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4–8 April 2011

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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, and is intended to serve as a counterpart and support for the ICES Baltic Fisheries Assessment Working Group (WGBFAS) as well as related HELCOM assessment efforts and projects, such as HELCOM CORESET and HELCOM FISH PRO. To this end, WGIAB has given itself three main tasks:

1) to conduct holistic ecosystem assessments based on large multivariate datasets;

2) to consider the use of ecosystem modelling in the assessment framework; and

3) to develop adaptive management strategies for the different Baltic Sea ecosystems.

WGIAB has focused most of its previous work on the first two tasks (ICES 2007, 2008, 2009a, 2010a), by (i) performing multivariate analyses of ecosystem status and trends in, until now, eight Baltic Sea subsystems, demonstrating large-scale shifts in ecosystem structure and functioning (Diekmann & Möllmann 2010), and by (ii) developing Biological Ensemble Modelling to further long-term management advice (ICES 2009a; Gårdmark *et al*., in prep.). During the 2011 meeting, the major activities undertaken therefore related to Task 3. The meeting was held 4–8 April at IMEDEA in Esporles, Spain, with 25 participants from 11 countries.

To develop adaptive management strategies for the Baltic Sea subsystems, WGIAB has decided to follow the broader understanding of Integrated Ecosystem Assessments (IEAs) as a full assessment- and management cycle (Levin *et al.* 2009, Tallis *et al.* 2010). Last year WGIAB identified indicator systems for ecosystem-based management as an aspect of the IEA-cycle that was not already covered by WGIAB activities under tasks 1 and 2. While WGIAB 2010 started working on indicator systems by e.g. evaluating indicators proposed in relation to the EC Marine Strategy Framework Directive and HELCOM Baltic Sea Action Plan, this 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 of this meeting 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 foodweb interactions in the Central Baltic Sea pelagic ecosystem?; (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 meeting also assessed the potential to derive indicators to forewarn of large ecosystem restructurings, by evaluating a set of proposed "early-warning indicator" methods on real monitoring data assembled by WGIAB. Application of six different types of early-warning indicators to spatio-temporally resolved data on a key ecosystem component in the central Baltic Sea, *Pseudocalanus acuspes*, showed that no single method provided sufficient early warning in real monitoring data. Instead, multiple methods should be applied to derive system-specific detections of ecosystem shifts.

WGIAB also continued to develop ecosystem-based fisheries advice. Due to large uncertainty in recent stock assessment estimates for the Eastern Baltic (EB) cod (Gårdmark *et al.* 2011), WGBFAS had asked for information on environmental conditions relevant for recruitment of Eastern Baltic cod. Based on tests of potential indicators, WGIAB developed and assessed two indicators of abiotic conditions for cod recruitment and growth (i.e. food levels). This showed favourable salinity conditions for recent cod year-classes, but poor conditions in terms of both reproductive volume and food abundance. The assessment of the cod recruitment environment was provided to the WGBFAS meeting to support the stock assessment (ICES 2011a). Detailed analyses of environmentally sensitive stock-recruitment functions were also made for Eastern Baltic cod and some coastal fish stocks.

The meeting further pursued a WGIAB core activity, the multivariate analyses of ecosystem status and trends, which were updated and further developed. The primary goal of this activity during WGIAB 2011 was to advance ecosystem status and trend analyses of coastal ecosystems across the Baltic Sea. A first review of data availability and quality was made for nine coastal and small-scale subsystems. Initial ecosystem status and trend analyses were made for six of these subsystems, demonstrating shifts in ecosystem structure in at least four systems. The databases and analyses will be further refined by WGIAB and used in comparative analyses across systems. In addition, the Central Baltic Sea (CBS) biotic dataset was updated to 2009. The analyses still demonstrated the major shift to be in the end of the 1980s, with no significant changes in foodweb composition in the most recent years. This suggests that the CBS foodweb currently remains in an ecosystem "regime" which has been characterized by e.g. low levels of cod and *Pseudocalanus acuspes*, and high sprat abundances, for which important changes in foodweb function in relation to in previous "regimes" has been shown (Casini *et al.* 2009).

In 2012 WGIAB will continue developing Integrated Ecosystem Assessment cycles for the Baltic Sea subsystems, by (i) improving knowledge of the processes causing shifts in ecosystem structure to further develop IEA indicators and modelling, and (ii) further developing the multivariate ecosystem trend and status analyses and their application to Baltic Sea subsystems.

1 Opening of the meeting

The Co-Chairs Anna Gårdmark (Sweden), Thorsten Blenckner (Sweden) and Martin Lindegren (Denmark) welcomed the participants (Annex 1) of the meeting. AG introduced the goals and focus of the meeting (see introduction) and the state of the different tasks to be conducted by the group.

The meeting has been given the following Terms of References (ToRs):

2010/2/SSGRSP03 The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB), chaired by Anna Gårdmark, Sweden; Thorsten Blenckner, Sweden; and Martin Lindegren*, Denmark, will meet in Palma de Mallorca, Spain, 4–8 April 2011 to:

a) Update the Integrated Status and Trends Assessments for the different Baltic Sea subsystems, especially conducting a comparison of coastal systems across the Baltic, and further developing datasets and analyses for the Western Baltic;

b) Continue developing the "Biological Ensemble Modelling (BEMA)" as a basis for analysing the risk of different anthropogenic and natural threats on ecosystem structure and function based on key indicators;

c) Evaluate economic consequences of different fisheries management strategies by coupling ecological to economic models considering the work of WKIMM;

d) Continue the work on indicator selection, testing, and target level evaluation in relation to the MSFD and the BSAP using WGIAB data sets and model outputs;

e) Further develop and promote ecosystem-based advice for Baltic Sea fish stocks based on (i) environmentally-sensitive stock-recruitment relationships (considering the work of WKSECRET) and (ii) fuzzy-logic based indicator systems;

f) Review the work of other integrated assessment activities within ICES (e.g. WGNARS, WGEAWESS, WGINOSE) and HELCOM (e.g. HOLAS) as well as in ongoing research projects;

g) Revisit WGIAB work on integrated monitoring strategies in order to contribute to the suggested Baltic Sea ecosystem observing system.

The following additional ToRs were received from SCICOM and ACOM, to aid the work of the strategic groups Marine Strategy Directive Framework Steering Group (MSFDSG) and the Strategic Initiative on Area Based Science and Management (SI-ASM):

- Identify elements of the EGs work that may help determine status for the 11 Descriptors set out in the Commission Decision [the Marine Strategy Framework Directive];
- Provide views on what good environmental status (GES) might be for those descriptors, including methods that could be used to determine status;
- Take note of and comment on the Report of the Workshop on the Science for area-based management: Coastal and Marine Spatial Planning in Practice (WKCMSP);

- Provide information that could be used in setting pressure indicators that would complement biodiversity indicators currently being developed by the Strategic Initiative on Biodiversity Advice and Science (SIBAS). Particular consideration should be given to assessing the impacts of very large renewable energy plans with a view to identifying/predicting potentially catastrophic outcomes;
- Identify spatially resolved data, for e.g. spawning grounds, fishery activity, habitats, etc.

2 Adoption of the agenda

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

3 Introduction

WGIAB is a forum for developing and combining ecosystem-based management efforts for the Baltic Sea, and intended to serve as a counterpart and support for the ICES Baltic Fisheries Assessment Working Group (WGBFAS) as well as related HELCOM assessment efforts.

To develop ecosystem-based adaptive management strategies for the Baltic Sea subsystems, WGIAB has decided (ICES 2010) to follow the broader understanding of Integrated Ecosystem Assessments (IEAs) as a full assessment- and management cycle (Levin *et al.* 2009, Tallis *et al.* 2010). The suggested IEA process covers five steps (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).

Within the three main WGIAB tasks: 1) to conduct holistic ecosystem assessments based on large multivariate datasets; 2) to consider the use of ecosystem modelling in the assessment framework; and 3) to develop adaptive management strategies for the different Baltic Sea ecosystems. Several of the activities undertaken since the start of WGIAB in 2007 cover aspects of the IEA-process. For example, the multivariate analyses on ecosystem status and trends contribute data and knowledge to step 1, 2 and 4, while the Biological Ensemble Modelling is a prerequisite for steps 2, 3 and 5. In 2010, WGIAB identified indicator systems for ecosystem-based management as one important aspect of the IEA cycle that was not already covered by WGIAB activities under tasks 1 and 2. While WGIAB 2010 started working on indicator systems by e.g. evaluating indicators proposed in relation to the EC Marine Strategy Framework Directive and HELCOM Baltic Sea Action Plan (ICES 2010a), WGIAB in 2011 has taken 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). The indicators therefore need to reflect important aspect of the ecosystem and be linked to natural and human "threats" or impacts on the ecosystem, as they are used in risk analyses, integrated ecosystem assessments, and management strategy evaluations of how alternative management options influence ecosystem status (Levin *et al.* 2009). Therefore, thorough understanding of ecosystem processes and responses to human pressures is needed to develop suitable indicators for an IEA cycle. A major goal of this meeting was therefore to start analyses towards a better understanding of processes leading to the shifts in ecosystem structure during the last three decades documented by the group (e.g. Diekmann and Möllmann, 2010), with the aim to use this for future developments of indicators for an IEA cycle. The questions addressed in these analyses were (i) Are there any discontinuous foodweb interactions in the Central Baltic Sea (CBS) pelagic ecosystem?; (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?

One aim is to also use this enhanced process-understanding to further develop the Biological Ensemble Modelling approach (BEMA; Gårdmark *et al.*, in prep), and the individual ecological models in the ensemble. To this end, spatial variation in environmental impacts on fish recruitment was investigated during the 2011 WGIAB meeting, and alternative modelling frameworks and recent initiatives to develop ecological-economical coupled models were discussed.

While management strategy evaluations and risk analytical modelling of indicators in an IEA cycle requires detailed process understanding, indicators of the state of ecosystems and of foodweb components known to be impacted by human activities also hold important information for management even without detailed knowledge on underlying processes. Such state indicators are particularly valuable if these can indicate forthcoming changes in ecosystem or population state. WGIAB has therefore in 2010 and 2011 developed indicators of the recruitment environment of Baltic Sea fish stocks (so far, the Eastern Baltic cod), and based on these provided WGBFAS with assessments of the environmental conditions experienced by year-classes to be recruited to the exploitable stock in the coming years. Since these relate only to the future state of populations, a major focus of WGIAB 2011 was to investigate possibilities of indicating future changes in ecosystem state. To this end, WGIAB 2011 tested a set of temporal and spatial early-warning detection methods, proposed in theoretical and experimental studies, on real monitoring data on a key ecosystem component in the central Baltic Sea, *Pseudocalanus acuspes*, and assessed their predictive ability to forewarn the major regime shift in 1988. These will be further developed in inter-sessional work (e.g. Lindegren *et al.*, in prep.). However, the analyses so far showed that there is no single solution to derive indicators or signals of regime shifts, as these may show no, weak, late, or contradictory signals of ecosystem change. The results suggests that multiple methods should be applied to derive system-specific detections of ecosystem shifts.

The multivariate analyses on ecosystem status and trends, which has been the core activity of WGIAB since its start, had until 2010 been performed for 8 subsystems.

The analyses demonstrated the presence of ecosystem "regime shifts" during the last 3 decades, related to climate variability and human exploitation (Möllmann *et al.* 2005, Möllmann *et al.* 2008, Möllmann *et al.* 2009, Lindegren *et al.* 2010, Blenckner *et al.* in prep.). The results have been summarised in an ICES Cooperative Research Report on "Integrated ecosystem assessments of seven Baltic Sea areas covering the last three decades" (Diekmann and Möllmann, 2010). As the majority of subsystems studied so far were offshore pelagic foodwebs, a major activity of the WGIAB 2011 was to expand the status and trend assessments to coastal ecosystems in the Baltic Sea. Data from nine coastal and small-scale subsystems were reviewed, and analyses of ecosystem trends were performed for six of these. The databases and analyses will be further refined, to further enable the inclusion of coastal ecosystems in the datasets and ecosystem analyses of WGIAB, and to compare and identify drivers of shifts in the structure of coastal ecosystems across the Baltic Sea.

In 2012 WGIAB intends to continue developing Integrated Ecosystem Assessment cycles for the Baltic Sea subsystems, by improving knowledge of the processes causing shifts in ecosystem structure to further develop IEA indicators and modelling, and by further developing the multivariate ecosystem trend and status analyses and their application to Baltic Sea subsystems.

Below we report on the WGIAB 2011 ecosystem trend and status analyses identifying changes in ecosystem structure in the subsystems assessed in 2011 (section 4), the evaluation of potential "early-warning" indicators of such ecosystem changes (section 5), and analyses of the processes underlying observed ecosystem changes (section 6).

4 Integrated Trend and Status Assessments (ToR a)

The primary goal of this activity during WGIAB 2011 was to advance ecosystem status and trend analyses of coastal ecosystems across the Baltic Sea (ToR a), and to update the integrated trend and status assessment of the open sea pelagic foodweb of the Central Baltic Sea. The analyses of individual systems are presented in Annex 4, and key findings summarised below.

4.1 Coastal and small-scale Baltic Sea subsystems

The multivariate analyses of the "coastal" systems (Annex 4) provide initial integrated trend assessments of coastal and small-scale ecosystems. These will be further developed in forthcoming WGIAB meetings, and combined in a comparative analysis to evaluate changes across the Baltic Sea at scales smaller than the basin-wide analyses previously applied by WGIAB (ICES 2010a). The aim for the 2011 meeting was to identify possible data sources representing multiple trophic levels, start compilations of common databases and run preliminary analyses.

Nine subsystems were included in the initial data screening. The data-sets compiled for available systems for the meeting were very diverse, varying in their coverage of trophic levels, of environmental and human pressures, as well as in time-series length and quality. Further quality assurance is therefore needed. The common period covered by most of the collected time-series is from the 1990s to current date. Based on evaluations of this screening, six small-scale systems were analysed (Figure 4.1.1): a North Sea-Kattegatt transition area ("NK", Limfjord), a coastal site in the eastern Kattegatt ("Kc", Vendelsö), a gulf in the southern Baltic Sea Proper ("GG", Gulf of Gdansk), and coastal sites in the western Baltic Sea Proper ("BPc", Kvädöfjärden), the eastern Bothnian Sea ("EBSc", Archipelago Sea), and the western Bothnian Bay

("BBc", Holmön). Three additional small-scale systems (Gulf of Riga coast, north-eastern Gulf of Riga, and the Curonian Lagoon) were described and data for potential future analyses presented (Annex 4).

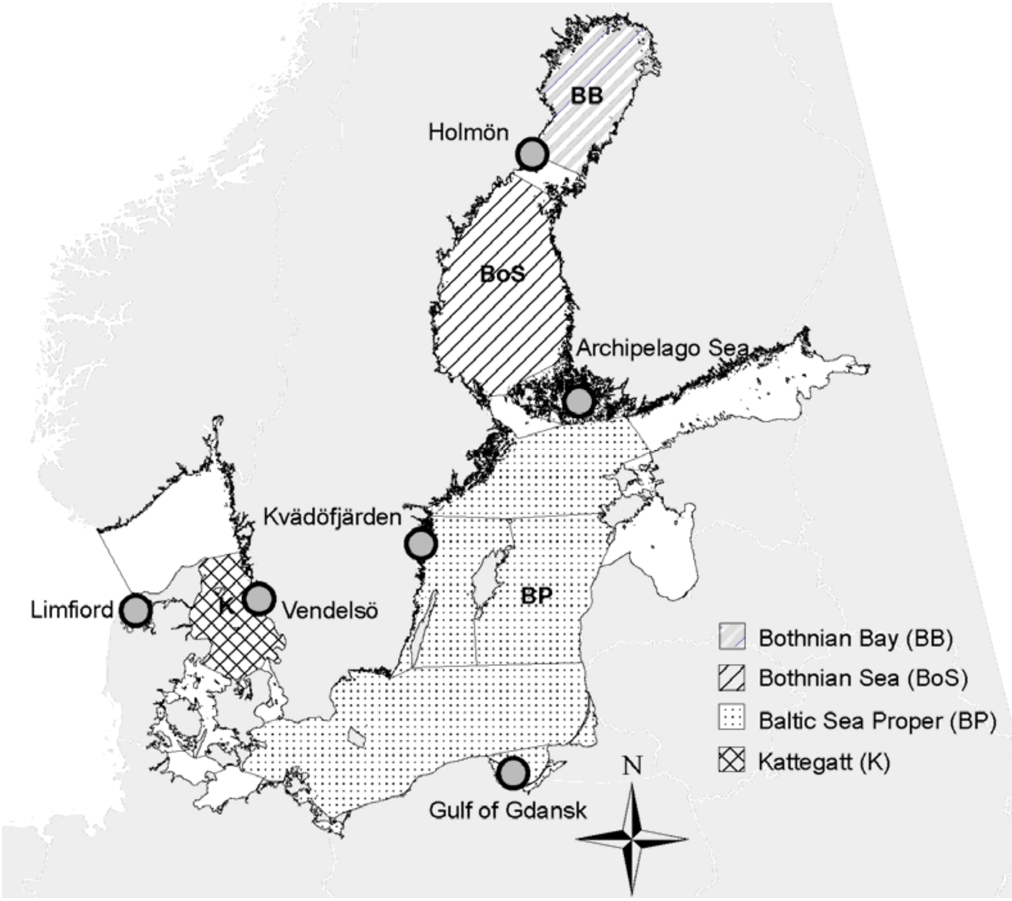

Figure 4.1.1. Coastal and small-scale systems for which integrated trend and status analyses were performed, from west to east: North Sea-Kattegatt transition area (Limfiord), E Kattegatt Coast (Vendelsö), W Baltic Sea Proper Coast (Kvädöfjärden), W Bothnian Bay Coast (Holmön), S Baltic Sea Proper Coast (Gulf of Gdansk), E Bothnian Sea Coast (Archipelago Sea).

Discontinuity analyses on biotic and abiotic variables showed significant changes in ecosystem structure in five of the analysed systems, NK, Kc, GG, EBSc, and BBc, whereas no changes to significantly different ecosystem compositions were found in BPc (Annex 4, Table 4.1.1). In EBSc one shift was found, whereas the other subsystems exhibited a transitional period between two states (Table 4.1.1). Most shifts occurred mid- to late 1990s, except for in GG, EBSc and BBc for which shifts occurred about a decade later (Table 4.1.1).

Table 4.1.1. Timing of regime shifts (RS), i.e. changes in ecosystem composition in coastal and small scale Baltic Sea subsystems, as suggested by discontinuity analyses (Constrained and/or chronological clustering).

System	RS1	RS2
Bothnian Bay Coast (Holmön) 1994–2009	1998/1999	2006/2007
Baltic Sea Proper Coast (Kvädödjärden) 1985–2009	-	-
Kattegatt Coast (Vendelsö) 1981–2009	1995/1996	1997/1998
Limfiord (central) 1984–2008	1992/1993	1997/1998
Gulf of Gdansk 1994–2010	1999/2000	2000/2001
Finnish Coast (Archipelago Sea) 1991–2009	2004/2005	

The reduced variable describing ecosystem dynamics, i.e. the first principal component ($PC1_{all}$), of all systems explained only between 22–27 % of the variation in the datasets. A comparison of variables most correlated with the PC1all (Table 4.1.2) across systems did not give a uniform picture. The biological response variables and the impact (environmental and human) factors were associated to a similar degree with the PC1all, making it difficult to compare and interpret the results. The low degree of explanation in the first two principle components showed that there is a clear need to balance the number of time-series among trophic levels, and in relation to abiotic factors. In addition, separate analysis of biological variables and abiotic factors need to be performed in many systems, allowing for direct comparison of foodweb changes, abiotic changes, and the impact of the most influential variables. These issues will be further addressed in the future by WGIAB.

Table 4.1.2. Variables with highest loadings (absolute values) on the first principal component (PC1) of biotic and abiotic time-series in each of the coastal and small-scale system.

System	PC1
Bothnian Bay Coast (Holmön)	Sal, Monoporeia affinis
Baltic Sea Proper Coast (Kvädödjärden)	Temp local, pH
Kattegatt Coast (Vendelsö)	Cumacea sp, Montacutidae sp.
Limfiord	Yield benthic fish Yield crust.
Gulf of Gdansk	Flatfish yield Herring yield
Finnish Coast (Archipelago Sea)	Perch rec., Chrysophyceae

4.2 Central Baltic Sea offshore pelagic foodweb

The integrated trend and status assessment of the offshore pelagic foodweb in the Central Baltic Sea was updated with biotic data extending to 2009, including 31 variables from four trophic levels (see Annex 4, section A4.10, for details). Due to large discrepancies in some of the abiotic data extracted (via the Baltic Environmental Database, http://nest.su.se/models/bed.htm, hosted by the Baltic Nest Institute) this year compared to those assembled for WGIAB 2010 (ICES 2010a), no multivariate analyses of the hydro-climatic, nutrient, and fishing variables were performed during the meeting. Instead, key hydro-climatic factors (with consistent data) were analysed in relation to recruitment of Eastern Baltic cod (see section 6.2.2), and provided as ecosystem-based stock advice to the ICES Baltic Fisheries Assessment Working Group (ICES 2011a). Analyses of the biotic time-series showed that 1989 remains the only significant shift in ecosystem composition detected consistently in two different discontinuity analyses, chronological clustering and constrained hierarchical clustering (using the broken-stick plots to identify significant differences). None of the methods indicate any recent changes in ecosystem composition (in the recent decade), despite possible increases in cod abundance and decreases of sprat in the last two years (ICES 2010b). This suggests that the foodweb currently remains in the ecosystem "regime" characterized by e.g. low levels of cod and *Pseudocalanus acuspes*, and high sprat stock, with consequent changes in foodweb function (Casini *et al.* 2009).

In addition to analyses of the updated biotic monitoring time-series assembled by WGIAB, the clustering and ordination methods were also applied on modelled biogeochemical data, to explore how known biogeochemical processes may result in shifts in hydro-climatic and nutrient conditions.

4.3 Alien species in the Gulf of Finland and Gulf of Riga – annual scale dynamics in response to environmental variability

Presentation by Henn Ojaveer

Alien species contribute to global change in all marine ecosystems. Environmental variability can affect species distribution and population sizes, and is therefore expected to influence alien species. In this study, we have investigated temporal variability of 11 alien species representing different trophic levels and ecological functions in two gulfs of the brackish Baltic Sea in relation to environmental change. Independent of the invasion time, organism group or the life-history stage, abundance and/or biomass of the investigated alien species was either stable or displayed abrupt increases over time. Timing in population shifts was species-specific and exhibited no generic patterns, indicating that the observed large shifts in environmental parameters have no uniform consequences to the alien biota. In general, the inter-annual dynamics of alien and native species was not largely different, though native species tended to exhibit more diverse variability patterns compared to the alien species. There were no key environmental factors that affected most of the alien species, instead, the effects varied among the studied gulfs and species. Non-indigenous species have caused prominent structural changes in invaded communities as a result of exponential increase in the most recent invasions, as well as increased densities of the already established alien species (Ojaveer *et al.* 2011).

5 Early warning of ecosystem changes (ToR d)

Regime shifts, large-scale shifts in ecosystem structure and function, have been demonstrated in marine ecosystems across the Northern Hemisphere, including the pelagic foodwebs in all Baltic Sea basins (ICES 2008, 2009a, Dieckmann & Möllmann 2010). Obtaining early warning of such shifts from monitoring is direly needed for resource management and conservation efforts to maintain key ecological functioning and important socio-economic goods and services. WGIAB in this year's meeting therefore focused our efforts to providing tools for ecosystem-based management on assessing potential early-warning signals of ecosystem regime shifts.

Recent advances in theory and analytical methods have improved our ability to identify abrupt shifts in real ecosystems (de Young *et al.* 2004, Andersen *et al.* 2008). However, detection of early-warning signals in real ecosystems previous to such abrupt shifts has mainly been restricted to experimental studies or paleo-climatic reconstructions over vast temporal scales (Dakos *et al.* 2008, Briggs *et al.* 2009, Scheffer *et al.* 2009). WGIAB therefore tested 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, *Pseudocalanus acuspes*. We applied six different types of early-warning indicators (Table 5.1) to this spatio-temporally resolved data set (covering the Bornholm basin, Gdansk deep, and Gotland basin in, at most, 1959–2010), and assessed their predictive ability to forewarn the major regime shift in 1988.

The preliminary results (Lindegren *et al.*, in prep.) and evaluations of underlying assumptions of the different methods (Table 5.1) 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. In general, the ability of the individual methods to demonstrate early-warning signal preceding the shift in 1988 is generally low, and highly dependent on methodological assumptions and data constraints (Lindegren *et al.*, in prep.). Furthermore, there was no major distinction in the predictive ability of temporal versus spatial methods. Several, but not all, temporal methods were sensitive to assumptions and time-series length, and some, but not all, spatial methods generated early-warning signals several years prior to the shift (Table 5.1). These analyses provide a first methodological comparison, which will be further developed in intersessional work (e.g. Lindegren *et al.*, in prep.). However, the application to the Baltic Sea dataset showed that there is no single solution to derive indicators or signals of regime shifts, as they may show no, weak, late, or contradictory signals of ecosystem change. Thus, multiple methods should be applied, based on the availability and quality of spatio-temporal monitoring data, to derive system-specific detections of ecosystem shifts.

Table 5.1 Potential early-warning methods and metrics applied to *Pseudocalanus acuspes* data, and their potential for detecting the major shift in 1988 (adapted from Lindegren *et al.*, in prep.)

Method	Metric	Source	Shift detection potential	Time prior to shift when detected
1. Temporal variance	Standard deviation	Carpenter & Brock (2006)	Low	1 yr
2. Temporal auto-correlation	First-order autoregression coefficient	Dakos *et al.* (2008)	Low	Not (0 yrs)
3. Spatial variance	Coefficient of variance	Litzow *et al.* (2008)	Medium	1 yr
4. Spatial autocorrelation	Significance of correlation	Legendre & Legendre (1998)	Low-High (depends on method)	≤ 1 to ≥ 3 yrs (depends on method)
5. Temporal generalized additive modelling	Second derivative of fitted values	Fewster *et al.* (2000), Trenkel & Rochet (2009)	Low	≤ 1 yr
6. Shiftogram	Corrected Akaike Information Criterion or p-joint	(Gröger *et al.* 2011)	High	≥ 3 yrs

6 Improved understanding of ecosystem processes (ToRs c, e)

6.1 What did we learn from WGIAB analyses so far?

The results from the WGIAB from the last years were summarized and reviewed in a scientific context, and presented at the meeting. Based on the long-term experience of the integrated assessment by using traffic light plots, principal component analysis, chronological clustering and regime shift tests of the different Baltic Sea sub-basins and coastal areas it becomes clear that in all basins a regime shift have occurred. By including abiotic and biotic variables in this analysis the shift occurred most coherently in the late 1980s, and in some systems also in the middle of the 1990s. This corresponds also to observations from many other marine areas where first a shift occurred and secondly also in the late 1980s. Most of these shifts are associated with changes in climate and fishing pressure. In the Baltic Sea, the most affected organism groups are zooplankton, macrozoobenthos and fish.

It has been reported in many studies (from experiments, observations and modelling studies) that such changes are often driven by species-specific responses to temperature, salinity and mutually dependent factors. For example, the fishing intensity can increase the climate sensitivity of certain fish species. In other words, the effects of drivers should not be considered individually as the responses often depend mutually on each other. Some new research challenges were presented. These are the quantification of thresholds, including the stochastic interplay of multiple drivers. Further, it has been mentioned that process understanding on different scales (spatial dynamics, for example coastal-offshore) needs to be improved, as not all species responses propagate to the whole ecosystem scale whereas other may link different ecosystems. Here it is further challenging to manifest non-linear responses and their connectivity to the other sub-basins. Another research challenge is to further identify feedbacks of the foodweb components; as for example certain positive feedbacks can keep the ecosystem in a certain state.

6.2 Environmentally sensitive stock-recruitment functions

6.2.1 Spatial variation in recruitment and environmental impacts in the Central Baltic Sea

The abundance and biological characteristics of cod, herring and sprat are heterogeneous both spatially (between subdivisions) and temporally (inter- and intra-annually). For example, population sizes of Central Baltic cod, as resolved by international bottom trawl (Sparholt and Tomkiewicz 2000) and ichthyoplankton surveys (Köster *et al.* 2001a), have revealed distinct distributional trends. Furthermore, for cod, substantial differences in weight at age and maturity ogives have been reported for different subdivisions (ICES 1997a; Tomkiewicz *et al.* 1997). The abundance and characteristics of herring and sprat have also been observed to vary spatially and temporally in the different subdivisions of the Central Baltic (e.g. Ojaveer 1989). The herring stock in the Central Baltic is composed of a number of different spawning components exhibiting variations in spawning period and growth rates as well as meristic, morphometric, and otolith characteristics (e.g. Ojaveer 1981; Parmanne *et al.* 1994). For sprat, the existence of distinct populations is controversial, as deviations in growth rates observed between subareas have been explained by immigration from the western Baltic and by migration between different basins (Parmanne *et al.* 1994). However, other authors stated that sprat in the eastern Central Baltic form local populations (Ojaveer 1989), which can be separated, primarily by otolith characteristics (Aps *et al.* 1981).

Regarding these patterns of spatial heterogeneity, it is hence questionable, if the effects of spawning stock biomass and environment on recruitment can be modelled on a whole Baltic scale, or if submodels on a basin-scale, which can be aggregated, are to prefer. In the worst case, pooling the subdivisions can lead to spurious dynamics biasing empirical SSB/R relationships.

Recruitment and SSB estimates (abundance of age-group 0 at quarter 3 and SSB at quarter 1) from the different ICES subareas Bornholm Basin (subdivision 25), Gdansk Basin (subdivision 26) and Gotland Deep (subdivision 28) were taken from Teschner *et al.* (2010). In a previous setup of the area-disaggregated MSVPA (Köster *et al.* 2001a), the model results were compared to survey data (Köster *et al.* 2001a). For cod, significant linear relationships were obtained between area-disaggregated MSVPA estimates of cod population size (age-group 2+) and abundance indices based on bottom trawl surveys in all three subdivisions. In contrast with cod, correlation between abundance estimates of herring from area-disaggregated MSVPA runs and hydroacoustic surveys revealed no significant relationships for any of the subdivisions. For sprat, the comparison between international hydroacoustic survey results and area-disaggregated MSVPA output revealed trends similar to those observed for cod (Köster *et al.* 2001a).

With the goal to develop best possible predictors for recruitment that can be applied in stock projections accounting for climatic changes, the aim of this exercise was to compare the SSB/R data from the different regions of the Baltic in order to get an idea, if the aggregated data, i.e. the sum over subdivisions, display the same qualitative SSB/R relationships as the ones derived for the subdivisions. Focus was also put on possible spill-over effects, and area-specific differences in environmental impacts on recruitment.

Using the sums of the regional recruitments in the ICES subdivisions 25, 26 and 28 implies an overall increasing linear trend of log-recruitment at increasing SSB (Figure 6.2.1.1 A) within the observed range of SSB and R. However, this apparent relationship between SSB and R of cod is mainly due to data from SD 26 (Figure 6.2.1.1 C) and SD 28 (Figure 6.2.1.1 D). There is no straightforward correlation in SD 25 (Figure 6.2.1.1 B). During periods of major inflow stagnation, as for example from 1977 to 1993, when cod recruitment is solely derived from SD 25, the overall SSB/R relationship would therefore be misleading.

Furthermore, the over-proportional decline in R at decreasing SSB below 1e7 (Figure 6.2.1.1 C and 1 D) cannot be seen when using the overall data. This over-proportional decline in the SSB/R relationship in SD 26 and SD 28 might erroneously be interpreted as being driven by decreasing SSB. However, using the SSB/R data only, it is not clear if the low R is due to low SSB, or due to unfavourable environmental conditions. It is hence not clear whether there would have been recruitment in recent years at possibly high SSB in SD 26 and 28, because the combination high SSB/bad environment could not be sampled, as in contrast to SD 25, where at times SSB was high even at low oxygen saturation/salinity conditions. The SSB/R relationship might hence differ nowadays. Using environmental variables as for example reproductive volume or integrated egg survival probability inside the reproductive volume will allow for separate the effects of low SSB from those of insufficient environment.

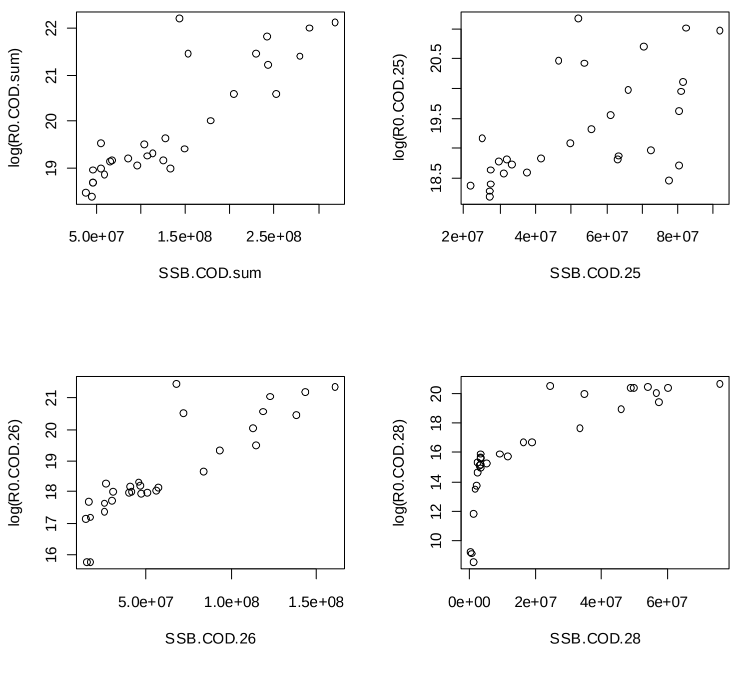

Figure 6.2.1.1. Cod recruitment versus spawning stock biomass for all subdivision aggregated (A), and separately for subdivisions 25, 26 and 28 (B, C and D).

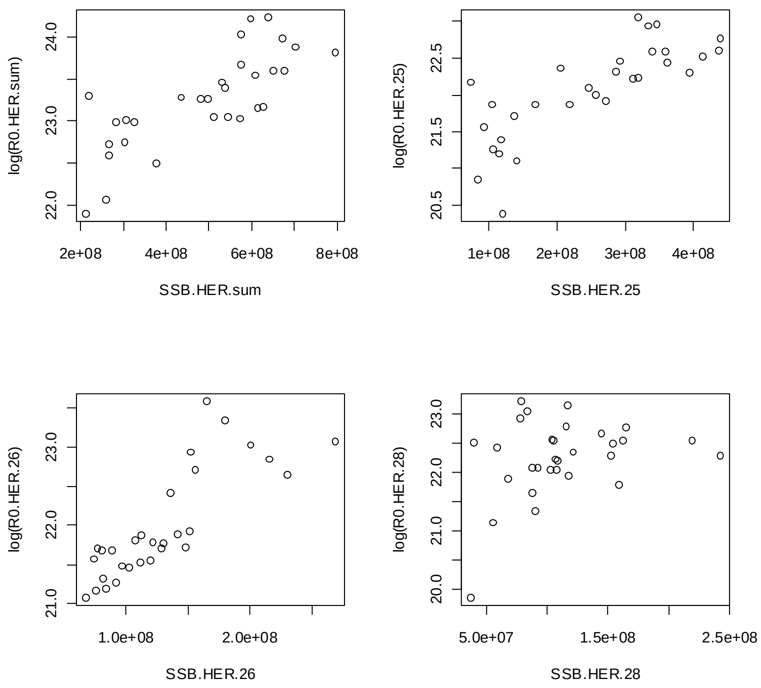

Figure 6.2.1.2. Herring recruitment versus spawning stock biomass for all subdivision aggregated (A), and separately for subdivisions 25, 26 and 28 (B, C and D).

Herring recruitment in subdivision 28 (Figure 6.2.1.2 D), with the exception of one possible outlier, seems independent of herring SSB within the range of observations, whereas subdivisions 25 and 26 (Figure 6.2.1.2 B and C) show an increasing trend of R at increasing SSB. The apparent relationship for the aggregate data (Figure 6.2.1.2 A) is hence not representing subdivision 28, where herring recruitment, on the other hand, is highest. However, as pointed out earlier, the fit between model estimated and survey data is not convincing for herring, in contrast to cod and sprat. For this reason, the analysis should be repeated based on survey data only.

For sprat, there is no straightforward relationship between sprat SSB and recruitment, neither aggregated not for the subdivision specific plots (Figure 6.2.1.3).

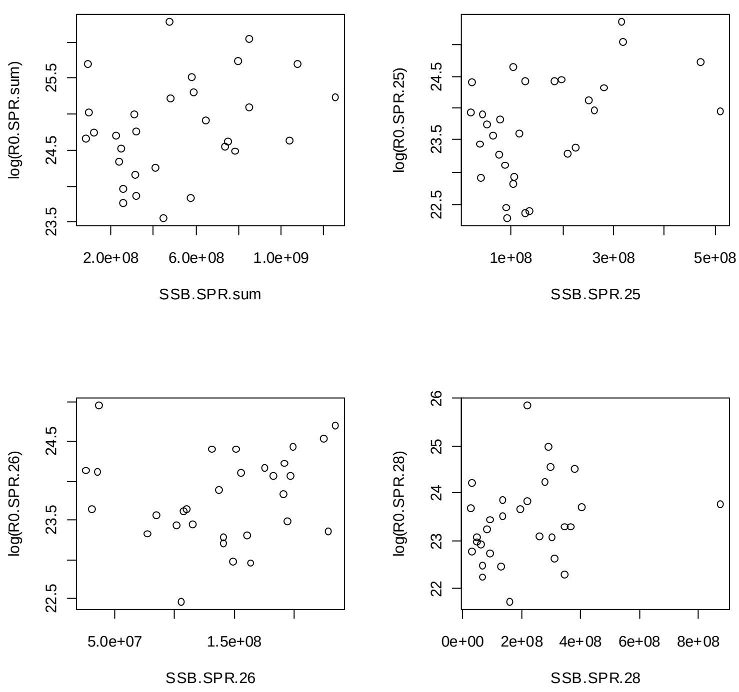

Figure 6.2.1.3. Sprat recruitment versus spawning stock biomass for all subdivision aggregated (A), and separately for subdivisions 25, 26 and 28 (B, C and D).

The SSB/R relationships for the single subdivisions and species are compared in figure 6.2.1.4. If the SSB/R relationship between adjacent subdivisions for a given species follows the same functional form, but is differently parameterized, then plotting R/SSB for the two adjacent subdivisions should show a clear pattern, often, but not necessarily, linear. This is the case for cod SSB/ R in subdivisions 25 and 26, 26 and 28, and hence also 25 and 28 (Figure 6.2.1.4 A-C). However, the relationship is decoupled at low recruitment intensities. This is due to failure of subdivision 28, which is a consequence of lack of oxygen (Köster *et al.* 2001b). The same is true for sprat (Figure 6.2.1.4 G-I), but without the decoupling observed for cod. These observations imply, that the recruitment is determined by the same functions for cod and sprat, in the case of sprat not necessarily driven by SSB (cf. Figure 6.2.1.3), and in the case of cod with intermittent failure of one spawning subarea, the Gotland Basin (Subdivision 28).

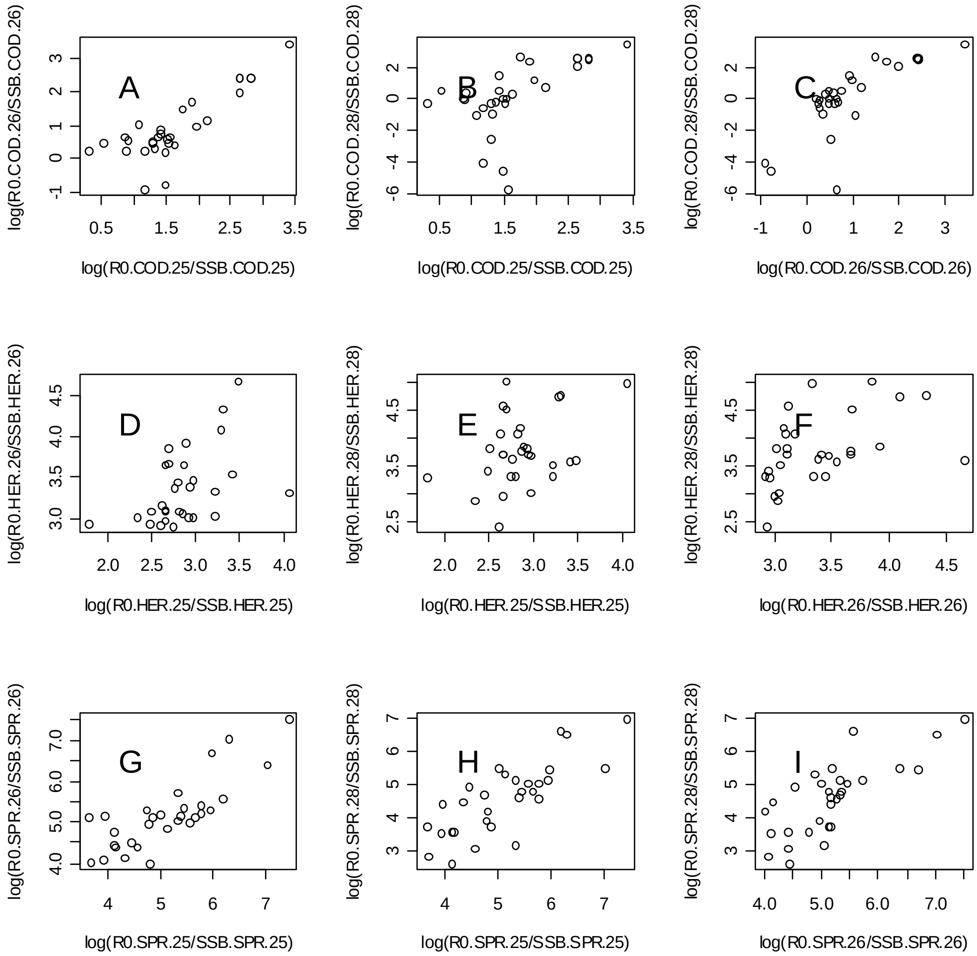

Figure 6.2.1.4. Comparison of subdivision specific SSB-R relationships across subdivisions For cod (upper panels), herring (mid panels), and sprat (bottom panels), pairwise comparisons between SD 25 and 26 (left panels), SD 25 and 28 (mid panels), and SD 26 and 28 (right panels) are shown.

For cod, the number of recruits per spawner decreased over time at decreasing SSB. Both for Beverton and Holt and for Ricker typed recruitment function, the opposite would have been to expect, i.e. that R/SSB increases when the slope of the SSB/R relationship increases at decreasing SSB. This phenomenon has been related to the oxygen and salinity conditions in the cod spawning areas (Köster *et al.* 2001b). It is hence important to include these in cod recruitment models. Herring SSB/R increased opposite to the trend observed for cod (Figure 6.2.1.5 D-F). This is not a predation effect due to the decreasing cod abundance, because this effect is accounted for by dividing SSB/R by cod SSB, as a proxy for predation pressure. Furthermore, SSB increased most probably, too, which in this case implies that the observed pattern is due to environmental conditions, since SSB/R should decrease at increasing SSB (or at least be constant). The pattern is furthermore clearest in subdivisions 26 and 28, hence possible environmental effects should be investigated on a subdivision spatial scale rather that aggregated over the whole Baltic Sea. The same is true for sprat (Figure 6.2.1.5 G-I). Especially after 1995 an increase in SSB/R for subdivisions 26 and 28 can be observed. This increase fits well to newer survey-based observations showing a shift of sprat biomass distribution to northerly areas, implying a temperature effect.

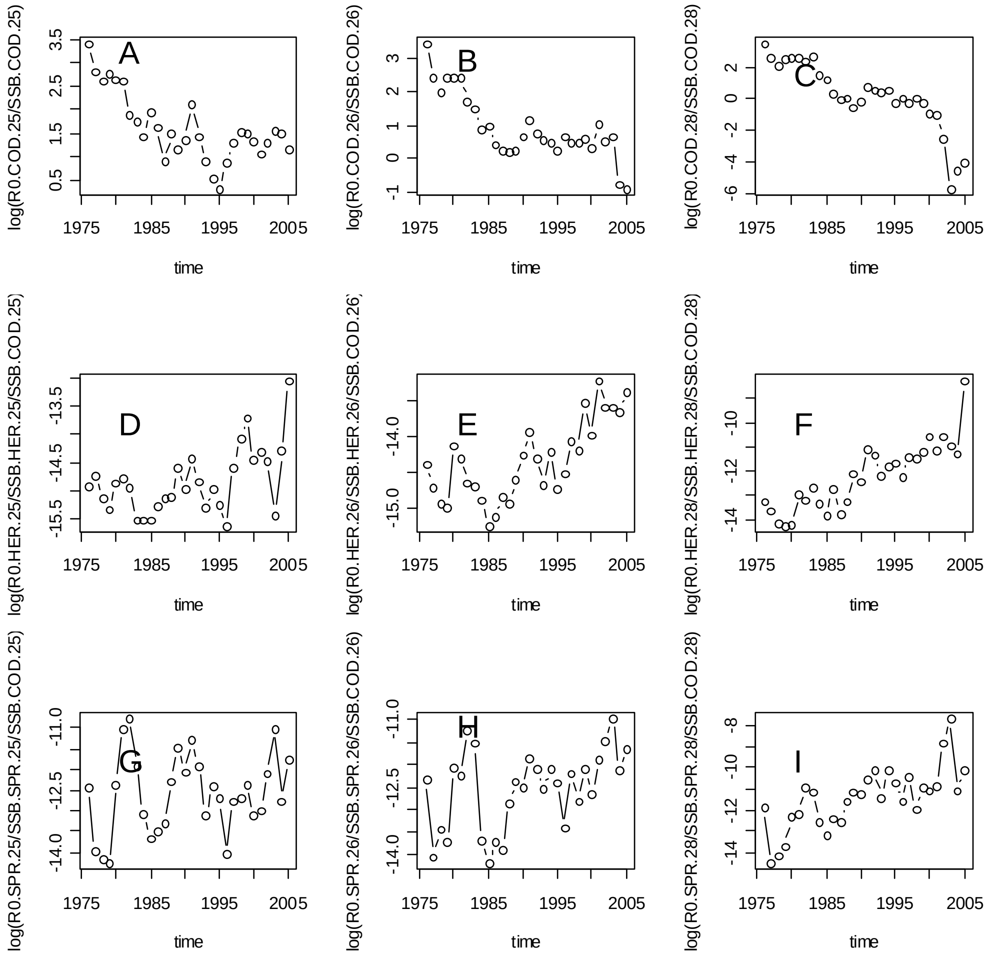

Figure 6.2.1.5. Trends in recruitment after standardizing for SSB and predator biomass, shown for cod (upper panels), herring (mid panels), and sprat (bottom panels), in subdivision 25, 26 and 28 (from left to right).

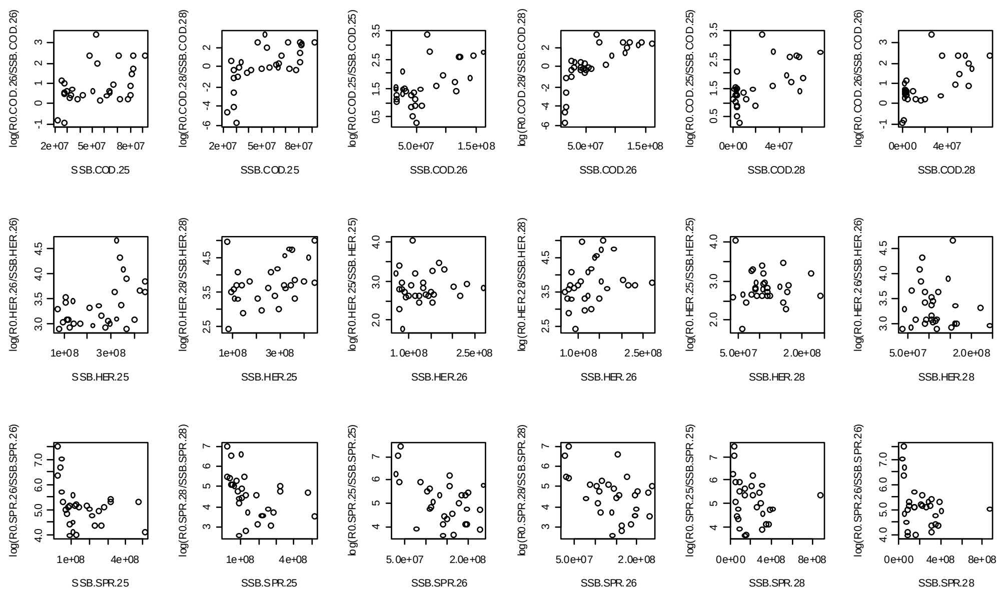

Figure 6.2.1.6. SSB-R-relationship versus SSB in the adjacent subdivision, shown for cod (upper panels), herring (mid panels), and sprat (bottom panels). See axes titles for subdivision specifications.

As was to expect from the different dynamics in the subdivision, there are no visible spill-over effects (Figure 6.2.1.6). No visible relationship between SSB/R and SSB in the adjacent subdivision was found for any of the species or subdivisions.

In conclusion, our results show that SSB/R relationships should be investigated independently by subdivision. The subdivisions used in these analyses each correspond to different basins of the Baltic Sea, and both SSB/R relationships and environmental effects appear to differ between subdivisions. Hence, when modelling recruitment, the relationships have to be derived by subdivision and then aggregated to the whole Baltic, instead of starting with the aggregated model. This practice will improve the predictive power of the recruitment models. Problems are still the weak representation of herring population dynamics by the multispecies model, and the obviously too narrow range of observed sprat SSB, since there is no identifiable breaking point when recruitment becomes dependent on SSB.

6.2.2 Indicators of the recruitment environment for Eastern Baltic cod

Following discussions during the 2010 back-to-back meeting of WGIAB and the Baltic Sea Fisheries Assessment Working Group (WGBFAS; ICES 2010b), WGIAB continued its work on developing ecosystem-based fisheries advice. Due to the great uncertainty of the estimates from the Eastern Baltic cod stock assessment in recent years (Gårdmark *et al.* 2011), WGBFAS had asked WGIAB to provide information on environmental conditions relevant for recruitment of Eastern Baltic cod. During the meeting, the indicators proposed by Gårdmark *et al.* (2011) were tested; these were mean age in the stock, mean weight (at age 5) in the stock, spring biomass of *Pseudocalanus acuspes* in the Gotland basin, total stock biomass of sprat (*Sprattus sprattus*), depth of the 11 psu isosaline in the Gotland basin, and reproductive volume. In order to only reflect the environmental effect on recruitment, the effect of spawning stock biomass was first removed by fitting a generalized additive model (GAM) to number of recruits, backshifted to year at birth (year-classes 1966–2008). Positive recruitment residuals from this 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.

To identify potential indicators of recruitment environment, the environmental variables were fitted to the recruitment residuals, as linear models of polynomials of first or second order of one variable at a time. Best significant models were chosen based on their corrected Akaike Information Criteria. No significant and ecologically meaningful relationships were found for mean age and mean weight at age. Sprat stock biomass was found to reflect the cod SSB effect, as it showed no significant relationship with the recruitment residuals, but with the raw recruitment values. None of these variables were therefore used as indicators. The reproductive volume and depth of the 11 psu isosaline both showed significant quadratic relationships with recruitment residuals (Figure 6.2.2.1; RV: $F_{1,39}=28.29$, $p<0.001$, $R^2=0.41$, Depth11psu: $F_{2,32}=12.42$ $p<0.001$, $R^2=0.45$). From these relationships, the values corresponding to zero recruitment relationship (no environmental effect on recruitment) were derived as 259 km^3 reproductive volume, and 112 m depth of the 11 psu isosaline. Reproductive volumes > 259 km^3, and shallower depths of the 11 psu isosaline, thus suggest beneficial environmental conditions for cod recruitment. Although not found to be a significant indicator of recruitment conditions as measured on 2-year-olds, *Pseudocalanus* biomass is also presented (Figure 6.2.2.2), as it has shown to be preferred food for cod larvae (Voss *et al.* 2003, Möllmann *et al.* 2003). The corresponding value for no environmental effect was 52 mg m^{-3}.

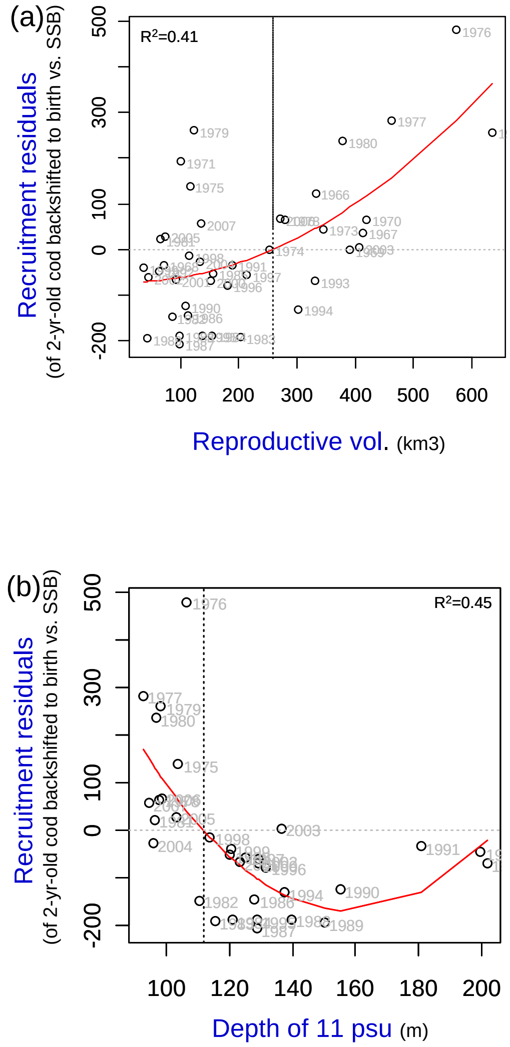

Figure 6.2.2.1. Relationships between Eastern Baltic cod recruitment residuals and (a) reproductive volume, or (b) depth of the 11 psu isosaline. Zero residuals (indicated by horizontal line) corresponds to no environmental effect, positive residuals to beneficial (and negative to poor) environmental conditions for recruitment. The corresponding reference value for each indicator, distinguishing poor from beneficial conditions, is indicated by a vertical line.

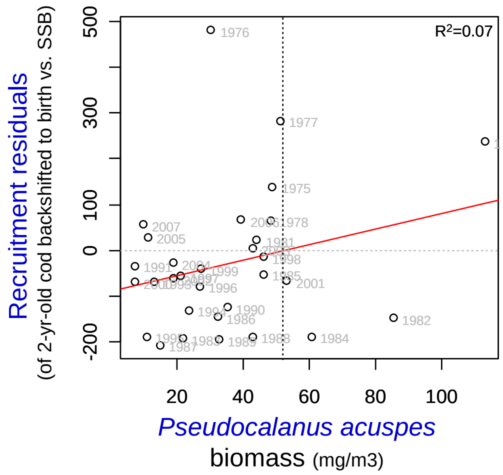

Figure 6.2.2.2. Relationship between Eastern Baltic cod recruitment residuals and biomass of *Pseudocalanus acuspes*, a preferred food item for larval cod. Zero residuals (indicated by horizontal line) corresponds to no environmental effect, positive residuals to beneficial (and negative to poor) environmental conditions for recruitment. The corresponding reference value for the *Pseudocalanus* biomass, distinguishing poor from beneficial food conditions, is indicated by a vertical line. Notice, however, that the relationship is not significant, and the variable cannot be considered an indicator of recruitment measured as number of 2-year-olds.

Environmental conditions, as suggested by the two abiotic indicators and the key zooplankton biomass, for Eastern Baltic cod recruitment of year-classes 2008–2010 were assessed by WGIAB based on the relationships and reference values derived above (Figure 6.2.2.3). The 11 psu depth indicator from Gotland basin suggests that salinity conditions were favourable for year-classes 2008–2009 (no data for YC 2010), but the reproductive volume integrated across all three basins (Bornholm, Gdansk and Gotland) indicates poor abiotic conditions for recruitment. *Pseudocalanus* biomasses in the Gotland basin, also suggest poor food conditions for larval cod of year-classes 2008–2010, although the poor relationship between this variable and cod recruitment measured as 2-year-olds should be noted.

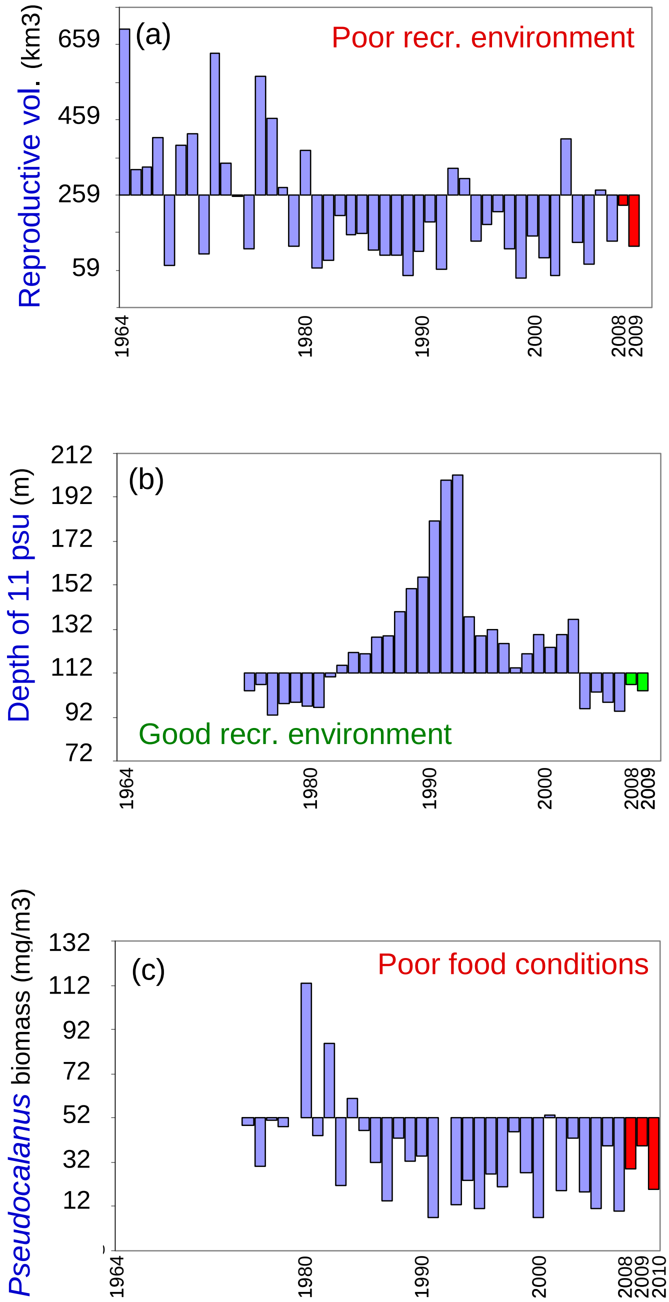

Figure 6.2.2.3. Time-series of two indicators of the abiotic recruitment environment for Eastern Baltic cod, (a) reproductive volume and (b) depth of the 11 psu isosaline, as well as of (c) biomass of *Pseudocalanus acuspes*, a key food resource for larval cod. Relationships between each variable and residuals from cod recruitment (backshifted) vs. cod SSB were derived 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 2008–2010 (corresponding to recruitment in 2010–2012), green bars indicate favourable environmental conditions, and red bars indicate poor conditions for cod recruitment.

These ecosystem-based indicators of cod recruitment conditions will be further developed by WGIAB. The separate tests of each environmental variable should be replaced by tests of joint effects on cod recruitment residuals. In their current form, the results can be used to indicate different aspects of the environmental conditions for

Eastern Baltic cod recruitment, but cannot be used to predict recruitment levels. The environmental variables used are annually updated by WGIAB, and can therefore be used also in the future as additional information for WGBFAS. WGIAB will continue to develop environmentally sensitive S-R relationships (see e.g. 6.2.1). To fully utilize environmental information to improve stock estimates, however, an assessment model with environmental covariates should be developed (e.g. in state-space assessment models like SAM).

6.2.3 Bayesian stock-recruitment relationship for Eastern Baltic cod

In addition to the spatially resolved analyses of environmental impacts on recruitment (6.2.1), overall recruitment of Eastern Baltic cod was also related to environmental variables. Time-series of the number of cod recruits and spawning stock biomass (SD 25–32; ICES 2010b) for the period 1978 to 2009 were used to estimate the parameters in a stochastic Ricker recruitment model, $R_t = SSB_t \exp(\alpha - \beta SSB_t + \varepsilon_t)$, where R_t is the number of cod recruits (thousands) in year t, SSB_t is spawning stock biomass (tonnes) in year t, α and β are model parameters and ε_t is a normal deviate with zero mean and standard deviation σ_P representing stochastic environmental variations (process noise). To test environmental influences on the cod recruitment a covariate was included in the Ricker model, $R_t = SSB_t \exp(\alpha - \beta SSB_t + cE_{t-2} + \varepsilon_t)$, where c is a regression coefficient for the environment variable E_t. The available environmental variables (from ICES 2010a) were salinity measured at 80–100 m depth in the Gotland basin, SAL_t and reproductive volume RV_t, which is the volume of water across all deep-basins with a salinity > 11 psu and an oxygen content > 2 ml/l. These data were taken from 1975 to 2009 to make it possible to test up to 3 years delayed effects for the environmental variables. The SAL and RV data were normalized to zero mean and unit standard deviation to make it possible to compare the relative size of their regression coefficients.

The model was fitted (as a non-linear regression) with salinity and reproductive volume as covariates and delayed responses between 0 and 3 years. It was found that a 2 year lag gave the highest regression coefficient for both salinity and reproductive volume. Of the two environmental variables, salinity gave the highest regression coefficient. The coefficient of determination (R^2) is also higher for salinity and the corrected Akaike's information criteria has the lowest value for the salinity model (smaller value means a more parsimonious model; Table 6.2.3.1).

In conclusion, environmental factors such as salinity and reproductive volume are influencing cod recruitment, and using such environmental information can improve explanations of recruitment variation. The best model is the one with salinity (2 years lag) as environmental variable. It explains 70 % of the inter-annual variation in cod recruitment from 1978 to 2009, whereas the model without environmental covariates only explains 53 % of the recruitment variation. Finally, these findings are well in line with previous studies on environmental effects of cod recruitment in the Baltic Sea (e.g. Heikinheimo, 2008).

Table 6.2.3.1 Result of nonlinear regression analysis for 3 stock-recruitment models for Eastern Baltic cod. Point estimates and 95% confidence intervals of model parameters, coefficient of determination (R^2) and corrected Akaike's information criteria (AICc).

Model	α	β	C	R^2	**AICc**
Only SSB	0.30 [0.04 0.56]	1.1 [0.31 1.8]10^{-6}	-	0.53	-49.29
SSB, SAL	0.46 [0.28 0.79]	1.7 [1.3 2.7]10^{-6}	0.29 [0.23 0.55]	0.70	-63.91
SSB, RV	0.36 [0.11 0.61]	1.3 [0.59 2.0]10^{-6}	0.20 [0.047 0.36]	0.62	-56.30

6.2.4 Recruitment functions for pikeperch and perch in the Archipelago Sea

Presentation by Outi Heikinheimo

Coastal species of freshwater origin, like pikeperch and perch, exhibit extensive year class fluctuations which are known to depend largely on summer temperatures (e.g. Lappalainen & Lehtonen 2002). The strong year classes, such as 1988, then produce large catches during several years starting from the recruitment to the fishery (Pekcan-Hekim *et al.* 2011).

VPA (Virtual Population Analysis) estimations based on long time-series (1980–2008) of catch statistics and catch samples from commercial fishery showed that the pikeperch stock size has increased during the study period in the Archipelago Sea. In the perch abundance, on the contrary, there has been a decreasing trend since the beginning of the 2000s (Heikinheimo *et al.*, in prep.).

Spawning stock-recruitment functions were fitted for pikeperch and perch, with summer temperature (average July/August or July temperature, respectively) as an environmental variable. The analysis on pikeperch showed that there was a density-dependent compensatory effect: the recruitment per unit spawning stock of pikeperch was negatively affected by the size of the spawning stock. This model, a Ricker model with temperature effect, explained 77% of the variance. With perch, a model with the average July temperature as an environmental variable and the abundance of the pikeperch stock, ages ≥1, as a second variable (negative effect) explained a larger proportion (78%) of the variance than a model with the density-dependent influence. The mechanism could be predation because pikeperch are also cannibalistic. However, in the eutrophicated Archipelago Sea there may be other variables that have synchronously changed with the pikeperch abundance and might have negatively affected the recruitment of perch. Such changes could be e.g. increased turbidity, the increase of cyprinids, mainly bream, in the fish assemblage, and deterioration of spawning grounds of perch due to sedimentation or filamentous algae. These factors need to be investigated further in future S-R models for these species.

6.3 Key trophic links and thresholds in the Central Baltic Sea foodweb

To further our understanding of the processes in the Central Baltic Sea foodweb, analyses were performed to study whether there are any discontinuous interactions, using the threshold generalized additive modelling (tGAM). The aim was to first test if thresholds are present, and, secondly, if they are present, whether it is also possible to quantify those. This is of importance to further improve the process understanding, in particular if a positive feedback in the Central Baltic Sea occurs as suggested by Möllmann *et al.* (2009). For example if it is possible to build statistical relationships between the foodweb components with a threshold that would indicate that the foodweb interactions are discontinuous, i.e. a certain driver determines the interactions between the foodweb components described in Möllmann *et al.* (2009). At the meeting a set of models was produced which need to be tested further in the near future. The preliminary results showed very few relationships with thresholds, as ordinary GAMs most often outperformed the corresponding tGAMs. Once tested in detail, the intention by the subgroup is to link these models for each trophic component together into one generalized additive model.

6.4 Understanding processes leading to observed ecosystem changes in the different Baltic Sea subsystems

A major goal of the 2011 meeting of WGIAB was to start analyses towards a better understanding of processes leading to the ecosystem changes ("regime shifts") documented by the group during the recent years (e.g. Diekmann and Möllmann, 2010). One approach that was pursued was to use data from several subsystems in a meta-analysis with the goal to study differences in (i) response to climate, and (ii) the trophic control pattern (bottom-up vs. top-down control).

The meta-analysis was conducted using data from 7 subsystems, i.e. the Kattegat, the Sound, the Central Baltic Sea, the Gulfs of Riga and Finland, as well as the Bothnian and Sea and Bay. A first step in the analysis was to evaluate the relationship between PC1 and PC2 from the integrated analyses on ecosystem status and trend (ICES 2008) and climate indices. Two indices were considered, i.e. the Baltic Sea Index (Lehmann *et al.* 2002), which is similar to the well known index of the North Atlantic Oscillation (NAO) and represents a high frequency atmospheric index. Additionally the index of the Atlantic Multidecadal Oscillation (AMO) is used which is based on North Atlantic temperatures and represents a lower frequency climate signal (Schlesinger and Ramankutty 1994). To create an effect size for a meta-analysis PC1 and PC2 of the ecosystem analyses were correlated with both indices and the strength of the correlation was compare among the different systems (Figure 6.4.1).

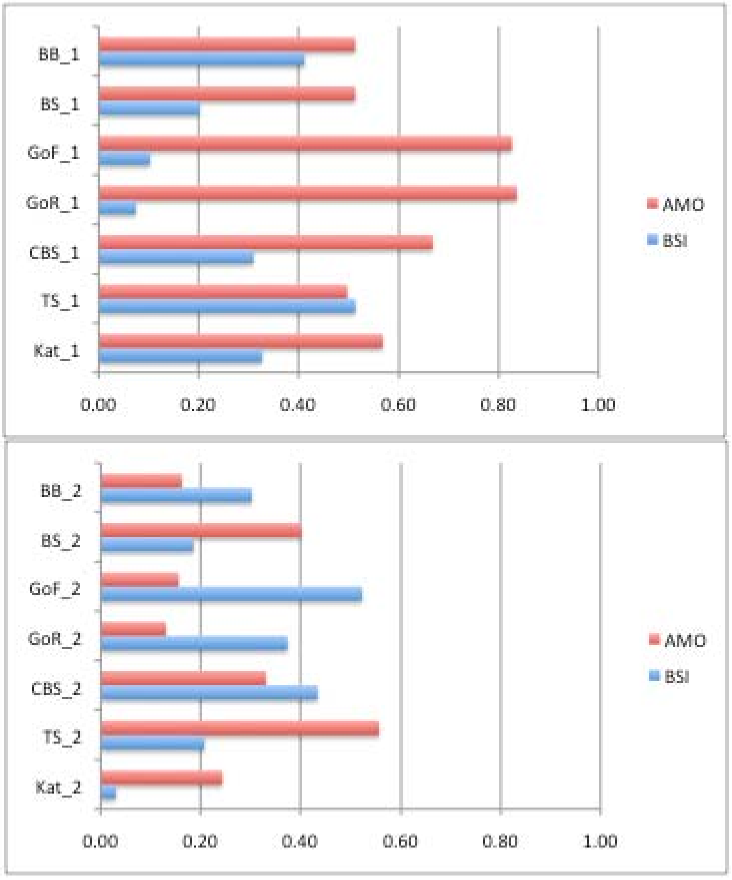

Figure. 6.4.1. Correlation coefficients of PC1 (above) and PC2 (below) of ecosystem analyses versus climate indices; BSI – Baltic Sea Index, AMO – Atlantic Multidecadal Oscillation; Kat – Kattegat, TS – the Sound, CBS – Central Baltic Sea, GoR – Gulf of Riga, GoF – Gulf of Finland, BS – Bothnian Sea, BB – Bothnian Bay; number after system abbreviation indicates PC1 or PC2.

On average correlations of PC1 with the AMO appear to be stronger than with the BSI (r=0.63 and r=0.28, respectively). Climate – PC2 correlations were on average similar (r=0.28 vs. r=0.29, respectively. Obvious spatial difference are evident between the more central areas CBS, GoR and GoF, where PC1s are stronger related to the low frequency AMO than the fringe areas close to the North Sea (Kat and TS) as well as the Bothnian areas. The Gulfs (GoR and GOF), which correlated strongest with the AMO, in turn correlated lowest with the BSI. This points towards a stronger impact of long-term climate fluctuations on the central and most enclosed areas of the Baltic, where the higher frequency atmospheric (BSI) influence is minor for the main ecosystem development. In contrast, correlations between PC2 and the climate indices show an opposite tendency, with higher correlations with BSI in the central areas. The difference between the relationships to the first 2 PCs and what changes in species composition are behind the observed patterns need further investigation.

As a next step in the analysis of climate effects, trophic level (TL) indicator for phytoplankton, zooplankton as well as planktivorous and piscivorous fish were created for all Baltic Sea subsystems. Following the approach outlined above, TLs were correlated with both climate indices and correlations coefficients were compared (Figure 6.4.2). Firstly, differences between climate effects were investigated were both spring and summer time-series were available. This was generally possible only for CBS, GoR and GoF and only for plankton. Generally, the climate influence is stronger in spring, were both climate indices correlate either positive compared to negative in summer, or stronger positive than in summer. Exceptions are obvious from GoF zooplankton (with BSI) and GoR phytoplankton (with AMO). Similar to PC-climate correlations, the AMO effect seems to be stronger on these central areas of the Baltic Sea.

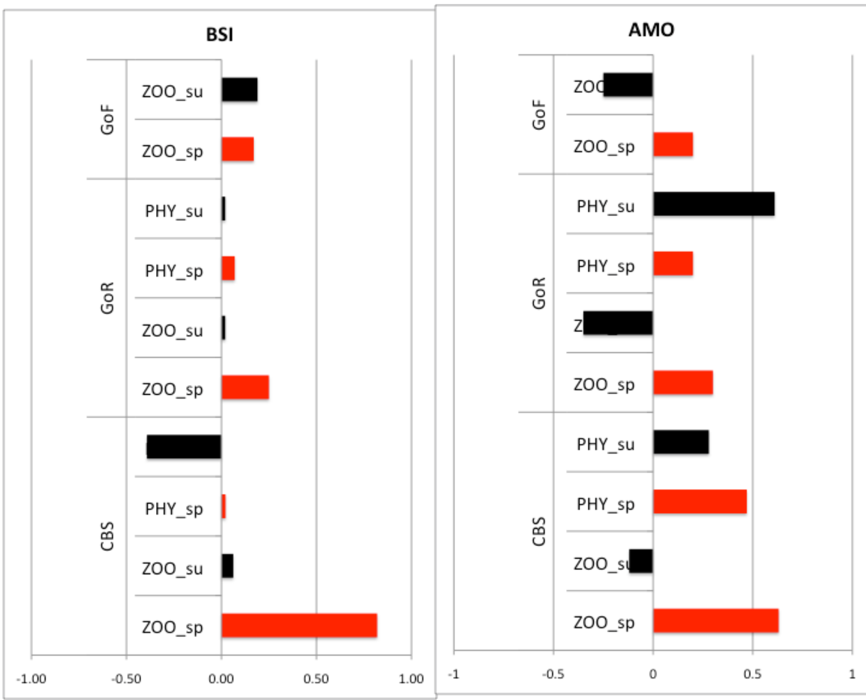

Figure 6.4.2. Correlation coefficients of trophic level indicators versus climate indices; BSI – Baltic Sea Index, AMO – Atlantic Multidecadal Oscillation; CBS – Central Baltic Sea, GoR – Gulf of Riga, GoF – Gulf of Finland; ZOO – zooplankton, PHY – phytoplankton; sp – spring, su – summer; red – spring, black summer.

Next climate effects on TL were studied for all systems in summer (Figure 6.4.3). Over all TLs were generally stronger related to the AMO to the BSI. Piscivores were generally negatively correlated to the climate indices, probably indicating the predominant importance of fishing for larger fish species. This may be supported by the the exception of TS, which displays the lowest correlation with the BSI and the only positive correlation with the AMO. In TS, the main planktivore cod (*Gadus morhua*) is protected by a long-term trawling ban and the only cod stock with a positive stock development over the whole time-series. Planktivores show the same pattern with both indices with negative correlations for BB, GoF and Kat, while in all other areas planktivores were positively related to climate. This pattern is explainable for BB and GoF, where the local herring stocks show strong long-term declines, compared to other areas. These are however generally uncertain estimates due to data quality and availability and should hence be taken with caution. The result for Kat, which is generally species richer, needs further investigation. The results for the plankton TLs are generally more variable with no clear pattern. This is potentially due to the different composition of the TL indicators, being composed of different species, with potentially different susceptibilities to hydro-climatic conditions.

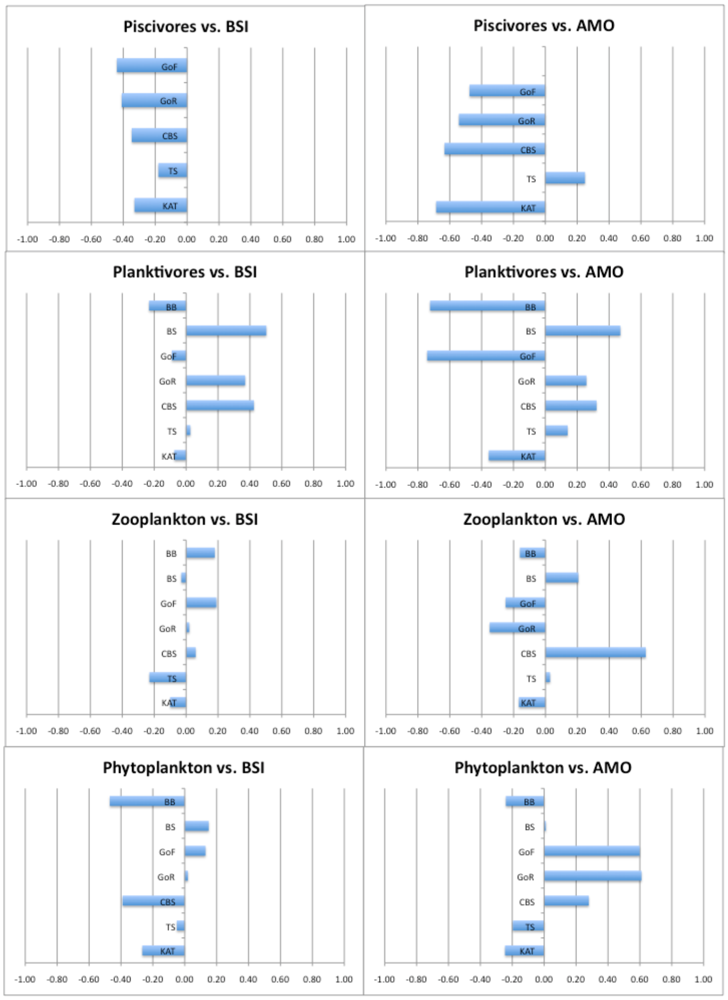

Figure 6.4.3. Correlation coefficients of trophic level indicators versus climate indices; BSI – Baltic Sea Index, AMO – Atlantic Multidecadal Oscillation; Kat – Kattegat, TS – the Sound, CBS – Central Baltic Sea, GoR – Gulf of Riga, GoF – Gulf of Finland, BS – Bothnian Sea, BB – Bothnian Bay.

In a further analysis step, we investigated the sign and strength of trophic control between the different trophic levels. This analysis assumes Bottom-up Control (BUC) when the sign of the correlation is positive, and Top-down Control (TDC) when the sign is negative. Correlations where only tested for summer (Figure 6.4.4), as here data for all systems were available, and as shown above, the climate influence is generally weaker.

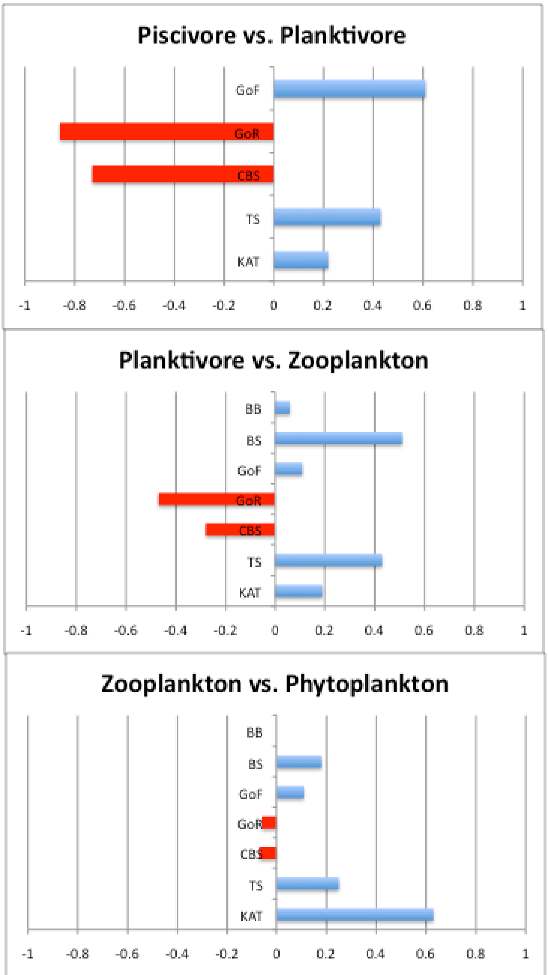

Figure 6.4.4. Correlation coefficients between trophic level indicators; Kat – Kattegat, TS – the Sound, CBS – Central Baltic Sea, GoR – Gulf of Riga, GoF – Gulf of Finland, BS – Bothnian Sea, BB – Bothnian Bay.

A clear result emerged from this analysis with negative correlations, hence top-down control over all TLs only in CBS and GoR. This result clearly indicates the existence of a trophic cascade over all TLs described for CBS (Möllmann *et al.* 2008, Casini *et al.* 2008) and for the GoR (Casini *et al.*, in press). The trophic cascade was initiated by the collapse of Eastern Baltic cod due to climate and overfishing (Eero *et al.* 2011). In all other systems, top-predators are generally absent or of low importance for foodweb regulation, like in the northern GoF, BS and BB, or top-predator stock did not show similar strong collapses like in TS and Kat. In the latter areas there is also higher piscivore diversity with more room for compensatory effects. A further result from this analysis is that in the two systems with top-down control, the strength of the trophic cascade diminishes with decreasing TL. This result is in accordance with earlier studies and points towards the importance of bottom-up control for lower TL.

The presented comparative analysis of climate effects and trophic control on the different Baltic Subsystems aimed towards a better process understanding of the observed changes. Nevertheless, these first analyses represent only a first step. Additional analysis and interpretation of the results will be conducted intersessionally. This especially includes an investigation of the temporal variability of the climate effect and the trophic controls. Confronting this with the here presented average relationship may lead to further insights into the factors controlling Baltic ecosystem dynamics.

7 Model-based advice for ecosystem-based management (ToRs b, c)

In 2009 WGIAB initiated work on model-based scenario analyses as a tool for ecosystem-based management, and developed the Biological Ensemble Modelling Approach, BEMA (ICES 2009a, Gårdmark *et al.*, in prep.). The approach provides a means to (i) present the full range of projected fish stock responses, (ii) assess whether these imply different advice on management, and (iii) draw general conclusions valid across all models used. Its application to the Eastern Baltic cod responses to future fishing and hydro-climatic changes showed that the results were sensitive to the stock-recruitment functions used in some of the models (Gårdmark *et al.*, in prep.). The work on furthering the stock-recruitment relationships (see section 6) performed during WGIAB 2011 is essential to the continued development of the BEMA. The BEMA will be used for additional scenario analyses on the Central Baltic Sea foodweb during WGIAB 2012 (see proposed ToRs in Annex 3).

In addition, the meeting also reviewed ongoing work on coupling of ecological and economical models and initiatives to integrated end-to-end models like Atlantis, in the Baltic Sea.

7.1 The Atlantis modelling approach

The EU Marine Strategy, the Baltic Action Plan and the Ecosystem Approach to Fishing all call for the integration of fisheries advice into the much larger context of marine environmental planning. This necessitates the development of tools suitable for quantifying the socioeconomic and biological effects of diverse management actions from effort limitations to regulations pertaining to offshore constructions, shipping, eutrophication and aquaculture facilities. Constructing or importing a marine ecosystem model useful for providing such a broad collections of tasks necessitates a well-defined purpose, sufficient knowledge and data, as well as logistical considerations of manpower and costs.

WGIAB already has a number of models designed to answer questions relevant for managing aquatic ecosystems and their components. These range from single-species models, generally focusing on cod to multispecies and entire foodweb models approaches, encompassing interactions between cod, herring and sprat, as well as with and other components and trophic levels of the ecosystem, respectively (ICES 2009a). While most models include deterministic equations to describe species or ecosystem dynamics, others apply empirical relationships based on statistical methods. Parameters are generally derived by fitting to, e.g. catch data and/or stock biomass estimates or parameterized based on published experimental results. Spatial aspects concerning, e.g. predator-prey overlap are generally overlooked though developments within the field are currently underway. Climate and environmental effects are mainly incorporated through (i) climate-sensitive stock recruitment relationships based on, e.g. SST, reproductive volume and bottom salinity, (ii) through direct model forcing (EwE) or (iii) via impacts on other physiological properties. This enables potential coupling with regional climate models in order to forecast population dynamics under climate change (see Ecosupport). Bottom-up forcing through potential changes in productivity from lower trophic levels are partly incorporated only in a limited number of approaches and potential linkages with bio-geochemical models (e.g., ERGOM) are limited and direct coupling in many aspects difficult to undertake.

In addition, only a limited number of models may account for spatial aspects, fleet-dynamics, bio-economy and Management Strategy Evaluation (MSE) routines. Therefore, without further development none of these models can be considered fully appropriate for providing the integrated advice necessary in the context of an Ecosystem Approach to Fisheries Management (EAFM) or the EU Marine Strategy.

ATLANTIS (Fulton *et al.* 2004; Fulton *et al.* 2007) is a spatially resolved biogeochemical ecosystem model build of a suite of biological, physical, social, economic, industry, monitoring, assessment and management modules, of which some are optional. The biophysical module is a spatially-resolved three dimensional model. The physical environment is represented by boxes constructed from horizontal polygons and vertical layers matched to the major geographical and bioregional features of the simulated system, with smaller polygons and thinner layers in areas of rapid flux or special interest. The biologically relevant components of Atlantis include various classes of nutrients (e.g. nitrogen, silica), detritus (labile, refractory, carrion), primary producers, bacteria, invertebrates and vertebrates (fish, mammals and birds). Nutrient-flows are tracked through the main biological groups in the system. Multiple functional groups can be defined within each of these components to capture key ecosystem functional characteristics while also addressing management issues. Lower (invertebrate) trophic levels are typically represented as biomass pools, while vertebrate populations usually are fully age-structured. Functional groups are influenced by environmental and habitat conditions in the water column and bottom sediments, and are also linked through trophic interactions, using a range of possible functional forms (see Plagányi 2007). The industry (or exploitation) module can be adjusted to include the impact of fisheries, pollution, coastal development, and broad-scale environmental change. The overall structure of Atlantis is summarized in Figure 7.1.1.

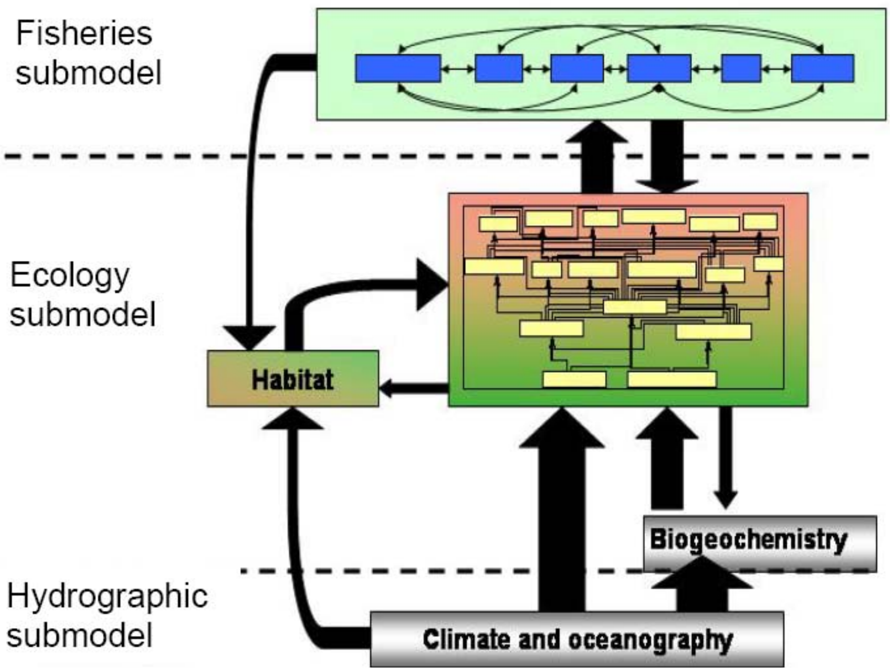

Figure 7.1.1. Overview of Atlantis modules for oceanography, ecology, and fishing.

In summary, the diversity of available modelling approaches in the Baltic Sea account together for most key processes and interactions necessary to fulfil the requirements of the ecosystem approach to marine and fisheries management and illustrate management actions robust across model approaches (ICES 2009a). Though model linking/coupling may in some cases be sufficient to overcome the structural shortcomings of a particular model and provide ecosystem-based advice on specific management issues, a comprehensive end-to-end framework to synthesize physical, biogeochemical, ecological and bio-economic information may in many aspects be seen as necessary and favourable. The ATLANTIS may indeed provide such a unified framework facilitating this integration, although risking the strong bias towards relying on advice originating from the inherit assumptions of a single model.

7.2 The Study Group on Integration of Economics, Stock Assessment and Fisheries Management (SGIMM)

The SGIMM, chaired by Rasmus Nielsen (DTU-Aqua, Denmark) and Jörn Schmidt (University of Kiel, Germany) emerged from a workshop meeting in 2010 in Kiel, Germany, which brought together economic and ecological researchers to explore possibilities of ecological-economic modelling in fisheries science (ICES 2010c). Fisheries are economic activities, which are dependent on and interact with the ecosystem in which they take place and management decisions are driven not only by changes in the environment but the economic activity itself. The rational of establishing such an activity within ICES was the perceived need to enhance the understanding of the effect of possible management options on the ecology and the economy and the feedback between these two. Thus, the focus was on looking at examples of integrated ecological-economic models, with different level of complexity of the ecosystem and the fishery.

Within the workshop two main approaches were identified, a long-term strategic planning and advice approach, with Ecopath with Ecosim (EwE) or Atlantis as possible model frameworks, and a short to medium term management evaluation and advice approach, with Fisheries Library in R (FLR) as one possible modelling framework.

It was realised that conceptual work is still needed to establish a model inventory, identify common modelling environments (frameworks) and to build up capacity to use these models, also within other groups or workshops. Agreement prevailed that the best way to tackle the challenge would be the use of existing models on concrete case studies. Possible case studies identified and suggested for the work of SGIMM are the North Sea mixed round fish fisheries, Central Baltic multispecies (cod, herring and sprat) and Chesapeake Bay as data rich systems and the Northern European Hake long term Management Plan as a data poor example.

One case study was developed at the meeting of the workshop on Including Socio-Economic considerations into the Climate-recruitment framework developed for clupeids in the Baltic Sea (WKSECRET, ICES 2010d). The existing modelling framework for predicting the population development of different Baltic herring stocks under climate change was extended with an economic optimisation, including age specific price and stock dependent harvest costs. The aim was to optimise profit and to investigate which F, especially in the transition of rebuilding the stock, and which SSB would be obtained in the long term using environmental sensitive stock-recruit functions. Interestingly, the optimal long term F is in a range suggested by the ICES workshop on long-term management plans for the Baltic Sea pelagic fish stocks (2009b). One important prerequisite for recruitment functions used in economic optimisation models is a density dependence of the stock. Thus, models using just environmental variables as predictor will not necessarily function, but have to include spawning stock biomass as predictor as well.

SGIMM will meet this year from 14 to 18 June at ICES Headquarters in Copenhagen.

8 Related integrated assessment and monitoring activities within ICES and HELCOM (ToRs f, g)

8.1 The Working Group on Integrated Assessments of the North Sea (WGI-NOSE)

The ICES Working Group on Integrated Assessments of the North Sea, WGINOSE, is a new initiative to develop the science-base for Integrated Ecosystem Assessments (IEA) in the ICES area (ICES 2011b). The group works towards this goal in cooperation with similar groups within the ICES SCICOM Steering Group on the Regional Seas Programme (SSGRSP). The first meeting attracted 40 scientists from 5 countries. Its focus was clearly on reviewing available (i) approaches to IEA, (ii) data for analyses on ecosystem status and trends, as well as (iii) modelling approaches to be used in a future IEA. The meeting was quite successful in that it attracted scientists from many different fields and hence set the baseline for its future work.

Concerning the framework for IEA to be developed for the North Sea and other ICES areas, WGINOSE considers the US approach towards IEA (Levin *et al.* 2009) to be a model for its future work. The approach is useful as it is based to a large degree on modelling approaches and data that are available for the North Sea. Still, the links between different modelling approaches need to be developed for conducting a full IEA management cycle. This development of IEA should be well coordinated between the different related groups within SSGRSP. WKBEMIA to be held in November 2011 will be a first step towards this goal. WGINOSE furthermore suggests a common meeting with the WGIAB in 2012 for coordination for IEA development and mutual methodological input. This needs to be decided during the ASC 2011 in Gdansk.

Based on the reviews of data availability and modelling approaches, WGINOSE has developed a roadmap for its future work concerning (i) ecosystem state and trend analyses, and (ii) ecosystem modelling:

i) A stronger regionalization of the ecosystem analyses is intended, i.e. conducting several separate analyses for North Sea subsystems. WGINOSE identified potential subareas of the North Sea to be dealt with in the future. Furthermore, Wadden Sea and Skagerrak ecosystems will be investigated in addition to “central” North Sea areas.

ii) Different approaches to conduct a WGINOSE modelling study have been discussed and it was concluded to initiate a multimodel study similar to the BEMA-approach developed within WGIAB. This study will conduct projections of the North Sea foodweb and fish stock dynamics based on projections of coupled atmosphere-ocean models. It is intended to use a number of single-, multispecies and foodweb models. The design of the study will be developed intersessionally. Eventually, the output of the study can be generalized using Bayesian Belief Networks.

iii) Management-related activities in addition to the development of a full IEA management cycle is complementary to the ongoing work related to the EU-MSFD descriptors and indicators. WGINOSE intends to provide the results of their work to European and national GES working groups.

This includes the further mapping of the available data and modelling outputs potentially valuable for EU-MSFD indicator and threshold development.

8.2 Workshop on Benchmarking Integrated Assessments (WKBEMIA)

A crucial future task of the ICES SCICOM Steering Group on the Regional Seas Programme (SSGRSP) is to develop Integrated Ecosystem Assessments for the ICES areas. In addition to WGIAB, three more regional groups work towards this goal, i.e. Working Group on Integrated Assessments of the North Sea (WGINOSE), Working Group on the Northwest Atlantic Regional Sea (WGNARS) and the Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS). In order to facilitate the integration of the different ICES SSGRSP groups a Workshop on Benchmarking Integrated Ecosystem Assessments (WKBEMIA) will be held at ICES Headquarters in November 2011. The meeting will have the following Terms of References:

The Workshop on Benchmarking Integrated Ecosystem Assessments (WKBEMIA), chaired by Steve Cadrin, USA, and Christian Möllmann, Germany, will work by correspondence and will meet at ICES HQ, Copenhagen, Denmark, 30 November–1 December 2011 to:

Starting a process on how to Benchmark Integrated Ecosystem Assessment (IEA) based on results in ongoing Integrated Ecosystem Assessments Expert Groups:

a) Make a brief review on the various concepts of Integrated Ecosystem Assessments including an evaluation of suitability to ICES needs in terms of Science and Advice;

b) Review the Integrated Ecosystem Assessments in the ongoing Regional Expert Groups, with regards to methods, models and results;

c) Identify a common framework which will act as a guideline for Integrated Ecosystem assessments performed in ICES;

d) Based on ToR c) identify the need of supporting data, processes and products.

8.3 A review of HELCOM HOLAS ('Ecosystem health of the Baltic Sea – HELCOM initial Holistic Assessment', Baltic Sea Environment Proceeding No. 122)

HELCOM has presented an initial holistic assessment of the Baltic Sea (HELCOM 2010), the HELCOM HOLAS. Holistic assessments or ecosystem-based management are broadly considered as necessary alternatives to the status-quo of decoupled analyses and assessment of ecosystem components and services in the Baltic Sea. The major challenge of holistic assessments is to condense vast amounts of data, measurements and qualitative information on extremely complex systems into information that is useful and understandable for stakeholders and managers on the one hand, but also accounting for the critical mechanisms driving the system on the other hand.

The ability of the condensed information, be it indices, reference points, distributional charts and so further, to account for critical mechanisms driving changes in the ecosystem and services is important, because only when mechanisms are accounted for, consequences of management options or natural changes can be predicted based on the actual assessment.

HELCOM's initial holistic assessment is based on visualization of two similar indices. The Baltic Sea Impact Index (BSII), and the Baltic Sea pressure index (BSPI). The basis for both indices is that, for a given assessment area (5 km x 5 km), anthropogenic pressures are translated to impacts on marine biotopes or species. It is not specified, if impacts are positive or negative. However, due to the definition of a healthy ecosystem as a system that is close to an unexploited state each impact is implicitly considered detrimental. For a given anthropogenic pressure, for example pelagic fisheries, input data (in this case data on landings) are transformed to a pressure index. This is done by taking the logarithm and then normalizing the input data. The result is a pressure index ranging from 0 to 1. In the example with pelagic fisheries, this means that landings data from the Working Group on Baltic Fish stock assessment, given by ICES rectangle, are assigned to assessment areas. Each assessment area was given the same value as the whole ICES rectangle, then logarithmized and normalized.

The way the data are normalized is not specified, but usually in the report an observation is divided by the sum of all observations. It remains unclear, though, which sum has been applied, probably the sum over ICES rectangles of total landings. In this case, each cell would represent the relative contribution of catches in the rectangle the cell is part of compared to the whole Baltic Sea.

For the BSII, subsequently the pressure is multiplied with either 1 or 0, because for the calculation of BSII, pressures are summed over the ecosystem components they act upon within a given assessment area. Thus, the index value in an assessment unit highly depends on the number of ecosystem components in that assessment unit. For the case of fishing pressure, it has to be considered problematic that fishing activities are very heterogeneously distributed within an ICES rectangle, as well as ecosystem components within an assessment area. The spatial overlap between fishing activity or other anthropogenic pressures and ecosystem components is, however, considered to be given, although this remains to be verified in order to assess the true impact of this or any other pressure.

The BSPI is calculated without summing over ecosystem units, hence, pressure are considered per assessment unit. The translation from pressure to impact is done by assigning weighting scores. The weighting scores are based on expert opinions gathered via questionnaires, asking to rank the pressures on the scale 0–4. Neither measurements nor quantitative models were used to deduct impacts from pressures. This leaves the impact assessment very subjective and dependent on the choice of experts. Finally, impacts are summed up per assessment unit, and all assessment units are plotted in a map.

In summary, the following points were raised:

1) The HELCOM approach developed for the Baltic Sea (HOLAS) is stating that human pressures are influencing the ecosystem state, but without quantitatively or qualitatively linking pressures to state.
2) HOLAS is, on the other hand, a valuable spatial, mapping and visualization tool for the complex set of anthropogenic pressures throughout the entire Baltic Sea.
3) Impacts are transformed from anthropogenic pressure by weighting scores, which are based on expert opinions. There are neither process models nor measurements behind the transformation from pressure to impact.

4) Climate effects and in particular the lack of inflows since 1976 and the subsequent change (i.e. regime shift) the BS underwent are not sufficiently considered in the definition of pressures.

5) Interactions between different types of pressures are not addressed.

6) The time-span of data considered is very short in order to evaluate the state of the ecosystem, or reference conditions; recent years are not included in the analyses, for example the positive development of the cod stock suggested by recent stock assessments is not accounted for.

7) The proposed tool for protecting the ecosystem is a system of Marine Protected Areas. While potentially useful, the single focus on MPAs does not consider the need for other management tools in cases where MPAs have shown not to be effective.

8) There are some problems in the input data, for example are 13 300 tonnes cod listed as caught in surface or mid-water fisheries, which is inconsistent with the stock assessment input data.

9 Input to developments of indicators for the EC Marine Strategy Framework Directive and the HELCOM Baltic Sea Action Plan (ToR f)

Responding to a letter from the ICES Chairs of the Science Committee and the Advisory Committee, WGIAB addressed two additional ToRs relating to the Marine Strategy Framework Directive (MSFD), to aid the work of the strategic group Marine Strategy Directive Framework Steering Group (MSFDSG) (see section 1). WGIAB was asked to describe elements of its work that may support determining status of the 11 descriptors in MSFD, to provide input on what good ecological status may be for these descriptors, as well as provide methodological advice.

The meeting noted that development of indicators for these descriptors, including methodological considerations, have been pursued in dedicated task groups organised through the Joint Research Centre during 2009 and 2010. The task groups, one per descriptor, consisted of key experts who were selected to also represent the different regions under the EU MSFD. These task groups described the attributes of the descriptors, the criteria of these which correspond to good ecological status, and categories of indicators and methods to derive the indicators (Cardoso *et al.* 2010 and references therein). WGIAB therefore refers the question of good ecological status of the different 11 descriptors to these reports.

During the meeting, activities relating to regional specification of indicators to assess the 11 descriptors were presented. WGIAB noted that whereas it is a national responsibility of EU member countries to develop indicators supporting the MSFD, regional co-ordination of these efforts in the Baltic Sea are occurring within both HELCOM and OSPAR (the latter for the Kattegat area) within their respective projects HELCOM CORESET (Development of the HELCOM core set of indicators for biodiversity and hazardous substances) and COBAM (Group on Coordination of Biodiversity Assessment and Monitoring) within OSPAR. Having noted this, WGIAB refrained from providing input of the definition of good ecological status for particular descriptors, but instead highlighted issues to be accounted for when developing indicators and target levels, based on insights from WGIAB analyses (ICES 2007, 2008, 2009a, 2010):

i) 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 foodweb must be set jointly to account for the presence of trade-offs among management objectives affecting different parts of the foodweb.

ii) Reference (and target) states change; 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.

iii) Multiple natural and anthropogenic drivers are related to shifts in ecosystem composition, and these drivers differ between Baltic Sea sub-basins (Lindegren *et al.* 2010, Möllmann *et al.* 2009, Blenckner *et al.* in prep.), as do trophic relations (see section 6.4). Therefore, indicators and targets need to be defined at a scale smaller than the whole Baltic Sea (e.g. sub-basins).

Since its start in 2007 WGIAB has collected and updated data sets that are used for describing and combining different aspects of the Baltic ecosystem, including abiotic and biotic variables (ICES 2007, 2008, 2009a, 2010a). Thus, yearly updated data sets are available for the Baltic as a whole, as well as for most of the Baltic subsystems, and can potentially be used further within the MSFD processes. 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 Marine Strategy Framework Directive (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). To contribute to the indicator development for the Baltic Sea, WGIAB (ICES 2010a) investigated how the datasets developed and held by the group can contribute and help specify the HELCOM and EU MSFD indicators systems. Candidate HELCOM and EU MSFD indicators were matched with the time-series of ecosystem data available to WGIAB. The product of this exercise was a document with a huge table which was not presented in the 2010 report due to its size, but is available through the co-chairs of WGIAB. Based on that example, Table 9.1 lists the MSFD indicators that could be addressed using the results and ecosystem data assembled by WGIAB.

Table 9.1. List of MSFD related state indicators, and the corresponding descriptor (Descr) and their aspects (denoted “criteria”) in the MSFD, that could be addressed in the context of WGIAB activities.

Descr.	Criteria	State indicator
D1	Population size	Population biomass
D1	Population size	Population abundance
D1	Population condition	Population demography (e.g. body size or age class structure, sex ratio, fecundity rates, survival/mortality rates)
D1	Population condition	Inter and intra-specific relationships
D1	Habitat distribution, extent and condition	Habitat distributional range
D1	Habitat distribution, extent and condition	Habitat extent
D1	Habitat distribution, extent and condition	The habitat condition relates to the physical, hydrological and chemical conditions
D1	Habitat distribution	Habitat Distributional range

D1	Habitat extent	Areal extent of habitat (area covered)
D1	Habitat extent	Habitat volume
D1	Habitat condition	Habitat condition relates to the physical (structure and associated physical characteristics, including structuring species), hydrological and chemical conditions
D1	Community condition	Community species composition
D1	Community condition	Community biomass
D4	Ratio of production or biomass between different trophic levels	Ratio of pelagic to demersal fish biomass and/or production
D4	Productivity (production per unit biomass) of key species or groups	Performance of key predator species using their production per unit biomass (productivity)
D4	Productivity (production per unit biomass) of key species or groups	Trophic relationships within the food web
D4	Abundance/distribution of key groups/species	Indicators of abundance trends
D5	Primary symptoms or directs effects of eutrophication	Nutrients concentration in the water column
D5	Primary symptoms or directs effects of eutrophication	Deviate from normal proportion of nutrient ratios (Si N P)
D5	Primary symptoms or directs effects of eutrophication	Chlorophyll due to an increased nutrient availability, measured monthly or more frequent as appropriate
D5	Secondary symptoms or indirect effects of eutrophication	Dissolved oxygen due to increased organic composition, measured monthly or more frequent
D5	Secondary symptoms or indirect effects of eutrophication	Annual to multi-year changes in frequency and/or duration of blooms. Changes in balance of diatoms/flagellates/cyanobacteria
D6	Oxygen concentrations in bottom water and/or upper sediment layer	Extent of area with spatial or temporal hypoxia
D7	Changes in habitat functions	Changes in habitat functions due to altered hydrographical conditions (e.g. spawning areas, breeding and feeding areas and migration routes of fish, birds and mammals)

Generic methodological challenges and related uncertainties involved in aholistic marine ecosystem assessment were recently investigated (Ojaveer and Eero 2011). The study evaluated the status and trends of the ecosystem of the central Baltic Sea by the three major strategic goals (biodiversity, eutrophiction and hazardous substances) and the agreed management targets as stated in HELCOM BSAP by utilising altogether about 140 state and pressure indicator datasets. It was evident, that the assessment results were sensitive to a selection of indicators for ecological quality objectives that are affected by a broad spectrum of human activities and natural processes (biodiversity), less so for objectives that are influenced by a relatively narrow array of drivers (eutrophications, hazardous substances). The choice of indicator aggregation rule appeared to be of essential importance for assessment results for all three segments, whereas the hierarchical structure of indicators had only a minor influence. Outcomes of this study can help to better interpret results of the already performed HELCOM thematic assessments, establish priorities for future efforts to improve assessment of environmental status, and assist to enhance the transparency of the assessment procedure in the Baltic Sea and also elsewhere.

Responding to the additional ToR from ACOM/SCICOM regarding data for pressure indicators on biodiversity, and on spatially resolved data (see section 1), WGIAB noted that several of the analyses performed by WGIAB provides the basis for selecting relevant pressure indicators. In particular the analyses of processes leading to observed ecosystem changes, conducted by WGIAB both in this meeting (e.g. section 6.3) and previously (Möllman *et al.* 2009, Lindegren *et al.* 2010, Blenckner *et al.* in prep.), are important for selecting appropriate indicators of pressures on biodiversity. WGIAB performs regular updates of multivariate analyses of ecosystem status and trends in all Baltic Sea sub-basins. For these, WGIAB assembles and updates databases with time-series of key species/groups from different trophic levels, as well as of natural and human pressures on these. These pressure data primarily concerns fishing and eutrophication, and no data on e.g. constructions in marine habitats (like energy production sites) have been assembled. The group has an increasing focus on spatial variation on smaller scales than sub-basins, e.g. spatial variation in environmental impacts on CBS fish stocks (section 6.2), which provides knowledge and data on state and pressures at finer spatial resolution (ICES sub-divisions).

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Annex 2: Agenda

Monday 04/04/11

1300 – 1330 **Welcome!** Practical information, discussion of the agenda, planning of the work and the reporting (Anna Gårdmark , Thorsten Blenckner & Martin Lindegren)

1330 – 1400 **Organisation of sub-group work: intro to tasks**

- *Group 1* Coastal ecosystem analyses and potential offshore updates [ToR a] (Maciej Tomczak)
- *Group 2* Process understanding & statistical modelling [ToR e] (Thorsten Blenckner)
- *Group 3* Testing early warning indicators [ToR d] (Martin Lindegren)
- Organising work on ToRs b, c, f, g + additional ToRs (Anna Gårdmark)

1400 – 1445 **Presentation** IMEDEA science and activities (Beatriz Morales Nin)

1445 – 1500 Coffee & Tea

1500 – 1545 **Presentations**

- Benchmarking Integrated ecosystem assessments (Christian Möllmann)
- Information from WGINOSE – Integrated Assessments of the North Sea (Christian Möllmann)
- Information from WKIMM and about SGIMM – Coupling Economics, Fisheries Ecology & Management (Jörn Schmidt)

1600 – 1630 **Presentation** Ecosystem changes in the Baltic, what did we learn from WGIAB so far? (Thorsten Blenckner)

1630 – 1730 **Parallel work in sub-groups** Organising sub-group work

1730 – 1800 **Plenary** Summary and planning of forthcoming plenaries

Tuesday 05/04/11

0900 – 1030 **Presentations**

- Climate effects on Baltic Sea sub-ecosystems – a comparison using a meta-analytical approach (Christian Möllmann)
- Early-warnings signals: from theory to identification (Martin Lindegren & Vasilis Dakos)
- Alien species in a brackish water temperate ecosystem: annual-scale dynamics in response to environmental variability (Henn Ojaveer)

1030 – 1045 Coffee & Tea

1045 – 1300 **Parallel work in sub-groups**

Group 1: Ecosystem Analyses

Presentations in sub-group

- Changes and drivers in Coastal Ecosystems I: Limfjorden (Maciej Tomczak)
- Changes and drivers in Coastal Ecosystems II: Kattegatt, Central Baltic Sea, Bothnian Sea fish and zoobenthic communities (Jens Olsson)

Tasks: new and updated coastal assessments, update assessments (e.g. CBS)

Group 2: Process understanding

Presentation in sub-group

- Process-based indicators for stock assessments – cod input to WGBFAS (Anna Gårdmark)

Tasks: test different methods to analyse the responses to drivers and trophic interactions in the particular systems, identify ecosystem indicators and thresholds

Group 3: Early warning Indicators

Presentation in sub-group

- Introduction and discussion on the suitability of different tools and methods for identifying early-warning signals (all involved).
- Discussion concerning data availability and selection of candidate time-series for comparative analysis using the tools selected above (all involved).

Tasks: apply and compare a range of different statistical tools to a selected set of basin-specific early warning indicators.

1300 – 1400	Lunch
1400 – 1545	**Parallel work in sub-groups**
1545 – 1600	Coffee & Tea
1600 – 1800	**Plenary** Status reports from each group
1930 –	Common Dinner (Esporles)

Wednesday 06/04/11

0900 – 1015 **Presentations**

- Climate-related decadal dynamics in Baltic Sea zooplankton: Interactive and additive effects of bottom-up and top-down controls (Saskia Otto)
- Atlantis and End-to-end modelling in the Baltic Sea (Martin Lindegren)
- Stock assessment results on pikeperch and perch in the Archipelago Sea, Finland: What determines the recruitment? (Outi Heikinheimo)

1015 – 1045	**Parallel work in sub-groups**
1045 – 1100	Coffee & Tea

1100 – 1300 **Parallel work in sub-groups**

1300 – 1400 Lunch

1400 – 1545 **Parallel work in sub-groups**

1545 – 1600 Coffee & Tea

1600 – 1700 **Plenary** Discussion of first Coastal Ecosystem Assessment results

1700 – 1730 **Plenary** Status report on Process understanding

1730 – 1800 **Plenary** Discussion of first Early Warning Indicator results

Thursday 07/04/11

0900 – 1000 **Presentations**

- Detection of regime and other shifts in marine time-series – the new shiftogram approach (Joachim Gröger)
- (Joachim Gröger)
- Indicators of Good Ecological Status in the Marine Directive – what's going on in the Baltic? (Anna Gårdmark)

1000 – 1045 **Parallel work in sub-groups**

1045 – 1100 Coffee & Tea

1100 – 1300 **Parallel work in sub-groups**

1300 – 1400 Lunch

1400 – 1545 **Parallel work in sub-groups**

1545 – 1600 Coffee & Tea

1600 – 1800 **Plenary** Discussion of results, presentation of plans for future work from each sub-group

1930 - Common activity

Friday 08/04/11

0900 – 1045 **Final Session**

- Wrap-up of sub-group work
- State of the report
- Discussion on next meeting (ToRs, venue, focus)
- Discussion on long-term strategy of WGIAB

1045 – 1100 Coffee & Tea

1100 – 1300 **Report writing**

1300 Closure of the meeting

Annex 3: WGIAB draft terms of reference for the next meeting

The **ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea** (WGIAB), chaired by Martin Lindegren, Denmark; Thorsten Blenckner, Sweden; and Lena Bergström*, Sweden, will meet in VENUE, 2–5 April 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 food-webs;

e) Further develop an Integrated Ecosystem Assessment cycle for the Baltic Sea accounting for the work of WKBEMIA, and in close co-operation 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 20 May 2011 (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	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, SGEH
Linkages to other organizations	HELCOM, BONUS, EU DGs.

Annex 4: Integrated Trend and Status Assessments

The nine coastal and small-scale subsystems included in the initial data screening are presented below, followed by the update of the integrated analyses of the pelagic foodweb in the open Central Baltic Sea (CBS). The small-scale systems are presented in the following order: the North Sea-Kattegatt transition area ("NK", Limfjord), a coastal site in the eastern Kattegatt ("Kc", Vendelsö), the Gulf of Gdansk ("GG"), the Curonian Lagoon ("CL"), the Gulf of Riga coast ("GoRc"), the north-eastern Gulf of Riga ("NEGoR"), and coastal sites in the western Baltic Sea Proper ("BPc", Kvädöfjärden), the eastern Bothnian Sea ("EBSc", Archipelago Sea), and the western Bothnian Bay ("BBc", Holmön). Integrated analyses were performed for NK, Kc, GG, BPc, EBSc, and BBc, as well as for the offshore CBS.

A4.1. The Limfjord – a North Sea-Kattegat transition area (NK)

The Limfjord is the largest Danish estuary with a coast line 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 NK-1). Due to freshwater influxes, salinity ranges between 0–34 psu with a decreasing gradient from west to east and south to north. The highly eutrophicated estuary suffers from frequent and extensive episode of hypoxia and anoxia causing mass mortality of benthic organisms.

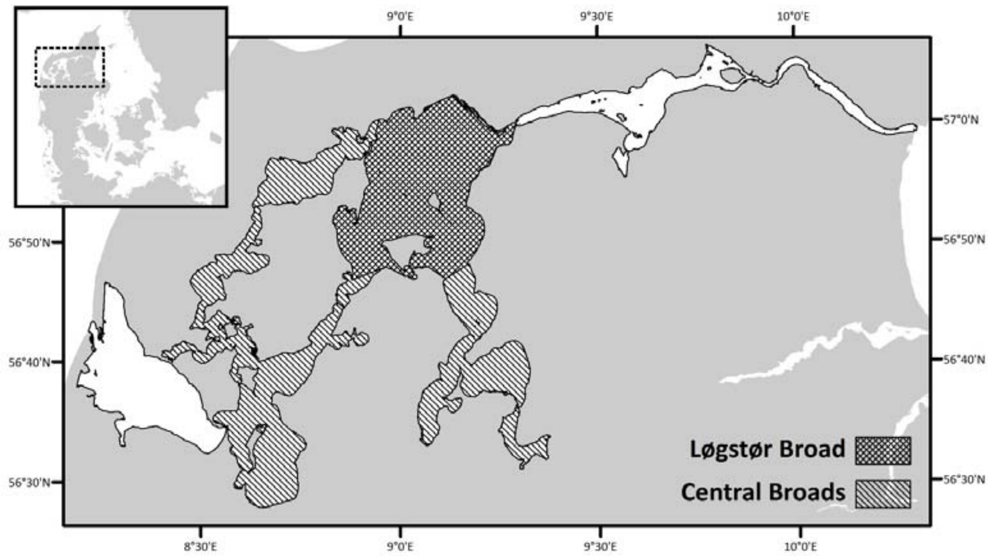

Figure NK-1. The study area, the Limfjord, Denmark.

Fish, jellyfish and fisheries data from the DTU Aqua database were retrieved from the Central Broads of the Limfjord estuary, while data on other organisms, nutrient pollution and climate from the AU NERI database were retrieved from the central embayment, Løgstør Broad, which is considered representative as an average area of the Limfjord estuary.

Time-series data initially selected for the IEA comprised 19 biological variables, 4 fishery related variables and 21 variables related to nutrient loadings and concentrations or climate (Table NK-1).

Time-series data on biomass indexes for targeted and non-commercial fish species originated from the DTU Aqua monitoring survey cruises in the Limfjord (Table NK-1). Annual biomass data were retrieved from the DTU Aqua data base (BABELFISH, www.aqua.dtu.dk). Data for polychaetes, molluscs, crustaceans, echinoderms, and Chl. a., originated from the national and former counties environmental monitoring programmes, and were retrieved from the AU NERI database (MADS, www.dmu.dk). The 'Hoffmann jellyfish-index' for the Limfjord (Hoffmann 2005, Møller & Riisgård 2007c) was used as a proxy for zooplankton, since time-series data of the later were not available.

Fisheries data on Limfjord landings of blue mussels, decapods and pelagic and benthic fish species were retrieved from account statistics of the Danish Directorate of Fisheries (see also www.fd.dk). Environmental time-series data related to nutrient pollution and climate impact were retrieved from the MADS database.

Total nitrogen loading has increased six-fold since the turn of the last century, peaking in the mid-1980s, corresponding to the beginning of the times series in this study. Since then loadings have decrease by 40% (N) and 71% (P) (Christensen *et al.* 2006). The finfish fishery declined dramatically and an increase in blue mussel, *Mytilus edulis* L., 1756, biomass supported a thriving mussel fishery, which became the largest harvest yield from the fjord (Hoffmann 1992, 1994, 2000, 2005).

Trend analyses

Hydrography

All hydrological parameters fluctuate and no clear trend has been notice. Only water column oxygen (annual and summer increase from low values in late 1980s).

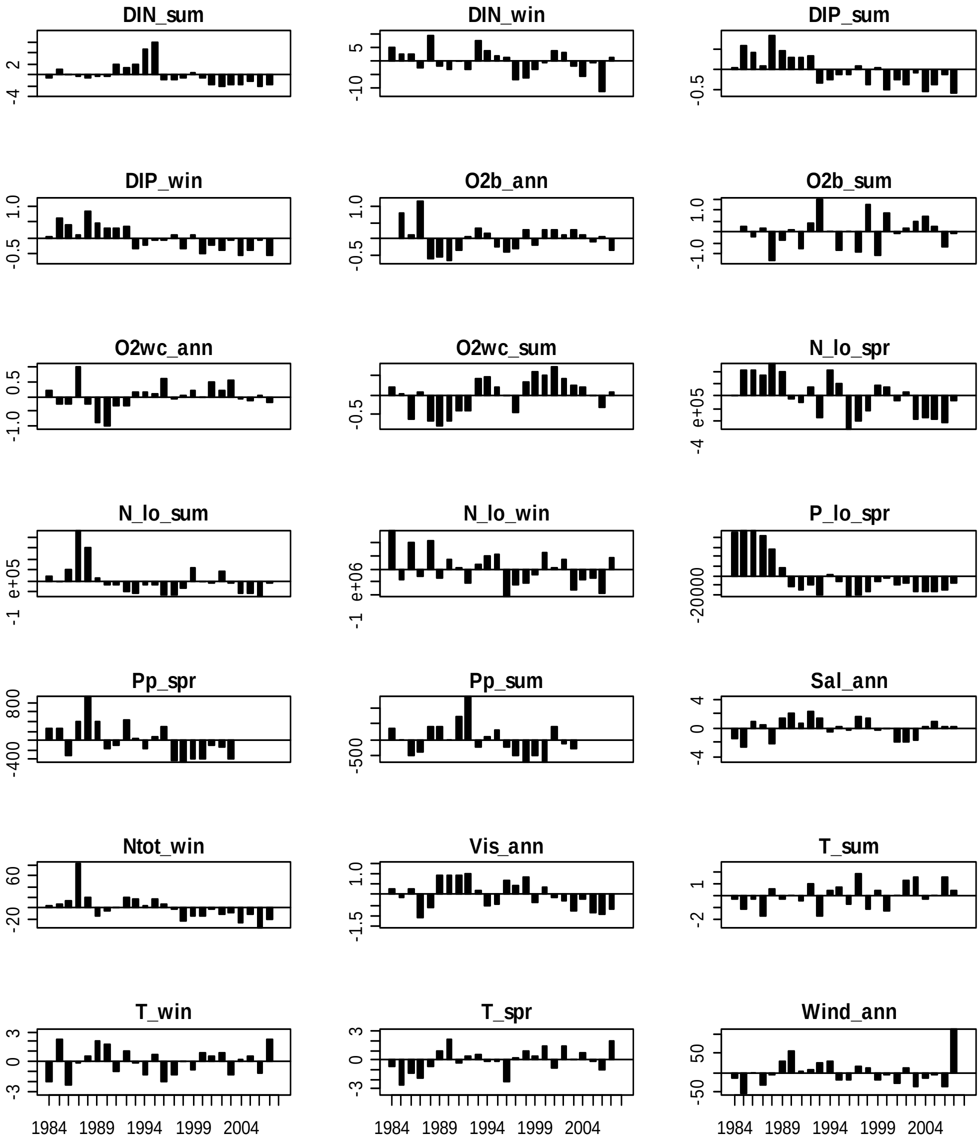

Figure NK-2. Long-term environmental changes in the Limfjord: anomalies of the overall mean presented for variable. Abbreviations and unit see table NK-1.

Nutrients

For all nutrients related time-series (dissolved inorganic nitrogen in summer, dissolved inorganic nitrogen in winter, dissolved inorganic phosphorus in summer, dissolved inorganic phosphorus in winter, spring and summer total nitrogen loadings, spring phosphorus loadings, and winter total nitrogen) decreasing trend is visible, both for loadings and winter concentrations.

Phytoplankton

Phytoplankton data have been representing by chlorophyll *a* (as a proxy of phytoplankton biomass) and primary production. For both a decreasing trend was observed.

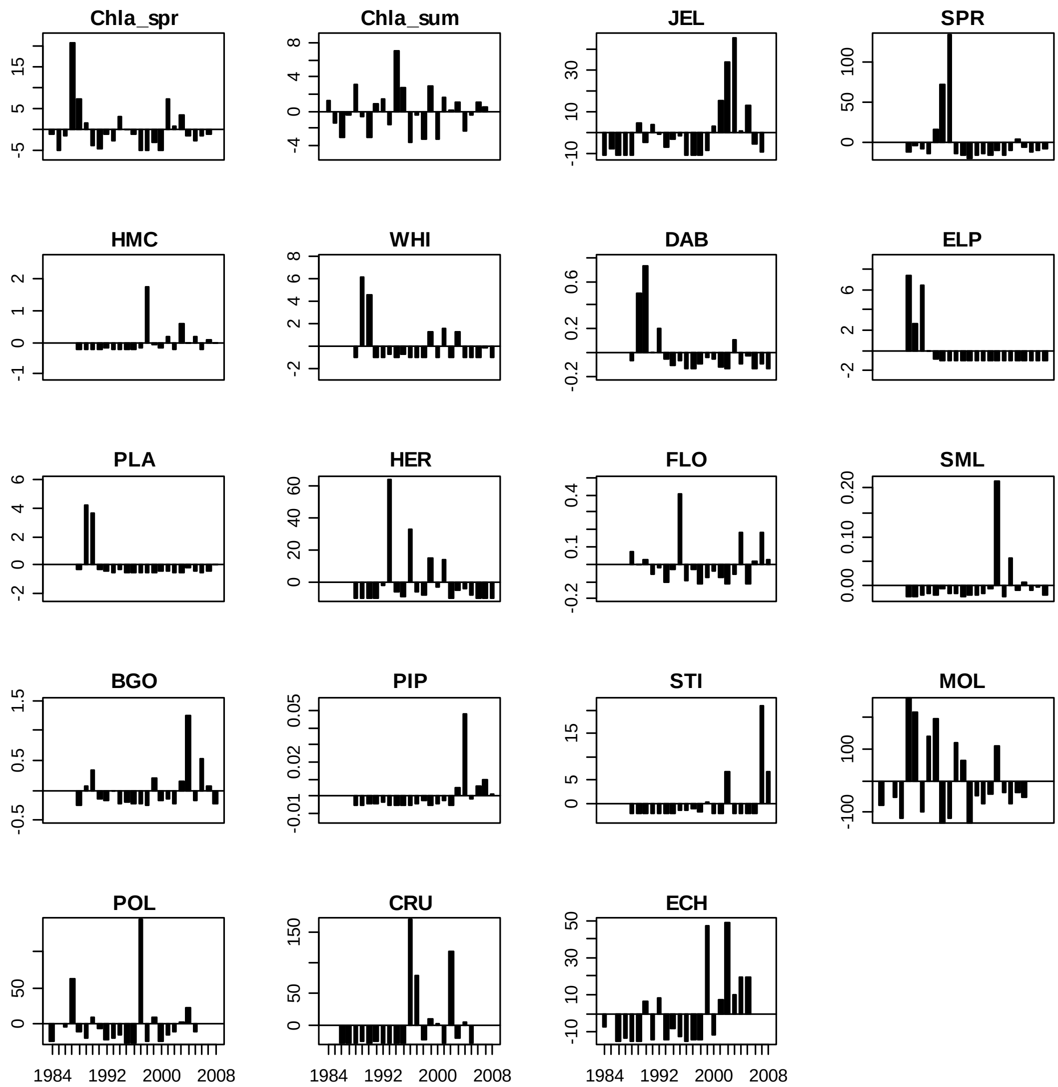

Figure NK-3. Long-term biological variables changes in the Limfjord: anomalies of the overall mean presented for variable name and unit see table NK-1.

Benthos

Concerning the benthos, a clear increasing trend in biomasses have been recognized for crustaceans and echinoderms. Groups like molluscs and polychaetes fluctuated around the mean. A strong increase and then a decrease was notice for landings of molluscs, while a clear increase in crustaceans fisheries was observed since 2004.

Fish

Decreasing trends were observed for most of the flatfishes, demersal species and gadoids (whiting, dab, eelpout, place, flounder, as well as herring). In opposite the biomass of small species, more pelagic and opportunistic species increased (jellyfish, horsemacrel, black goby, pipefish, and stickleback). Decreases in demersal species are clearly visible as the landings decline. At the same time, a clear increasing trend was noticed for landings of pelagic species.

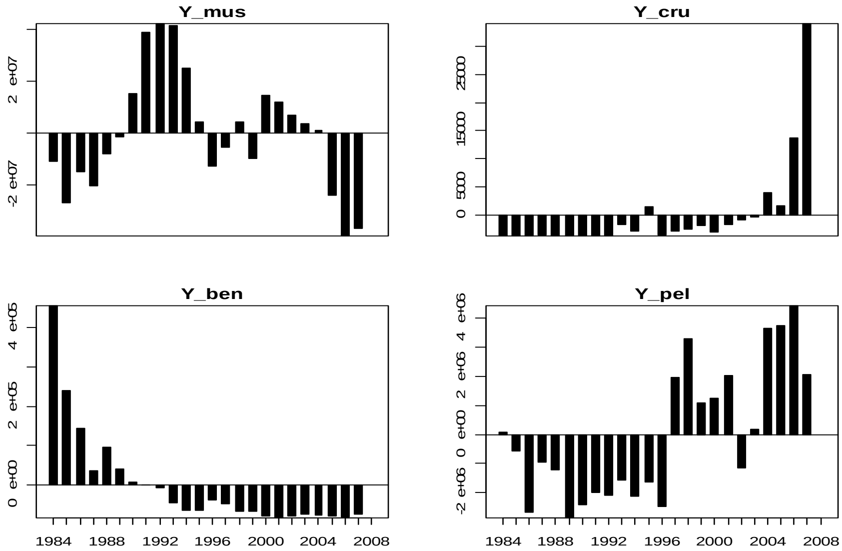

Figure NK-4. Long-term landings changes in the Limfjord: anomalies of the overall mean presented; for variable name and unit see table NK-1. [Presented from top left to bottom right]

Integrated analyses

The period 1984–2008 was included in the integrated analysis. All 44 variables were considered. For the biota analysis 19 biological variables were used (Figure NK-5). The presented results are a first attempt to conduct a IEA for Limfjord. and have been performed for the full datasets. However an analysis was performed on a shorter time period, due to gaps in fish community data.

