ICES WGIAB REPORT 2018

INTEGRATED ECOSYSTEM ASSESSMENTS STEERING GROUP

ICES CM 2018/IEASG:08

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

16-20 April 2018

Tartu, Estonia

ICES CIEM International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

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Executive summary

The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) meeting was held at the Estonian University of Life Sciences in Tartu (Estonia) on 16–20 April 2018. The meeting was arranged to partly overlap with the annual meeting of the BONUS project "BLUEWEBS" organized at the same venue. Thanks to shared research interests and overlap in participants, we hope this could lead to some interesting and fruitful synergies and collaborations in future. The meeting was chaired by Saskia Otto (Germany), Martin Lindegren (Denmark), Lauréne Pécuchet (Finland), and Matilda Valman (Sweden).

This was the third and final year of the three-year Terms of Reference (ToR) for WGIAB. The main working activities in 2018 were to i) investigate and compare long-term trends in community weighted mean (CWM) traits across subsystems; (ii) discuss and prepare an Ecosystem Overview document for the Baltic Sea; (iii) plan an overall synthesis paper of past and recent ecosystem trends and dynamics across Baltic Sea subsystems, (iv) revisit the Integrated Ecosystem Assessment (IEA) cycle and discuss ways to better align our work within this conceptual framework in future. In terms of the first activity, we have completed preliminary trait-based assessments of CMW traits in the Kattegat, Central Baltic Sea, and Gulf of Riga. These assessments demonstrate long-term changes in CWM traits across areas and multiple organism groups (including phytoplankton, zooplankton, benthos, and fish), largely related to changes in temperature, salinity, oxygen, and nutrients. Regarding the second activity, we have provided a qualitative (expert judgement based) ranking of key stressors and their impacts on ecosystem states, as well as distributed writing tasks among members to draft the ecosystem overview document. In terms of the third activity, we made a work plan outlining what areas, variables and methods to use for the synthesis paper, as well as assigned coordinators for each subsystem and an overall project leader. Due to time constraints, work on this activity will be carried out intersessionally. Under the fourth activity, we discussed the various steps in the IEA cycle, primarily focusing on the first and crucial "scoping" process that aims to identify key ecosystem objectives. Consensus was reached to focus on already available policies (e.g. the Marine Strategy Directive and the Baltic Sea Action Plan) from which key objectives and indicators have been defined and can be used in future efforts to close the IEA loop and make it operational for management.

In summary, the studies on changes in the Baltic Sea ecosystems and functional traits composition in relation to external drivers is expected to feed into the development of methods to assess the environmental status of Baltic Sea subsystems, and to ecosystem-based advice for fisheries management. The work to develop integrated assessments of social-ecological systems is anticipated to feed into integrated management towards the objectives of the common fisheries policy and the MSFD.

1 Administrative details

Working Group name

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

Year of Appointment within the current three-year cycle

2016

Reporting year concluding the current three-year cycle

2018

Chairs

Saskia A. Otto, Germany

Martin Lindegren, Denmark

Lauréne Pécuchet, Finland

Matilda Valman, Sweden

Meeting venue(s) and dates

18–22 April 2016, Helsinki, Finland, (26 participants)

24–28 April 2017, Lisbon, Portugal, (31 participants)

16–20 April 2018, Tartu, Estonia, (25 participants)

Participants of WGIAB 2018.

2 Terms of Reference a) – b)

ToR	Description
a	Increase understanding of Baltic Sea ecosystem functioning, with a focus on functional diversity in relation to species diversity and changes of species traits over different temporal and spatial scales, and the identification of key traits and processes for maintaining functioning ecosystems and the services they provide.
b	Explore potential new options for management, including for example studies on indicators of foodweb status, implications for ecosystem functioning, and societal drivers, in order to support integrated fisheries advice and marine management, focusing on biodiversity and ecosystem function.

3 Summary of Work plan

Year 1	Annual meeting, intersessional work on research articles, interaction with suggested WKDEMO to develop on the outcomes of the DEMO project, focus on Tor a and b
Year 2	Annual meeting, intersessional work on research articles, focus on Tor a and b
Year 3	Annual meeting, intersessional work on research articles, focus primarily on Tor b

4 Summary of Achievements of the WG during 3-year term

4.1 Publications based on WGIAB activities, published in 2016–2018

Pekcan-Hekim, Z., Gårdmark, A., Karlson, A.M.L., Kauppila, P., Bergström, L. (2016) The role of climate and fisheries on the temporal changes in the Bothnian Bay food web. ICES Journal of Marine Science. doi:10.1093/icesjms/fsw032.

Pécuchet, L., Törnroos, A., and Lindegren, M. 2016. Patterns and drivers of fish community assembly in a large marine ecosystem. Marine Ecology-Progress Series, 546: 239–248

Haapasaari, P. Uusitalo, L. Bergström, L., Heikinheimo, O., Peltonen,H., Romakkaniemi, A. (2016) A response to the challenge of including the human dimension in integrated ecosystem assessment – Baltic salmon and clupeid examples. Oral presentation. ICES CM 2016/ F:312

ICES (2016) Report from ICES Annual Science conference 2016, Theme Session F – Integrated ecosystem assessment and decision support to advance ecosystem-based fisheries management: Conveners: John Pope (UK), Lena Bergström (Sweden), Melania Borit (SAF21 ETN project, Norway), Rapporteurs: Charlotte T. Weber (SAF21 ETN project, Norway), David Reid, (Ireland)

Lindegren, M., Pécuchet, L., Weigel, B., Nordström, M., Otto, S.A., Zagrodska, Z., Kleis, R., Frelat, R., Blenckner, T., Möllmann, C., Bergström, L., Uusitalo, L. (2016) A trait-based assessment towards understanding long-term changes in ecosystem functioning: the Central Baltic Sea as a case study. Oral presentation. ICES CM 2016/F:328

Otto, S.A., Schmidt, J. Ottersen, G., Johannesen, E., Möllmann, C. (2016) Lessons learned: Successes and pitfalls in IEA methods. Oral presentation. ICES CM 2016/F:489

Torres, M.A., Otto, S.A., Suikkanen, S., Putnis, I., Haas, B., Peltonen, H., Ikauniece, A., Möllmann, C., Bergström, L. (2016) Productivity changes across the Baltic Sea – linking abiotic changes to lower trophic level dynamics. Poster presentation. ICES CM 2016/F:615

Podgornyj, K.A., Dmitrieva, O.A., Semenova, A.S., Leonov, A.V. (2017) Investigation of the relationships of the size and production characteristics of phyto- and zooplankton in the Vistula and Curonian lagoons of the Baltic Sea. Part 1. The statistical analysis of long-term observation data and development of the structure for the mathematical model of the plankton food chain. Computer Research and Modeling. Vol. 9, No 2, 211–246. [In Russian with English abstract]. DOI: 10.20537/2076-7633-2017-9-2-211-246

Podgornyj, K.A., Dmitrieva, O.A., Semenova, A.S., Leonov, A.V. (2017) Investigation of the relationships between the size and production characteristics of phyto- and zooplankton in the Vistula and Curonian lagoons of the Baltic Sea // Book of Abstracts of the BONUS SYMPOSIUM: Science delivery for sustainable use of the Baltic Sea living resources, Tallinn, Estonia, 17–19. October 2017. – Tallinn: Estonian Research Council, p. 38–39. Poster presentation.

Dmitrieva, O.A., Semenova, A.S., Gusev, A.A., Rudinskaya, L.V., Podgornyj, K.A. (2017) Role of phytoplankton, zooplankton and zoobenthos as indicators in water bodies of various trophic status of the south-eastern part of the Baltic Sea. Oral presentation on the Third International Conference «Bioindication in monitoring of freshwater ecosystems» (October 23-27, 2017, St. Petersburg, Russia). St. Petersburg, p. 99–102. [In Russian]

Torres, M.A., Casini, M., Huss, M., Otto, S.A., Kadin, M., Gårdmark, A. (2017) Food-web indicators accounting for species interactions respond to multiple pressures. Ecol. Indic. 77, 67–79.

Otto, S.A., Kadin, M., Casini, M., Torres, M.A., Blenckner, T. (2018) A Quantitative Framework for Selecting and Validating Food Web Indicators. Ecol. Indic. 84, 619-31.

Frelat, R., Orio, A. Casini, M., Lehmann, A., Mérigot, B., Otto, S.A., Sguotti, C., Möllmann, C. (2018): A Three-Dimensional View on Biodiversity Changes: Spatial, Temporal, and Functional Perspectives on Fish Communities in the Baltic Sea." ICES J. Mar. Sci., fsy027-fsy27.

Pecuchet, L., Lindegren, M., Otto, S., Putnis, I., Nordström, M. (2018) Structural and functional changes of multi-trophic communities in a large marine ecosystem. Oral presentation. EC-CWO/S11

Bauer, B., Meier, H. E., Casini, M., Hoff, A., Margoński, P., Orio, A., ... & Tomczak, M. T. (2018). Reducing eutrophication increases spatial extent of communities supporting commercial fisheries: a model case study. ICES Journal of Marine Science.

4.2 Advisory products

Development of the first Ecosystem Overview document for the Baltic Sea.

4.3 Datasets and modelling outputs

No datasets are produced, but time-series datasets on open sea and coastal marine communities are regularly collated and updated for analyses (ToR a). The last three years, effort was especially undertaken to collect multi-trophic datasets to characterize temporal changes in different organism groups across different Baltic Sea basins. We were interested in surveys that sampled the whole community (i.e. every species recorded) and started before the late 1980s regime shift as we aimed to study long-term changes in community weighted mean traits (CWM) across different trophic levels and areas. Obtaining such data proved to be challenging with few areas with information on more than two trophic levels. Kattegat and Gulf of Riga were the only two areas for which good-quality community data were available for four organism groups (phytoplankton, zooplankton, benthos, and fish) from the 1980s. The other areas are covered by shorter datasets (from 1990s) and often missing offshore phytoplankton or fish data. The main community data that are still missing are: offshore fish and phytoplankton community in northern Baltic, zooplankton in western Baltic Sea and phytoplankton in eastern Baltic Sea. Still, the many datasets that were collected cover the entire Baltic Sea area from the 1990s with at least two trophic levels per ICES subdivision (Table 1 Annex 5).

4.4 Methodological developments

4.4.1 Expansion of ITA methods to analyse spatio-temporal and functional dynamics

Current Integrated Trend Analyses (ITA) greatly focus on the temporal component of ecosystem dynamics and account for spatial differences by repeating the analyses for the different subsystems. However, understanding changes of entire communities requires the application of novel approaches that fully account for the interactions between the dimensions of species, time, and space (Mørup, 2011). The body condition of Baltic sprat (*Sprattus sprattus*) and its proposed linkage to the distributional shift of the Eastern Baltic cod stock (*Gadus morhua*) (Casini *et al.*, 2014) clearly demonstrates the need to broaden our set of ITA tools to incorporate spatio-temporal dynamics. Since all spatio-temporal methods require sufficiently long time-series over several spatial data points, first attempts were made on the most complete dataset currently available, i.e. the environmental conditions in the Baltic Sea offshore regions, using a multivariate method that proved beneficial for the North Sea (Frelat *et al.*, 2017) (section 5.1.2). Extending the focus to ecosystem functions and species traits as a third dimension brings another methodological challenge. Recent advances were made by developing a framework of complementary multivariate statistical methodologies to simultaneously investigate the effects of environmental conditions on the spatial, temporal and functional dynamics of species assemblages (Frelat *et al.*, 2018). The framework was tested using survey data collected during more than 4000 fisheries hauls over the Baltic Sea between 2001 and 2016. The approach revealed the Baltic fish community to be structured into three sub-assemblages along a strong and temporally stable salinity gradient decreasing from West to the East. Additionally, a mismatch between species and functional richness associated with a lower functional redundancy in the Baltic Proper compared with other subareas was found, suggesting an ecosystem more susceptible to external pressures.

In addition to the application of multivariate ITA tools that can deal with multidimensional datasets (i.e. including time, space, and traits), progress is made in evaluating ITA tools applied in the past by WGIAB and all other ICES IEA groups. This work is linked to the project "IEA-Exchange" (Exchange of knowledge for Integrated Ecosystem Assessment) funded by the ICES Science Fund and the ICES WKIDEA (Workshop on Integrated Ecosystem Assessment Methods) (ICES, 2017) and will be followed up in a second workshop in September (Workshop on integrated trend analyses in support to integrated ecosystem assessment, WKINTRA).

5 Summary of achievements in relation to the ToRs

5.1 Tor A: Baltic Sea ecosystem structure and functioning

"Increase understanding of Baltic Sea ecosystem functioning, with a focus on functional diversity in relation to species diversity and changes of species traits over different temporal and spatial scales, and the identification of key traits and processes for maintaining functioning ecosystems and the services they provide."

The main aim of the work carried out under ToR A throughout the reporting period was to perform what we wish to term a "Trait-based Integrated Trend Analysis" (tbTA). This analysis builds on our previous work on Integrated Trend Analyses across the Baltic Sea basin (e.g. Diekmann and Möllmann, 2010), but extend the analysis beyond considering changes in abundances of a few dominant species, to account for community-wide changes in a number of key morphological, physiological or behavioral characteristics (Violle *et al.*, 2007), so-called "traits" (e.g. size, growth, and diet preferences) across multiple trophic levels. The underlying rational is that these traits, either separately, or in combination represent various ecosystem functions (e.g. nutrient cycling and biomass production) (Díaz *et al.*, 2007; Violle *et al.*, 2007; Mouillot *et al.*, 2011; Törnroos *et al.*, 2015; Pecuchet *et al.*, 2016) upon which we derive important ecosystem services (e.g. seafood and climate regulation). By tracking temporal changes in these community weighted mean (CWM) traits we wish to understand whether or not functional changes have occurred across the Baltic Sea as a result of the 1980s regime shift (e.g. Möllmann *et al.*, 2009). To that end, our work will not only strive to highlight and answer some fundamental ecological questions regarding the functioning (and biodiversity) of marine ecosystems and the underlying processes of regime shifts (Scheffer *et al.*, 2001; Cardinale *et al.*, 2012), but put our findings in a framework that can provide guidance and advice to ecosystem-based marine management in the Baltic Sea and beyond. As case studies, we choose to focus on three geographically separated subareas for which we have a comparable set of abiotic and biotic information regarding species abundances and traits from the late 1970s and onwards, namely Kattegat, the Central Baltic Sea (ICES Subdivision 28) and the Gulf of Riga (Table 1 in Annex 5). Furthermore, these areas differ markedly in their environmental conditions and community composition and therefore allow for interesting comparisons in terms of CWM traits. The tbITA is based on following working steps:

1. Collect long-term time-series of phytoplankton, zooplankton, fish, and zoobenthos from various Baltic Sea sub-basins. These time-series should preferably encompass the entire, or at least a major part, of the community in question, specified at the level of species or genera and include abundances or biomasses.
2. Collect long-term time-series of environmental conditions in each sub-basin corresponding to the abiotic time-series used in our previous IEAs, e.g. nutrients, temperature, salinity, oxygen, ice coverage, fishing pressure etc.
3. Collect, use and/or update existing trait databases of phytoplankton, zooplankton, fish, and zoobenthos species made available by meeting participants. These traits should refer to any measurable morphological, physiological or behavioral feature of all, or at least a large part of the species or genera included in the monitoring time-series (collected under step 1). Although the available databases cover a wide range of traits, an important decision to be made is to select a core set of particularly informative traits (e.g. size) upon which we can derive comparative time-series of CWM traits across trophic levels.
4. Estimate CWM traits based on available "species x abundance" and "species x trait" information as follows:

$$CWM = \sum_{i=1}^{n} p_i * trait_i$$

where n is number of species, p_i is the relative abundance of species i and $trait_i$ the trait value of species i (Lavorel *et al.*, 2008). If traits are binary or categorical data, for each trait level or trait category the proportion of occurrence is calculated based on the species x abundance table and used as single variable in the multivariate analyses.

5. The derived time-series of CWM traits and abiotic conditions (see step 2) will be combined into a number of multivariate dataset, each representing a specific basin or subarea. These multivariate datasets will be analysed for common trends and patterns in biotic (traits) and abiotic time-series using a number of multivariate statistical methods.

5.1.1 Summary of results from the trait-based Integrated Trend Analyses (tbITA)

5.1.1.1 The Central Baltic Sea

The tbITA was performed in the Central Baltic Sea by doing a Principal Component Analysis (PCA) of CWM traits time-series from all organism groups, with the PCs representing the dominant modes of CWM traits variability. The Central Baltic Sea (i.e. Gotland Basin) show pronounced temporal trends in CWM traits with a marked change in "ecosystem state" (i.e. characterized by PC1) occurring in the late 1980s (Figure 5.1.), hence coinciding with the previous changes observed when considering only key species abundances (Möllmann *et al.*, 2009). However, PC1 was mainly driven by the fish CWM traits, indicating that the different group of organisms might have different community trait dynamics. Furthermore, our results show that changes in ocean drivers – represented by decadal fluctuation and changes in Baltic Sea salinity, temperature and oxygen and nutrients explain a large part of the variability for each PC (Figure 5.2).

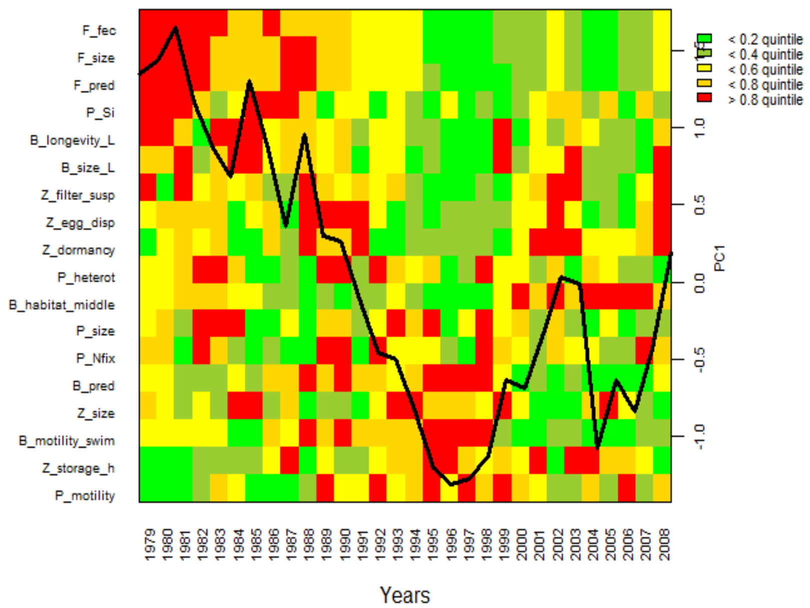

Figure 5.1. A traffic-light plot summarizes the temporal trajectories of CWM traits in the Gotland Basin. The variables are transformed to quintiles and sorted according to their loadings on the first principal component of a PCA including all CWM trait time-series. Hence, variables listed at the top are positively correlated to the first principal component and vice versa. The first principal component is shown by a solid black line.

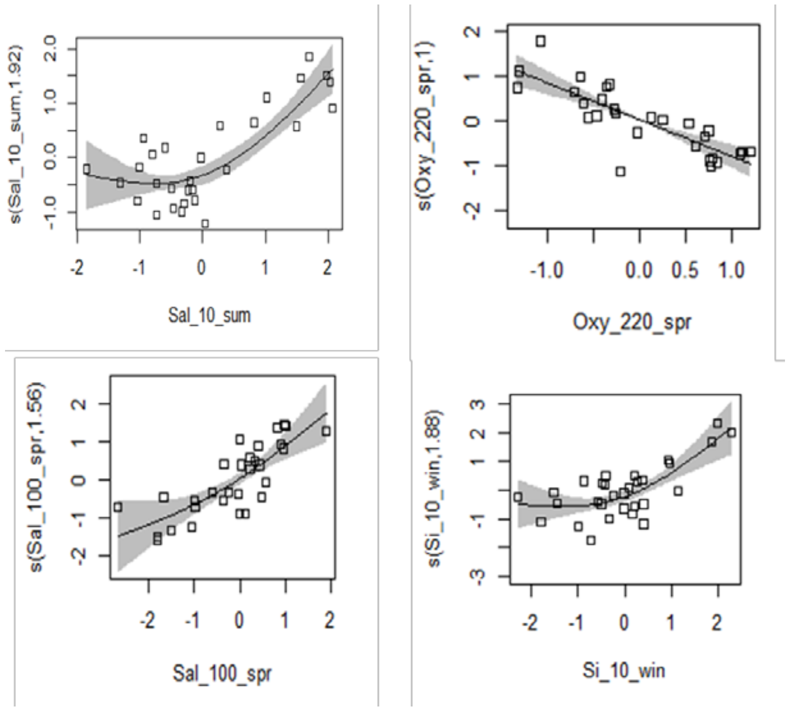

Figure 5.2. The primary abiotic drivers of ecosystem dynamics in the Central Baltic Sea. The functional relationship between PC1 and surface salinity (a), PC2 and bottom oxygen (b), PC3 and bottom salinity (c) and PC4 and winter silica concentrations (d). Black lines show fitted relationships and the grey shaded area the 95% confidence intervals.

5.1.1.2 Kattegat

The tbITA was performed in the Kattegat by doing a Dynamic Factor Analysis (DFA; Zuur *et al.*, 2003) on the CWM traits time-series of the four organism groups (fish, benthos, zooplankton, and phytoplankton). The DFA is a dimension-reduction technique especially developed for time-series which takes into account the inherent properties of time-series such as temporal autocorrelation and non-stationarity. This method was used instead of the usual PCA analysis after a study from Planque *et al.* (2017) demonstrated that trends extracted from PCA were often the results of methodological artefacts. The DFA analysis was performed in R using the package MARSS.

The first temporal dynamic (T1) corresponds to an overall increase with a rather low slope and high interannual variability before the early 2000s and thereafter a higher slope and low variability (Figure 5.3). T1 is driven by phytoplankton traits such as 'motile', 'chain forming' and 'heterotrophy'/'autotrophy' and to a lesser extent by the benthos traits' 'lecitotrophic' vs. 'planktotrophic' larvae and the zooplankton traits' 'ambush' vs. 'filter' feeder. The second trend (T2) represents an almost linear decrease and is predominantly driven by phytoplankton traits and to a smaller degree by fish traits (Figure 5.4). The tbITA in the Kattegat did not reveal any abrupt changes in the ecosystem state but instead rather a continuous changes, though it has to be noted that the first two trends were mainly driven by the CWM traits of only one organism group.

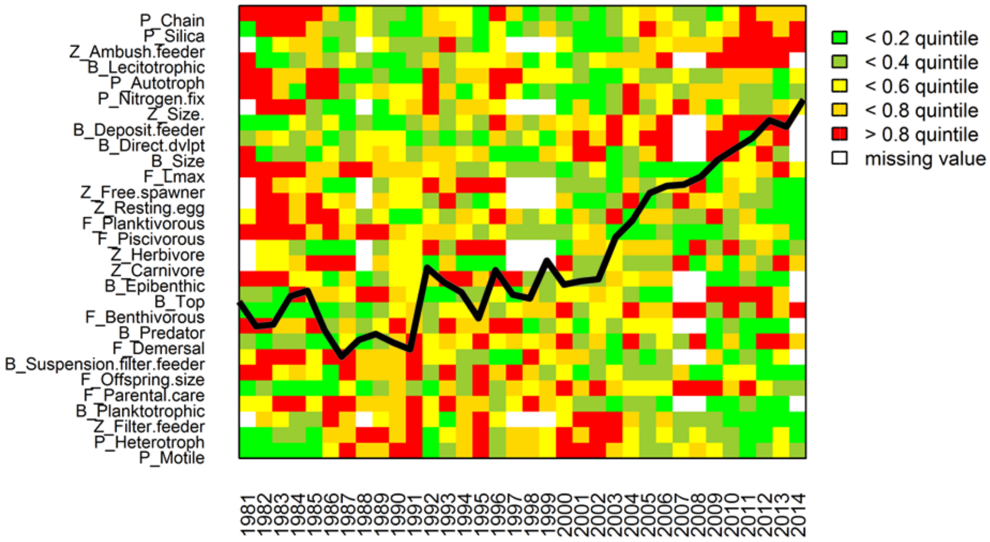

Figure 5.3. A traffic-light plot summarizes the temporal trajectories of CWM traits in the Kattegat. The variables are transformed to quintiles and sorted according to their loadings on the first trend (T1) of a DFA including all CWM trait time-series. Hence, variables listed at the top are positively correlated to T1 and vice versa. T1 is shown by a solid black line.

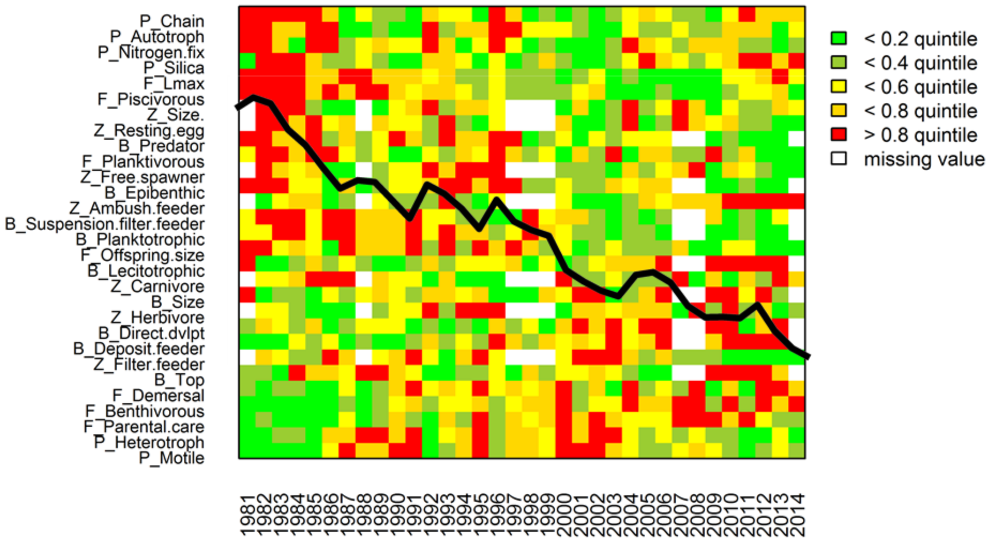

Figure 5.4. A traffic-light plot summarizes the temporal trajectories of CWM traits in the Kattegat. The variables are transformed to quintiles and sorted according to their loadings on the second trend (T2) of a DFA including all CWM trait time-series. Hence, variables listed at the top are positively correlated to T2 and vice versa. T2 is shown by a solid black line.

5.1.1.3 Gulf of Riga

Compared with the Kattegat, the temporal trends of cross-trophic trait analysis in the Gulf of Riga from a DFA analysis were non-linear. T1 was predominantly driven by the zoobenthos traits and was characterized by a high interannual variability until early 1990s and thereafter almost a flat line. T2 was also mainly driven by benthos traits, but also by some phytoplankton and zooplankton traits. T2 was characterized by a decrease until the early 1990s, in a similar fashion than the Central Baltic Sea’s PC1, and thereafter only moderate change with no trend. The traits that decreased in the GoR community, following T2, were benthos 'suspension' and 'deposit-feeder', zooplankton 'herbivore' and fish 'piscivorous'. The traits that increased were benthos 'predator', 'carnivore' zooplankton or 'motile' phytoplankton. The tbITA in the Gulf or Riga showed an abrupt change in the ecosystem state (T2) in the late 1980s, similar to the one observed in the Central Baltic Sea.

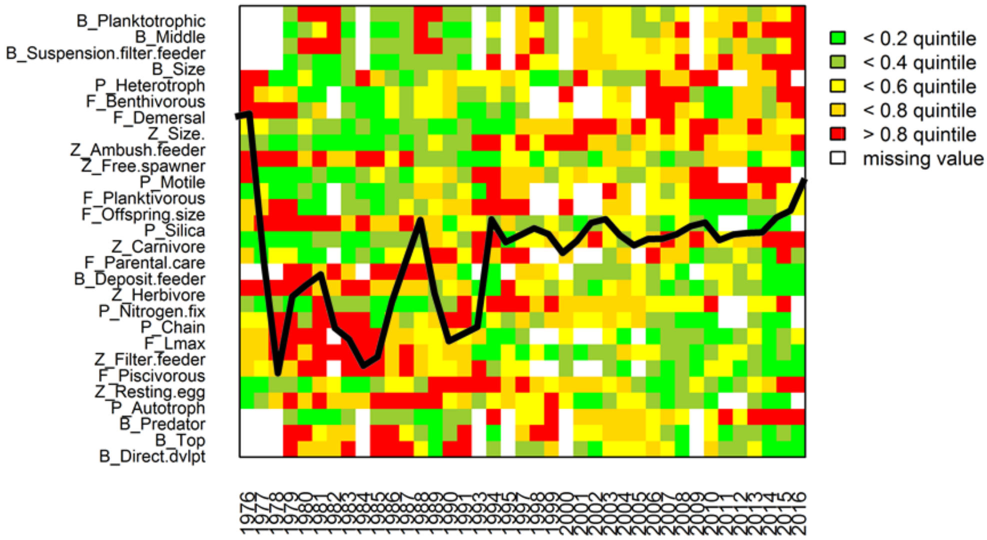

Figure 5.5. A traffic-light plot summarizes the temporal trajectories of CWM traits in the Gulf of Riga. The variables are transformed to quintiles and sorted according to their loadings on the first trend (T1) of a DFA including all CWM trait time-series. Hence, variables listed at the top are positively correlated to T1 and vice versa. T1 is shown by a solid black line.

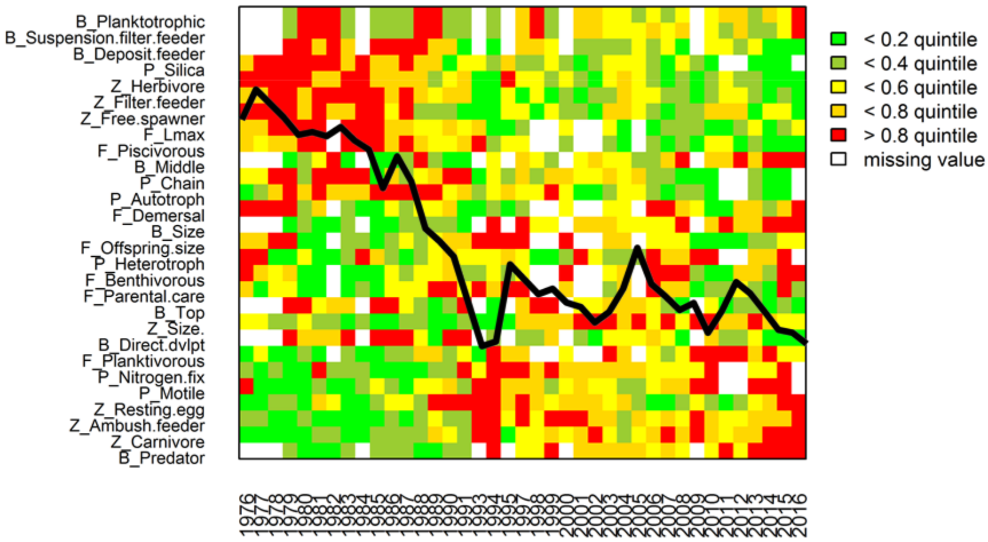

Figure 5.6. A traffic-light plot summarizes the temporal trajectories of CWM traits in the Gulf of Riga. The variables are transformed to quintiles and sorted according to their loadings on the second trend (T2) of a DFA including all CWM trait time-series. Hence, variables listed at the top are positively correlated to T2 and vice versa. T2 is shown by a solid black line.

5.1.2 Use of tensor decomposition to identify spatio-temporal patterns in environmental conditions

In the Baltic Sea, significant changes in the foodweb during the late 1980s were caused by the combined effects of changing physical oceanographic conditions, eutrophication, and unsustainable fishing pressure. During the past two decades, Baltic Sea food-webs have been continuously subject to long periods of poor oxygen conditions, with only occasional saltwater inflows alleviating the salinity and oxygen conditions, while winter phosphate concentrations and summer temperature continued to increase. These recent trends have so far not been documented and compared in relation to changes at the lower trophic level. During the last years' meetings, time-series of environmental variables were updated and analysed by applying Principal Component Analyses (PCAs) for each sub-basin separately (i.e. for the Central Baltic Sea, Gulf of Riga, Gulf of Finland, Bothnian Sea, and Bothnian Bay). Tensor decomposition (TD) is an extension of a two-dimensionalimensional multivariate analysis in multiple dimensions that allow the synchronized study of multiple ecological variables measured repeatedly through time and space (Leibovici, 2010). A first preliminary application of this technique on the basin-specific environmental data identifies three principal tensors (PT) that explained best the spatio-temporal summer conditions. The PTs describe two major temporal trends present across the entire Baltic Sea study area (PT1 and PT2) and one spatial gradient that divides mainly the Central Baltic Sea basins from areas further north (PT3) (Figure 5.7). PT1 shows a strong change in the late 1980s that occurred in all stations but at slightly different magnitudes. This change is mainly caused by the increase in summer temperature (Temp_surf_sum and Temp_deep_sum) and Chl *a* with a simultaneous decrease in surface salinity conditions (Sal_surf_sum) (Figure 5.8. and Figure A6.1 in Annex 6). PT2 shows a similar broad-scale shift in the early 1990s but also a return to the former state in the late 1990s. This development is particularly driven by the nutrient concentrations, which changed from high phosphate (DIP_deep_sum) and silicate (SILI_deep_sum) to higher nitrate concentrations (DIN_deep_sum) and vice versa. These shifts were particularly pronounced in the Gotland Basin (GB) and Northern Baltic Proper (NBP2). Stronger spatial patterns are captured in PT3 (Figure A6.1 in Annex 6), which shows for the most northern and southern areas a reversed temporal trend: a sharp drop in the late 1980s and a constant increase since then, also in the most recent years and with high interannual fluctuations (Figure 5.7, middle right panel), is positively related to Chl *a* and negatively to phosphate concentrations (Figure 5.8). However, this strong temporal pattern is only found in the Bornholm and Gotland Basins (Figure 5.7, upper right panel), while in the Bothnian Bay the opposite but more moderate trend occurred. This division between the two Central Baltic Sea basins and the northern areas is also captured in the hierarchical cluster analysis on the 3 PTs (Figure A6.2 in Annex 6). Together with the dynamics captured by PT1 and PT2 this interprets as changes in hydrographical conditions acting at broader scales with little changes in recent years, while nutrient concentrations and primary productivity vary distinctly between the Central Baltic Sea and the northern areas.

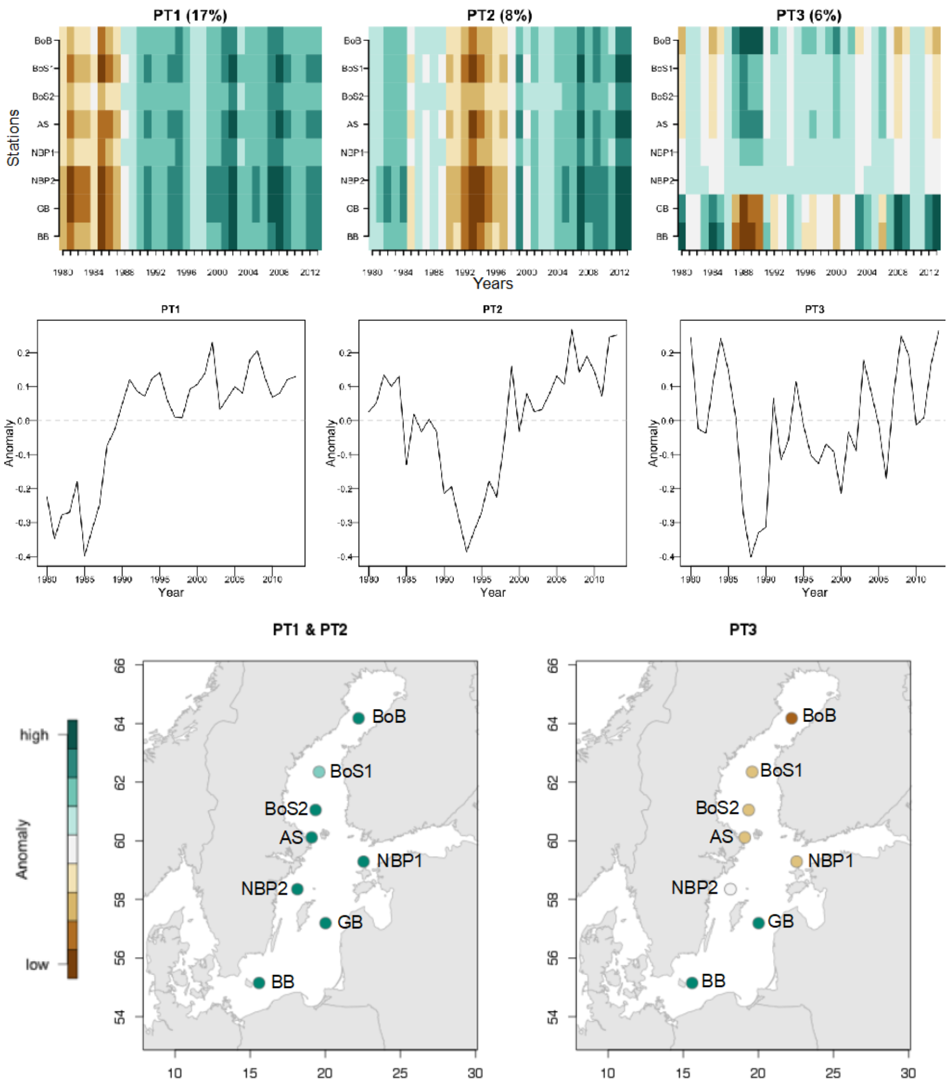

Figure 5.7. Results of the Principal Tensor Analysis with 3 principal tensors (PT) explaining together 31% of the total variability of the environmental conditions of Baltic Sea offshore regions. PT-specific results are shown in terms of their station-specific time-trends (upper row), their overall temporal dynamics (middle row), and their general spatial patterns (lower row), which is the same for both PT1 and PT2.

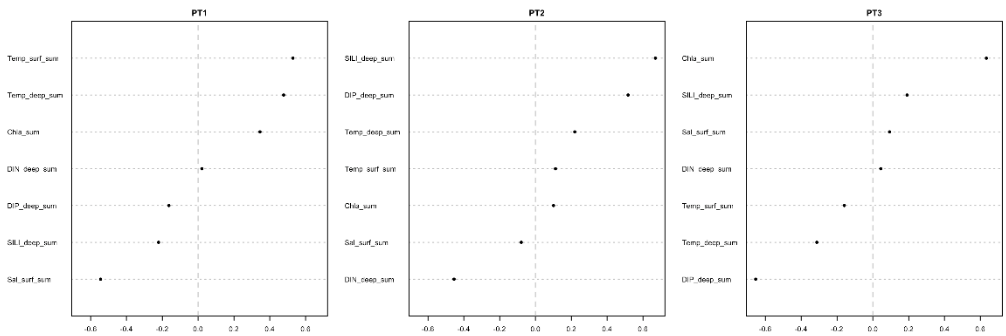

Figure 5.8. Environmental loadings on the first three principal tensors.

5.1.3 Baltic Health Index

The Baltic Health Index is an assessment method that evaluates current conditions comprehensively from social, economic, and environmental perspectives. In this approach, a healthy ocean is defined as one that sustainably delivers a range of benefits to people now and in future. This assessment method, the Ocean Health Index, has a global scope. For the first time, we apply this approach to a regional transboundary water. We call it the Baltic Health Index project, where the focus is to measure progress towards a suite of key societal 'goals' representing the benefits and services people expect healthy oceans to provide: food provision, fishing opportunities, natural products, coastal protection, tourism, carbon storage, coastal livelihoods, sense of place, clean waters, and biodiversity. In a completely transparent process, which integrates existing major players such as HELCOM and ICES as well as interdisciplinary scientists, we calculate the status of the goals named above. The main interest is to understand their interplay and the underlying processes. The Baltic Health Index aims to integrate system dynamics into the overall health, to make it communicable and manageable for a sustainable future. The Baltic Health Index project is led by Thorsten Blenckner at the Stockholm Resilience Centre (SRC) at Stockholm University, together with the Ocean Health Index team in Santa Barbara, California. The research is inspired by and based on the Ocean Health Index (OHI, http://www.oceanhealthindex.org/) which was created by a group of frontline researchers in Santa Barbara, California. The Baltic Health Index formally started in 2015 and the results will be published after summer 2018. It involves researchers from all around the Baltic Sea. The preliminary findings are discussed, improved and presented to the WGIAB group.

5.1.4 Selected presentations and abstracts on ToR A at the 2016–2018 meetings

Foodweb structure and function: examples from the Baltic Sea

by Marie Nordström

To understand the consequences of changes in diversity we need to consider the functional characteristics (traits) of species, as well as the trophic setting the taxa are part of. How networks are structured, has implications for how they function, how they react to external perturbations, and how they recover following disturbance. Biological traits, on the other hand, determine how species react to changes in the environment, how species contribute to functioning and how they interact with other taxa. Three recent studies on Baltic Sea foodweb structure and function were presented. (1) Assessing changes in network topology along a gradient of increasing disturbance, we found a general simplification of benthic macroinvertebrate foodwebs, with lower diversity, complexity, as well as changes in the types of consumers present at affected sites. (2) A comparison of motif structure of coastal and offshore webs before and after a regime shift revealed that fundamental processes may continue to structure marine foodwebs despite major reorganization of the communities. (3) Finally, assessing how structural foodweb attributes (nestedness, generality, vulnerability) relate to multiple biological traits of interacting taxa, we found traits, such as body size, environmental habitat, and body form, to determine feeding interactions among marine taxa. In conclusion, we suggest continued development of an approach integrating functional diversity with foodweb topology to effectively assess community structure, function, and species interactions, and ultimately identify ecological impacts in the changing Baltic Sea ecosystem.

Spatio-temporal patterns in species and functional diversity of phytoplankton

by Zuzanna Zagrodtzka and Saskia Otto

Phytoplankton is known to have contributed to the observed foodweb changes in various basins of the Baltic Sea. While previous studies have looked at long-term changes at a high taxonomic level (e.g. diatoms, dinoflagellates, and cyanobacteria) we here studied the temporal variability of individual species and genera across the Baltic Sea gradient. Using spring data from eight different stations between the Belt Sea and the Eastern Gotland Sea covering the period 1980–2012, we identified key taxa that contributed to the major long-term shifts and whether long-term pattern were synchronous across basins. Furthermore, we assessed if changes of individual taxa affected also the species and functional diversity. The analysis of functional traits and its spatio-temporal variability has just recently gained attention. Based on multivariate and breakpoint analyses we identified synchronous shifts in the species composition as well as species and functional diversity across all basins around the late 1980s and early 1990s. The breakpoints found, however, showed slight lags between basins and between different diversity indices used. Often, more than one breakpoint was found indicating great temporal fluctuations in the phytoplankton spring community. The key taxa that contributed to the shift in species composition were mainly the diatom *Achnanthes taeniata* (downward trend in all basins), the dinoflagellates *Peridiniella catenata, Plagioselmis prolonga, Gymnodinium* spp., and *Scrippsiella complex* (upward trend after the shift) as well as the recoiling algae *Dinophysis norvegica.* Another general pattern that emerged was the increase in diversity after the basin-wide shift, particularly in species and trait richness. In addition, along the salinity gradient we found higher species richness at stations closer to the Kattegat, while trait richness was higher at the more brackish stations in the Easter basins.

Spatial and temporal patterns in zoobenthic functional diversity

by Benjamin Weigel

Ecological studies based on time-series often investigate community changes centered on species abundance or biomass but rarely expose the consequential functional aspects underlying such changes. We studied a coastal system in the northern Baltic Sea, where long-term changes in zoobenthic communities have been observed over a 40-year time frame with contrasting developments in sheltered and exposed areas, which have been affected by system-specific environmental drivers. Furthermore, the system also encompasses the large-scale invasion of a non-native species, the polychaete *Marenzelleria* spp., which became highly dominant especially in the exposed areas over the past decade. This background creates a suitable case study to demonstrate how changing community patterns may also result in altered functional properties. Despite the contrasting community developments, with characteristics traditionally suggesting different environmental quality status in the two habitats, we found that the functional diversity (FDis) of zoobenthic communities in both habitats remained similar and increased with the introduction of *Marenzelleria*. Although showing maintained functional diversity across time and space, the functional identity, measured as community-weighted means of trait expression (CWM) changed significantly and irrespective of taxonomical differences. Inter alia community shifts in palatability proxies of zoobenthos for fish, such as size, protection, energy content and environmental position suggest altered food quality and functionality of zoobenthos over time.

Assembly rules shaping the composition of demersal fish communities in the Baltic Sea

by Lauréne Pécuchet

The presence and survival of the species in a community depend on their abilities to maximize fitness in a given environment. The study of the processes that control survival and coexistence, termed 'assembly rules', follows various mechanisms, primarily related to biotic or abiotic factors. To determine assembly rules, ecological similarities of co-occurring species are often investigated. This can be evaluated using trait-based indices summarizing the species' niches in a given community. In order to investigate the underlying processes shaping community assembly in marine ecosystems, we investigated the patterns and drivers of fish community composition in the Baltic Sea, a semi-enclosed sea characterized by a pronounced environmental gradient. Our results showed a marked decline in species- and functional richness, largely explained by decreasing salinities. In addition, habitat complexity and oxygen were found to be significant drivers. Furthermore, we showed that the trait composition of the fish community in the western Baltic Sea is more similar than expected by random chance alone. This implies that environmental filtering, acting along the salinity gradient, is the dominant factor shaping community composition. However, community composition in the eastern part, an area beyond the steep decline in salinity, was characterized by fewer species with largely different trait characteristics, indicating that community assembly is also affected by biotic interactions. Our results add to the knowledge base of key abiotic drivers affecting marine fish communities and their vulnerability to environmental changes, a key concern for fisheries and marine ecosystem management.

The first FUNBAZOO (FUNctional diversity of Baltic ZOOplankton) workshop held in Hamburg 2015

by Saskia Otto

The project FUNBAZOO is funded by the Hamburg Ministry of Science and part of the new Baltic Science Network initiative. The aim of the project is to identify the *status quo* of the diversity of functional traits in zooplankton communities in the Baltic Sea. Furthermore, potential long-term changes in the functional diversity and their key drivers will be evaluated. These research questions will be investigated during two workshops and a continuous collaborative effort between universities of various Baltic Sea region states. The key scientific motivation for FUNBAZOO is to increase the understanding of Baltic Sea ecosystem functioning and processes affecting ecosystem structural and functional changes, i.e. regime shifts. In marine, pelagic ecosystems, zooplankton plays a key role as it mediates the energy transfer between primary producers and secondary consumers, such as commercially important fish species. Strong contributions of zooplankton species to large-scale community shifts have been globally identified in the past years, also in the Baltic. Despite advances in identification and detection of trophic cascades and regime shifts in open and coastal ecosystems, the coherence in timing between shifts in different basins and areas or the identification of key drivers underlying regime shifts and changes in key zooplankton species, several key questions remain unsolved, or are only partly addressed. These primarily concern understanding the potential changes in ecosystem functioning, particularly of key groups such as zooplankton. In order to provide answers to these challenges and sound scientific advice to management, a coordinated effort is needed, an effort that could be accommodated by joint workshops. The first workshop held in November 2015, in Hamburg served as platform to exchange knowledge of trait analyses including gaps and pitfalls. Various general issues such as trait data collection, trait selection, data type of traits (e.g. binary vs. categorical), etc. were discussed and a metafile of trait collections across all taxonomic groups assembled, which served as basis for this year WGIAB meeting.

Bayesian machine learning approach for analysing dependencies between coastal fish indicators and environmental pressure

by Annukka Lehikoinen, Laura Uusitalo, Jens Olsson, Lena Bergström, Ulf Bergström, Andreas Bryhn, Ronny Fredriksson

Joint effects and mutual importance of multiple environmental pressures and natural drivers affecting the coastal fish indicators *abundance of perch* and *abundance of cyprinids* were investigated using Bayesian machine learning methods. The data included 41 sites along the eastern coast of Sweden, 10 of which are areas with low human impact and yearly fish monitoring data from years 2002–2013, and 31 were more or less affected areas with 1–10 years of monitoring data between 2004 and 2013. The studied environmental factors included water quality variables, direct human-induced pressures, natural variability, ecological pressures, and sampling-related variables. Several discretization approaches and model structures were tested and analysed in order to explore how the models built under different assumptions differ from each other. Discretization of the target variable (i.e. indicator) affects the composition of the set of statistically informative explanatory variables (i.e. the environmental variables) and thus the model framing. Different model structure learning algorithms find different statistical dependencies between the variables, given the discretization and model framing. Alternative models were compared in the context of research question and their plausibility evaluated based on their predictive power. It has to be noted though that the definition of an "optimal" model depends on what is the intended use of the model. A model with the highest predictive capacity does not necessarily correspond the logical causal representation of the system's functioning. For example for communication purposes, simple models with plausible causal structure are typically preferred. Management models, in turn, often require extension of ranges to not yet observed areas, which makes the predictive capacity a useless evaluation criterion.

The 2014 saltwater inflow

by Karin Wesslander

In December 2014, an inflow of salt water entered the Baltic Sea. The inflow has been estimated as one of the third largest Major Baltic Inflows (MBI) since 1880, with a total volume of 198 km^3 (Mohrholtz *et al*., 2015). The latest MBI's occurred 2003 and 1993. SMHI make monthly monitoring cruises in the Baltic Proper, Kattegat and Skagerrak and the effect of the inflow can be seen in the results from the cruises after December 2014. In February 2015, the Hanö Bight and the Bornholm Basin was filled with new water and were completely oxygenated. In March 2015, the inflow had reached the deepest part of the Gotland Deep (station BY15) where the oxygen concentration was 1.12 ml/l in the bottom layer but there was still an anoxic layer on top of this. In April 2015, the oxygen concentration at the Gotland Deep had increased to 2.61 ml/l at 220 m but still a hydrogen sulphide layer was present above. During summer, the intermediate layer of hydrogen sulphide at the Gotland Deep was oxygenated and its position moved upwards. In October, the whole water column at the Gotland Deep was oxygenated and no hydrogen sulphide was observed. After summer 2015, the oxygen levels at the Gotland Deep decreased and in January 2016, hydrogen sulphide was again present nearest bottom. However, during the autumn 2015 several smaller inflows entered the Baltic and continued to push new water through the basins. Apart from January 2016, the Gotland Deep is still (May 2016) oxygenated as has been seen at SMHI monitoring cruises. According to data from the monitoring cruises, effects of the inflow could partly be seen at Fårö Deep (station BY20) as lower concentrations of hydrogen sulphide at some depths but not any further north.

A retrospective view on the development of the Gulf of Bothnia ecosystem

by Harri Kuosa, Vivi Fleming-Lehtinen, Sirpa Lehtinen, Maiju Lehtiniemi, Henrik Nygård, Mika Raateoja, Jari Raitaniemi, Jarno Tuimala, Laura Uusitalo, Sanna Suikkanen

Long-term monitoring data from 1979 to 2012 in the Gulf of Bothnia, the northernmost extension of the Baltic Sea, have been analysed to gain a view on occurring changes in foodweb structure in the entire ecosystem except for microbes and in the phyto- and zooplankton community compositions. We aimed at revealing factors causing the observed community changes. Of the two sub-basins in the Gulf of Bothnia, the Bothnian Sea is more dynamic in its hydrography and foodweb structure than the Bothnian Bay due to the variable influence of the more eutrophic and brackish Baltic Proper. Variation in deep-water intrusion from the main Baltic Proper, and its effect on salinity and stratification had a clear effect on the phyto- and zooplankton communities in the Bothnian Sea. The nutrient status in this same basin has also changed towards nitrogen limitation with subsequent class- and genus-level changes in phytoplankton community composition. The migration of cod to the Bothnian Sea during the 1980s had profound effects on the herring population, but cascading effects affecting the basis of the foodweb were not obvious. The Bothnian Bay foodweb was mostly driven by hydrography and climate, with major changes observed in its basis. Community changes were observed in both basins in the Gulf of Bothnia throughout the entire period. Human influence considerably affects both the basis of the foodweb (symptoms of eutrophication) and its very top, where man has substituted the natural top predators. Results point to a deteriorating, though not yet alarming, eutrophication trend in the Bothnian Sea, and to the fact that the management of Baltic herring stocks requires understanding, and thus monitoring, of the entire foodweb.

Long-term dataseries of phytoplankton

by Kalle Olli

The motivation of the work was to honor the thousands of hours of expert work, which has been done by highly qualified experts while working up phytoplankton samples in environmental monitoring programs. The data has been accumulating for decades, but the potential knowledge in the joint data has not been revealed. The main findings form the quality check phase: It is common to have ca. 20–40% of the phytoplankton biomass not identified to species level, and 10–20% not to even genus level. There are differences between operators, however. The most frequently reported taxa have one common feature -- they are easily recognized in light microscope. Not necessarily the most common phytoplankton taxa. The spatial and temporal autocorrelation of community structure is measurable, but not very strong. Spatial autocorrelation strongly depends on the spatial scale of the study. Rarefaction, with asymptotic non-linear function fitting, can be used to estimate the total number of taxa. By using community ordination (NMDS) we did detect a smooth decadal-scale drift in the phytoplankton community composition, without abrupt jumps (or we used a method not suitable for regime shifts). A major change has been in the proportion of diatoms and dinoflagellates in the Baltic Sea spring bloom. Particularly in the western Gulf of Finland, dinoflagellates have become dominant in the spring bloom. However, for the whole Baltic Sea there is no common overall trend in the diatom: dinoflagellate proportion. The causes for the shifts in the proportion are basin dependent, ranging from short-term depletion of Si (Gulf of Riga), to winter weather effects, and life-history traits like massive spreading of benthic resting cysts by some dinoflagellates. An intriguing common feature is the increase of species richness of the phytoplankton community in the Baltic Sea. This increase has been strong enough to affect ecosystem functions like resource use efficiency. This biodiversity effect on ecosystem functioning translates into 1.2–1.4 times higher phytoplankton biomass per unit limiting resource (N or P) today, compared to decades earlier. Overall the Baltic Sea phytoplankton community structure and biodiversity compares well with other large coastal ecosystems, like the Chesapeake Bay, San Francisco Bay, North Sea, etc. Though, the overall taxon richness in the Baltic Sea tends to be higher, which is foremost a function of the ecosystem size.

5.2 Tor B: Support new and integrated management options

"Explore potential new options for management, including for example studies on indicators of foodweb status, implications for ecosystem functioning, and societal drivers, in order to support integrated fisheries advice and marine management, focusing on biodiversity and ecosystem function."

5.2.1.1 Summary of activities and discussions

Under this ToR the concept of social ecological systems (SES) was discussed, as well as different modelling and analysis approaches to study such systems. In particular, the term "human dimension" was discussed. This is a term that is mentioned increasingly often in the context of integrated assessment of the seas. It covers a wide range of issues related to societies' and individuals' relationship with and impact on the sea. Below, we outline various aspects that can be included under the "human dimension" umbrella. In the Table 5.1, we also outline the WGIAB work relevant to human dimensions, and how that links to the identified aspects.

Table 5.1. Aspects that can be included under the "human dimension" umbrella in integrated assessment, and an analyse on how it links to ongoing WGIAB work.

Human Dimension Aspects	WGIAB work
	Overall: Improved conceptual model for social-ecological systems
Using understanding of the ecosystem in fisheries and ecosystem management	
Indicator development, including:	
State of the ecosystem, including relationship between pressure and state	Indicators of ecosystem structure, functioning, and pressure-state links
Pressure levels	Pressure assessment for EO
Assessment of good status, integration of individual indicators into a unified assessment	
Taking stock of the value of the ecosystem	
Assessment of ecosystem goods and services provision. Several classifications of ecological systems have been proposed for marine and coastal ecosystems (TEEB 2008, 2012, UK NEA 2011, 2014, CICES 2010, MAES 2013).	Salmon case study Herring case study
Natural Capital Accounting has been proposed as a way to include the monetary value of natural resources into national accounting processes	
Human well-being indicators linked to ecosystem goods and services	Salmon case study Herring case study
Understanding the social-ecological system	Ecosystem overview
Governance setting limits to the management measures that can be used	Food consumption as driver of nutrient inputs
Governance and human well-being linked to modes of governance	

Ecosystem-based management requires a recognition and understanding of the interrelationships within an ecosystem as well as between the ecosystem and society. Assessment models that can address a wide range of biological and human aspects, however, need still to be developed. The WGIAB group tried to develop a better conceptual model that could be used to understand and discuss about the SES (Figure 5.9). It should be noted that the group does not commit itself to working exclusively with a specific conceptual model or framework.

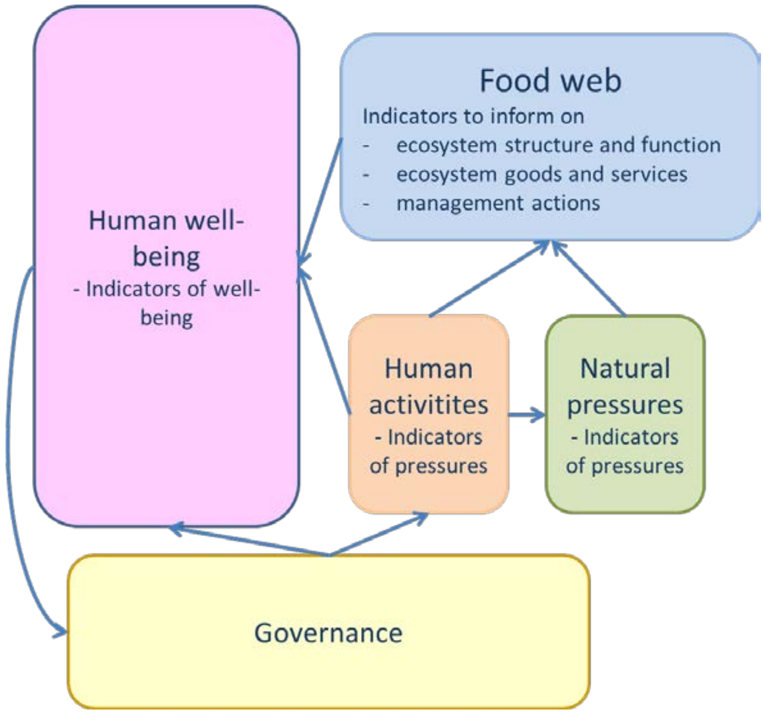

Figure 5.9. Conceptual model to facilitate understanding and discussion on the Baltic Sea social-ecological system.

5.2.2 Case studies: salmon and herring

We created two conceptual causal models to map factors to be accounted for in the ecosystem-based management of Baltic salmon (model 1) and clupeid species i.e. Baltic herring and sprat (model 2). These species are widely distributed in the Baltic Sea and interact with elements of the marine ecosystem and the social system. The models depict 1) the structure of the foodweb relevant to the target species, 2) the key community level and population traits that contribute to the state of the species, 3) the main pressures affecting the foodweb and their effects on the species, 4) the key management measures, and 5) the benefits that the species can produce for society. The models highlight the potential of ecosystem-based governance in managing pressures and in enhancing the well-being of a social-ecological system. The approach shows how social indicators can be used in parallel with biological indicators in an integrated assessment framework and illustrates their importance for evaluating the success of management. The case studies serve as a problem framing for developing quantitative integrated assessment models and for considering data availability and requirements. In the following steps, the salmon model and the clupeid model could also be integrated to provide an even more holistic social-ecological assessment surrounding these species.

5.2.3 Selected presentations and abstracts on ToR B at the 2016–2018 meetings

Nash equilibrium to understand productivity in a multispecies system during environmental change –The Baltic Sea as a case study

by Niclas Norrström, Michele Casini, Noél Holmgren

The current fisheries management goals set by the European Commission states that fish stocks should be harvested to deliver maximum sustainable yields (MSY) and simultaneously, management should take ecosystem considerations into account. This creates unsolved trade-offs for the management of the stocks.

We show one way in which the MSY conflicts can be solved through the game theoretic concept of Nash equilibrium. This equilibrium exists when no single player can get a higher reward given that the strategies of the other players are unchanged. The Nash equilibrium is defined in a fisheries context as a multispecies-MSY (MS-MSY) target when a stock cannot have an increased yield, given a fixed harvest strategy of the other stocks. We maximize the sustainable yield of each stock at a fixed F of the other stocks.

As a case study, we have developed a Multispecies Interaction Stochastic Operative Model (MSI-SOM), which contains a SOM for each of the three dominant species of the Baltic Sea, the predator cod (*Gadus morhua*), and its prey herring (*Clupea harengus*), and sprat (*Sprattus sprattus*). The species are influenced by the environmental variables salinity, temperature, and reproductive volume. By harvesting the stocks at MS-MSY in prognoses of environmental change we find that sprat will further its dominance in productivity as salinity and the reproductive volume decrease and the temperature increases.

Ecosystem-based management to reduce dioxin concentrations in Baltic salmon and herring and the risks to human health: main challenges

by Päivi Haapasaari and Annukka Lehikoinen

Baltic herring and salmon provide a rich source of protein, Omega 3 fatty acids and vitamin D for humans, but they also contain high levels of dioxins, which questions their positive health effects. Owing to dioxins, selling Baltic herring and salmon within the EU is restricted, and export outside the EU is difficult. BONUS GOHERR project (Integrated governance of Baltic herring and salmon stocks involving stakeholders) combines biological, public health and social scientific perspectives to explore the potential of ecosystem-based / integrated management of Baltic salmon and herring in reducing dioxins and the related risk to humans. Thus the project contributes to developing the ecosystem-based approach to fisheries management, which requires holistic thinking and comprehensive representations of the ecosystem, including social components. One of the main challenges of the project relates to understanding the system and its functioning, and to analysing how the system could be manipulated. For this, a decision support model is being built that integrates probabilistic information on 1) the predator–prey interaction between salmon and herring and the impact of this on bioaccumulation of dioxins, and 2) the impacts of fish intake on humans, given the dioxin concentrations. The model allows assessing the effectiveness of alternative fisheries management actions to decrease the dioxin concentration, and the effectiveness of alternative fish-eating recommendations on the consumption of Baltic herring and salmon. The model evaluates the utility of different decision combinations from the human health perspectives, sustainable fishing, ecosystem health, and social effects, in parallel. Another major challenge of the project relates to analysing the role, scale and scope of governance to support the ecosystem-based/integrated management of these fisheries and the dioxin risk, taking into account societal values.

Evaluation of sustainable exploitation of major Baltic fish stocks based on an integrated end-to-end modelling framework

by Sieme Bossier, J. Rasmus Nielsen, Francois Bastardie, Asbjørn Christensen, Stefan Neuenfeldt

The newly developed Baltic spatially-explicit end-to-end Atlantis ecosystem model is in its phase of implementation. Preliminary results are presented from an updated model with new and existing, significant knowledge of fish recruitment, growth, consumption processes, and species interactions. The RCO-SCOBI model (Rossby Center

Ocean Model – Swedish Coastal and Ocean Biogeochemical Model) will be linked with the Atlantis model which will be used to provide physical and bio-geo-chemical and hydrodynamic forcing. This will replace the physical forcing of Atlantis from the HBM-ERGOM model (Hiromb-BOOS model coupled to the Ecological Regional Ocean Model) developed so far. Furthermore, we will integrate socio-economic parameters, dynamics and fisheries (technical) interactions in the holistic ecosystem and fisheries system model instead of using the current constant fishing mortality rates. This integrates dynamics on catch, effort, revenue, costs, fish prices, profit, fleet capacity, and exit-entry dynamics, as well as fuel consumption according to area, time, and Baltic fishing fleets. Accordingly, this involves estimation of economic and energetic processes and efficiency, e.g. greenhouse gas emissions and carbon footprint minimization potentials. The model application will evaluate impacts of eutrophication and climate forcing scenarios on biological interactions, resource availability and fisheries bioeconomic dynamics with a high resolution according to space, time and fleet components on a long-term strategic basis.

Evaluating the suitability of foodweb indicators under environmental gradients and non-linear interactions - is there a universal indicator?

by Saskia Otto, Martina Kadin, Michele Casini, Marian Torrres, Anna Gårdmark, Thorsten Blenckner

Finding a suitable indicator for assessing health status can be cumbersome depending on the system. For closed, small-scale systems such as the human cardiovascular system it might be an easy task where the blood pressure represents a fairly sensitive and robust indicator. In larger-scale, open systems such as marine, pelagic habitat challenges for identifying an optimal indicator for foodwebs, as required by the MSFD, are by far greater. Particularly the lack of boundaries, the high level of complexity due to species interactions, and the inherent stochasticity hinder a simple solution for assessing the foodweb status. In this study, we developed a simple framework to statistically evaluate the performance of MSFD D4 indicator candidates based on a set of criteria. We further applied this framework to assess six zooplankton and six newly developed fish indicator candidates for three basins of the Baltic Sea. Following the proposed evaluation process based on Generalized Additive Models, including threshold formulations and mixed model extensions, we identified basin-specific suites of indicators that complemented each other in their responses to anthropogenic pressures. We show that both zooplankton and fish indicators can be suitable for detecting bottom–up and top–down effects. Zooplankton indicators, however, have the advantage to respond faster and relate statistically to a greater range of pressure variables. Contrasting to other regions, abundance-based fish indicators of key species in the CBS performed better than the aggregated and widely adopted large fish indicator. This demonstrates the unlikelihood of a universal indicator and the need of regional evaluations for which our framework can serve as guidance.

Foodweb indicators accounting for species interactions respond to multiple pressures (relating to Tor A and B)

by Marian Torres, Michele Casini, Magnus Huss, Anna Gårdmark, Martina Kadin, Thorsten Blenckner, Ingo Fetzer, Saskia Otto

There has been much progress on indicator development aiming to support an Ecosystem Approach to Fisheries over the last years. In Europe, the Marine Strategy Framework Directive (MSFD) requires indicators of the status of marine environment that respond to manageable anthropogenic pressures. Particularly, MSFD foodweb indicators are aimed to describe the functioning and structure of foodwebs, and thus both species interactions and external pressures should be considered when developing new indicators. Still, this is rarely done. Here we focus on the Central Baltic Sea pelagic foodweb, which is characterized by strong trophic links between cod (*Gadus morhua*) and its main fish prey sprat (*Sprattus sprattus*) and herring (*Clupea harengus*). The dynamics of these fish populations in the area are governed by predator–prey interactions, density-dependence and changing environmental conditions. Making use of a novel indicator testing framework we apply multivariate autoregressive models (MAR) to identify how fish indicators in the pelagic habitat relate to fishing, climate and eutrophication, while accounting for the linkages between indicators caused by species interactions. First, we analyse abundance-based indicators of key piscivores (cod) and planktivores (sprat and herring). In the second part, we test two new size-based indicators: biomass of large predatory fish (cod >38 cm) and biomass of small prey fish (sprat and herring <10 cm). We use time-series from the past thirty years from Bornholm Basin to test the foodweb indicators. Our results show that for both types of indicators, predator–prey feedbacks, and intraspecific density-dependence were essential to explain temporal variation in the indicators. The results also suggest that the indicators respond to multiple pressures acting simultaneously rather than to single pressures, as no pressure alone could explain how the indicators developed over time. The manageable pressures fishing and eutrophication, as well as the prevailing hydrological conditions influenced by climate, are all needed to reproduce the interannual changes in these foodweb indicators in the study area. We conclude that the indicator testing framework introduced in this paper provides a suitable tool to track the temporal variation in the foodweb indicators and should therefore be considered in the implementation of the MSFD.

INDperform - development of an R package for validating ecological indicator performances

by Saskia Otto, Alexander Keth, