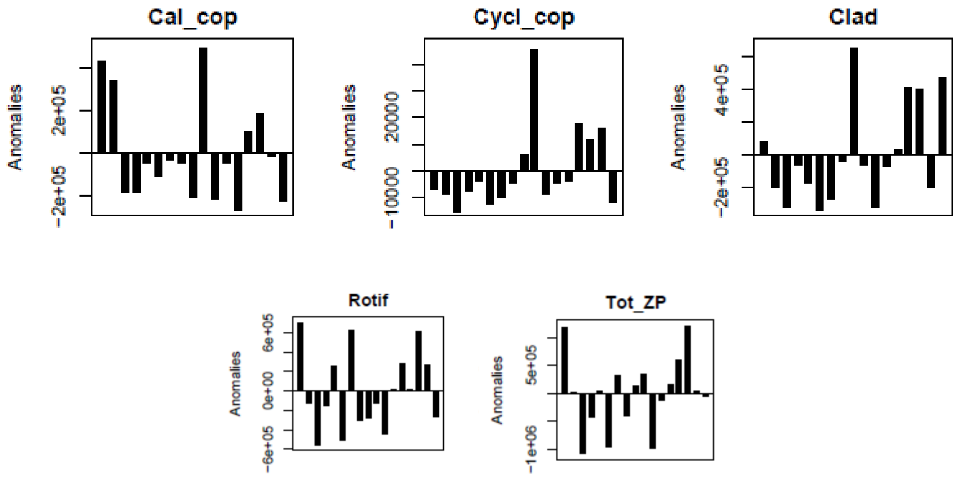

Figure HO-4. Long-term changes in the zooplankton variables in the Holmön area: anomalies from the overall mean in calanoid copepods (Cal_cop), cyclopoid copepods (Cycl_cop), cladocerans (Clad), rotifers (Rotif) and total zooplankton (Tot_ZP).

4.2.5. Benthos

In the analyses five time-series representing the zoobenthic community in the Holmön area was considered; the bivale *Macoma baltica*, the polychaete *Marenzelleria sp.* which is an alien species in the Baltic, the amphipod *Monoporeia affinis*, oligochaetes and the isopod *Saduria entomon*. Data on the abundance of these species was collected in late May to early June at a depth of approximately 20 meters.

Over the time-period assessed the abundance of *Monoporeia* and *Saduria* show a rather dramatic decrease, whereas the abundance of *Marenzelleria* exhibited a strong increase. *Macoma* and oligochaetes show strong interannual variation in their abundance, but no trend is discernable for either of the species/group between 1994–2010 (Figure HO-5).

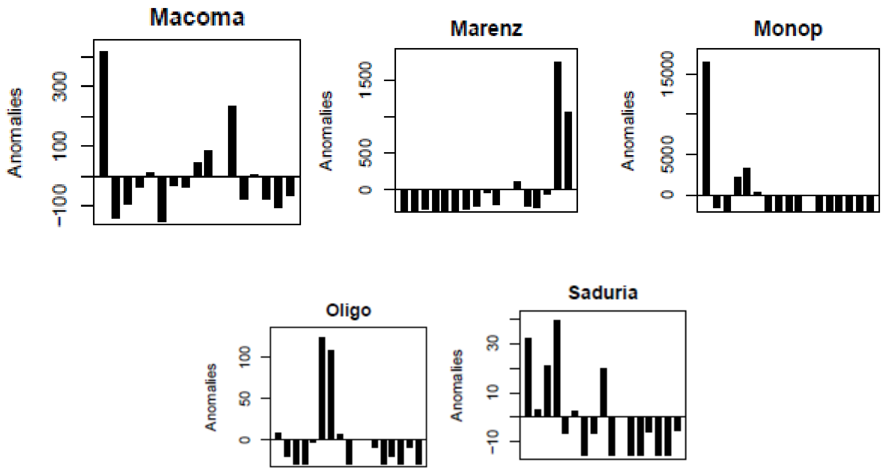

Figure HO-5. Long-term changes in the abundance of zoobenthos in the Holmön area: anomalies from the overall mean abundance (ind/m²) of *Macoma baltica* (Macoma), *Marenzelleria sp.* (Marenz), *Monoporeia affinis* (Monop), *Oloigochaetae sp.* (Oligo) and *Saduria entomon* (Saduria).

4.2.6. Fish

The five time-series included to represent the local fish community was the freshwater species perch (*Perca fluviatilis*), ruffe (*Gymnocephalus cernus*), roach (*Rutilus rutilus*), the anadromous whitefish (*Coregonus maranea*), and also herring (*Clupea harengus*) that is one of the few marine species found in the Bothnian Bay. Samples were obtained from gillnets set in August when species of a freshwater origin preferring higher water temperatures (i.e. perch, ruffe and roach) are well represented. Whitefish, which typically prefers lower water temperatures, and herring are, however, reasonably well represented in the gillnet monitoring program in August.

There has been pronounced interannual variations in the abundances of the species, but the abundance of ruffe and whitefish has decreased during the time-period assessed, whereas there has been an increase in roach (Figure HO-6).

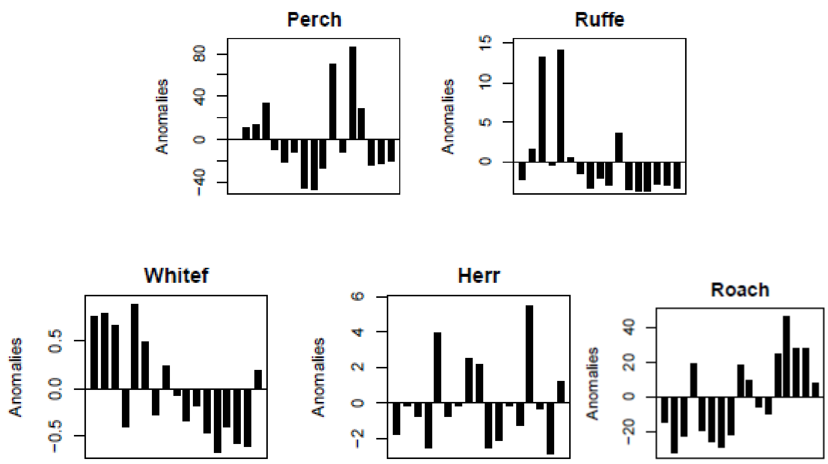

Figure HO-6. Long-term changes in the abundance of fish in the Holmön area: anomalies from the overall mean in numbers per night and gillnet of perch, ruffe, whitefish (Whitef), herring (Herr) and roach during sampling in August.

4.2.7. Seal

One time-series of the temporal development of grey seals (*Halichoerus grypus*) at Sydvästbrotten area was included in the analyses. Despite that this area is situated some distance from the other monitoring sites, it harbours the closest colony of grey seals in the Holmön area.

The abundance of grey seals has increased significantly in 1994–2010 (Figure HO-7).

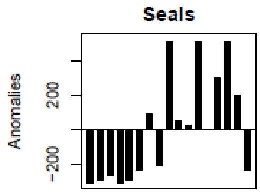

Figure HO-7. Long-term changes in the abundance of grey seal in the Sydvästbrotten area: anomalies from the overall mean in numbers.

4.3. Results of integrated trend analyses based on all variables

An overview of the temporal development of all the variables in Holmön time-series is presented in figure HO-8. Variables are sorted according to their PC1 loadings of the subsequently performed PCA, generating a pattern with variables at the bottom exhibiting an increasing trend over time (green to red), with the highest values in the recent 7 years, to variables at the top demonstrating the opposite trend (red to green) with the highest values between 1994–1999. Despite that some data is missing (as indicated by the white gaps in the figure) and many variables lacks a strong and directional temporal development, the values for offshore salinity, *Monoporeia*, offshore fishing pressure, ruffe, whitefish, local and regional phosphorous discharge from land and *Saduria* were generally high during the first five years of the time-period assessed. In contrast, the values for *Marenzelleria*, coastal summer temperature, cyclopoid copepods, grey seal and roach was on average relatively high between the years 2002–2010.

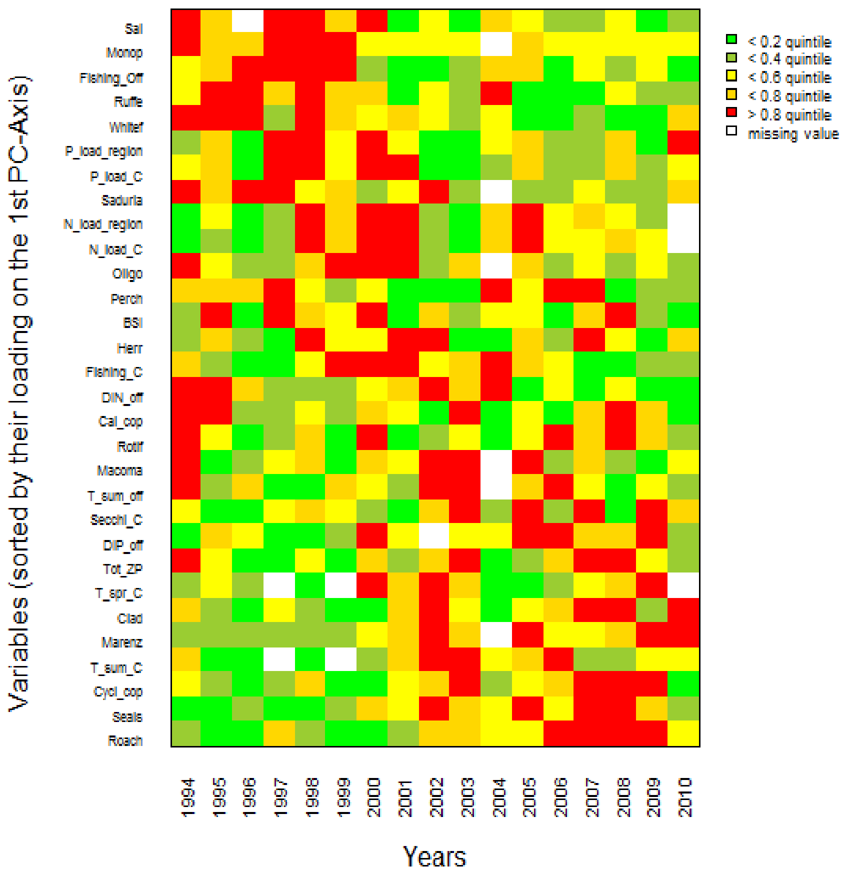

Figure HO-8. Traffic-light plot of the temporal development of 30 time-series in the Holmön area. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component.

The ordination of yearly averages by a standardized PCA resulted in 28.5 and 15.8% of the explained variance on the first two principal components. The first PC generally reflects both biotic and abiotic variables, and there seems to be some clustering of years. The years before 2001 generally have negative scores on PC 1 and is best characterised by higher salinity and offshore fishing pressure as well as high regional and local phosphorous discharge from land (Figure HO-9). During these years the ecosystem was chartersied by high abundances of *Monoporeia*, ruffe, whitefish and *Saduria*. The years from 2002–2010 generally have positive values of PC 1 and is best characterised by high coastal spring and summer temperatures, higher concentrations of total zooplankton, clodocerans and cyclopoid copepods, higher abundance of *Marenzelleria*, grey seals and roach.

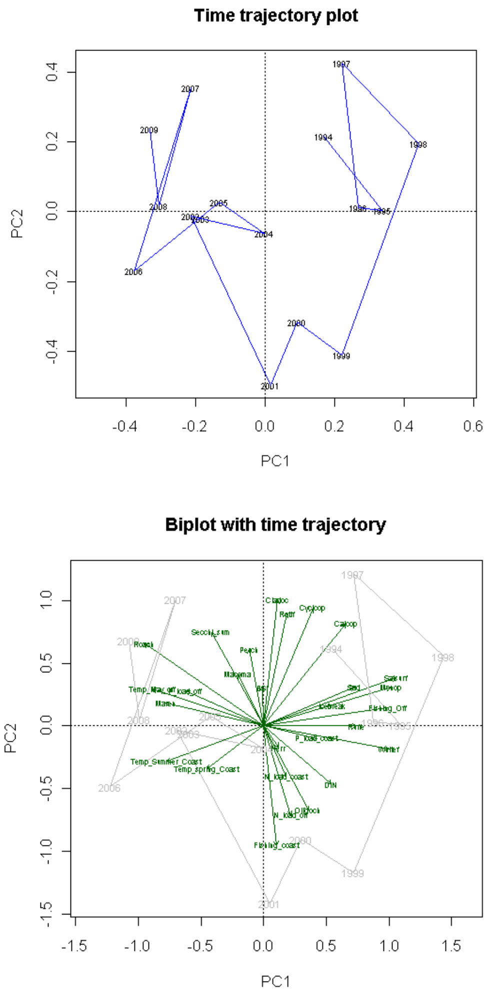

Figure HO-9. PCA output with sample scores and time-trajectory. Results of the standardized principal component analysis using all 30 variables assembled for the Holmön area showing the time trajectory on the first factorial plane (left; PC1 = 28.5 %, PC2 = 15.8 % explained variance) and the biplot with loading of each variable and time-tajectory plot (right).

The outcome of the discontinuity analysis (chronological clustering) supported the PCA ordination; the strongest shift was observed in 2001/2002 (at both alpha 0.01 and 0.05) grouping the years 1994–2001 and the years 2002–2010. An additional shift was suggested in 2003/2004 (alpha 0.05; Figure HO-10).

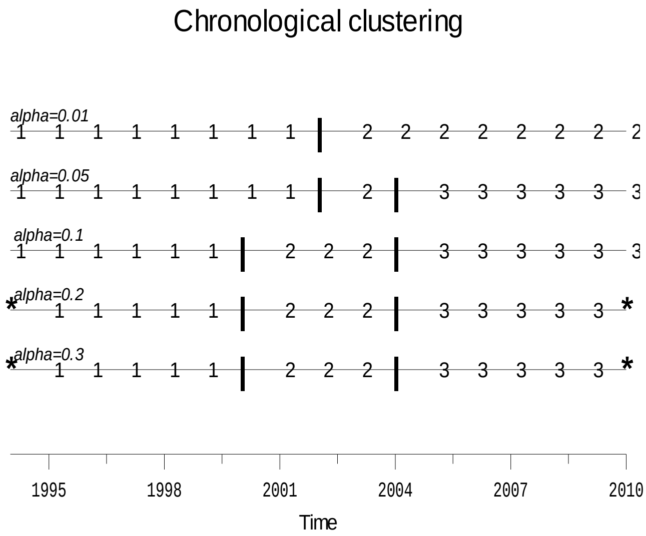

Figure HO-10. Results of the chronological cluster analyses performed on all 30 variables.

4.4. Results of integrated trend analyses based on abiotic and fisheries related variables only

The temporal development of the abiotic variables in the Holmön area does not follow as an obvious pattern as the analysis using all variables (Figure HO-11). The two first components of the ordination of the PCA explained 36.8 and 17.6 % respectively of the total variation. There is no obvious pattern for PC 1, but the years between 1997 and 2001 are best characterised by higher levels of salinity, offshore fishing pressure and local and regional discharge of nitrogen and phosphorous from land. The later years are best characterised by higher coastal and offshore water temperatures. For PC 2 there is a grouping where the years before 1999 have negative scores and is characterised by higher levels of salinity and offshore fishing pressure. The years 2000–2010 generally have positive loadings on PC 2 and are characterized by higher coastal and offshore water temperatures, higher levels of offshore DIP, local and regional nitrogen load and higher coastal fishing pressure.

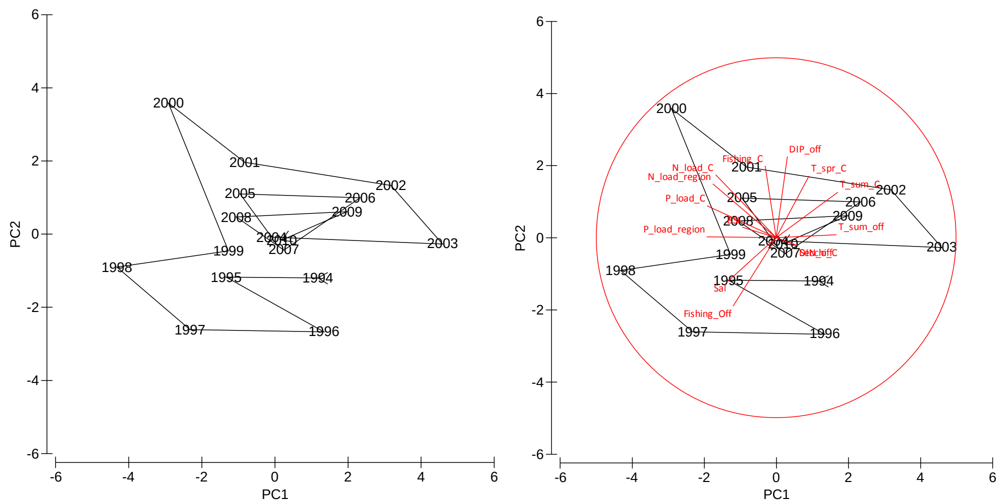

Figure HO-11. PCA output with sample scores and time-trajectory. Results of the standardized principal component analysis using the 14 abiotic variables assembled for the Holmön area showing the time trajectory on the first factorial plane (left; PC1 =36.8 %, PC2 = 17.6 % explained variance) and the biplot with loading of each variable and time-tajectory plot (right).

The outcome of the discontinuity analysis (chronological clustering) detected no shift at the alpha 0.01 level. Somewhat weaker shifts (at alpha 0.05) was suggested between 2001/2002 and 2003/2004 (Figure HO-12).

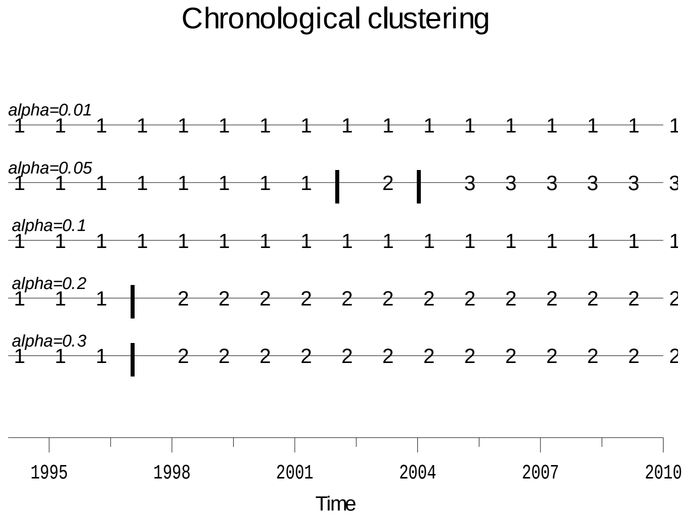

Figure HO-12. Results of the chronological cluster analyses performed on the 14 abiotic variables.

4.5. Results of integrated trend analyses based on biotic variables only

The temporal development of the biota in Holmön generally follows what was seen for the data set including all variables, but there is a stronger ordination and grouping of years (Figure PCBio). The two first components of the PCA explained 35.5 and 16 % respectively of the total variation. The years before 2001 generally have positive scores on PC 1 and is best characterised by high abundances of *Monoporeia*, ruffe, whitefish and *Saduria* (Figure HO-13). The years from 2002–2010 generally have negative values of PC 1 and is best characterised by higher concentrations of total zooplankton, cladocerans, rotifers and cyclopoid copepods as well as higher abundance of *Marenzelleria*, grey seals and roach. The strongest correlation between the temporal development of PC 1 and abiotic variables was observed for salinity (0.73), offshore fishing pressure (0.73) and coastal summer temperature (-0.52). For PC 2 the strongest correlation was obtained with BSI (-0.44) and local discharge of phosphorous (-0.43). As such, change in ecosystem structure might be related to a decrease in salinity and offshore fishing pressure and a concurrent increase in temperature and phosphorous loading from land. Interestingly species favoured by lower water temperatures as *Monoporeia* and whitefish has decreased, whereas there has been an increase in species favoured by warmer and more eutrophic conditions as roach and total zooplankton concentration.

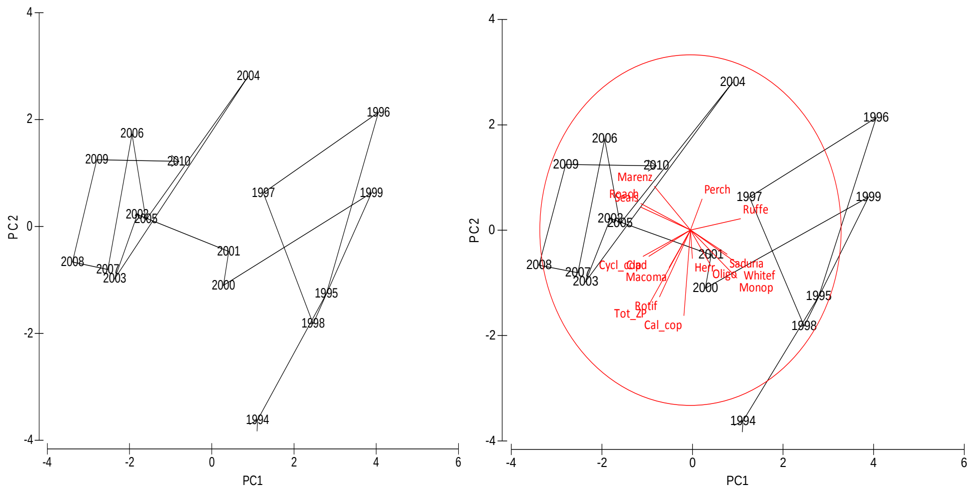

Figure HO-13. PCA output with sample scores and time-trajectory. Results of the standardized principal component analysis using the 16 biotic variables assembled for the Holmön area showing the time trajectory on the first factorial plane (left; PC1 = 35.5 %, PC2 = 16 % explained variance) and the biplot with loading of each variable and time-tajectory plot (right).

The outcome of the discontinuity analysis (chronological clustering) supported the PCA ordination to some extent. Only one shift was detected, in 1999/2000 (Figure HO-14), grouping the 1994–1999 and the years 2000–2010.

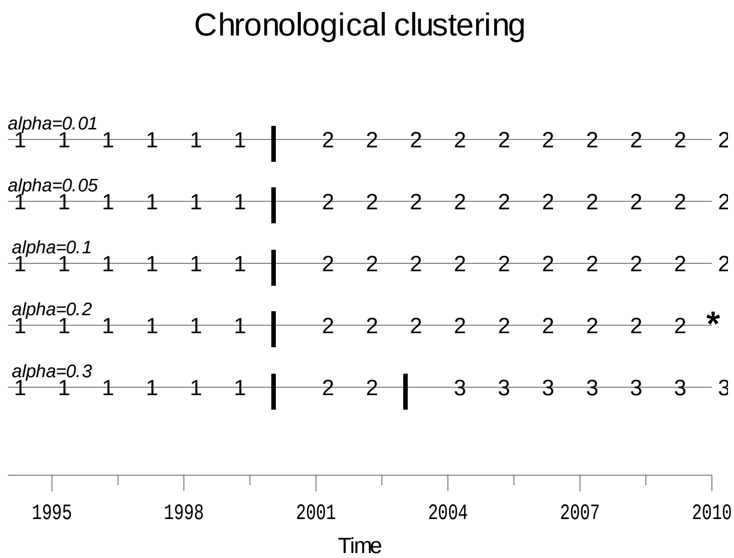

Figure HO-14. Results of the chronological cluster analyses performed on the 16 biotic variables.

4.6. References

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5. Bothnian Sea coast – Forsmark (FM)

5.1. Area description

An integrated assessment was performed for the coastal area of Formsark in the southern Bothnian Sea (Figure FM-1). The area has not been assessed within WGIAB before. Trends were assessed for the period 1987–2010.

The Forsmark area is a small archipelago area facing open sea. The surrounding land area is not densely populated. The level of local fishing pressure is low. However, the area is located close to a nuclear power plant with three reactors. A local, semi-enclosed artficial basin and its closest vicinity are subject to erosion and increased water temperatures caused by cooling water from the power plant. The data included in this assessment is, however, not collected from the affected areas, as verified by temperature loggers. The salinity level in the areas is around 5 psu.

Data used in the assessment covered abundance of coastal fish species, soft bottom benthic fauna and seals for the biotic variables. For the abiotic variables, data on local nutrient load and hydrographical information from monitoring stations in the nearby coastal area were included. For some abiotic variables, local measurements were not obtainable. In these cases, data from surface measurements in the closest relevant open sea monitoring station were included (SR5). No data on phytoplankton or zooplankton were included. This is because local in-formation was not available and corresponding open sea information was not considered representative enough.

Figure FM-1. Location of Forsmark area at the Central Baltic Sea coast of Sweden.

5.2. Variable descriptions

5.2.1. Hydrography

Hydrographical variables on temperature and salinity were included. Two temperature variables were included, one representing conditions during summer (august) and one during spring (May/June). Data on salinity was not available on a local scale, and was instead represented by data from the open sea. Additionally, the Atlantic oscillation index (AOI) was included in the analyses. The temperature variables and AOI did not show any significant changes over the studied time period, and salinity showed a decreasing trend.

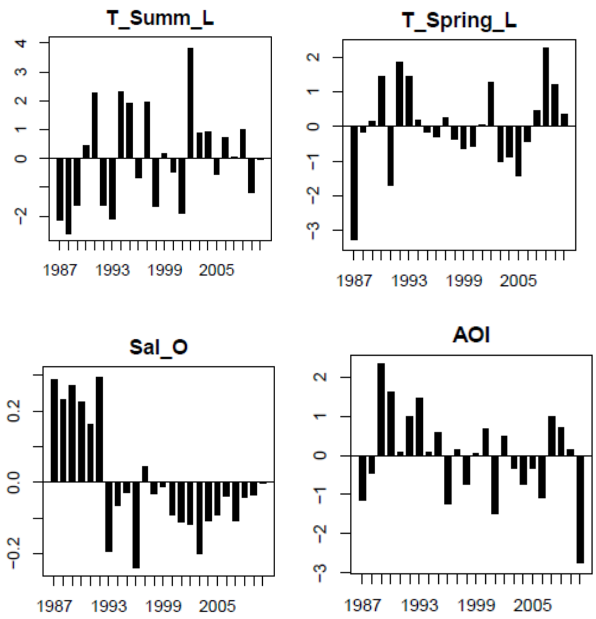

Figure FM-2. Long-term hydrographic changes in the Forsmark area: anomalies from the overall mean for T_Summ_L= coastal temperature during summer (°C, August), T_Spring_L= coastal temperature during spring (°C, May/June), Sal= surface salinity in the open sea during summer (psu, annual average), and AO=the Atlantic oscialltion index.

5.2.2. Nutrients

Nutrient data was represented by estimates of local nitrogen and phosphate loading from land (riverine runoff) and of influence from off shore areas, using data on total dissolved inorganic nitrogen and phosphorous from the nearest available open sea monitoring station (surface data). Additionally, the variable water transparency was included in order to indicate local changes in water clarity, as measured by Secchi depth measurements. No trend over time was seen in water transparency or nitrogen loading from land, but a decreasing trend was seen in phosphate loading. The concentrations of dissolved inorganic nutrients in the open sea showed opposite trends, with DIN decreasing and DIP increasing.

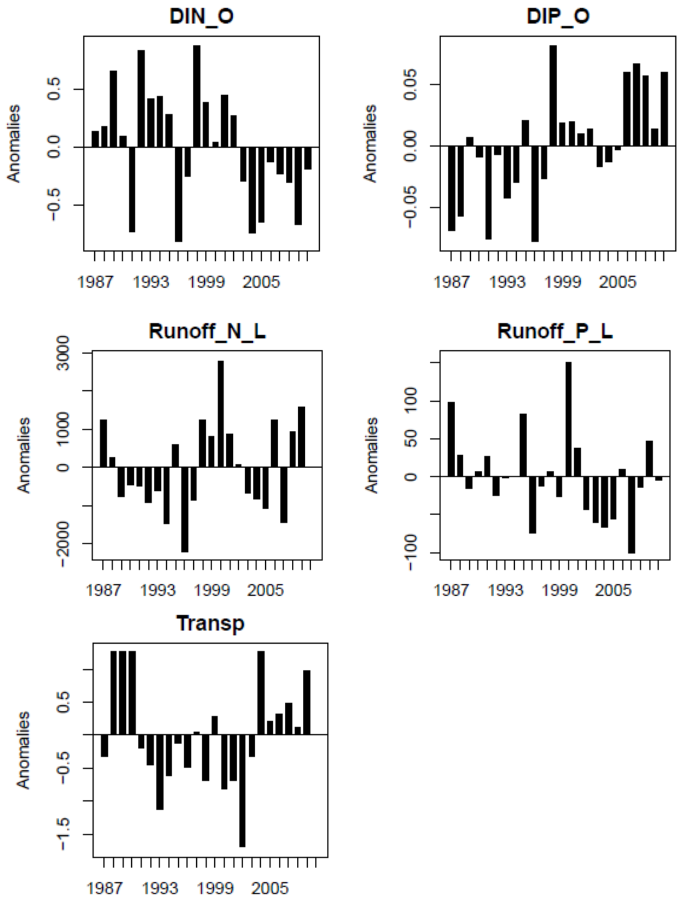

Figure FM-3. Long-term changes in nutrient-related variables in the Forsmark area, given as anomalies from the overall mean; Runoff_N_L= local nitrogen loading from land, Runoff_P_L= local phosphate loading from land (both tonnes per year), DIN=dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorous (umol*L^{-1}, both from open sea station BY15, 0-10 m depth, winter values), Transp= water transparency (meters).

5.2.3. Zoobenthos

Data on four commonly occurring taxa of soft bottom macrozoobenthos were included, based on data from a local monitoring program. The bivalve *Macoma baltica*, the isopod *Saduria entomon* as well as the invasive polychaete *Marenzelleria* spp. showed an increasing trend over the studied time period. No trend over time was seen in for the amphipod *Monoporeia affinis*.

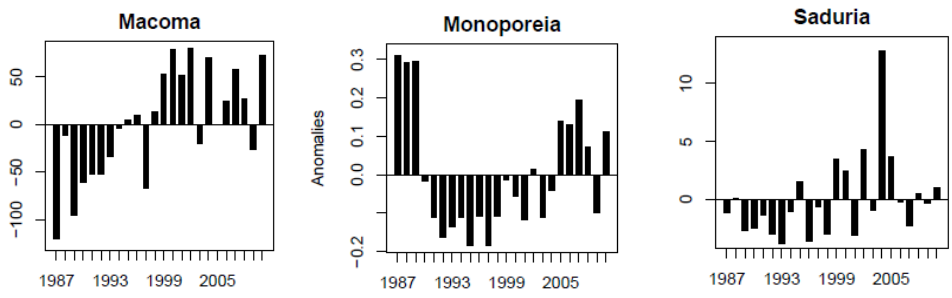

Figure FM-4. Long-term chan in zoobenthos in the Formsmark area: anomalies from the overall mean in biomass of Macoma baltica, Saduria entomon, and Monoporeia affinis, estimated as grams per square meter.

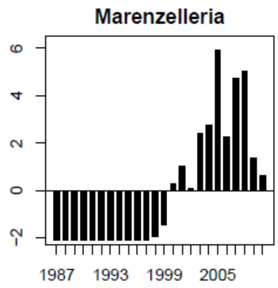

Figure FM-5. Alien species in the Forsmark area: anomalie of the overall mean for the polychaete *Marenzelleria* sp., which was observed in the area for the first time in 2004

5.2.4. Fish

Data on four species of fish were included. These were the freshwater species perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*), and whitebream (*Blicca bjoerkna*), as well as Baltic herring *(Clupea harengus)*. No significant linear trends over time were seen.

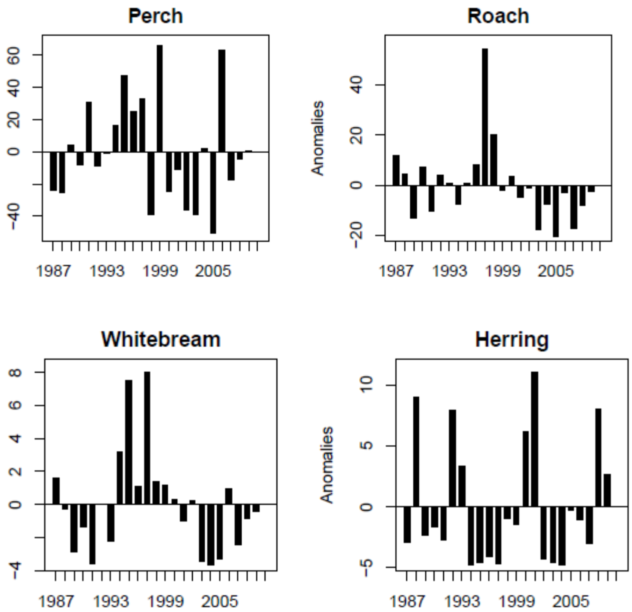

Figure FM-6, 7. Long term changes in fish species in the Forsmark area: anomalie of the overall mean for perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*), whitebream (*Blicca bjoerkna*) and herring (*Clupea harengus membrans*), estimated as catch per net and night in numbers (data from local monitoring programmes).

5.2.5. Seals

Number of grey seals (*Halichoerus grypus*) counted in the area showed an increasing trend, with a longer period of low abundances in the beginning of the time-series.

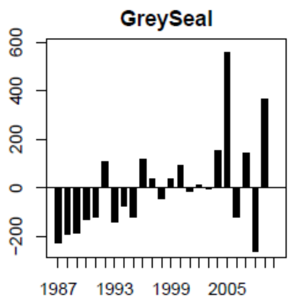

Figure FM-8. Long term changes in grey seal abundance in the Forsmark area: figure show anomalie from the overall mean of estimated total abundance in the region, based on national monitoring.

5.2.6. Fishing

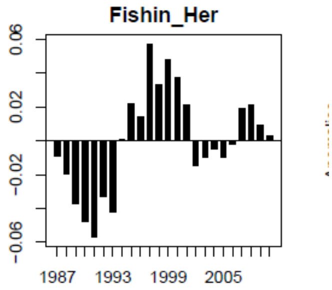

Figure FM-9. Long term changes in fishing pressure on herring: anomalie from the overall mean of the index (proportion removed for herring age 3-7, F-based, in the total Central Baltic Sea fisheries).

5.3. Results of integrated trend analyses based on all variables

The integrate analyses covered data within the time period 1987–2010. In all, 9 abiotic, 10 biotic and one fisheries-related variable were included (as presented in the section above). The traffic light plot in figure FM-10 compares the overall trends over time in the included variables.

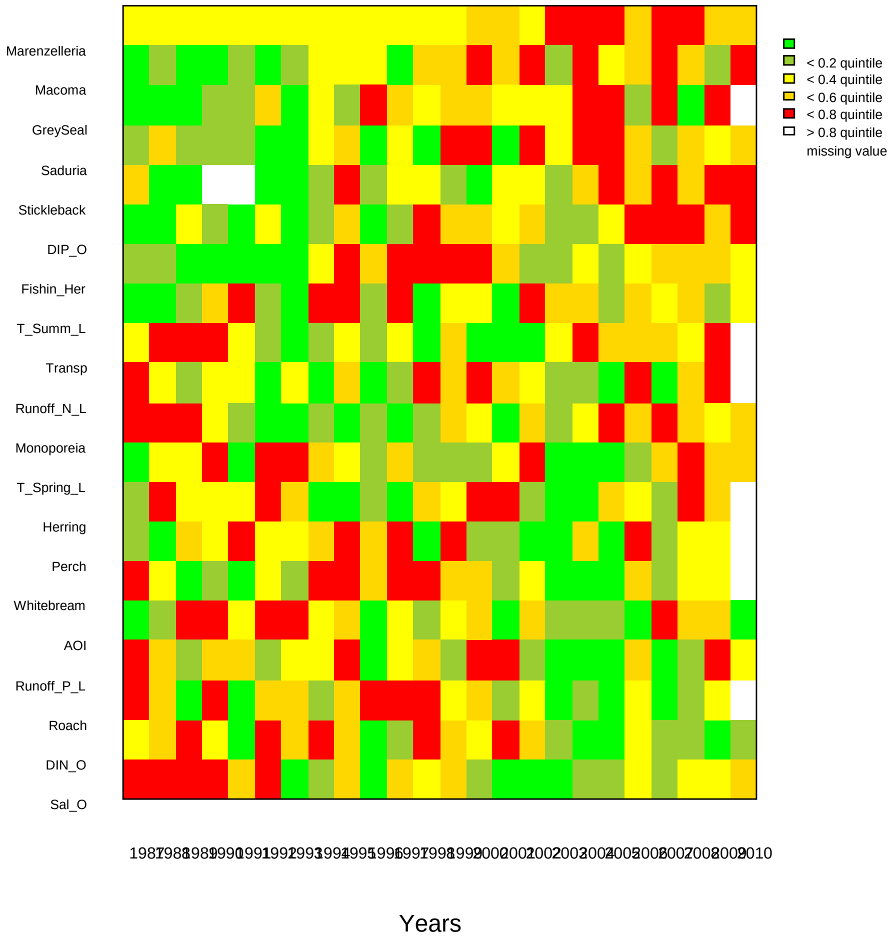

Figure FM-10. Traffic-light plot of the temporal development of 20 variables during 1987–2010 in the Forsmark coastal area. Variables were transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component of a PCA on all variables (see text below).

In the PCA on all variables, the first principal component accounted for 20.6 % of the observed variation, PC2 for 15.6% and PC3 for 13.9%. Changes along the first principal component mainly indicated a gradual change over time, mainly related to n increase in *Marenzelleria and Macoma*, but also in grey seal, stickleback and *Saduria.* For the abiotic variables, it was mainly associated with a decrease in salinity and DIN. The second principal component was mainly associated to relatively high levels of whitebream and herring fishery in the middle of the studied time period, and by relatively low levels of *Monoporeia* within the same time period. Chronological clustering analysis showed no main shifts in the multivariate pattern at alpha 0.05 or less.

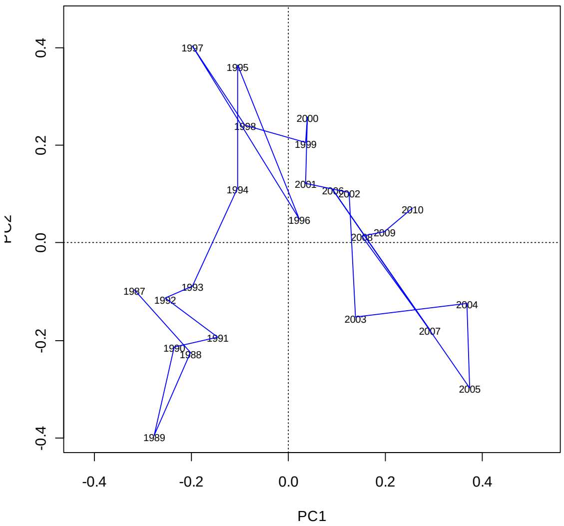

Figure FM-11 Results of the standardized principal component analysis using all 20 variables assembled for the Forsmark area showing the time trajectory on the first factorial plane (PC1 = 20.6 %, PC2 = 15.6% explained variance).

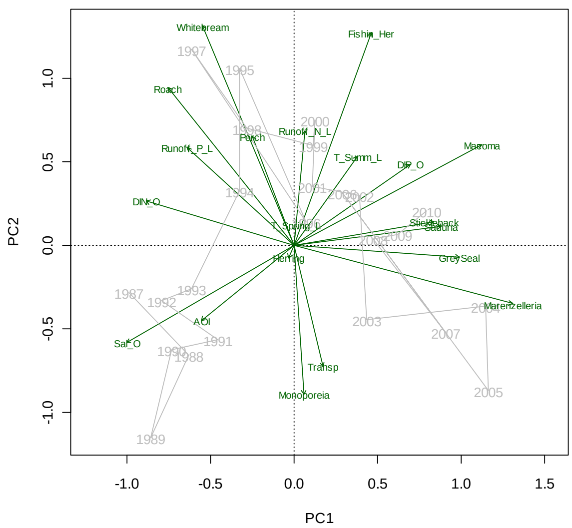

Figure FM-12. Results of the standardized principal component analysis using all 20 variables assembled for the Kvadöfjärden coastal area showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey) (PC1 = 20.6 %, PC2 = 15.6% explained variance).

5.4. Results of integrated trend analyses based on abiotic and fisheries related variables only

Nine abiotic and one fisheries related variable were included. The first principal component accounted for 22.5% of the variation, and the second component for 21.2%. The PCS indicated no distinct changes over time along PC1 but to some extent on PC2. Changes along PC1 were mainly related to N and P runoff. Changes along PC2 reflected a relatively lower salinity in more recent years. Chronological clustering analysis showed no main shifts in the multivariate pattern during the time period studied at alpha =0.05 or less.

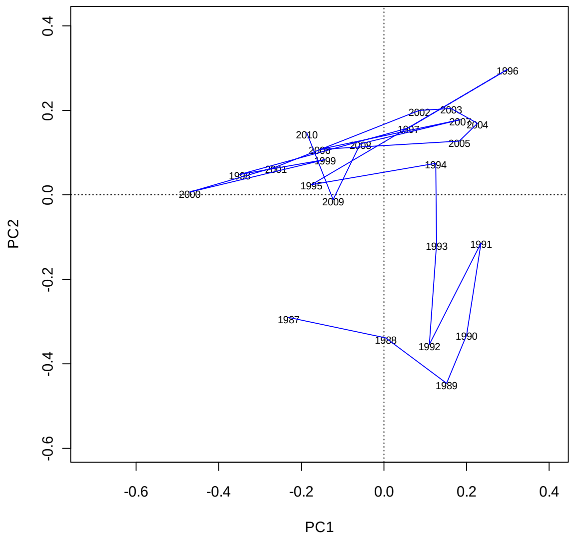

Figure FM-13. Results of the standardized principal component analysis using 9 abiotic and one fisheries-related variable assembled for the Forsmark area showing the time trajectory on the first factorial plane (PC1 = 22.5 %, PC2 = 21.2 % of total explained variance).

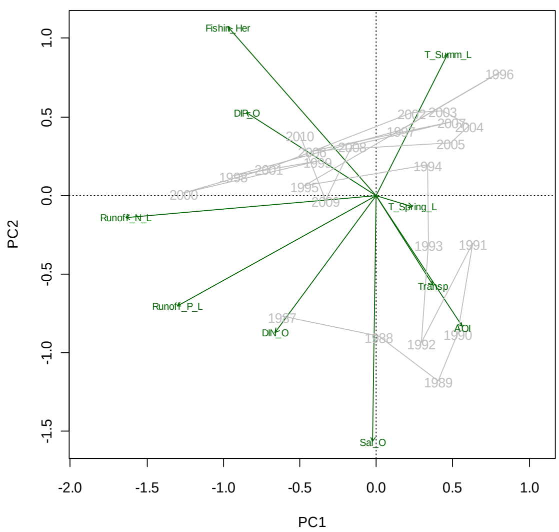

Figure FM-14. Results of the standardized principal component analysis using 9 abiotic and one fisheries related variable, showing variable loadings on the first factorial plane (for orientation: time trajectory in light grey) (PC1 = 22.5 %, PC2 = 21.2 % explained variance).

5.5. Results of integrated trend analyses based on biotic variables only

In the analyses based on biotic variables only, 10 variables were included. The first principal component accounted for 31.4% of the variation, and the second component for 18.0 %. The earliest years were characterised by relatively high levels of herring and Monoporeia, and some years in the middle of the time-series (especially 1995 and 1997) by high levels of the freshwater fish species roach, whitebream and perch. The 2000s were characterised by relatively high levels of all studied species, with the exception of these three. Chronological clustering analysis indicated a shift in the multivariate pattern around 2003/2004 at alpha= 0.01, corresponding to increased levels of stickleback, grey seal, *Macoma* and *Saduria*. Additional shifts were indicated around 1994/1995 as well as 2007/2008 at alpha = 0.05.

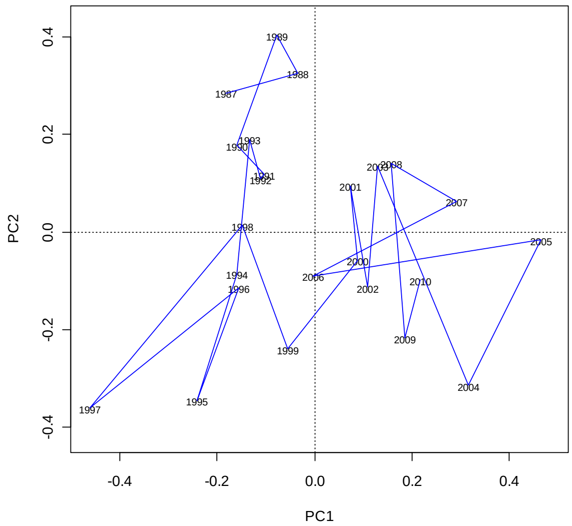

Figure FM-15. Results of the standardized principal component analysis using 10 biotic variables assembled for the Forsmark coastal area, showing the time trajectory on the first factorial plane (PC1 = 31.4 %, PC2 = 18.0% explained variance).

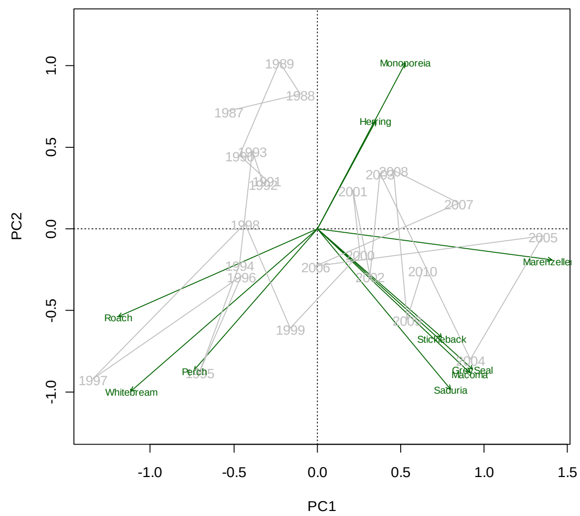

Figure FM-16. Results of the standardized principal component analysis using 10 biotic variables assembled for the Forsmark coastal area showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey) (PC1 = 31.4 %, PC2 = 18.0% explained variance).

6. Gulf of Finland coast - Narva Bay (NB)

Narva Bay with area approximately 3500 km^2 is the largest bay in the south-eastern Gulf of Finland. The water exchange between the bay and the open gulf is good. Seasonal fluctuations in water temperature occur above 30 m depth, mainly from May to November. Maximum temperatures of 22–24 °C are usually observed in July. In the deeper parts of the bay the temperature is stable throughout the year at 2–5 °C. During the winter, the bay is usually covered with ice. Maximum depth is 80 m, but most of the bay is only 20–40 m deep. Current analysis is based on data, collected mostly from two shallow (8 and 12m) coastal stations. The River Narva enters the bay in the southeastern corner and constitutes the most prominent nutrient source of Narva Bay. River Narva is the largest river of Estonia (average runoff 400 m^3/s) and second largest river flowing into the Gulf of Finland. The open parts of Narva Bay are influenced by water from the River Neva, the largest river in the whole Baltic Sea catchment area.

6.1. Univariate trend analyses

Data was compiled for integrated trend analysis for 46 variables covering the period 1993–2010. During this period, the water temperature has become warmer in the same time salinity has dropped. Nutrient concentrations during summer were also showing increasing trend as did the chlorophyll a concentration averaged for summer. Among biotic variables macrozoobenthos biomass and density had clear increasing trend. Diatom biomass in spring has clearly dropped since the beginning of time-series and other phytoplankton groups have become more abundant. *Keratella spp* biomass in spring is the only zooplankton variable with clear increasing trend.

6.2. Integrated analysis

In a PCA analysis on all variables, the first principal components explained 12.1 and 6.9 %, respectively. The most important variables explaining PC1 were non-dominating phytoplankton groups, *Keratella* and temperature in spring and chlorophyll a in; for PC2 air temperature on first half of the year and *Acartia* spp biomass and chlorophyll a in spring.

Discontinuity analyses showed that there were at least two states of ecosystem in Narva bay during the time-series, with the shift in year 2000. The shift of several parameters during years 1997–2000 was seen already in trend analyses. With that shift Narva Bay has become a less saline and warmer waterbody. Some variables related to eutrophication (nutrients, chlorophyll a and smaller zooplankton) were also increasing since 2000. However, there is some evidence of improvement during last few years (Anon, 2012).

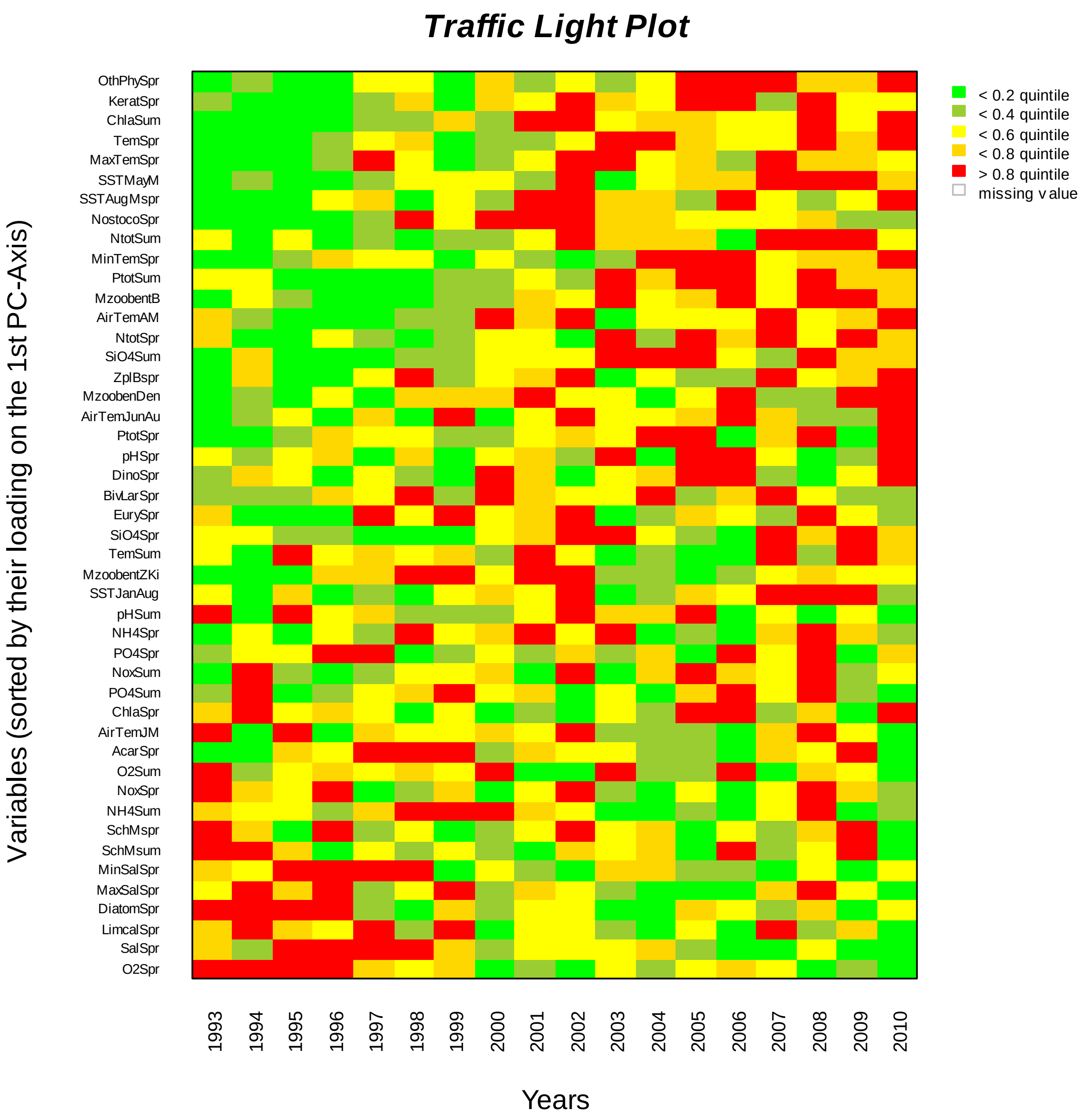

Figure NB-1. Traffic-light plot summarizing the temporal development of the variables studied for the Narva Bay (1993–2010). Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component of a PCA.

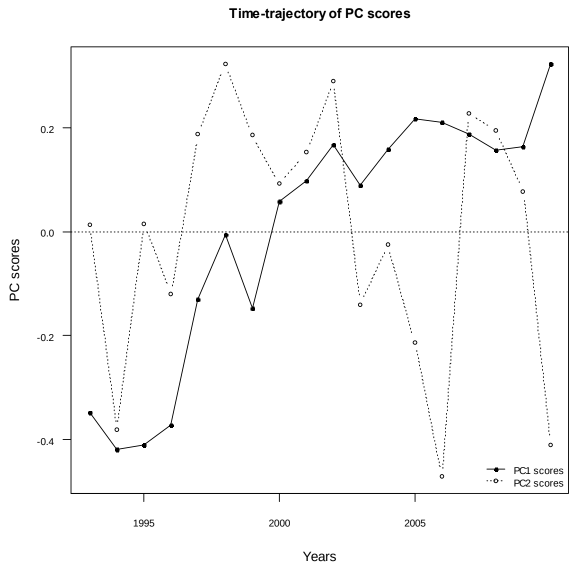

Figure NB-2. Results of the standardized principal component analysis using the 46 variables for Narva Bay showing PC1 (black circles) and PC2 scores (white circles) against time during 1993–2010.

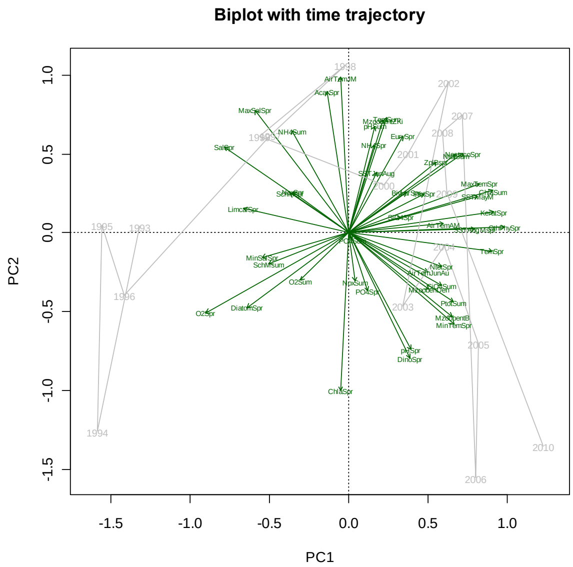

Figure NB-3. Results of the standardized principal component analysis using all time-series in Narva Bay in 1993–2010. The grey graph shows sample scores (years) on the first factorial plane, with a time trajectory, green arrows showing the corresponding variable loadings.

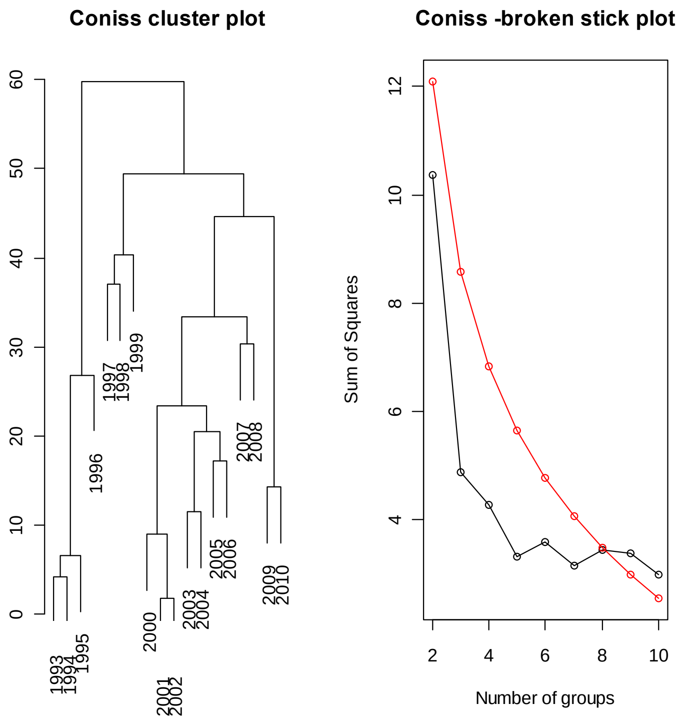

Figure NB-4. Results for Narva Bay; plot showing result of Constrained Clustering analysis and a broken stick model to determine the number of significant groups in the cluster analysis.

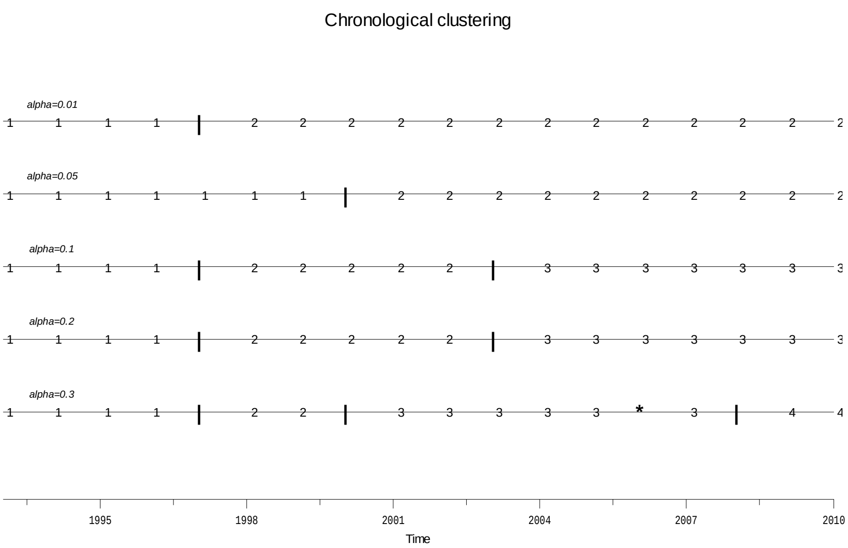

Figure NB-5. Results of the chronological cluster analysis for Narva Bay for the period of 1993–2010.

6.3. References

Anon 2012. Operational monitoring of Estonian coastal sea. Estonian Marine Institute, University of Tartu. Final report, Tallinn, 165 pp.

7. NE Gulf of Riga Coast - Pärnu Bay (PB)

Pärnu Bay is a relatively closed and very shallow (maximum depth 15 m) sea area in the northeastern part of the Gulf of Riga, Baltic Sea covering approximately 700 km^2. The hydrological conditions of the bay are formed under the complex influence of meteorological processes, direct river discharge from Pärnu River and water exchange with the open part of the Gulf of Riga. The currents are generally weak in the area and are mainly wind-induced (Suursaar *et al.* 2002). The bay is covered with ice in winter. In summer, the water is mixed down to the bottom with the long-term mean surface water temperature reaching to 21.5 °C. The salinity of the bay fluctuates from almost fresh water conditions in the river inflow area to 5.3 PSU (Anon 2012). The study area suffers under substantial eutrophication and multiple other human impacts like fisheries, recreation and tourism. Freshwater, but mostly euryhaline organisms dominate in the fauna of the bay.

7.1. Trend analyses

The trend analysis was performed for three different time periods: 1960–2010, 1969–2010 and 1993–2010. The following data were used for these three time periods:

i) 1960–2010: in total, 22 variables with 7 on climate and hydrography (air temperature in winter, spring and summer; annual river inflow; time of ice retreat, water transparency, surface salinity in the Gulf of Riga), 11 on zooplankton (abundance of *Cercopagis pengoi*, *Acartia* spp., *Eurytemora affinis*, *Keratella* spp., copepod *nauplii*, *Evadne nordmannii*, *Synchaeta* spp., *Pleopis polyphemoides*, *Bosmina* spp., *Limnocalanus macrurus*, and meroplankton) and 4 on fish (duration and abundance of herring larvae, pikeperch landings and mean weight of pikeperch in trapnet catches in spring).

ii) 1969–2010: in total 26 variables with 7 on climate and hydrography (air temperature in winter, spring and summer; annual river inflow; time of ice retreat, water transparency, surface salinity in the Gulf of Riga), 11 on zooplankton (abundance of *Cercopagis pengoi*, *Acartia* spp., *Eurytemora affinis*, *Keratella* spp., copepod *nauplii*, *Evadne nordmannii*, *Synchaeta* spp., *Pleopis polyphemoides*, *Bosmina* spp., *Limnocalanus macrurus*, and meroplankton) and 8 on fish and fisheries (duration and abundance of herring larvae; pikeperch, whitefish, smelt, vimba and perch landings, mean weight of pikeperch in trapnet catches in spring).

iii) 1993–2010: in total 34 variables with 13 on climate hydrography and water chemistry (air temperature in winter, spring and summer; water temperature; annual river inflow; time of ice retreat; water transparency; salinity in the Gulf of Riga and Pärnu Bay; concentration of O_2, P_{tot}, N_{tot} and SiO_4), 2 on phytoplankton (chlorophyll *a* and phytoplantkon biomass), 11 on zooplankton (abundance of *Cercopagis pengoi*, *Acartia* spp., *Eurytemora affinis*, *Keratella* spp., copepod *nauplii*, *Evadne nordmannii*, *Synchaeta* spp., *Pleopis polyphemoides*, *Bosmina* spp., *Limnocalanus macrurus*, and meroplankton) and 8 on fish and fisheries (duration and abundance of herring larvae; pikeperch, whitefish, smelt, vimba and perch landings, mean weight of pikeperch in trapnet catches in spring).

7.1.1. Hydroclimate

In general, air temperature has became warmer over time. This is evidenced by more positive anomalies since the late 1980s and with less frequent negative anomalies since then. Water transparency has dropped sharply since the mid-1970s, but exhibited close to neutral anomalies during a few past years. Anomalies of the annual river inflow were mostly negative until the second half of the 1970s and have shown fluctuations around the log-term mean since the late 1980s with mostly positive values in the 2000s. Sea surface salinity started to decline since the mid 1970s and reached minimum during the late 1980s. Since then, there is a clear trend for reduction of negative anomalies. During the past years, salinity has exceeded the long-term mean. Anomalies of the timing of ice retreat also exhibit substantial variability and dynamics over time: since after the later 1980s, ice retreat has shifted to earlier compared to the previous time. This shift has accompanied by large variability (both negative and positive anomalies were recorded after the end of the 1980s) compared to that before the shift.

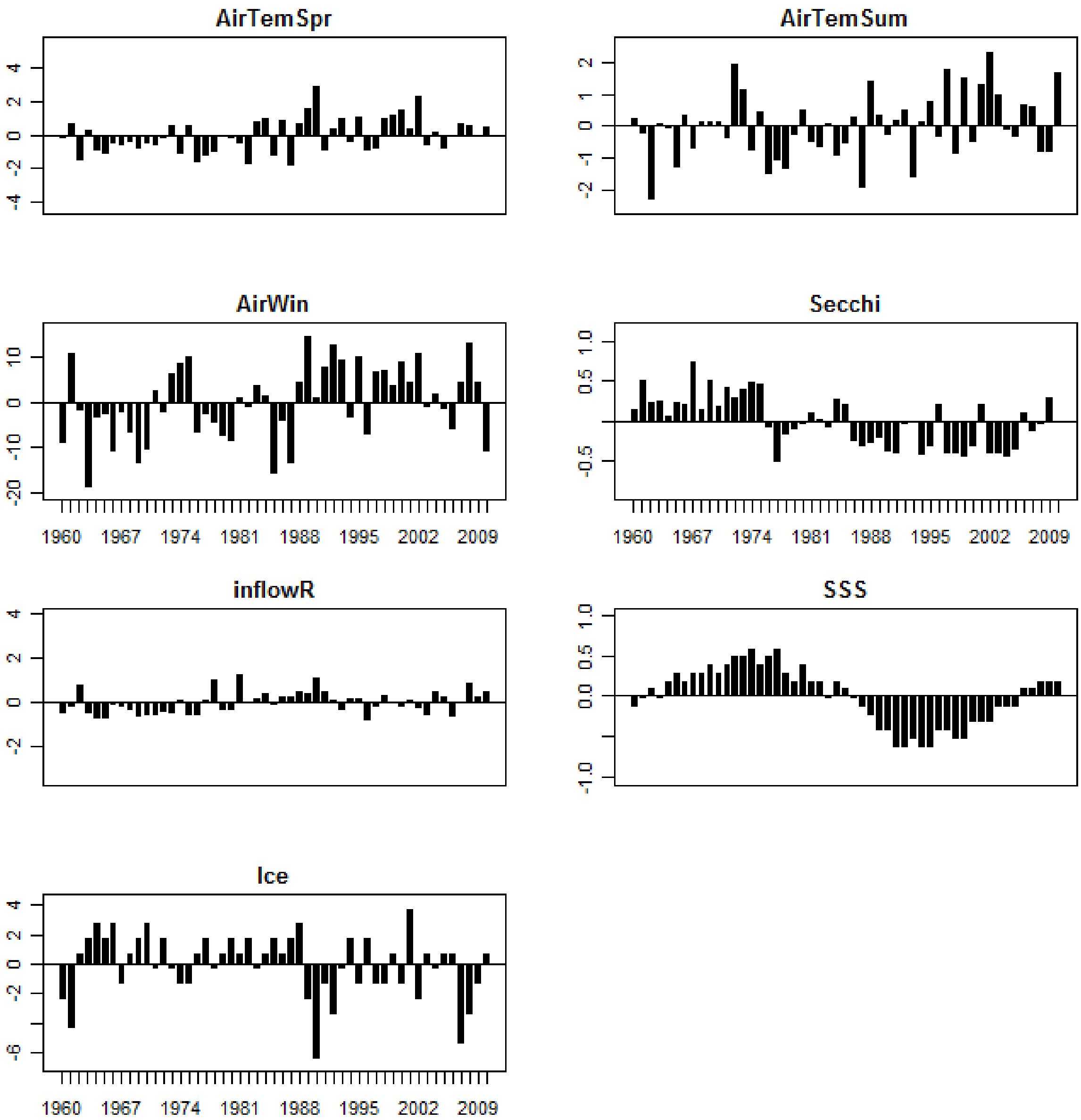

Figure PB-1. Long-term hydroclimatic changes in the NE Gulf of Riga: anomalies of the air temperature in spring (AirTempSpr), air temperature in summer (AirTempSum), air temperature in winter (AirWin), water transparency (Secchi), annual river inflow (inflowR), sea surface salinity (SSS), and timing of ice retreat (Ice).

7.1.2. Biota

As abiotic, the biotic component also has undergone substantial changes since 1960.The dominating copepods (*Eurytemora affinis* and *Acartia* spp.) show mainly positive anomalies since the 1990s while the arctic large copepod *Limnocalanus marcurus* has fallen into depression since the early 1980s. Two positive (until early 1970s and after late 1990s) and one negative phase (between early 1970s and late 1990s) was observed for copepod *nauplii*. Both studied rotifer taxa – *Keratella* spp. and *Synchaeta* spp. – substantially fluctuate over time with less frequent negative anomalies since mid 1990s. The dominating cladoceran - *Bosmina* spp. - varied substantially until the mid 1970s, since when only positive anomalies were recorded. However, after the invasion of predatory alien cladoceran *Cercopagis pengoi*, only negative anomalies of *Bosmina* spp. were observed. Broadly similar long-term behaviour was also recorded for *Pleopis polyphemoides*. Another cladoceran – *Evadne nordmanii* – has mainly shown negative abundance anomalies until the mid 1970s, since when no clear annual long-term pattern is evident. Meroplankton shows positive anomalies in the 1960s and since the mid 1990s, while mostly negative anomalies were recorded in between.

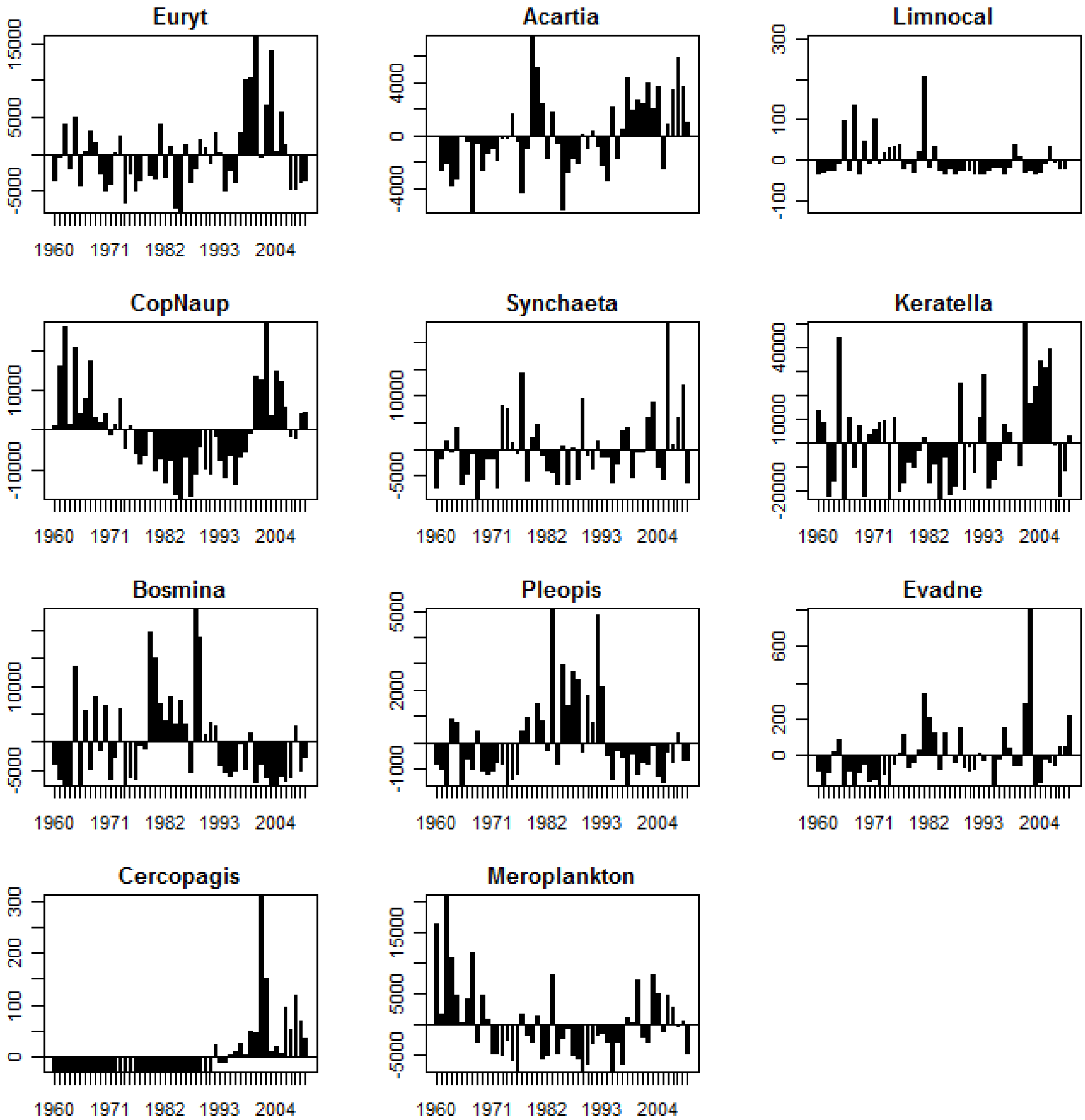

Figure PB-2. Long-term changes in the zooplankton community in the NE Gulf of Riga: anomalies of the overall mean presented for *Eurytemora affinis* (Euryt), *Acartia* spp. (Acart), *Limnocalanus macrurus* (Limnocal), copepod *nauplii* (CopNaup), *Synchaeta* spp. (Synchaeta), *Keratella* spp. (Keratella), *Bosmina* spp. (Bosmina), *Pleopis polyphemoides* (Pleopis), *Evadne nordmanii* (Evadne), *Cercopagis pengoi* (Cercopagis) and meroplankton (Meroplankton).