For overall system analysis the variables with high values in the beginning of the period and lower values towards the end of the 2008 were e.g. dissolved inorganic phosphorus, eelpout biomass and landings of benthic fish species. The variables which showed an increasing trend with time were e.g. landings of crustaceans and pelagic species as well as biomass of crustaceans and echinoderms.

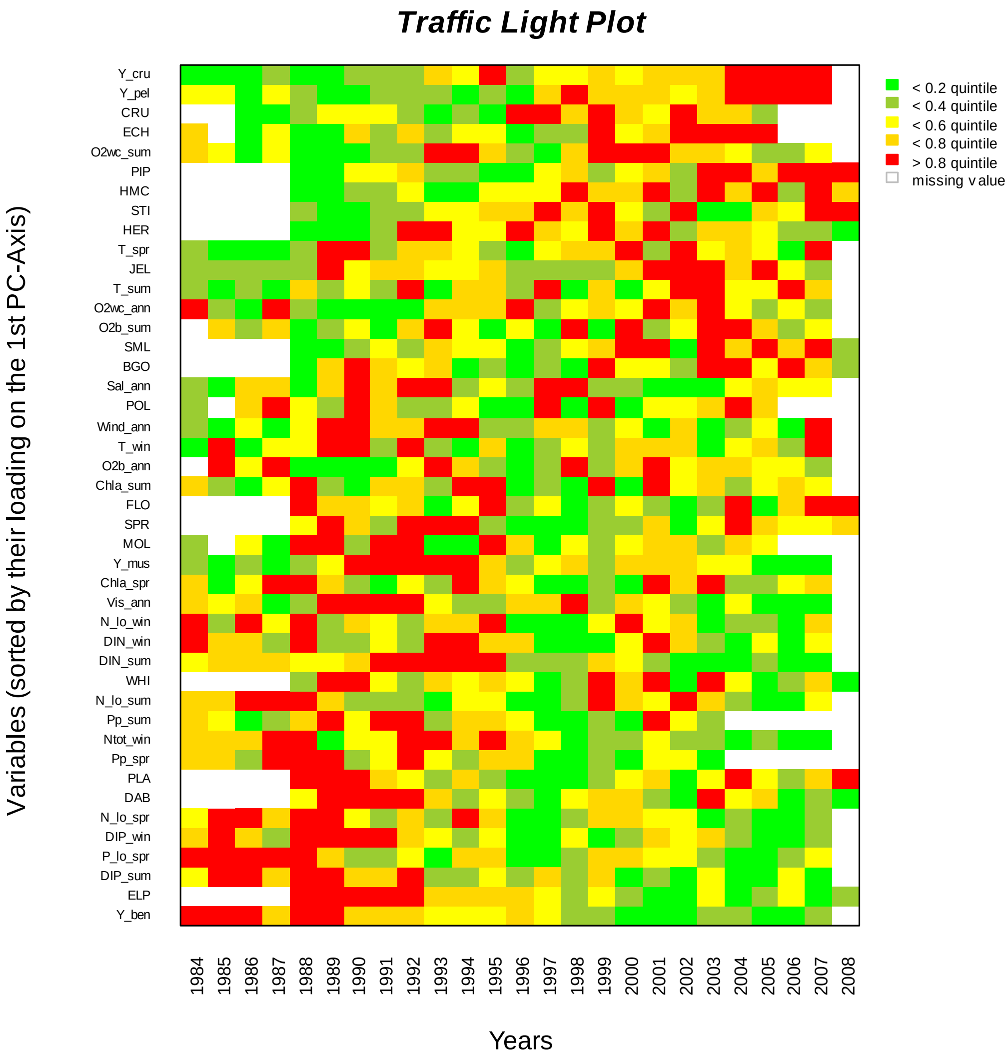

Figure NK-5. Traffic-light plot of the temporal development of the Limfjord time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in Table NK-1.

In the PCA analysis, the first two principal components explained 27% and 11% of the variance, respectively. The most important variables in PC1 were landings of benthic fishes (mostly flatfishes community) and landings of crustaceans (both of the variables shop contradictory trends). The PC2 are mainly associated with oxygen and salinity variables. The time trajectory plot indicates that the system had two states with a transition period of 4 years (1992–1996) .

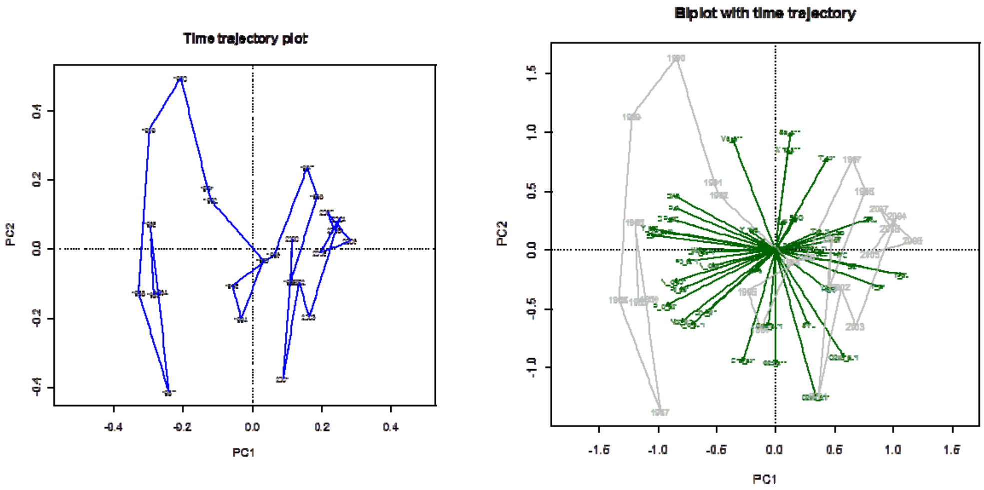

Figure NK-6. Results of the standardized principal component analysis using all 44 variables in the Limfjord. The graph to the left shows sample scores (years) on the first factorial plane, with a time trajectory. The graph to the right shows the corresponding variable loadings.

In the PCA analysis performed only for biological variables, the first two principal components explained 24% and 14% of the variance, respectively. The most important variables in PC1 were benthic fish biomass (mostly flat fishes and ellpout) and biomass of crustaceans, stickleback and polychaetes (both of the variables show contradictory trends). The PC2 are mainly associated with an increase in black gobies and echinoderms and decrease of herring. Time trajectory plot indicate that biota system had to states from one to another between 1990–1992.

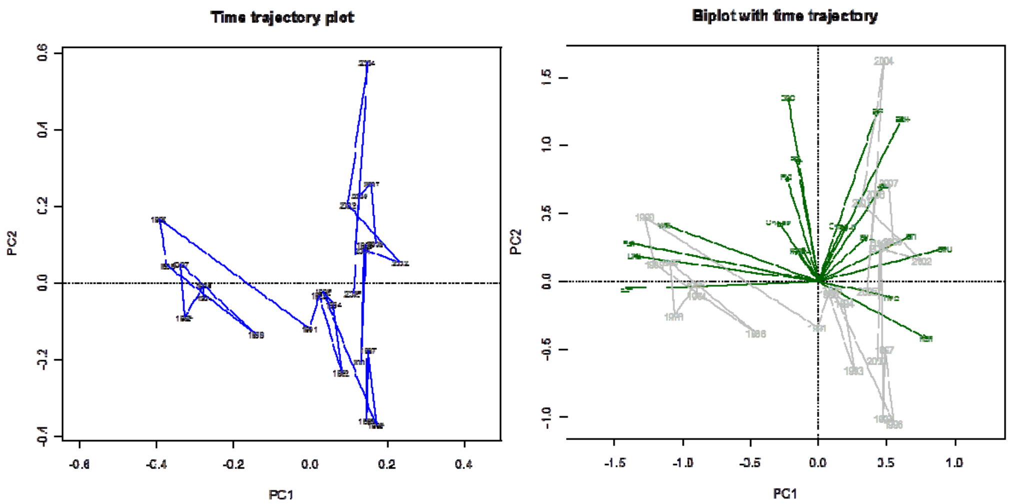

Figure NK-7. Results of the standardized principal component analysis using only biotic variables in the Limfjord (19 variables were included). The graph to the left shows sample scores (years) on the first factorial plane, with a time trajectory. The graph to the right shows the corresponding variable loadings.

STARS applied on $PC1_{all}$ (Figure NK-8) index estimated for Limfiord (cut-of length 8 years with a Huber index of 3) showed two significant shifts in the whole ecosystem (biotic and abiotic) at the beginning of 1990s (1990/1991) and late 1990s (1996/1997). Analysis of $PC1_{biol}$ index showed one strong significant shift in the biota of the Limfiord, indicating pronounced changes in the living part of the Limfjord system and foodweb. The shift occurred in 1991.

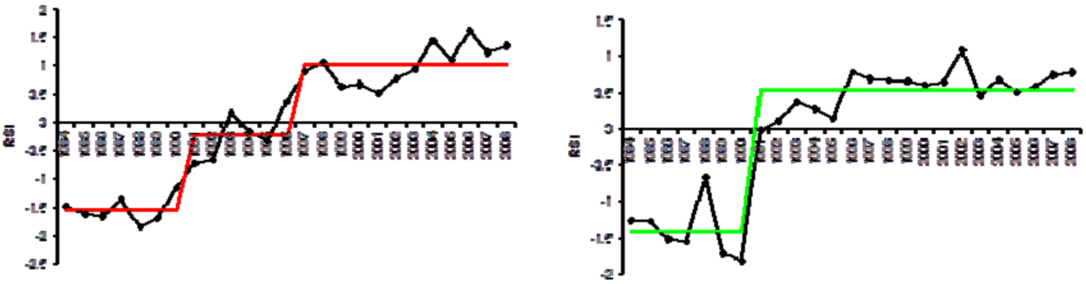

Figure NK-8. Results of STARS analysis on the first principal component based on all variables PC1all (to the left) and biotic variables only PC1biol (to the right) for Limfjord ecosystem.

The constrained hierarchical clustering applied for all dataset identified two periods, 1984–1992 and 1993–2008, which was in line with results from the STARS on PC1all (Figure NK-9). A closer look at Figure NK-9 also indicates two system states (1894–1192 and 1998–2008) with a transitional period between 1993–1997. However, it seems that the transitional period is more associated with the second system state.

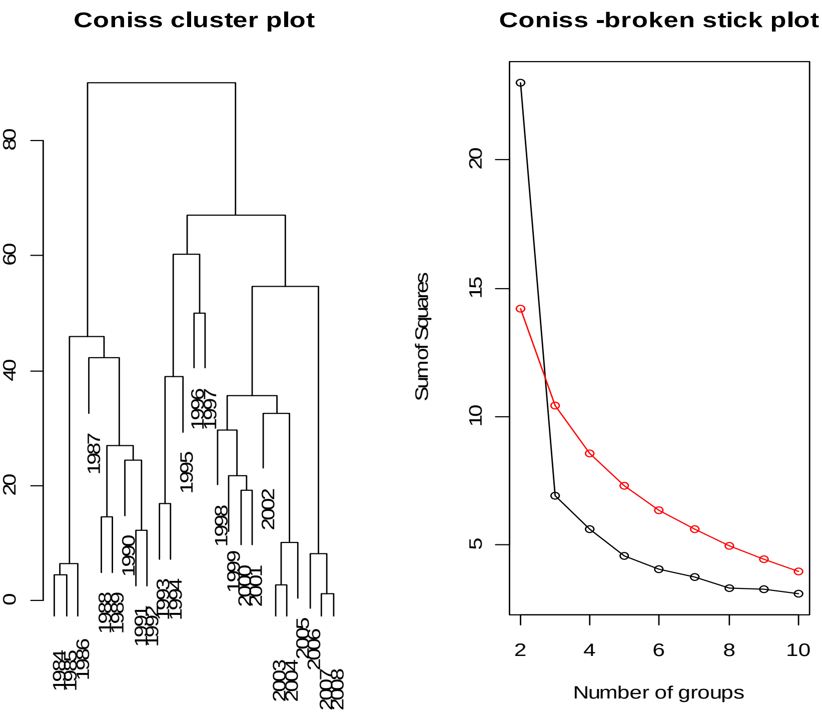

Figure NK-9. Results of the constrained hierarchical clustering analysis for Limfjord.

Table NK-1. Time-series used for the integrated ecosystem analysis in the Limfjord (Denmark).

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/Weblinks
Chlorophyll a, spring	Chla_spr	mg/m3	Logstor Broads	spring	March-May	1984-2007	MADS		**Grete E. Dienesen gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Chlorophyll a, summer	Chla_sum	g/l	Logstor Broads	summer	Jun-Aug	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Hoffmann Jellyfish index	JEL	%	Central Brods, Limfiord	annual		1984-2007	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Sprat	SPR	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Horse mackerel	HMK	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Whiting	WHI	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Dab	DAB	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Eel pout	ELP	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Plaice	PLA	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Herring	HER	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/Weblinks
Flounder	FLO	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Smelt	SML	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Black goby	BGO	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Pipefish	PIP	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Sticklebacks	STI	t*0.5h-1	Logstor Broads	annual		1988-2008	DTU-Aqua		**gdi@aqua.dtu.dk**	DTU-Aqua
Polychaetes	POL	g*m-2	Logstor Broads	annual		1984, 1986-2005	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Molluscans	MOL	g*m-2	Logstor Broads	annual		1984, 1986-2005	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Crustaceans	CRU	g*m-2	Logstor Broads	annual		1987-2005	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Echinoderms	ECH	g*m-2	Logstor Broads	annual		1984, 1986-2005	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/Weblinks
Dissolved inorganic nitrogen, summer	DIN_sum	µmol l-1	Logstor Broads	summer	Jun-Aug	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Dissolved inorganic nitrogen, winter	DIN_win	µmol l-1	Logstor Broads	winter	Dec-Feb	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Dissolved inorganic phosphor, summer	DIP_sum	µmol l-1	Logstor Broads	summaer	Jun-Aug	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Dissolved inorganic phosphor, winter	DIN_win	µmol l-1	Logstor Broads	winter	Dec-Feb	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Bottom oxygen, annual average	O2b_ann		Logstor Broads	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Bottom oxygen, summer	O2b_sum		Logstor Broads	summer	Jun-Aug	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Water column oxygen, annual average	O2wc_ann		Logstor Broads	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/Weblinks
Water column oxygen, summer	O2wc_sum		Logstor Broads	summer	Jun-Aug	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Nitrogen loadings, spring	N_lo_spr	µmol l-1	Logstor Broads	spring	March-May	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Nitrogen loadings, summer	N_lo_sum	µmol l-1	Logstor Broads	summer	Jun-Aug	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Nitrogen loadings, winter	N_lo_win	µmol l-1	Logstor Broads	winter	Dec-Feb	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Phosphor loadings, spring	P_lo_spr	µmol l-1	Logstor Broads	spring	March-May	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Primary production, spring	PP_spr		Logstor Broads	spring	March-May	1984-2003	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Primary production, summer	PP_sum		Logstor Broads	summer	Jun-Aug	1984-2003	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/Weblinks
Salinity, annual average	Sal_ann	psu	Logstor Broads	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Nitrogen total, winter	Ntot_win	µmol l-1	Logstor Broads	winter	Dec-Feb	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Visibility, annual	Vis_ann	m	Logstor Broads	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Sea surface temperature, summer	T_sum	°C	Logstor Broads	summer	Jun-Aug	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Sea surface temperature, winter	T_win	°C	Logstor Broads	winter	Dec-Feb	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Sea surface temperature, spring	T_spr	°C	Logstor Broads	spring	March-May	1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Wind, annual	Wind_ann	m*s-1	Logstor Broads	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	http://www.dmu.dk/vand/havmiljoe/mads/
Mussel yield, landings	Y_mus	ton	Central Brods, Limfiord	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/Weblinks
Decapods yield, landings	Y_cru	ton	Central Brods, Limfiord	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	
Benthic fish yield, landings	Y_ben	ton	Central Brods, Limfiord	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	
Pelagic fish yield, landings	Y_pel	ton	Central Brods, Limfiord	annual		1984-2007	MADS		**gdi@aqua.dtu.dk**	

(Data info and requests to Grete E. Dienesen email: gdi@aqua.dtu.dk or Maciej T. Tomczak maciej.tomczak@stockholmresilience.su.se).

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A4.2. Vendelsö – the eastern Kattegatt coast (Kc)

The Vendeslö 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 mainly 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. This area also serves as a reference are 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 28 variables were considered: 8 physical, 5 nutrient, 8 macro-zoobenthos and 7 fish datasets. No data on phytoplankton, zooplankton and higher trophic levels (i.e. seals and birds) were hence included. The rationale for this was that reliable local information was not available for these variables at the time for the analyses, and corresponding open sea information was not considered representative enough. For the physical and nutrient variables, both coastal (4) and offshore (9) time-series were included. All datasets were compiled to one estimate per year and covered the period 1981–2009.

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

Trend analyses

Hydrography

Variables as temperature, salinity, pH and a proxy for large-scale atmospheric conditions (Arctic Oscillation index, AO) were included 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 was considered on both scales. Since no local data was available, only offshore values of salinity (annual average) and pH (annual average) were used. 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.

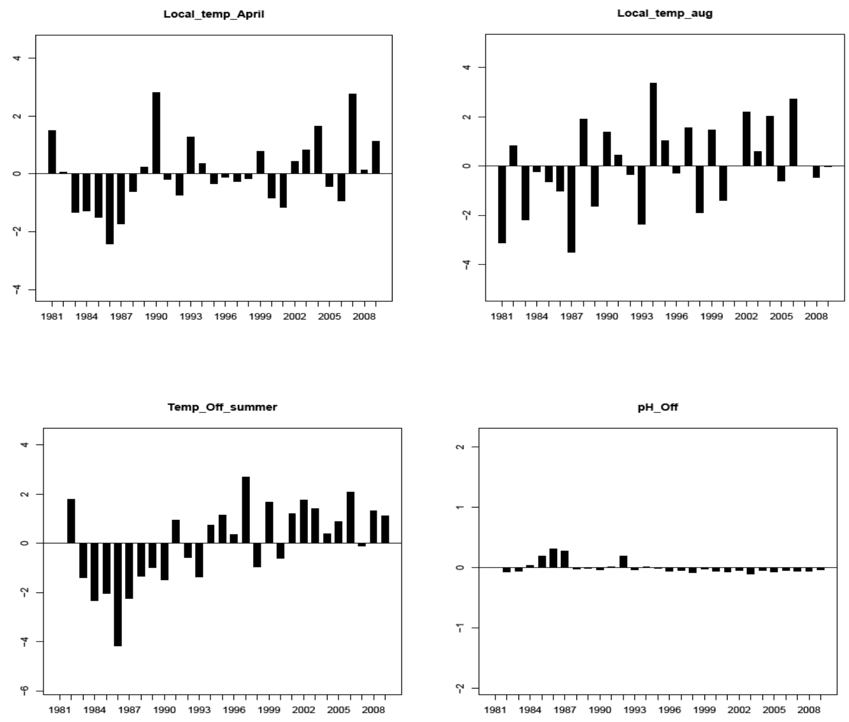

Figure Kc-2. Long-term hydrographic changes in the Vendelsö area: anomalies from the overall mean in temperature (°C) and pH. Local_temp_April denotes local spring temperature (April), Local_temp_aug denotes local summer temperature (August), Temp_off_summer denotes off-shore surface summer temperature (July–September), and pH_Off denotes offshore surface pH (annual).

Nutrients

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

There was an increase in local water transparency and offshore DIP between 1981 and 2009.

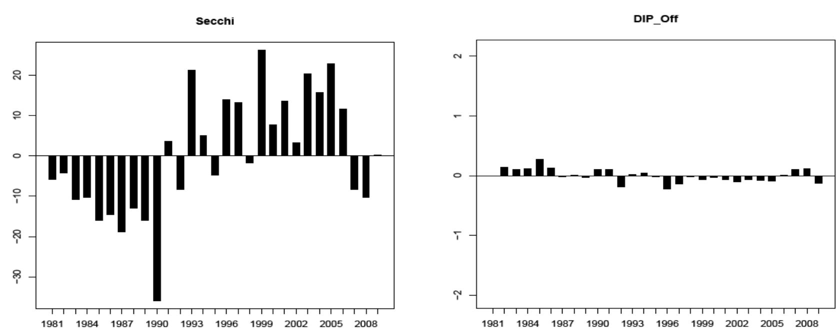

Figure Kc-3. Long-term changes in nutrients in the Vendelsö area. Secchi denotes local water transparency in August, and DIP_Off winter concentration (November–January) of dissolved inorganic phosphorous.

Fishing

As a proxy for fishing pressure the F-based estimate of proportion of 3–5 year old cod in the Kattegat was used. Despite that there has been an overall increase in the fish pressure for cod since the 1970s in this basin (ICES 2010), there is no increase in the variable for the time-period assessed. No local information on fishing pressure was available for the time-period assessed.

Benthos

In all, eight time-series representing the zoobenthic community in Vendeslö was considered. Data on shore crab (*Carcinus maenans*) 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 1981–2009, manifested as a decrease in amphipods (*Amphipoda*), polychaetaes (*Capitellidae* and *Spionidae*), hooded shrimps (*Cumacea*) and bivalves (*Montacutidae*). The only taxonomic group that has increased during the time-preiod assessed is the brittle stars (*Amphiuridae*). Moreover, shorecrab exhibit an almost significant increase between 1981–2009.

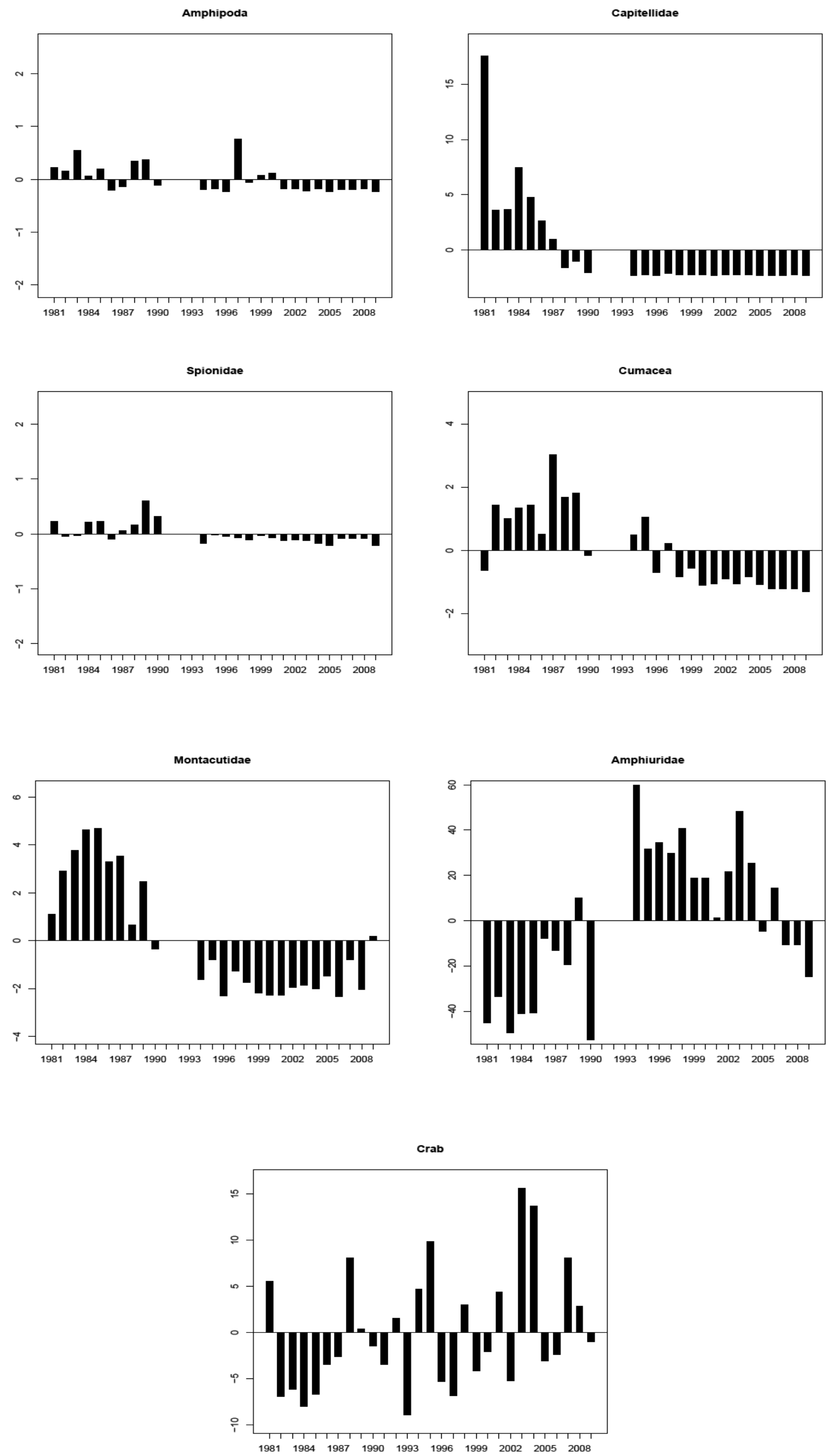

Figure Kc-4. Long-term changes in the abundance of zoobenthos in the Vendelsö area: anomalies from the overall mean in biomass of *Amphipoda*, *Capitellidae*, *Spionidae*, *Cumacea*, *Montacutidae* and *Amphiuridae*. Data for shorecrab (crab) are numbers per night an fyke net.

Fish

The seven time-series included to represent the local fish community was goldsinny wrasse (*Ctenolabrus rupestris*), corkwing wrasse (*Symphodus melops*) and eel (*Anguilla anguilla*) from the August sampling, since these species are more abundant during the warmer season, 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 and shorthorn sculpin between 1981 and 2009.

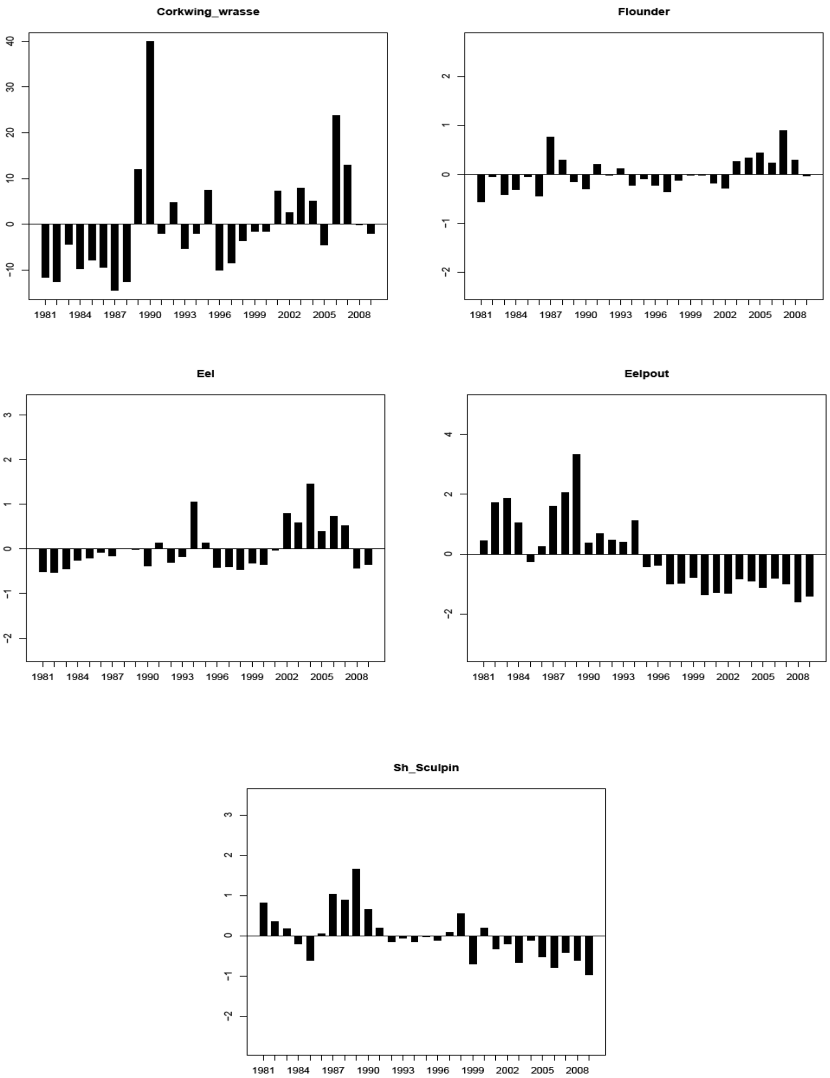

Figure Kc-5. Long-term changes in the abundance of fish in the Vendelsö area: anomalies from the overall mean in numbers per night an fyke net of corkwing wrasse (August sampling), flounder (August sampling), eel (August sampling), eelpout (April sampling) and shorthorn sculpin (Sh_sculpin, April sampling).

Integrated analyses

Biotic and abiotic variables

An overview of the temporal development of the variables in Vendelsö time-series is presented in Figure Kc-6. Variables are sorted according to their PC1 loadings of the subsequently performed PCA, generating a pattern with variables at the bottom that revealed an increasing trend over time (green to red), with the highest values in the recent 14 years, to variables at the top demonstrating the opposite trend (red to green) with the highest values during the 1980s. The first group of variables comprises e.g. the brittle stars (*Amphiuridae*), corkwing wrasse, eel, local and offshore summer temperature as well as local water transparency in August. Decreasing values is observed for the zoobenthos groups hooded shrimps (*Cumacae*), the polychateas (*Spionidae* and *Capitellidae*) and bivalves (*Montacutidae*), as well as shorthorned sculpin, eelpout, pH and dissolved inorganic phosphorous in the off-shore area.

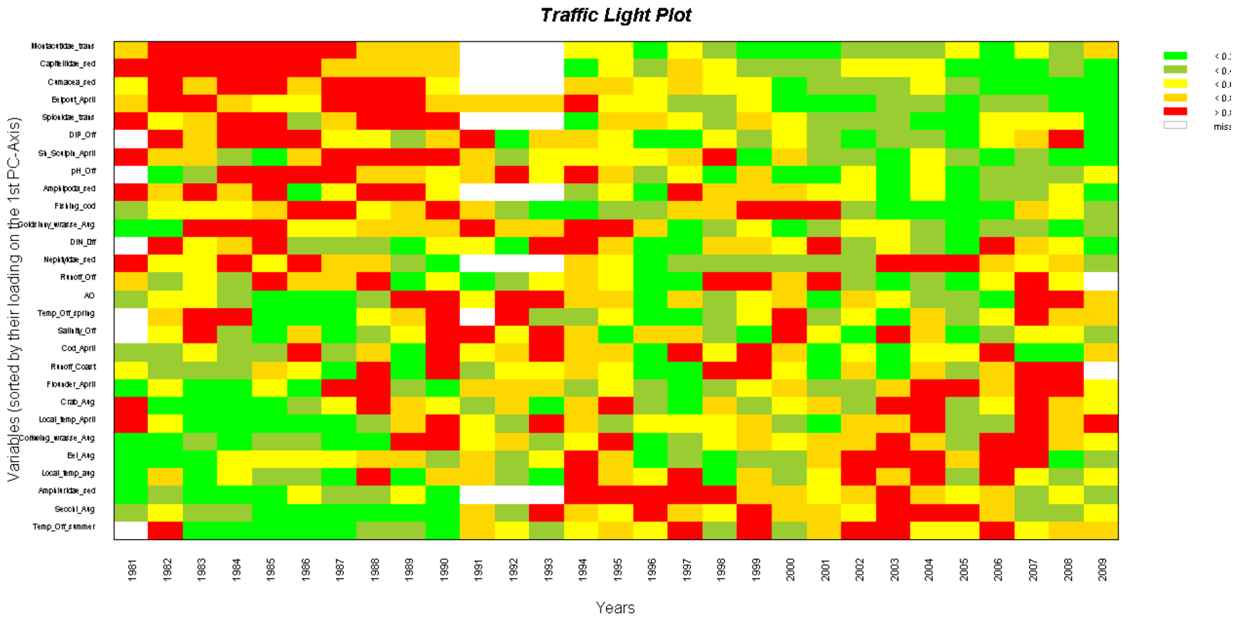

Figure Kc-6. Traffic-light plot of the temporal development of the Vendelsö time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Abbreviations are explained in the table below.

The ordination of yearly measures by a standardized PCA resulted in 26.7 and 11.3% of the explained variance on the first two principal components (PCs; Figure Kc-7). The first PC generally reflects the biotic variables. The years between 1981–1990 generally has positive loadings and is characterised by high biomasses of hooded shrimps (*Cumacae*), the polychateas (*Spionidae* and *Capitellidae*) and bivalves (*Montacutidae*), and abundances of eelpout and shorthorn sculpin (Figure Kc-7). The years 1992–2009 have a negative loading for PC1 and mainly reflect high biomass and abundance of brittle stars and corkwing wrasse respectively. Offshore DIP and pH also had relatively strong positive loadings on PC1, whereas local water transparency in August and offshore summer temperature had negative loadings. The second PC generally reflects abiotic variables such as local (spring) and offshore (summer) temperatures and local nutrient load (Figure Kc-7). The abundance of corkwing wrasse is the only biotic variables associated with this PC. In contrast to the first PC, there is no obvious temporal development of the year scores for this principal component.

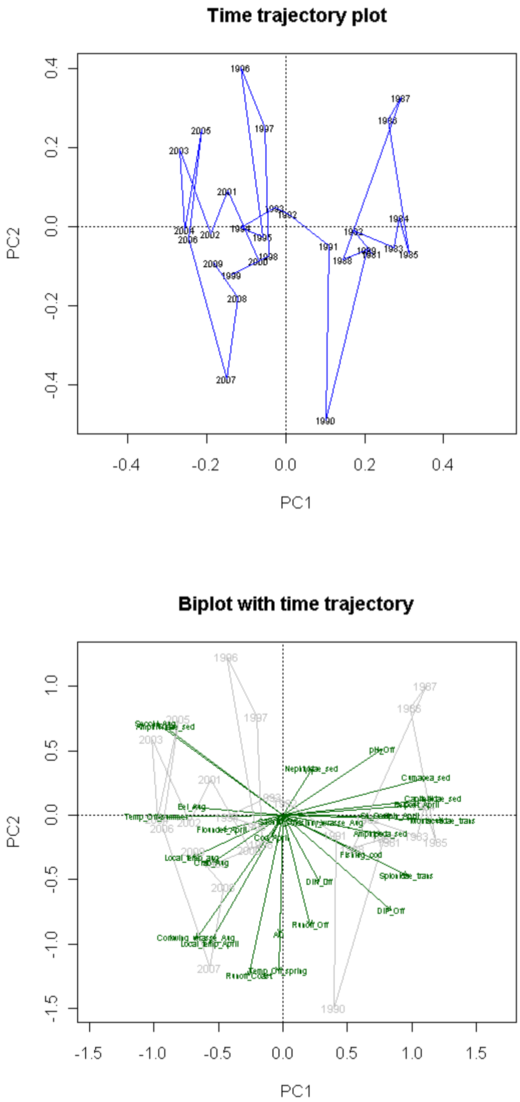

Figure Kc-7. Results of the standardized principal component analysis using all time-series in the Vendelsö area. The upper graph shows sample scores (years) on the first factorial plane, with a time trajectory. The lower graph shows the corresponding variable loadings. PC1 accounted for 26.7 % of the variation and PC2 for 11.3 %.

The two-dimensional, phase space (PC1 vs. PC2) is not readily straight forward, but suggests that changes in ecosystem states most likely occurred in 1995/1996 and 1997/1998 (Figure Kc-7). This was confirmed by Chronological Clustering (CC), which additionally suggested two shifts in the mid-2000s (Figure Kc-8). The two shifts in 1995/1996 and 1997/1998 are likely representing one shift, and are comparably stronger than the ones identified in 2002/2003 and 2005/2006. The signal of change from the biotic variables (1991/1992, PC1) is likely masked by the abiotic variables in the combined analysis.

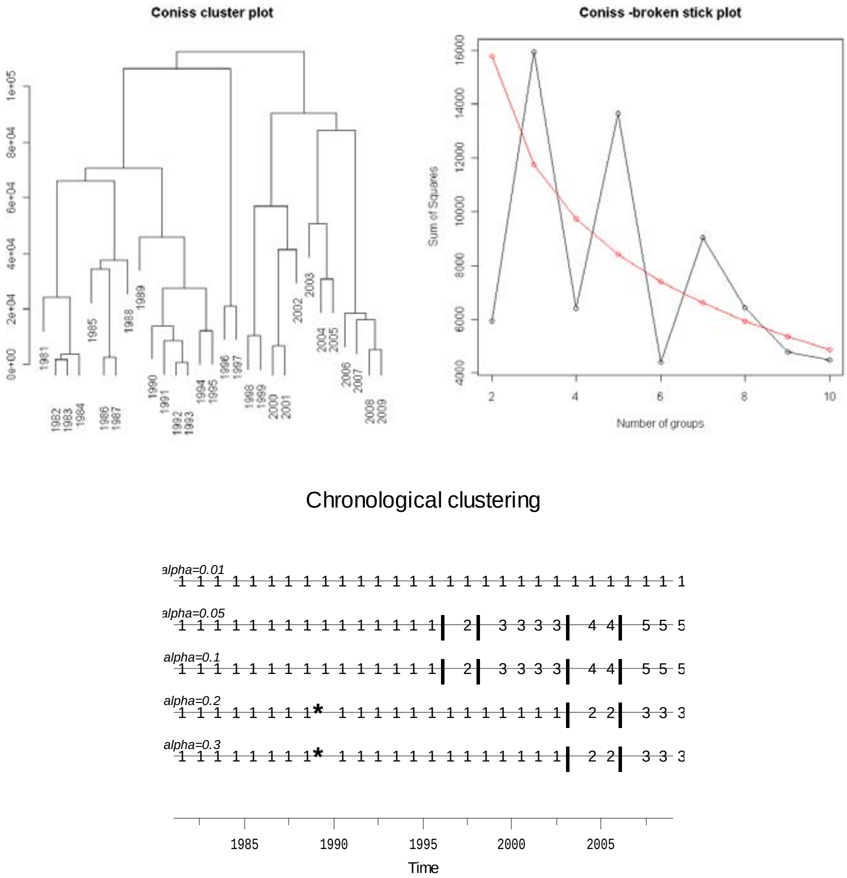

Figure Kc-8. Results of the discontinuity analysis (above constrained clustering, below chronological clustering) performed on all variables.

Biotic variables

The temporal development of the biota in Vendelsö follows what is seen for the data set including all variables (PCs; Figure Kc-9). *Amphiuridae* (brittle stars), eel and corkwing wrasse has increased, whereas the zoobenthos groups *Cumacae* (small crustaceans), *Spionidae* (ploychaetaes), *Capitellidae* (ploychaetaes) and *Montacutidae* (bivalve), as well as shorthorned sculpin, and eelpout have decreased.

The two first components of the ordination of yearly measures by a standardized PCA together explained much more compared to the all variables data set, 36.7 and 12.5 % respectively (Figure Kc-9), suggesting that the abiotic variables included only explained a fraction of the temporal development of the studied trophic levels. As for the all data set, year scores of PC1 displayed a gradual change from positive to negative values over the time period considered (PCs; Figure Kc-9), where the years before 1992 generally had positive values and those after 1992 negative values. Indicative for this component were the zoobenthos amphipods (*Amphipoda*), polychaetaes (*Capitellidae* and *Spionidae*), hooded shrimps (*Cumacea*) and bivalves (*Montacutidae*), as well as eelpout and shorthorn sculpin (PCs; Figure Kc-9). The second PC showed a more fluctuating development, and was mainly influenced by eel and goldsinny wrasse.

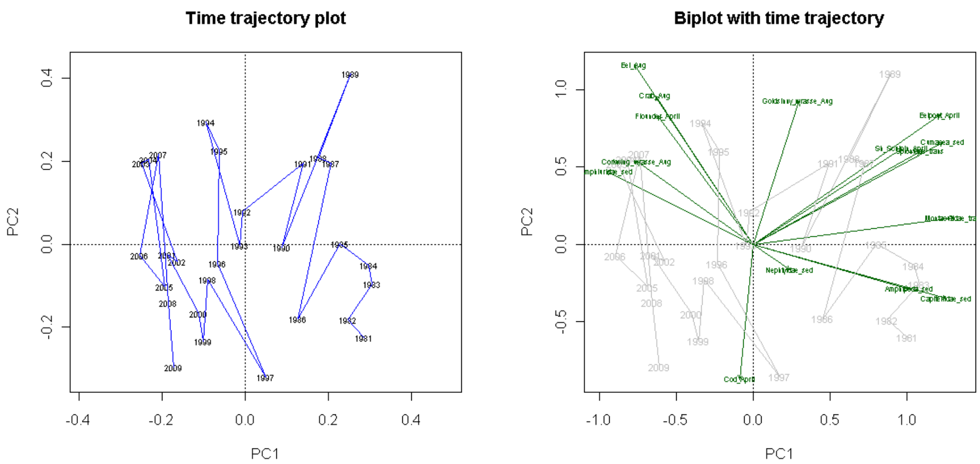

Figure Kc-9. Results of the standardized principal component analysis using only biotic time-series in the Vendelsö area. The left graph shows sample scores (years) on the first factorial plane, with a time trajectory. The right graph shows the corresponding variable loadings. PC1 accounted for 36.7 % of the variation and PC2 for 12.5 %.

The two-dimensional, phase space (PC1 vs. PC2) suggests that the main change in the ecosystem state most likely occurred in 1990/1991 (Figure Kc-9). This was confirmed by Chronological Clustering (CC), additionally identifying a shift in 2006/2007 (Figure Kc-10).

