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

10–14 February 2014

Kiel, Germany

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Contents

Executive summary

The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) was established in 2007 as a forum for developing and combining ecosystem-based management efforts for the Baltic Sea. The group is intended to serve as a scientific counterpart and support for the ICES Baltic Fisheries Assessment Working Group (WGBFAS) as well as for efforts and projects related to Integrated Ecosystem Assessments (IEA) within ICES and HELCOM. The group works in cooperation with similar groups within the ICES SCICOM Steering Group on the Regional Seas Programme (SSGRSP).

The WGIAB meeting was held in Kiel, Germany, from 10–14 February 2014, with 27 participants from five Baltic countries. The meeting was chaired by Lena Bergström, Sweden, Christian Möllmann, Germany and Maciej Tomczak, Sweden.

Within the Second year of its three-year terms of references, the main working activities of WGIAB in 2014 were to i) conduct Integrated Trend Assessments (ITAs) of several Baltic Sea subsystems with the goal to publish these as a Special Issue in a peer-reviewed journal, ii) prepare a demonstration IEA for Baltic fish stocks (codename: DEMO), and iii) to start the application of Bayesian Networks for analyses of Baltic Sea ecosystem functioning.

A central point of the meeting was to discuss and design a demonstration IEA for the assessment and advice of the main Baltic Sea fish stocks. The group developed a strategy for the DEMO-IEA that is intended to be conducted during a special workshop in Askö (Sweden) in August 2014 and to be presented during the ICES ASC 2014 in A Coruña (Spain). However, recent problems with the assessment of Eastern Baltic cod might result in changes in the setup of the workshop.

For the further work of WGIAB and the DEMO activity, data collation activities with other expert groups within ICES and especially establishing a tighter connection to HELCOM is considered important by WGIAB.

1 Administrative details

Working Group name

ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea

Year of Appointment

2014

Reporting year within current cycle (1, 2 or 3)

2

Chairs

Christian Möllmann, Germany

Lena Bergström, Sweden

Maciej T. Tomczak, Sweden

Meeting venue

Kiel, Germany

Meeting dates

10–14 February 2014

Figure 1. Participants of WGIAB 2014. Upper row from the left: Pavel Gasjukov, Marcos Llope, Jörn Schmidt, Anna Gårdmark, Saskia Otto, Christian Möllmann, Margit Eero, Laura Uusitalo, Maciej T. Tomczak, Joachim Gröger. Front row: Martin Lindegren, Lauréne Pécuchet, Andrea Rau, Jan Dierking, Henn Ojaver, Burkhard von Dewitz, Thorsten Blenckner, Phil Levin, Lena Bergström, Rabea Diekman, Kerli Laur, Heikki Peltonen, Ivars Putnis, Jens Olson, Michele Casini. Not on the picture Rudi Voss and Stefan Neuenfeldt.

2 Terms of Reference a) – e)

ToR	Description
A	Increase understanding of Baltic Sea ecosystem structure and functioning, with a focus on species interactions and trends over different temporal and spatial scales, and the identification of key species and processes for maintaining functioning ecosystems and sustainable use of these;
B	Support development of a framework for integrated advice for fisheries management, by data exchange, model evaluation and scientific interaction with the Baltic Sea assessment working groups.
C	Further develop the integrated ecosystem assessment cycle, and apply case studies to investigate trade-offs between different management objectives, including effects on ecosystem services and effects at different spatial and temporal scales.
D	Identify potential regional observing assets (both inside and outside ICES) necessary to support development of regional ecosystems assessments.
E	Produce an approach for monitoring and developing assessment methods for the top three anthropogenic pressures on ecological characteristics described in the national MSFD reports (submitted in October 2012) for the appropriate regions.

3 Summary of Work plan

2013	Annual meeting, intersessional work on research articles, Focus on ToR a and b Additional ToR d and e
2014	Annual meeting, intersessional work on research articles, Focus on ToR b and c
2015	Annual meeting, intersessional work on research articles Focus on ToR b and c

4 List of Outcomes and Achievements of the WG in this delivery period

Publications based on WGIAB activities, published 2013–2014

Arula, T., Gröger, J., Ojaveer, H., and Simm, M. 2014. Shifts in the Spring Herring (*Clupea harengus membras*) Larvae and Related Environment in the Eastern Baltic Sea over the Past 50 Years. PloS one, 9(3), e91304.

Bartolino, V., Margonski, P., Lindegren, M., Linderholm, H., Cardinale, M., Rayner, D., and Casini, M. 2014. Forecasting fish stock dynamics under climate change: Baltic herring (*Clupea harengus*) as a case study. *Fisheries Oceanography*, *23*(3), 258–269.

Gårdmark, A., Lindegren, M., Neuenfeldt, S., Blenckner, T., Heikinheimo, O., Müller-Karulis, B., Niiranen, S., Tomczak, M., Aro, E., Wikström, A., and Möllmann, C. 2013. Biological Ensemble Modelling to evaluate potential futures of living marine re-sources. Ecological Applications, 23(4), 742–754.

Möllmann, C., Lindegren, M., Blenckner, T., Bergström, L., Casini, M., Diekmann, R., and Gårdmark, A. 2013. Implementing ecosystem-based fisheries management: from single-species to integrated ecosystem assessment and advice for Baltic Sea fish stocks. *ICES Journal of Marine Science: Journal du Conseil*, fst123.

Olsson, J., Bergström, L., Gårdmark, A. 2013. Top-Down Regulation, Climate and Multi-Decadal Changes in Coastal Zoobenthos Communities in Two Baltic Sea Areas. PLoS ONE 8(5): e64767. doi:10.1371/journal.pone.0064767

Otto, S. A., Kornilovs, G., Llope, M., and Möllmann, C. 2014. Interactions among density, climate, and foodweb effects determine long-term life cycle dynamics of a key copepod. *Marine Ecology Progress Series*, *498*, 73-U408.

Otto, S. A., Diekmann, R., Flinkman, J., Kornilovs, G., and Möllmann, C. 2014. Habitat Heterogeneity Determines Climate Impact on Zooplankton Community Structure and Dynamics. *PloS one*, *9*(3), e90875.

Tomczak, M. T., Heymans, J. J., Yletyinen, J., Niiranen, S., Otto, S. A., and Blenckner, T. 2013. Ecological Network Indicators of Ecosystem Status and Change in the Baltic Sea. *PloS one*, *8*(10), e75439.

Walther, Y. M., and Möllmann, C. 2013. Bringing integrated ecosystem assessments to real life: a scientific framework for ICES. *ICES Journal of Marine Science: Journal du Conseil*, fst161.

Advisory products

Analyses of indicators of recruitment environment for Gulf of Riga herring and Eastern Baltic Cod for input to WGBFAS (Section 6)

Input on ToR B and C are reported in Sections 6 and 7.

Datasets

One core activity of the group is to maintain and regularly update datasets representing open sea and coastal foodwebs, including biotic variables, environmental variables and anthropogenic pressures (ToR A). A synthesis of main trends and drivers of coastal foodwebs were presented by Jens Olson (Olsson *et al.*, in prep.). The update of the open sea dataset (Central Baltic Sea – CBS) until 2012 and results of the respective Integrated Trend Analysis (ITA) was given by Maciej T. Tomczak (prepared by Tomczak and Müller-Karulis). During the meeting datasets for Gulf of Riga (GoR), Gulf of Finland (GoF) and Western Baltic Sea have been compiled. A summary of results of the ITAs are given in Section 5 and Annex 3.

Methodological developments

WGIAB continuously collects data and develops tools and models as well as strategies to support the evolution of a Baltic Sea Integrated Ecosystem Assessment framework. Progress in relation to this activity is further reported in Section 7.

Modelling outputs

Not included as a planned activity in 2014

5 Progress report on ToR A – Baltic Sea ecosystem structure and functioning

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

In addition to the main activities (ToR B and C, ToR A has been adressed during the meeting through the presentation and discussion of ITA results, and by planning of activities for common publications. Some main focal points were:

5.1 Historical regime shifts in the Baltic Sea

A summary of current understanding on long-term temporal patterns in the Baltic Sea open seafood web was presented by Maciej T. Tomczak (Tomczak and Müller-Karulis *et al.*, in prep). Analyses of changes in foodweb components over time clearly show the presence of long-term changes and regime shifts, relating to climate-related drivers and fishing pressure (Möllmann *et al.*, 2009). The results also show links between changes in fish stocks and eutrophication symptoms (Casini *et al.*, 2012), since eutrophication first caused a productivity increase, which only after a time-lag decreased bottom-water oxygen concentrations sufficiently to impair cod recruitment.

However, as the currently used WGIAB datasets typically extend only back to the 1975, it is not possible to assess trends occurring earlier than that, or to identify any potential historical regime shifts prior to the 1970s. It would be of great value to increase knowledge also on past events, in order to support the assessment of reference states in Baltic Sea marine management. In some cases, historical information can be improved by data collation, if information is available but not yet accessible longer back in time (e.g. Baltic Sea fish stocks, macrozoobenthos). In other cases, modelling is the most useful approach.

Integrated analyses based on reconstructed time-series on hydrographical and biogeochemical and biological variables (using the BALTSEM model; Gustafsson *et al.*, 2012) in combination with historical data (i.e. Eero *et al.*, 2012), when available, may be useful for assessing long-term trends and regime shifts further back in time, and to provide information of past and potential future ecosystem configurations (Müller-Karulis *et al.*, in prep, Tomczak *et al.*, in prep). The approach was considered promising to support the identification of management targets and WGIAB will continue to explore a combination between modelling and data analysis to expand the present analysis to higher trophic levels.

The updated ITA analysis on long-term historical trends of Baltic biota showing importance of including benthic component into integrated analysis. Very high catches of flatfish (plaice and flounder) together with data on oxygen, salinity and fishing pressure during end 1930s and beginning of 1940 suggest substantial changes or regime-shift at the ecosystem structure from benthic to more pelagic community. Results of that investigation are planned for publication in 2014 by Tomczak *et al.* (in prep.).

5.2 Regeneration potential of the Baltic Sea inferred from historical records

Marcos Llope was invited to give a seminar for WGIAB members about a study on the “Regeneration potential of the Baltic Sea inferred from historical records”. Overfishing of large predatory fish populations has resulted in lasting restructurings of entire marine foodwebs worldwide, with potential immense socio-economic consequences. Fortunately, some degraded ecosystems have started to show signs of regeneration. A key challenge for resource management is to anticipate the degree to which regeneration is possible, given the multiple threats ecosystems face. He showed that under current hydroclimatic conditions, complete regeneration of a heavily altered ecosystem such as the Baltic Sea would not be possible. Instead, as the ecosystem regenerates it moves towards a new ecological baseline. This new baseline is characterized by lower and more variable biomass of the commercially important Atlantic cod, even under very low exploitation rates. Consequently, societal costs increase due to higher risk premium caused by increased uncertainty in biomass and reduced consumer surplus. Specifically, the combined economic losses amount to about 120 million € per year, which equals half of today's maximum economic yield for the Baltic cod fishery. The presented analyses suggest that shifts in ecological and economic baselines, in combination with increased biomass variability, lead to higher economic uncertainty and costs for exploited ecosystems, in particular under climate change.

5.3 Update of ITA for Baltic sub-basins (CBS and WBS) and Gulfs (GoR and GoF)

In order to support the regular ITA work, the group updated a number of open sea datasets. A new system included in the ITA work is the Western Baltic. Initiatives were also put forward to revise the Gulf of Finland datasets in recognition of, and by potentially mutual benefit from, the Gulf of Finland Year 2014 programme that is currently conducted in co-cooperation by Finland, Russia and Estonia (www.gof2014.fi). Information and results from these two areas are presented in Annex 4.

5.3.1 Central Baltic Sea (CBS)

In total, 61 variables were included in an integrated analysis, 27 characterizing abiotic conditions (climate, hydrography, nutrients, oxygen) and 34 describing biotic conditions (phytoplankton, zooplankton, fish). The principal component analysis of the entire dataset picked up mostly the properties of the biotic data, overlain by a temperature signal contributing to PC1 for the combined dataset. Therefore, the principal component year scores mainly follow the changes in fish stocks and zooplankton. Also in the analysis of the entire dataset the change in year scores for 2011 and 2012 caused presumably by the gradual recovery of the cod stock, is clearly visible.

5.3.2 Gulf of Riga, open sea (GoR)

For the Gulf of Riga, not all time-series could be updated. Due to cuts in the Latvian marine monitoring programme, no winter nutrient data are available for 2010, 2011 and 2013; also, load calculations for the Gulf of Riga were not updated for 2012–2013. However, Daugava River run-off was available as a load proxy. In total, 25 variables were included in the analysis. They describe climatic conditions (1 variable), nutrient load and run-off to the Gulf (3 variables), hydrographic conditions (3 variables), nutrient concentrations (2 variables), phytoplankton (4 variables), zooplankton (7 variables), as well as fish and fisheries (5 variables). Analysis of available data identifies two regime shifts in PC1 for the Gulf of Riga dataset, in 1982/1983 and 1988/1989. The first regime shifts marks a slight summer warming in the Gulf and initial higher summer phytoplankton biomass, whereas 1988/1989 initiated the major restructuring in water temperatures, zooplankton biomass and herring stock size in the Gulf of Riga. All details of ITA for GoR are presented in Annex 4.

5.3.3 Gulf of Finland (GoF)

For the Gulf of Finland, a new integrated trend analysis was conducted. The analysis encompassed 27 hydrographic, chemical and biological variables monitored during 1979–2011. As the selected variables were somewhat different from the previous analysis conducted by the WGIAB in 2010, the analysis was not exactly an update of the previous trend analysis.

The analyses suggested that the data from the years 1979–1990 constituted a relative uniform group, but during 1991–1995 the system shifted into a different state, and the data from 1996–2011 was again grouped closely together possibly indicating a shift to an alternative relatively stable state. The transitional period in 1991–1995 occurred at the time when the halocline in the Gulf of Finland eroded and eventually disappeared as the halocline shifted deeper in the Baltic proper towards the end of the 18-year long stagnation period, which lasted until 1993. The transitional period was, unlike the other two time sections, characterized by e.g. a high abundance of benthic fauna on the deep areas. The first period until 1991 is characteristically more oceanic, while the last one represents more a eutrophic and a relatively warm era.

5.3.4 Western Baltic Sea (WBS)

The integrated trend analysis (ITA) for the Western Baltic Sea started with an inventory of available time-series for the important parameters concerning hydrographic, climatic and nutrient conditions as well as biological components such as phytoplankton, zooplankton and fish community and direct anthropogenic influences like fishing pressure (WGIAB 2013). Building on the data collection work done, during this year's WGIAB meeting data issues and statistical analyses to be incorporated were discussed.

For the analyses, the study area encompassing Subdivision 22 and 24 in the Western Baltic Sea will be divided into two main parts: A more salty area in the west including Kiel Bay and Bay of Mecklenburg and a deeper part in the east, the Arkona Basin. Since these areas are very homogeneous concerning topography as well as hydrological and biological characteristics, it seems probable that subregional ITAs are needed incorporating the particular most important parameters.

5.4 Application of the shiftogram

An introduction was given on how to detect structural breaks (including regime shifts) in marine time-series using the shiftogram approach and what the underlying statistical concept of the shiftogram method is. The shiftogram method has been illustrated using CBS data (CBS cod, herring, spratt, reproductive volume).

Short description of the algorithm: The iterative shiftogram procedure combines econometric, time-series and quantile producing a graphic display referred to as a "shiftogram". The reason is that detecting structural breaks in natural processes turns out to be an ambitious task because the lack of well-defined target values and reference periods renders application of standard statistical (process or quality) control methods all but impossible. However, among others the shiftogram approach seeks to address four major questions using one combined approach:

1) How can we design a rather general type of a structural break that holds for many situations?

2) How can we tackle the break-finding problem?

3) How can we avoid the „Bonferroni" problem of serial tests?

4) How can the concept be designed to also hold for small time-series?

In the shiftogram approach, the potentially rather complex dynamic structure of the time-series is approximated by a quite parsimoniously parameterized linear specification consisting of a set of linear combinations that address a deterministic trend with autocorrelated errors and a complex but flexible breakpoint approximation. Then, a potential shift point t0 is moved iteratively over the time-series (by incrementing t0 by 1 year each step). Applying an appropriately defined structural break model based on dummy variables allowing the trend parameters, the autocorrelation coefficient and/or the error variance of the trend model to change in t0, relevant decision criteria described below are recorded during each iteration. The results are displayed in a compound diagrammatic illustration termed as the shiftogram. A shiftogram consists of 10 synchronized elementary diagrams (panel plots) that comprehensively summarize the results of all relevant time-series properties and decision criteria (quality-of-fit criteria, marginal p values), respectively: Panel 1: plot of the time-series; Panel 2: quality-of-fit plot using the corrected Akaike information criterion; Panel 3: plot of the empirical first order autocorrelation coefficient of the model residuals, given the particular structural break specification; Panel 4: p value of the first order autocorrelation coefficient from the shiftogram (t-test); Panel 5: p value of the statistical test of joint significance of all parameters related to the particular structural break specification (F-test); Panel 6: power plot to indicate the risk of false no-warning; the larger the power, the lower the risk of false no-warning (power = 1 – ß); Panel 7: p value of the statistical test of the pure impulse (F-test); Panel 8: p value of the statistical test of a break in slope (F-test); Panel 9: p value of the statistical test of identical levels before and after the shock (ANOVA F-test); Panel 10: p value of the statistical test of the variances before and after the shock (Levene-s test on homoscedasticity).

5.5 Cross-basin comparisons of Baltic Sea coastal seafood webs and the assessment of main drivers

A synthesis of main trends and drivers in Baltic Sea coastal foodwebs was given by Jens Olsson (Olsson *et al.,* in prep.). A similar synthesis of main trends in the open sea is also under development (Blenckner *et al.,* in prep.).

Many marine ecosystems worldwide have gone through substantial structural and functional change during recent decades. In this respect, coastal areas have received little attention despite that they face strong and variable anthropogenic impact and exhibit a substantial production potential. In this study, Olsson and colleagues assess development of ecosystem components in 13 coastal areas in the Baltic Sea region, during the past two decades. The data covers between two to six trophic levels per area, and include time-series dating back to the early 1990s. Using multivariate analyses, the authors show that the biological ecosystem components have in many areas gone through a directional development with a similar timing of change. As expected given the strong environmental gradients in the Baltic Sea, however, the specific key ecosystem components in each system describing these developmental trajectories generally differed across systems. There was a correlation between the development of the biological ecosystem components in the different areas and driving variables related to climate, hydrography and fishing pressure, but nutrient loading and con-centration was overrepresented as the variables associated with the overall direction-al development in the assessed areas. The results of this study indicate strengths and future challenges for integrated status assessments and ecosystem-based management of coastal ecosystems in the Baltic Sea, and highlight the potential for developing multi-sectorial management advice for these systems to ensure their long-term socio-ecological sustainability.

5.6 Connection to the ICES Ecosystem Overviews as an HELCOM holistic assessment

The results of ToR A (and B, see below) will contribute to the ecosystem overviews by identifying key environmental signals of significance for fisheries and marine management. Activities during the 2014 meeting are to be continued intersessionally. As data and results are still in preparation, their inclusion in relevant sections of the ecosystem overviews was postponed until they are ready.

WGIAB 2014 also recognized the importance of an aligning its ongoing work in this direction with current activities within HELCOM, mainly HELCOM Coreset and the planned updated holistic assessment. This will also be continued intersessionally.

6 Progress report on ToR B – Support integrated advice for fisheries management

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

Input was provided to the Baltic Fisheries Assessment Working Group (WGBFAS) concerning indicator of recruitment environment for Baltic cod (Section 6.1) and Gulf of Riga herring (Section 6.2).

6.1 The Baltic cod recruitment environment

Since 2011, WGIAB has provided WGBFAS with information on environmental conditions relevant to recruitment of Eastern Baltic cod, to supplement the regular assessment of this stock (ICES, 2011; 2012a; 2013). Potential indicators of the recruitment environment were identified by WGIAB (ICES, 2011) by fitting indicators proposed by Gårdmark *et al.* (2011) to the residuals of a stock–recruitment relationship (for details see ICES, 2011), and updated information on the recruitment environment has been provided annually since then. In recent intersessional work, Kroll *et al.* (in prep.) has evaluated the impact of spatial resolution and choice of period for the selection of indicators. Kroll *et al*. (in prep.) showed that the only environmental variable that consistently has a significant relationship with variation in cod recruitment not explained by cod SSB across all periods tested (1963–2009, 1975–2009, 1985–2009) is the depth of the 11 psu isosaline in the Gotland basin. This is therefore the only indicator of cod recruitment environment that is presented by WGIAB.

The reference level at which no effect on cod recruitment is found for the 11 psu isosaline varies with the period chosen for analyses (Kroll *et al*., in prep.). However, independent of the choice of reference level, the indicator shows poor abiotic environmental conditions in 2012–2013 (Figure 6.1). This suggest that the abundance of 2-year old cod recruiting to the fishable stock in 2014 and 2015 will be less than expected from cod spawning-stock biomass alone.

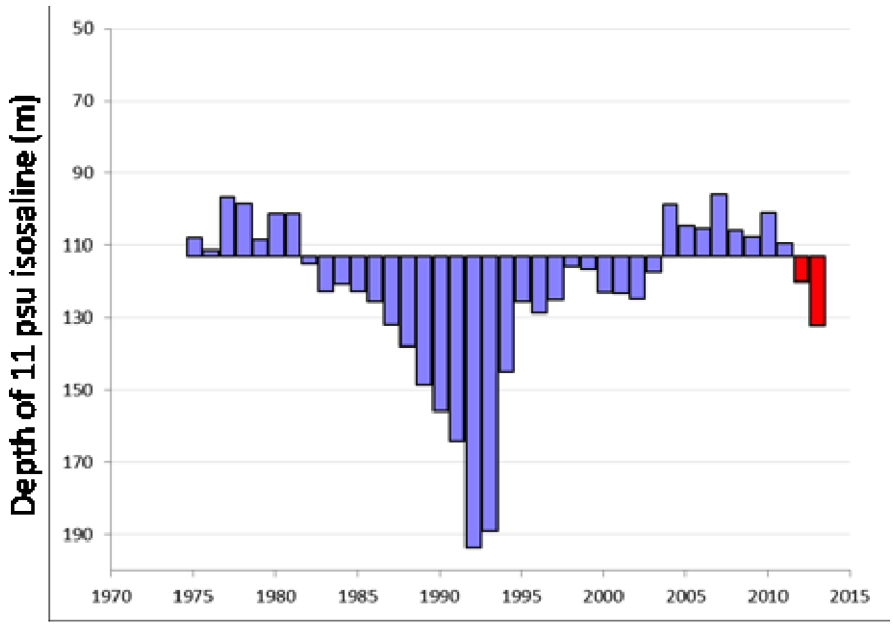

Figure 6.1. Time-series of the depth of the 11 psu isosaline, an indicator of the abiotic recruitment environment for Eastern Baltic cod. Bars indicate the values relative to the reference value (derived from the fitted relationships on cod recruitment residuals from 1977–2009, as the point where there is no environmental effect on recruitment; see ICES 2011, 2012a and Kroll *et al*. in prep. for methods). For the assessed years 2012–2013 (corresponding to cod recruitment as 2-year-olds in 2014–2015), green bars indicate favourable environmental conditions, and red bars indicate poor environmental conditions for cod recruitment. Acknowledgements to Karin Wesslander (Swedish Meterological and Hydrological Institute) for data updates. The indicator suggests that the abundance of 2-year old cod recruiting to the fishable stock in 2014 and 2015 will be less than expected from cod spawning-stock biomass alone.

6.2 Indicator of recruitment environment for Gulf of Riga herring

During the last year WGIAB (2013) meeting, relationships between the Gulf of Riga herring recruitment and environmental factors were analysed. It was stated that highly variable recruitment success could depend mostly on feeding conditions during spring and summer-time. In the previous WGIAB (2013) the environmental variables were integrated in a Ricker stock–recruitment relationship. However, the stock–recruitment relationship works poorly for this stock. An explorative study of cross-correlation between the SSB and the recruitment demonstrated that for this stock there is rather a recruitment-stock relationship with the SSB being significantly driven by the recruitment with a 2 years lag. Therefore, for the following analysis stock–recruitment relationship will not be used but instead the spawning-stock biomass will be used as an explanatory variable of herring recruitment alongside eight other variables.

Nine relevant abiotic (temperature) and biotic (SSB, number of herring at age 1, herring condition factor, biomass of zooplankton *Eurytemora affinis* and *Limnocalanus macrurus*) variables are tested regarding their relationship with abundance of herring recruits at 1 year lag. Temperature and zooplankton biomass time-series are available for May and August to investigate the feeding conditions in spring and summer respectively. Data are obtained from the Institute of Food Safety Animal Health and Environment BIOR and WGBFAS (2013) and analysed using a GAM approach. A preselection of the variables with a time-series in May and August is made to avoid correlated explanatory variables in the model. The initial model includes six selected variables. A backward stepwise selection based on statistical significance of individual variables and model overall generalized cross validation (GCV) value is used. The final model consists of zooplankton *E. affinis* biomass in May and average water temperature in August (76.9% of the deviance explained). Zooplankton *E. affinis* biomass in May is identified as the main indicator for recruitment environment (70.7% of the deviance explained). As the temperature parameter does not add valuable information to the single parameter model with *E. affinis* biomass – and especially it does not help to improve the prediction for high recruitment – the latter model is selected for the recruitment prediction.

<u>Full model:</u>

Log(Recruitment) ~ $E.\ affinis_{May}$ + $Temperature_{August}$ + log(SSB) + log(Age1) + $L.\ Macrurus_{august}$ + CF

<u>First model:</u>

Log(Recruitment) ~ $E.\ affinis_{May}$ *** + $Temperature_{August}$ ** Dev. Expl. = **76.9%** GCV score = 0.11824

<u>Second model:</u>

Log(Recruitment) ~ $E.\ affinis_{May}$ *** Dev. Expl. = **70.7%** GCV score = 0.14274

The relationship between herring recruitment and $E.\ affinis_{May}$ concentration permits to identify a threshold value of 42 mg dry weight/m3 of $E.\ affinis_{May}$ (Figure 6.2a) corresponding to no environmental effect on recruitment (recruitment equals to the mean of the period studied). This threshold value is then used to assess the quality of the environmental conditions acting on herring recruitment (Figure 6.2b). The indicator suggests that environmental conditions are favourable for the year-classes 2012–2013.

Biomass of zooplankton *E. affinis* in May is a suitable environmental indicator of recruitment for this herring stock and it could be used to predict the level of the ongoing year-class. This indicator works especially well to predict low recruitment but it may fail to predict years with very high recruitment.

(a)	(b)

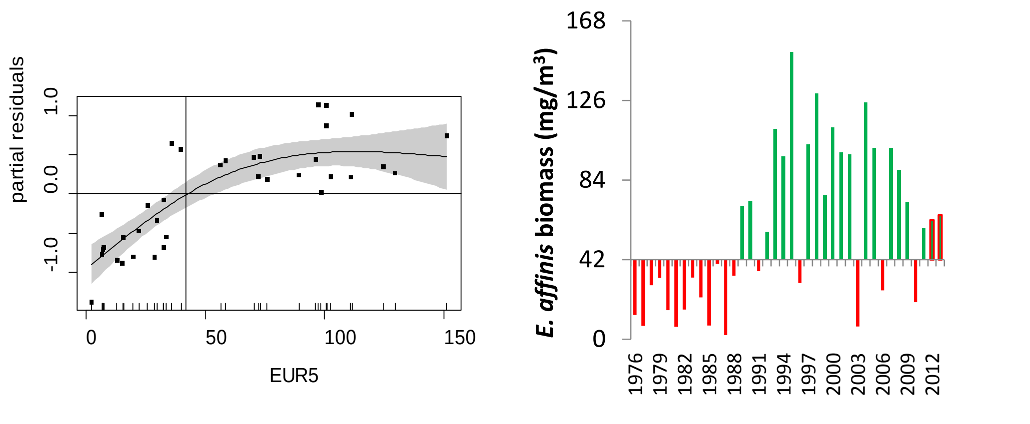

Figure 6.2. (a) Relationship between the Gulf of Riga herring recruitment and the biomass of zooplankton *Eurytemora affinis* in May, a food resource for herring. This relationship permits to identify a threshold concentration (42 mg/m³). (b) Time-series of *Eurytemora affinis*, the key indicator of the environmental conditions for the Gulf of Riga herring recruitment. Bars indicate the values relative to the reference. The green bars indicate good environmental conditions whereas the red bars indicate poor conditions. For the ongoing year-classes 2012–2013, green bars indicate favourable environmental conditions (corresponding to recruitment of age 1 in 2013–2014).

7 Progress report on ToR C – Develop the integrated ecosystem assessment cycle

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

An overview of the integrated ecosystem assessment and advice framework on West Coast of USA with respect to fisheries management was given by Phil Levin (NOAA; USA). The presentation provided a background for identifying further development priorities in order to support a Baltic IEA framework.

WGIAB recognized potential benefits from coordinating its activities in this respect with a number of FP7 and BONUS projects such a DEVOTES, INSPIRE, VECTORS or BIOC3 projects. The DEVOTES project (EU FP7 research project, http://www.devotes-project.eu/) is currently compiling a catalogue and performing gap analysis on indicators of biodiversity, alien species, foodwebs, and seabed integrity (MSFD descriptors 1, 2, 4, 6).

The focal points of the 2014 meeting are presented below.

To further develop the IEA framework, a number of talks were presented by participants regarding methods of integrated assessment and modelling frameworks potentially useful for Baltic Sea.

7.1 Ocean Health Index

As a one of the method for IEA the Ocean Health Index was presented by Thorsten Blenckner and discussed by the group. The Ocean Health Index (OHI), developed by a team of researchers in the USA, was first published in Nature 2012. It is the first comprehensive global measurement of ocean health that includes people as part of the ocean ecosystem. It can be used as a communication tool for scientists and policy-makers, describing which actions that are needed and where. The OHI evaluates the world's oceans according to 10 goals that represent key benefits of healthy marine ecosystems. By integrating information from many disciplines and sectors, the Index is a significant advance over conventional single-sector approaches to assessing ocean condition. Since 2012, Professor Halpern and his team have evaluated 133 Exclusive Economic Zone worldwide in two global assessments, regional ones for Brazil, the US West Coast and Fiji, and are now working with governments in Colombia, China, Israel, and Canada to conduct assessments with greater focus on management. These regional assessments allows for finer-resolution evaluations of ocean health for local managers and policy-makers and comparison of state or province scores within a region. In addition, they provide possibilities to reflect regional priorities by modifying goal weights according to local priorities and to assess the impact of potential actions through "management scenarios" studies. An application of the OHI for the Baltic Sea will start in May 2014 and progress will be presented at the 2015 WGIAB meeting.

7.2 Potential use of Bayesian Networks in the Baltic Sea IEA framework

Laura Uusitalo gave a talk outlining the principles behind Bayesian network modelling, and how they can be used in Environmental modelling and decision support, as well as an overview of some case studies. She lead an exercise on developing a small Bayesian Network on excel to illustrate the principles of the BN modelling

WGIAB will continue the development of Bayesian approaches to support the Baltic Sea IEA framework. The immediate usage will be to test combining of input and output from existing models and link them together in a Bayesian framework, aiming to apply these to estimate the effects of different management strategies. The approach can also be used to test the sensitivity and stability of foodwebs, as well as the sensitivity of foodweb models to assumptions in lower trophic levels and the sensitivity of low-troph models to foodweb processes.

7.3 The DEVOTES project. Indicators of biodiversity

Laura Uusitalo gave a presentation about the DEVOTES project (http://www.devotes-project.eu/) work relevant to the interests of WGIAB members: the catalogue of biodiversity-related indicators and overview of model capabilities to address indicators, with emphasis on the Baltic Sea results

7.4 Ecological-economic multispecies modelling

An introduction to multispecies Ecological-economic modelling for the Baltic Sea IEA Framework was given by Rudi Voss, and discuss within group as a tool for IEA framework and DEMO application.

A combined three-species, age-structured ecological-economic optimization model, including the predatory cod (*Gadus morhua*) and the two forage fish species herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) was developed and applied. The age-structured multispecies population dynamics are described as in standard fisheries stock assessment. For the forage fish species (sprat and herring) the age-specific survival rates depend on the predator and prey's spawning-stock biomass, capturing the effect of cod predation.

Data and estimation of model parameters are mainly based on International Council for the Exploration of the Sea (ICES) stock assessment data (ecological data) and the Scientific, Technical and Economic Committee for Fisheries (STECF) of the European Commission (economic data). The objective for model optimization can be varied between pure profit maximization to include conservation and/or equity considerations.

We introduced such a triple-bottom line approach (ecological, economical, and social goals) to the management of multispecies fisheries in the Baltic Sea. We applied the coupled ecological-economic optimization model to address the actual fisheries management challenge of trading-off the recovery of collapsed cod stocks vs. the health of ecologically important forage fish populations.

Management strategies based on profit maximization would rebuild the cod stock to high levels but may cause the risk of stock collapse for forage species with low market value, such as Baltic sprat. Economically efficient conservation efforts to protect sprat would be borne almost exclusively by the forage fishery as sprat fishing effort and profits would strongly be reduced. Unless compensation is paid, this would challenge equity between fishing sectors. Optimizing equity while respecting sprat biomass precautionary levels would reduce potential profits of the overall Baltic fishery, but may offer an acceptable balance between overall profits, species conservation and social equity

Considering trade-offs in multispecies fisheries in a transparent way requires analytical tools for assessing conflicts among fisheries, as well as suitable visualization tools be able to offer society options to solve common conflicts between different resource uses. Adding equity considerations to the traditional trade-off between economy and ecology will greatly enhance credibility. We furthermore demonstrate that the regional distribution of profits strongly depends on the management goals.

7.5 Developing a demonstration exercise for Integrated Ecosystem Assessment and Advice of Baltic Sea fish stocks (DEMO)

Theory behind ecosystem-based management (EBM) and ecosystem-based fisheries management (EBFM) is now well developed. However, the implementation of EBFM exemplified by fisheries management in Europe is still largely based on single-species assessments and ignores the wider ecosystem context and impact. The reason for the lack or slow implementation of EBM and specifically EBFM is a lack of a coherent strategy. Such a strategy is offered by the Integrated Ecosystem Assessment (IEA) framework, a formal synthesis tool to quantitatively analyse information on relevant natural and socio-economic factors, in relation to specified management objectives (Levin *et al.*, 2009

As one-step towards IEAs for the Baltic Sea, WGIAB decided to focus on implementing the IEA approach for Baltic Sea fish stocks by combining both tactical and strategic management aspects into a single strategy that supports the present Baltic Sea fish stock advice conducted (ICES). A strategy towards this goal has been published by the group in the Special Issue of the ICES Journal of Marine Science on IEAs (Möllmann *et al.*, 2014). The strategy is based on the work of WGIAB towards IEA and integrates fish stock advice and IEAs for the Baltic Sea. The approach intentionally focused on the Central Baltic Sea and its three major fish stocks cod (*Gadus morhua*), herring (*Clupea harengus*), and sprat (*Sprattus sprattus*), but may be applied to other parts and stocks of the Baltic, as well as other ocean areas.

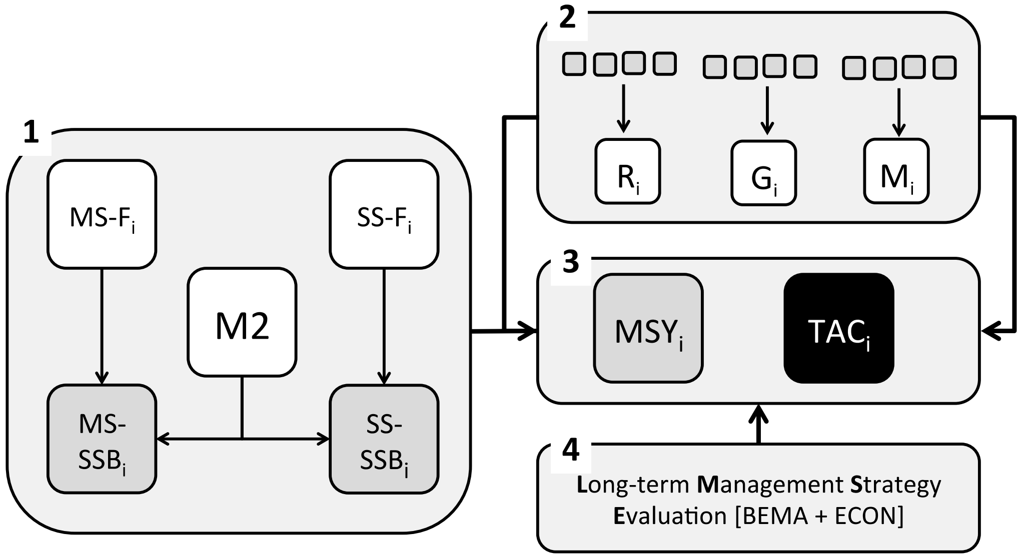

Figure 7.1. Conceptual schema of the work planned during the DEMO-workshop in August 2014: 1 – Combining Multispecies (MS) and Single-Species (SS) assessments [F – Fishing Mortality, M2 – Predation Mortality]; 2 – Environmental indicators (small squares) for biological process [R – Recruitment, G – Growth, M – Mortality]; Estimating MSY [Maximum Sustainable Yield] and setting TAC [Total Allowable Catch]; Long-term Management Strategy Evaluation using BEMA [Biological Ensemble Modelling; Gardmark *et al.*, 2013] and coupled ecological-economic modelling [ECON].

One main aim of WGIAB in 2014 was to further develop the strategy by Möllmann *et al*. (2014) and to prepare a workshop in summer 2014, where the practical work would be conducted. During the meeting, WGIAB discussed and modified the approach and a conceptual schema is given in Figure 7.1. The strategy is composed of 4 components: (1) Single-species assessments (using SAM) of cod, herring and sprat, that are informed by predation mortalities (M2) derived from Multispecies runs using SMS; (2) a selection of ecosystem indicators that represent the biological processes of recruitment, growth and mortality of the three fish stocks; (3) Estimation of MSY and TAC using the environmental information; and (4) Long-term Management Strategy Evaluation using BEMA [Biological Ensemble Modelling] and coupled ecological-economic modelling [ECON].

During the discussions, it appeared that the crucial point would be to find ways on using the environmental information for recruitment, growth and mortality of the three fish stocks in the assessment and advice framework. First, environmental information will be used to assess the credibility of the stock assessment outputs in terms of SSB and recruitment. Second, environmental information will be used (i) to assess the credibility of short-term forecasts and/or (ii) will be directly used in the short-term forecasts. Technical details of the approaches have been discussed and will be further developed during intersessional work (see arrows between 2 and 3 in Figure 7.1). As a preparation, a preliminary list of potential indicators (Table 7.1) based on expert knowledge, published factors and data availability has been developed, that will be slimmed down during intersessional work and during the DEMO workshop. Eventually all process-based indicators will be weighed into a single value until the last stock assessment year.

As mentioned above details of the process will be refined intersessionally. Eventually WGIAB planned the DEMO workshop for 25–28 of August at the field station of Stockholm University (SU) on the island of Askö. SU will kindly provide the accommodation as well as meals for ca 15 participants. All other expenses have to be paid by participants themselves. A core group of participants has been identified however, participation is free. WGIAB Chairs should be notified by participants. Eventually an abstract has been submitted for the ICES ASC 2014 in A Coruña (Spain).

Table 7.1. Selected indicators to be included in the DEMO exercise.

Species	Recruitment	Growth	Mortality
Cod	Salinity in the Gotland Basin, RV, cod predation mortality at ages 0-1, mean weight at age, abundance (alt. frequence of) spawners at size (or skewness of size distribution of spawners), LFI, Pseudocalanus acupes biomass, abundance of small sprat & herring, zoobenthos, larval transport	Per capita abundance of sprat & herring & cod at a certain size, benthos	Grey seal consumption
Herring	August SST, mean weight at age, cod predation on age0, abundance (alt. frequence of) spawners at size (or skewness of size distribution of spawners), LFI, Pseudocalanus acupes biomass, abundance of small sprat & herring, zoobenthos, larval transport	Total zooplankton, amphipods, total zooplankton/capita of clupeids	Cod predation M2 that is based on cod stock size and accounts for spatial overlap of cod-sprat, grey seal consumption
Sprat	Temperature in 60 m during spring, August SST, cod predation on age 0, mean weight at age, abundance (alt. frequency of) spawners at size (or skewness of size distribution of spawners], LFI, Acartia spp. biomass, larval transport	Total zooplankton, total zooplankton/capita of sprat	Cod predation M2 that is based on cod stock size and accounts for spatial overlap of cod-sprat, grey seal consumption

COMMENT: There are two recent developments, that might (or likely will) change the plans made during the WGIAB 2014 meeting. These are 1) the recent problems with the stock assessment of Eastern Baltic cod (personal information from WGBFAS participants), and 2) funding of a project by SU applied for by Maciej Tomczak. The latter encompasses funding for three more DEMO workshops. This would allow a more detailed analyses of Baltic ecosystem changes in relation to uncertainty in especially the development of the Eastern Baltic cod stock, but as well as a more thorough and extended work on the IEA of Baltic fish stocks. The potentially new setup of the DEMO workshop(s) is currently being discussed among core WGIAB participants and will be finalized before the summer break to allow targeted work during the Askö DEMO workshop in August 2014.

8 Revisions to the work plan and justification

No revisions of the work plan were made (Section 3)

9 Next meeting

The next meeting of WGIAB will be held in Cádiz (Spain) during 9–13 March 2015 based on an invitation of Dr Marcos Llope from IEO Cádiz. The meeting will be chaired by Lena Bergström, Sweden and Christian Möllmann, Germany. Based on a request from the chair of the ICES Working Group on Integrated Ecosystem Assessment of the Barents Sea (WGIBAR) Edda Johannesen, a back-to-back meeting with this new group is planned.

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Annex 1: List of participants

Name	Institute and address	E-mail
Lena Bergström **Chair**	Swedish University of Agricultural Sciences, Department of Aquatic Resources, Skolgatan 6, SE-742 42 Öregrund , Sweden	lena.bergstrom@slu.se
Thorsten Blenckner	Stockholm Resilience Centre, Stockholm University, Kräftriket 2B, SE-11419 Stockholm, Sweden	thorsten.blenckner@su.se
Michele Casini	Department of Aquatic Resources, Institute of Marine Research, Swedish University of Agricultural Sciences, PO Box 4, SE-54330 Lysekil, Sweden	michele.casini@slu.se
Burkhard von Dewitz	GEOMAR, Helmholtz-Zentrum für Ozeanforschung Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany	bdewitz@geomar.de
Rabea Diekmann	Thünen Institute of Fisheries Ecology, Palmaille 9, 22767 Hamburg, Germany	rabea.diekmann@ti.bund.de
Jan Dierking	GEOMAR, Helmholtz-Zentrum für Ozeanforschung Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany	jdierking@geomar.de
Margit Eero	DTU Aqua, Jægersborg Allé 1, DK-2920 Charlottenlund, Denmark	mee@aqua.dtu.dk
Anna Gårdmark	Swedish Univeristy of Agricultural Sciences, Department of Aquatic Resources, Skolgatan 6, SE-742 42 Öregrund, Sweden	anna.gardmark@slu.se
Pavel Gasjukov	AtlantNIRO, Kaliningrad, Russia	pg@atlant.baltnet.ru
Joachim Gröger	Thünen Institute for Sea Fisheries, Palmaille 9, 22767 Hamburg, Germany	joachim.groeger@ti.bund.de
Kerli Laur	University of Tartu, Estonian Marine Institute, Department of Ecodynamics, Lootsi 2a, 80012 Pärnu, Estonia	kerli.laur@ut.ee
Martin Lindegren	DTU Aqua, Jægersborg Allé 1, DK-2920 Charlottenlund, Denmark	mli@aqua.dtu.dk
Phil Levin	Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, USA	phil.levin@noaa.gov

Name	Institute and address	E-mail
Marcos Llope	Instituto Español de Oceanografía, Centro Oceanográfico de Cádiz, Spain	marcos.llope@cd.ieo.es
Christian Möllmann **Chair**	University of Hamburg, Institute of Hydrobiology and Fishery Science, Grosse Elbstrasse 133, D-22767 Hamburg, Germany	Christian.moellmann@uni-hamburg.de
Stefan Neuenfeldt	DTU Aqua, Jægersborg Allé 1, DK-2920 Charlottenlund, Denmark	stn@aqua.dtu.dk
Henn Ojaveer	University of Tartu, Estonian Marine Institute, Department of Ecodynamics, Lootsi 2a, 80012 Pärnu, Estoni	henn.ojaveer@ut.ee
Jens Olsson	Swedish Univeristy of Agricultural Sciences Department of Aquatic Resources Skolgatan 6 SE-742 42 Öregrund Sweden	jens.olsson@slu.se
Saskia Otto	University of Hamburg, Institute of Hydrobiology and Fishery Science, Grosse Elbstrasse 133, D-22767 Hamburg ,Germany	saskia.otto@uni-hamburg.de
Laurène Pécuchet	DTU Aqua, Jægersborg Allé 1, DK-2920 Charlottenlund, Denmark	laupe@aqua.dtu.dk
Heikki Peltonen	Finnish Environment Institute, Marine Research Centre, POBox 140, FI-00251, Helsinki, Finland	heikki.peltonen@ymparisto.fi
Ivars Putnis	Institute of Food Safety, Animal Health and Environment,BIOR, Fish Resources Research Department Daugavgrivas 8, LV-1048 Riga, Latvia	Ivars.putnis@bior.gov.lv
Andrea Rau	Thuenen-Institute of Baltic Sea Fisheries, Alter Hafen Süd 2, D-18069 Rostock, Germany	andrea.rau@ti.bund.de
Jörn Schmidt	Dep. of Economics, University of Kiel, Sustainable Fisheries, Wilhelm-Seelig Platz 1, 24118 Kiel, Germany	jschmidt@economics.uni-kiel.de
Maciej T. Tomczak **Chair**	Baltic Nest Institute Stockholm University, SE-106 91 Stockholm, Sweden	maciej.tomczak@su.se
Laura Uusitalo	Finnish Environment Institute, Marine Research Centre, PO Box 140, 00251 Helsinki, Finland	laura.uusitalo@ymparisto.fi (laura.uusitalo@iki.fi)

Name	Institute and address	E-mail
Rudi Voss	Dept. of Economics, University of Kiel, Sustainable Fisheries, Wilhelm-Seelig Platz 1, 24118 Kiel, Germany	voss@economics.uni-kiel.de

Annex 2: Agenda of WGIAB 2014

ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea [WGIAB]; Kiel, Germany, 10–14 February 2014

Monday 10/02/14

1100 – Arrival of participants

1200 – 1300 Lunch

1300 – 1330 **Welcome, practical information and discussion of the agenda** (Jörn Schmidt, Lena Bergström, Maciej Tomczak, Christian Möllmann)

1330 – 1400 **Goals and setup of the 2014 meeting** (Lena Bergström, Maciej Tomczak, Christian Möllmann)

1400 – 1445 **Introduction to subgroups, discussion and forming of subgroups**

Group 1: Integrated Trend Analyses (ITAs)