Larval herring has been more abundant between early 1970s and early 2000s, while during the 1960s and since the early 2000s mostly negative anomalies were observed. Presence of larval herring has also undergone substantial changes: it has almost gradually increased since the beginning of the time-series to until the late 1980s, after when sharp drop to negative anomalies has occurred. Pikeperch landings have two major peaks over time (turn of the 1960/1970s and second half of the 1990s) while during most other years negative anomalies were recorded. Mean weight of pike-perch in trapnet catches in spring was at the highest levels during the second half of the 1970s, but sharply decreased since then, reached the lowest values during the second half of the 1990s and has remained low until now.

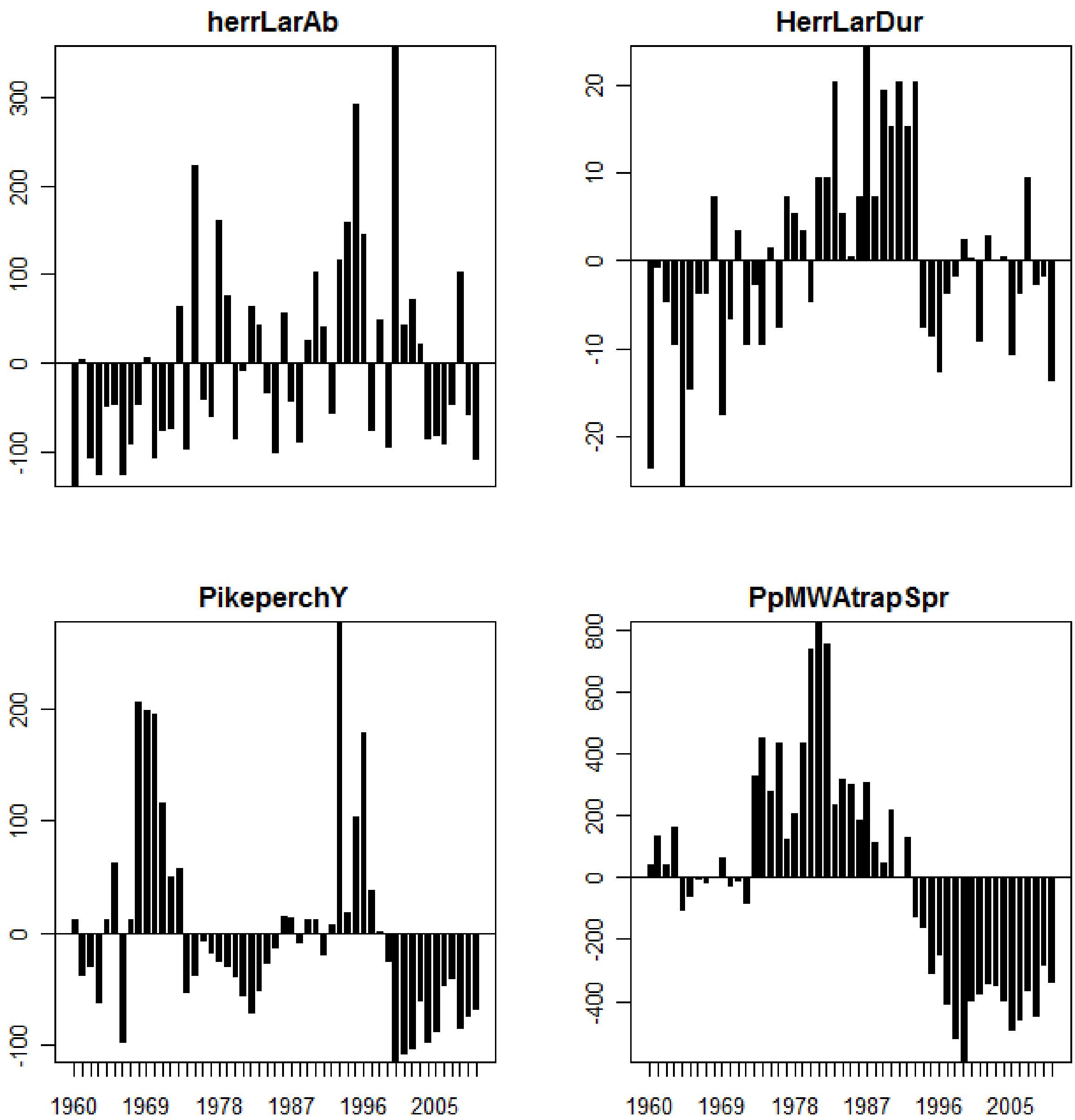

Figure PB-3. Long-term changes in fish in the NE Gulf of Riga: anomalies of the overall mean presented for herring larval abundance (HerrLarAb), duration of presence of larval herring (HerrLarDur), pikeperch *Stizostedion lucioperca* landings (PikeperchY) and mean weight of pikeperch in trapnet catches in spring (PpMWAtrapSpr).

7.2. Integrated analysis

We present here results graphically for the period of 1960–2010 with inclusion of 22 variables. In general, Gulf of Riga surface salinity, pikeperch mean weight in trapnet catches, ice coverage, Secchi depth, *Limnocalanus macrurus* abundance and *Bosmina* spp. abundance tended to be higher in the 1960s and the 1970s while spring and winter air temperature, abundance of *Acartia* spp., *Eurytemora affinis* and *Keratella* spp. were higher recently. In addition, several variables had higher values during the beginning and towards the end of the time-series with lower values in between. These were, for instance, abundance of copepod *nauplii* and meroplankton.

For the period of 1969–2010 (with 26 variables), whitefish, perch and smelt landings were, in addition to the already named variables above, high in the beginning of the time-series while landings of vimba were higher more recently.

For the period of coverage of the national monitoring programme (1993–2010) in total 34 variables were included. Although substantial number of data for additional variables was obtained, significant contraction of the time-scale has taken place. Therefore, the system dynamics and relative situation has considerably changed compared to that to the longer time perspective described above. Total phosphorus and oxygen content, salinity, landings of pikeperch and vimba and duration of herring larvae were the highest in the beginning of the time-series while SiO_4 content, surface salinity of the Gulf of Riga, smelt and perch landings, abundance of copepod *nauplii* and *Cercopagis pengoi* were higher more recently.

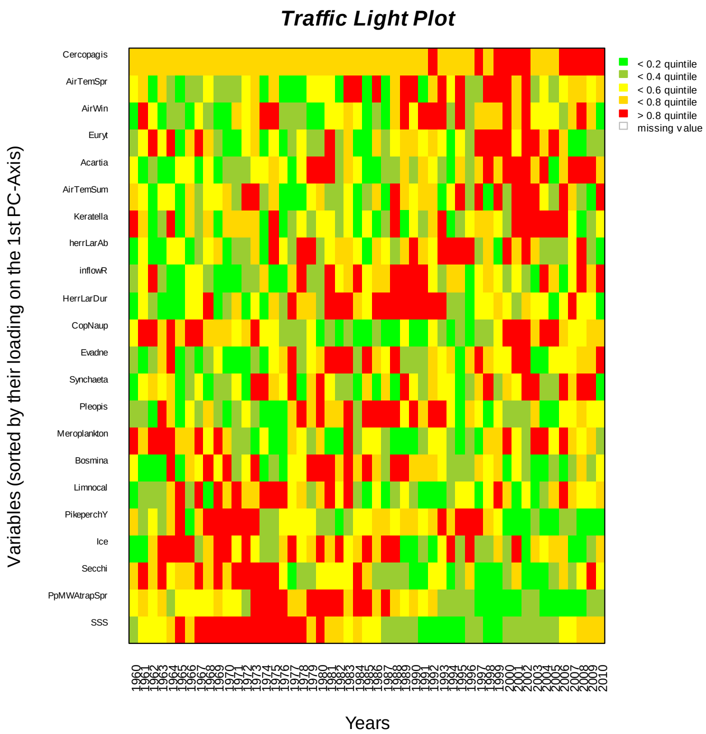

Figure PB-4. Traffic-light plot of the temporal development of Pärnu Bay time-series during 1960–2010. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component.

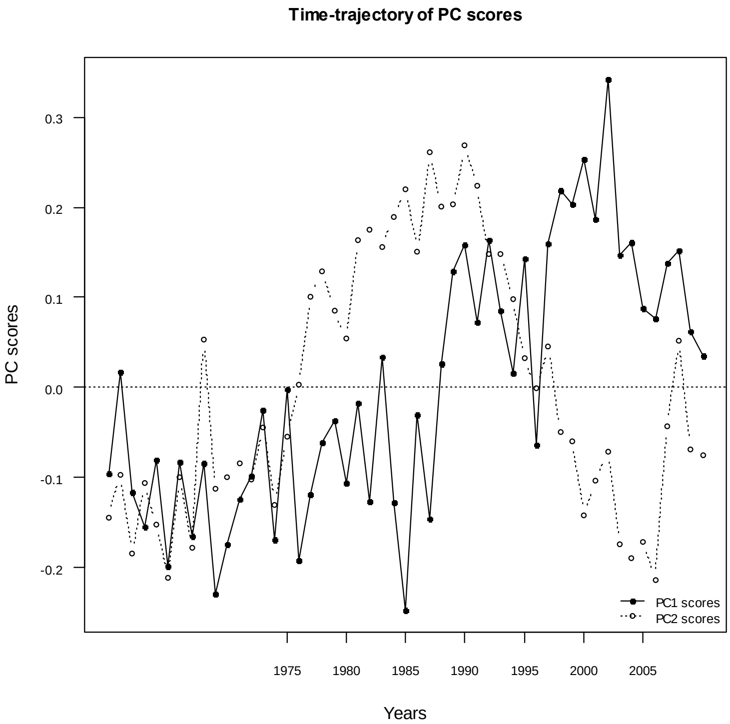

Figure PB-5. Results of the standardized principal component analysis using the 22 variables for Pärnu Bay showing PC1 (black circles) and PC2 scores (white circles) against time during 1960–2010.

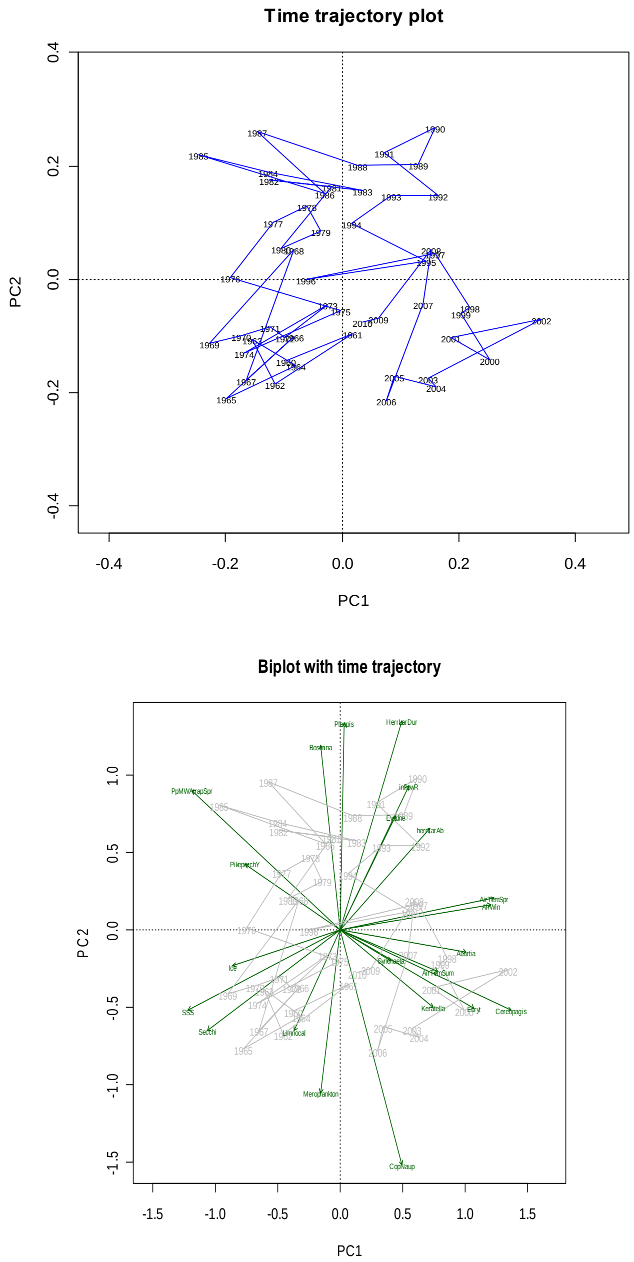

Figure PB-6. Results of the standardized principal component analysis using all time-series in Pärnu Bay in 1960–2010. The left graph shows sample scores (years) on the first factorial plane, with a time trajectory. The right graph shows the corresponding variable loadings.

In the PCA analysis, the first principal components explained 21.5 and 16.4 %, respectively. The most important variables explaining PC1 were *Cercopagis pengoi* abundance, spring and winter air temperatures and Gulf of Riga surface salinity and for PC2 copepod *nauplii* abundance, duration of larval herring and *Pleopis polyphemoides* abundance. The constrained hierarchical clustering indicates that there might be a shift in the early 1990s (1991/1992), but potentially also in the mid 1970s (1976/1977). However, the chronological cluster analysis (at alpha 0.05) points to ecosystem transition periods in the mid 1970s and during the turn of 1980–1990. Since the early 1990s, the temperatures are generally higher and water salinity and Secchi depth are lower. Of the biota, the abundance of brackish *Eurytemora affinis* and warm water preferring *Acartia* spp. has been high and that of small-sized cladocerans (*Bosmina* spp., *Evadne* *nordmannii*) low since early 1990s. Catch composition of the most valuable commercial commercial fish – pikeperch – indicates that larger fish are already taken out from the sea and catch is dominated by relatively small fish. Shift in some of these changes are already visible during the mid 1970s, when sharp drop in the Gulf of Riga surface salinity, water transparency and abundance of the arctic *Limnocalanus macrurus* has taken place. In addition, larval herring abundance was lower until the mid 1970s than afterwards. However, several variables exhibit periodically fluctuating values with low/high values in the 1960s and the 1970s, opposite pattern afterwards until the turn of 1980–1990 after which they have returned to the earlier state. These are, for instance, river inflow, abundance of copepod *nauplii*, *Evadne nordmanii* and *Pleopis polyphemoides* abundance, and duration of occurrence of herring larvae.

For the period of 1969–2010, the first principal components explained 25.7 and 15.4 %, respectively. The most important variables explaining PC1 were whitefish landings, *Cercopagis pengoi* abundance and Gulf of Riga salinity, and for PC2 abundance of copepod *nauplii*, duration of larval herring and *Pleopis polyphemoides* abundance. The constrained hierarchical clustering indicates that there might be three shifts in the mid 1980s (1983/1984), early 1990s (1991/1992) and late 1990s (1998/1999).

For the period of 1993–2010, the first principal components explained 23.9 and 12.4 %, respectively. The most important variables explaining PC1 were smelt landings, copepod *nauplii* and total phosphorus content, and for PC2 Secchi depth, salinity of Pärnu Bay and abundance of *Pleopis polyphemoides*. The constrained hierarchical clustering indicates that there might be only one shift with timing in the late 1990s (1998/1999).

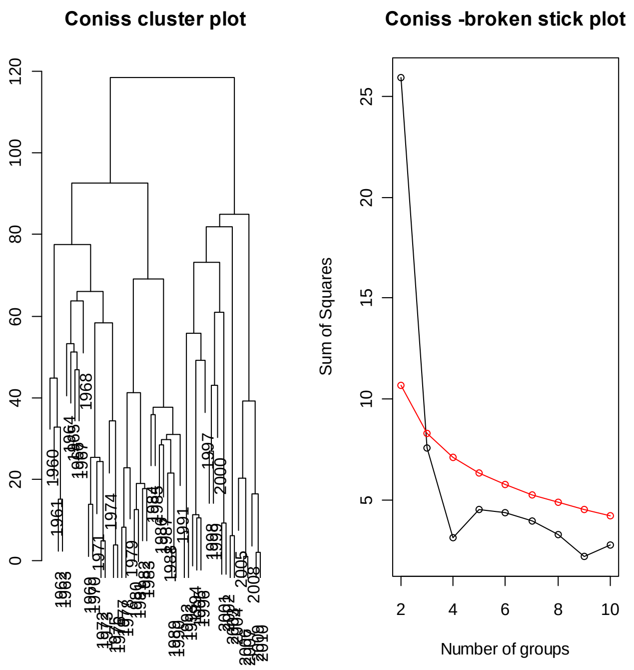

Figure PB-7. Results for Pärnu Bay: A cluster plot from the Constrained Clustering analysis and a broken stick model to determine the number of significant groups in the cluster analysis.

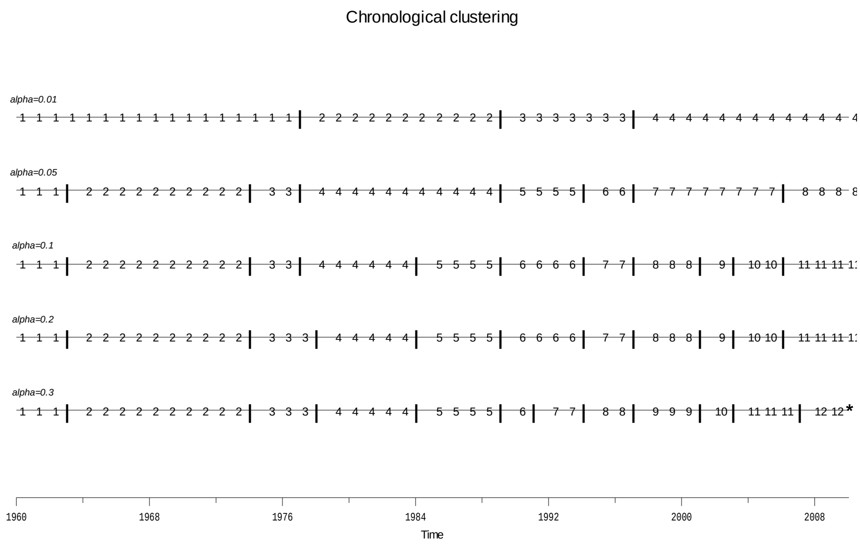

Figure PB-8. Results of the chronological cluster analysis for Pärnu Bay for the period of 1960–2010.

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Table PB-2. Description of the dataset for the analysis of the northeastern Gulf of Riga coast.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Abiotic										
Winter air temperature	AirWin	°C	Pärnu	Winter		1960–2010	EMI			Laur *et al.* subm., Arula *et al.* in prep
Spring air temperature	AirTempSpr	°C	Pärnu	Spring		1960–2010	EMI			Laur *et al.* subm., Arula *et al.* in prep
Summer air temperature	AirTempSum	°C	Pärnu	Summer		1960–2010	EMI			Laur *et al.* subm., Arula *et al.* in prep
Water transparency	Secchi	m	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Secchi disc		Laur *et al.* subm., Arula *et al.* in prep
River runoff	inflowR	m^{-3}	Pärnu	Annual	Ice-free season	1960–2010	EMI			Laur *et al.* subm., Arula *et al.* in prep
Sea surface salinity	SSS	PSU	Gulf of Riga	Annual		1960–2010				Omstedt 2011

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Timing of ice retreat	Ice	Jualian day	Gulf of Riga			1960–2010	EMHI			Laur *et al.* subm., Arula *et al.* in prep
Water temperature		°C	NE GoR coast	Spring-autumn	June-September	1993-2010	EMI			Anon 2011a
Salinity		PSU	NE GoR coast	Spring-autumn	June-September	1993-2010	EMI			Anon 2011a
Concentration of O_2		mg l^{-1}	NE GoR coast	Spring-autumn	June-September	1993-2010	EMI			Anon 2011a
Concentration of SiO_4		µmol l^{-1}	NE GoR coast	Spring-autumn	June-September	1993-2010	EMI			Anon 2011a
Concentration of Ntot		µmol l^{-1}	NE GoR coast	Spring-autumn	June-September	1993-2010	EMI			Anon 2011a
Concentration of Ptot		µmol l^{-1}	NE GoR coast	Spring-autumn	June-September	1993-2010	EMI			Anon 2011a
Phytoplankton										
Chla		mg/m^3	NE GoR coast	Spring-Autumn	June-September	1993-2010	EMI			Anon 2011a
Phytoplankton biomass		mg l^{-1}	NE GoR coast	Spring-Autumn	June-September	1993-2010	EMI			Anon 2011a
Zooplankton										

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Eurytemora affinis	Euryt	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al*. 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Acartia spp.	Acart	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al*. 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Limnocalanus macrurus	Limnocal	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al*. 2009, Põllupüü 2010, Anon 2011a, Unpubl. data

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Copepod nauplii	CopNaup	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al*. 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Synchaeta spp.	Synchaeta	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al*. 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Keratella spp.	Keratella	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al*. 2009, Põllupüü 2010, Anon 2011a, Unpubl. data

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Bosmina spp.	Bosmina	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al.* 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Pleopis polyphemoides	Pleopis	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al.* 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Evadne nordmannii	Evadne	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al*. 2004, Kotta *et al.* 2009, Põllupüü 2010, Anon 2011a, Unpubl. data

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Cercopagis pengoi	Cercopagis	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al.* 2004, Kotta *et al.* 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Meroplankton	Meroplankton	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960–2010	EMI	Juday net		Ojaveer *et al.* 2004, Kotta *et al.* 2009, Põllupüü 2010, Anon 2011a, Unpubl. data
Fish										
Herring larvae	HerrLarAb	ind m^{-3}	NE GoR coast	Spring-summer	May-July	1960-2010	EMI	Hensen net		Ojaveer *et al.* 2011, Anon. 2011b
Duration of presence of larval herring	HerrLarDur	Days	NE GoR coast	Spring-summer	May-July	1960-2010	EMI	Hensen net		Ojaveer *et al.* 2011, Anon 2011b
Pikeperch landings	PikeperchY	tons	NE GoR coast	Annual	Jan-Dec	1960-2010	EMI	Catch statistics		Unpubl.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Mean weight of pikeperch in trapnet catches	PpMWAtrapSpr	kg	NE GoR coast	Spring	May	1960-2010	EMI			Unpubl.
Whitefish landings		tons	NE GoR coast	Annual	Jan-Dec	1969-2010	EMI	Catch statistics		Unpubl.
Smelt landings		tons	NE GoR coast	Annual	Jan-Dec	1969-2010	EMI	Catch statistics		Unpubl.
Vimba landings		tons	NE GoR coast	Annual	Jan-Dec	1969-2010	EMI	Catch statistics		Unpubl.
Perch landings		tons	NE GoR coast	Annual	Jan-Dec	1969-2010	EMI	Catch statistics		Unpubl.

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8. W Gulf of Riga Coast (GoRW)

8.1. Area description

Located in the eastern part of the Baltic Sea, the Gulf of Riga west coast is a part of the larger Gulf of Riga basin (Figure GoRW-1). The Gulf of Riga is a shallow sub-system of the Baltic Sea with restricted water exchange with the surface water of the Baltic Proper. The Gulf is highly influenced by riverine runoff, with 18–56 km^3 of freshwater discharging annually into the 424 km^3 large Gulf. Consequently, the Gulf of Riga is considered to be one of the most eutrophic regions of the Baltic Sea (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, the hydrographical and biological characteristics of the Gulf differs distinctly from the western and central Baltic Sea. Study area covered:

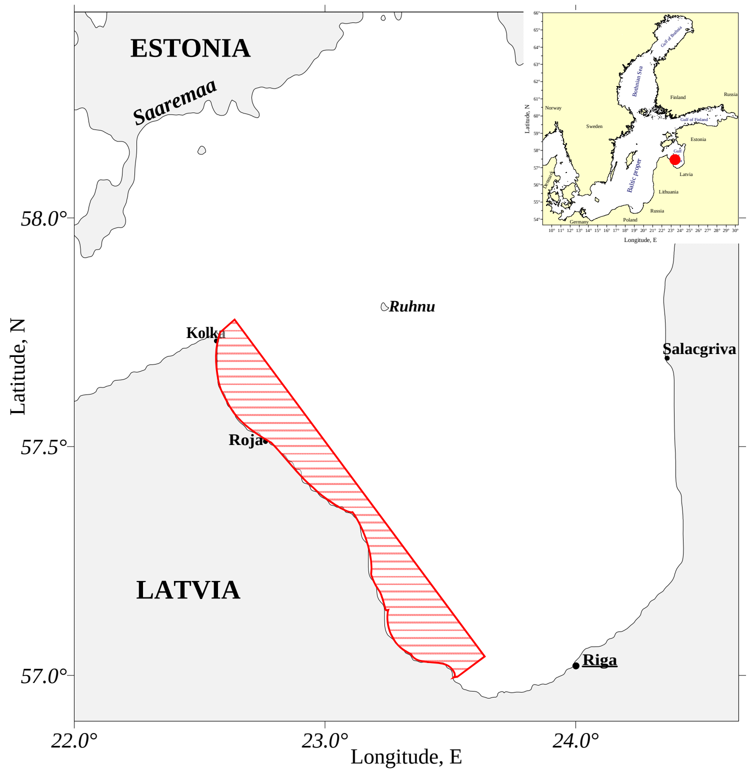

Figure GoRW-1. The Gulf of Riga with the red shaded area included in the analysis.

8.2. Variable descriptions

For the integrated analyses of the Gulf of Riga west coast in total 23 variables were considered: 2 physical, 4 nutrient, 4 zooplankton, 11 fish and fishery-related datasets and 2 others (BSI, chlorophyll *a*). No data on phytoplankton, and higher trophic levels (i.e. seals and birds) were included by fact that reliable local or open sea datasets was not available for these variables. For the zooplankton and part of fish (herring) variables only offshore time-series were used. For other variables data from stations restricted to 10m depth were used. All datasets were compiled to one estimate per year (July/August) and covered the period 1986–2011 with several gaps that were replaced by means of nearby values.

8.2.1. Hydrography

The Gulf of Riga west coast as well as entire part of the Gulf of Riga lacks a permanent halocline and the water column is completely mixed during autumn and winter. Freshwater input by precipitation and river runoff, and restricted water exchange with the surface layer of the Baltic Proper determines low salinity in the Gulf of Riga. For hydrologic variables only water temperature and salinity were available with no clear trends over time (Figure GoRW-2).

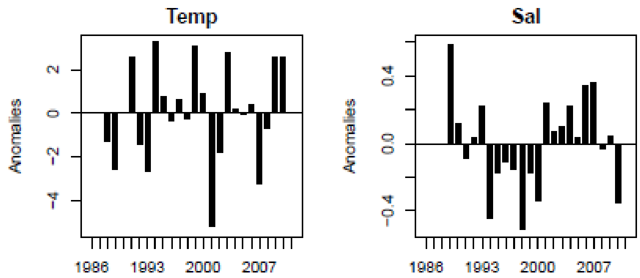

Figure GoRW-2. Long-term hydrographic changes in the Gulf of Riga west coast: anomalies of the overall mean presented for Water temperature (°C) and Water salinity (psu); (Presented from left to right).

8.2.2. Nutrients

From nutrient variables only for dissolved inorganic nitrogen NH4 and total nitrogen decreasing trend over time have been observed (Figure GoRW-3).

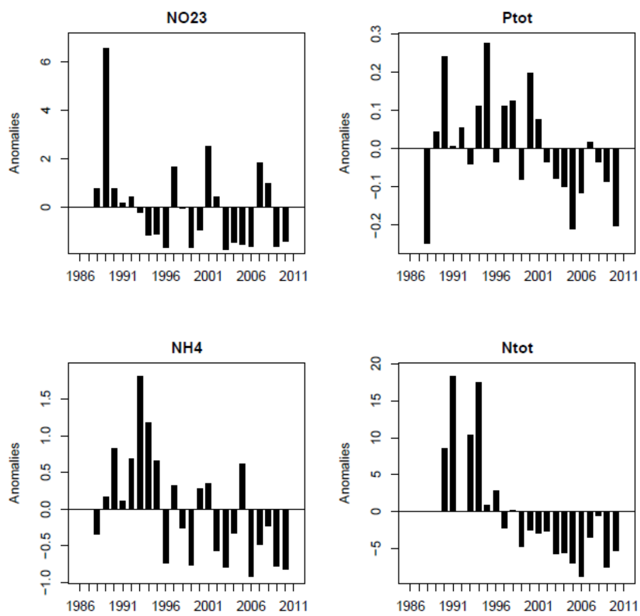

Figure GoRW-3. Long-term nutrient changes in the Gulf of Riga west coast: anomalies of the overall mean presented for Dissolved nitrate + nitrite – NO23, Total phosphorus – Ptot, Ammonium – NH4, Total nitrogen – Ntot (all nutrients are given in µmol*l-1); (Presented from top left to bottom right).

8.2.3. Zooplankton

Zooplankton variables were with no clear trends and in 2 cases with opposite trends - Acartia decreasing and Cercopagis increasing over time (Figure GoRW-4). Invasive predatory cladoceran *Cercopagis pengoi* is a significant component of the zooplankton community in the Gulf of Riga since the mid-1990s. Its biomass was record-high in 2007 and 2009, however there are significant fluctuations from year to year.

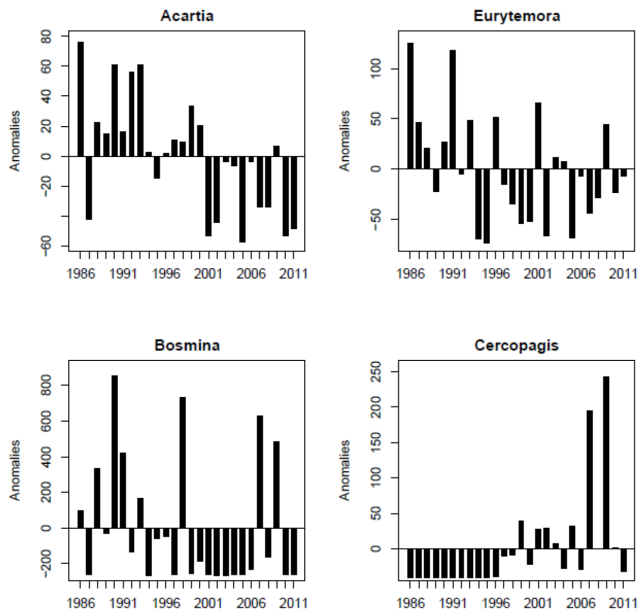

Figure GoRW-4. Long-term zooplankton changes in the Gulf of Riga in August: anomalies of the overall mean presented for *Acartia* spp. *Eurytemora affinis*, *Bosmina longispina*, *Cercopagis pengoi* (all zooplankton are given in mg/m^3); (Presented from top left to bottom right).

8.2.4. Fish

Clear positive trends for fish variables were found only for perch CPUE. Three-spined and nine spined stickleback species represented decreasing trends. Other variables were with no clear trends and in most cases with some extreme values over period (Figure GoRW-5). Fluctuations and extreme high values in some years are caused by fact that most of fish variables were obtained from annual beach seine catches in coastal zone up to 3 meters depth (Vitins, 1989) Fish communities of shallow coastal zones are not stable and mainly affected by wind directions and upwelling events. Herring is the dominating commercial fish species in the Gulf of Riga and the main planktivorous predator with spawning grounds located in the coastal zones. During the last decade there are large scale fluctuations in strength of herring year classes - very strong year classes are followed by weak recruitment in next year.

Cod was present in the Gulf of Riga at the beginning of the 1980s, when the Baltic cod stock was on its highest recent level, then virtually disappeared and now is present again when stock is rebuilding. Datasets for cod in the Gulf of Riga west coast as in entire part of the Gulf of Riga are not available.

Sprat is permanently found in the Gulf of Riga, but its abundance was comparatively low and fluctuated depending on the stock abundance in the Central Baltic.

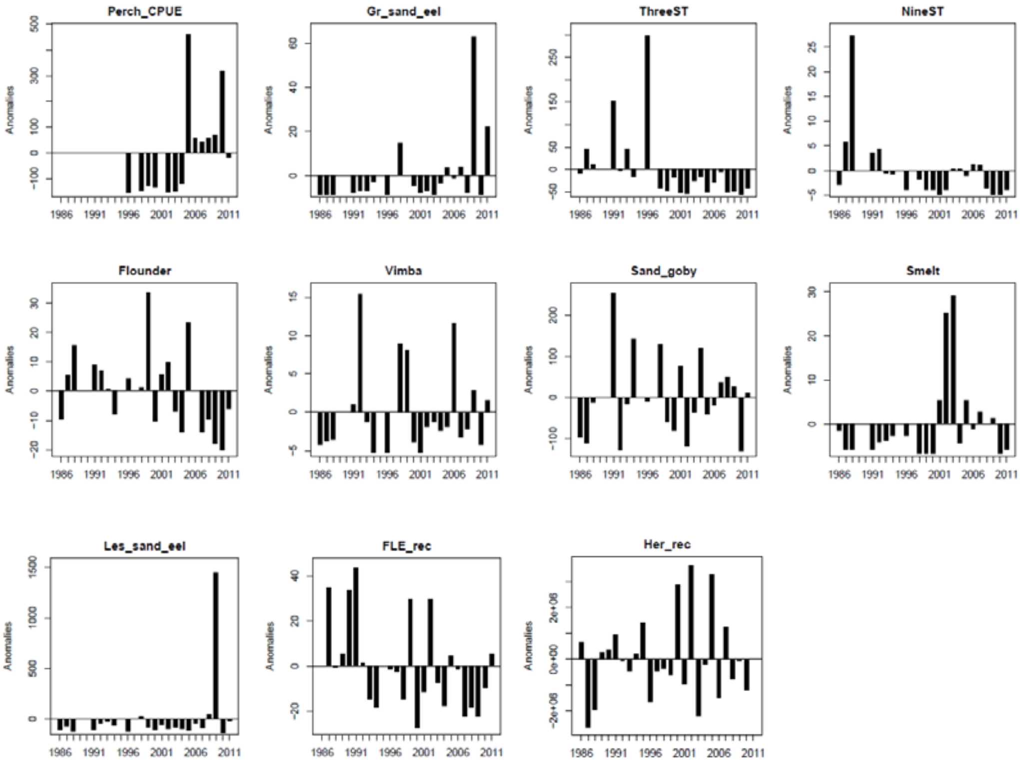

Figure GoRW-5. Long-term fish communities changes in the Gulf of Riga west coast: anomalies of the overall mean presented for Perch CPUE (numbers/net), Great sandeel (numbers), Three-spined stickleback (numbers), Nine spined stickleback (numbers), Flounder (numbers), Vimba bream (numbers), Sand goby (numbers), Smelt (numbers), Lesser sandeel (numbers), Flounder recruitment (numbers) and Herring recruitment (numbers); (Presented from top left to bottom right).