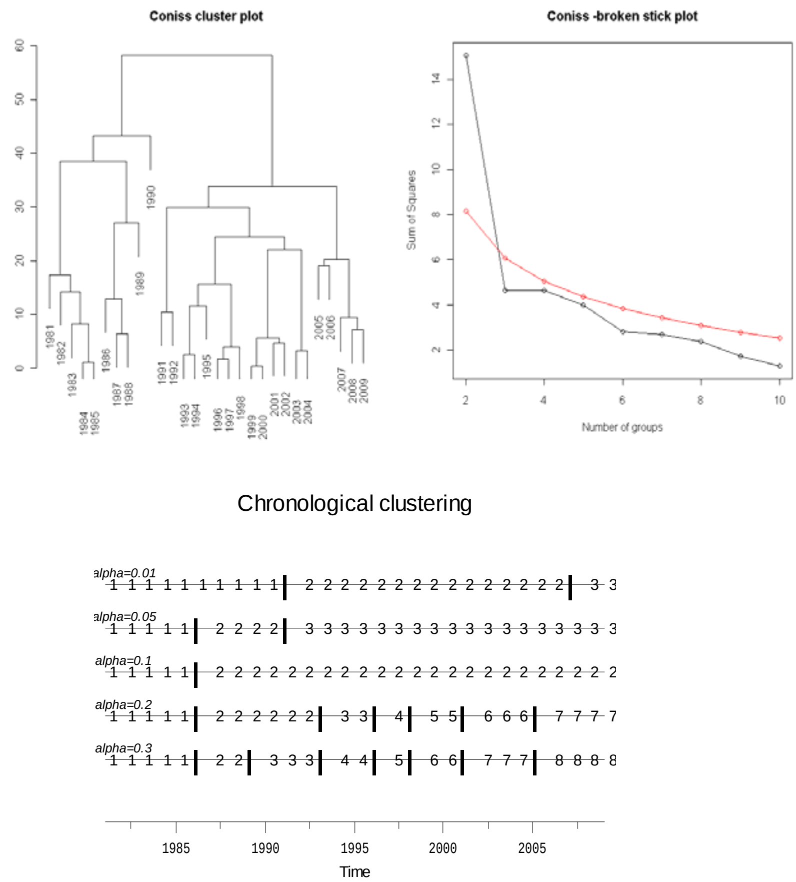

Figure Kc-10. Results of the discontinuity analysis (above constrained clustering, below chronological clustering) performed on biotic variables.

Based on these preliminary analyses, it is obvious that there has been a transition of the abiotic environment in the Vendelsö area, from a period before the early/ mid-1990s with higher nutrient levels and lower water temperatures to a period with decreased nutrient levels and increased temperatures. The change of the fish community has generally responded to the change in temperature regime, with a decrease in species favoured by lower water temperatures such as eelpout and shorthorn sculpin, to species favoured by increased temperatures such as eel, corkwing wrasse and flounder. The increase in smallbodied species like wrasses might also be accompanied by predatory release via the collapse in the offshore stock of cod (Eriksson *et al.*, in revision). Some of the species representing the four groups of zoobenthos (*Cumacae*, *Spionidae*, *Capitellidae* and *Montacutidae*) having high abundances during the early period are acknowledged to be more tolerant to eutrpohic conditions, and a potential link to abiotic drivers might be the comparably higher DIP during and reduced water transparency during recent years.

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Table Kc-1. Time-series used for the integrated ecosystem analysis in Vendelsö.

Variable	Acronym	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	Weblinks
biotic										
Amphipoda	Amphipoda_sed	g*m-2	Vendelsö	Spring	April-June	1981-2009	SBF	Grab Sampler	AG/JO	www.fiskeriverket.se
Amphiuridae	Amphiuridae_sed	g*m-2	Vendelsö	Spring	April-June	1981-2009	SBF	Grab Sampler	AG/JO	www.fiskeriverket.se
Capitellidae	Capitellidae_sed	g*m-2	Vendelsö	Spring	April-June	1981-2009	SBF	Grab Sampler	AG/JO	www.fiskeriverket.se
Cumacea	Cumacea_sed	g*m-2	Vendelsö	Spring	April-June	1981-2009	SBF	Grab Sampler	AG/JO	www.fiskeriverket.se
Nephtyidae	Nephtyidae_sed	g*m-2	Vendelsö	Spring	April-June	1981-2009	SBF	Grab Sampler	AG/JO	www.fiskeriverket.se
Montacutidae	Montacutidae_trans	g*m-2	Vendelsö	Spring	April-June	1981-2009	SBF	Grab Sampler	AG/JO	www.fiskeriverket.se
Shore crab (*Carcinus maenans)*	Crab_Aug	CPUE (abundance)	Vendelsö	Summer	August	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
Goldsinny wrasse (*Ctenolabrus rupestris*)	Goldsinny_ wrasse_Aug	CPUE (abundance)	Vendelsö	Summer	August	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
Corkwing wrasse (*Symphodus melops*)	Corkwing_wrasse_Aug	CPUE (abundance)	Vendelsö	Summer	August	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
Eel (*Anguilla anguilla)*	Eel_Aug	CPUE (abundance)	Vendelsö	Summer	August	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
Flounder *(Platichtys flesus)*	Flounder_ April	CPUE (abundance)	Vendelsö	Spring	April	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
Eelpout (*Zoarces vivparous*)	Eelpout_ April	CPUE (abundance)	Vendelsö	Spring	April	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
Cod (Gadus morhua)	Cod_April	CPUE (abundance)	Vendelsö	Spring	April	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
Shorthorn sculpin (*Myxocephalus scorpio*)	Sh_Sculpin_April	CPUE (abundance)	Vendelsö	Spring	April	1981-2009	SBF	Fyke net	AG/JO	www.fiskeriverket.se
abiotic/environmental										
Water transparency	Secchi_Aug	meters	Vendelsö	Summer	August	1981-2009	SBF	Secchi depth	AG/JO	www.fiskeriverket.se
Coastal temperature in summer	Local_temp_aug	degrees C	Vendelsö	Summer	August	1981-2009	SBF	Water sample	AG/JO	www.fiskeriverket.se
Coastal temperature in Spring	Local_temp_April	degrees C	Vendelsö	Spring	April	1981-2009	SBF	Water sample	AG/JO	www.fiskeriverket.se
Local nitrogen loading	Runoff_Coast	tonnes	Local county, Halland (N)	Annual	NA	1981-2009	SLU	Water sample	AG/JO	www.slu.se
Offshore surface temperature, spring	Temp_Off_spring	degrees C	412 (Anholt E)	Spring	April-May	1981-2009	SMHI	Water sample	AG/JO	www.smhi.se
Offshore surface temperature, summer	Temp_Off_summer	degrees C	412 (Anholt E)	Summer	Jul-Sep	1981-2009	SMHI	Water sample	AG/JO	www.smhi.se
Offshore salinity surface	Salinity_Off	psu	412 (Anholt E)	Annual	NA	1981-2009	SMHI	Water sample	AG/JO	www.smhi.se
pH	pH_Off	-	412 (Anholt E)	Annual	NA	1981-2009	SMHI	Water sample	AG/JO	www.smhi.se
Dissolevd inorganic nitrogen	DIN_Off	mmol*l-1	412 (Anholt E)	Winter	Nov-Jan	1981-2009	SMHI	Water sample	AG/JO	www.smhi.se
Dissolevd inorganic phosphorous	DIP_Off	mmol*l-1	412 (Anholt E)	Winter	Nov-Jan	1981-2009	SMHI	Water sample	AG/JO	www.smhi.se
Regional nitrogen loading	Runoff_Off	tonnes	Kattegatt, M-,N-, & O-county	Annual	NA	1981-2009	SLU	Water sample	AG/JO	www.slu.se
Fishing index, F 3-5 years	Fishing_cod	-	Kattegatt (SD 21)	Annual	NA	1981-2009	ICES (WGBF	see text	AG/JO	www.ices.dk
Arctic Oscillation Index	AO	-	Global	Winter	Dec-March	1981-2009	NOAA	NA	AG/JO	www.cpc.ncep.noaa.gov

A4.3. Gulf of Gdansk (GG)

Located in the southern part of the Baltic Sea, the Gulf of Gdansk is a part of the larger Gdansk Basin (Figure GG-1). 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 to the Gulf and one of the most important sources for the Baltic Proper as it drains the substantial part of Poland.

Due to the large investments in water treatment plants during the last decade as well as the implementation of the Common Agricultural Policy the sanitary conditions improved and nutrient loads were significantly reduced. The improvement is apparent especially in the coastal waters even they are still under the considerable anthropogenic pressure. Eutrophication is still regarded as one of the major problems of the Gulf with content of organic matter in the sediments, relatively low Secchi depth and low oxygen content in the deeper near-bottom layers.

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 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.

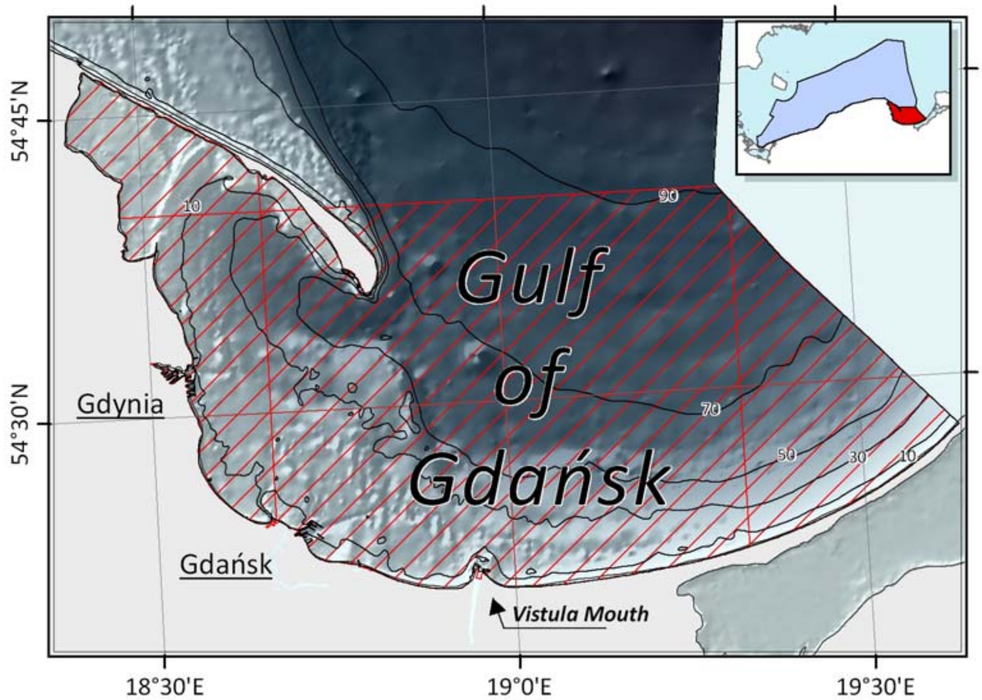

Figure GG-1. The Gulf of Gdansk with the shaded area included in the analysis.

Trend analyses

In total, 33 variables were considered: 9 physical, 7 nutrient, 6 phytoplankton, 8 fish and fishery-related datasets and 3 others (BSI, chlorophyll *a*, primary production). Data series were compiled to one estimate per year for the area of interest. Overall common data coverage was 1994–2010, with several gaps that were replaced by means or nearby values. Primarily we were looking for data after 1987, therefore most data series begin that time.

The hydrological data covered the years 1987–2010; nutrient data 1994–2010 (without 2 years in between); primary production 1987–2010 (without 3 years in between); phytoplankton data 1987–2009 (without 7 years in between); chlorophyll *a* and Secchi depth data covered the years 1987–2010 without 2 missing years of data; Baltic Sea Index 1987–2009. Fish CPUE data covered the time: 1991–2010 and fish landings data 1987–2009 (without 2 years in between).

In the next attempt the existing data series should be completed and if it is possible, time-series range will be broaden. We will also try to incorporate zoobenthos, zooplankton and normalized run-off (for Vistula river) data into the IEA analysis.

Moreover, to improve the analysis it would be important to include other fish data, for species more typical to the coastal and estuary ecosystem of the Gulf of Gdańsk than to the whole area of the southern Baltic Sea.

Hydrography

No clear trends were recognized for most of the hydrological variables. Only am increasing trend for sea surface salinity in summer and a decreasing trend for near-bottom oxygen concentration have been observed.

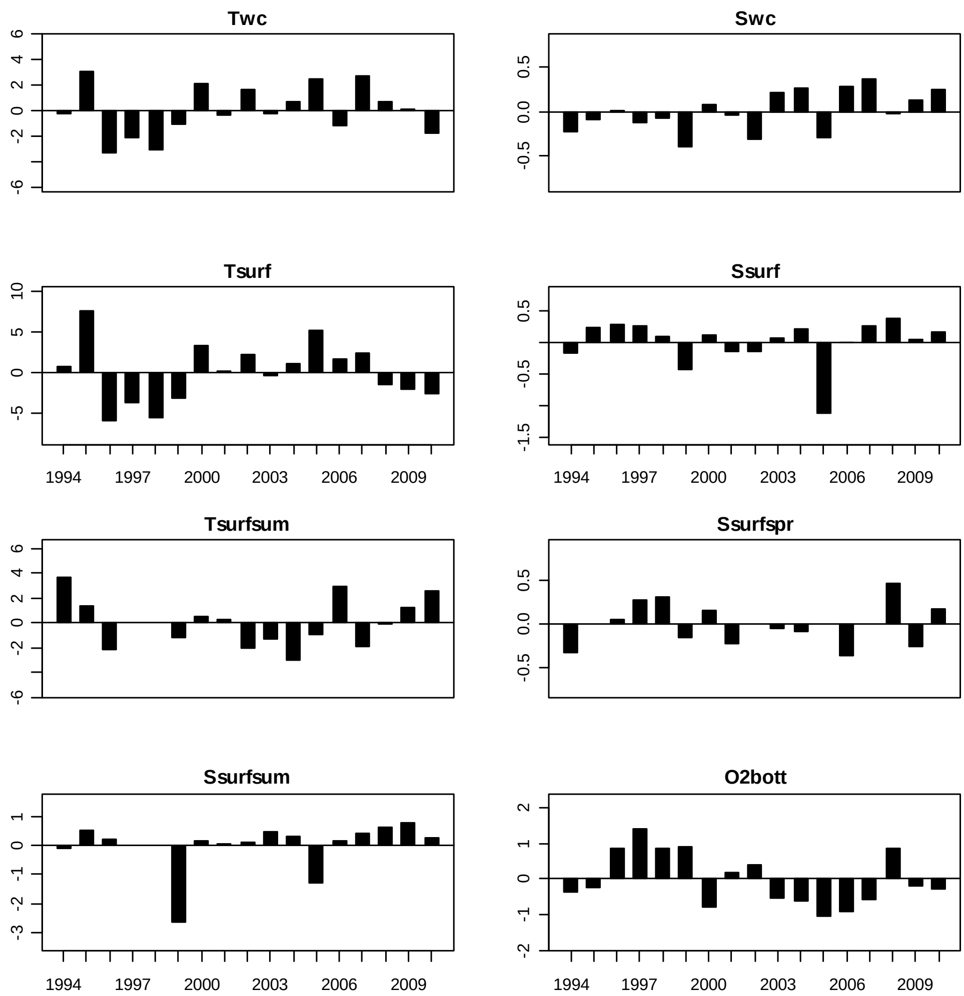

Figure GG-2. Long-term hydrographic changes in the Gulf of Gdansk: anomalies of the overall mean presented for Temperature water column (°C) Salinity water column (psu), Sea surface temperature (°C) and Sea surface salinity (psu) Sea surface temperature summer (°C) and Sea surface salinity spring (psu), Sea surface salinity summer (psu) and near-bottom oxygen ($ml*l^{-1}$). [Presented from top left to bottom right]

Nutrients

No clear trends were recognized for most of the nutrient time-series. Only a decreasing trend for the water column dissolved inorganic nitrogen has been observed.

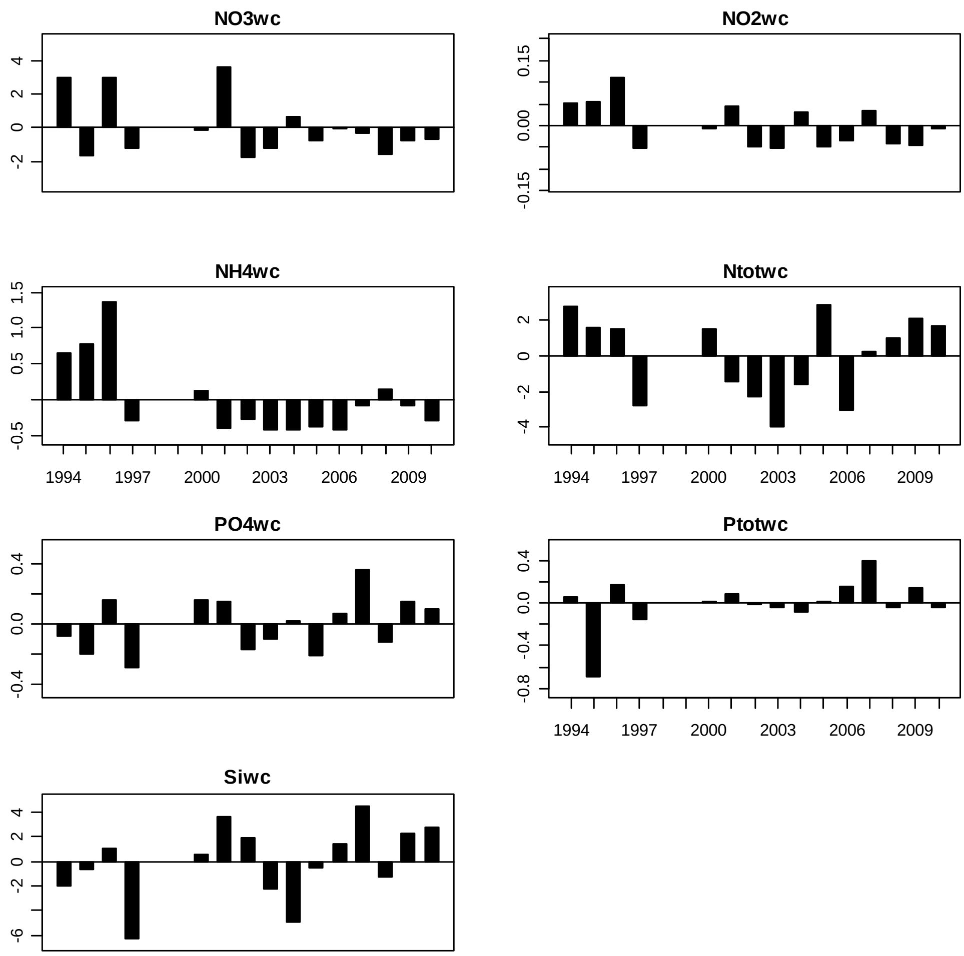

Figure GG-3. Long-term changes in the Gulf of Gdansk: anomalies of the overall mean presented for Dissolved inorganic nitrogen – NO3-N, Dissolved inorganic nitrogen – NO2-N, Dissolved inorganic nitrogen – NH4-N, Total nitrogen, Dissolved inorganic phosphorus – PO4-P, Total phosphorus, Silicate (all nutrients are given in μmol*l^{-1}). [Presented from top left to bottom right]

Phytoplankton

No clear trends were recognized for phytoplankton groups.

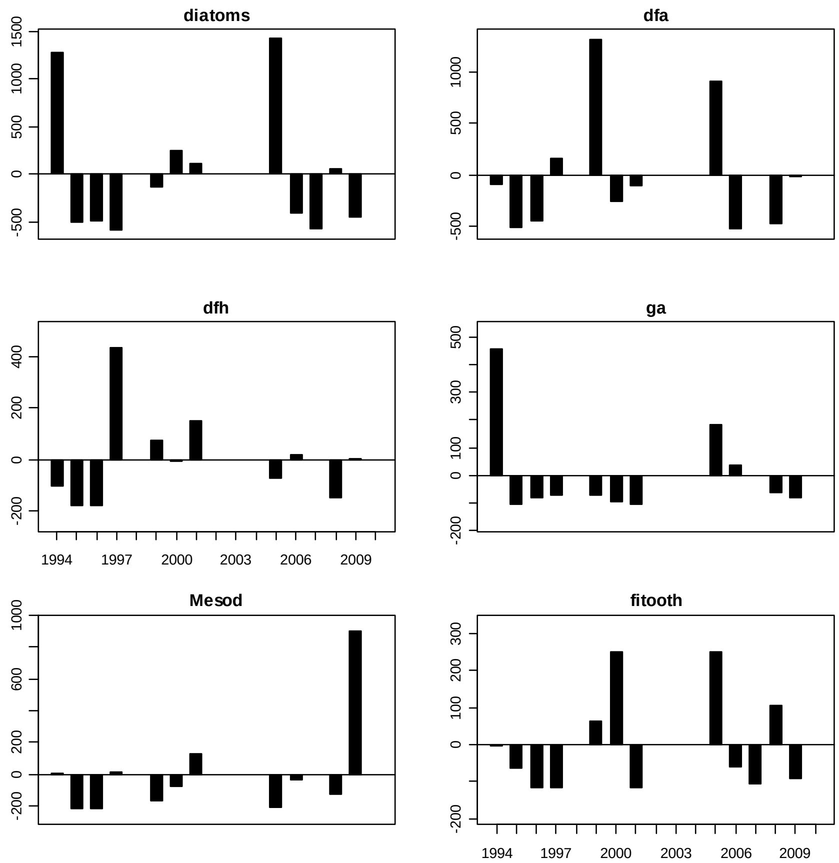

Figure GG-4. Long-term changes in the Gulf of Gdansk: anomalies of the overall mean presented for diatoms, autotrophic dinoflagellates, heterotrophic dinoflagellates, green algae, *Mesodinium rubrum*, other phytoplankton (all phytoplankton groups given at μg*l^{-1}). [Presented from top left to bottom right]

Fish

Fish related data set was divided for two subsets : index of biomass represent as CPUE from local BITS surveys (Figure GG-5). Positive trends in biomass have been found for cod and sprat and a negative trend was observed for herring. The data on flat fish biomass need to be revised due to extremely high values for year 2007. Subset of data related to fisheries, represented by landings showed clear decrease in landings of cod and flat fishes and an increase in sprat landings (Figure GG-6).

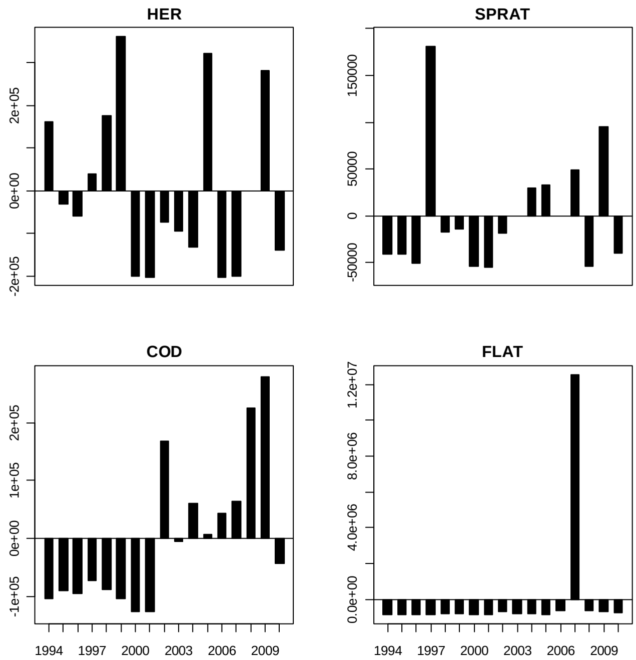

Figure GG-5. Long-term changes in the Gulf of Gdansk: anomalies of the overall mean presented for CPUE of Herring, Sprat, Cod and Flat fishes (all groups given at kg/h). [Presented from top left to bottom right]

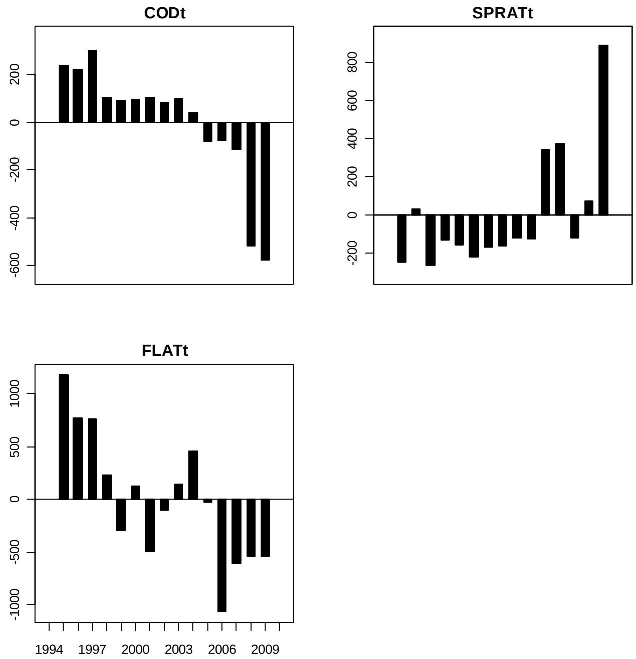

Figure GG-6. Long-term changes in the Gulf of Gdansk: anomalies of the overall mean presented for landings of Cod, Sprat and Flat fishes (all groups given at tones). [Presented from top left to bottom right]

Other variables

For the given time period only a clear increasing trend have been observed in PP time-series.

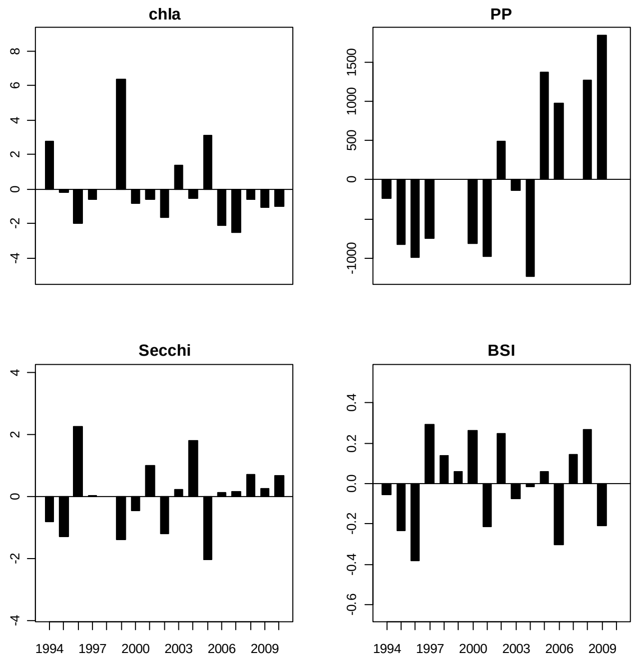

Figure GG-7. Long-term changes in the Gulf of Gdansk: anomalies of the overall mean presented for Chlorophyll a (mg*m^{-3}), Primary production (mgC*m^{-2}*d^{-1}), Secchi depth (m) and Baltic Sea Index. [Presented from top left to bottom right]

Integrated analyses

The period 1994–2010 was included in the integrated analysis with 33 variables. The variables which had high values in the beginning of the period but decreased towards the end of the 2010s were e.g. landings of cod, landings of flatfishes, and chlorophyll *a*. The variables which showed an increasing trend with time were e.g. landings of herring, Baltic Sea Index and flat fishes groups.

Separate runs for biotic variables have not been done.

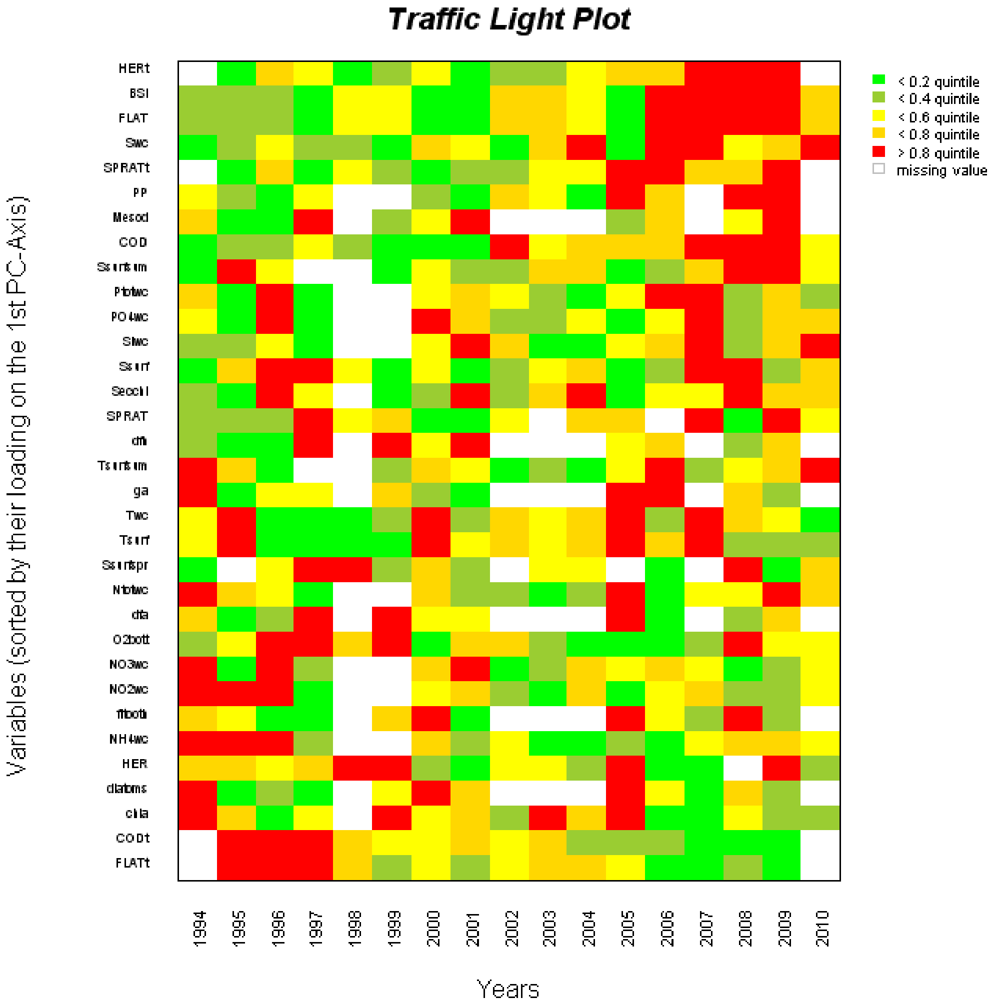

Figure GG-8. Traffic-light plot of the temporal development of the Gulf of Gdansk time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in Table GG-1.

In the PCA analysis, the first two principal components explained 22% and 17% of the variance, respectively. The most important variables in PC1 were landings of all included fish species and BSI. The time trajectory plot indicates that the system move from one to another state with a transition period of 2004–2006.

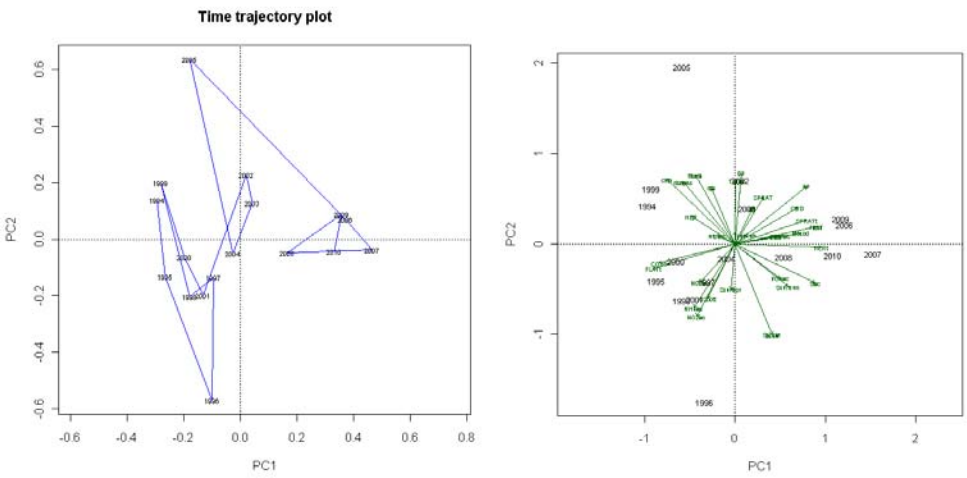

Figure GG-9. Results of the standardized principal component analysis using all 33 variables in the Gulf of Gdansk. The graph to the left shows sample scores (years) on the first factorial plane, with a time trajectory. The graph to the right shows the corresponding variable loadings.

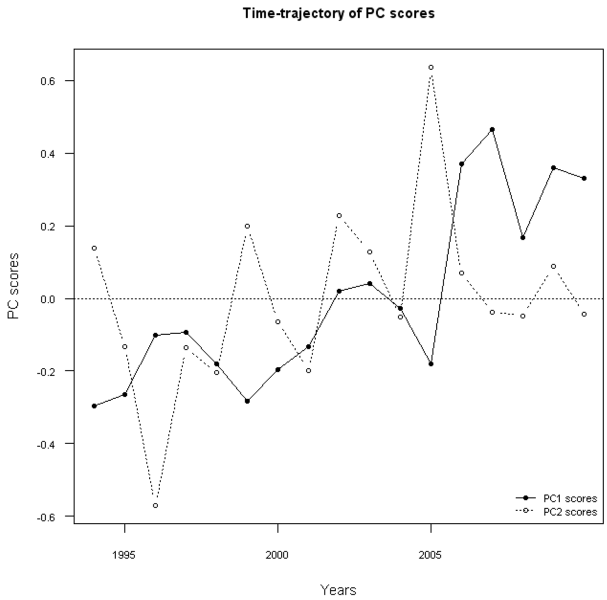

Figure GG-10. Results of the standardized principal component analysis using the 33 variables for the Gulf of Gdansk PC1 (black circles) and PC2 scores (white circles) against time.

The result of the STARS on PC1 estimated on all variables indicate a shift in 2005. At PC2 no significant shift has been found.

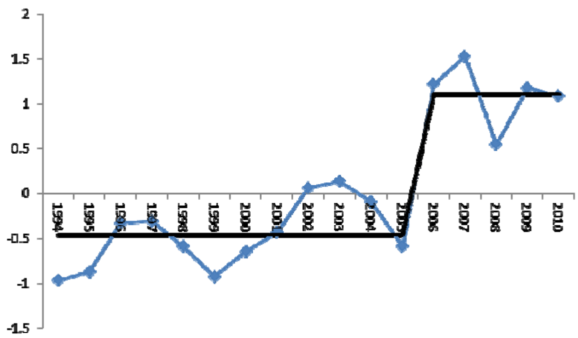

Figure GG-11. Results of STARS analysis on the first principal component based on all variables (Shifts in the mean for PC1, 1994–2010 Probability = 0.05, cutoff length = 8, Huber parameter =3).

The constrained hierarchical clustering indicates that there might be a shift in 1999/2000, and in 2001/2002.

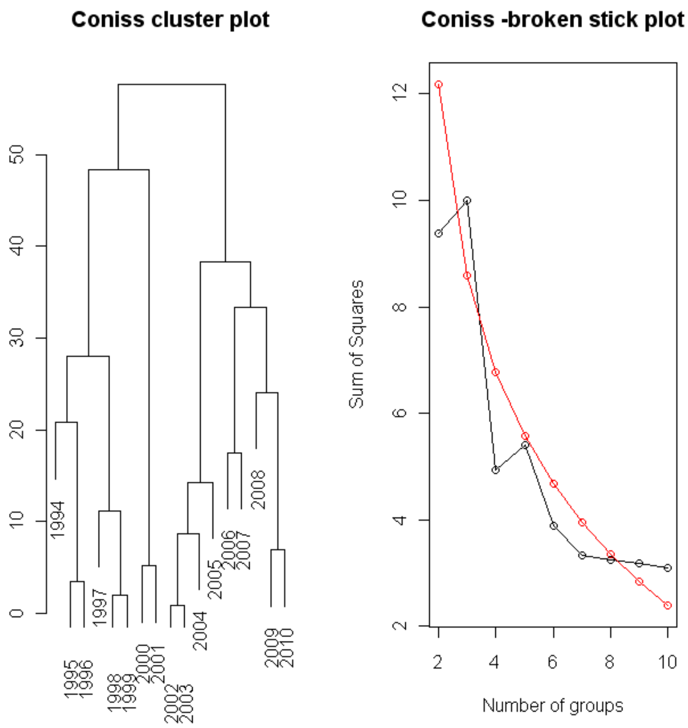

Figure GG-12. Results of the constrained hierarchical clustering analysis (to be used as basis for text preparation – may not be included in final report).

Table GG-1. Time-series used for the integrated ecosystem analysis in Gulf of Gdansk.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/ Gear	Contact	References/ Weblinks
Water column temperature	Twc	°C	Gulf of Gdańsk	Annual		1987-2010	SFI			SFI in Gdynia
Water column salinity	Swc	psu	Gulf of Gdańsk	Annual		1987-2010	SFI			SFI in Gdynia
Sea surface temperature	Tsurf	°C	Gulf of Gdańsk	Annual		1987-2010	SFI			SFI in Gdynia
Sea surface salinity	Ssurf	psu	Gulf of Gdańsk	Annual		1987-2010	SFI			SFI in Gdynia
Sea surface temperature	Tsurfsum	°C	Gulf of Gdańsk	Summer		1987-2010	SFI			SFI in Gdynia
Sea surface salinity	Ssurfspr	psu	Gulf of Gdańsk	Spring		1987-2010	SFI			SFI in Gdynia
Sea surface salinity	Ssurfsum	psu	Gulf of Gdańsk	Summer		1987-2010	SFI			SFI in Gdynia
Near-bottom oxygen	O2bott	ml*l-1	Gulf of Gdańsk	Annual		1987-2010	SFI			SFI in Gdynia
Chlorophyll a	chla	mg*m-3	Gulf of Gdańsk	Annual		1987-1989 1991-1997 1999-2010	SFI			SFI in Gdynia
Primary production	PP	mgC*m-2*d-1	Gulf of Gdańsk	Annual		1987-1989 1991-1997 2000-2010	SFI			SFI in Gdynia

Secchi depth	Secchi	m	Gulf of Gdańsk	Annual		1987-1989 1991-1997 1999-2010	SFI			SFI in Gdynia
Baltic Sea Index	BSI		Central Baltic	Winter		1987-2009	IFM			
Dissolved inorganic nitrogen – NO3-N	NO3wc	µmol*l-1	Gulf of Gdańsk	Annual		1994-1997 2000-2010	SFI			SFI in Gdynia
Dissolved inorganic nitrogen – NO2-N	NO2wc	µmol*l-1	Gulf of Gdańsk	Annual		1994-1997 2000-2010	SFI			SFI in Gdynia
Dissolved inorganic nitrogen – NH4-N	NH4wc	µmol*l-1	Gulf of Gdańsk	Annual		1994-1997 2000-2010	SFI			SFI in Gdynia
Total nitrogen	Ntotwc	µmol*l-1	Gulf of Gdańsk	Annual		1994-1997 2000-2010	SFI			SFI in Gdynia
Dissolved inorganic phosphorus – PO4-P	PO4wc	µmol*l-1	Gulf of Gdańsk	Annual		1994-1997 2000-2010	SFI			SFI in Gdynia
Totall phosphorus	Ptotwc	µmol*l-1	Gulf of Gdańsk	Annual		1994-1997 2000-2010	SFI			SFI in Gdynia
Silicate	Siwc	µmol*l-1	Gulf of Gdańsk	Annual		1994-1997 2000-2010	SFI			SFI in Gdynia
Diatoms	diatoms	µg*l-1	Gulf of Gdańsk	Annual		1987-1988 1992-1997 1999-2001 2005-2009	SFI			SFI in Gdynia
Autotrophic Dinoflagellates	dfa	µg*l-1	Gulf of Gdańsk	Annual		1987-1988 1992-1997 1999-2001 2005-2009	SFI			SFI in Gdynia

Heterotrophic Dinoflagellates	dfh	µg*l-1	Gulf of Gdańsk	Annual		1987-1988 1992-1997 1999-2001 2005-2009	SFI			SFI in Gdynia
Green algae	ga	µg*l-1	Gulf of Gdańsk	Annual		1987-1988 1992-1997 1999-2001 2005-2009	SFI			
Mesodinium rubrum	Mesod	µg*l-1	Gulf of Gdańsk	Annual		1987-1988 1992-1997 1999-2001 2005-2009	SFI			
Other Phytoplankton	fitooth	µg*l-1	Gulf of Gdańsk	Annual		1987-1988 1992-1997 1999-2001 2005-2009	SFI			
Herring CPUE	HER	kg*h (of catch)	Gulf of Gdańsk	Annual		1991-2010	ICES			
Sprat CPUE	SPRAT	kg*h (of catch)	Gulf of Gdańsk	Annual		1991-2010	ICES			
Cod CPUE	COD	kg*h (of catch)	Gulf of Gdańsk	Annual		1991-2010	ICES			
Flat fishes CPUE	FLAT	kg*h (of catch)	Gulf of Gdańsk	Annual		1991-2010	ICES			
Cod landings	CODt	Tonnes	Gulf of Gdańsk	Annual		1987-1990 1992-1993 1995-2009	Polish FMC /SFI			
Sprat landings	SPRATt	Tonnes	Gulf of Gdańsk	Annual		1987-1990 1992-1993 1995-2009	Polish FMC /SFI			

Herring landings	HERt	Tonnes	Gulf of Gdańsk	Annual		1987-1990 1992-1993 1995-2009	Polish FMC /SFI			
Flat fishes landings	FLATt	Tonnes	Gulf of Gdańsk	Annual		1987-1990 1992-1993 1995-2009	Polish FMC /SFI			

(Data info and requests to Lena Szymanek lena@mir.gdynia.pl or Piotr Margonski pmargon@mir.gdynia.pl)

A4.4. Curonian and Vistula Lagoons (CL)

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

Table CL-1. Characteristics of the Curonian and Vistula Lagoons.