Group 2: DEMO-IEA for Baltic fish stocks

Group 3: Bayesian Networks

- Potential additional groups tbd

1445 – 1500 Coffee and Tea

1500 – 1700 **Parallel work in subgroups**

1700 – 1800 **Short summary and preparation of next day**

Tuesday 11/02/14

0900 – 1030 **Presentations**

- State of the IEA implementation in the US (Phil Levin) [15min]
- ATLANTIS for the Baltic Sea (Stefan Neuenfeldt) [15min]
- Bayesian networks (Laura Uusitalo) [30min]

1030 – 1100 Coffee and Tea

1100 – 1300 **Parallel work in subgroups**

1300 – 1400 Lunch

1400 – 1445 **Plenary**

- reports on progress in groups

1445– 1500 Coffee and Tea

1500 – 1700 **Parallel work in subgroups**

1700 – 1800 **Plenary**

- reports on progress in groups
- summary and preparation of next day

1930 – Common Dinner

Wednesday 12/02/14

0900 – 1030 **Presentations**

- The DEVOTES project (Laura Uusitalo) [15min]
- The INSPIRE and VECTORS projects (Henn Ojaveer) [15min]
- The BIOC3 project (Stefan Neuenfeldt) [15min]
- "Changes in standing genetic variation in Eastern Baltic cod related to oxygen depletion and fishing pressure" (Jan Dierking) [30min]

1030 – 1100 Coffee and Tea

1100 – 1300 **Parallel work in subgroups**

1300 – 1400 Lunch

1400 – **Boat trip on the Kiel Fjord and the German Bowling experience called "KEGELN" (incl.-fried chicken)**

Thursday 22/04/10

0900 – 1030 **Presentations**

- "The Ocean Health Index for the Baltic Sea" (Thorsten Blenckner) [15min]
- SGSPATIAL (Michele Casini) [15min]
- SGIMM (Jörn Schmidt) [15min]
- WGCOMEDA (Anna Gårdmarkand Christian Möllmann) [15min]

1030 – 1100 Coffee and Tea

1100 – 1300 **Parallel work in subgroups**

1300 – 1400 Lunch

1400 – 1445 **Plenary**

- reports on progress in groups

1445– 1500 Coffee and Tea

1500 – 1700 **Parallel work in subgroups**

(In parallel for those interested: Seminar by Marcos Llope "Regeneration potential of the Baltic Sea inferred from historical records")

1700 – 1800 **Plenary**

- Wrap-up of subgroup work
- Discussion on next meeting (TORs, venue, focus)
- Planning of the report

1930 - Common Dinner if wanted

Friday 23/04/10

0900 – 1045 **Final Session**

	• Report writing
1045 – 1100	Coffee and Tea
1100 – 1300	**Report preparation**
1300 -	Closure of the meeting

Annex 3: Integrated trend analyses for CBS, GoR and GoF

Central Baltic Sea (CBS)

Hydrography

Despite the cold winters in 2011/2012 and 2012/2013, spring water temperatures in the Gotland Basin were above the long-term average and summer temperatures were high (Figure 1). No salt water inflows occurred that were strong enough to replace the bottom water in the Gotland Deep since 2003. A major inflow in winter 2011/2012 reached only the Bornholm Basin and the southern part of the Gotland Basin (Nausch *et al.*, 2013). Therefore, salinity in the halocline region and deep-water of the Gotland Basin continued to decrease, while surface salinity is now close to its long-term average. Due to the lack of inflows bottom-water oxygen conditions continued to deteriorate, anoxic bottom area is large and reproduction conditions for cod are poor (Figure 2).

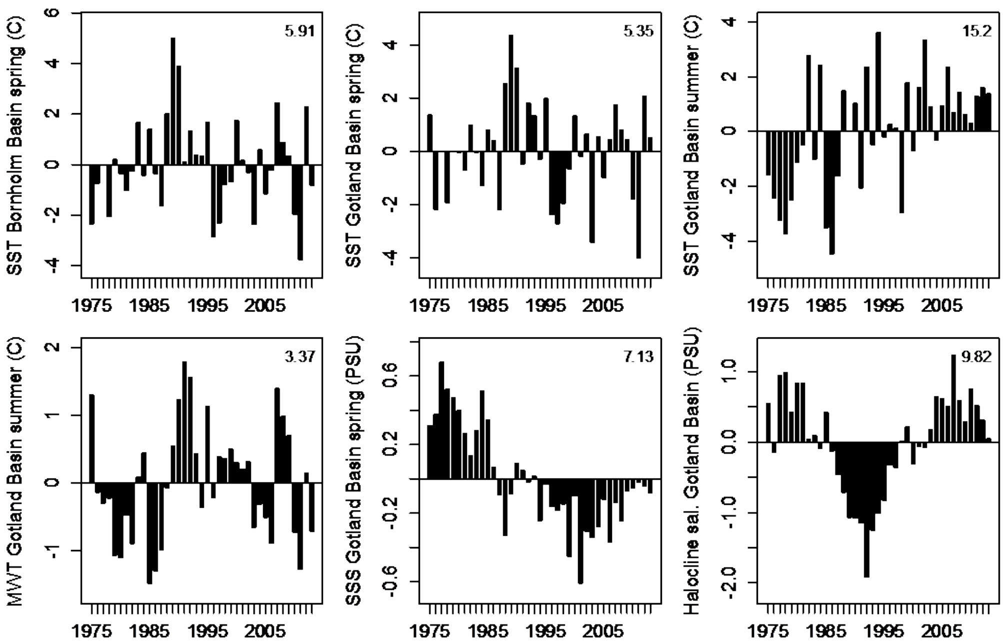

Figure 1. Temperature and salinity in the Central Baltic in 1975–2013. Anomaly plots show surface water temperatures in May in the Bornholm (top left) and Gotland Basin (top middle) as well as summer surface (top right) and midwater temperatures (40–60 m, bottom left) in the Gotland Basin. Salinity is shown in the Gotland Basin surface layer in May (bottom middle) and at 80–100 m depth in summer (bottom right). Data means are given in the top right corner of each graph.

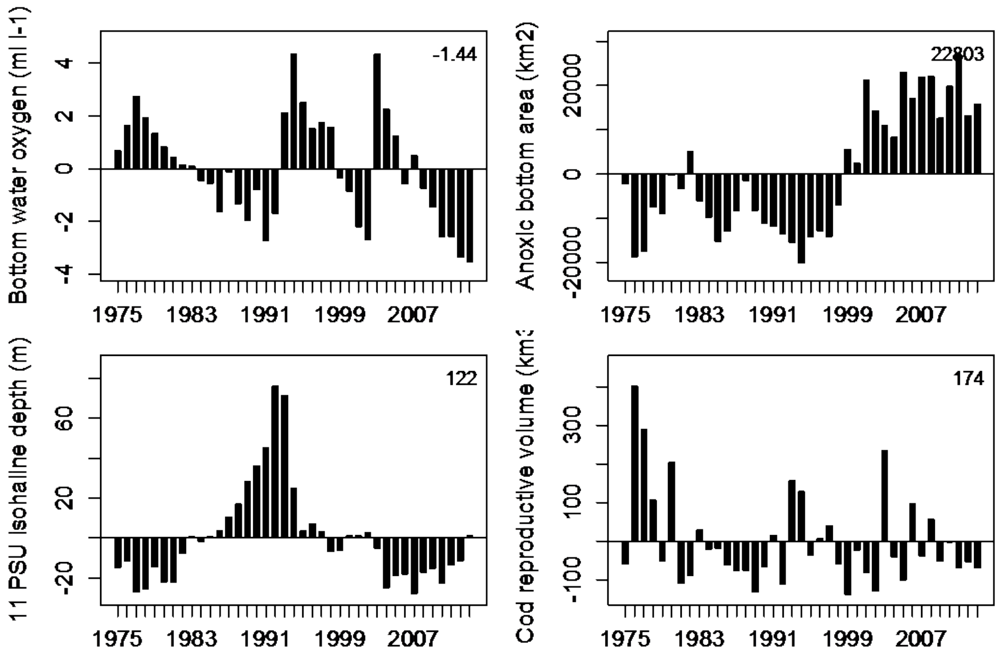

Figure 2. Oxygen conditions in the central Baltic Sea in 1975–2013. Anomaly plots show oxygen concentrations at 200–220 m depth in the Gotland deep (top left), anoxic bottom area in the Baltic Proper, Gulf of Finland and Gulf of Riga (top right), depth of the 11 PSU isohaline (bottom left) and cod reproductive volume (bottom right). Data means are given in the top right corner of each graph.

Nutrients

Both in the Bornholm and the Gotland Basin, surface winter DIN concentrations increased since 2006, but are still much lower than the peak values observed at the end of the 1980s. Winter DIP concentrations in 2013 were lower than the large winter DIP values observed during the last decade. In the bottom water, both DIN and DIP concentrations reflect saltwater inflow patterns.

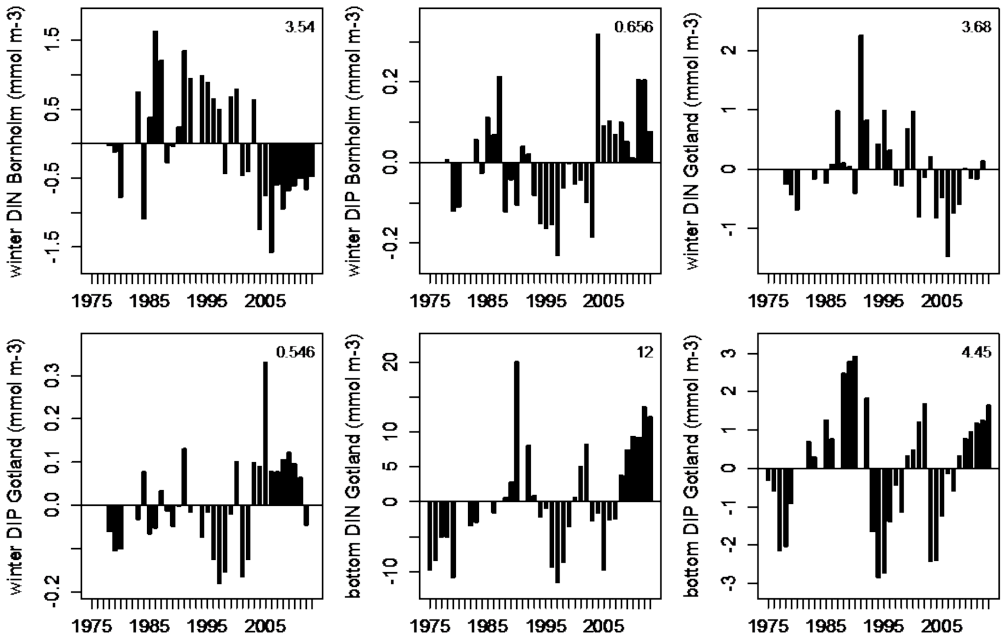

Figure 3. Nutrient conditions in the central Baltic Sea in 1975–2013. Anomaly plots show surface winter DIN and DIP concentrations in the Bornholm and Gotland Basin as well deep water (200–220 m) nutrient concentrations in the Gotland Basin. Data means are given in the top right corner of each graph.

Phytoplankton

Chlorophyll *a* data suggests a break from increasing summer phytoplankton biomass in the Gotland Sea after 2006 (Figure 4), while species data show large cyanobacteria biomass in 2009, 2011 and 2012. Patterns in the Bornholm basin differed from the Gotland Sea with fluctuating summer chlorophyll *a* and low cyanobacteria biomass during recent years.

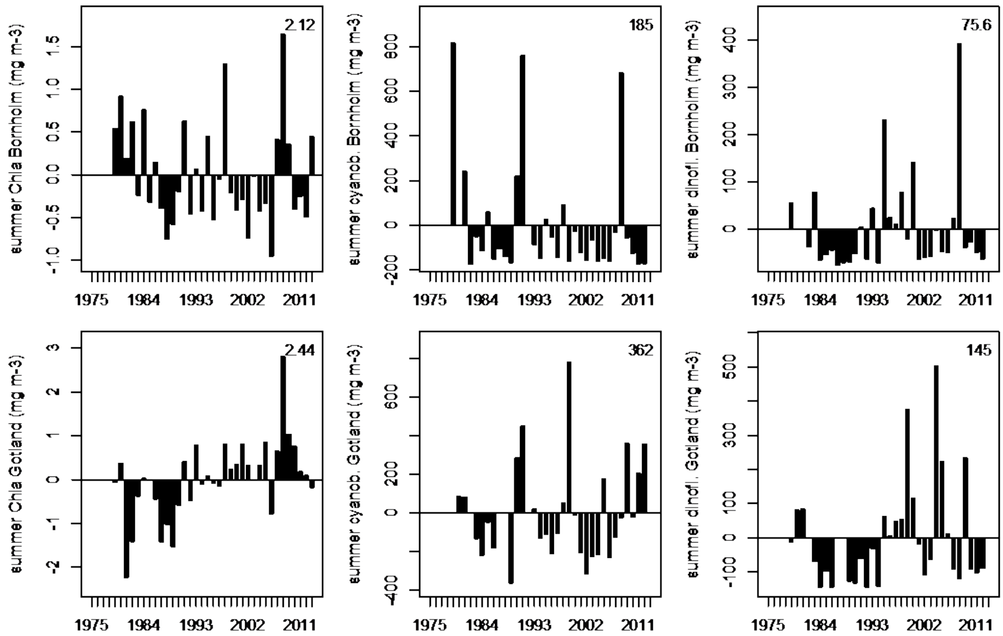

Figure 4. Summer chlorophyll a concentrations and phytoplankton group biomass in the Central Baltic Sea in 1979/1980 – 2012. Anomaly plots show chlorophyll a concentrations (left), cyanobacteria (middle) and dinoflagellate biomass (right) in the Bornholm (top row) and Gotland Basin (bottom row). Data means are given in the top right corner of each graph.

Zooplankton

The relatively cold winters since 2009 are reflected in low spring abundances of *Acartia* spp., while fluctuations are larger for *Temora longicornis* (Figure 5), the other dominating copepod species above the Central Baltic halocline. During summer, the abundance of both species remained low since 2010. *Pseudocalanus acuspes*, which is primarily distributed in the halocline region of the Central Baltic basins, has remained at low biomass levels since the beginning of the 1990s.

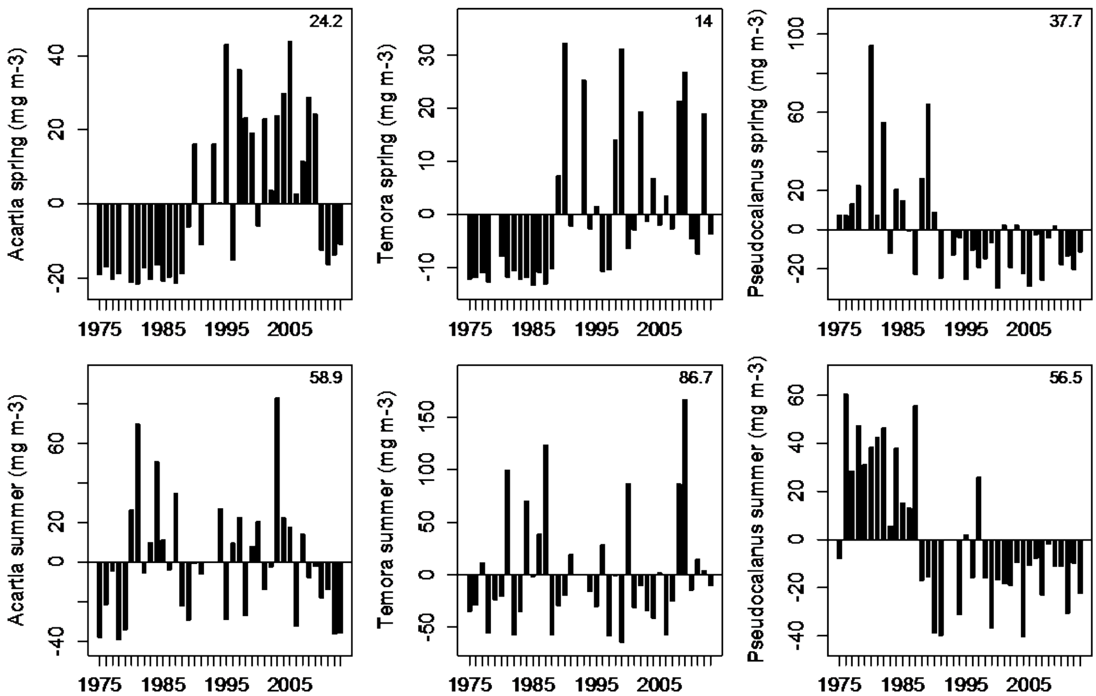

Figure 5. Zooplankton biomass in the Central Baltic Sea in 1975 – 2013. Anomaly plots show biomass in spring (top row) and summer (bottom row) for *Acartia* spp. (left), *Temora* spp. (middle) and *Pseudocalanus* spp. (right). Data means are given in the top right corner of each graph.