8.2.5. Other variables

No clear trends were recognized for other variables (Figure GoRW-6).

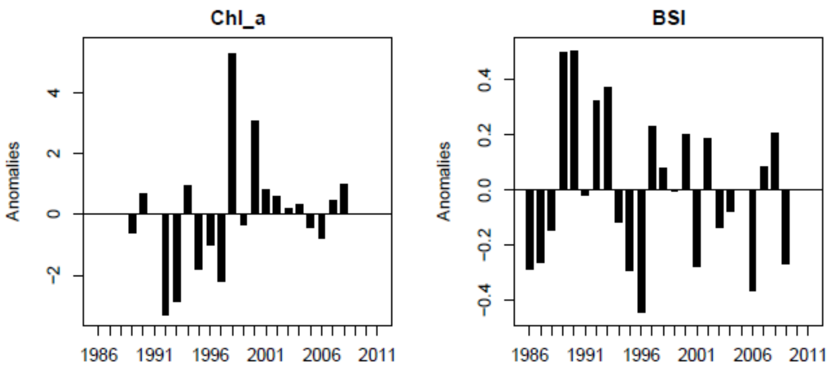

Figure GoRW-6. Long-term changes of other variables in the Gulf of Riga west coast: anomalies of the overall mean presented for Chlorophyll a (mg/m^3) and Baltic Sea Index; (Presented from left to right).

8.3. Integrated analyses based on all variables

In total 23 variables were considered: 2 physical, 4 nutrient, 4 zooplankton, and 11 fish and fisheries-related datasets. All data-series were compiled to one estimate per year (July/August) and covered the period 1986–2011. An overview of the temporal changes of all Gulf of Riga west coast time-series is presented in Figure GoRW-7. Variables are sorted according to their PC1 loadings of the subsequently performed PCA generating a pattern with variables at the top showing an increasing trend over time (green-red), to variables at the bottom showing the opposite trend (red-green) with highest values at the beginning of the time-series. The first group of variables comprises *e.g*. biomass of the invasive zooplankton species *Cercopagis pengoi*, perch CPUE, chlorophyll *a*, great sandeel abundance and water temperatures. Variables with a decreasing trend included total nitrogen concentrations, three-spined and nine-spined stickleback abundance, zooplankton *Acartia* biomass and ammonium concentrations. Part of variables shifted in values somewhere between 1996 and 1997 but larger part of variables fluctuated all over the period. Upwelling events are characteristic for the coastal zone and significantly determines fish communities in samplings from year to year. In order to exclude upwelling impact on physical and nutrient variables, stations with extreme low water temperatures were excluded (less than 5 °C).

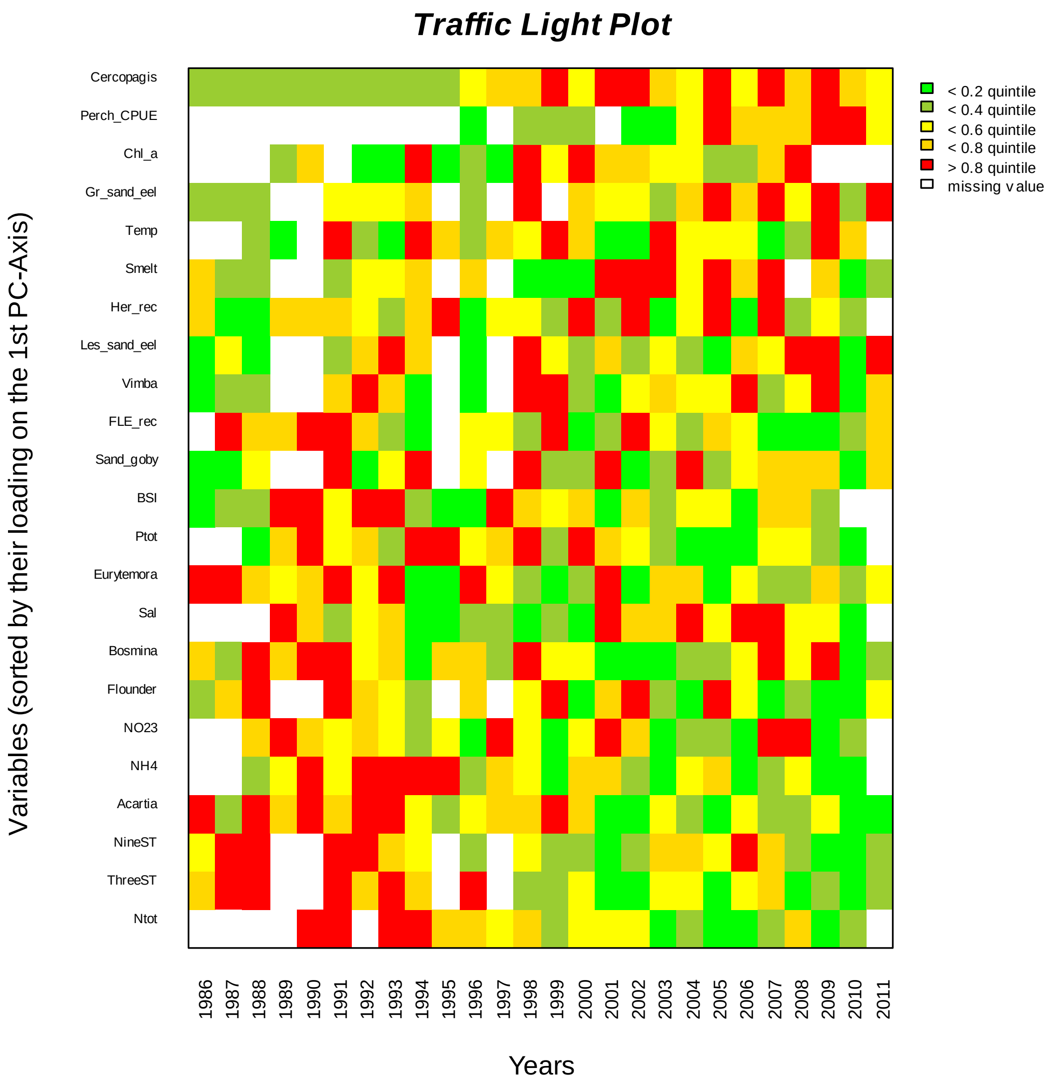

Figure GoRW-7. Traffic-light plot of the temporal development of the Gulf of Riga west coast time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in table GoRW-1.

In the PCA analysis, the first two principal components explained 25.4% and 13.5% of the variance (Figure GoRW-8). The most important variables in PC1 were total nitrogen concentrations, three-spined stickleback and Perch CPUE. The most important variables in PC2 were total phosphorous concentrations, recruitment of herring and great sandeel. Time trajectory plot indicates that the system moved in 1990s from one to another state with a transition period of 1997/1998.

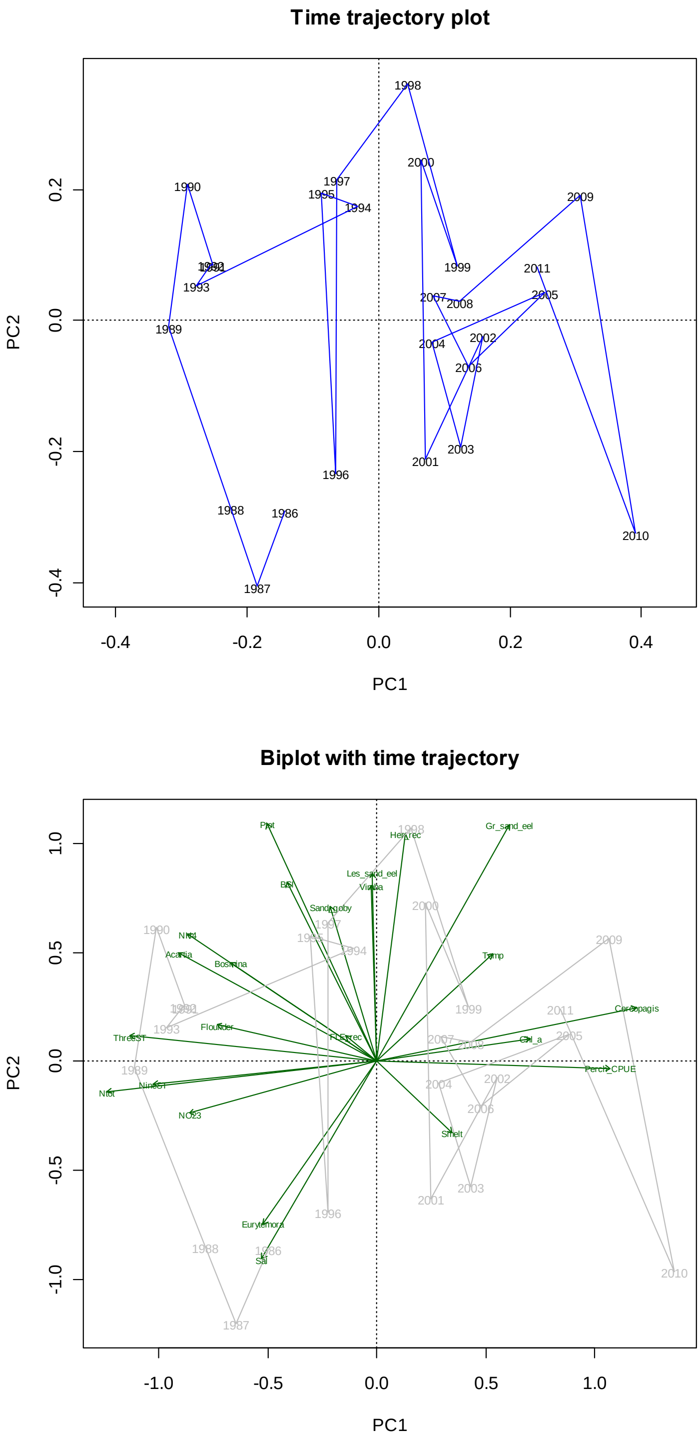

Figure GoRW-8. Results of the standardized principal component analysis using all 23 variables assembled for the Gulf of Riga west coast showing the time trajectory on the first factorial plane. The lower graph shows corresponding variable loadings, with a time trajectory in light grey (PC1 = 25.4 %, PC2 = 13.5% explained variance).

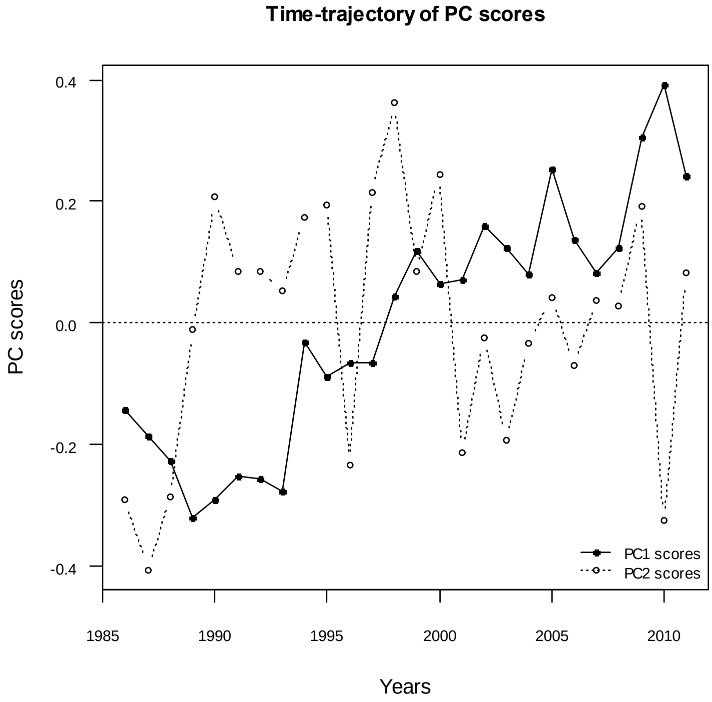

Figure GoRW-9. Results of the standardized principal component analysis using the 23 variables for the Gulf of Riga west coast PC1 (black circles) and PC2 scores (white circles) against time.

The constrained hierarchical clustering detected one regime shift in 1996/1997 (Figure GoRW-10).

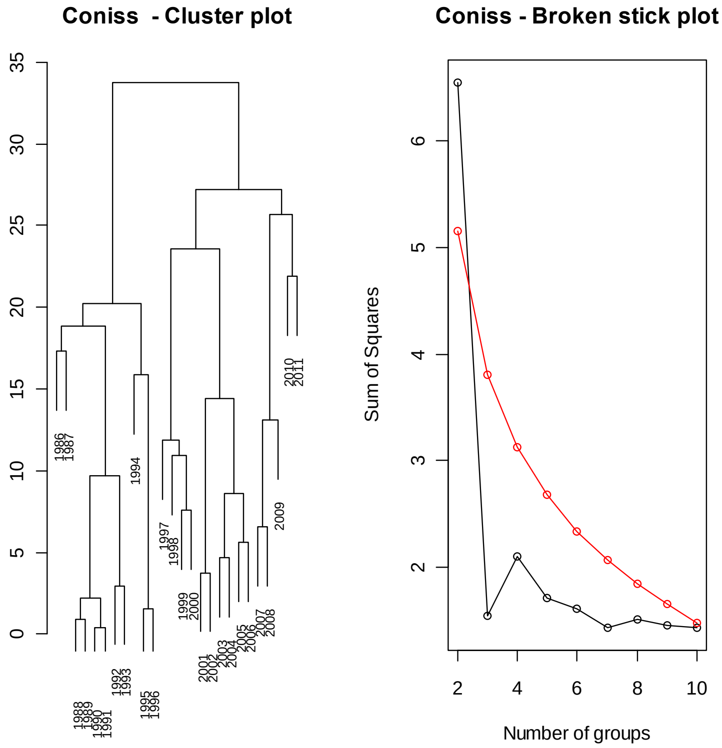

Figure GoRW-10. Results of the constrained hierachical clustering analyses for the Gulf of Riga west coast performed on all variables.

8.5. Results of integrated trend analyses based on abiotic variables only

In the PCA analysis, the first two principal components explained 38.4% and 22.9% of the variance (Figure GoRW-11). The most important variables in PC1 were Dissolved nitrate + nitrite, Ammonium, Total nitrogen. The most important variables in PC2 were Salinity, Total phosphorus and temperature.

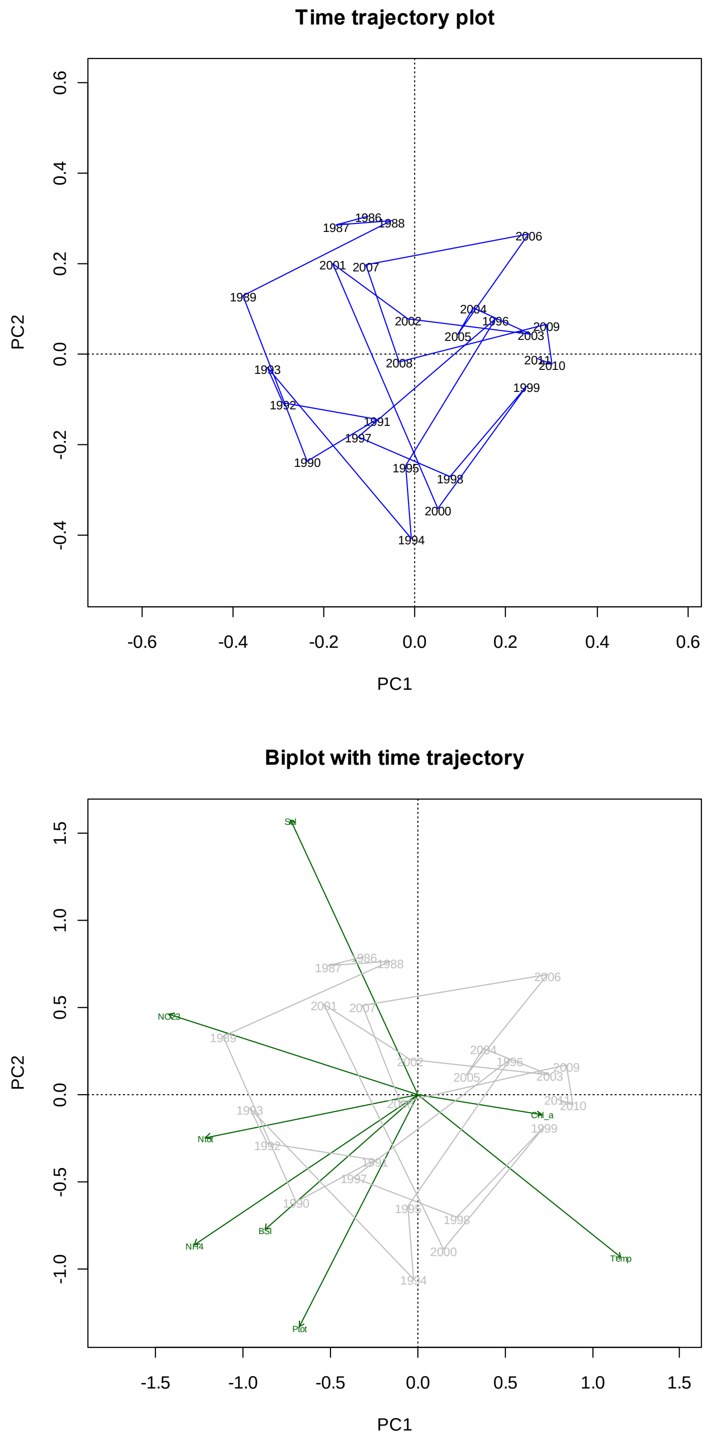

Figure GoRW-11. Results of the standardized principal component analysis using only abiotic variables (8 variables) assembled for the Gulf of Riga west coast showing the time trajectory on the first factorial plane. The lower graph shows corresponding variable loadings, with a time trajectory in light grey (PC1 = 38.4 %, PC2 = 22.9% explained variance).

8.5. Results of integrated trend analyses based on biotic variables only

In the PCA analysis, the first two principal components explained 27.6% and 16.6% of the variance (Figure GoRW-12). The most important variables in PC1 were Three spinned stickleback, Cercopagis, Acartia and Perch CPUE. The most important variables in PC1 were lesser and greater sandeel and Bosmina.

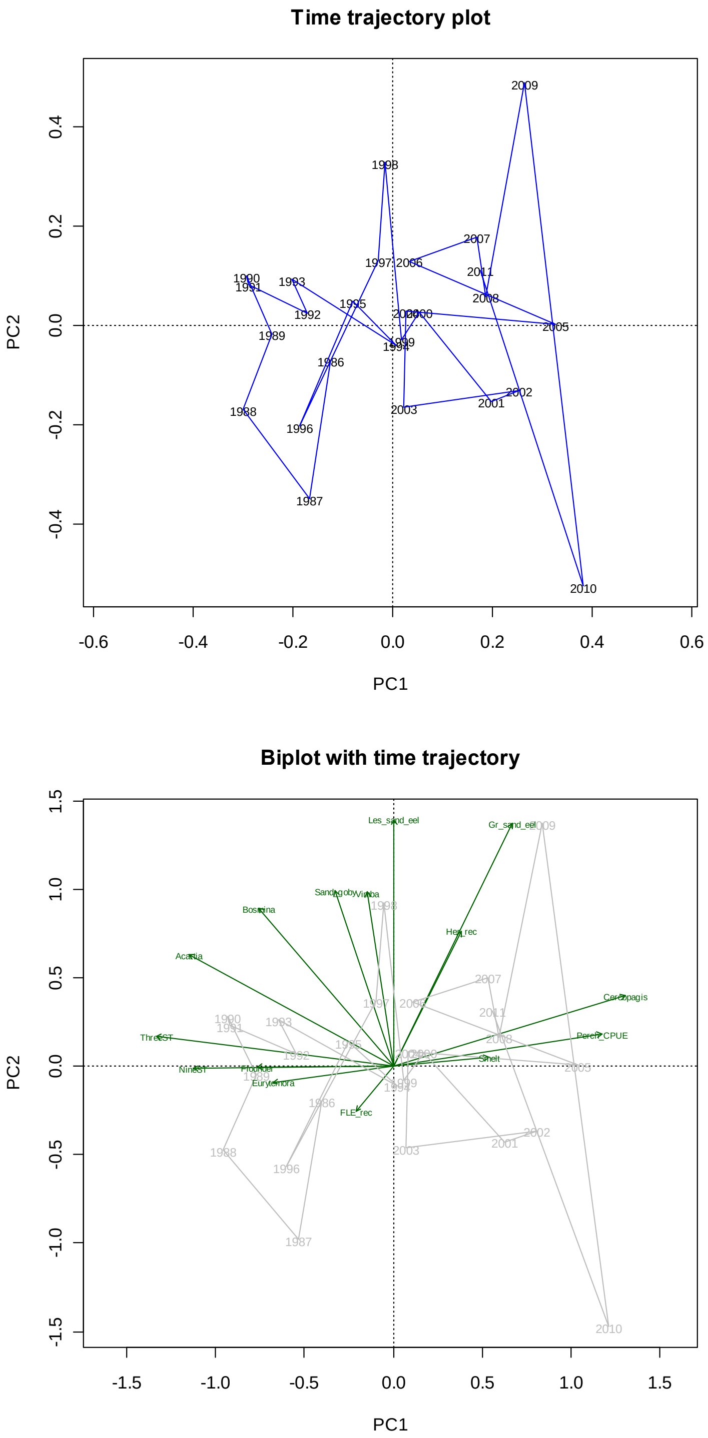

Figure GoRW-12. Results of the standardized principal component analysis using only biotic variables (15 variables) assembled for the Gulf of Riga west coast showing the time trajectory on the first factorial plane. The lower graph shows corresponding variable loadings, with a time trajectory in light grey (PC1 = 27.6 %, PC2 = 16.6% explained variance).

8.6. References

Wasmund, N., Andrushaitis, A., Lysiak-Pastuszak, E., Müller-Karulis, B., Nausch, G., Neumann, T., Ojaveer, H., Olenina, I., Postel, L., Witek, Z. 2001. Trophic status of the south-eastern Baltic Sea: A comparison of coastal and open areas. Estuarine Coastal and Shelf Science 53(6), 849-864.

Vitins M. 1989. Methods and Results of Estimating the Abundance of Flounder and Turbot in the Eastern Baltic, 1986–1987. Fisherei-Forshung, Rostock 27, 59–61 (in Russian).

Table GoRW-1. Time-series used for the integrated ecosystem analysis in Gulf of Riga west coast.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/ Gear	Contact	References/ Weblinks
Baltic Sea Index	BSI	-	Global	Winter		1986-2011			DU/IP/BMK	
Water temperature	Temp	°C	Gulf of Riga west coast	Summer	July-August	1986-2011	LHEI	Water sample	DU/IP/BMK	LHEI in Riga
Water salinity	Sal	psu	Gulf of Riga west coast	Summer	July-August	1986-2011	LHEI	Water sample	DU/IP/BMK	LHEI in Riga
Nitrite + nitrate	NO23	μmol*l-1	Gulf of Riga west coast	Summer	July-August	1986-2011	LHEI	Water sample	DU/IP/BMK	LHEI in Riga
Total phosphorous	Ptot	μmol*l-1	Gulf of Riga west coast	Summer	July-August	1986-2011	LHEI	Water sample	DU/IP/BMK	LHEI in Riga
Total nitrogen	Ntot	μmol*l-1	Gulf of Riga west coast	Summer	July-August	1986-2011	LHEI	Water sample	DU/IP/BMK	LHEI in Riga
Ammonium	NH4	μmol*l-1	Gulf of Riga west coast	Summer	July-August	1986-2011	LHEI	Water sample	DU/IP/BMK	LHEI in Riga
Chlorophyll a	Chl_a	mg/m3	Gulf of Riga west coast	Summer	July-August	1986-2011	LHEI	Water sample	DU/IP/BMK	LHEI in Riga
Acartia sp.	Acartia	mg/m3	Gulf of Riga	Summer	August	1986-2011	BIOR	Juday net	DU/IP/BMK	BIOR in Riga
Eurytemora affinis	Eurytemora	mg/m3	Gulf of Riga	Summer	August	1986-2011	BIOR	Juday net	DU/IP/BMK	BIOR in Riga
Bosmina longispina	Bosmina	mg/m3	Gulf of Riga	Summer	August	1986-2011	BIOR	Juday net	DU/IP/BMK	BIOR in Riga
Cercopagis pengoi	Cercopagis	mg/m3	Gulf of Riga	Summer	August	1986-2011	BIOR	Juday net	DU/IP/BMK	BIOR in Riga
Three-spined stickleback (*Gasterosteus aculeatus*)	ThreeST	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Nine-spined stickleback (*Pungitius pungitius*)	NineST	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Sand goby (*Pomatoschistus* sp.)	Sand_goby	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Great sandeel (*Hyperoplus lanceolatus*)	Gr_sand_eel	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Flounder (*Platichthys flesus*)	Flounder	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Smelt (*Osmerus eperlanus*)	Smelt	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Lesser sandeel (*Ammodytes tobianus*)	Les_sand_eel	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Vimba bream (*Vimba vimba*)	Vimba	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Flounder (*Platichthys flesus*) recruitment	FLE_rec	numbers	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Beach seine	DU/IP/BMK	BIOR in Riga
Perch (*Perca fluviatilis*)	Perch_CPUE	CPUE num./net	Gulf of Riga west coast	Summer	July-August	1986-2011	BIOR	Net survey	DU/IP/BMK	BIOR in Riga
Herring (*Clupea harengus membras*) recruitment	Her_rec	numbers	Gulf of Riga west coast	Annual	Jan-Dec	1986-2011	ICES	ICES XSA	DU/IP/BMK	ICES

9. Baltic Sea Coast – Kvädöfjärden (KF)

9.1 Area description

An integrated assessment was performed for the coastal area of Kvädöfjärden in the northern Baltic Proper (Figure KF-1). The same area was previously assessed for the periods 1971–2008 (at WGIAB 2009) and 1989–2009 (at WGIAB 2011). Trends were now assessed for the period 1989–2010. The purpose of using a shorter time-series than in previous years was to be able to include data from monitoring programmes for seals and marine fish species beginning in 1989.

The Kvädöfjärden area is an archipelago area with a heterogeneous coastline facing open sea. The surrounding land area is not densely populated, and has no major rivers. The level of local fishing pressure is also assumed to be low.

Data used in the assessment covered abundance of coastal fish species, soft bottom benthic fauna and seals for the biotic variables. For the abiotic variables, data on local nutrient load and hydrographical information from monitoring stations in the nearby coastal area were included. For some abiotic variables, local measurements were not obtainable. In these cases, data from surface measurements in the closest relevant open sea monitoring station were included (BY15).

No data on phytoplankton or zooplankton were included. This is because local information was not available and corresponding open sea information was not considered representative enough.

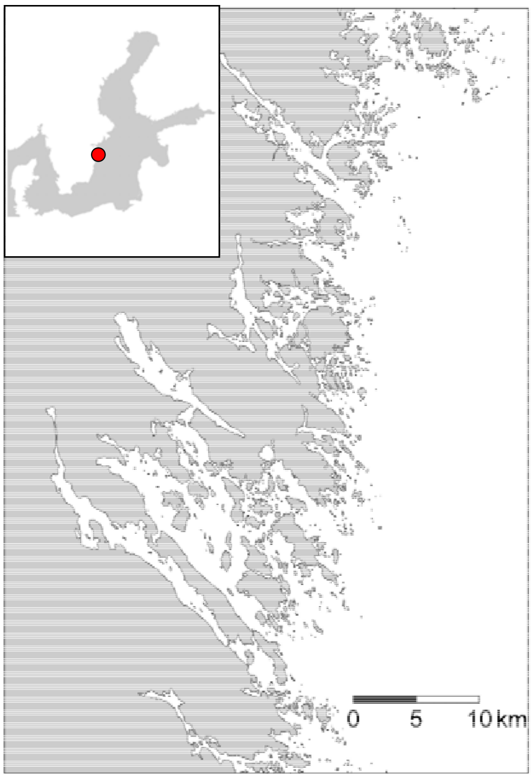

Figure KF-1. Location of Kvädöfjärden area at the Central Baltic Sea coast of Sweden.

9.2. Variable descriptions

9.2.1. Hydrography

Hydrographical variables on temperature and salinity were included. Two temperature variables were included, one representing conditions during summer (August) and one during spring (May/June). Data on salinity was not available on a local scale, and was instead represented by data from the open sea. Additionally, the Atlantic oscillation index was included in the analyses. The temperature variables did not show any significant changes over the studied time period, nor did salinity. The Atlantic Oscillation index showed a decreasing trend over time.

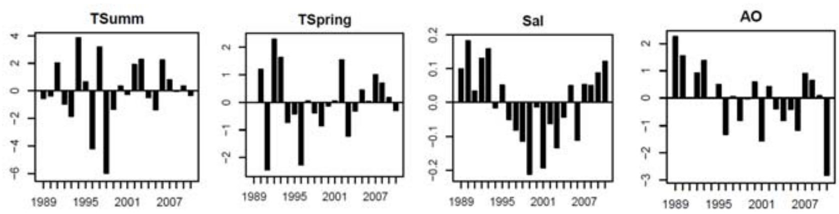

Figure KF-2. Long-term hydrographic changes in the Kvädöfjärden area: anomalies from the overall mean for Tsumm= coastal temperature during summer (°C, August), TSpring= coastal temperature during spring (°C, May-Jun), Sal= surface salinity in the open sea during summer (psu, annual average), and AO=the Atlantic oscillation index.

9.2.2. Nutrients

Nutrient data was represented by estimates of local nitrogen loading from land (riverine runoff) and of influence from off shore areas, using data on total dissolved inorganic nitrogen and phosphorous from the nearest available open sea monitoring station (surface data). Additionally, the variable water transparency was included in order to indicate local changes in water clarity, as measured by Secchi depth measurements. No trend over time was seen in nutrient loading from land. Small changes over time were seen in the other variables. The concentration of dissolved inorganic nitrogen showed a decreasing trend, as did the variable water transparency. A small increasing trend was seen in dissolved inorganic phosphorous.

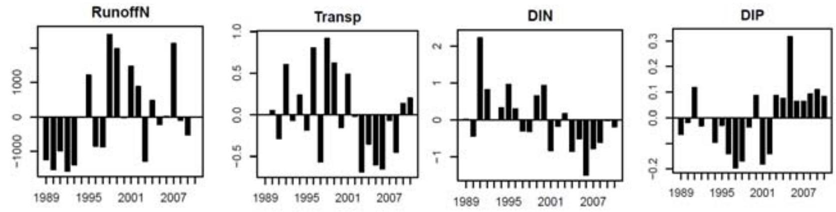

Figure KF-3. Long-term changes in nutrient-related variables in the Kvädöfjärden area, given as anomalies from the overall mean; RunoffN= local nitrogen loading from land (tonnes per year), Transp= water transparency (meters), DIN=dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorous (umol*L^{-1}, both from open sea station BY15, 0–10 m depth, winter values).

9.2.3. Zoobenthos

Data on four commonly occurring taxa of soft bottom macrozoobenthos were included, based on data from a local monitoring program. The bivalve *Macoma baltica* showed an increasing trend over the studied time period. The amphipod *Monoporeia affinis* showed a small decreasing trend overall, however, variation among years was remarkable. The biomass of *Halicryptus spinulosus* (Priapuloidea) and freshwater Chironomidae (Insecta) showed no significant trends over time. Additionally, the PCA analyses were performed with and without data on the alien species *Marenzelleria* sp., which occurred in the data set from 2004 onwards.

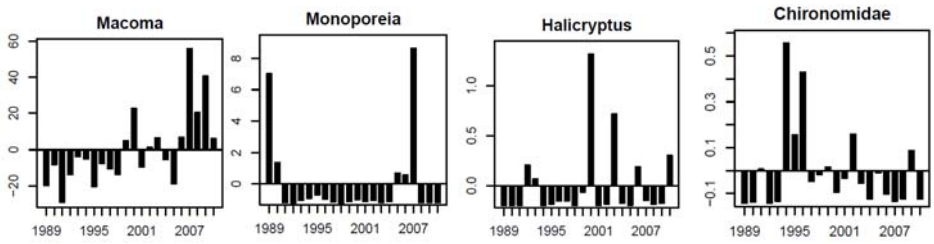

Figure KF-4. Long-term changes in zoobenthos in the Kvädöfjärden area: anomalies from the overall mean in biomass of *Macoma baltica*, *Monoporeia affinis*, *Halicryprus spinulosus*, and Chironomidae, estimated as grams per square meter.

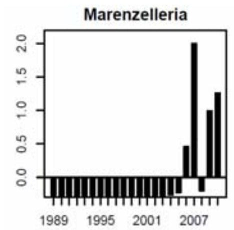

Figure KF-5. Alien species in the Kvädöfjärden area: anomalie of the overall mean for the polychaete *Marenzelleria* sp., which was observed in the area for the first time in 2004

9.2.4. Fish

Data on five species of fish were included. These were the freshwater species perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*), and the marine species flounder (*Platichtys flesus*), Cod (*Gadus morhua*) and herring (*Clupea harengus*). Over the studied time period, a decreasing trend was observed for perch and roach. An increasing trend was observed for cod. No trends in the abundance of flounder and herring were observed.

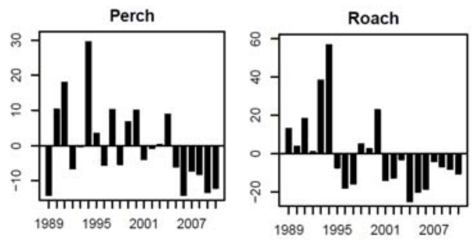

Figure KF-6. Long term changes in freshwater fish species in the Kvädöfjärden area: anomaly of the overall mean for perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*), estimated as catch per net and night in numbers (data from local monitoring programme).

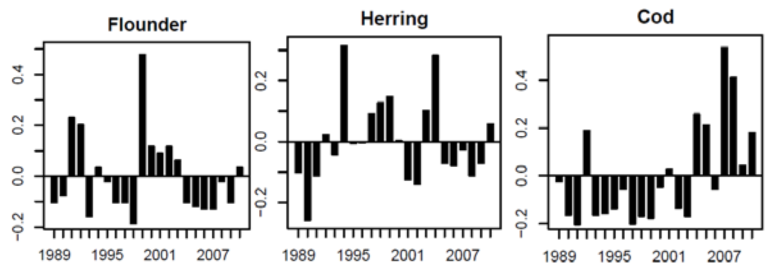

Figure KF-7. Long term changes in marine fish species in the Kvädöfjärden area: anomalie of the overall mean for flounder (*Platichtys flesus*), herring (*Clupea harengus*), and cod (*Gadus morhua*), estimated as catch per net and night in numbers (data from local monitoring programme).

9.2.5. Seals

Number of grey seals (*Halichoerus grypus*) counted in the area showed an increasing trend, with a longer period of low abundances in the beginning of the time-series.

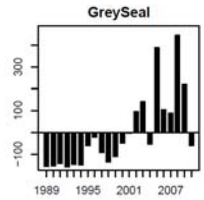

Figure KF-8. Long term changes in grey seal abundance in the Kvädöfjärden area: figure show anomalie from the overall mean of estimated total abundance in the region, based on national monitoring.