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

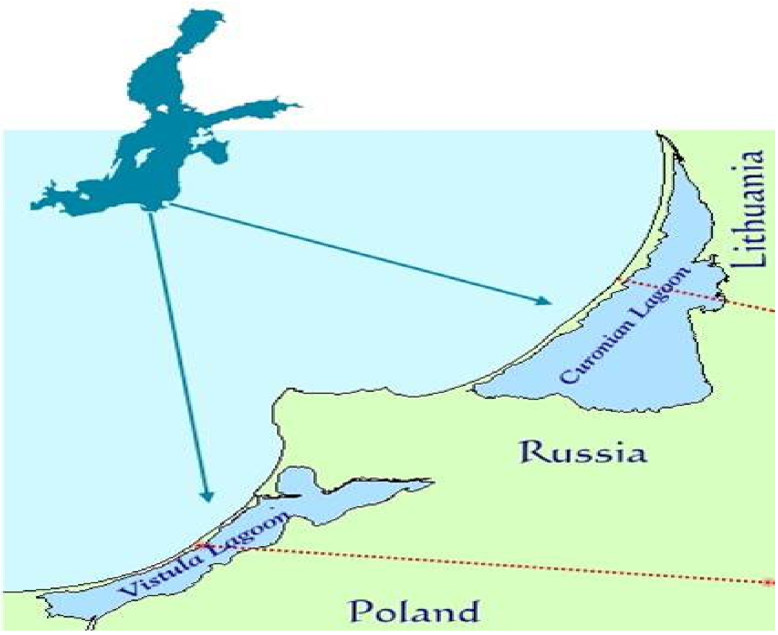

Figure CL-1. Map of the location of the Curonian and Vistula lagoons.

Data collection in these areas started many years ago and standard data are available since 1992. Two bottom surveys and one young fish survey usually carried out each year (Table CL-2).

Table CL-2. Specification of the fish surveys in the Lagoons.

	Trawl surveys	Trawl surveys	Young fish surveys	Ichtioplancton surveys
Where?	C.l. 12 stations V.l.9 stations	C.l. 14 stations V.l.9 stations	C.l. 14 stations V.l.9 stations	V.l.10 stations
Fishing gear	Bottom trawl, 23m Mesh-size 12 mm	Bottom trawl, 23m Mesh-size 12 mm	Pelagic trawl, 7m Mesh-size 0.5 mm	Ichtioplancton net, 5 m, opening0.8 m
When ?	October November	October November	August-October May-June November	April - June
Main objectives	Fish community, Stock assessment	Fish community, Recruitment	Year-class strength Rectuitment	Year-class strength Rectuitment
What is estimated?	Fish abundance, Length, weight, Age, matur.	Fish abundance, Length, weight, Age, matur.	Fry abundance, length, weight	Larvae bundance, Length, weight

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, ruffe, and establishment of quota for each species.

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

The fish monitoring is conducted till now with the same fishing gears at the same locations. 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 Curonian and Vistula Lagoons.

A4.5. Coastal Gulf of Riga (GoRc)

Coastal fish data are available from two areas in the Latvian EEZ, the Daugava mouth area in the Southern Gulf of Riga and the Kolka region in the Irbe Strait in the northwest of the gulf (Figure GoRc-1). Data collection in the Daugava mouth area was started in 1993 under the HELCOM coastal fish monitoring programme, creating time-series of fish community data (catch per unit effort (CPUE) and weight per unit effort (WPUE) per species). Sampling was mainly directed towards the warm-water season fish communities. Fishing is performed annually in August at fixed stations near the estuary of river Daugava by gillnets. Perch (Percafluviatilis), white bream (Blicca bjoercna), roach (Rutilus rutilus) and ruffe (Gymnocephalus cernua) are caught regularly in significant numbers, which makes it possible to evaluate the long–term development trends for these populations, but data are not representative for pelagic species such as Baltic herring (Clupea harengus), European smelt (Osmerus eperlanus), and flounder (Platychthys flesus) and are also not suitable to assess small species like sandeels and gobies. In addition to fish community data, number of fishing days in the coastal zone per fishing gear and per coastal municipality is available to describe fishing pressure.

National marine monitoring data on hydrographic parameters (temperature, salinity), nutrients, phytoplankton and zooplankton in the transitional waters of the Southern Gulf of Riga are available from the Latvian Institute of Aquatic Ecology. River runoff and nutrient loads are available from the Latvian Environment, Geology and Meteorology Centre.

Regular data collection in Irbe Strait/Kolka area was started in 1986 (1995 is missing). Sampling was mainly directed to flatfish juveniles (flounder Platychthys flesus and turbot Psetta maxima) but also information about other fish species are available. Fishing is performed usually twice per year: in cold water conditions in May/ beginning of June and warm water conditions in the end of June/July. Fish are sampled with a beach seine that covers approximately 4000 m2 area, starting 130 m from the coastline. Totally more than 600 stations were sampled and 46 different fish species were found. Dominant species were flounder, turbot, lesser sandeel (Ammodytes tobianus) thre-spinned stickleback (Gasterostus aceuleatus), smelt (Osmerus eperlanus), vimba (Vimba vimba), herring (Clupea harengus membras). In addition to fish community data, water temperature as well as wind direction and speed are available.

Figure GoRc-1. Sampling locations for coastal fish monitoring in the Southern Gulf of Riga and the Kolka/Irbe Strait area.

A4.6. NE Gulf of Riga (NEGoR)

For NE Gulf of Riga the dataset possible to use in the next phase of subsystems and coastal system IEA was presented (Table NEGoR-1). The dataset consists of 83 variables range (partly) from 1957–2010 and includes 19 abiotic parameters, 9 variables related to phytoplankton and phytobenthos, 38 zooplankton related variables, 3 for macrozoobenthos, 12 fish related variables. The data cover multiple trophic levels and will hopefully be used in for further analysis.

Table NEGoR-1. Description of the dataset for the analysis of the north-eastern Gulf of Riga coast (preliminary).

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Abiotic										
Winter air temperature		°C	Pärnu	Annual	Dec-March	1951–2010	EMI			Unpubl.
Spring air temperature		°C	Pärnu	Annual	April-May	1951–2010	EMI			Unpubl.
Summer air temperature		°C	Pärnu	Annual	June-Aug	1951–2010	EMI			Unpubl.
Autumn air temperature		°C	Pärnu	Annual	Sept-Dec	1951–2010	EMI			Unpubl.
Wind speed/direction		m/sec	NE GoR coast	Annual	Jan-Dec	1966–2010	EMHI			Unpubl.
Water transparency		m	NE GoR coast	Annual	May-July	1958–2010	EMI	Secchi		Unpubl.
River runoff		m^{-3}	NE GoR coast	Annual	Ice-free season	1922–2010	EMI			Unpubl.
Sea level		mm	NE GoR coast	Annual	Jan-Dec	1957–2010	EMHI			Unpubl.
Salinity		‰	NE GoR coast	Annual	May-July	1957–2010	EMI	Lab/CTD		Unpubl.
Ice conditions			NE GoR coast	Annual		1958–2010	EMHI			Unpubl.
pH			NE GoR coast	Annual	June-Sept	1996–2010	EMI			Anon 2011a
NOx		µmol N/l	NE GoR coast	Annual	June-Sept	1996–2010	EMI			Anon 2011a
NH_4		µmol N/l	NE GoR coast	Annual	June-Sept	1996–2010	EMI			Anon 2011a

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
N_t		µmol TotN/l	NE GoR coast	Annual	June-Sept	1996–2010	EMI			Anon 2011a
PO_4		µmol P/l	NE GoR coast	Annual	June-Sept	1996–2010	EMI			Anon 2011a
P_t		µmol P/l	NE GoR coast	Annual	June-Sept	1996–2010	EMI			Anon 2011a
SiO_4		µmol Si/l	NE GoR coast	Annual	June-Sept	1996–2010	EMI			Anon 2011a
Ntot		µmol l^{-1}	Pärnu Bay	Annual	June-Sept	1993–2010	EMI			Anon 2011a
Ptot		µmol l^{-1}	Pärnu Bay	Annual	June-Sept	1993–2010	EMI			Anon 2011a
Phytoplankton, -benthos										
Chla		mg/m^3	NE GoR coast	Annual	April-May	1999–2010	EMI			Anon 2011a
Chla		mg/m^3	NE GoR coast	Annual	June-Sept	1999–2010	EMI			Anon 2011a
Phytoplankton biomass		mg l^{-1}	NE GoR coast	Annual	April-May	1999–2010	EMI			Anon 2011a
Phytobenthos										

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Proportion of green algae in phytobenthos community		% (dw)	NE GoR coast	Annual		1999–2010	EMI			Anon. 2011a
Proportion of brown algae in phytobenthos community		% (dw)	NE GoR coast	Annual		1999–2010	EMI			Anon. 2011a
Proportion of red algae in phytobenthos community		% (dw)	NE GoR coast	Annual		1999–2010	EMI			Anon. 2011a
Proportion of charophyte in phytobenthos community		% (dw)	NE GoR coast	Annual		1999–2010	EMI			Anon. 2011a
Proportion of higher plants in phytobenthos community		% (dw)	NE GoR coast	Annual		1999–2010	EMI			Anon. 2011a
Max. depth of phytobenthos distribtion		m	NE GoR coast	Annual		1995–2000	EMI			Anon. 2011a
Zooplankton										
Pleopis polyphemoides		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Bosmina longispina		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Evadne nordmannii		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Cercopagis pengoi		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Eurytemora affinis		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Acartia spp.		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Copepod nauplii		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Limnocalanus macrurus		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Balanus improvisus larvae		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Lamellibranchiata larvae		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Gastropoda larvae		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Polychaeta larvae		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Synchaeta baltica		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
S. monopus		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
S. littoralis		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
S. fennica		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Keratella quadrata		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
K. cohlearis		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
K. c. eichwaldi		ind m^{-3}	NE GoR coast	Annual	May-July Ice-free season	1957–2010 1971–2010	EMI	Juday net		Unpubl.
Macrozoobenthos										
Number of species		No.	NE GoR coast	Annual	May-June	1996–2010	EMI	van Veen, Ekman		Anon 2011a
Population biomass		dw	NE GoR coast	Annual	May-June	1996–2010	EMI	van Veen, Ekman		Anon 2011a
ZKI index			NE GoR coast	Annual	May-June	1996–2010	EMI	van Veen, Ekman		Anon 2011a
Fish										
Goby larvae		ind m^{-3}	NGoR coast	Annual	May-July	1958–2010	EMI	Hensen net		Anon. 2011b
First appearance of goby larvae		No. of week	NGoR coast	Annual	May	1958–2010	EMI	Hensen net		Anon. 2011b
Herring larvae		ind m^{-3}	NGoR coast	Annual	May-July	1947–2010	EMI	Hensen net		Ojaveer *et al*. 2011, Anon. 2011b
Duration of presence of larval herring		Days	NGoR coast	Weekly	May-July	1947–2010	EMI	Hensen net		Ojaveer *et al*. 2011, Anon 2011b

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	References/ Weblinks
Smelt landings		tons	NGoR coast	Annual	Jan-Dec	1969–2010	EMI	Catch statistics		Unpubl.
Eel landings		tons	NGoR coast	Annual	Jan-Dec	1969–2010	EMI	Catch statis-tics		Unpubl.
Whitefish landings		tons	NGoR coast	Annual	Jan-Dec	1969–2010	EMI	Catch statis-tics		Unpubl.
Bream landings		tons	NGoR coast	Annual	Jan-Dec	1969–2010	EMI	Catch statis-tics		Unpubl.
Perch landings		tons	NGoR coast	Annual	Jan-Dec	1969–2010	EMI	Catch statis-tics		Unpubl.
Pikeperch landings		tons	NGoR coast	Annual	Jan-Dec	1960–2010	EMI	Catch statis-tics		Unpubl.
Pikeperch SSB		tons	NGoR coast	Annual	Jan-Dec	1960–1999	EMI	VPA		Eero 2004
Pikeperch R		millions	NGoR coast	Annual	Jan-Dec	1960–1999	EMI	VPA		Eero 2004

(Data info and requests to Henn Ojaveer henn.ojaveer@ut.ee)

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A4.7. Kvädöfjärden – the W Baltic Proper coast (BPc)

An integrated assessment was performed for the coastal area of Kvädöfjärden in the northern Baltic Proper (Figure BPc-1). The same area was assessed for the period 1971–2008 (ICES 2009), but was now assessed for the period 1985–2009. The purpose of using a shorter time-series was to be able to include data from revised monitoring programmes beginning in 1985, which were considered to be more reliable.

The Kvädöfjärden area is an archipelago area with a heterogenous 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 (Swedish Board of Fisheries 2010). The current ecological status of the area was classified as moderate according to the Water Framework Directive (www.viss.lansstyrelsen.se).

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.

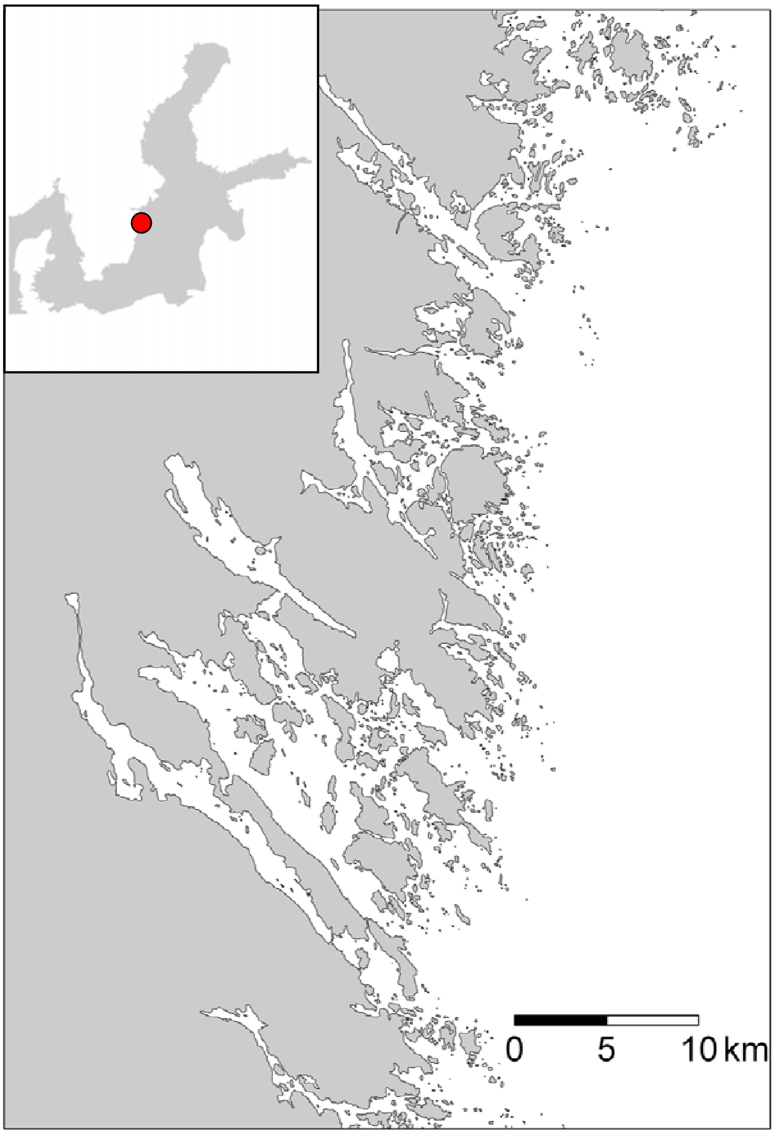


Figure BPc-1. Location of Kvädöfjärden area at the Central Baltic Sea coast of Sweden.

Trend analyses

Hydrography

Hydrographical variables on temperature, salinity and pH were included. Three temperature variables were included, representing conditions during summer on a local scale and on a larger scale (represented by data from the open sea), as well as local temperatures during spring, which is expected to have a relatively strong influence on the yearly recruitment success of fish and zoobenthos. Of these, an increasing trend in local temperature during summer was observed during the studied time period. Data on salinity and pH was not available on a local scale, and these features were represented by data from the open sea. The variable salinity showed a decreasing trend during the time period as whole. No trend was observed in pH.

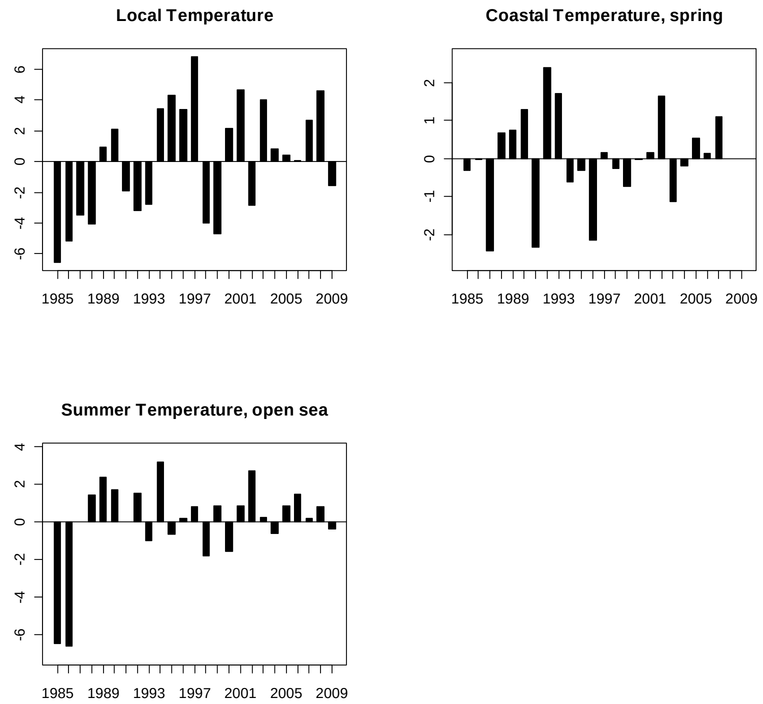


Figure BPc-2. Long-term hydrographic changes in the Kvädöfjärden area: anomalies from the overall mean in temperature (°C), measured as i) coastal temperature during summer (August); ii) coastal temperature during spring (May/June); and iii) temperature in the open sea during summer (surface values, June–August), all units are °C. [Presented from left to right]

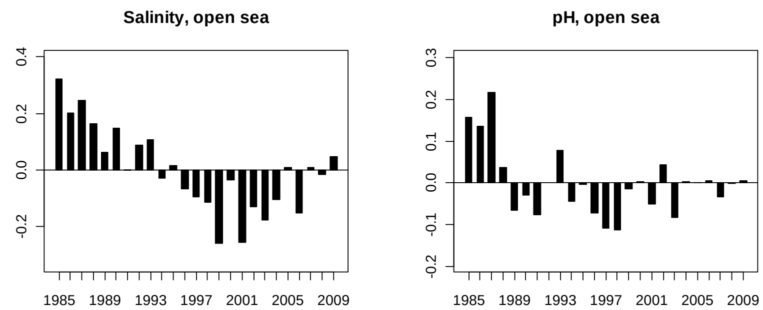


Figure BPc-3. Long-term hydrographic changes in the Kvädöfjärden area. The variables salinity (PSU) and pH were represented by data from the open sea. Figures show the anomalies from the overall mean.

Nutrients

Data on nutrient loading was represented by estimates of total riverine runoff of nitrogen from land, at local and a regional scale. No measurements of local nutrient concentration in the coastal area were available. Therefore, data on total dissolved nitrogen and phosphorous were included from the corresponding open sea area (Gotland basin surface water). The concentration of dissolved nitrate showed a decreasing trend over the studied time period. Additionally, the variable water transparency was included in order to indicate local changes in water clarity, as measured by Secchi depth measurements. The variable water transparency showed a decreasing trend during the studied time period, which probably reflects increases in Chl-*a* or particulate organic materials.

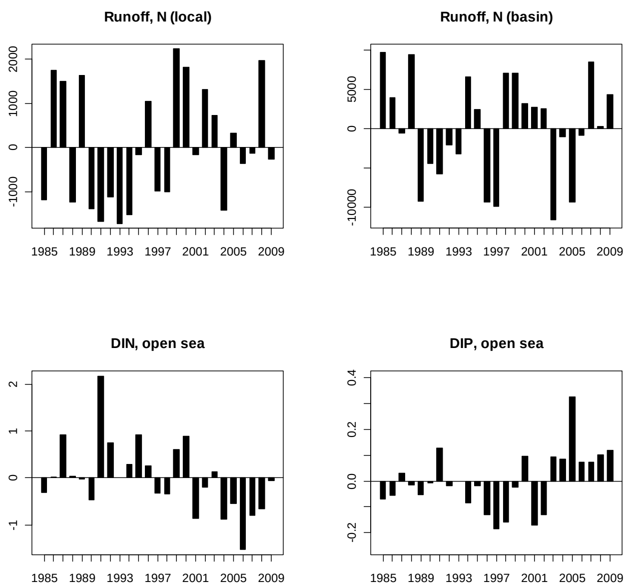


Figure BPc-4. Long-term changes in nutrients in the Kvädöfjärden area: the upper panel shows anomalies from the overall mean for estimated runoff of nitrate from land on a local (left) and basin (right) scale, measured as tonnes per year. The lower panel show anomalies of the overall mean for DIN and DIP in the open sea surface water (Gotland Basin, no corresponding data from coastal areas was available).

Benthos

Data on four species of soft bottom macrozoobenthos were included, based on prevalence in the monitoring program for zoobenthos in the Kvädöfjärden area. The bivalve *Macoma baltica* showed an increasing trend over the studied time period and the amphipod *Monoporeia affinis* showed a decreasing trend. The abundance of the two other species included, *Halicryptus spinulosus* (Priapuloidea) and *Harmothoe sarsi* (Polychaeta), showed no trends over time. Additionally, the PCA analyses were performed with and without including the alien species *Marenzelleria* sp., which occurred in the data set from 2004 onwards.

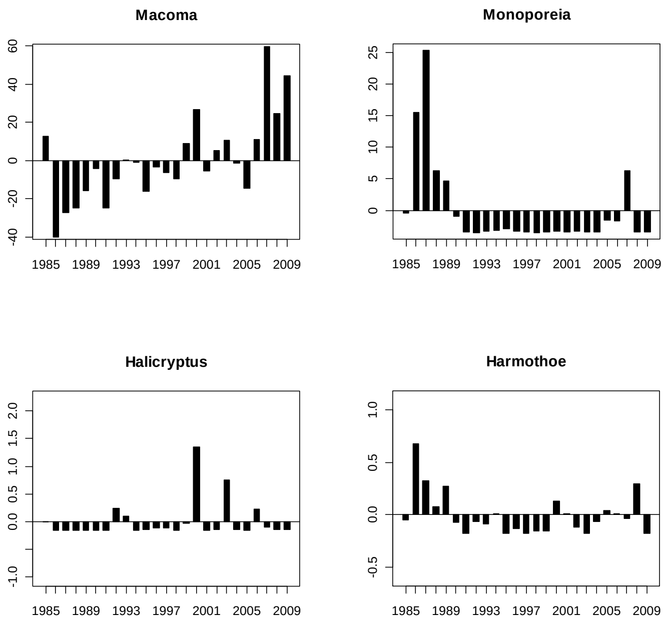


Figure BPc-5. Long-term changes in zoobenthos in the Kvädöfjärden area: anomalies from the overall mean in biomass of *Macoma baltica*, *Monoporeia affinis*, *Harmothoe sarsi* and *Halicryprus spinulosus*, estimated as grams per square meter.

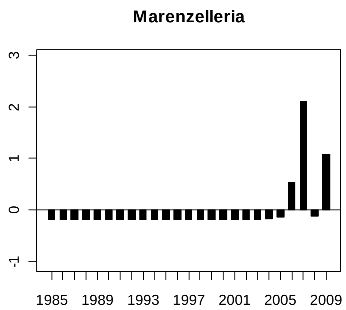


Figure BPc-6. Alien species in the Kvädöfjärden area: anomalie of the overall mean for the polychaete *Marenzellria* sp., which was observed in the area for the first time in 2004.

Fish

Data on six species of fish were included. These were the freshwater species perch (*Perca fluviatilis*), white bream (*Blicca bjoerkna*), and roach (*Rutilus rutilus*), and the marine species flounder (*Platichtys flesus*), Cod (*Gadus morhua*) and herring (*Clupea harengus*). Over the time period as a whole, an increasing trend was observed in perch, but not in any of the other species.

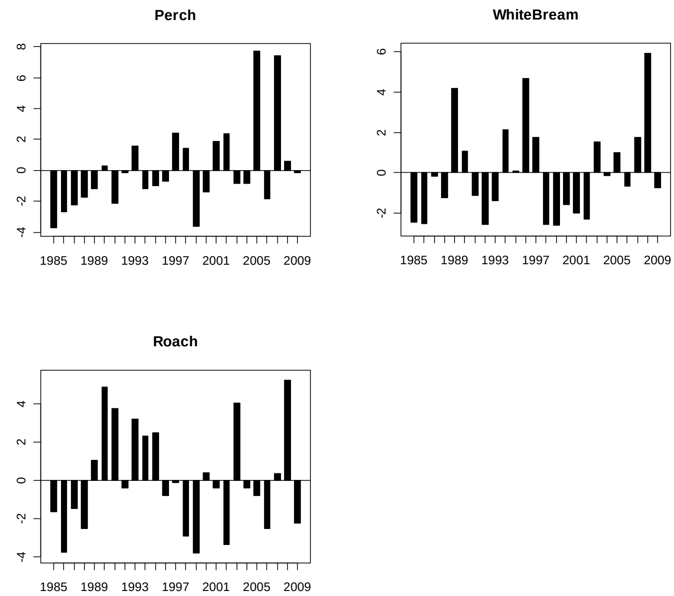


Figure BPc-7. Long term changes in freshwater fish species in the Kvädöfjärden area: anomalie of the overall mean for perch (*Perca fluviatilis*), white bream (*Blicca bjoerkna*), and roach (*Rutilus rutilus*), estimated by the fish monitoring program of the area (catch per net and night in numbers).

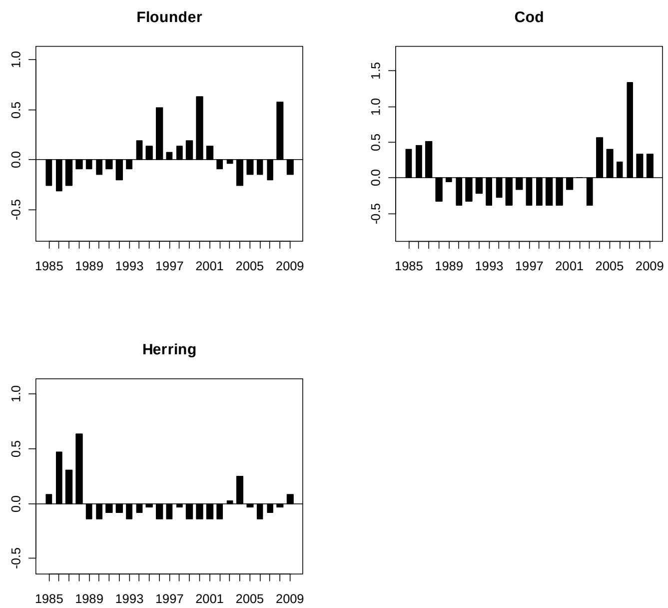


Figure BPc-8. Long term changes in marine fish species in the Kvädöfjärden area: anomalie of the overall mean for flounder (*Platichtys flesus*) cod (*Gadus morhua*) and herring (*Clupea harengus*), estimated by the fish monitoring program of the area (catch per net and night in numbers).

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.

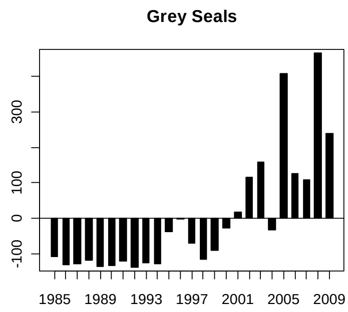


Figure BPc-9. Long term changes in grey seal abundance in the Kvädöfjärden area: figure show anomalie from the overall mean of estimated total abundance in the region, based on national monitoring.

Fishing

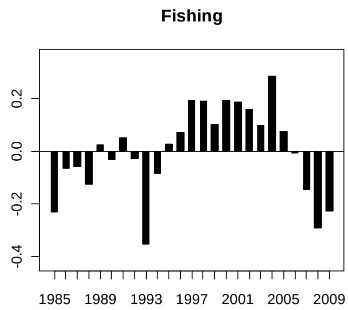


Figure BPc-10. Long term changes in fishing pressure index of the Kvädöfjärden area: anomalies from the overall mean of the index (sum of proportion removed from herring (age 3–6), sprat (age 3–5) and cod (age 4–7), F-based, in the total Central Baltic Sea fisheries.

Integrated analyses

The integrate analyses covered data within the time period 1985–2009. In all, 12 biotic and 12 biotic variables were included. These were the variables presented above, and additionally the Baltic Sea Index.

The traffic light plot compares trends over time in the included variables. For many of the variables, no clear trends over time were observed. Abiotic variables showing high values in the beginning of the studied time period were salinity, water transparency and open sea DIN, whereas temperature values during summer were slightly higher in the end of the time period. Of the biotic variables, the abundances of herring (*Clupea harengus*), the amphipod *Monoporeia* and the polychaete *Harmotoe sarsi* were relatively high in the beginning of the time-series, whereas grey seal (*H. grypus*), perch (*Perca fluvuatilis*), the bivalve *Macoma*, and the polychaete *Marenzelleria* were relatively more abundant in the end of the studied time period.

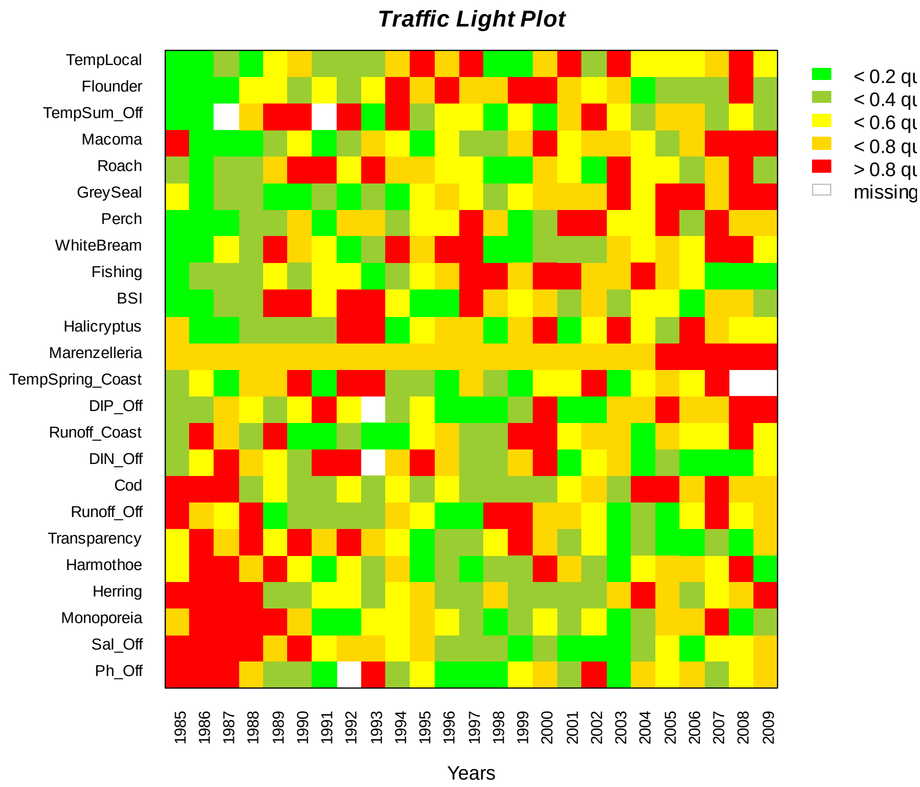


Figure BPc-11. Traffic-light plot of the temporal development of the Kvädöfjärden time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in the table below.

In the PCA on all variables, a change along the first principal component was indicated mainly within the years 1985–1990, whereas changes in years thereafter were mainly indicated on the second principal component. The first principal component accounted for 25.4 % of the observed variation and was, for the abioitic variables, mainly associated with decreasing salinity, nutrient loading and pH, and with increasing summer temperatures. For the biotic variables, the first principal component was mainly associated with decreasing abundances of herring, *Monoporeia* and *Harmothoe,* and with an increasing abundance of roach and flounder. The second principal component accounted for 15.6 % of the variation and was mainly associated with DIN (decreasing with time) and DIP (increasing) for the abiotic variables. For the biotic variables, the second principal component was mainly associated with increasing abundances of *Marenzelleria*, cod and grey seals with time.

When *Marenzelleria* was excluded from the analyses, the main observed pattern remained and the explained variation changed to 26.5 % on PC 1 and 14.4% on PC2.

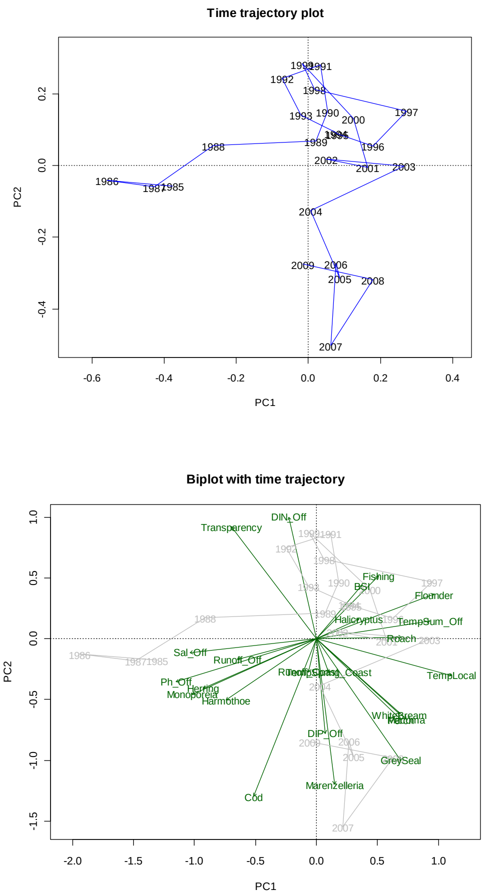
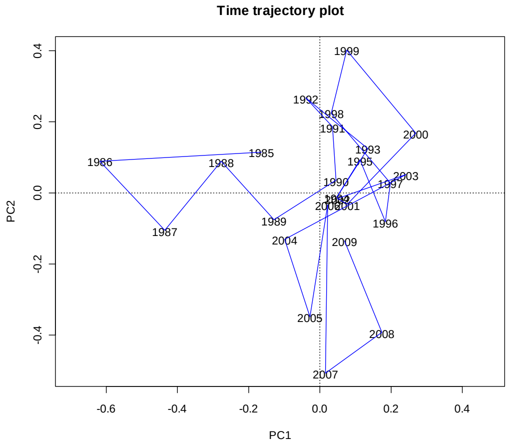


Figure BPc-12. Results of the standardized principal component analysis using all 23 variables in the Kvädöfjärden area. The upper graph shows sample scores (years) on the first factorial plane, with a time trajectory. The lower graph shows the corresponding variable loadings. PC1 accounted for 25.4 % of the variation and PC2 for 15.6%.

The PCA was repeated for biotic variables only and excluding the alien species Marenzelleria. Thus, in total 11 variables were included. In this analysis, the first principal component accounted for 32.9% of the variation, and the second component for 18.7 %. The overall pattern observed along the first two principal components was similar to that of the corresponding PCA on all variables. The main change along the first principal component was for the years 1985–1990, whereas changes in years thereafter were mainly indicated on the second principal component. The first principal component was mainly associated with decreasing abundances of herring, Monoporeia and Harmothoe, and increasing abundances of flounder and Macoma. The second principal component was mainly associated with increasing abundances of cod and grey seals, as above, but also by increasing abundances of perch and white bream in later years.



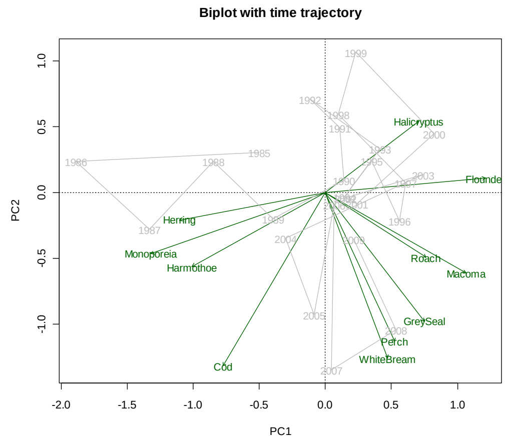


Figure BPc-13. Results of the standardized principal component analysis using biotic variables only in the Kvädöfjärden area. The upper graph shows sample scores (years) on the first factorial plane, with a time trajectory. The lower graph shows the corresponding variable loadings. PC1 accounted for 32.9 % of the variation and PC2 for 18.7 %.

The chronological clustering analyses indicated no significant shifts at any alpha-level < 0.1. When smaller differences between clusters are investigated (alpha ≥ 0.2) shifts in 1989, 1994 and early 2000s are found (Figure BPc-14).

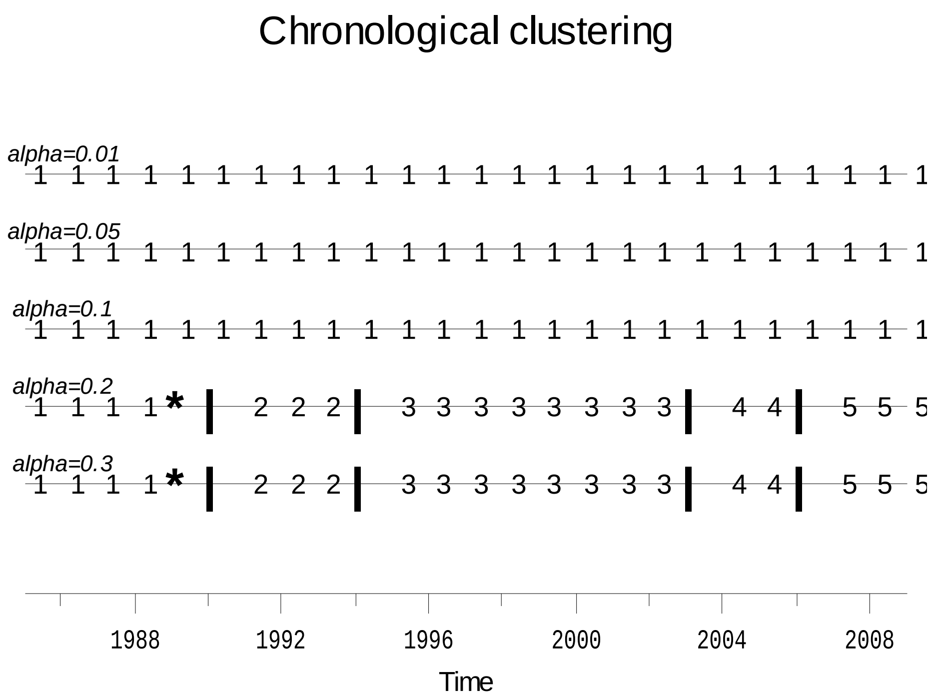


Figure BPc-14. Results of the Chronological clustering analysis performed on all variables.

Table BPc-1. Time-series used for the integrated ecosystem analysis in the Kvädöfjärden area.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/Gear	Contact	Weblinks
biotic										
Grey seal (*Halichoerus grypus*)	GreySeal	No.	Örösankor	NA	NA	1985-2009	NRM	Counting	AG/LB	www.nrm.se
Perch (*Perca fluviatilis*)	Perch	CPUE (abundance)	Kvädofjärden	Summer	August	1985-2009	SBF	Net survey	AG/LB	www.fiskeriverket.se
White bream (*Blicca bjoerkna*)	WhiteBream	CPUE (abundance)	Kvädofjärden	Summer	August	1985-2009	SBF	Net survey	AG/LB	www.fiskeriverket.se
Roach (*Rutilus rutilus*)	Roach	CPUE (abundance)	Kvädofjärden	Summer	August	1985-2009	SBF	Net survey	AG/LB	www.fiskeriverket.se
Flounder (*Platichtys flesus*)	Flounder	CPUE (abundance)	Kvädofjärden	Summer	August	1985-2009	SBF	Net survey	AG/LB	www.fiskeriverket.se
Cod (*Gadus morhua*)	Cod	CPUE (abundance)	Kvädofjärden	Autumn	October	1985-2009	SBF	Net survey	AG/LB	www.fiskeriverket.se
Herring (*Clupea harengus membrans*)	Herring	CPUE (abundance)	Kvädofjärden	Autumn	October	1985-2009	SBF	Net survey	AG/LB	www.fiskeriverket.se
Marenzelleria sp.	Marenzelleria	g*m-2	Kvädofjärden	Spring	April-May	1985-2009	SBF	Grab Sampler	AG/LB	www.fiskeriverket.se
Halicryptus spinulosus	Halicryptus	g*m-2	Kvädofjärden	Spring	April-May	1985-2009	SBF	Grab Sampler	AG/LB	www.fiskeriverket.se
Harmothoe sarsi	Harmothoe	g*m-2	Kvädofjärden	Spring	April-May	1985-2009	SBF	Grab Sampler	AG/LB	www.fiskeriverket.se
Macoma balthica	Macoma	g*m-2	Kvädofjärden	Spring	April-May	1985-2009	SBF	Grab Sampler	AG/LB	www.fiskeriverket.se
Monoporeia affinis	Monoporeia	g*m-2	Kvädofjärden	Spring	April-May	1985-2009	SBF	Grab Sampler	AG/LB	www.fiskeriverket.se
abiotic/environmental										
Water transparency	Transparency	meters	Kvädofjärden	Summer	August	1985-2009	SBF	Secchi depth	AG/LB	www.fiskeriverket.se
Coastal temperature in August	TempLocal	degrees C	Kvädofjärden	Summer	August	1985-2009	SBF	Water sample	AG/LB	www.fiskeriverket.se
Coastal temperature in Spring	TempSpring_Coast	degrees C	Kvädofjärden	Spring	May-June	1985-2007	SBF	Water sample	AG/LB	www.fiskeriverket.se
Local nitrogen loading	Runoff_Coast	tonnes	Local county	Annual	NA	1985-2008	SLU	Water sample	AG/LB	www.slu.se
Offshore surface temperature, spring	TempSum_Off	degrees C	Off shore (BY15)	Spring	April	1985-2009	SMHI	Water sample	AG/LB	www.smhi.se
Salinity	Sal_Off	psu	Off shore (BY15)	Annual	NA	1985-2009	SMHI	Water sample	AG/LB	www.smhi.se
Acidity	Ph_Off	-	Off shore (BY15)	Annual	NA	1985-2009	SMHI	Water sample	AG/LB	www.smhi.se
Dissolevd inorganic nitrogen	DIN_Off	mmol*l-1	Off shore (BY15)	Winter	Jan-Feb	1985-2009	SMHI	Water sample	AG/LB	www.smhi.se
Dissolevd inorganic phosphorous	DIP_Off	mmol*l-1	Off shore (BY15)	Winter	Jan-Feb	1985-2009	SMHI	Water sample	AG/LB	www.smhi.se
Regional nitrogen loading	Runoff_Off	tonnes	Basin (Sweden)	Annual	NA	1985-2008	SLU	Water sample	AG/LB	www.slu.se
Fishing index	Fishing	-	SD 25-28.2+32	Annual	NA	1985-2009	ICES (WGBFAS)	see text	AG/LB	www.ices.dk
Baltic Sea Index	BSI	-	Baltic Sea	Annual	NA	1985-2009		NA		

(Data info and requests to anna.gardmark@fiskeriverket or lena.bergstrom@fiskeriverket.se)

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ICES. 2009. Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB), 16–20 March 2009, Rostock, Germany. ICES CM 2009/BCC:02. 80pp.