Fish and fisheries

Because of the reduced fishing pressure and consequently low fishing mortality, the recovery of the cod stock (Figure 6) continued despite still below-average recruitment. However, since the mid-1990s cod condition has declined and in 2012 weight-at-age in catches of most year classes was at its all-time minimum. The sprat stock is currently at its time-series average, after record high biomasses in the mid-1990s. Recruitment conditions continue to be favourable for sprat, but highly variable. Since 2011, fishing mortality for the stock has declined. Central Baltic Sea herring SSB has stabilized slightly below its long-term average. Recruitment has been low since the mid-1980s, but low fishing mortality since the end of the 1990s has permitted a gradual recovery of the stock.

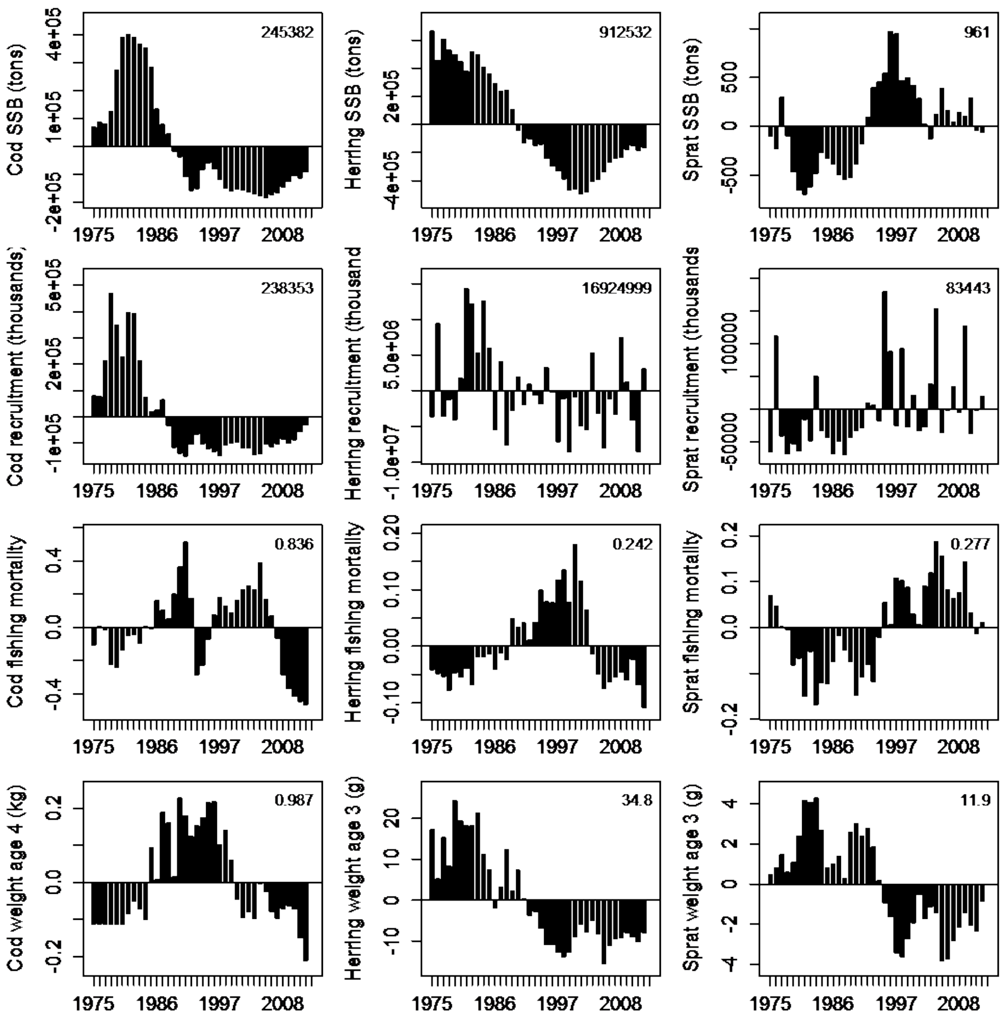

Figure 6. Fish and fishery indicators for the Central Baltic Sea in 1975–2012. Anomaly plots show spawning-stock biomasses (top row) of cod, herring and sprat, recruitment (second row), fishing mortality F (third row) and weight at age (bottom row). Data means are given in the top right corner of each graph.

Integrated trend analysis

In total, 61 variables were included in an integrated analysis, 27 characterizing abiotic conditions (climate, hydrography, nutrients, oxygen) and 34 describing biotic conditions (phytoplankton, zooplankton, fish). The traffic light plot (Figure 7) shows alterations in fish stocks (decline of cod and herring and parallel increase in sprat biomass), and zooplankton abundance (increase of *Acartia* and *Temora* biomass in spring, decrease of *Pseudocalanus*) to be the most pronounced changes in the Central Baltic ecosystem. However, during the last five years some trends are interrupted. Most noticeable, the decrease in cod and herring SSB has turned into a small increase. Harsh winters have also put a halt to the warming of the Baltic at least below the seasonal thermocline, with cold midwater temperatures following ice winters.

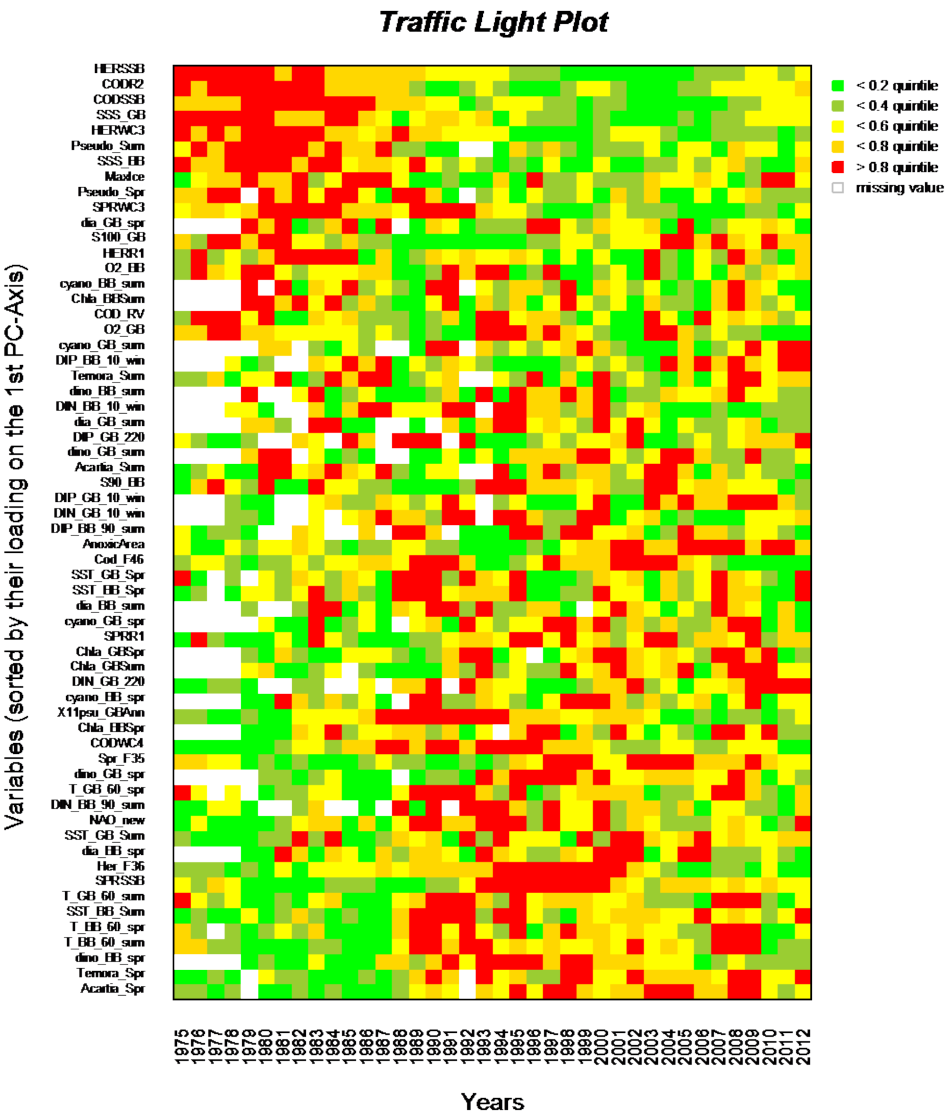

Figure 7. Traffic-light plot of the temporal development of the Central Baltic Sea time- series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1).

Patterns in ecosystem change are dominated by biotic variables, while abiotic time-series show high interannual fluctuation (Figure 8). More gradual changes in biotic variables are caused by the longevity of fish, where fish stocks integrate the fluctuations of several year classes. Biotic principle components organize the data into a fish/zooplankton axis (biotic PC1), which show the transition from a cod and herring dominated system with high *Pseudocalanus* abundance to a sprat dominated system, coinciding with high spring *Acartia* and *Temora* biomass. Summer phytoplankton biomass, and with negative correlation cod fishing mortality are the second most important structuring element in the biotic dataset (biotic PC2). Year scores for biotic principal components trace the changes in fish stocks and single out a transition period in 1987 – 1989 where high fishing mortality accelerated the decline of the cod stock. For the most recent years, the PC biotic year scores indicate a return to a slightly higher cod stock and most likely lower summer phytoplankton biomass.

Abiotic variables are structured into a temperature axis (abiotic PC1) and an oxygen – DIP axis (abiotic PC2). In the mid-1970s the year scores depict the Central Baltic Sea as a cold, fairly toxic and phosphorus poor system. In contrast, after year 2000 the system is phosphorus rich and below the halocline mostly anoxic. Abiotic PC1 also captures temperatures fluctuations, which separate the warm 1990s from most other years. Because the major Baltic inflows in 1993 and 2003 oxygenated the bottom water in the Gotland Sea, PC2 abiotic increased strongly for these years, followed by a fast return to the previous anoxic state.

Simultaneous principal component analysis of the entire dataset picked up mostly the properties of the biotic data, overlain by a temperature signal contributing to PC1 for the combined dataset. Therefore, the principal component year scores mainly follow the changes in fish stocks and zooplankton. Also in the analysis of the entire dataset the change in year scores for 2011 and 2012 caused presumably by the gradual recovery of the cod stock, is clearly visible.

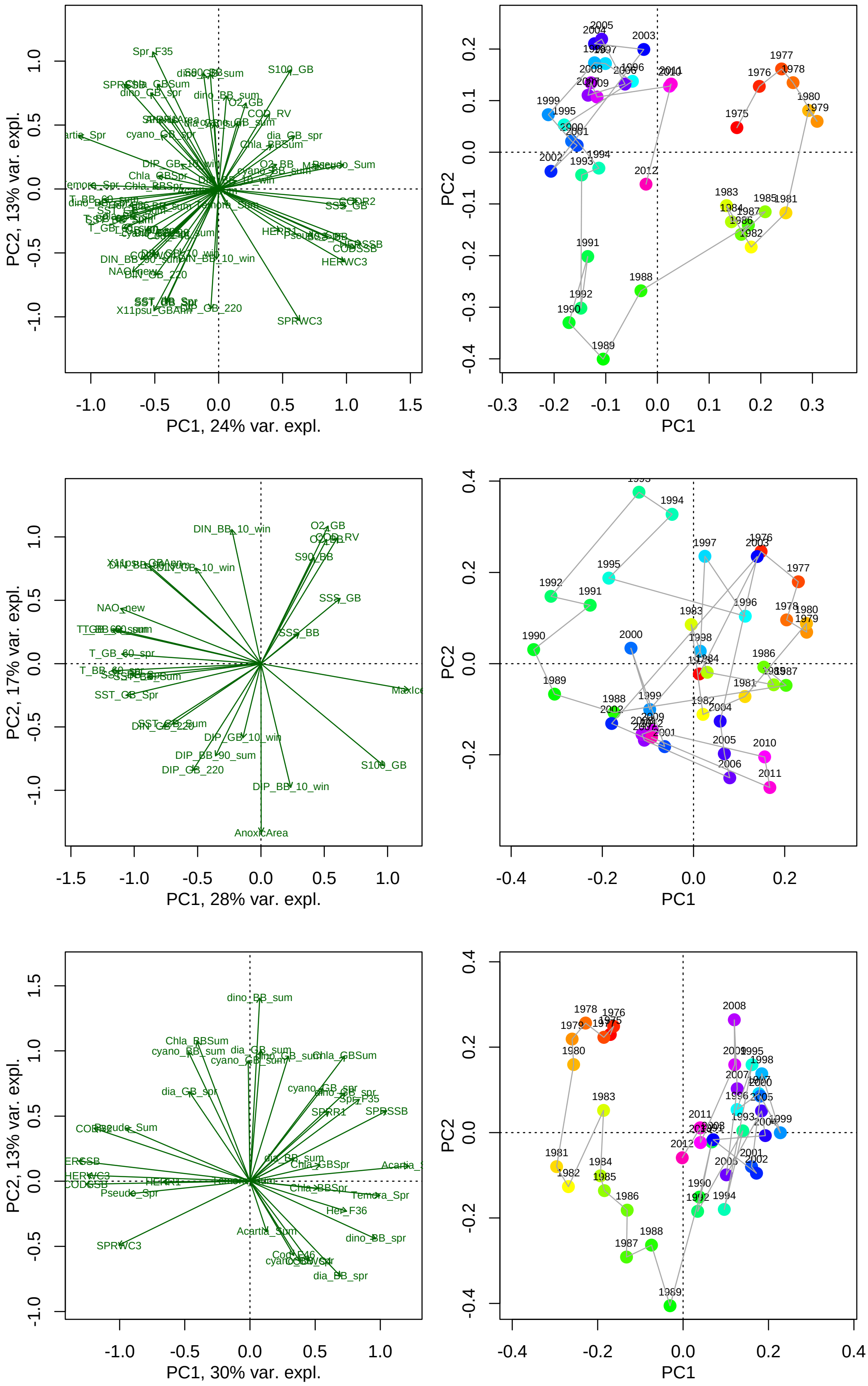

Figure 8: Biplots of variable loadings (left) and time-trajectories of year scores (right) in the in the PC1-PC2 plane for the Central Baltic Sea time-series. Rows show changes in all variables (top), abiotic (middle) and biotic (bottom) variables. Year scores are colour-coded into red (1970s), orange-green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

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Gulf of Riga

Hydrography

May water temperatures above the thermocline were slightly above their long-term average in 2012 and 2013 (Figure GoR-1, top left). Euphotic zone also was warmer than average in summer. Salinity, which had steadily increased since its minimum in the second half of the 1990s, remained low in 2012 and 2013. Run-off from the Daugava River, the largest river draining into the Gulf, has fluctuated around its long-term average since 2004. Run-off was above the long-term average in 2012 and 2013.