9.2.6. Fishing

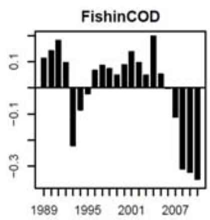

Figure KF-9. Long term changes in fishing pressure on cod: anomalie from the overall mean of the index (proportion removed for cod age 4-7, F-based, in the total Central Baltic Sea fisheries).

9.3. Results of integrated trend analyses based on all variables

The integrate analyses covered data within the time period 1989–2010. In all, 8 abiotic, 11 biotic and one fisheries-related variable were included (as presented in the section above).

The traffic light plot compares trends over time in the included variables. For some of the variables, no clear trends over time were observed. Stronger trends over time were generally observed for the biotic than for the abiotic variables. Abiotic variables showing higher values in the beginning of the studied time period were open sea DIN and the Atlantic Oscillation index, whereas values for open sea DIP were slightly higher in the end of the time period. Also, fishing pressure on cod was higher in the beginning of the time period. Of the biotic variables, the abundances of perch, roach, flounder and Chironomidae were higher in the beginning of the time-series, whereas cod, grey seal, the bivalve *Macoma*, and the polychaete *Marenzelleria* were more abundant in the end of the studied time period.

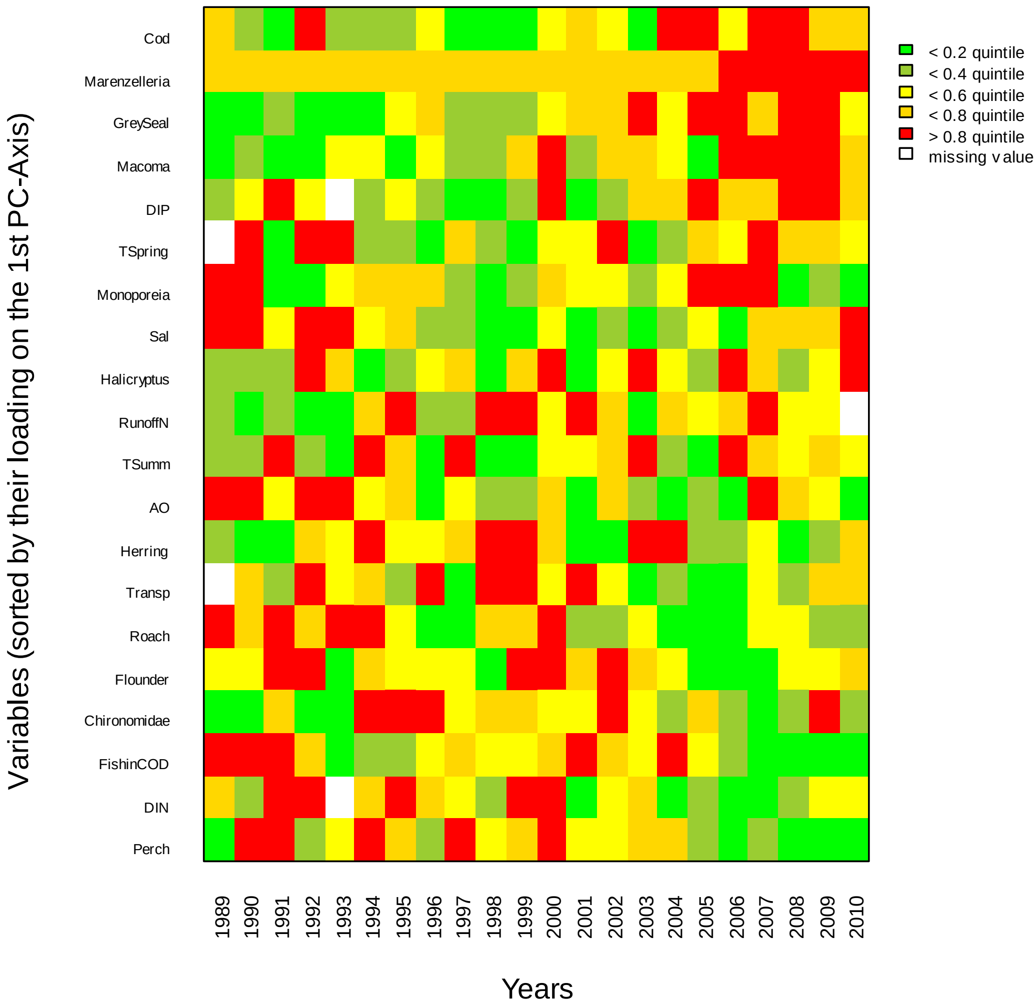

Figure KF-10. Traffic-light plot of the temporal development of 20 variables during 1989–2010. Variables were transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component.

In the PCA on all variables, changes along the first principal component mainly indicated a difference between the years 1985–2004 vs. 2005–2010, whereas changes on the second principal component indicated a difference within the period 1985–2004. The first principal component accounted for 24.2 % of the observed variation and was mainly associated with bioitic variables, by an increase in cod, *Marenzelleria* and *Macoma*, and by a decrease in perch. Also, it was associated with a decreasing fising pressure on cod. The second principal component accounted for 16.4 % of the variation and was mainly associated with runoff N (decreasing with time) and AO (increasing). When *Marenzelleria* was excluded from the analyses, the main observed pattern remained. Chronological clustering analysis showed no main shifts in the multivariate pattern at alpha = 0.01, and a shoft between years 1993/1994 at alpha = 0.05.

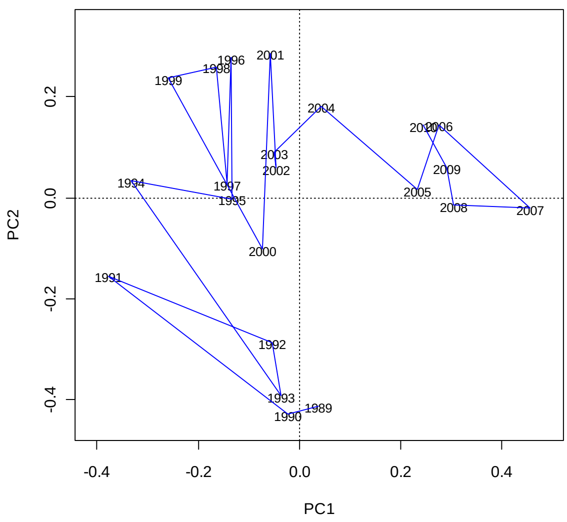

Figure KF-11. Results of the standardized principal component analysis using all 20 variables assembled for the Kvädöfjärden area showing the time trajectory on the first factorial plane (PC1 = 24.0 %, PC2 = 16.4% explained variance).

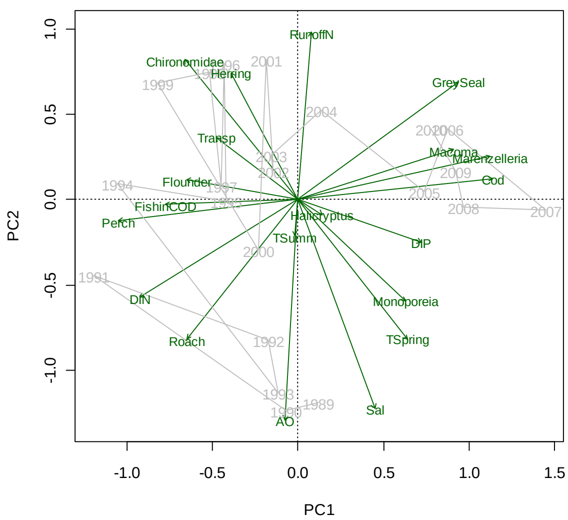

Figure KF-12. Results of the standardized principal component analysis using all 20 variables assembled for the Kvadöfjärden coastal area showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey; PC1 = 24.0 %, PC2 = 16.4% explained variance).

9.4. Results of integrated trend analyses based on abiotic and fisheries related variables only

In the analyses based on abiotic and fisheries related variables only, 9 variables were included. The first principal component accounted for 19.3% of the variation, and the second component for 19.3 %. A few years in the end of the 1990s differed from the other years by slightly higher levels on N runoff and higher water transparency. No other main changes were indicated. The chronological clustering analysis showed the same pattern as for the analyses on all variables shown above.

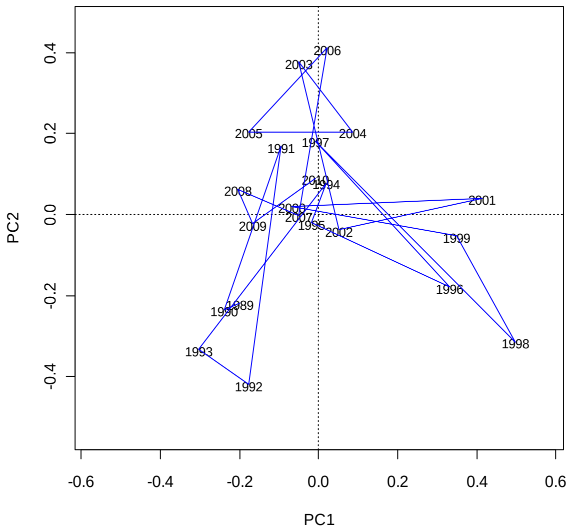

Figure KF-13. Results of the standardized principal component analysis using 8 abiotic and obe fisheries-related variable assembled for the Kvädöfjärden area showing the time trajectory on the first factorial plane (PC1 = 28.7 %, PC2 = 19.2 % of total explained variance).

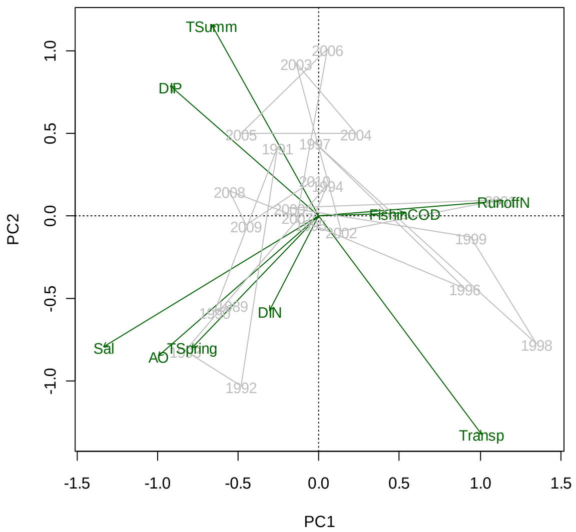

Figure KF-14. Results of the standardized principal component analysis using 8 abiotic and one fisheries related variable, showing variable loadings on the first factorial plane (for orientation: time trajectory in light grey; PC1 = 28.7 %, PC2 = 19.2 % explained variance).

9.5. Results of integrated trend analyses based on biotic variables only

In the analyses based on biotic variables only, 11 variables were included. The first principal component accounted for 32.9% of the variation, and the second component for 15.8 %. The earliest years (1989/1990) were characterised by high levels of *Monoporeia*, whereas the most recent years assessed where characterised by relatively high levels of cod, grey seal, *Macoma* and *Marenzelleria*. The chronological clustering analysis showed the main shifts to have occurred at 1994/1995, and at 2004/2005 (alpha= 0.01). The same result was observed at alpha =0.05).

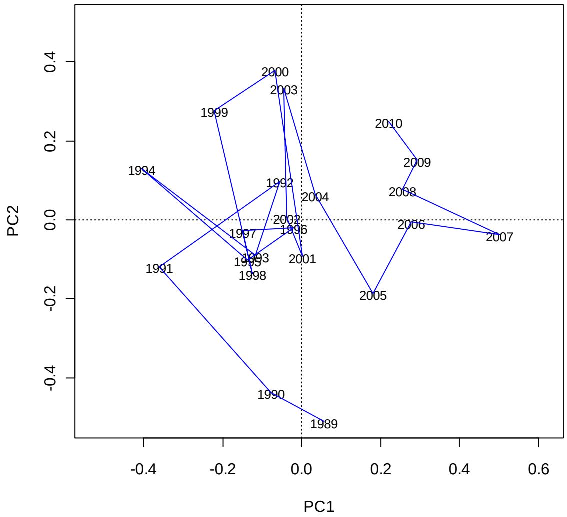

Figure KF-15. Results of the standardized principal component analysis using 11 biotic variables assembled for the Kvädöfjärden coastal area, showing the time trajectory on the first factorial plane (PC1 = 32.9 %, PC2 = 15.8% explained variance).

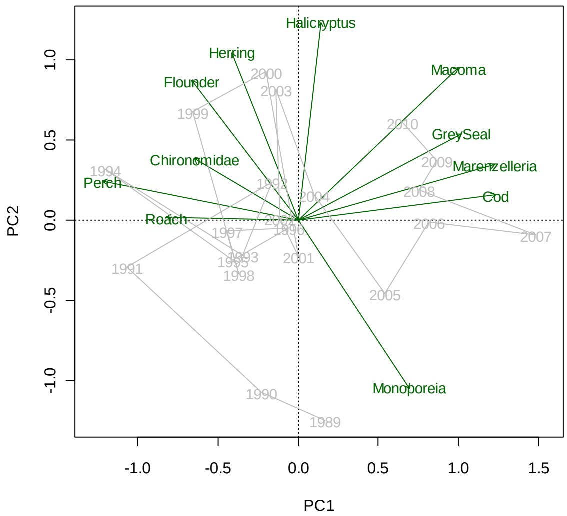

Figure KF-16. Results of the standardized principal component analysis using 11 biotic variables assembled for the Kvädöfjärden coastal area showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey) (PC1 = 32.9%, PC2 = 15.8% explained variance).

10. Curonian Lagoon (CL)

Coastal fish monitoring in the Russian parts of the Vistula and Curonian Lagoons was performed for fish community control, stock assessment and management of fisheries (Figure CL-1). These lagoons are the productive places with characteristics as in Table CL-1.

Table CL-1. Characteristics of the Vistula Lagoon.

Parameters	Curonian Lagoon	Vistula Lagoon
Area (km^2)	1548	838
Russian part	3/4	>1/2
Depth (m)	3.8	2.6
Salinity (psu)	freshwater	1-8 (3,3)
Transparency	0.7	0.7
Trophic status	hypertrophic	Eutrophic

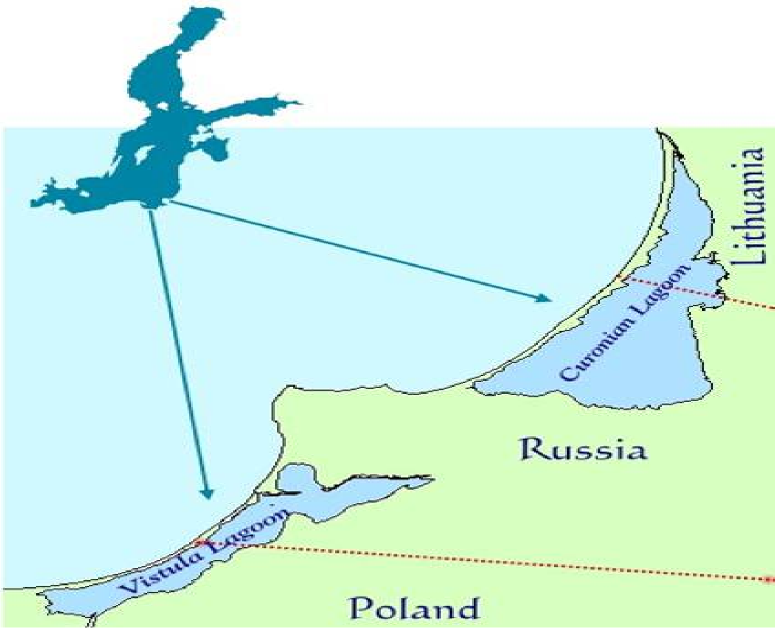

Figure CL-1. Map of the location of the Curonian and Vistula lagoons.

The integrated analysis of the Curonian lagoon was based on the set of 44 variables and covered the period 1992–2011 years. It contained 10 environmental data (temperature, nitrogen loading in spring and summer, oxygen in spring and summer, phosphorus in spring and summer), 22 biotic variables (benthos, phytoplankton, zooplankton,) and 16 fish and fisheries variables (4 species with spawning biomass estimates, recruitment. mean weight and fishing mortality). Time-series used in the integrated analysis are presented in the Table CL-2.

Data collection in these areas was started many years ago and standard data are available since 1992. Two bottom surveys and one young fish survey usually carried out each year. Collected information is used: i)To reveal trends in fish community (species composition, temporal and spatial distribution in different environmental conditions); ii) To reveal trends in fish stocks abundance (indices of abundance and biomass); iii) To provide background data for stock assessment by VPA method (age structure, mean weight at age, stock recruitment); iv) Estimation of TAC for bream, pike-perch, sichel, Baltic herring, smelt, roach, ruffle, and establishment of quota for each species.

The target fish species in the Curonian lagoon are the next: *Abramis brama* (Bream), *Rutilus rutilus* (Roach), *Pelecus cultratus* (Sichel), *Sander lucioperca* (Pike-perch), *Perca* *fluviatilis* (Perch), *Osmerus eperlanus* (European smelt), *Gimnocephalus cernuus* (Ruffe), *Anguilla anguilla* (European eel), *Gasterosteus aculeatus* (Three-spined stickleback).

Above mentioned fish monitoring is conducted till now with the same fishing gears at the same occasions. The analysis of long-time trends in the fish community show the prevailing effect of increasing fishing activity and type of fishery even in the such hypertrophic (eutrophic) and severely polluted basins like the Curonian and Vistula Lagoons.

10.1. Trend analysis

10.1.1. Hydrography

Long-term environmental changes in the Curonian lagoon are shown in the Figure CL-2. Only low values of oxygen concentration in summer and low values of nitrogen in spring have been observed. In the other hydrological parameters, no clear trends have been noticed.

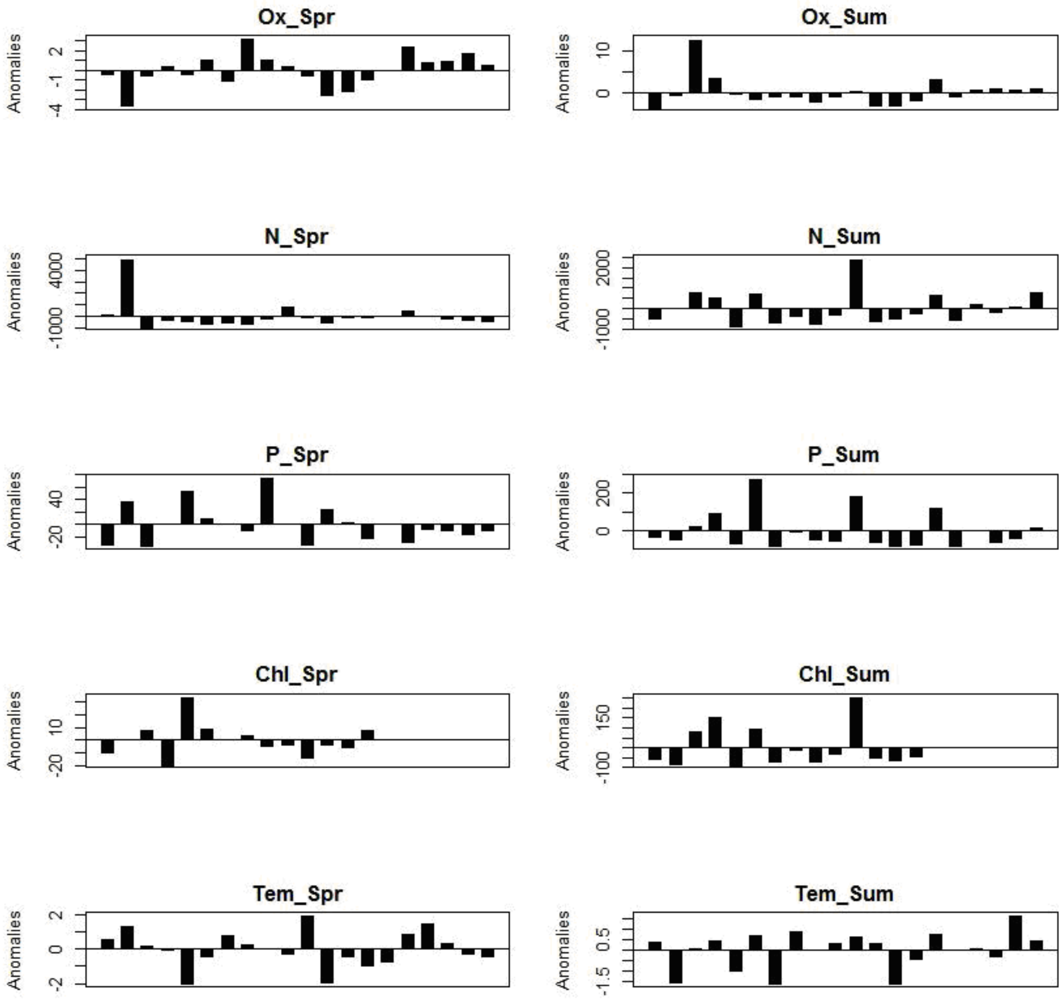

Figure CL-2. Long-term environmental changes in the Curonian lagoon: anomalies of the overall mean presented for variable. For abbreviations and units see table CL-2.

10.1.2. Zoobenthos and zooplankton

Concerning zooplankton, a clear increasing trend in biomass in last year have been recognized for rotifers, no clear trends and fluctuation around the mean were recognized for cladocers and copepods. Concerning benthos, a clear increasing trend in biomass in last year has been recognized for molluscs only. Groups like chironomidae and oligochaeta fluctuated around the mean.

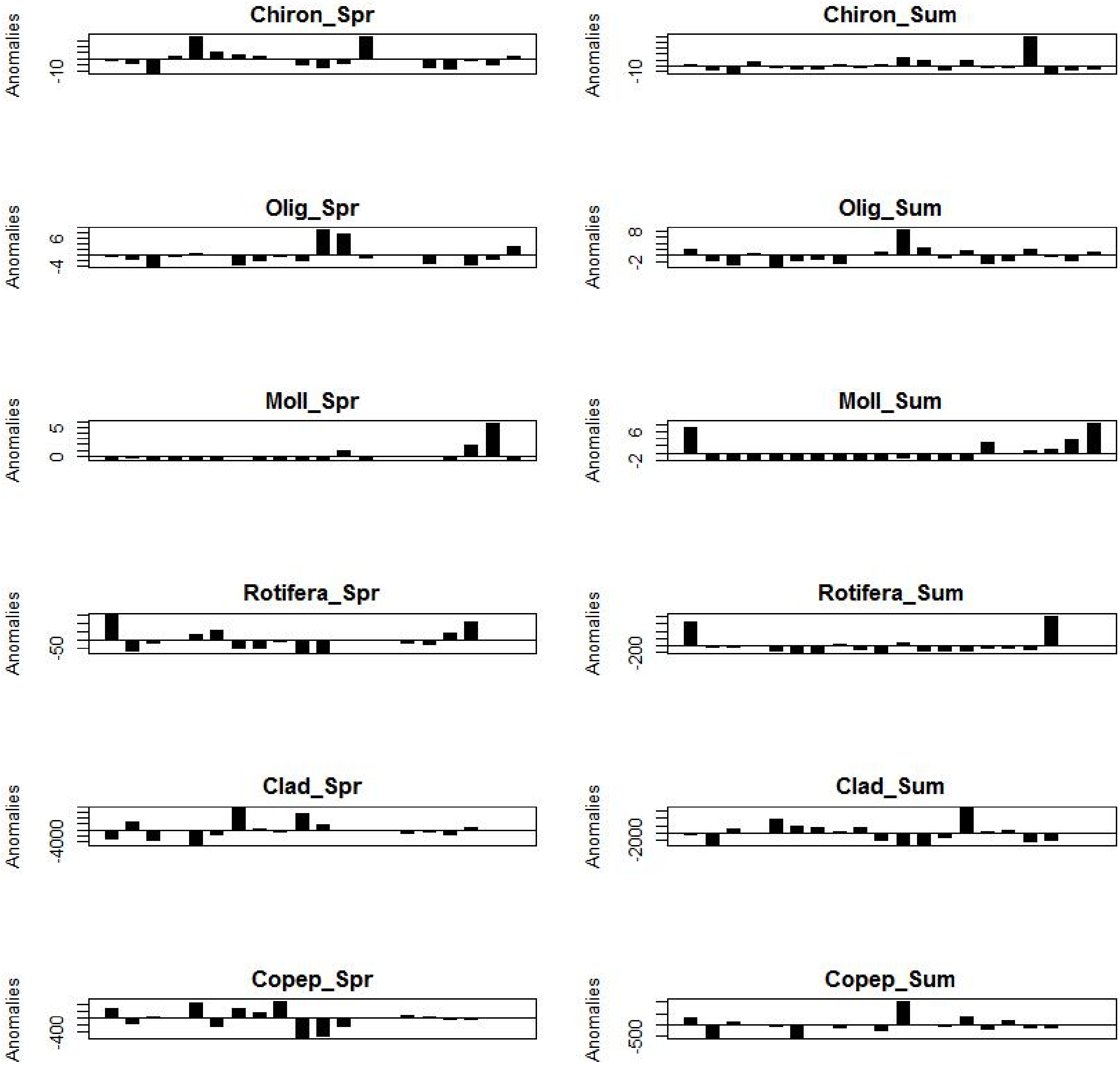

Figure CL-3. Long-term biological variables changes in the Curonian lagoon: anomalies of the overall mean presented for variable name and unit table CL-2.

10.1.3. Fish

Clear trends of increasing spawning biomass have been recognized for all commercial species (bream, pikeperch, sabrefish, roach). No clear trends have been recognized for other population parameters (recruitment, mean weight, fishing mortality).

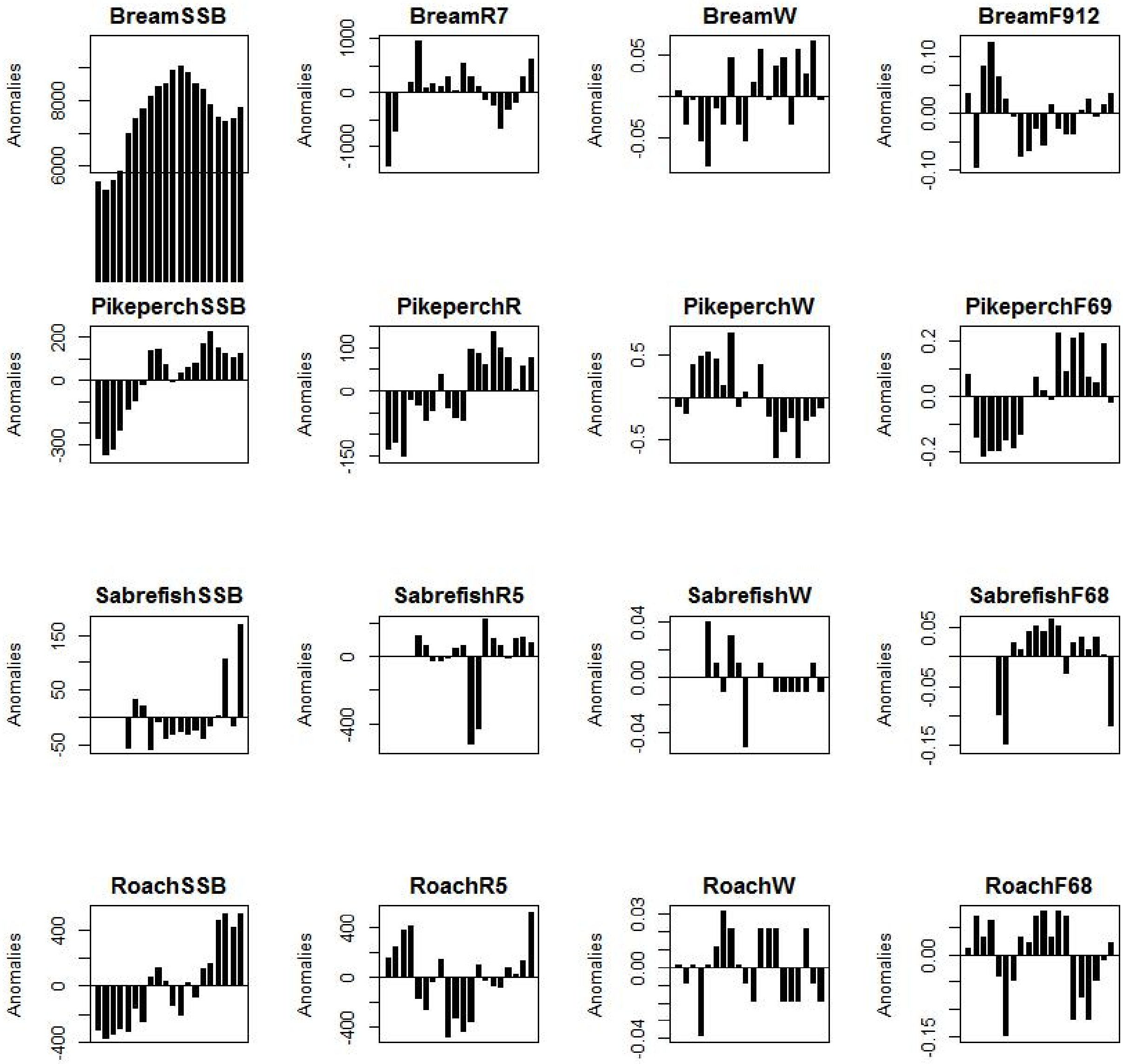

Figure CL-4. Long-term fish population parameters changes in the Curonian lagoon: anomalies of the overall mean presented for variable name and unit table CL-2.

10.2. Integrated analyses

The period 1992–2011 was included in the integral analysis. All 44 variables were considered. The presented results are the first attempt to conduct an IEA for the Curonian lagoon and have been performed for the full available datasets.

It was revealed the key variables in the Curonian lagoon ecosystem as the following: pikeperchW, SabarefishW, Clad_Sum, Chl_Spr., Copep_Spr, BreamF912 .

In the PCA analysis, the first two principal components explained 17.6% and 15% of variance, respectively. The time trajectory plot indicates that an anomaly state of the Curonian lagoon ecosystem was likely occurred in 1993 and 1996.

Time-trajectory of PC1 revealed a significant changes from 1996 to 2002. Time-trajectory of PC2 showed a decrease from 1995 to 2002 and then a increase from 2002 to the present time.

The constrained hierarchical clustering applied for all datasets identified two periods, 1992–1995 and 1996–2011. It may be suggested that these periods stipulated by different state of ecosystem.

The STARS analysis applied on $PC1_{all}$ index estimated for the Curonian lagoon revealed the shift in the whole ecosystem (biota and abiotic) regime occurred in 2001/2002

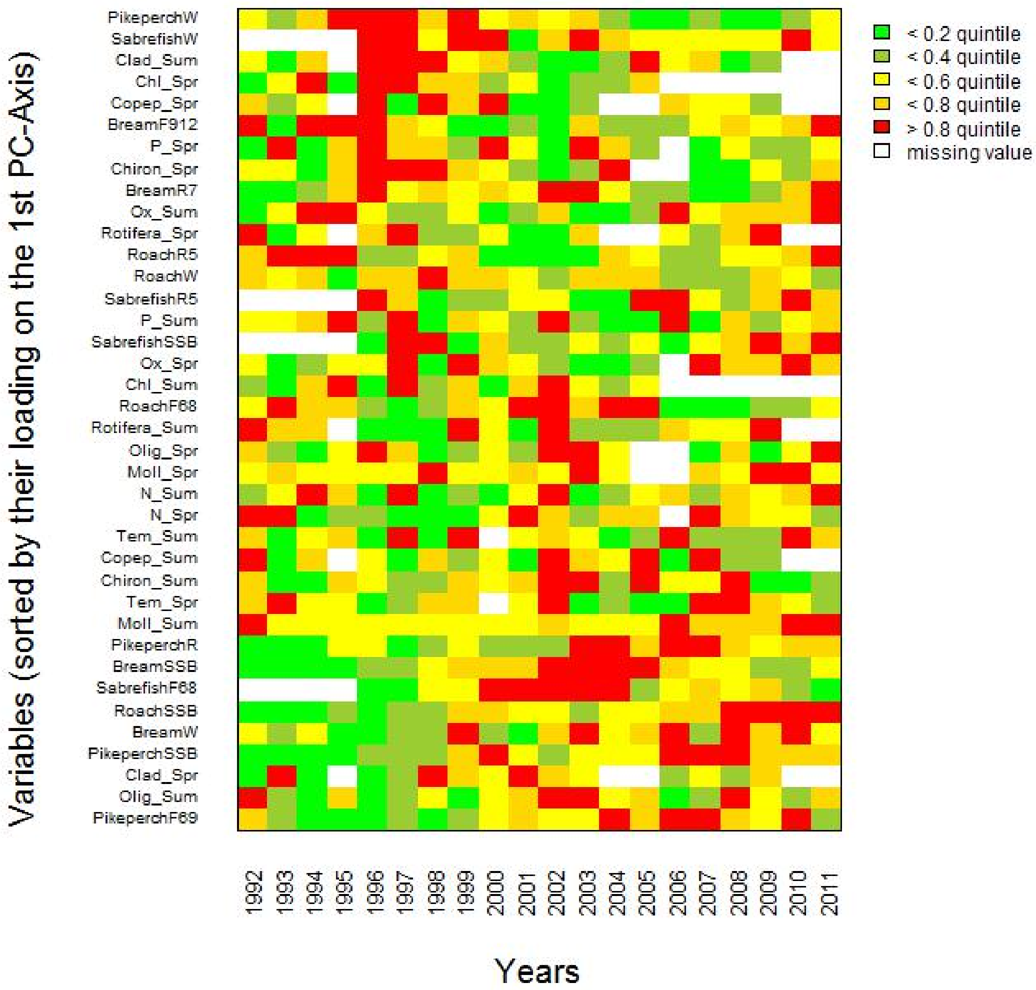

Figure CL-5. Traffic-light plot of the temporal development of the Curonian lagoon time-series. Variables are transformed to quintiles, colour coded (green=low values, red=high values) and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in Table CL-2.

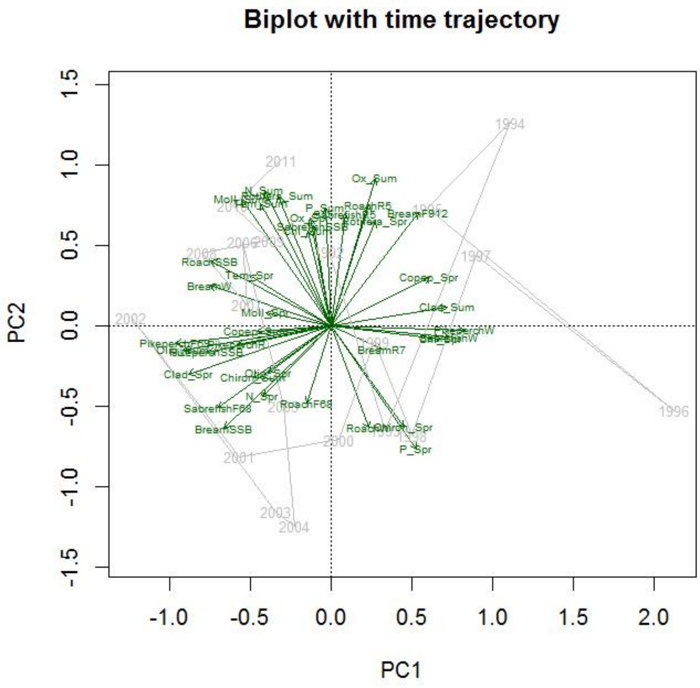

Figure CL-6. Results of the standardized principal component analysis using all 44 variables assembled for the Curonian lagoon. The graph shows time trajectory (in light green) and a correlation biplot of variables.