A4.8. The Archipelago Sea – E Bothnian Sea coast (EBSc)

Archipelago Sea is a part of the Baltic Sea between the Gulf of Bothnia, the Gulf of Finland and the Sea of Åland. The area has very complex topography and it is among the largest archipelagos in the world by the number of islands - c. 25 000 (Hänninen *et al.* 2000), but most of the islands are very small. The average water depth in the area is only 23 m and the largest depth is 146 m (Hänninen *et al.* 2000). The area is characterized by a strong seasonality with ice cover during winter.

Like other Baltic Sea areas, the Archipelago Sea is heavily loaded with nutrients. The main sources of excess nutrients have been industrial and municipal wastewater, forestry, agriculture, fish farming and air-borne loads (e.g. Bonsdorff *et al.* 1997, Hänninen *et al.* 2000). The archipelago acts as a buffer or filter for nutrients between the coastline and the open sea. The areas close to the coast receive in general higher loads of nutrients than the areas close to open sea, but decreased vertical mixing due to halocline can cause anoxia in deeper areas (Bonsdorff *et al.* 1997).

The Archipelago Sea is an important commercial and recreational fishing area. Both marine and freshwater species are caught. In the coastal fisheries the main target species are pikeperch and perch. Perch and pikeperch catches are mainly taken with gill nets, but rod fishing is common among the recreational fishers. Recently, the increased abundance of cyprinids and decreasing perch stocks have hampered the gillnet fishing.

Bonsdorff *et al.* (1997) found that the total phosphorus and nitrogen concentrations in water did increase significantly during 1968–1993. Hänninen *et al.* (2000) reported that the development of the N:P-ratio indicated that during the 1980s and 1990s nitrogen developed towards the limiting nutrient in the area.

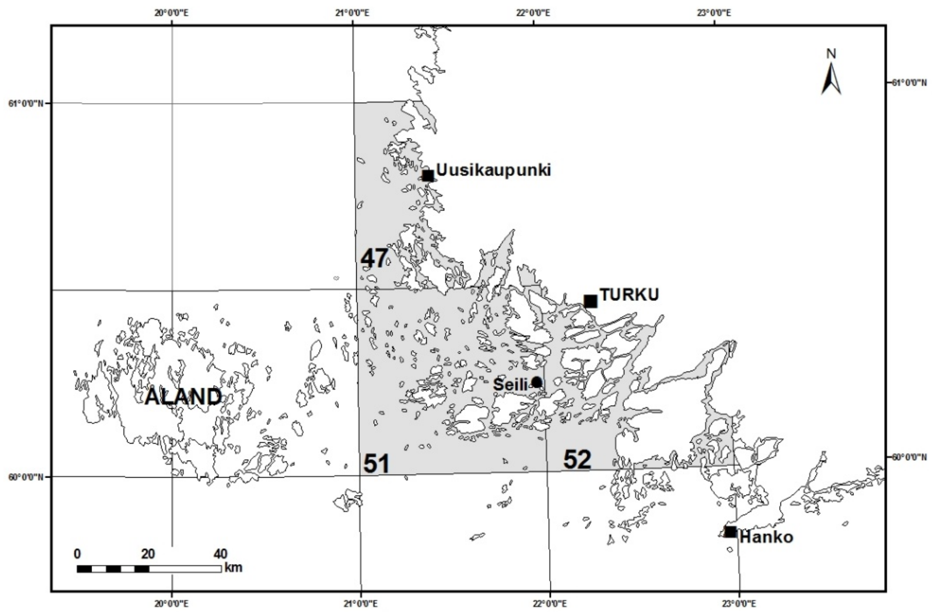

Figure EBSc-1. The Archipelago Sea with the environmental monitoring station (Seili) and the shaded statistical rectangles from which the fish stock assessment data was collected.

Trend analyses

In total, 26 variables were considered: 10 water chemistry and hydrogaphic variables, 12 phytoplankton groups, and 4 variables related to fish stocks (pikeperch and perch). All datasets were compiled to one estimate per year. The water chemistry and hydrographic data covered the years 1983–2009; phytoplankton data years 1991–2009; fish recruitment data about perch 1980–2005 and about pikeperch 1980–2007, and fish stock data covered the years 1980–2008. In the fish data, the values for the most recent years can be assumed as the most uncertain because of the characteristics of the applied stock assessment estimation method (VPA).

The hydrographic and chemical water quality data was collected at the monitoring station close to the island of Seili (Figure EBSc-1). The recorded variables were secchi-depth (m), total nitrogen concentration (μgl^{-1}), chlorophyll-a concentration (μgl^{-1}), salinity (PSU), water temperature (°C), dissolved inorganic nitrogen (μgl^{-1}), phosphate-phosphorus (μgl^{-1}), total phosphorus (μgl^{-1}), oxygen concentration (mgl^{-1}), oxygen saturation (%). The values were averages from 5 to 7 samples taken at about two weeks intervals during July to September.

The phytoplankton dataset included 12 variables recorded during 1991 to 2009, excluding the years 1995 and 2005. The dataset was collected as the hydrographic and water chemistry data close to the island of Seili, from the water column two times secchi depth. The following groups were included: three groups of cyanobacteria (Chroococcales, Oscillatoriales, Nostocales), Cryptophyceae, Dinophyceae, Prymnesiophyceae, Chrysophyceae, Diatoms (Eupodiscales and other Diatomophyceae), Euglenophyceae, Chlorophyceae and Prasinophyceae. The values were summertime July to September average biovolumes ($mm^3\ l^{-1}$).

The fish data were based on VPA (Virtual Population Analysis) using pikeperch and perch catch statistics and samples from the commercial catches. The recruitment is expressed as the number of 1-year-old or 3-year-old fish for pikeperch and perch, respectively, for each year class (millions). The abundances of the fish stocks in each year include ages ≥3 in millions.

While substantial dataset on phytoplankton, hydrography and water chemistry were included, e.g. the zooplankton data was not available. To increase the ability of the analyses to find trends and break-points, it would be important to include data about other fish species than of perch and pikeperch, e.g. catches per unit of effort. If suitable datasets exist, benthic fauna should be included as well. Other future tasks might include more detailed areal analyses e.g. comparisons of the different zones from inner to intermediate and to the outer archipelago.

Hydrography

The main trends in the hydrography were decrease in salinity, increase in temperature, decrease in the transparency (Secchi depth), and decrease in the oxygen content. The changes indicate eutrophication and climate warming. The decrease in salinity could be a sign of increased river runoff (Figure EBSc-2). In the secchi depth there may have been an inflection in or levelling of the trend in 21st century.

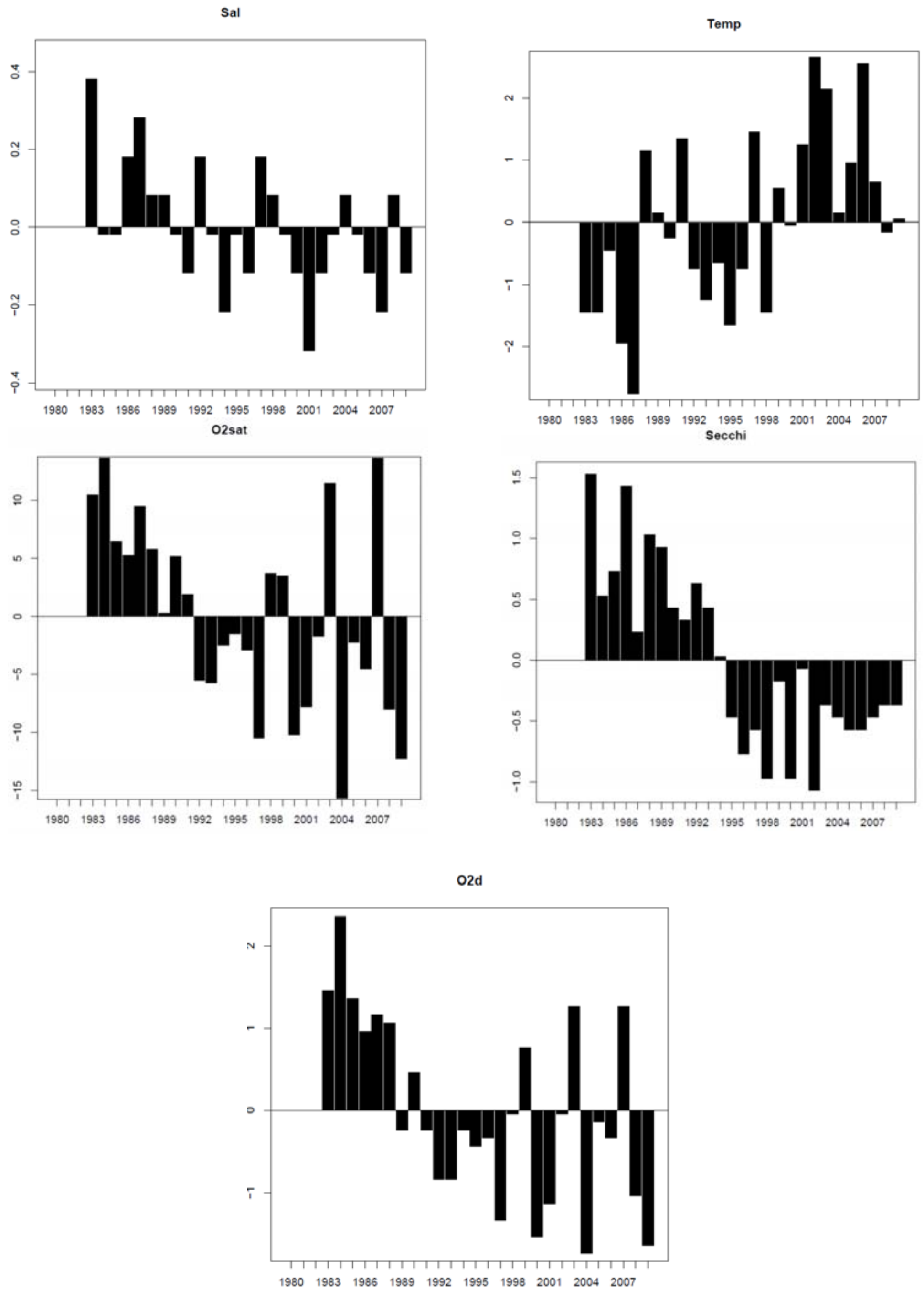

Figure EBSc-2. Long-term hydrographic changes in the Archipelago Sea: anomalies of the overall mean presented for salinity (PSU), temperature (°C), O_2 saturation (%), Secchi depth (m) and dissolved O_2 (mgl^{-1}). [Presented from top left to bottom right]

Nutrients

The general trend during the considered period has been an increase in the nutrient concentrations, and in chlorophyll *a*, which all indicate eutrophication. However, in most recent years some of the values, such as total nitrogen, dissolved nitrogen and chrolophyll *a* may have decreased, which is in concordance with the secchi depth data.

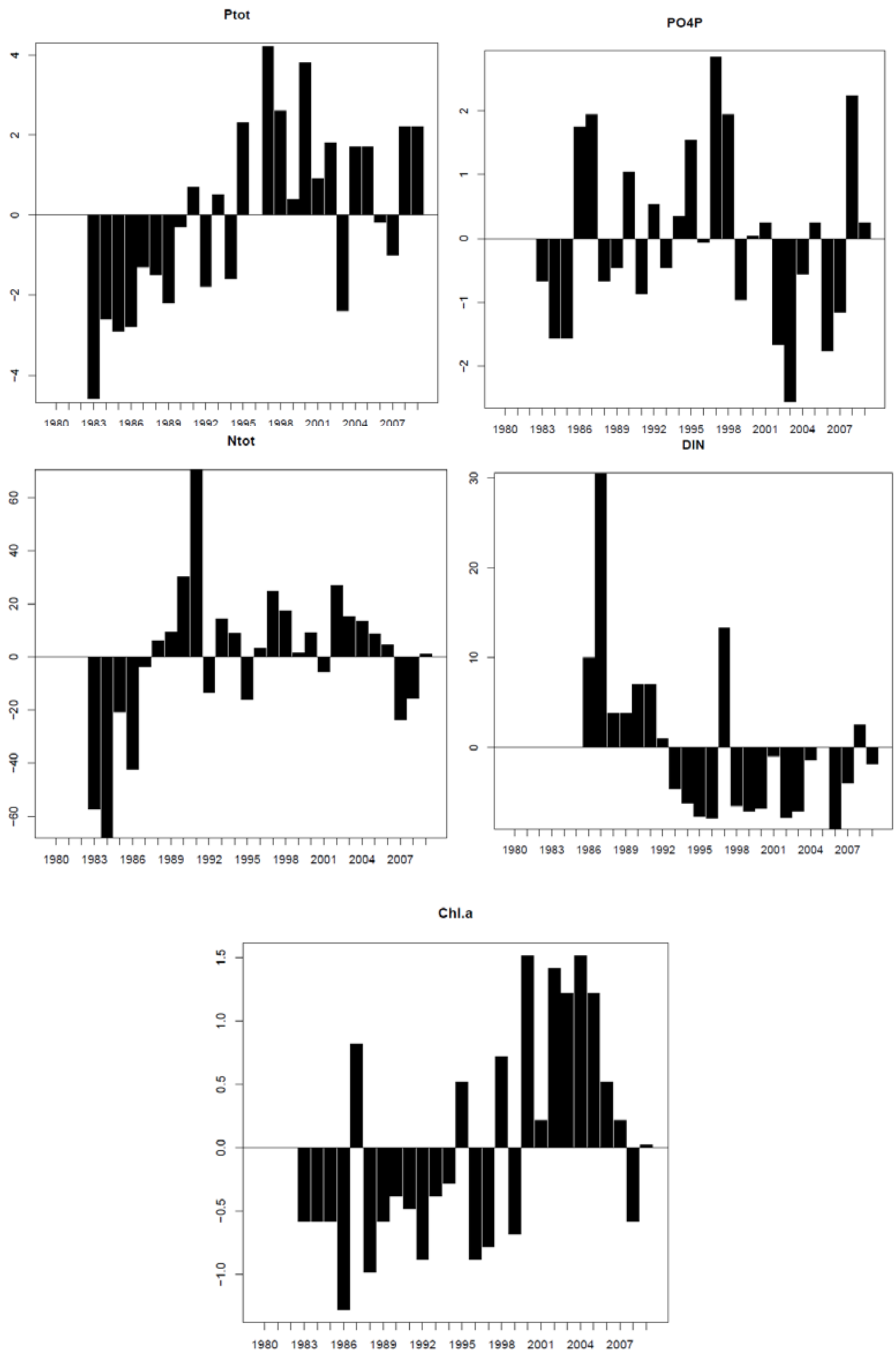

Figure EBSc-3. Long-term changes in nutrient and chlorophyll-a contents in the Archipelago Sea: anomalies of the overall mean presented for Ptot (total phosphorus) (µgl^{-1}), PO4P (PO_4 phosphorus) (µgl^{-1}), Ntot (total nitrogen) (µgl^{-1}), DIN (dissolved inorganic nitrogen) (µgl^{-1}) and Chl_a (Chlorophyll-a)(µgl^{-1}). [Presented from top left to bottom right]

Phytoplankton

The blue-green algae seem to have increased during the period, similarly as e.g. Chrysophyceae. Some phytoplankton groups showed opposite trends, such as Cryptophyceae and Eupodiscales, and Dinophyceae in the latter part of the period.

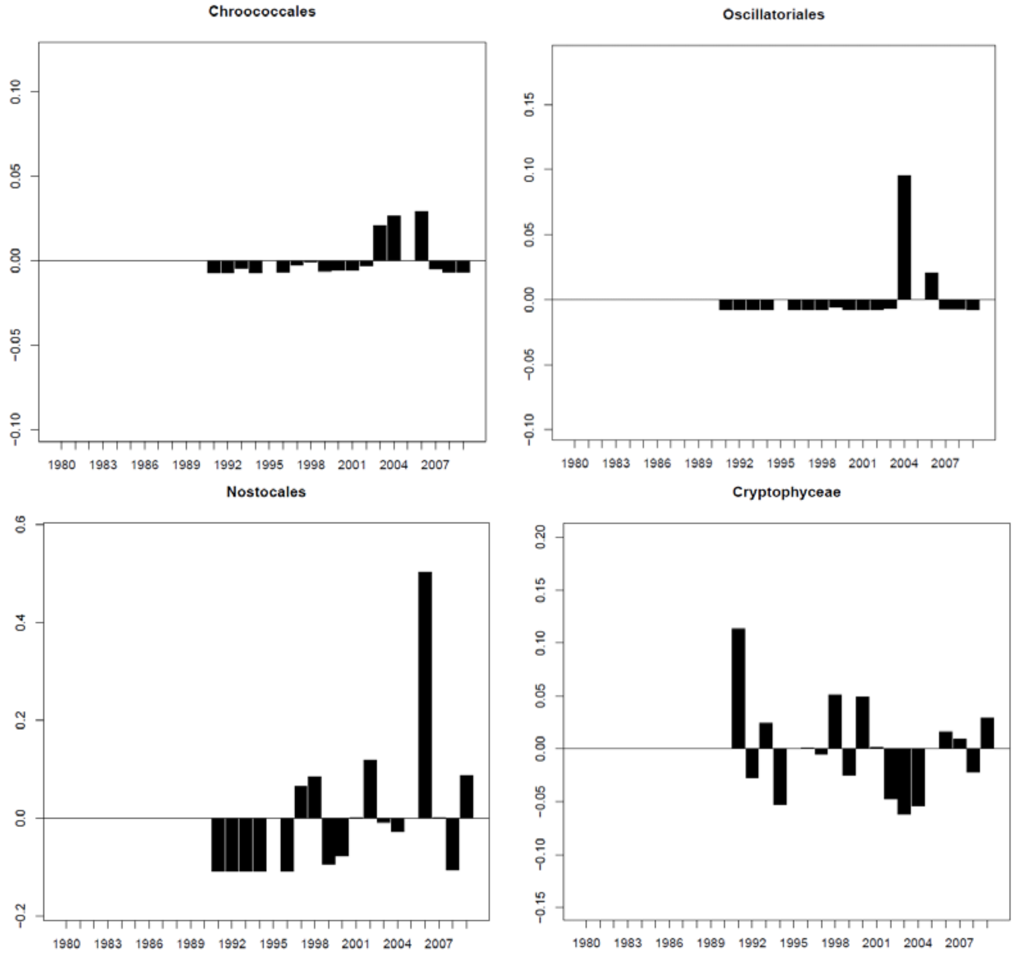

Figure EBSc-4. Long-term changes the abundance of phytoplankton groups in the Archipelago Sea: anomalies of the overall mean presented for Chroococcales ($mm^3\ l^{-1}$) , Oscillatioriales ($mm^3\ l^{-1}$), Nostocales ($mm^3\ l^{-1}$) and Cryptophyceae ($mm^3\ l^{-1}$). [Presented from top left to bottom right]

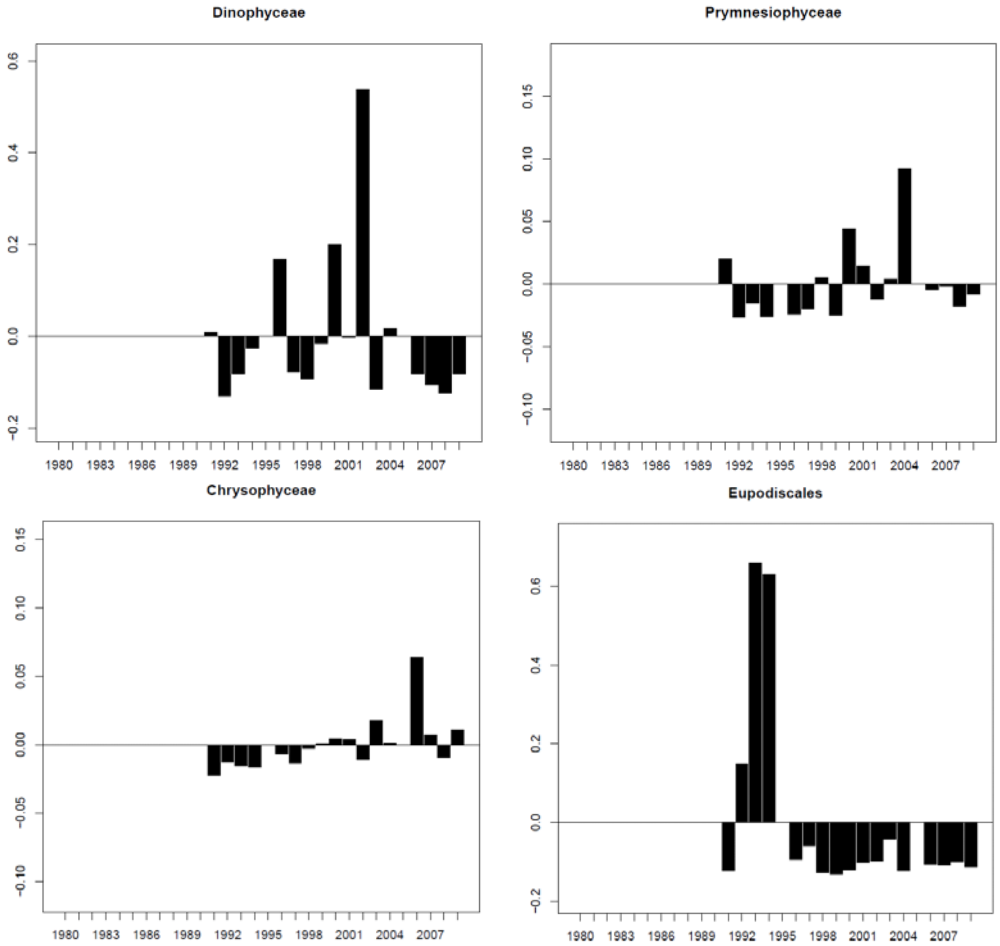

Figure EBSc-5. Long-term changes the abundance of phytoplankton groups in the Archipelago Sea: anomalies of the overall mean presented for Dinophyceae ($mm^3\ l^{-1}$), Prymnesiophyceae ($mm^3\ l^{-1}$), Chrysophyceae ($mm^3\ l^{-1}$), and Eupodiscales ($mm^3\ l^{-1}$). [Presented from top left to bottom right] Data from 1980–1990 is missing.

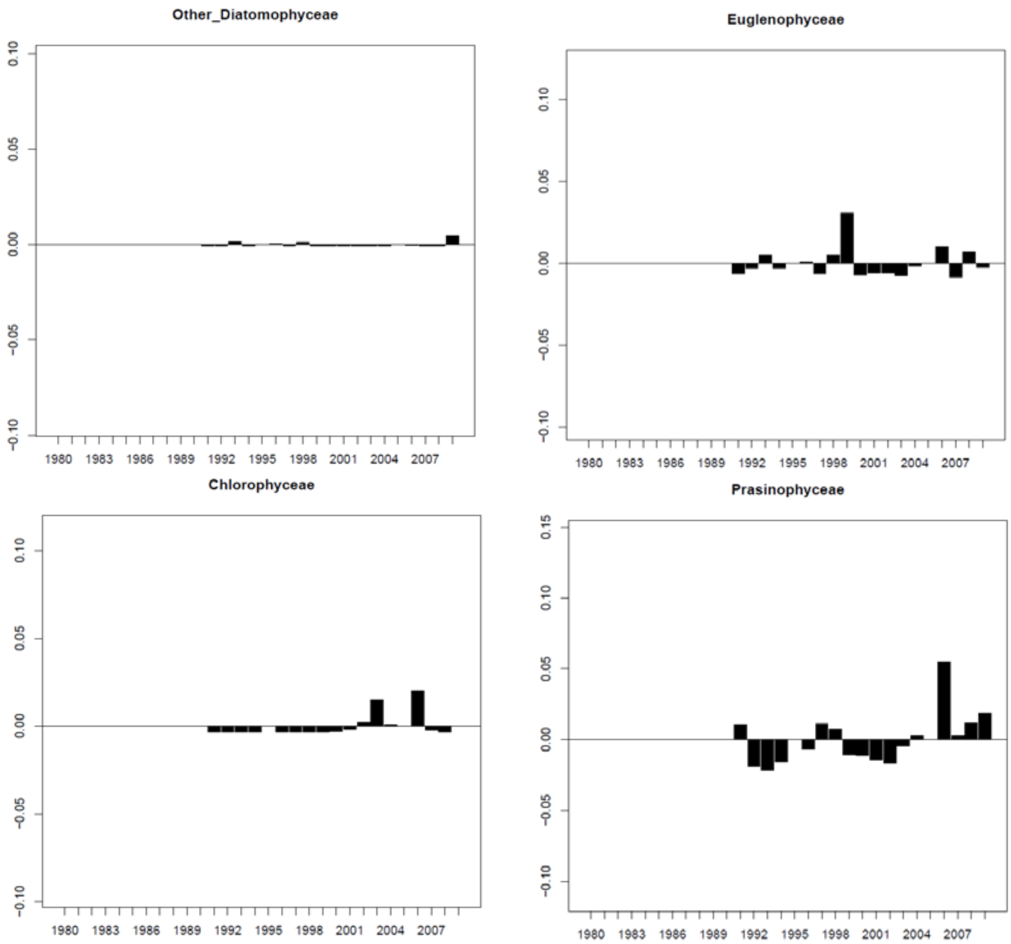

Figure EBSc-6. Long-term changes the abundance of phytoplankton groups in the Archipelago Sea: anomalies of the overall mean presented for other Diatomophyceae (mm^3 l^{-1}), Euglenophyceae (mm^3 l^{-1}), Chlorophyceae (mm^3 l^{-1}), and Prasinophyceae (mm^3 l^{-1}). [Presented from top left to bottom right] Data from 1980–1990 is missing.

Fish

The pikeperch and perch stocks have been favoured from the eutrophication and warming of the Archipelago Sea. The recruitment is mainly regulated by summer temperatures, and in favourable conditions strong year classes were born, such as the year classes 1988 and 1997. In the 2000s, there has been a decreasing trend in the perch stock. The abundance of perch has decreased due to several weak year classes. Perch is known to suffer from high level of eutrophication, which may be due to changes in the fish assemblage and deterioration of spawning grounds (e.g. Persson *et al.* 1991).

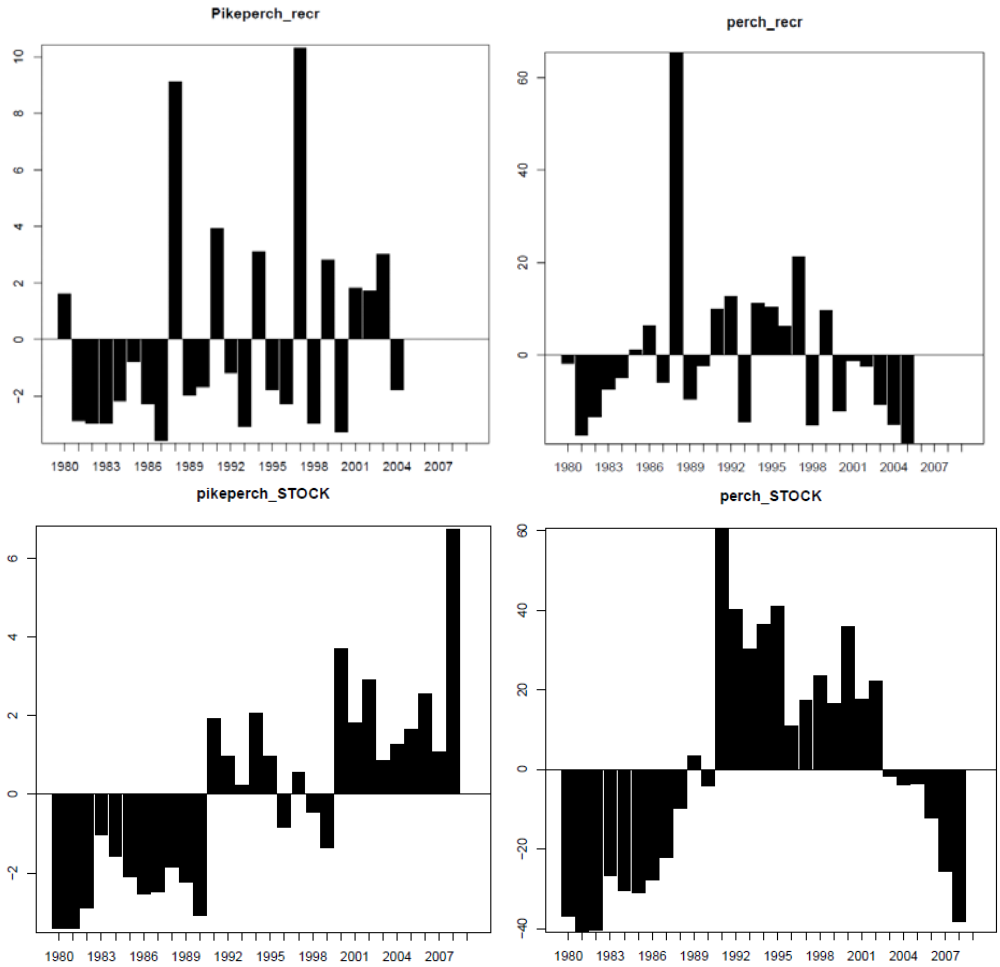

Figure EBSc-7. Long-term changes in the fish stocks in the Archipealgo Sea: anomalies of the overall mean presented for pikeperch recruitment (1-year-old recruits, millions) , perch recruitment (3-year-old recruits, millions), pikeperch stock in numbers (ages ≥3, millions) and perch stock in numbers (ages ≥3, millions). [Presented from top left to bottom right]

Integrated analyses

The period 1991–2009 was included in the integrated analysis because the phytoplankton data did not cover the period 1980–1990. All 26 variables were considered. The variables which had high values in the beginning of the period but decreased towards the end of the 2010s were e.g. perch recruitment and abundance, dissolved nutrients, salinity, Secchi depth, and some of the phytoplankton groups, such as Cryptophyceae and Eupodiscales. The variables which showed an increasing trend with time were e.g. some phytoplankton groups, Chrysophyceae and the blue-green algae, temperature, chlorophyll-a, and pikeperch.

Separate runs for biotic variables have not been done.

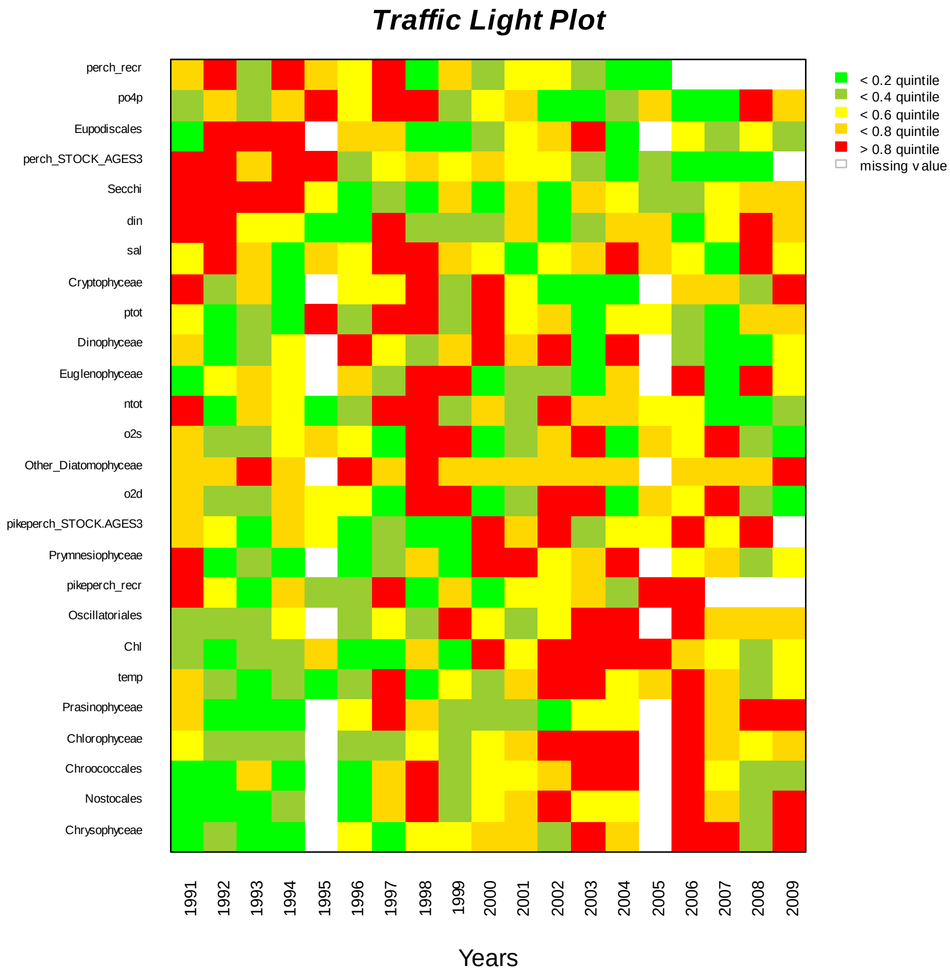

Figure EBSc-8. Traffic-light plot of the temporal development of the Archipelago Sea time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component in the PCA. Variable names are explained in Table EBSc-1.

In the PCA analysis, the first two principal components explained 24% and 16% of the variance, respectively. The most important variables in PC1 were perch recruitment and Chrysophyceae, and in PC2 total phosphorus and dissolved oxygen.

The constrained hierarchical cluster analysis indicates that there might be a shift in 1996–1998, and in 2004–2005.

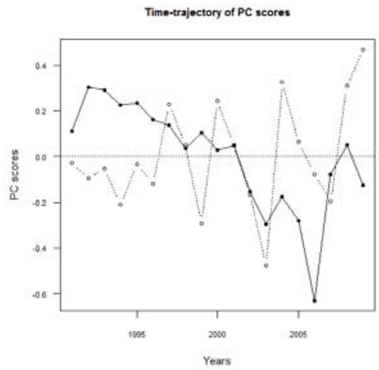

Figure EBSc-9. Results of the standardized principal component analysis using the 26 variables for the Archipelago Sea showing PC1 (black circles) and PC2 scores (white circles) against time.

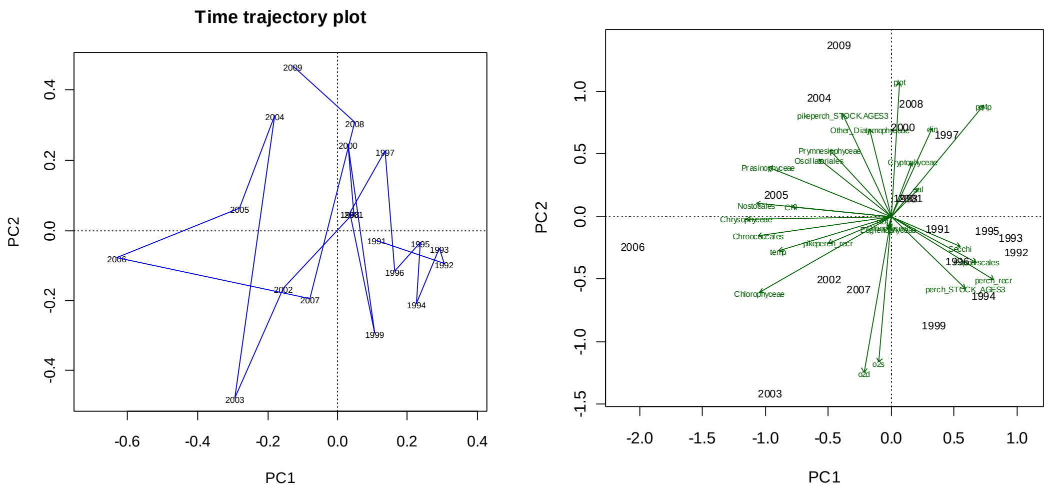

Figure EBSc-10. Results of the standardized principal component analysis using all 26 variables in the Archipelago Sea. The graph to the left shows sample scores (years) on the first factorial plane, with a time trajectory. The graph to the right shows the corresponding variable loadings.

Based on displayed system trajectories (Figure EBSc-10) it is difficult to distinguish any alternative system states. The constrained hierarchical clustering suggests a shift in composition between 2004 and 2005 (Figure EBSc-11).

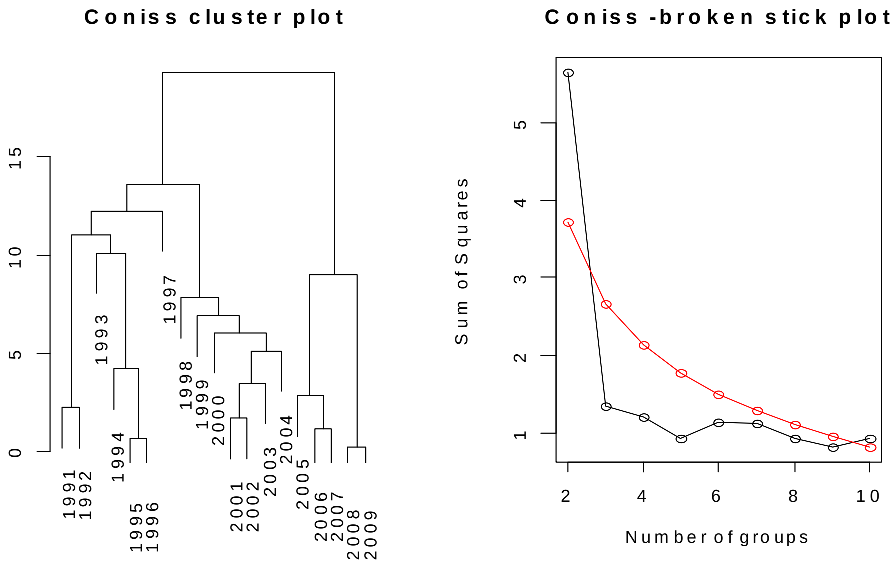

Figure EBSc-11. Results for the Archipelago Sea: A cluster plot from the Constrained Clustering analysis and a broken stick model to determine the number of significant groups in the cluster analysis.

Table EBSc-1. Time-series used for the integrated ecosystem analysis in the Archipelago Sea.

Variable	Abbreviation	Unit	Area	Season	Month	Years	Source	Method/ Gear	Contact	References/ Weblinks
Water column temperature (depth 1-5 m)	Temp	°C	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Water column salinity (depth 1-5 m)	Sal	psu	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Dissolved oxygen	O2d	mg*l-1	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Oxygen saturation	O2sat	%	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Chlorophyll a	Chl.a	µg*l-1	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Secchi depth	Secchi	m	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Dissolved inorganic nitrogen	DIN	µg*l-1	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Total nitrogen	Ntot	µg*l-1	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Dissolved inorganic phosphorus – PO4-P	PO4P	µg*l-1	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Total phosphorus	Ptot	µg*l-1	Archipelago Sea	Summer	July-Sept.	1983-2009	SYKE			
Chroococcales	Chroococcales	mm^3*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			

Oscillatoriales	Oscillatoriales	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Nostocales	Nostocales	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Cryptophyceae	Cryptophyceae	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Dinophyceae	Dinophyceae	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Prymnesiophyceae	Prymnesiophycea e	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Chrysophyceae	Chrysophyceae	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Eupodiscales	Eupodiscales	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Other Diatomophyceae	Other Diatomophyceae	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Euglenophyceae	Euglenophyceae	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Chlorophyceae	Chlorophyceae	mm³*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			

Prasinophyceae	Prasinophyceae	mm^3*l-1	Archipelago Sea	Summer	July-Sept.	1991-2009, excl. 1995, 2005	SYKE			
Pikeperch recruitment	Pikeperch_recr	million 2-year-old recruits	Archipelago Sea	Annual		1980-2006	FGFRI			
Perch recruitment	Perch_recr	million 3-year-old recruits	Archipelago Sea	Annual		1980-2005	FGFRI			
Pikeperch stock (ages ≥3)	Pikeperch_ STOCK	million individuals	Archipelago Sea	Annual		1980-2007	FGFRI			
Pikeperch stock (ages ≥3)	Perch_STOCK	million individuals	Archipelago Sea	Annual		1980-2007	FGFRI			

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Hänninen, J., Vuorinen, I. Helminen, H., Kirkkala, T. and Lehtilä, K. 1997. Trends and Gradients in Nutrient Concentrations and Loading in the Archipelago Sea, Northern Baltic, in 1970–1997. Estuarine, Coastal and Shelf Science 50, 153–171.

Persson, L., Diehl, S., Johansson, L., Andersson, G. & Hamrin, S. F. 1991. Shifts in fish communities along the productivity gradient of temperate lakes -- patterns and the importance of size-structured interactions. Journal of Fish Biology 38, 281-293.

A4.9. Holmön – W Bothnian Bay coast (BBc)

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

For the integrated analyses in the Holmön area in total 28 variables were considered: 8 physical, 6 nutrient, 4 zoopankton, 5 macro-zoobenthos and 5 fish datasets. No data on phytoplankton and higher trophic levels (i.e. seals and birds) were hence included. The rationale for this was that reliable local information was not available at the time for the analyses, and corresponding open sea information was not considered representative enough. For the physical and nutrient variables, both coastal (6) and offshore (8) time-series were included. All datasets were compiled to one data point e per year and covered the period 1994–2009.

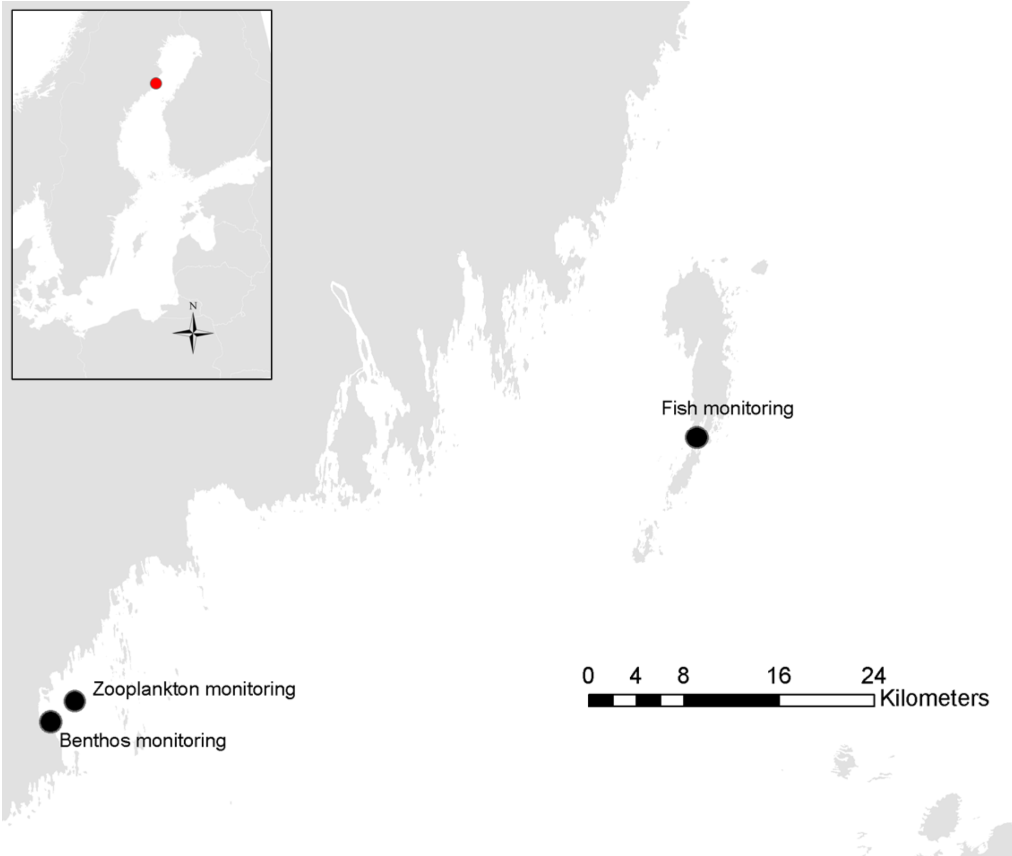

Figure BBc-1. Location of the Holmön area at the coast of Bothnian Bay.

Trend analyses

Hydrography

Variables as temperature, salinity, ice break date 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. Spring temperature was included both at the local and offshore (basin wide) scale, and the coastal data also included summer temperature. Since no local data was available, only offshore values of salinity (annual average) were used. Ice break date was included in the analyses since the area is covered by ice for a substantial period of the year, and the abundance of some species is anticipated to be related to the extent of ice coverage. Previous studies have suggested that large-scale climatic conditions influence the structure of offshore (Möllman *et al.*, 2009, Dieckman and Möllman 2010) and coastal systems in the Baltic Sea (Olsson *et al.*, in review). In this analysis we used the Baltic Sea index as a proxy for large-scale climatic perturbation in the area. 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, there has been a decrease in salinity and increase in offshore spring temperature, and a tendency for an earlier onset of ice break. Hence, there was no temporal trend for any of the coastal hydrographical variables considered.

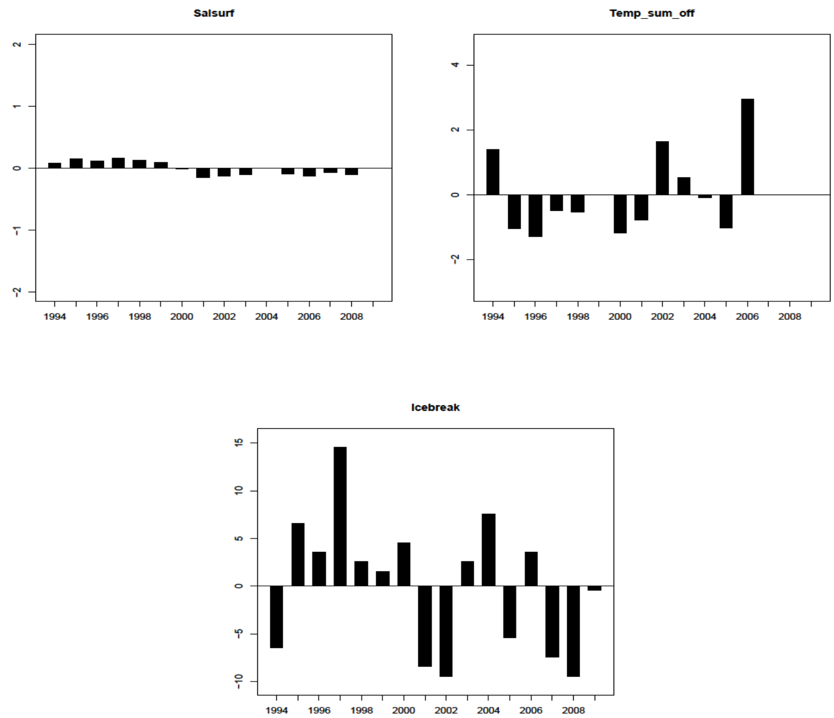

Figure BBc-2. Long-term hydrographic changes in the Holmön area: anomalies from the overall mean in salinity (psu), temperature (°C) and ice break date. Salsurf denotes offshore surface salinity (annual averages), Temp_sum_off denotes local spring temperature (May), and Icebreak denotes ice break date.

Nutrients

Impact of nutrient concentrations and eutrophication 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 as well as total discharge of nitrogen and phosphorous from land to the Bothnian Bay was used.

There was a decrease in offshore concentrations of DIN and an increase in the total discharge of phosphorous for the whole of Bothnian Bay between 1994–2009. In addition, there has been an almost significant increase in local water transparency.

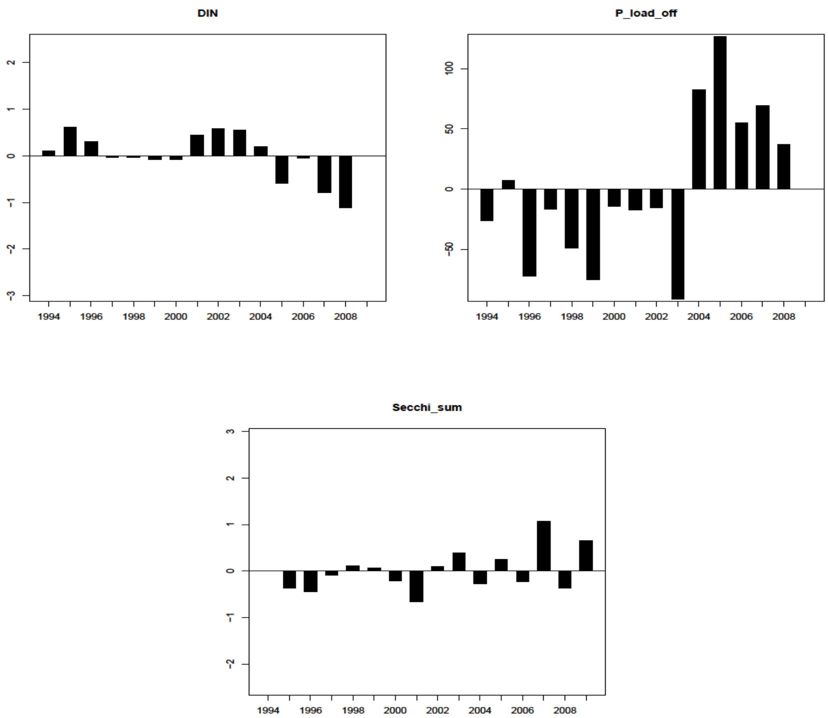

Figure BBc-3. Long-term changes in nutrients in the Holmön area. DIN denotes offshore concentration of inorganic nitrogen, P_load_off denotes total discharge of phosphorous from land to the Bothnian Bay, and Secchi_sum denotes local water transparency in August.

Fishing

As a proxy for local fishing pressure the total landed catch (all species and gear) 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 has been strong interannual fluctuations but no temporal trend in coastal fishing pressure, whereas the fishing mortality of herring decreased during the time-period assessed.

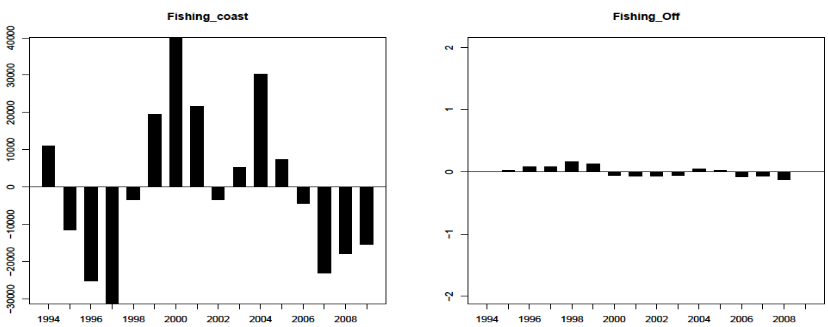

Figure BBc-4. Long-term changes in fishing pressure (coastal left panel; regional right panel) in the Holmön area: anomalies from the overall mean in total catches of all species and gears (coast) and fishing mortality for herring (3–7 years old, regional).

Zooplankton

Four 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.*) and rotifers (*Keratella sp.* and *Synchatea sp.*). Samples represent the concentration of each group of zooplankton at 17–20 meters depth.

Based on this taxonomic grouping the zooplankton community has exhibited large interannual fluctuations, but the concentration of calanoid copepods has decreased quite dramatically between 1994–2009.

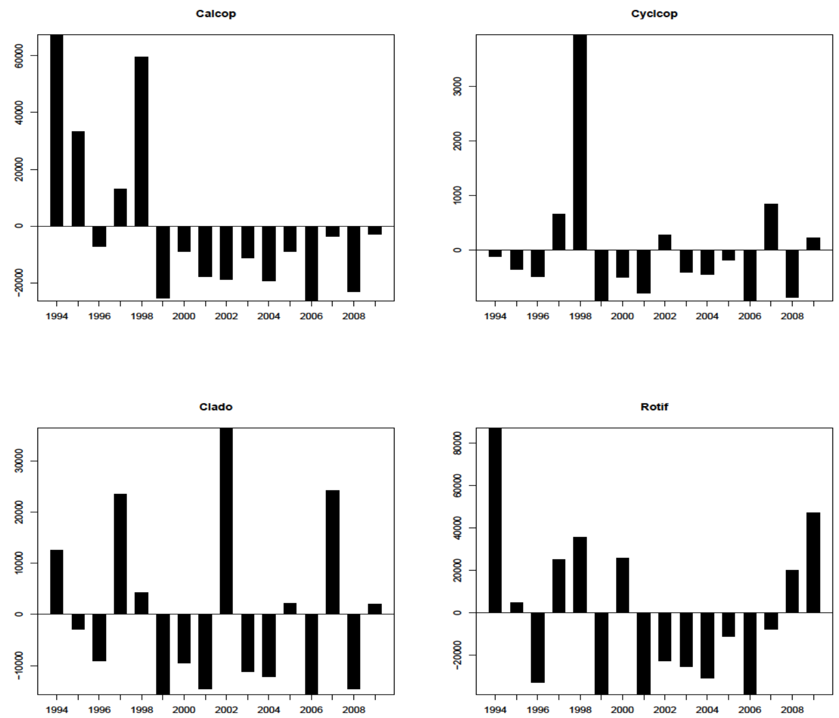

Figure BBc-5. Long-term changes in zooplankton groups in the Holmön area: anomalies from the overall mean in concentrations (ind/m³). Calcop denotes calanoid copepods, Cyclcop denotes cyclopoid copepods, Clado denotes cladocerans and Rotif denotes rotifers.

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* exhibit 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 1994–2009.

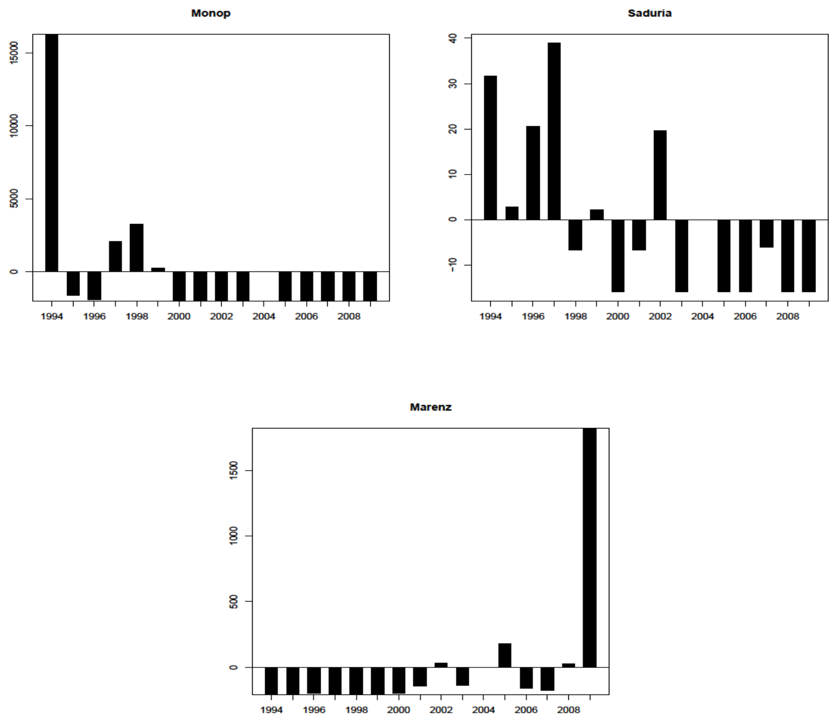

Figure BBc-6. Long-term changes in the abundance of zoobenthos in the Holmön area: anomalies from the overall mean abundance (ind/m²) of *Monoporeia affinis* (Monop), *Saduria entomon* (Saduria) and *Marenzelleria sp.* (Marenz).

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*) and 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 perch, ruffe and herring during the time-period assessed. The abundance of roach has, however, increased, whereas the abundance of whitefish during recent years has decreased with a factor eight in comparison to the mid-1990s.

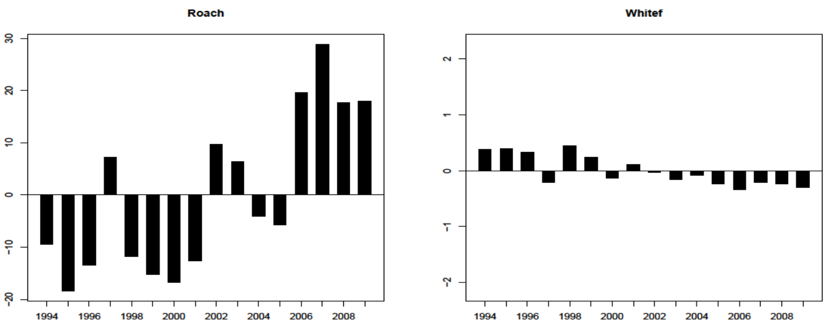

Figure BBc-7. Long-term changes in the abundance of fish in the Holmön area: anomalies from the overall mean in numbers per night an gillnet of roach and whitefish (Whitef) during sampling in August.

Integrated analyses

All variables

An overview of the temporal development of the variables in Holmön time-series is presented in Figure BBc-8. Variables are sorted according to their PC1 loadings of the subsequently performed PCA, generating a pattern with variables at the bottom that revealed 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 a lot of 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*, whitefish, regional fishing pressure, ruffe, *Saduria* and calanoid copepods where generally high during the first five years of the time-period assessed. Despite less obvious, the values for coastal summer temperature, *Marenzelleria*, offshore spring temperature and roach was on average relatively high between 2002–2009.

The first group of variables comprises e.g. the brittle stars (*Amphiuridae*), corkwing wrasse, eel, local and offshore summer temperature as well as local water transparency in August. Decreasing values is observed for the zoobenthos groups hooded shrimps (*Cumacae*), the polychateas (*Spionidae* and *Capitellidae*) and bivalves (*Montacutidae*), as well as shorthorned sculpin, eelpout, pH and dissolved inorganic phosphorous in the off-shore area.

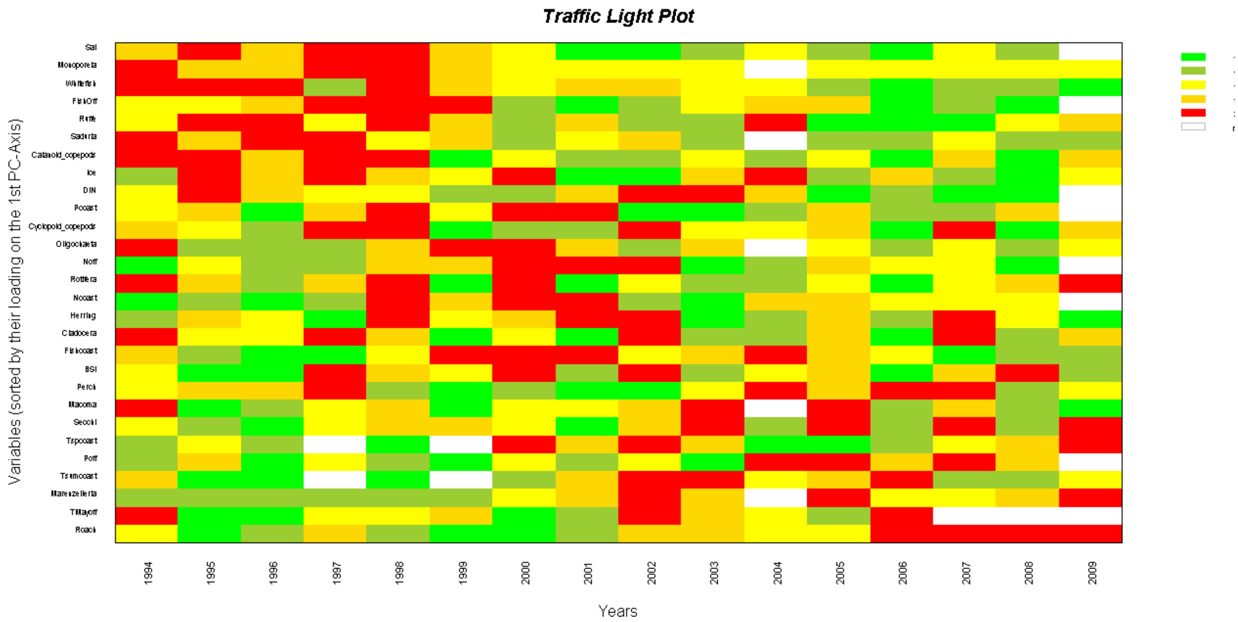

Figure BBc-8. Traffic-light plot of the temporal development of the Holmön time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Acronyms are explained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

The ordination of yearly measures by a standardized PCA resulted in 26.6 and 15.8% of the explained variance on the first two principal components (PCs; Figure BBc-9). The first PC generally reflects both biotic and abiotic variables, and the years 1994–1998 represents a cluster all having positive loadings. According to the first PC, the state of the system has gone through a transitional period during 1998–2002 where after the last eight years cluster together and all years have negative scores. Offshore salinity, regional fishing effort, *Monoporeia*, calanoid copepods and whitefish generally have strong positive loading on PC1 (i.e. higher values before 2001), whereas offshore spring temperature, coastal summer temperature, roach and *Marenzelleria* have the strongest negative loadings. The temporal development of the second PC is not as straight forward but generally separates the years during the early 2000s from the remaining years in the time-series. High values of coastal fishing pressure and discharge of nitrogen as well as oligochates characterise the early 2000s, whereas the abundance of cyclopoid copepods, cladocerans and rotifers were below average during this time-period.

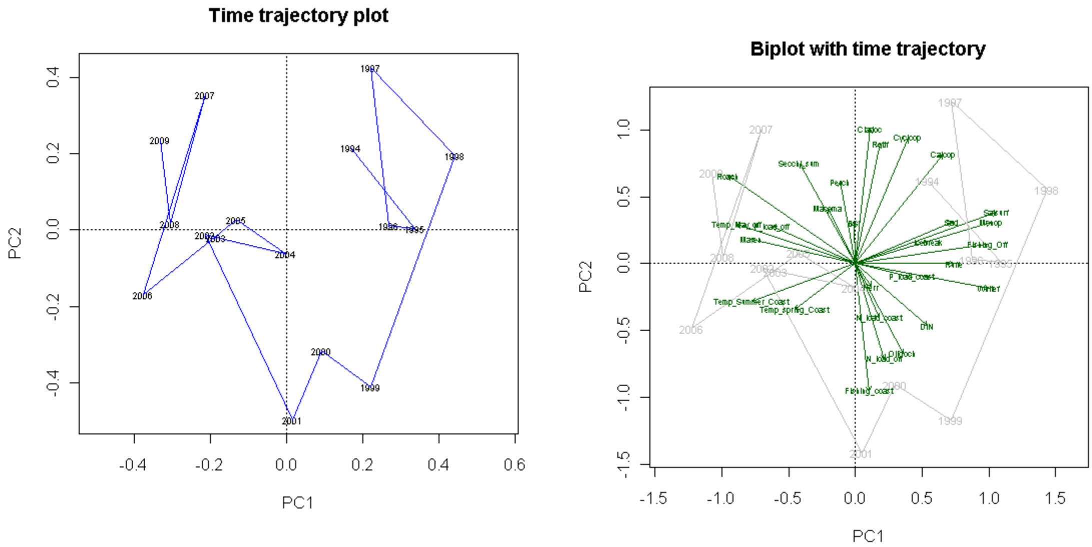

Figure BBc-9. Results of the standardized principal component analysis using all time-series in the Holmön area. The left graph shows sample scores (years) on the first factorial plane, with a time trajectory. The right graph shows the corresponding variable loadings. PC1 accounted for 26.6 % of the variation and PC2 for 15.8 %.

The outcome of the two forms of discontinuity analyses departed from each other. Whereas the results from the conciss cluster- and broken stick analysis suggested at least two shifts (1998/1999 and 2006/2007), the chronological clustering analysis failed to detect any shifts at the four lowest levels of alpha (0.01, 0.05, 0.1 and 0.2; Figure BBc-10).

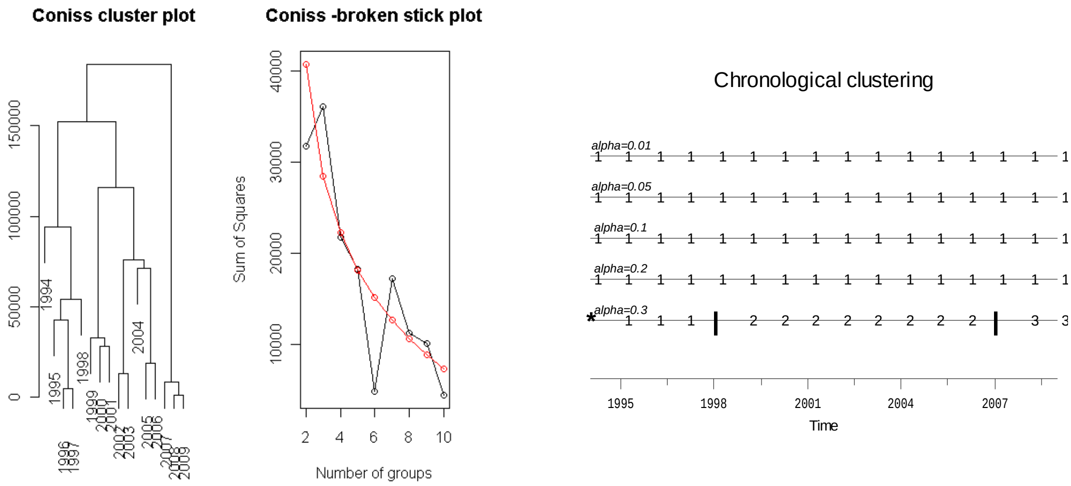

Figure BBc-10. Results of the Conciss- and chronological cluster analyses performed on all variables.

Biotic variables

The temporal development of the biota in Holmön generally follows what was seen for the data set including all variables (PCs; Figure BBc-11). The two first components of the ordination of yearly measures by a standardized PCA explained 30.9 and 22.6 % respectively of the total variation (Figure BBc-11). As for the first PC of the all variables data set the years 1994–1998 group (all years having negative values), the following five years represent a transitional period and the period between 2002–2009 cluster and all years having positive loadings. Whitefish, calanoid copepods, *Monoporeia* and *Saduira* all had a strong negative association with the first PC, whereas roach and *Marenzelleria* exhibited the strongest positive correlation with the axis. For the second PC, 1999 represents an outlier in having the highest negative loading compared to the other years. Interestingly, in 1999 the value of the majority of biotic variables was among the lowest over the period assessed, whereas the abundance of oligochaetes peaked and the catches of whitefish was among the highest in this very year. Worth noting is that none of the abiotic variables had an exceptional value in 1999, but the value of both coastal and regional fishing pressure was above average.

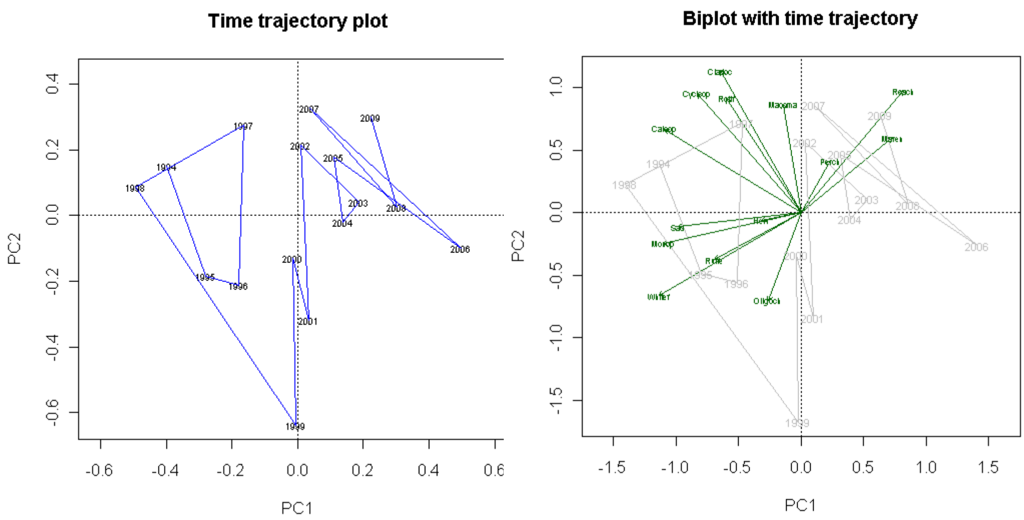

Figure BBc-11. Results of the standardized principal component analysis using the biotic time-series in the Holmön area. The left graph shows sample scores (years) on the first factorial plane, with a time trajectory. The right graph shows the corresponding variable loadings. PC1 accounted for 30.9 % of the variation and PC2 for 22.6 %.

The conciss cluster- and broken stick analysis is hard to interpret and in total seven clusters are recognised. The first one is as suggested by the traffic light plot 1994–1998, then each of the years during the "transitional period" (1999, 2000, 2001 and 2002) are identified as a single cluster. The two last shifts are 2002/2003 (grouping 2003–2006) and 2006/2007 (grouping 2007–2009). As for the all variables data set, the chronological clustering analysis failed to detect any shifts at the four lowest levels of significance (alpha = 0.01, 0.05, 0.1 and 0.2; Figure BBc-12).

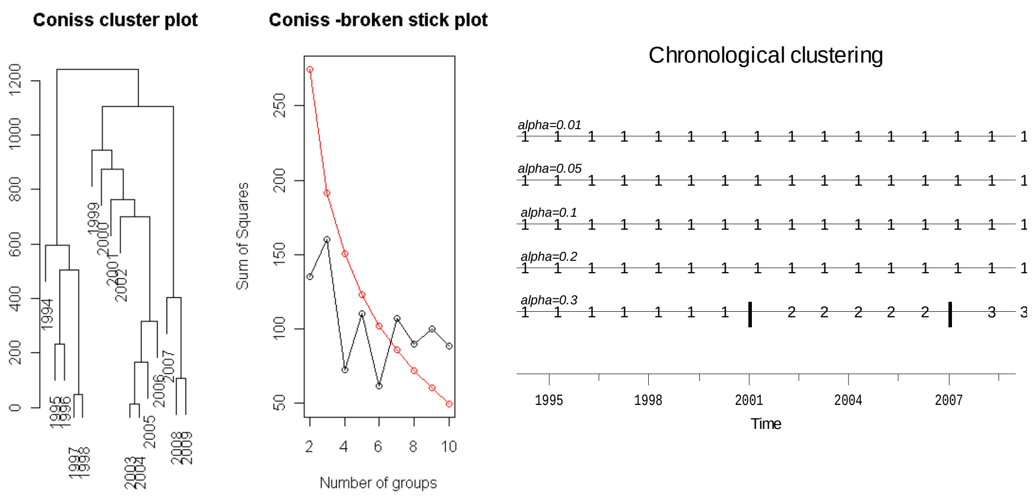

Figure BBc-12. Results of the Conciss- and chronological cluster analyses performed on biotic variables.

The outcome of these preliminary analyses is not that straight forward when it comes to the discontinuity analyses. There is, however, generally some coherence across the two data sets (all variables and biotic variables only) in both the conciss cluster- and broken stick and PCA analyses in that the years 1994–1998 and 2002–2009 cluster. The period between these two groups of years seems to represent a transitional period with a comparably high rate of change. The abiotic conditions during the first period (1994–1998) was characterised by above average values of offshore salinity and regional fishing pressure and below average values for coastal summer and offshore spring temperature. The last period (2002–2009) is in contrast characterised by the opposite conditions; decreased salinity and fishing pressure and increased coastal and offshore temperatures. During the transitional period, the discharge of nitrogen and phosphorous, coastal spring temperature and coastal fishing pressure was above average. The biotic variables have changed in accordance to this where the abundance of species favoured by lower water temperatures like whitefish and *Monoporeia* and *Saduria* was above average between 1994–1998. During these years the abundance of calanoid copepods was also above average. The biotic response of the transitional period with above average abundance of oligochaetes and low abundance of perch is not that easy to explain. There might, however, be links between the increased nutrient concentrations and the high abundance of the oligochaetes that are typically detritus feeders and the high coastal fishing pressure and low abundance of perch. During the last years the above average abundance of roach is likely a response to decreased salinity and increased temperature. The high abundance of *Marenzelleria* during recent years is likely an effect of colonisation in the area rather than a response to abiotic conditions.

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Table BBc-1. Time-series used for the integrated ecosystem analysis in Holmön.

Variable	Acronym	Unit	Area	Season	Month	Years	Source
biotic							
Calanoid copepods (*Acartia sp., Eurytemora sp. and Limnocalanus macrurus*)	Calcop	ind*m-3	B3 Norrbyn	Summer	May-Oct	1994-2009	SMHI
Cyclopoid copepods	Cyclcop	ind*m-3	B3 Norrbyn	Summer	May-Oct	1994-2009	SMHI
Cladocerans (*Bosmina coregoni maritime, Evadne nordmanni and Podon sp.*)	Clado	ind*m-3	B3 Norrbyn	Summer	May-Oct	1994-2009	SMHI
Rotifers (*Keratella sp. and Synchatea sp.*)	Rotif	ind*m-3	B3 Norrbyn	Summer	May-Oct	1994-2009	SMHI
Macoma baltica	Macoma	ind*m-2	N7 Norrbyn	Spring	May	1994-2009	SMHI
Marenzelleria sp.	Maernz	ind*m-2	N7 Norrbyn	Spring	May	1994-2009	SMHI
Monoporeia affinis	Monop	ind*m-2	N7 Norrbyn	Spring	May	1994-2009	SMHI
Oligochaeta sp.	Oligoch	ind*m-2	N7 Norrbyn	Spring	May	1994-2009	SMHI
Saduria entomon	Saduria	ind*m-2	N7 Norrbyn	Spring	May	1994-2009	SMHI
Perch (*Perca fluviatilis)*	Perch	CPUE (abundance)	Holmön	Summer	August	1994-2009	SBF
Ruffe *(Gymnocephalus cernus)*	Ruffe	CPUE (abundance)	Holmön	Summer	August	1994-2009	SBF
Roach (*Rutilus rutilus*)	Roach	CPUE (abundance)	Holmön	Summer	August	1994-2009	SBF
Whitefish (Coregonus maranea)	Whitef	CPUE (abundance)	Holmön	Summer	August	1994-2009	SBF
Herring (*Clupea harengus*)	Herr	CPUE (abundance)	Holmön	Summer	August	1994-2009	SBF
abiotic/environmental							
Water transparency	Secchi_Sum	meters	Holmön	Summer	August	1994-2009	SBF
Coastal temperature in summer	Temp_Summer_Coast	degrees C	Holmön	Summer	July-Sept	1994-2009	SBF
Coastal temperature in Spring	Temp_spring_Coast	degrees C	Holmön	Spring	May-June	1994-2009	SBF
Local nitrogen loading	N_load_Coast	tonnes	Local county, Västerbotten (AC)	Annual	NA	1994-2009	SLU
Local phosphorous loading	P_load_Coast	tonnes	Local county, Västerbotten (AC)	Annual	NA	1994-2009	SLU
Fishing pressure, coast (all gears and species)	Fishing_coast	kg	ICES rectangel 5665	Aunnal	NA	1994-2009	SBF
Offshore surface temperature, spring	Temp_sum_off	degrees C	Stations BO3/A3,F2,F3/A5,RR1,RR7	Spring	May	1994-2009	SMHI
Offshore salinity surface	Salsurf	psu	Stations BO3/A3,F2,F3/A5,RR1,RR7	Annual	Dec-March	1994-2009	SMHI
Dissolevd inorganic nitrogen	DIN	mmol*l-1	Stations BO3/A3,F2,F3/A5,RR1,RR7	Winter	Nov-Jan	1994-2009	SMHI
Regional nitrogen loading	N_load_off	tonnes	Bothnian Bay, AC & BD county	Annual	NA	1994-2009	SLU
Regional phosphorous loading	P_load_off	tonnes	Bothnian Bay, AC & BD county	Annual	NA	1994-2009	SLU
Ice break date	Icebreak	-	Bothnian Bay	Annual	NA	1994-2009	SMHI*
Fishing index, F 3-7 years herring	Fishing_off	-	Bothnian Bay	Annual	NA	1994-2009	ICES (WGBFAS)
Baltic Sea index	BSI	-	Baltic Sea	Winter	Dec-March	1994-2009	IFM

*** Calculated as date when the ice cover in the Baltic Sea was less than 1000 km², by Lars Axell, SMHI.**

A4.10. The Central Baltic Sea offshore pelagic foodweb

The integrated trend and status assessment of the offshore pelagic foodweb in the Central Baltic Sea was updated with biotic data extending to 2009, including 31 variables from four trophic levels. Due to large discrepancies in some of the abiotic data extracted (via the Baltic Environmental Database, http://nest.su.se/models/bed.htm, hosted by the Baltic Nest Institute) this year compared to those assembled for WGIAB 2010 (ICES 2010), no multivariate analyses of the hydro-climatic, nutrient, and fishing variables were performed during the meeting. Instead, key hydro-climatic factors (with consistent data) were analysed in relation to recruitment of Eastern Baltic cod (see section 6.2.2), and provided as ecosystem-based stock advice to the ICES Baltic Fisheries Assessment Working Group (ICES 2011).

For the multivariate ecosystem status and trend analyses, the biotic data were first ln(x+1)-transformed to enhance linearity. A principal component analysis (PCA) was then performed on the correlation matrix and chronological clustering was made on the normalized data matrix to be comparable with the PCA results. In addition to analyses of the updated monitoring time-series assemble by WGIAB, the clustering and ordination methods were also applied on modelled biogeochemical data, to explore how known biogeochemical processes may result in shifts in hydro-climatic and nutrient conditions.

Central Baltic Sea biotic changes

When performed only on the biotic variables, the first two axes of the PCA explained 33% and 12%, respectively. The variables with highest negative loading on PC1 were herring and cod variables as well as summer *Pseudocalanus* biomass, whereas sprat SSB, spring *Acartia spp.* and *Temora* biomasses, and summer chloroplyll *a* (chl *a*) were positively related to PC1 (Figure CBS-1). PC2 were mainly driven by changes in the phytoplankton communities, with Bornholm Basin summer biomasses of dinoflagellates, cyanobacteria and chl *a* having highest loadings. The dominant changes in the set of biotic variables, as a whole, can be described by the time scores in the PC1-PC2 plane, and time trajectories of these principal components (Figure CBS-2). Whereas PC1 (dominated by fish and zooplankton) exhibits a gradual change, PC2 (dominated by phytoplankton) decreased until 1989 where after it increased rapidly, and again in the last two years of the assessment (Figure CBS-2). Chronological clustering indicates four significantly different compositions of the biota, with shifts in 1985/1986, 1989/1990, and 1995/1996 (robust across alpha=0.01, 0.05, 0.1), whereas when using the broken stick method, only the 1989 shift is significant. Thus, none of the methods indicate any recent changes in ecosystem composition (in the recent decade), despite possible increases in cod abundance and decreases of sprat in the last two years (ICES 2011). This suggests that the foodweb currently remains in the ecosystem "regime" characterized by e.g. low levels of cod and *Pseudocalanus acuspes*, and high sprat stock with consequent changes in foodweb function (Casini *et al.* 2009).

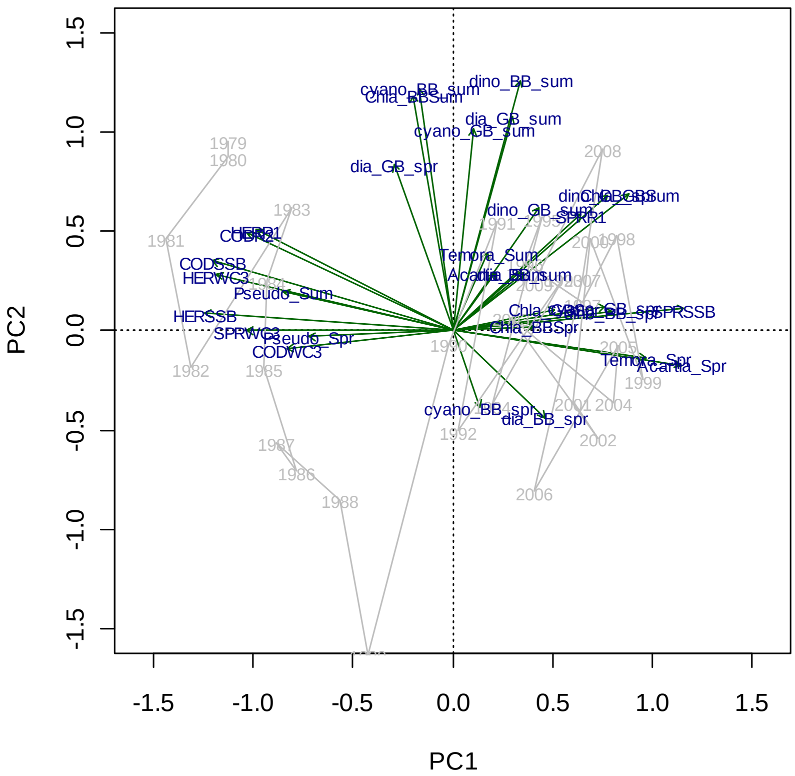

Figure CBS-1. Principal component analysis using 31 biotic variables from the Central Baltic Sea foodweb. Sample scores (years) on the first factorial plane with a time trajectory are shown in grey, and corresponding variable loadings in grey. PC1 accounted for 33 % of the variation and PC2 for 12%.

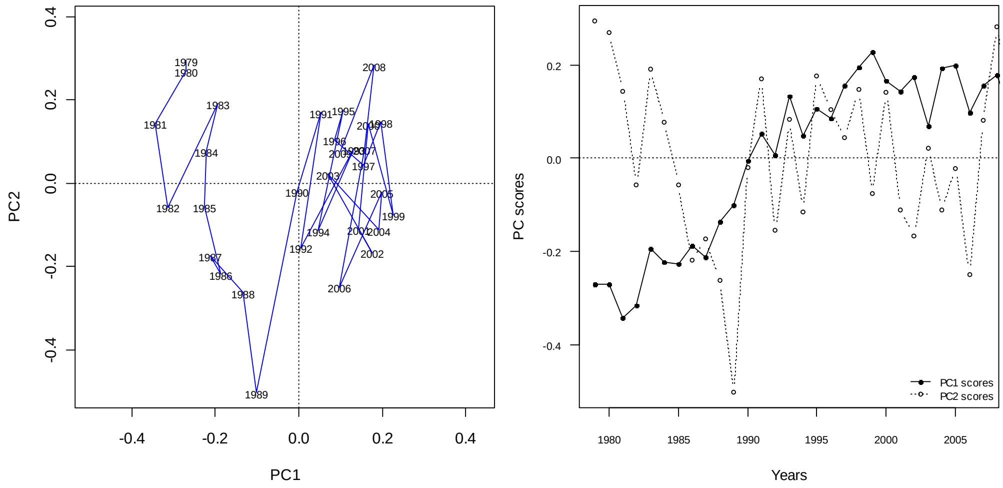

Figure CBS-2. Time trajectory of year scores in the PC1-PC2 plane (left) and time trajectories of PC1 (filled circles) and PC2 (open circles) from the PCA on biotic variables from the Central Baltic Sea (right).

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