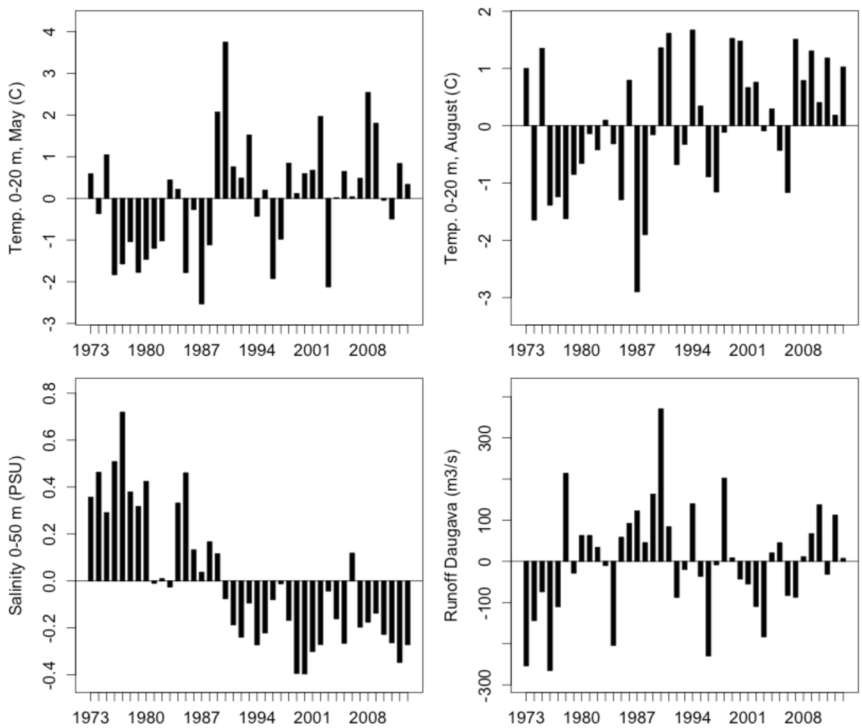

Figure GoR-1. Temperature, salinity and run-off to the Gulf of Riga. Anomaly plots show surface water temperatures in May (top left, mean = 4.4 C) and the August (top right, mean = 16.3 C) as well as water column average salinity in August (bottom left, mean = 5.7 PSU) and freshwater run-off from the Daugava River to the Gulf (mean = 619.4 m3 s-1).

Nutrients

Winter nutrient concentrations show a decrease of DIN values since their maximum in 1991 and mostly high DIP pools since the end of the 1980s (Figure GoR-2). Due to the missing data, it is unknown whether this trend continues in 2010, 2011 and 2013.

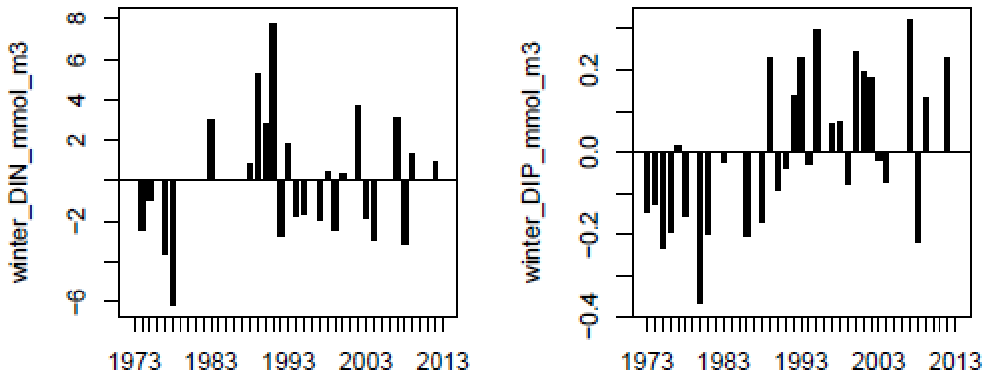

Figure GoR-2. Nutrient conditions in the Gulf of Riga. Anomaly plots show surface winter DIN (left, mean = 11.58 mmol m-3) and DIP (right, mean = 0.82 mmol m-3).

Phytoplankton

The Gulf of Riga shows very variable spring blooms with an increasing trend (FigureGoR-3, left). Summer phytoplankton biomass is less variable and has strongly increased at the end of the 1990s, declined steadily to below average values in 2011 and increased again in 2012 and 2013. The high summer phytoplankton biomass in the 2000s has been linked both to weaker top-down control by zooplankton as well to expanding cyanobacteria blooms (Jurgensone *et al.*, 2011).

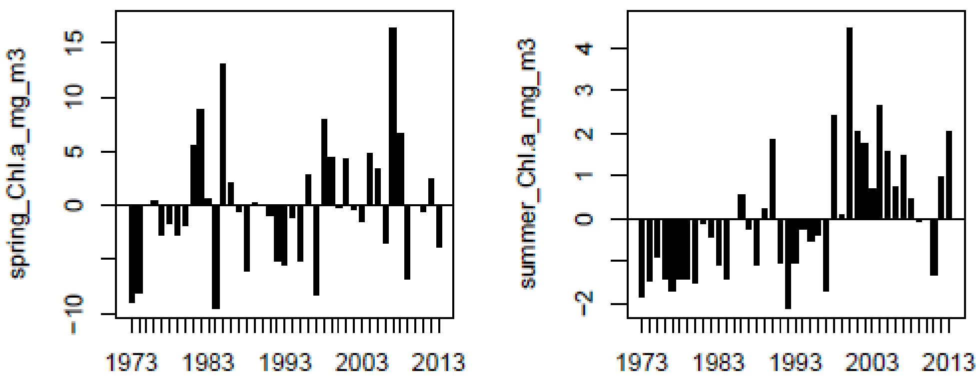

Figure GoR-3. Phytoplankton conditions in the Gulf of Riga. Anomaly plots show spring (left, mean = 14.04 mg m-3) and summer (right, mean = 3.51 mg m-3) chlorophyll *a* concentrations.

Zooplankton

Since the mid-1990s, also the increasing trend in spring copepod biomass seems to be broken in the Gulf of Riga. Both spring biomasses of *Eurytemora* and *Acartia* (Figure GoR-4) have started to fluctuate strongly and showed even opposite trends in 2012 and 2013. No recent changes are obvious in summer and the biomass of both species continues to remain on low levels. The glacial relict species *Limnocalanus macrurus* (Figure GoR-4, bottom left) shows strong interannual variations, but the population seems to recover from low biomasses observed during the 1980s and 1990s. *Cercopagis pengoi* (Figure GoR-4, bottom right) is an invasive species to the Gulf of Riga that is present since 1997. Its biomass is fluctuating strongly, especially in warm summers.

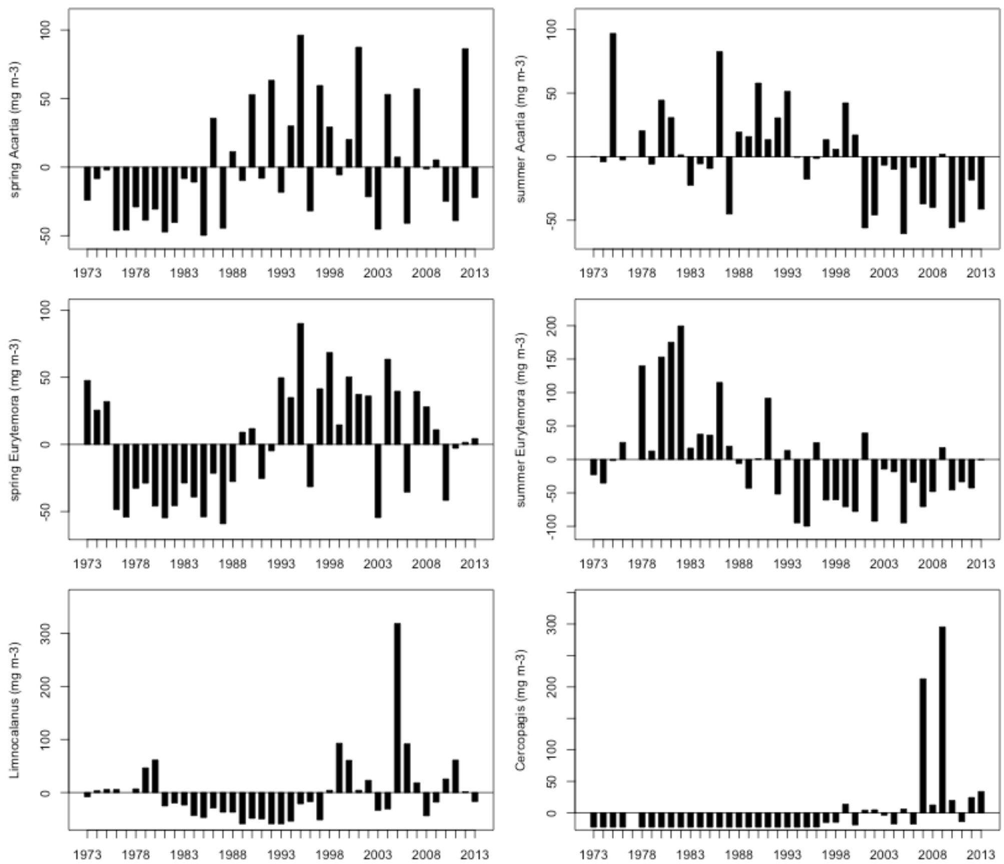

Figure GoR-4. Zooplankton conditions in the Gulf of Riga. Anomaly plots show spring (top left, mean = 59.3 mg m-3) and summer (top right, mean = 73.8 mg m-3) biomasses of *Acartia* spp. and *Eurytemora* spp. (middle, means 61.3 mg m-3 and 151.2 mg m-3) as well as summer biomass of *Limnocalanus macrurus* (mean = 58.9 mg m-3) and *Cercopagis pengoi* (mean = 22.8 mg m-3).

Fish and fisheries

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

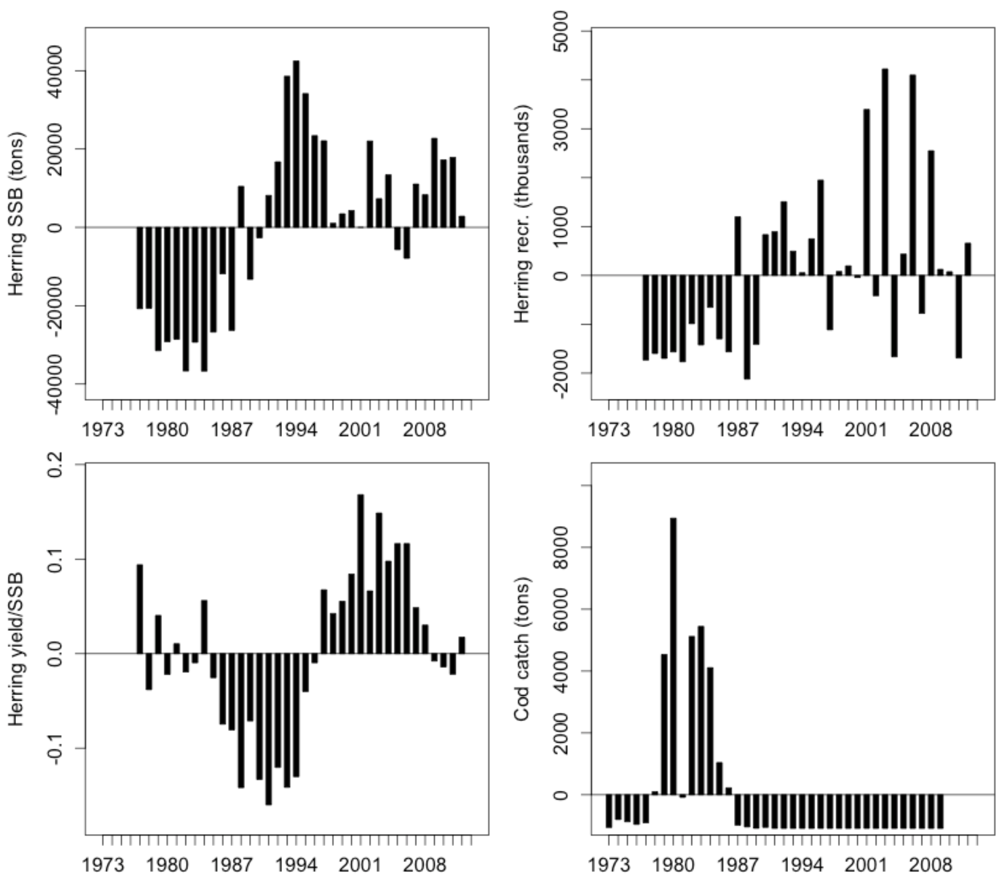

Figure GoR-5. Fish and fishery indicators for the Gulf of Riga. Anomaly plots show herring SSB (top left, mean = 77 426 tons), herring recruitment-at-age 1 (top right, mean = 2 675 * 103), herring yield (catch/SSB, bottom left, mean = 0.33) and reported cod catches (bottom right, mean = 1 088 tons).

Integrated analysis

In total, 25 variables were included in the analysis. They describe climatic conditions (1 variable), nutrient load and run-off to the Gulf (3 variables), hydrographic conditions (3 variables), nutrient concentrations (2 variables), phytoplankton (4 variables), zooplankton (7 variables), as well as fish and fisheries (5 variables). The traffic light plot for the Gulf of Riga identifies both trends in herring stock, zooplankton biomass, temperature and salinity as well as winter phosphate concentrations and summer phytoplankton biomass as major changes in the Gulf of Riga. The increase in herring biomass observed is paralleled by a decline in summer biomass of *Eurytemora* and a decline of individual herring weight. This indicates strong competition for zooplankton prey in the Gulf. In contrast to summer, spring copepod biomass has increased, driven by higher water temperatures. Winter nutrient concentrations show differing trends for phosphate and nitrate. While winter nitrate concentrations correlate well to nitrogen loads and river run-off, winter phosphate dynamics are decoupled from their inputs and belong, according to the principal component analysis, to the structuring factors of the Gulf of Riga ecosystem. The rise in winter phosphate concentrations has, together with low summer zooplankton biomass, triggered an increase in summer phytoplankton biomass, potentially also due to an increase in cyanobacteria blooms (see Jurgensone *et al.*, 2011).

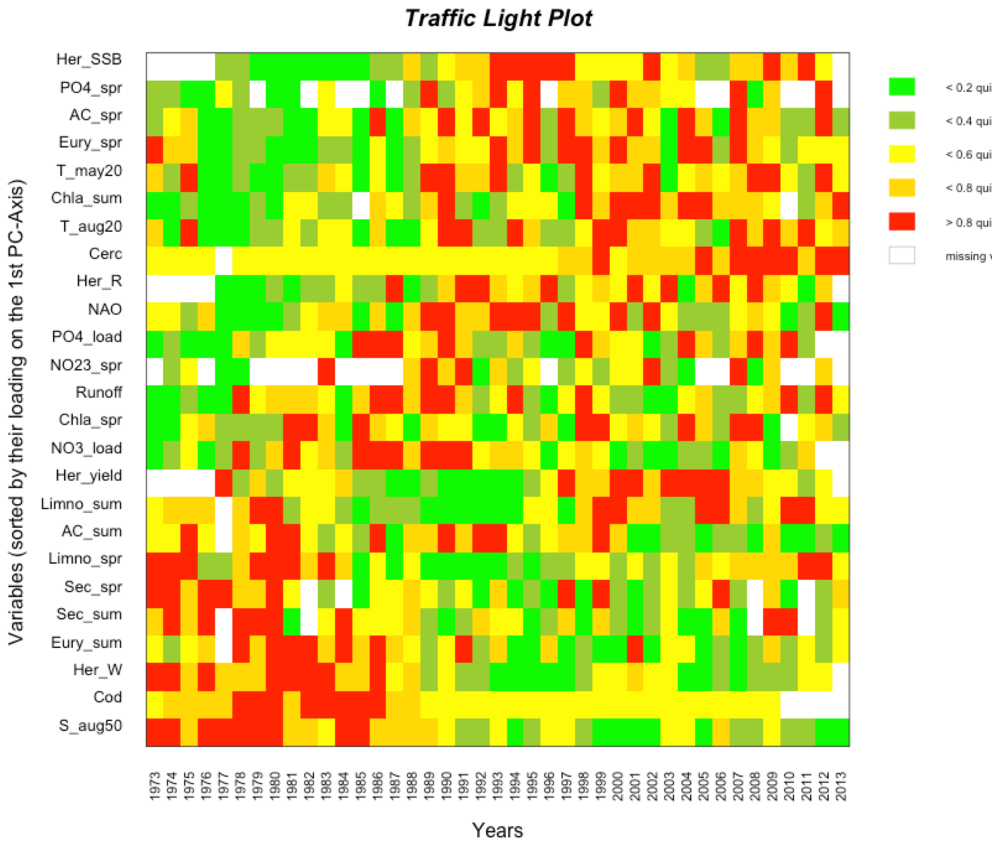

Figure GoR-6. Traffic-light plot of the temporal development of the Gulf of Riga time-series. Variables are transformed into quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component (PC1).

The decoupling between winter phosphate concentrations and loads, together with the opposite relationship for nitrogen, is also confirmed by the PCA biplot, as well as the high correlation between winter phosphate and summer chlorophyll *a*. The biplot further indicates, that the herring stock dynamics is more closely related to recruitment than to fishing pressure. STARS identifies two regime shifts in PC1 for the Gulf of Riga dataset, in 1982/1983 and 1988/1989. The first regime shifts marks a slight summer warming in the Gulf and initial higher summer phytoplankton biomass, whereas 1988/1989 initiated the major restructuring in water temperatures, zooplankton biomass and herring stock size in the Gulf of Riga.

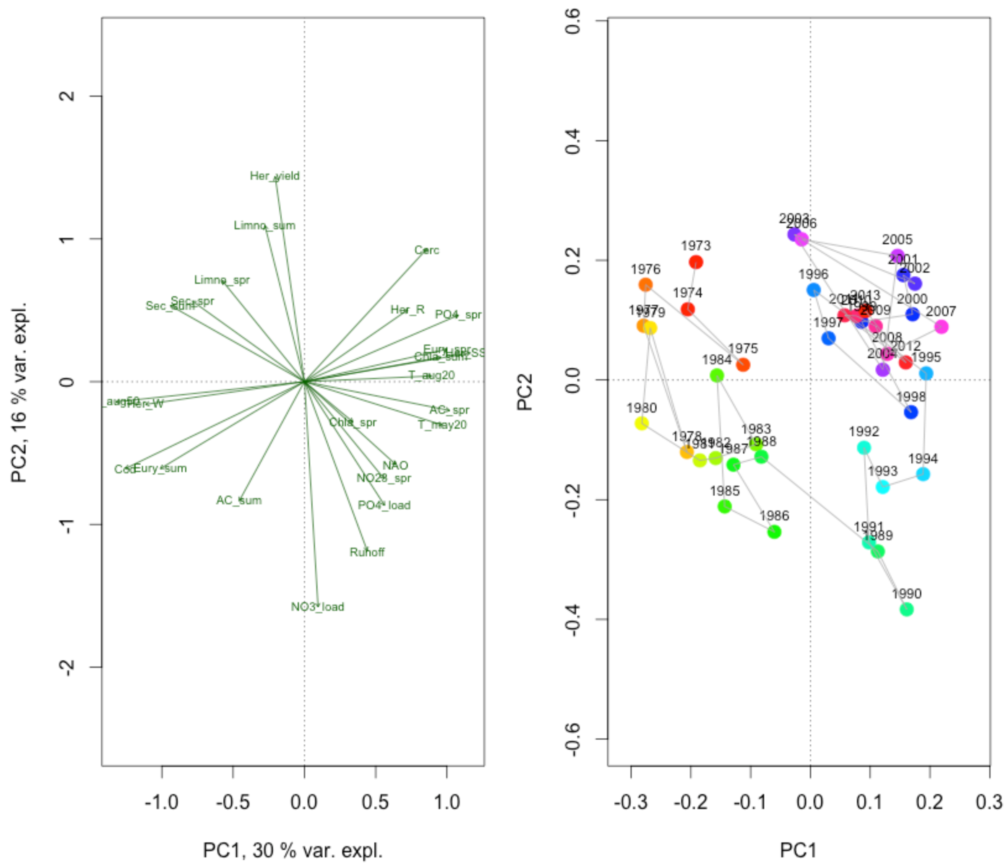

Figure GoR-7. Biplot of variable loadings (left) and time-trajectories of year scores (right) in the in the PC1-PC2 plane for the Gulf of Riga time-series. Year scores are colour-coded into red (1970s), orange-green (1980s), light blue (1990s) and blue-purple (2000s).

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Gulf of Finland

Area description

The Gulf of Finland is adjacent to the Baltic Proper and the wide entrance between these basins without any sills does enable plentiful water exchange. Therefore, the physical and chemical variations in the Baltic proper strongly influence the dynamics of the Gulf of Finland. The characteristics of the flow pattern in the Gulf of Finland include inflow of saline water and abundant freshwater inflow from the Neva River, the largest river in the Baltic Sea drainage area, and from several other rivers draining into the Gulf. Mixing of these water masses induces steep vertical and horizontal salinity gradients in the Gulf. As saline, oxygen-depleted and nutrient rich water occasionally enter the deep areas of the Gulf from the Baltic Proper, the salinity and dissolved oxygen conditions change rapidly. Substantial anthropogenic nutrient loads enter the Gulf also from the drainage area as well as via the nutrient release from the sediments. During winter, the coastal areas of the Gulf of Finland are usually ice covered and in severe winters, the whole Gulf can be ice covered. Extensive ice cover delimits the mixing of the water column contributing to oxygen depletion in the near-bottom layers, to decreasing biomass of benthic organisms, and to increases in nutrient release from the sediment. Nevertheless, during spring and early summer, stratification can build up rapidly again resulting in deep-water stagnation. The Gulf is facing intensive human exploitation and climatic change is assumed to increasingly influence the ecosystem, but e.g. shifts in the nutrients loads can potentially rapidly influence the status of this ecosystem.

Material and methods

The current trend analysis covers the period from the onset of the HELCOM Monitoring Programme in 1979 to the year 2011. The analysis included 27 variables covering hydroclimate, water chemistry and biota (4 tropic levels: phytoplankton, zooplankton, macrozoobenthos and fish). The physical and chemical variables included temperature, salinity, and length of the ice covered period, pH, and the concentrations of dissolved inorganic nutrients (DIN, DIP, SiO_4). The biomasses of the taxa *Bacillariophyceae, Chrysophyceae, Cryptophyceae, Cyanophyceae* and *Dinophyceae* were included to enable analysing the shifts in phytoplankton community. The zooplankton data included the spring and summer abundances of copepods *Pseudocalanus* spp., *Limnocalanus macrurus* and small copepods. The analysis included benthic fauna (biomasses of *Monoporeia affinis*, *Pontoporeia femorata*, *Marenzelleria* sp. and *Saduria entomon*). Fish were represented by two variables i.e. weight-at-age of two- and six-year-old herring (*Clupea harengus*). All data were compiled to one value year^{-1}.

We utilized the physical, chemical and phytoplankton data compiled and described by Suikkanen *et al*. (2013), but we extended the time-series with three more years and added the ice cover data provided by the Finnish Meteorological Institute. The physical and chemical data were from the marine monitoring database Sumppu of the Finnish Environment Institute and the Finnish Meteorological Institute (nodc.fmi.fi/grafeio), and from the Hertta database (wwwp2.ymparisto.fi/scripts/oiva.asp), which is maintained by the Finnish Environment Institute. The phytoplankton data to cover the last three years was from the Finnish Environment Institute. The zooplankton data were from the Finnish Environment Institute and the Estonian Marine Institute (EMI). The herring weight-at-age data were delivered from the Finnish Game and Fisheries Research Institute.

The analyses followed those applied and described by the WGIAB in the different basins of the Baltic Sea. The temporal development of selected variables was graphically displayed as anomalies from the overall mean. Subsequently, integrated ecosystem assessment (IEA) was performed on the time-series using a combination of exploratory ordination methods and inferential statistics. Initially, principal component analysis (PCA) was used as a time-series tool. For methodological reasons the missing values, although few, were replaced by the average of the four nearest data points. To improve linearity between variables and to reduce the relationship between the mean and the variance, the values were ln (x + 1) transformed. Subsequently, a standardized PCA based on the correlation matrix was performed on the transformed values of the full dataset, as well as of the explanatory and response variables separately. Variable loadings and year scores were displayed on the first factorial plane, and the years were connected in chronological order. Year scores along the two principal components, principal components 1 (PC1) and 2 (PC2) were also plotted against time in order to visualize temporal relationships and the occurrence of abrupt ecosystem changes. To illustrate the systematic patterns in the time-series, the "traffic-light" framework (Link *et al*., 2002; Choi *et al*., 2005) was used. Raw values of each variable were categorized into quintiles, and the values in each quintile were assigned a specific colour: green in the lowest quintile, red in the highest quintile, and a gradation of colours in between.

The variables were then sorted according to their loadings along the PC1 axis in order to obtain a temporal pattern.

Discontinuity analysis with a clustering technique was applied to identify the years in which the largest shifts in the mean value of the time-series occurred. The first was a clustering technique capable of grouping sequential years based on the time-variable matrix (chronological clustering; Legendre *et al*., 1985). To demonstrate the most important breakpoints in the dataset, the significance level (α), which can be considered as a clustering-intensity parameter, was set to 0.01 and the connectedness level to 50%. In accordance with the use of the correlation coefficient in the PCA, data were first normalized, and then the Euclidean distance function was calculated to determine similarity between years.

Results

<u>Trend analysis</u>

The temperature data shows consistent increase throughout the time-series. At the same time, salinity has been variable, with a slightly decreasing trend. The analyses suggested that the ice cover (observations from the western Gulf of Finland) decreased on average by c. 0.6 days per year. These results are in concordance with other analyses and modeming projections from the Baltic Sea.

The anomalies of concentrations of dissolved nutrients (DIN and DIP) indicate increases towards the end of the time-series. However, the DIP concentration may have been lower when halocline was absent at the midways of the time-series. The halocline in the Gulf of Finland eroded and eventually disappeared as the halocline shifted deeper towards the end of the long stagnation period in the Baltic proper which lasted until 1993. At this time, the convection of the whole water column enabled oxygenation of the near-bottom-water layers. SiO_4 concentrations were apparently decreasing until the end of the 20th century, while an increasing trend may have occurred subsequently.

Towards the end of the long stagnation period, oxygen concentrations increased in the near-bottom layers enabling the colonization of the deep areas by macrozoobenthos. The anomaly plots clearly show how the colonization of the deep areas by macrozoobenthos began around 1986 but the populations collapsed again until the beginning of the 21st century. The species-specific shifts suggest that not only the shifts in abiotic environment, but also the biotic interactions may have induced these variations in the benthic communities. In particular, *M. balthica* rapidly colonized the deep benthic areas when the conditions were favourable, but the population collapsed when the benthic amphipods colonized the bottoms. This could be linked to the hypothesis that feeding of *M. affinis* on the spat can delimit the abundance of *M. balthica* (see Rousi *et al*., 2013). In line with this, *M. balthica* increased again and a population was established for some years after the populations of amphipods collapsed. The colonization of the deep hypoxic areas by the invasive alien species *Marenxelleria* sp. was obvious during the last few years of the time-series data.

Zooplankton data indicated some variability but trends were not very clear. The abundance of *Pseudocalanus* sp. in the spring samples show some decrease while the summer samples indicate fewer changes. The abundances of small copepods show variations but without any consistent trend, and *L macrurus* show high values especially midways of the time-series but no trends over the whole analysed time span.

The total phytoplankton biomass does not show a consistent trend. Anyhow, the total chlorophyll-a concentration suggest a substantial increase, but the trend may have been turning down during the last four to five years. *Cyanophyceae* indicated an increasing trend until around 2001, after which they have been close to the average level. The biomass of *Cryptophyceae* was high during the first few years while a substantial decrease occurred thereafter. Other trends in the phytoplankton data are less obvious.

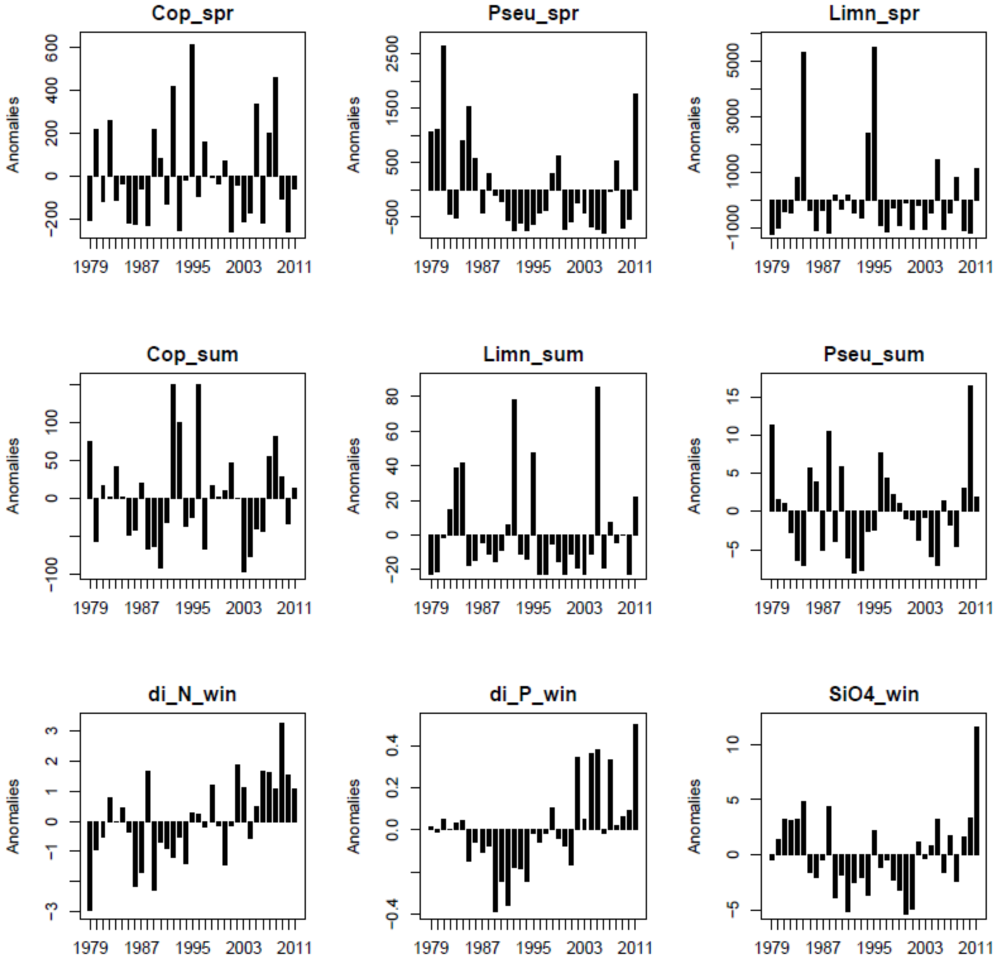
The trend analyses did not contain the abundances of fish, but the shifts in the weight-at-age of herring are obvious – substantial decrease both in two-year-old and six-year-old specimens. Anyhow, the weight-at-age in the age two may have somewhat increased towards the end of the analysed time section.

Results of integrated trend analyses based on all variables

In the traffic-light-plot (Figure 2) the variables are sorted according to their PC1 loadings with variables at the top that reveal the most important decreasing trends over time. In this analyses the high values of variables linked to marine species such as herring weight-at-age and *Pseudocalanus* sp. biomass, as well as to physical environment i.e. ice cover and salinity were at the top of the plot.

It is interesting to note that the time trajectory of the sample scores from the PCA indicated different phases in the time-series data: (1) the years 1979–1990 constituted a relative uniform group, (2) the system shifted during 1991–1995 into a different state and (3) the data from 1996–2011 is again grouped closely together possibly indicating a shift to an alternative relatively stable state. The PC1 shows a step-like shift around the year 1990, while PC2 indicates a shift around five years later. The loading plot (Figure 3) with the time trajectory, points to that the transitional period in 1991–1995 was characterized by the high abundances of benthic fauna, and also by high abundance of *L. macrurus*, low salinity, low SiO_4 concentration, short annual duration of ice cover, as well as low abundance of *Pseudocalanus* sp. The first period until 1991 is characteristically oceanic while the last period represents a eutrophic and a relatively warm era. While the Constrained Clustering analysis for the time-series (Figure 4) gives some support that the time section encompassed three phases, the broken stick analysis suggests that the shifts are not statistically significant (the black line is below the critical value represented by the red line).

Figures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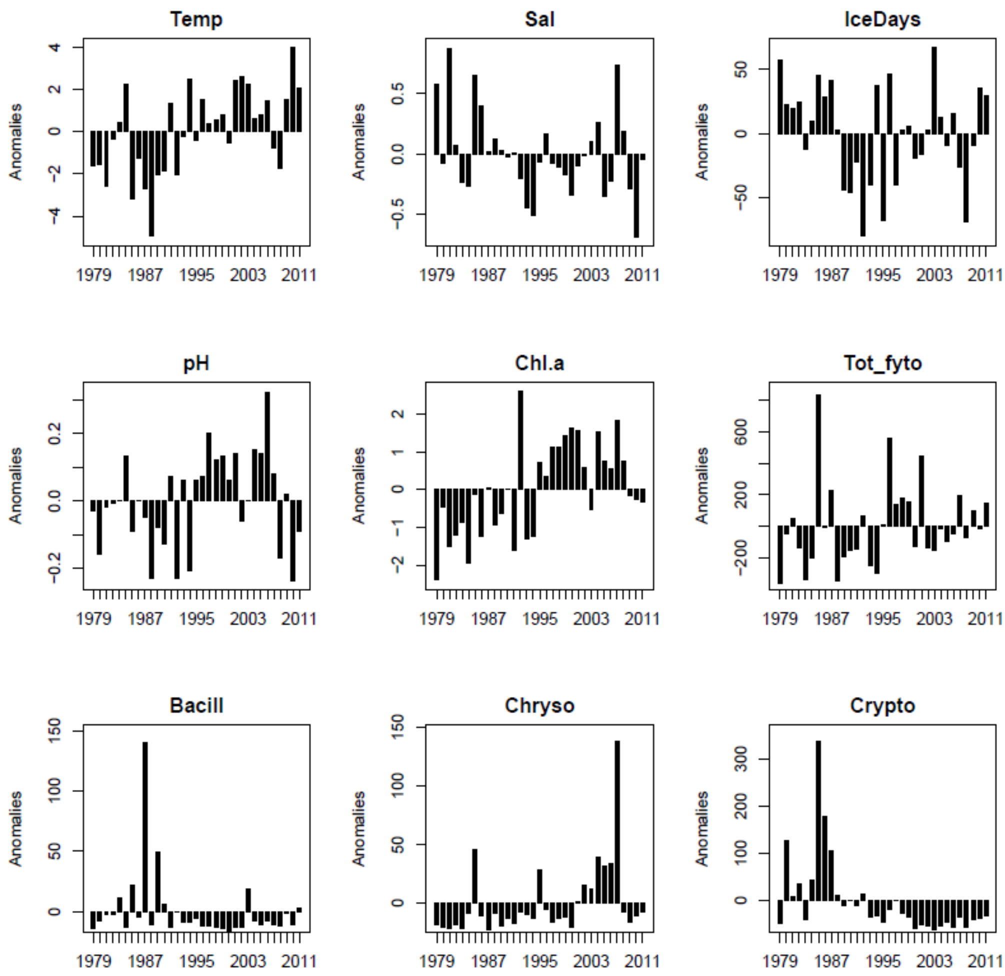
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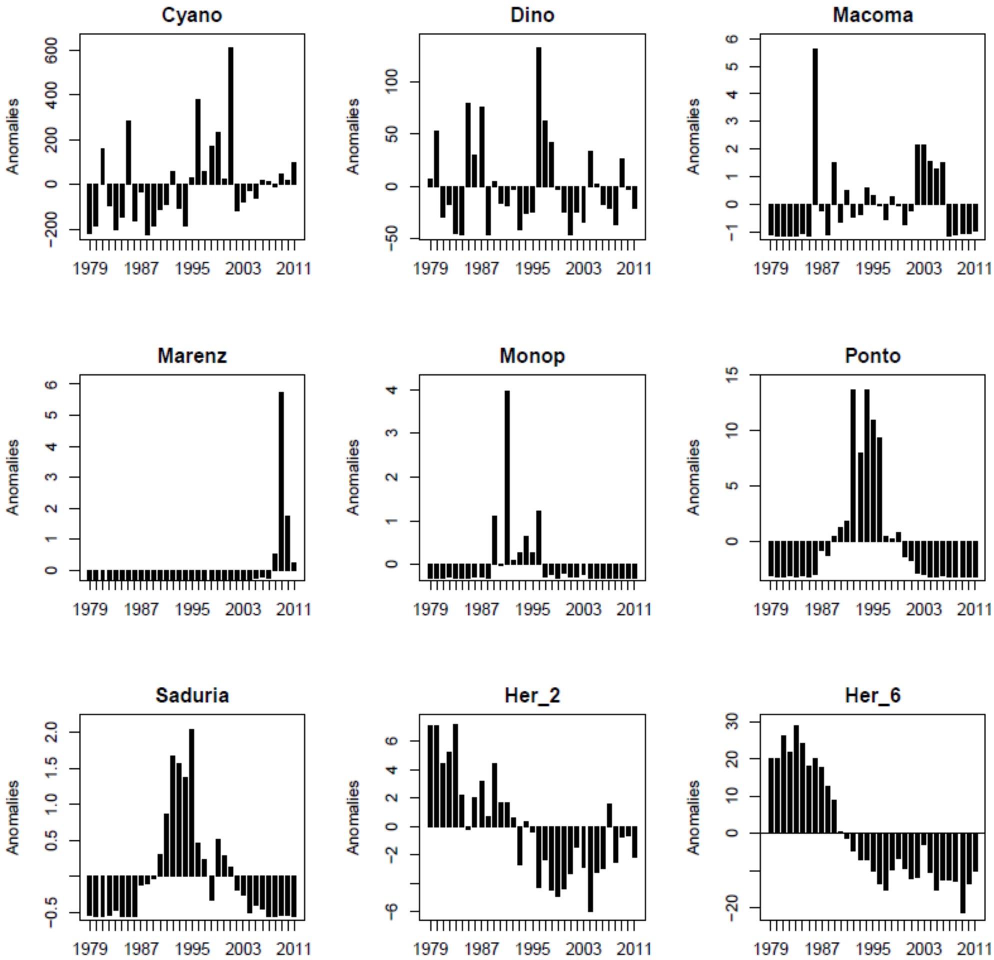

Figure 1. Long-term changes in the anomalies of the analysed variables.

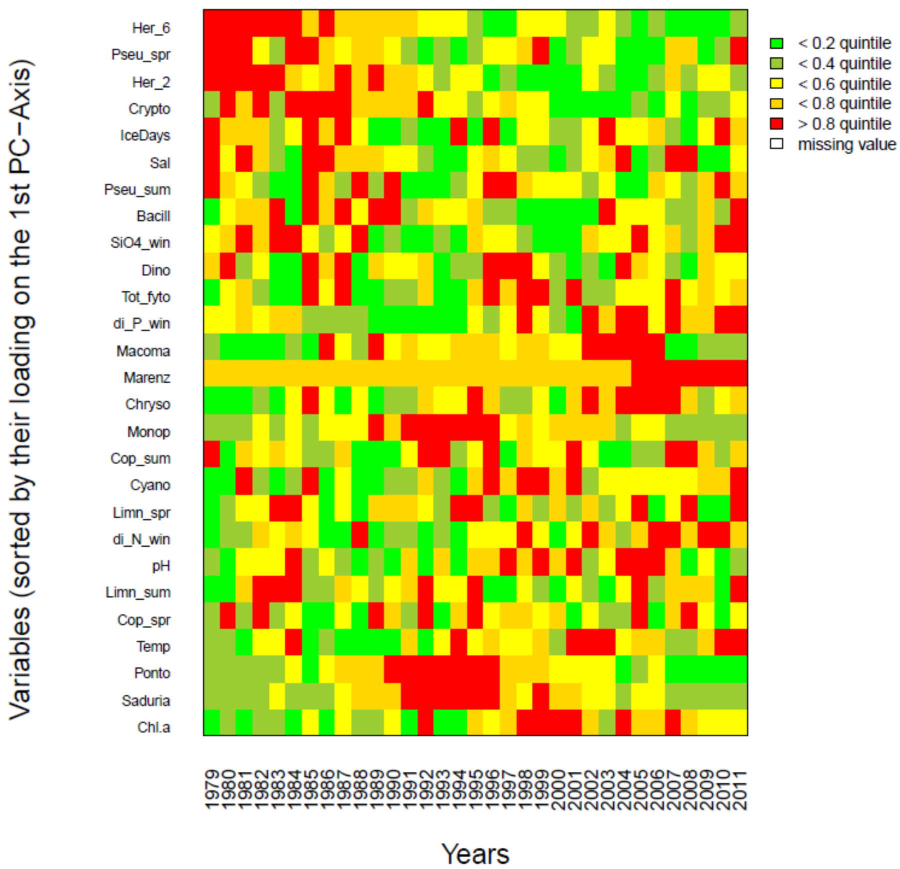

Figure 2. Traffic-light plot of the temporal development of the Gulf of Finland time-series. Colour-coding indicates the magnitude of the variables (green = low values; red = high values). The variables are sorted in numerically descending order according to their loadings on the first principal component.

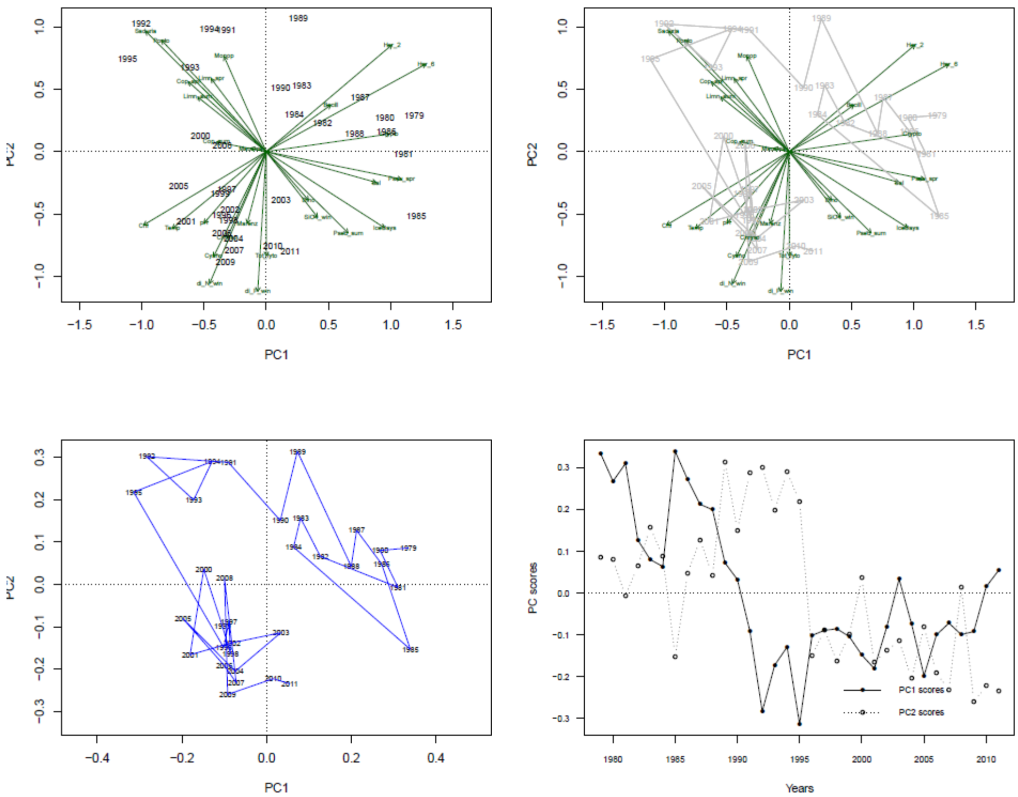

Figure 3. Results of the standardized principal component analysis (PCA) for the Gulf of Finland showing the variable loadings on the first factorial plane. The time-trajectory is shown in light grey. The lower panel on the left shows the time trajectory of the yearly loadings and the one on the right indicates the scores along the two first principal axes.

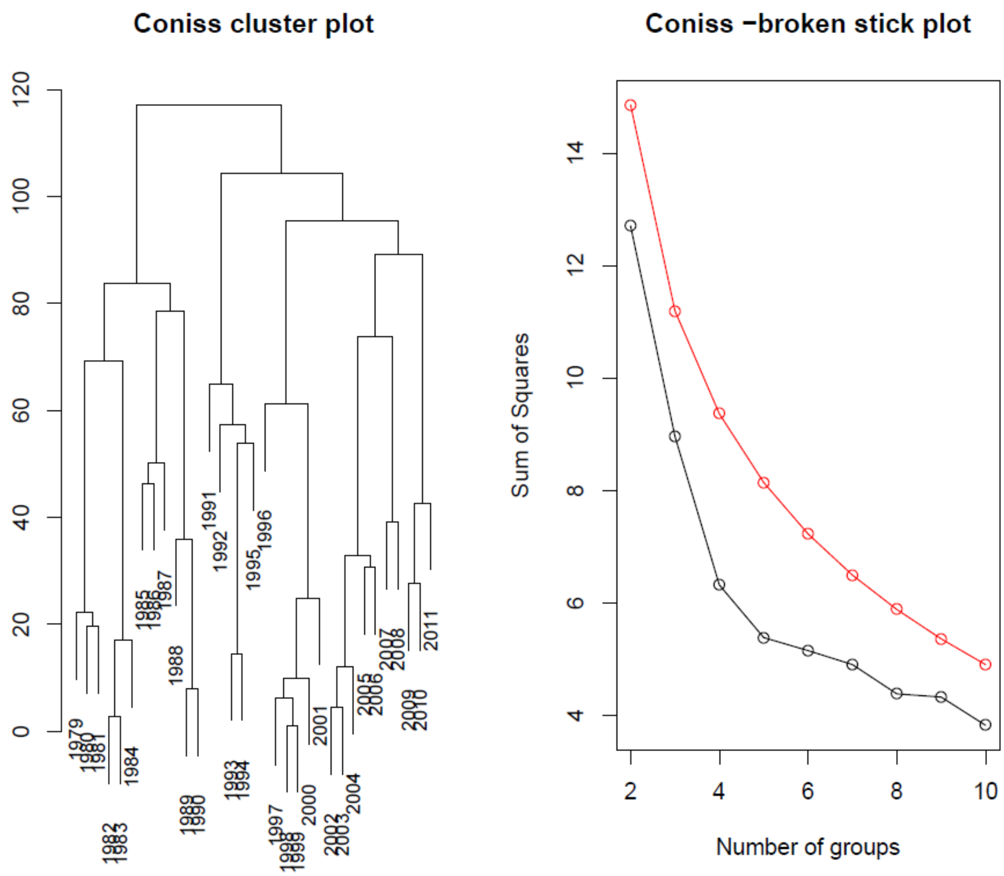

Figure 4. A cluster plot from the Constrained Clustering Analysis and a broken stick model to determine the number of significant groups in the cluster analysis. The red curve indicates the critical values.

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