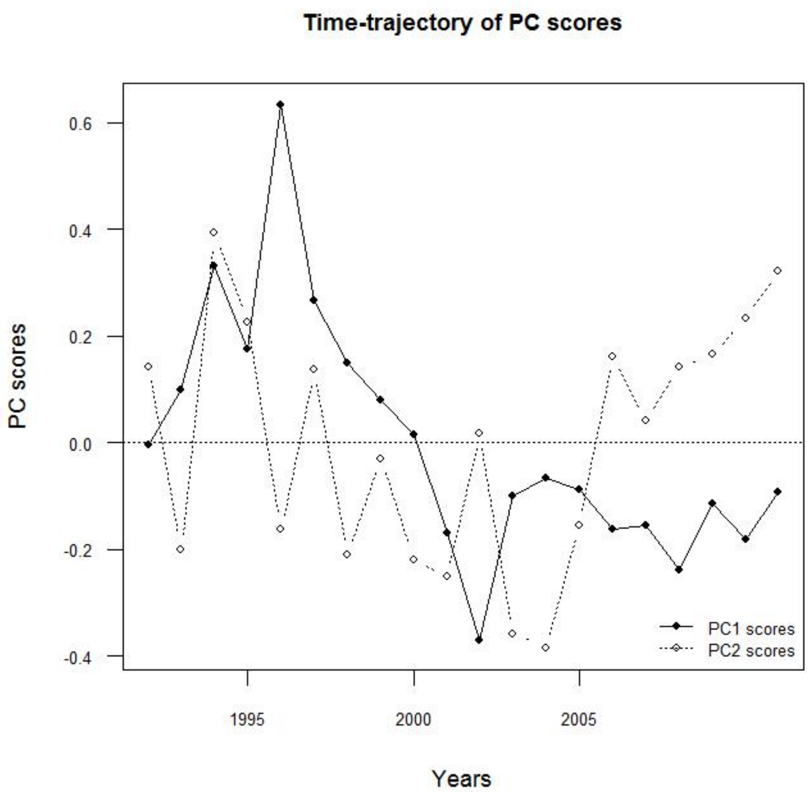

Figure CL-7. Results of the standardized principal component analysis using 44 variables assembled for the Curonian lagoon showing PC1 (black circles) and PC2 (white circles).

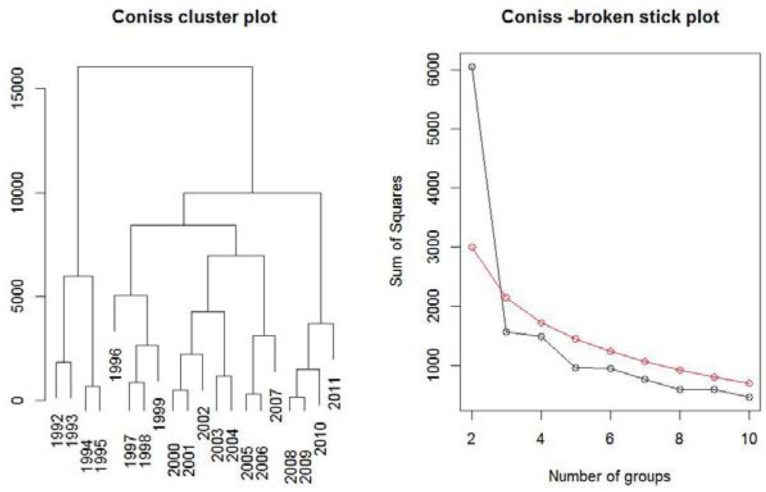

Figure CL-8. Results of the constrained hierarchical clustering analysis for the Curonian lagoon.

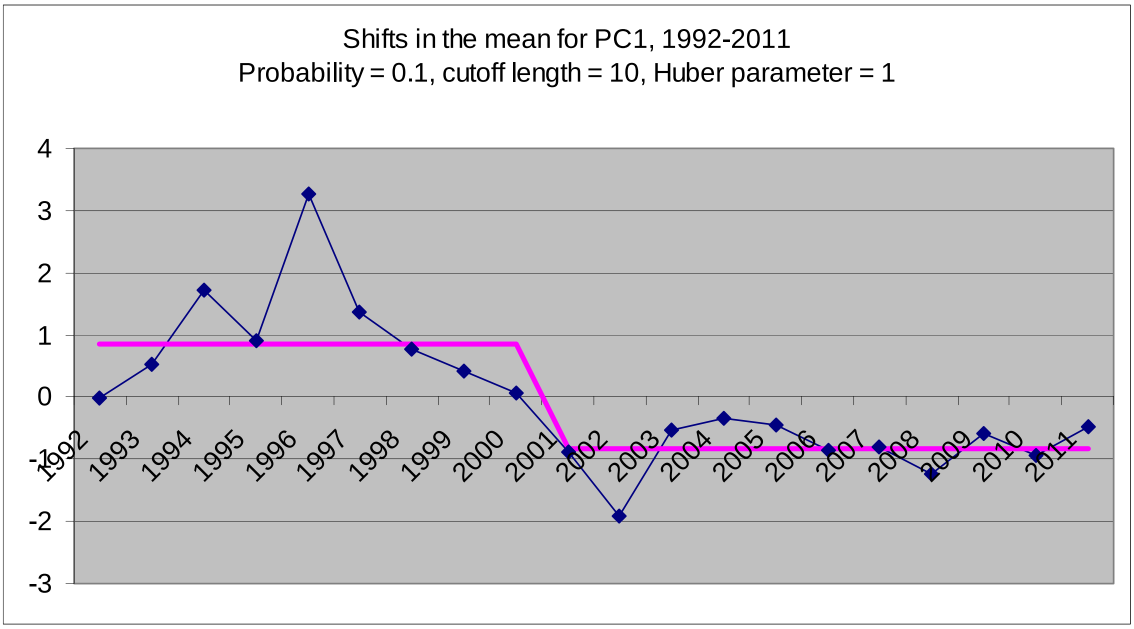

Figure CL-9. Results STARS analysis on the first component based on all variables (Shifts in the mean for PC1, 1992–2011.

Table CL-2. Time-series used for the integrated ecosystem analysis of Vistula and Curonian lagoons.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Contact
Bream Spawner biomass	BreamSSB	tonnes	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
Bream recruitment	BreamR5	10^3	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
Bream weight	BreamW	kg	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
Bream fishing mortality	BreamF912	age 9-12	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
PikeperchSSB	PikeperchSSB	tonnes	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
PikeperchR	PikeperchR	10^3	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
PikeperchW	PikeperchW	kg	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
PikeperchF	PikeperchF69	age 6-9	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Alexandrova M.B.
SabrefishSSB	SabrefishSSB	tonnes	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
SabrefishR	SabrefishR5	10^3	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
SabrefishW	SabrefishW	kg	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
SabrefishF	SabrefishF68	age	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
RoachSSB	RoachSSB	tonnes	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
RoachR	RoachR5	10^3	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
RoachW	RoachW	kg	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
RoachF	RoachF68	age	Vistula/Curonian lagoons	annual		1992-2011	AtlantNIRO	Bazhenova A.A.
Chironomidae	Chiron_Spr	g/m2	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Rudinskaya L.V.
Chironomidae	Chiron_Sum	g/m2	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Rudinskaya L.V.
Oligochaeta	Olig_Spr	g/m2	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Rudinskaya L.V.
Oligochaeta	Olig_Sum	g/m2	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Rudinskaya L.V.
Mollusca	Moll_Spr	g/m2	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Rudinskaya L.V.
Mollusca	Moll_Sum	g/m2	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Rudinskaya L.V.
Rotifera	Rotifera_Spr	mg/m3	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Naumenko E.N.

Rotifera	Rotifera_Sum	mg/m3	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Naumenko E.N.
Cladocera	Clad_Spr	mg/m3	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Naumenko E.N.
Cladocera	Clad_Sum	mg/m3	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Naumenko E.N.
Copepoda	Copep_Spr	mg/m3	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Naumenko E.N.
Copepoda	Copep_Sum	mg/m3	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Naumenko E.N.
Oxygen	Ox_Spr	mg/L	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Smyslov V.A.
Oxygen	Ox_Sum	mg/L	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Smyslov V.A.
Nitrogen	N_Spr	мкгN/л	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Smyslov V.A.
Nitrogen	N_Sum	мкгN/л	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Smyslov V.A.
Phosphorus	P_Spr	мкгP/л	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Smyslov V.A.
Phosphorus	P_Sum	мкгP/л	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Smyslov V.A.
Chlorophyll	Chl_Spr	мкг/л	Vistula/Curonian lagoons	spring		1992-2011	AtlantNIRO	Smyslov V.A.
Chlorophyll	Chl_Sum	мкг/л	Vistula/Curonian lagoons	summer		1992-2011	AtlantNIRO	Smyslov V.A.
Temperature	Tem_Spr	^{0}C	Vistula/Curonian lagoons	spring		1992-2011	Gidromet	Gidromet
Temperature	Tem_Sum	^{0}C	Vistula/Curonian lagoons	summer		1992-2011	Gidromet	Gidromet

11. Vistula Lagoon

Coastal fish monitoring in the Russian parts of the Vistula and Curonian Lagoons was performed for fish community control, stock assessment and management of fisheries. For the location and characteristics of the areas, see Figure CL-1and Table CL-1, and for a summary of the data included, see Table CL-2 in the previous section.

The target fish species in the Vistula lagoon are the next: *Clupea harengus membras* (Baltic herring), *Abramis brama* (Bream), *Rutilus rutilus* (Roach), *Pelecus cultratus* (Sichel), *Sander lucioperca* (Pike-perch*), Perca fluviatilis* (Perch), *Anguilla anguilla* (European eel).

11.1. Trend analysis

11.1.1. Hydrography

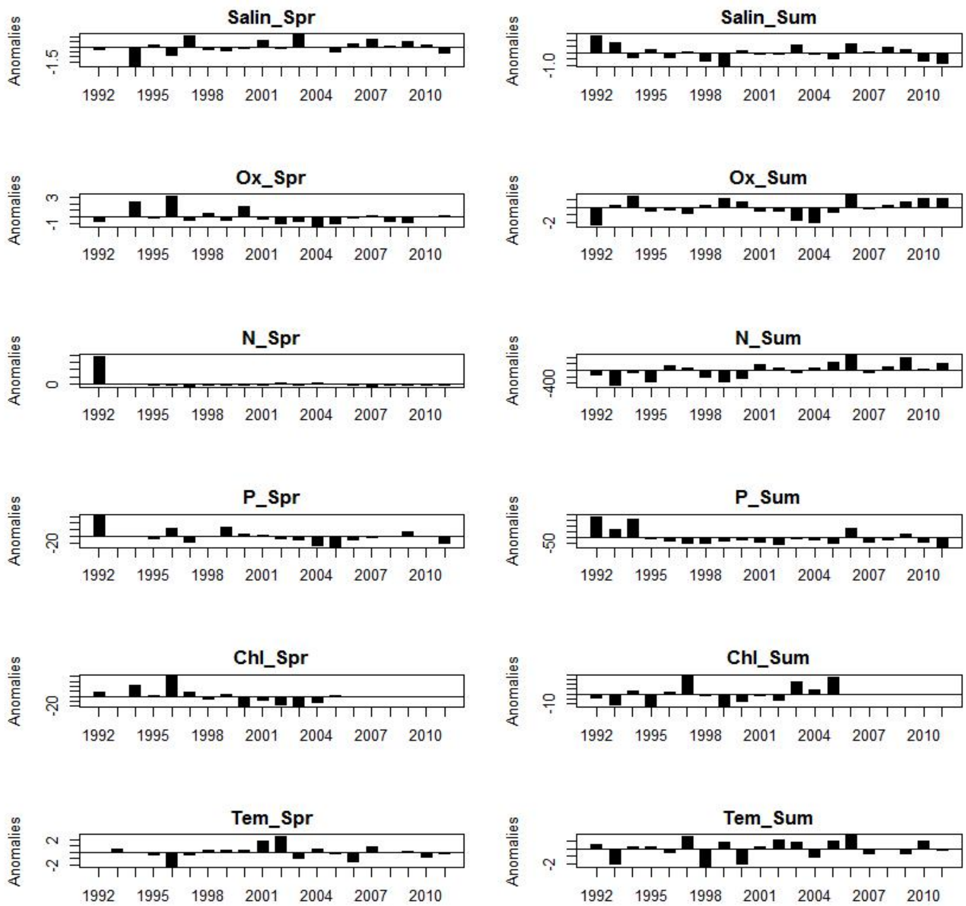

Figure VL-1. Long-term environmental changes in the Vistula lagoon: anomalies of the overall mean presented for variable. For abbreviations and units, see table CL-1.

For nitrogen and chlorophyll in summer increasing trend is visible, but spring concentrations of nitrogen and chlorophyll have decreasing trend. Only low values of oxygen concentration in summer and low values of nitrogen in sprint have been observed. The other hydrological parameters fluctuate, and no clear trends have been noticed.

11.1.2. Zoobenthos and zooplankton

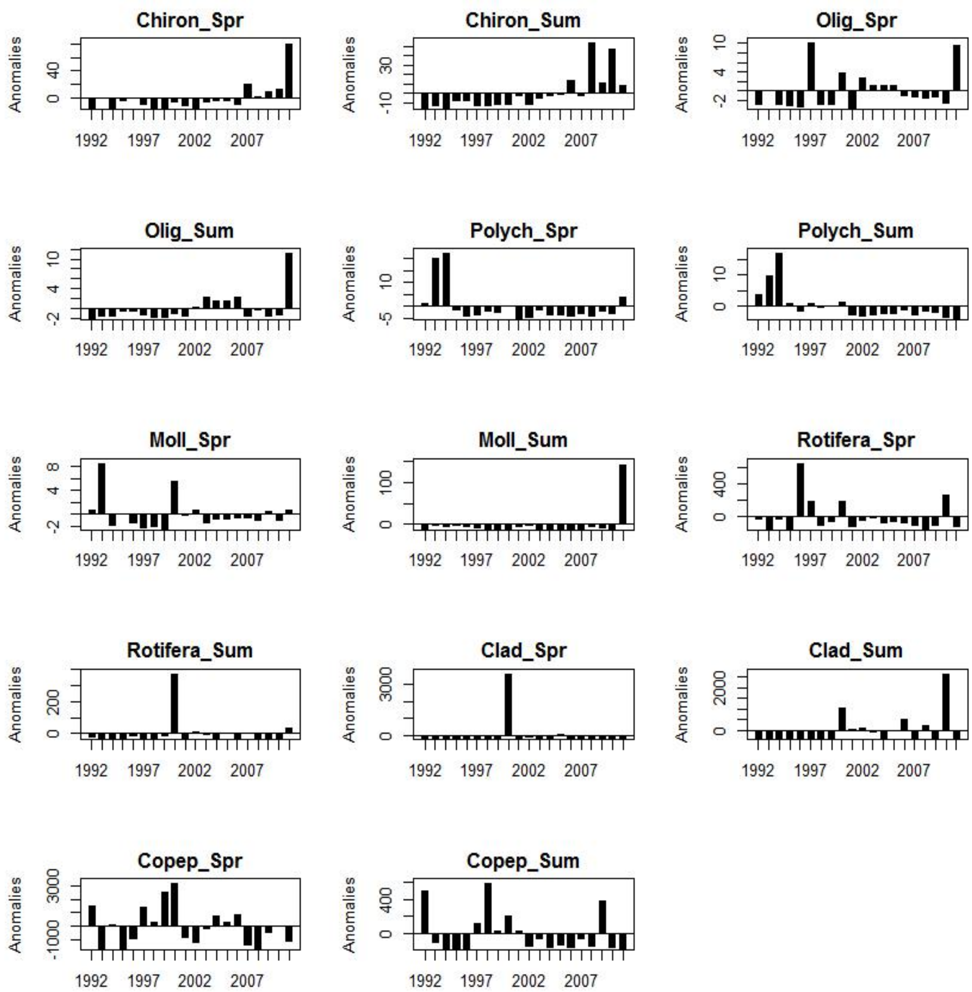

Figure VL-2. Long-term biological variables changes in the Vistula lagoon: anomalies of the overall mean presented for variable name and unit table CL-1.

Zooplankton data have been presented by rotifers, cladocers and copepods. Copepods fluctuated around the mean. A clear decreasing trend in biomass has been recognized for other groups.

Concerning benthos, a clear increasing trend in biomass has been revealed for churonomidae. Groups as molluscs and polychaetes have degreasing trends. For oligochaetas fluctuation around the mean was observed.

11.1.3. Fish

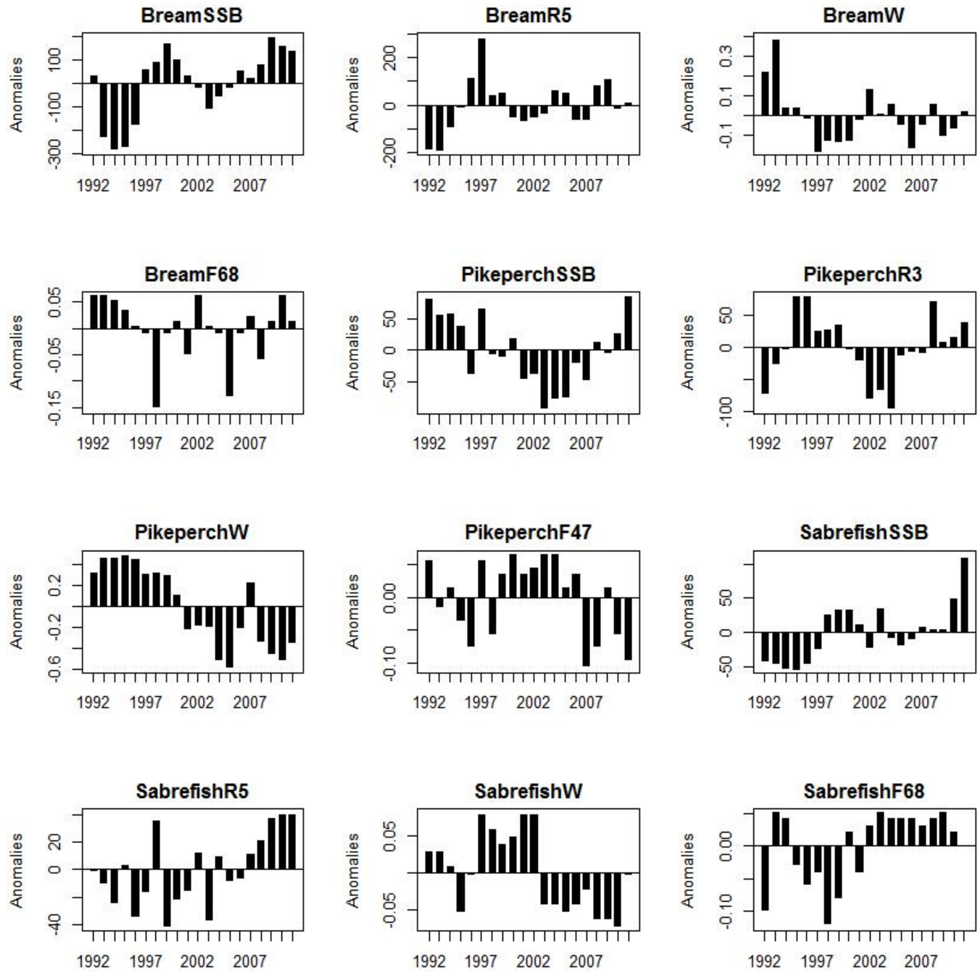

Figure VL-3. Long-term fish population parameters changes in the Vistula lagoon: anomalies of the overall mean presented for variable name and unit table CL-1.

A clear trend of degreasing weight has been recognized for commercial fish species (bream, pikeperch, sabrefish). For fishing mortality increasing trend is visible. Other population parameters (recruitment, mean weight, fishing mortality) fluctuated around the mean and no clear trends has been notice.

11.2. Integrated analyses

The period 1992–2011 was included in the integral analysis. All 46 variables were considered. The presented results are the first attempt to conduct an IEA for the Vistula lagoon and have been performed for the full available datasets.

It was revealed the key variables in the Vistula lagoon ecosystem as the following: Chiron_Sum, N_Sum, SarefishSSB, BreamSSB, Chiron_Spr, Olig_Spr,Chl_Sum, Olig_Sum.

In the PCA analysis, the first two principal components explained 24% and 14% of variance, respectively. The time trajectory plot indicates that the hole ecosystem (biota and abiotic) had to states from one to another between 1992–1997. An anomaly state of the Vistula lagoon ecosystem was likely occurred in 2011.

Time-trajectory of PC1 revealed a clear trend of increasing from 1993 to the present time. Time-trajectory of PC2 showed significant changes in trends: a decrease from 1992 to 1995, a increase from 1996 to 2000 and then a decrease from 2001 to the present time.

The STARS applied on $PC1_{all}$ index estimated for the Vistula lagoon showed the significant shift in the whole ecosystem (biota and abiotic) regime occurred in 1997/1998 and in 2009 with transition period from 1998 till 2008.

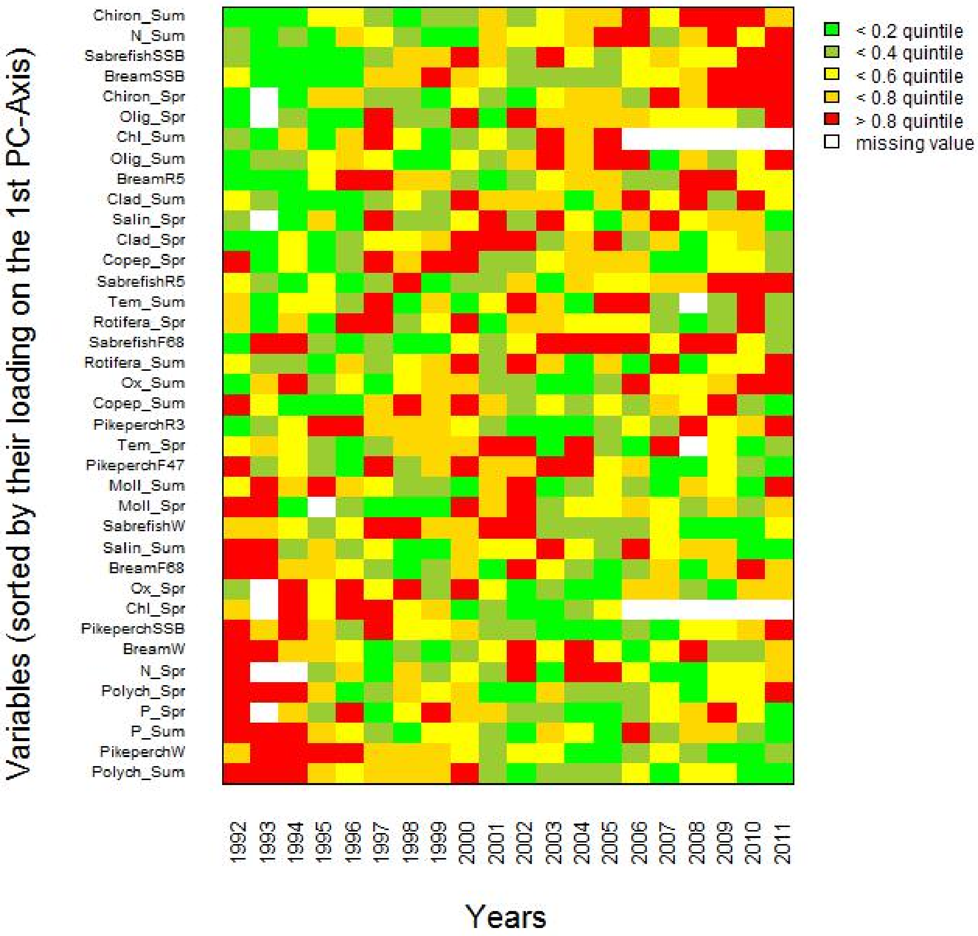

Figure VL-4. Traffic-light plot of the temporal development of the Vistula lagoon time-series. Variables are transformed to quintiles, colour coded (green=low values, red=high values) and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in Table CL-1.

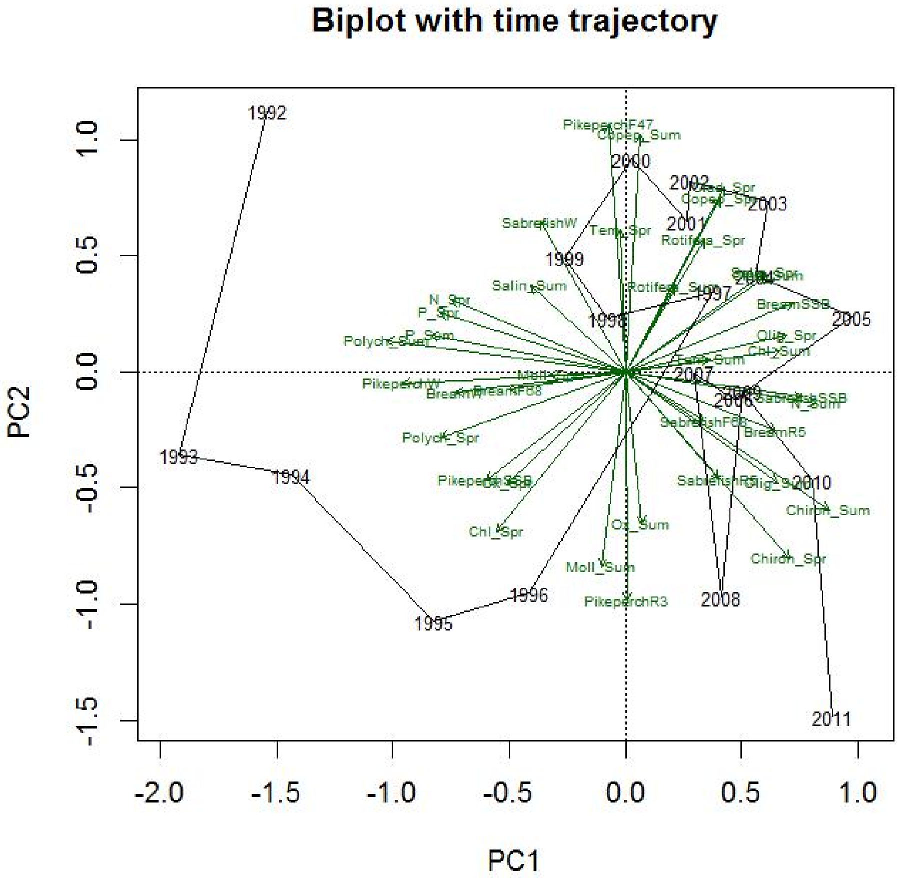

Figure VL-5. Results of the standardized principal component analysis using all 46 variables assembled for the Vistula lagoon. The graph shows time trajectory (in light green) and a correlation biplot of variables.

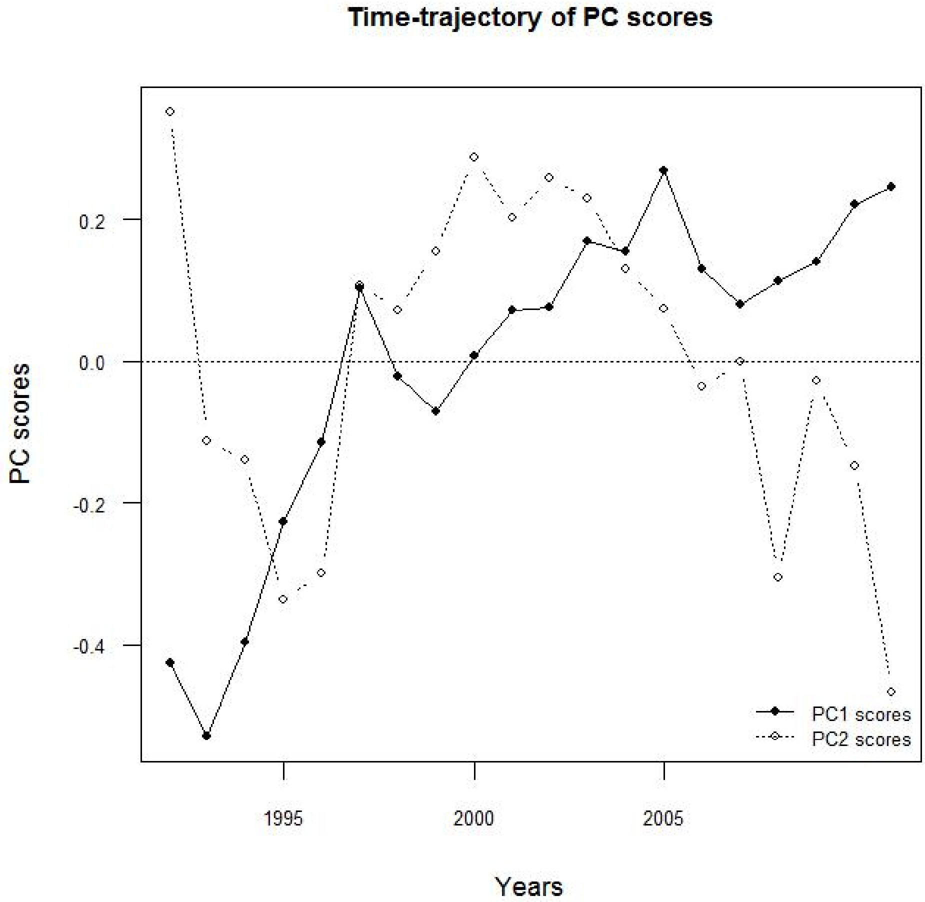

Figure VL-6. Results of the standardized principal component analysis using 46 variables assembled for the Vistula lagoon showing PC1 (black circles) and PC2 (white circles).

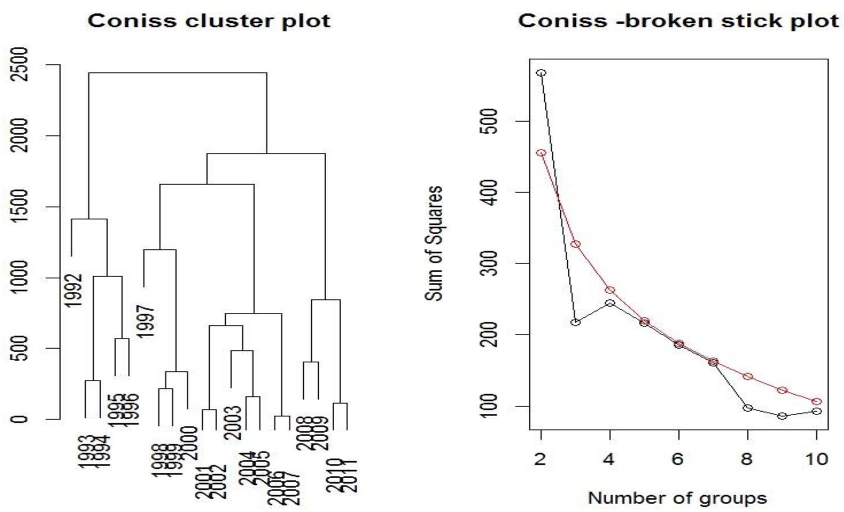

Figure VL-7. Results of the constrained hierarchical clustering analysis for the Vistula lagoon.

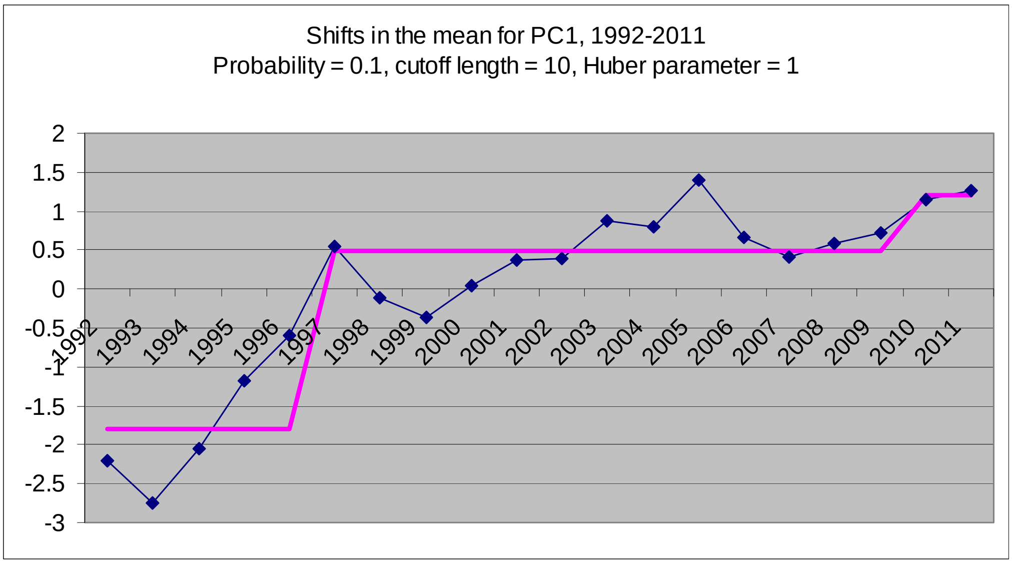

Figure VL-8. Result of STARS analysis on the first component based on all variables (Shifts in the mean for PC1, 1992–2011).

12. Gulf of Gdansk (GoG)

12.1. Area description

Located in the southern part of the Baltic Sea (ICES SD 26), the Gulf of Gdansk is a part of the larger Gdansk Basin. The environmental conditions are influenced by the open sea waters and the discharge of the Vistula River in the same time. The Vistula River is the major source of nutrients and pollutants for the Gulf and one of the most important sources for the Baltic Proper as it drains the substantial part of the total

Baltic Sea drainage basin (Draganik, 1996; 1997; Grelowski and Pastuszak, 1996). Water column in deeper parts of the Gulf is divided into two layers: the surface one with relatively low salinity (~7 PSU) and significant seasonal temperature variability and the near-bottom one of higher salinity (more than 12 PSU) and relatively stable temperature. Cyanobacteria blooms length and intensity have increased since the 1990s. In the most coastal waters the domination of filamentous brown algae is evident. The impact of an increasing eutrophication is especially apparent in the alteration of the current vertical and horizontal range of macrophytes. Suspension and deposit feeders dominate the zoobenthos community. Gulf of Gdansk is an important, commercial fishing ground with domination of sprat, herring and cod in terms of biomass but the area has also a long history of small-boat, coastal fishery focused on herring, flat fish, salmonids and freshwater species entering coastal waters.

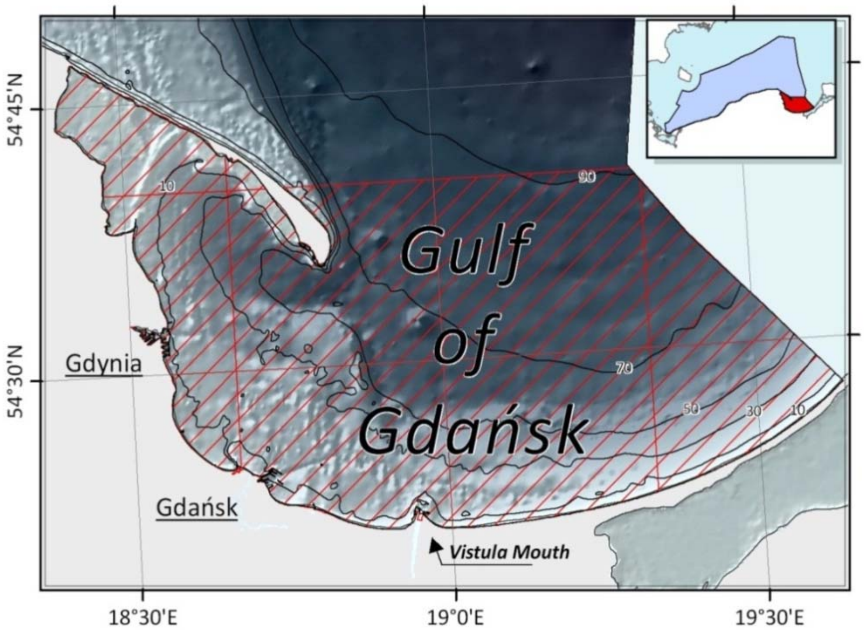

Figure GoG-1. Gulf of Gdansk.

12.2. Variable descriptions

In total, 36 variables were considered: 5 physical, 7 nutrient, 6 phytoplankton, 14 fish and fishery-related datasets and 4 others (BSI, chlorophyl *a*, primary production - PP). Data series were compiled to one estimate per year for area of interest

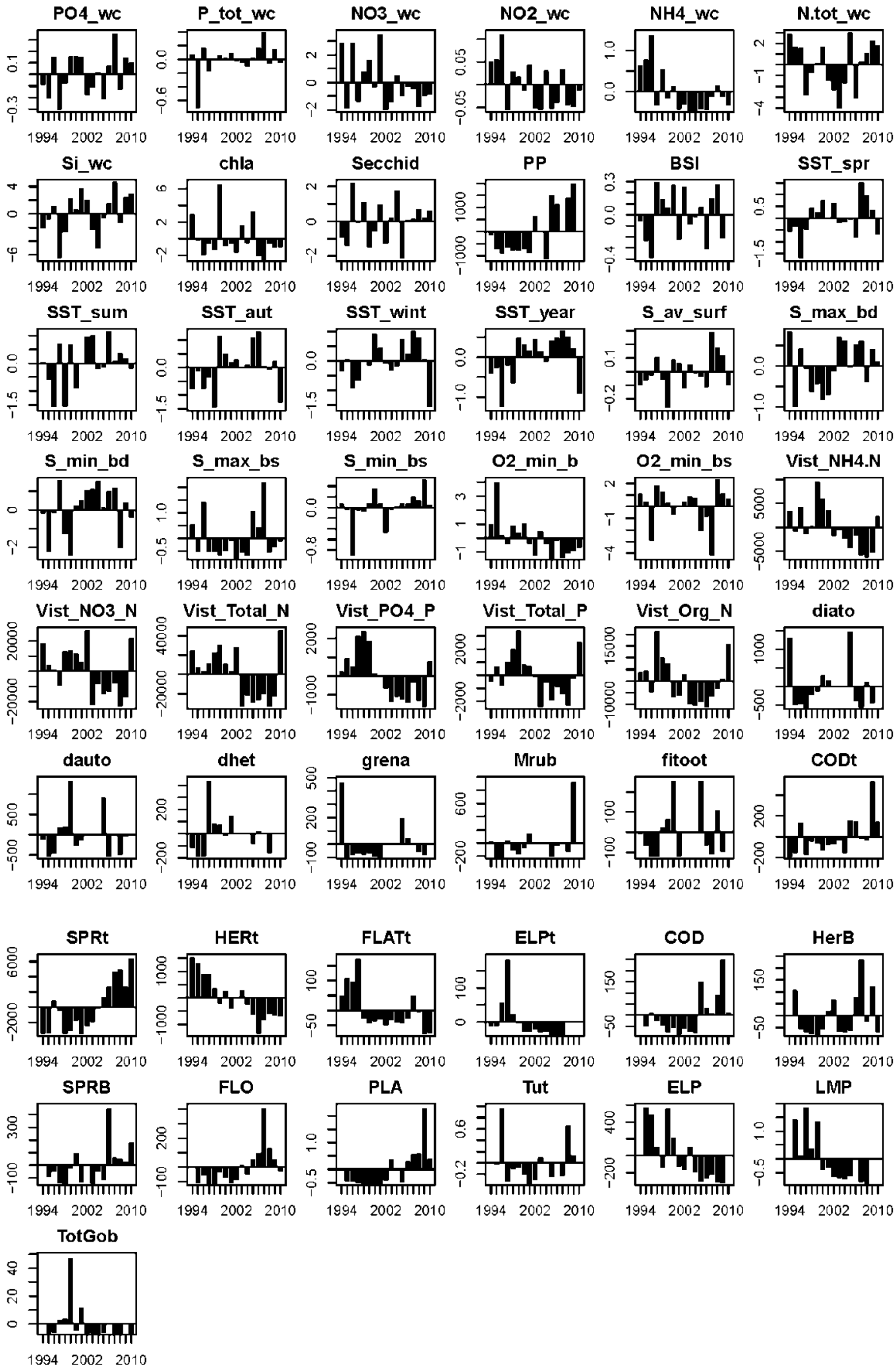

Figure GoG-2.

12.3. Results of integrated trend analyses based on all variables

To illustrate temporal changes of all-time-series GoG dataset "traffic light plot" was displayed (Figure GoG-3). Variables were sorted according to their loadings along the first PC, and by PC order this plot shows a trend from variables placed at the bottom left corner with high quintile values from mid1990s to the end of 1990s, to variables at the upper right corner with high quintile values in the last 5 year of analysis.

For the PCA on all variables, variables with the most positive trends and positive values of PC1 were: place, flounder, cod biomass, primary production rate (biotic variables) and cod, sprat landings,, sea surface temperature in spring (abiotic factors). Highly correlated with PC1l with decreasing trend are for lumpfish, eelpout and total gobides biomass, and eelpout, herring and flat fishes landings as well as bottom oxygen concentrations.

Variables positively correlated with PC2 based on all variables represent biomass of phytoplankton (other phytoplankton as well as auto- and heterotrophic dinoflagellates), while negative values were for such abiotic variables as sea surface salinity, nitrate water column concentrations and Secchi depth.

PC1l and PC2 explained 28 and 15% of variation, respectively. System trajectories (Figure GoG-4) represent ecosystem changes and possible system states. Changes might be observed when PC1 vs. PC2 scores are plotted, and it is possible to identify two or three ecosystem states: 1994–1998, 1999–2004, and 2006–2010. Data discontinuity was detected between 2004 and 2005 by Coniss Broken Stick method (Figure GoG-6).

Separate analysis for abiotic and biotic was not performing due to data restrictions and availability.

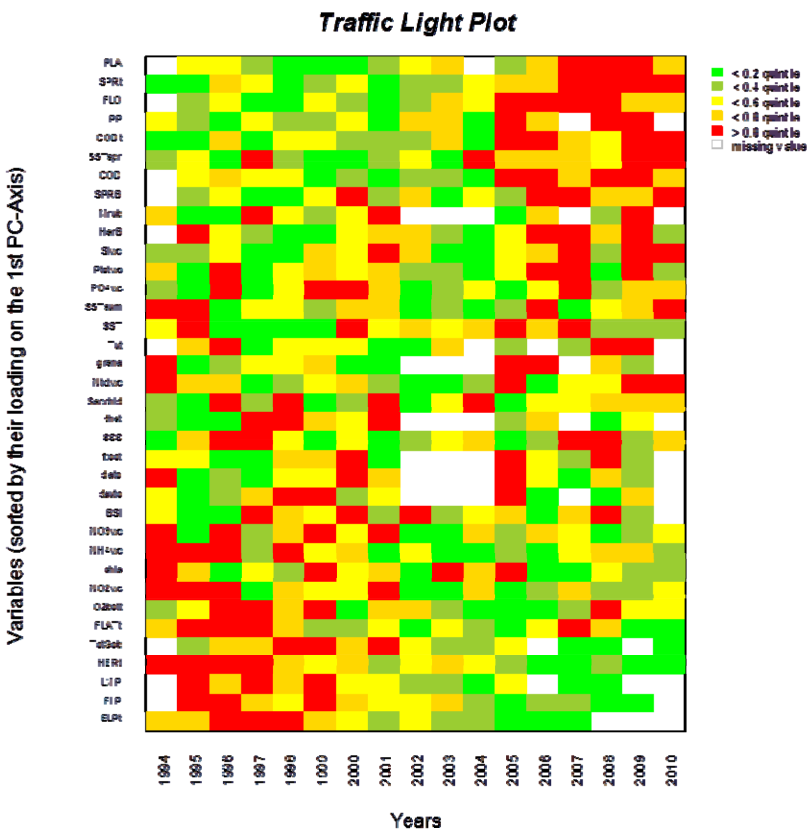

Figure GoG-3. Traffic-light plot of the temporal development of 36 time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component.

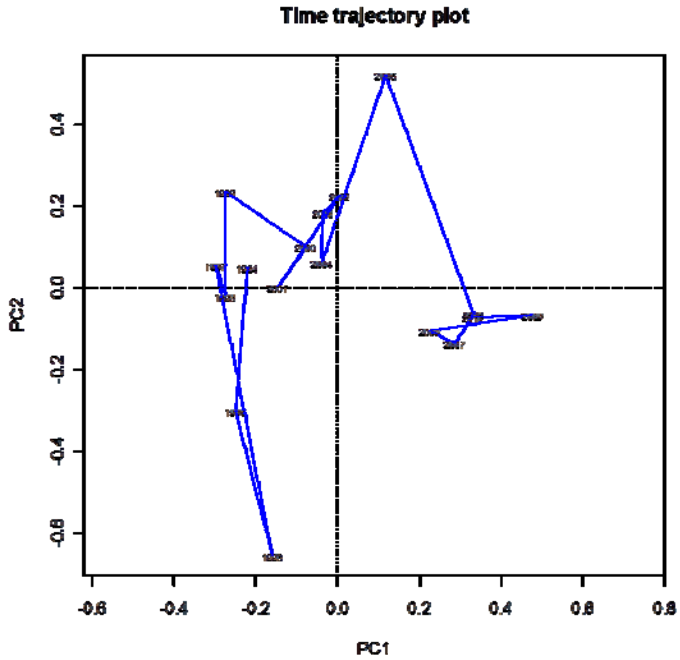

Figure GoG-4. Results of the standardized principal component analysis using all 36 variables showing the time trajectory on the first factorial plane (PC1 = 28 %, PC2 = 15% explained variance).

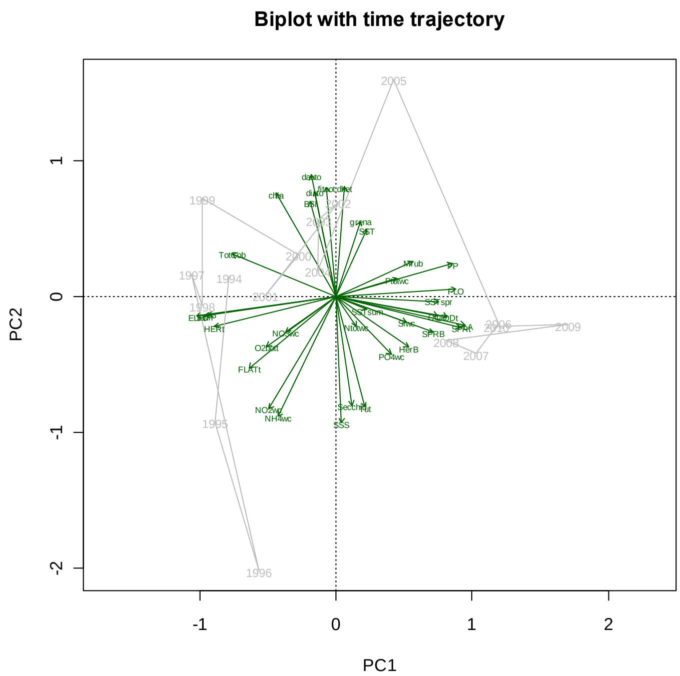

Figure GoG-5. Results of the standardized principal component analysis using all 36 variables showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey) (PC1 = 28%, PC2 = 15% explained variance).

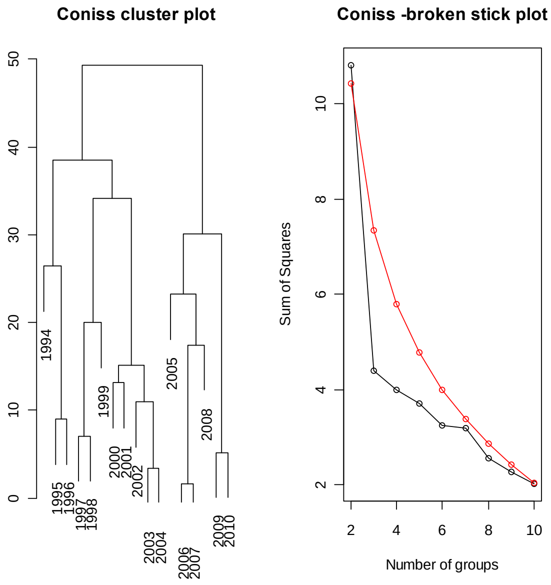

Figure GoG-6. Coniss Cluster plot and output of broken stick analysis for the Gulf of Gdansk.

12.4. References

Draganik, B. 1996. Polish inshore waters, their properties and role in the coastal area economy. Proceedings of Polish-Swedish Symposium on Baltic coastal fisheries resources and management. Gdynia, 2-3 April 1996; 51-70.

Draganik, B. 1997. Effect of river inflow on fish assemblages in the Polish coastal waters. ICES C.M. 1997/S: 05.

Grelowski, A. and M. Pastuszak 1996. Odpływ wody oraz zrzuty zanieczyszczeń z polskich rzek do Bałtyku w latach 1988-1994 [Water and pollutants discharged by Polish rivers into the Baltic Sea in 1988-1994]. Studia i Materiały Mor. Inst. Ryb, Gdynia, 34/A; 1-34.

13. Kattegat coast- Vendelsö (VO)

Area description

The Vendelsö area is situated in the central parts of Kattegat. The area is exposed to the open sea and is rather shallow with a maximum depth not exceeding 10 meters. Neighbouring areas are, however, much deeper, and the average psu is in the range of 17–20. The bottom substrate is dominated by hard bottom with segments of sand. The main local antrophogenic impact comes from agriculture and smaller rural areas. Influence from perturbations in the offshore area is, however, also anticipated to affect the coastal system in Vendelsö (Olsson *et al.*, in press). This area also serves as a reference site to the nuclear power-plant in Ringhals, and are hence considered to be unaffected by the discharge of cooling water from the power-plant (Swedish Board of Fisheries, 2009).

For the integrated analyses of Vendelsö in total 30 variables were considered: seven physical, seven nutrient, one related to fishing pressure, eight macro-zoobenthos and seven fish datasets. No data on phytoplankton, zooplankton and higher trtophic levels (i.e. seals and birds) were hence included. The rationale for this was that reliable local information was not available for these variables, and corresponding open sea information was not considered representative enough. For the physical and nutrient variables, both coastal (five) and offshore (eight) time-series were included. All datasets comprised one value per year and covered the period 1981–2010.

Figure VO-1. Location of the Vendelsö area at the west coast of Sweden.

13.2. Variable descriptions

13.2.1. Hydrography

Variables as temperature, salinity, pH and a proxy for large-scale atmospheric conditions, Arctic Oscillation Index (AO), were considered as the hydrohraphical variables potentially affecting the coastal system in Vendelsö. Temperature was included both at the local and offshore (basin wide) scale, and data for both the spring and summer season was considered. Since no local data was available, only offshore values of salinity (annual average) and pH (annual average) were used. As previous studies have suggested that large-scale climatic conditions influence the structure of offshore (Möllmann *et al.*, 2009, Dieckmann and Möllmann 2010) and coastal systems (Olsson *et al.*, *in press*) in the Baltic Sea, the Arctic Oscillation index was included to represent the overall conditions in atmospheric pressures influencing the direction of winds in the area and thus potentially impacting the local sea-surface temperatures (Kalnay *et al.*, 1996).

Over the time-period assessed, there has been an increase in local and offshore summer temperature, an almost significant increase in local spring temperatures, and a general acidification of the open sea as indicated by a decrease in the yearly average pH.

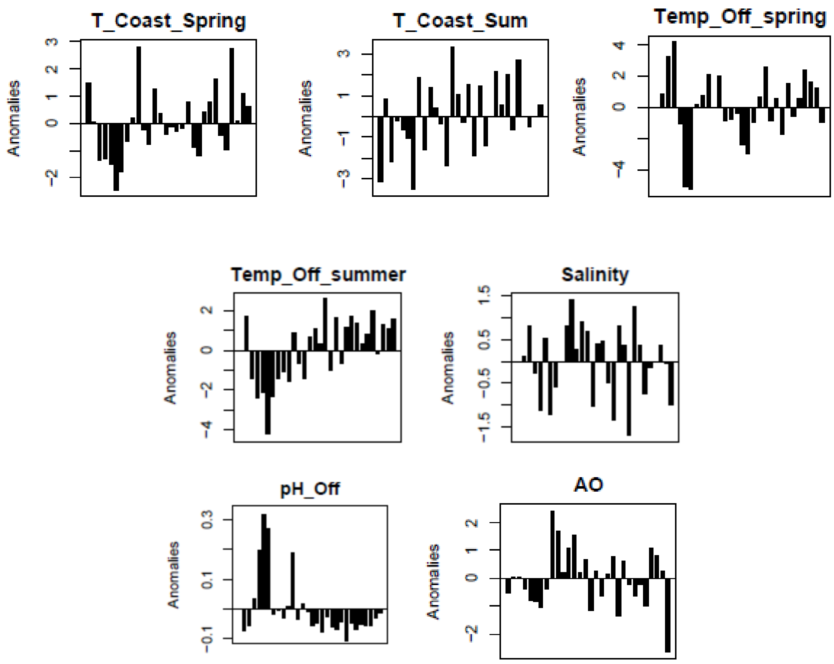

Figure VO-2. Long-term hydrographic changes in the Vendelsö area: anomalies from the overall mean in coastal spring – (T_Coast_Spring), coastal summer – (T_Coast_Sum), offshore spring – (Temp_Off_spring) and offshore summer (Temp_Off_summer) temperature (°C), salinity (psu), pH and Arctic Oscillation Index (AO).

13.2.2. Nutrients

Impact of nutrient concentrations and eutrophication on the local scale was represented by local water transparency in August and total discharge of nitrogen and phosphorous from land within the county (Halland, N) where Vendeslö is situated. As proxies for nutrient load on the larger scale, offshore concentrations of DIN (dissolved inorganic nitrogen) and DIP (dissolved inorganic phosphorous) as well as total discharge of nitrogen and phosphorous from land to Kattegat was used.

There has been an increase in local water transparency and a decrease in offshore DIP between 1981–2010 (Figure VO-3).

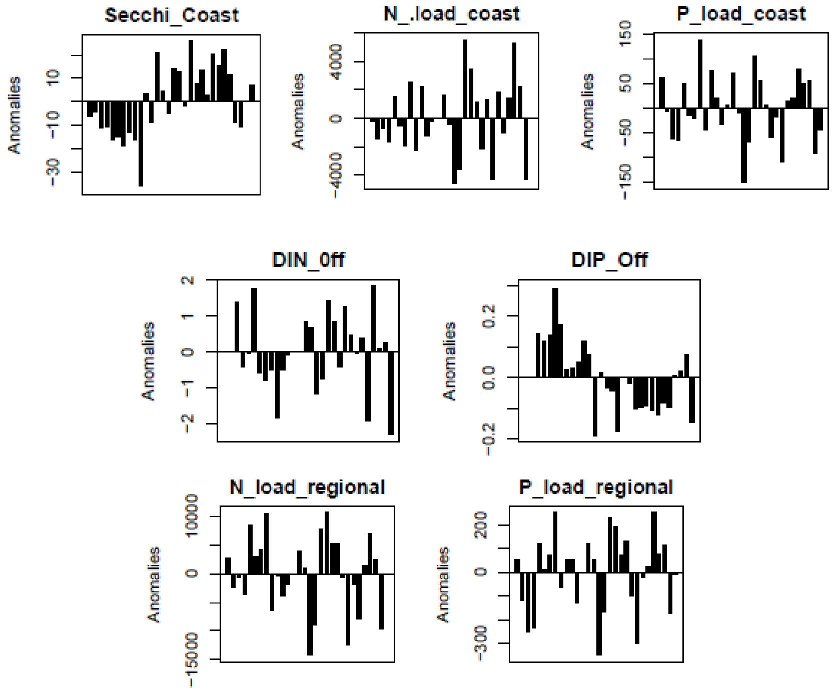

Figure VO-3. Long-term changes in nutrient related variables in the Vendelsö area: anomalies from the overall mean in local water transparency (Secchi_Coast), local discharge from land in nitrogen (N_load_coast) and phosphorous (P_load_coast), offshore concentrations of DIN (DIN_Off) and DIP (DIP_Off), as well as total discharge of nitrogen (N_load_regional) and phosphorous (P_load_regional) from land to the Kattegat.

13.2.3. Fishing

As a proxy for fishing pressure, the F-based estimate of the proportion of 3–5 year old cod in the Kattegat was used. There has been an overall increase in the fishing pressure for cod since the 1970s in this basin (ICES 2010), but when considering the period 1981–2010 no trend is discernible. The recent drop in fishing pressure rather reflects the collapse of the cod stock in the basin (Figure VO-4). No local information on fishing pressure was available for the time-period assessed.

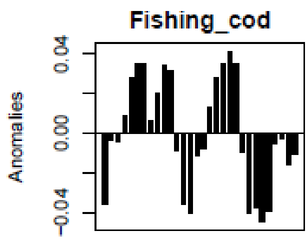

Figure VO-4. Long-term changes in offshore fishing pressure in Kattegat: anomalies from the overall mean.

13.2.4. Benthos

In all, eight time-series representing the zoobenthic community in Vendeslö was considered. Data on shore crab (*Carcinus maenas*) was collected during fish sampling in August, whereas the remaining seven taxonomic groups (*Amphipoda*, *Amphiuridae*, *Capitellidae*, *Cumacea*, *Nephtyidae*, *Montacutidae* and *Spionidae*) was sampled during spring (April-June). Except for *Montacutidae* and *Spionidae*, which were collected on a transportation bottom, samples were collected on a sedimentation bottom.

There was a strong turnover of the zoobenthic community during 1981–2010, manifested as a decrease in amphipods (*Amphipoda*), polychaetaes (*Capitellidae* and *Spionidae*), hooded shrimps (*Cumacea*) and bivalves (*Montacutidae*). At the same time the brittle stars (*Amphiuridae*) and shore crab has increased in abundance (Figure VO-5).

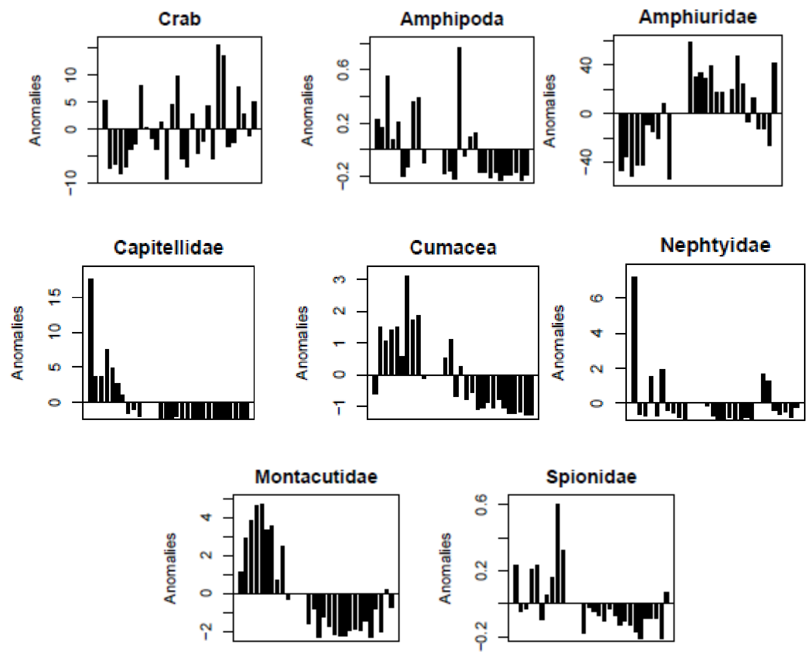

Figure VO-5. Long-term changes in the abundance of zoobenthos in the Vendelsö area: anomalies from the overall mean abundance (ind/m^2) of shore crab (Crab), *Amphipoda*, *Amphiuridae*, *Capitellidae*, *Cumacea*, *Nephtyidae*, *Montacutidae* and *Spionidae*.

13.2.5. Fish

The seven time-series included to represent the local fish community was for goldsinny wrasse (*Ctenolabrus rupestris*), corkwing wrasse (*Symphodus melops*) and eel (*Anguilla anguilla*) from the August sampling, and cod (*Gadus morhua*), eelpout (*Zoarces vivparous*), flounder (*Platichtys flesus*) and shorthorn sculpin (*Myxocephalus scorpio*) from the spring sampling when water temperatures are substantially lower and the abundance of these species higher.

There has been an increase in corkwing wrasse, flounder and eel, and decrease in eelpout, shorthorn sculpin and goldsinny wrasse between 1981–2010 (Figure VO-6).

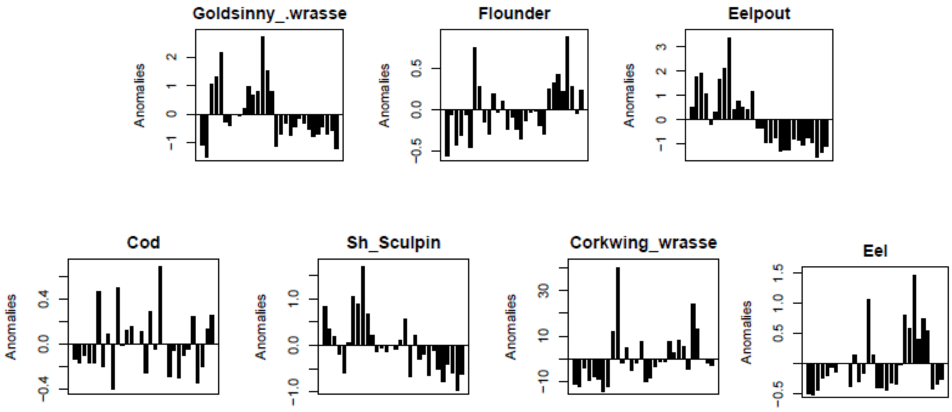

Figure VO-6. Long-term changes in the abundance of fish in the Vendelsö area: anomalies from the overall mean in numbers per night and fyke net goldsinny wrasse, flounder, eelpout, cod, shorthorn sculpin (Sh_sculpin), corkwing wrasse and eel.

13.3. Results of integrated trend analyses based on all variables

An overview of the temporal development of the variables in the Vendelsö time-series is presented in figure VO-7. Variables are sorted according to their PC1 loadings of the subsequently performed PCA, generating a pattern with variables at the top that revealed an increasing trend over time (green to red), with the highest values in the recent 14 years, to variables at the bottom demonstrating the opposite trend (red to green) with the highest values during the 1980s. Despite not as obvious as for the group of variables exhibiting a negative development over time, off-shore and coastal summer temperatures and coastal water transparency have increased between 1981–2010. The biotic variables with an increase in abundance are the brittle stars (*Amphiuridae*), corkwing wrasse and eel. In contrast, pH and dissolved inorganic phosphorous in the off-shore area as well as the biotic variables hooded shrimps (*Cumacae*), the polychateas (*Spionidae* and *Capitellidae*), amphipods, bivalves (*Montacutidae*), shorthorned sculpin and eelpout exhibit decreasing values with time.

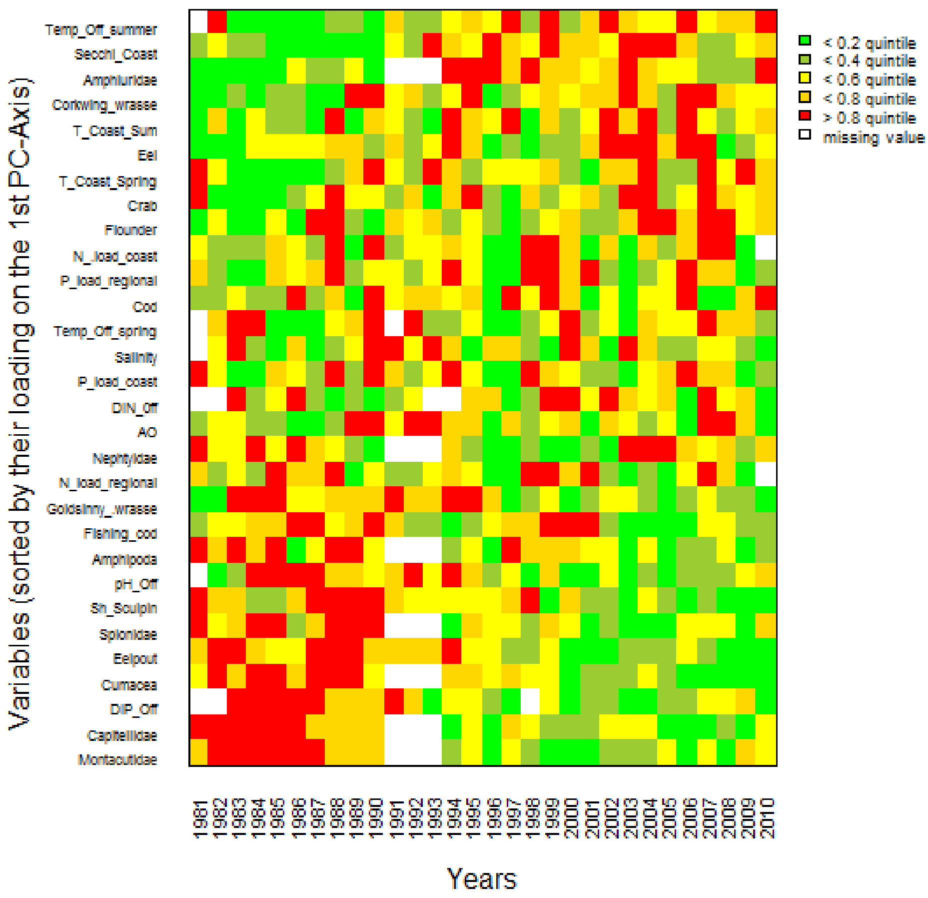

Figure VO-7. Traffic-light plot of the temporal development of 30 time-series in the Vendelsö area. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component.

The ordination of yearly averages by a standardized PCA resulted in 26.2 and 13.3 % of the explained variance captured by the first two principal components. The first PC generally reflects both biotic and abiotic variables, and there seems to be some clustering of years. The years between 1981–1992 generally has negative loadings and is characterised by high biomasses of hooded shrimps (*Cumacae*), the polychateas (*Spionidae* and *Capitellidae*), amphipods and bivalves (*Montacutidae*), and abundances of eelpout and shorthorn sculpin (Figure VO-8). As a contrast, the years 1993–2010 have positive loadings for PC1 and mainly reflect high biomass of brittle stars and high abundances of shore crabs, flounder, eel and corkwing wrasse. Offshore DIP and pH also had relatively strong negative loadings on PC1, whereas local water transparency in August and offshore and coastal summer temperature had poitive loadings. The second PC generally reflects abiotic variables such as those realted to discharge from land of nutrients, salinity and water transparency (Figure VO-8). In contrast to the first PC, there is no obvious temporal development of the year scores for this principal component.

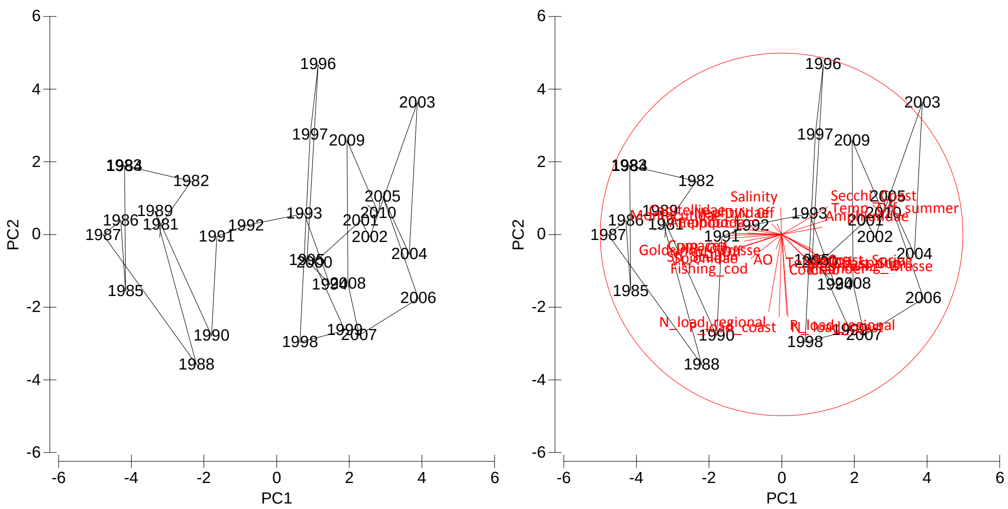

Figure VO-8. PCA output with sample scores and time-trajectory. Results of the standardized principal component analysis using all 30 variables assembled for the Vendelsö area showing the time trajectory on the first factorial plane (left; PC1 = 26.3 %, PC2 = 13.2 % explained variance) and the biplot with loading of each variable and time-tajectory plot (right).

The outcome of the discontinuity analysis (chronological clustering) suggested several shifts in ecosystem structure; the strongest shifts was observed in 1988/1989 and 1997/1998 (both at alpha 0.01; Figure VO-10). Additional shifts was suggested in 1985/1986, 1990/1991, 1995/1996 and 2001/2002 (all at alpha 0.05; Figure VO-10).

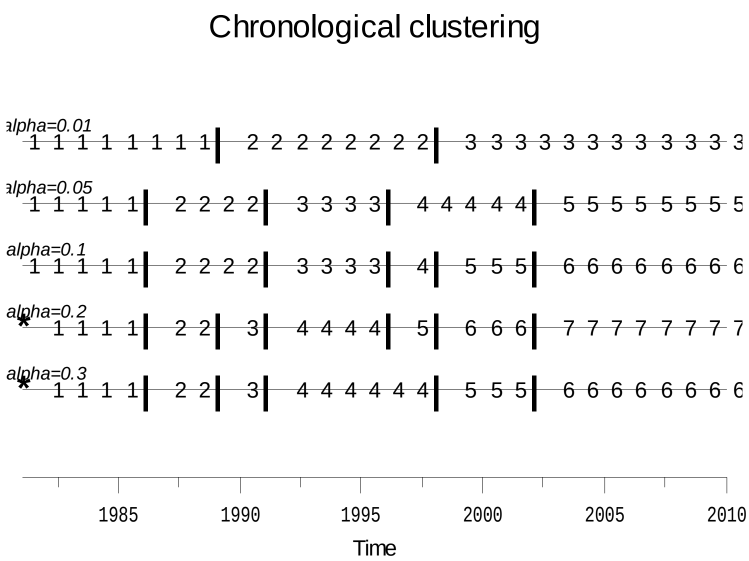

Figure VO-10. Results of the chronological cluster analyses performed on all 30 variables.

13.4. Results of integrated trend analyses based on abiotic and fisheries related variables only

The temporal development of the abiotic variables in the Vendelsö area does not follow as an obvious pattern as the analysis using all variables (Figure VO-11). The two first components of the ordination of the PCA explained an almost equal share of the variation captured 26.8 and 22.3 % respectively. There is no obvious pattern for either PC 1 or 2, and all variables related to nutrient discharge from land, pH, offshore DIP, summer temperature and fishing pressure, as well as coastal water transparency had high loadings for the first PC. For the second PC, variables related to nutrient discharge from land, pH, offshore DIP and all temperature related variables exhibited the highest scores.

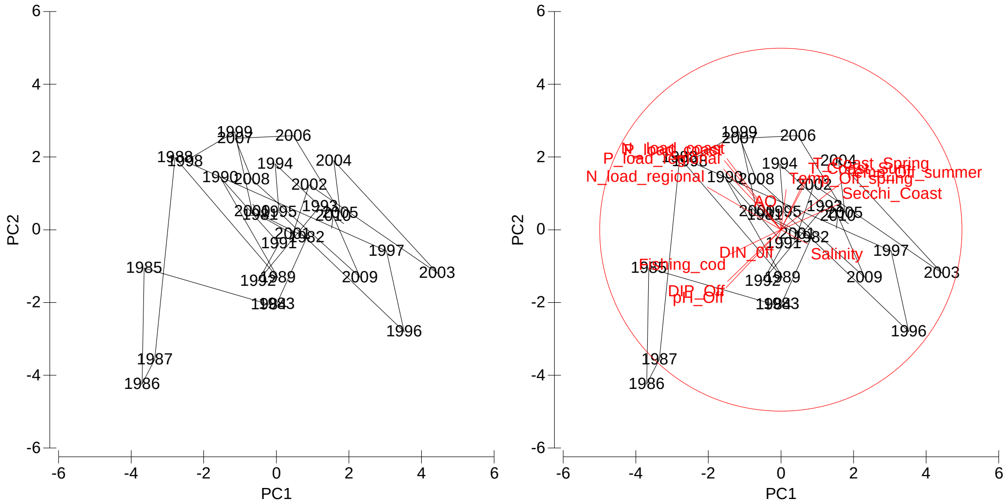

Figure VO-11. PCA output with sample scores and time-trajectory. Results of the standardized principal component analysis using the 15 abiotic variables assembled for the Vendelsö area showing the time trajectory on the first factorial plane (left; PC1 =26.8 %, PC2 = 22.3 % explained variance) and the biplot with loading of each variable and time-tajectory plot (right).

The outcome of the discontinuity analysis (chronological clustering) detected the strongest shift in 1987/1988 (both alpha 0.01 and 0.05; Figure VO-12). A somewhat weaker shift (at alpha 0.05) was suggested between 1984/1985.

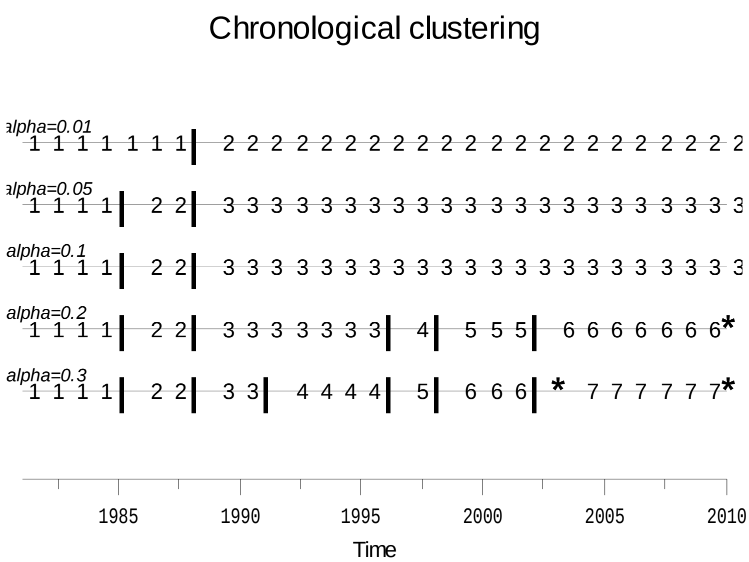

Figure VO-12. Results of the chronological cluster analyses performed on the 15 abiotic variables.

13.5. Results of integrated trend analyses based on biotic variables only

There has been an even stronger transition of the system when only concidering the biotic variables compared to the data set including all variables (Figure VO-13). The two first components of the PCA explained 37 and 12.2 % respectively of the total variation. The years before 1993 generally have negative scores on PC 1 and is best characterised by high biomass of amphipods (*Amphipoda*), polychaetaes (*Capitellidae* and *Spionidae*), hooded shrimps (*Cumacea*) and bivalves (*Montacutidae*), as well as high abundances of eelpout, goldsinny wrasse and shorthorn sculpin. The years from 1994–2010 generally have positive values of PC 1 and is best characterised by higher biomass of brittle stars and high abundances of shore crabs, flounder, eel and corkwing wrasse. The strongest correlation between the temporal development of PC 1 and abiotic variables was observed for offshore DIP (-0.68), coastal water transparency (0.61) and offshore summer temperature (0.56). For PC 2, no abiotic variable exhibited a correlation above 0.2.

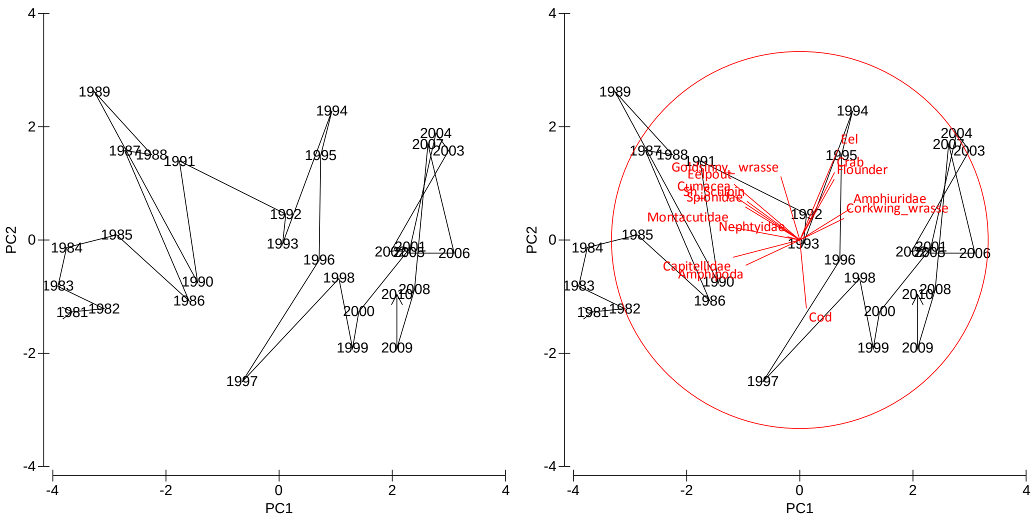

Figure VO-13. PCA output with sample scores and time-trajectory. Results of the standardized principal component analysis using the 15 biotic variables assembled for the Vendeslö area showing the time trajectory on the first factorial plane (left; PC1 = 37 %, PC2 = 12.2 % explained variance) and the biplot with loading of each variable and time-tajectory plot (right).

The outcome of the discontinuity analysis (chronological clustering) did to some extent support the PCA and suggested several shift in ecosystem structure. The strongest shift (occurring at alpha 0.01) was suggested between 1996/1997 (VO-14). Additional shifts (all at alpha 0.05) was suggested between the years 1986/1987, 1989/1990, 1995/1996 and 2002/2003.

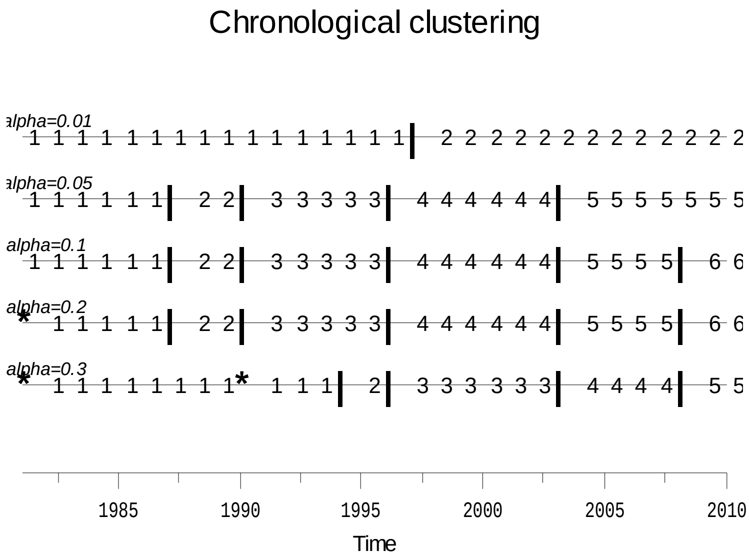

Figure VO-14. Results of the chronological cluster analyses performed on the 15 biotic variables in the Vendelsö area.

Based on these analyses, it is obvious that there has been a transition of the assessed ecosystem in the Vendelsö area potentially linked to changes in the level of eutrophication and thermal regime. There has been a change from a state characterised by high biomass of the zoobenthos groups assessed and species of fish favoured by lower water temperatures as eelpout and shorthorn sculpin, to a state where brittle stars and shore crab as well as species of fish favoured by higher water temperatures as flounder, eel and corkwing wrasse has increased in occurrence. It is reasonable to assume that the decrease in biomass of the zoobenthos groups *Cumacae*, *Spionidae*, *Capitellidae* and *Montacutidae* might be linked to the decrease nutreint levels (decreased off-shore DIP and increased coastal water transparency), as suggested by the cross-correlation analyses between PC 1 and the abiotic variables. These zoobenthic groups are all acknowledged to be tolerant to eutrophic conditions. There was a reasonable high positive correlation between PC 1 and offshore summer temperatures supporting that the decrease of eelpout and shorthorn sculpin and the concurrent increase in flounder, eel and corkwing wrasse could have been fostered by increasing water temperatures. The increase in small-bodied species of fish like corkwing wrasse and shore crab might also have been affected by predatory release triggered by the collapse in the offshore stock of cod in Kattegat (Eriksson *et al.*, 2011).

13.6. References

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14. Limfjord (LF)

14.2. Area description

The Limfjord is the largest Danish fjord system with a coastline of 1500 km, a surface area of 7526 km2 and a mean depth of ~6 meters. It connects the North Sea in the west with the Kattegat in the East (Figure LF-1). There is an overall salinity gradient decreasing from west to east (from 34 to 26 ‰). Due to freshwater influxes, salinity ranges between 0–34 ‰ in some embayments. The highly eutrophicated fjord system suffers from frequent and extensive episodes of hypoxia and anoxia causing mass mortality of benthic organisms.

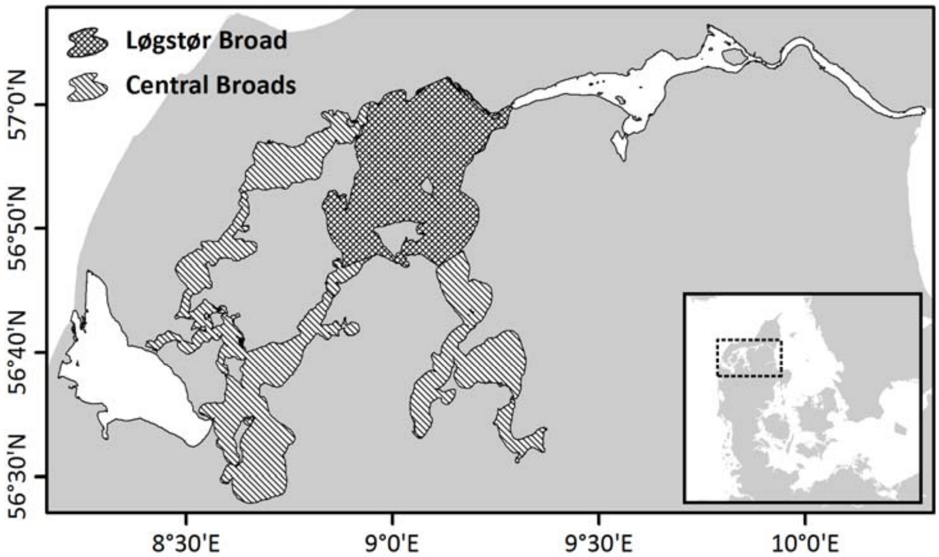

Figure LF-1. Limfjord.

14.2. Variable descriptions

Time-series data for the period 1988–2008 initially selected for the IEA comprised 19 biological response variables, 21 explanatory variables related to environmental and climatic conditions, and 4 fisheries related explanatory variables. Selected climatic variables cover longer period 1984–2008. Metadata and all details will be given at Tomczak *et al.*, (in preparation).

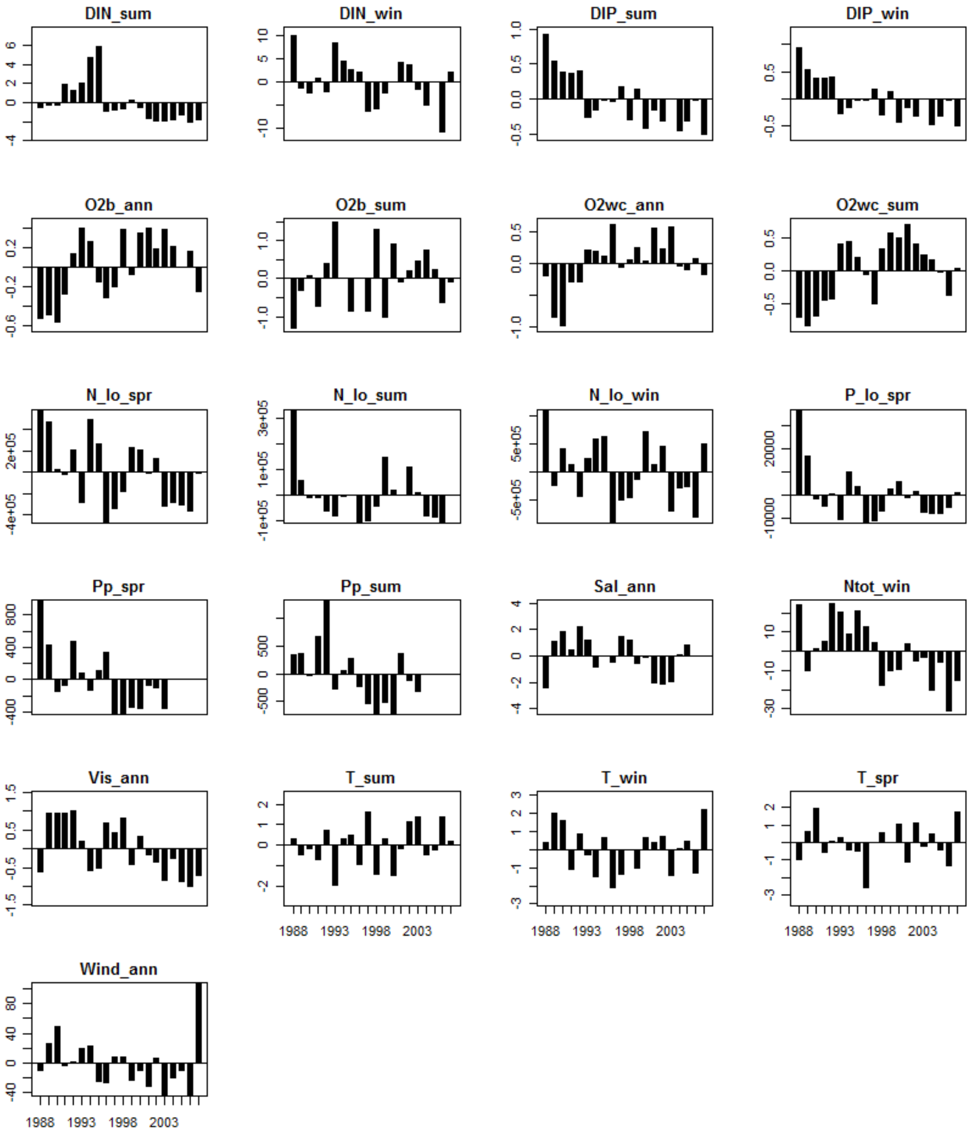

Figure LF-2. Environmental variables.

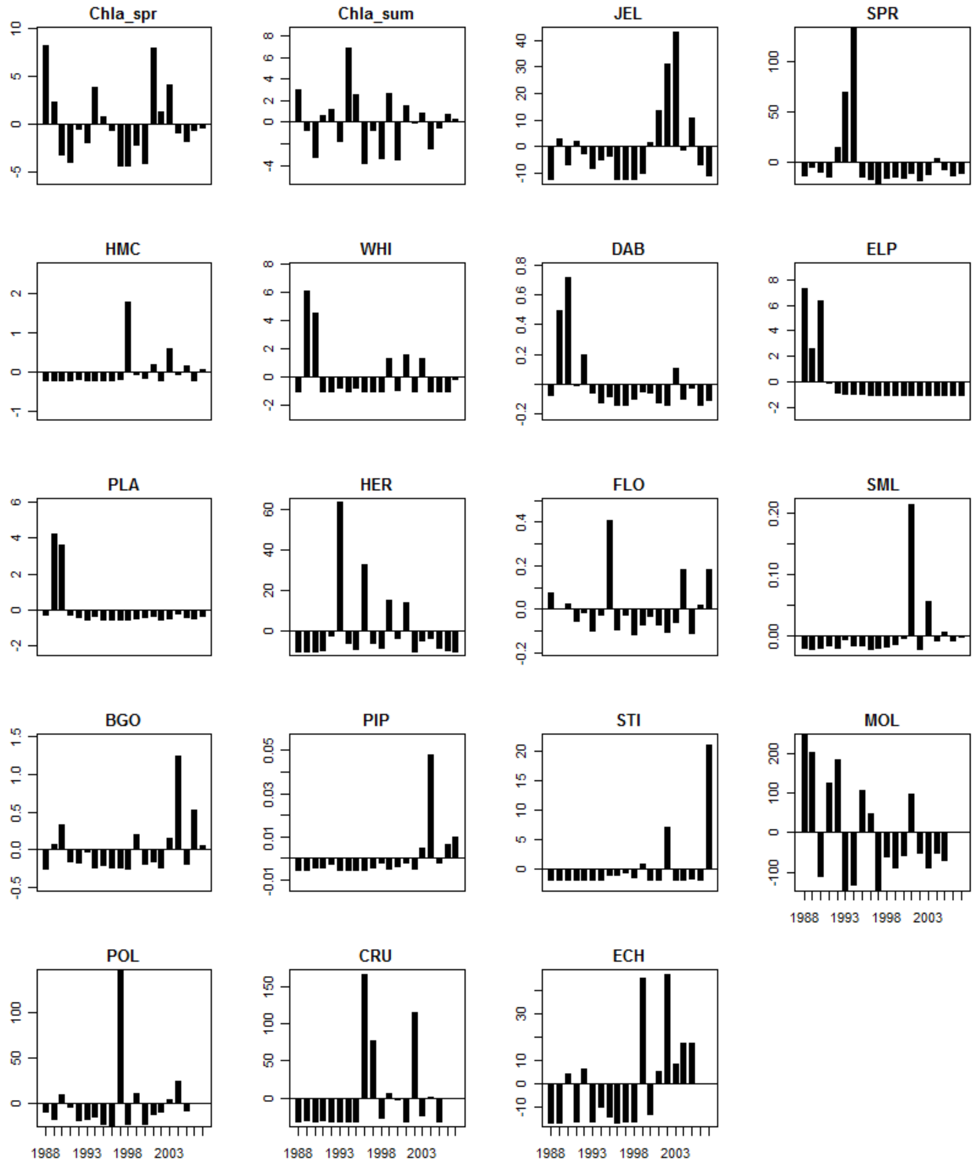

Figure LF-3. Biological variables.

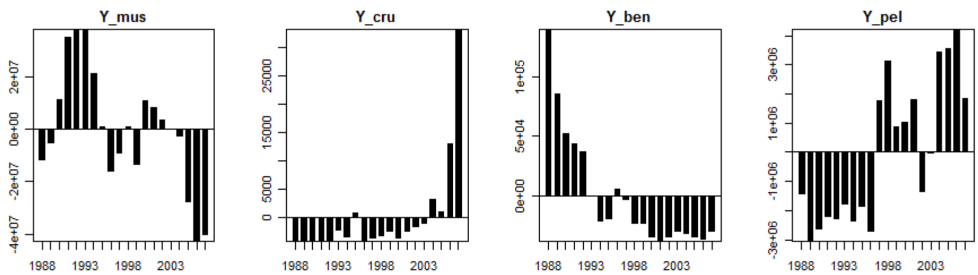

Figure LF-4. Fisheries variables.

14.3. Results of integrated trend analyses based on all variables

The first two principal components for the ecosystem explained 26% (PC1l) and 13% (PC2l), respectively, of the variability in the entire dataset. The temporal development of PC1 scores was characterized by a rapid increase from negative to positive values at the end of the 1980s to mid 1990s, and remained positive until the end of the period. The PC2 displayed a rapid, high amplitude fluctuation, changing from positive to negative values (Figure LF-6). The time-trajectories of the entire ecosystem showed a shift from left to right-hand side of the plot with a loop around zero in the mid 1990s (1993–1996) and concentrated on the right hand-side during the late 1990s–2007 (Figure 6). The PCA loadings biplot for all variables (Figure 7) showed correlations between nitrogen loads and Chl. a. Plaice and dab were correlated with temperature and annual water visibility, whereas eelpout was correlated with yield of demersal fish.

Temporal changes of the Limfjord ecosystem are shown in figure LF-5. The plot showed a trend from variables placed at the bottom left with high values during the 1980s and early 1990s, to variables at the upper right with high values in the last 5 year of the period analysed. The pattern with highest deviation from the mean was highly defined in the beginning of the time-series but becomes more scattered toward the end of the period. The first group comprised the demersal fish, eelpout, plaice and dab, P loadings (summer and winter), N loading (spring), primary production and catches of demersal fish species and displayed a general negative trend. The second group included larger benthic crustaceans, echinoderms and the pelagic fish, herring and horse mackerel, and the demersal zooplanktivorous pipefish, whose biomass values showed a general increasing temporal trend. A third group with PC1 loadings close to zero showed high inter-annual variations and no clear trend. These were flounder, sprat, molluscs, Chl. a concentration, wind, winter temperature, and salinity.

Coniss clustering detected also most of the shifts in the 1990s (Figure LF-8). Mainly between 1992/93 and 1997/98.

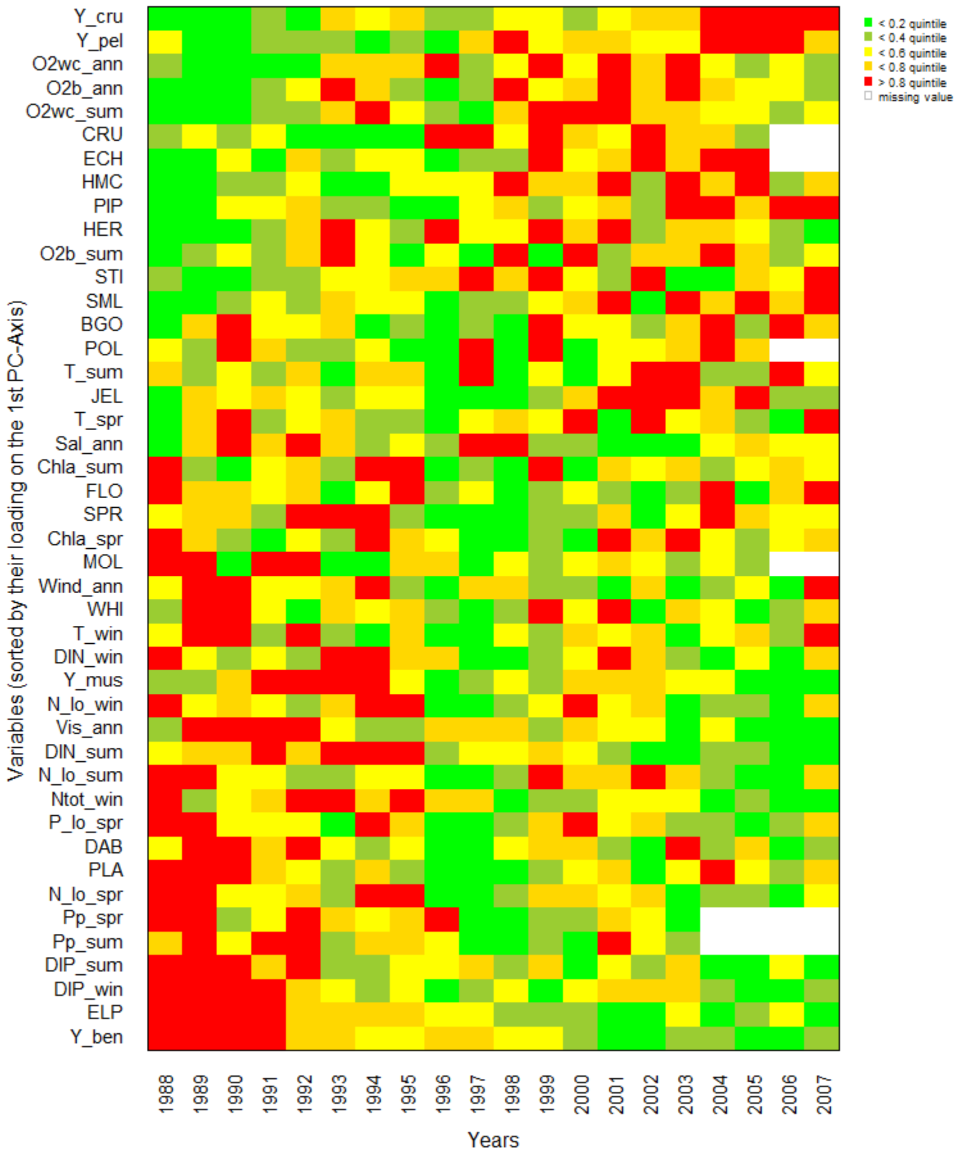

Figure LF-5. Traffic-light plot of the temporal development of 44 time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component.

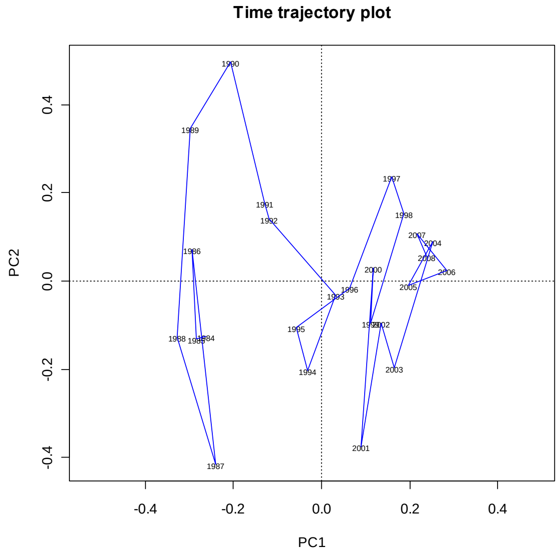

Figure LF-6. Results of the standardized principal component analysis using all 44 variables showing the time trajectory on the first factorial plane (PC1 = 26 %, PC2 = 13% explained variance).

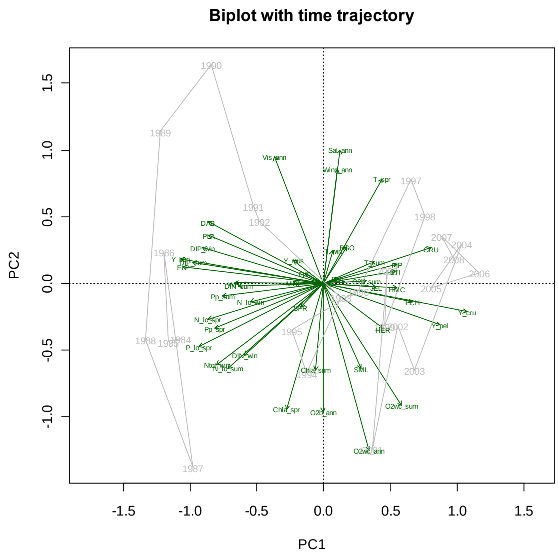

Figure LF-7. Results of the standardized principal component analysis using all 44 variables showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey); (PC1 = 26%, PC2 = 13% explained variance).

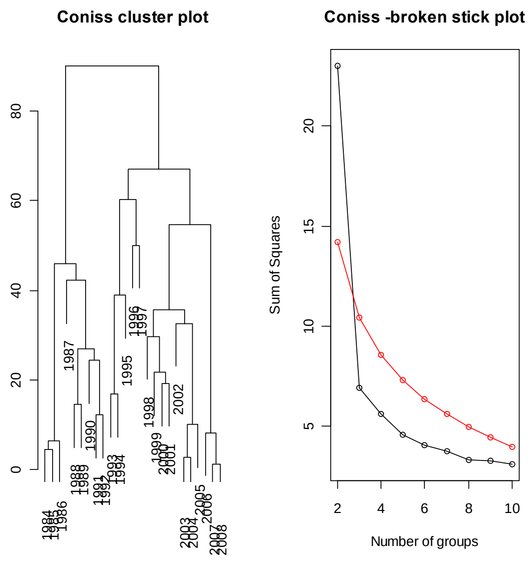

Figure LF-8. Coniss Cluster plot and output of broken stick analysis for the Limfjord based on all variables.

14.4. Results of integrated trend analyses based on abiotic and fisheries related variables only

For the explanatory variables, PC1 and PC2 explained 35% and 16% of the variance (Figure LF-9-10). The pressure index (PC1) trend was opposite to that of the ecosystem and food-web, and decreased continually from positive to negative values with small fluctuations. This indicated that the key drivers in the Limfjord changed substantially over the period. PC2 displayed high fluctuations and was similar to that for the ecosystem. There was an indication that pressure variables towards the end of the time-series had returned to conditions similar to those of the mid 1980s. The time-trajectory for the overall impact was different to that for the entire ecosystem and food-web. The transition period in the late 1980s and early 1990s is clearly visible, after which impact variables fluctuated mainly in the upper left corner. The PC loadings of explanatory variables showed three to four distinct groups, with yield of demersal fish opposite to yield of crustaceans and pelagic fish, and the latter two closely correlated also with annual average of oxygen near the bottom and in the water column.

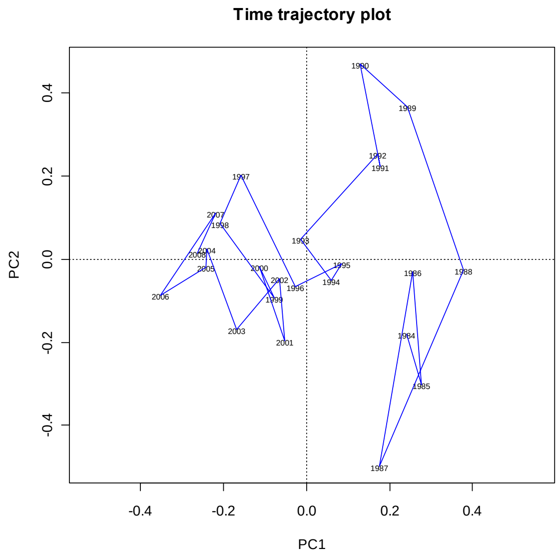

Figure LF-9. Results of the standardized principal component analysis using 25 abiotic and fisheries related variables showing the time trajectory on the first factorial plane (PC1 = 35 %, PC2 = 16% explained variance).

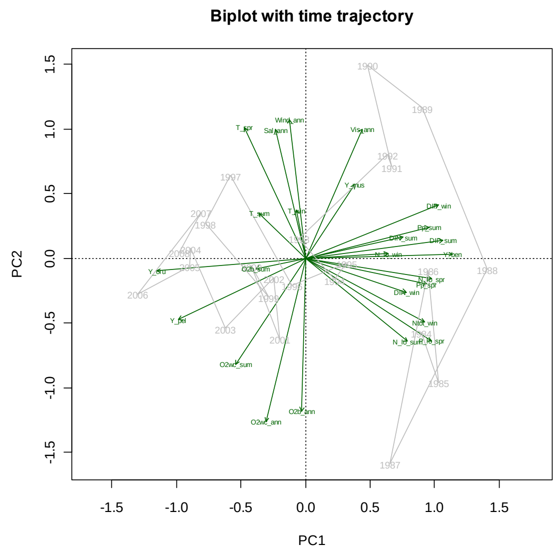

Figure LF-10. Results of the standardized principal component analysis using 25 abiotic and fisheries related variables showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey) (PC1 = 45%, PC2 = 16% explained variance).

14.5. Results of integrated trend analyses based on biotic variables only

For biological variables, PC1 and PC2 explained 21% and 15% of the variability (Figure LF-11). The time-scores of PC1biol showed a pattern similar to that of the entire ecosystem. However, the change from negative to positive in PC1 scores in the beginning of the 1990s was more abrupt. The PC2 showed a clear increase from negative to positive values at the turn of the century, and thus differed from the PC2 for the entire system (based on all variables). Similar to the result for the entire system, the time trajectories of the food-web concentrated on the right hand-side after the late 1990s. This indicated a change of the food-web to a separate regime. The PC loadings (Figure LF-12) showed close correlation between plaice, dab and eel pout, between crustaceans and three-spined sticklebacks, between echinoderms and pipefish, and between Chl. a, jellyfish, polychaetes and black goby.

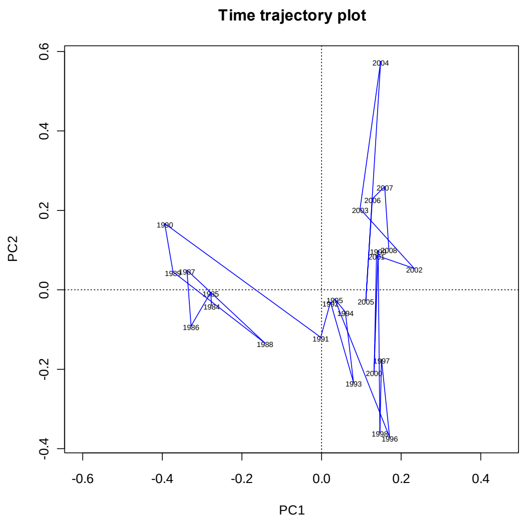

Figure LF-11. Results of the standardized principal component analysis using 19 biotic variables showing the time trajectory on the first factorial plane (PC1 = 21 %, PC2 = 15% explained variance).

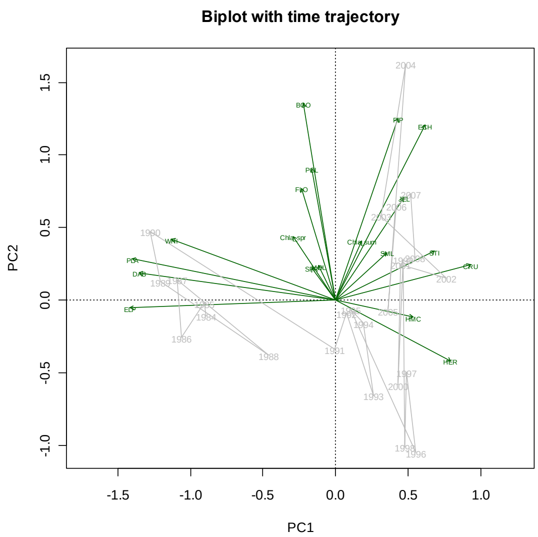

Figure LF-12. Results of the standardized principal component analysis using 19 biotic variables showing the variable loadings on the first factorial plane (for orientation: time trajectory in light grey); (PC1 = 21%, PC2 = 15% explained variance).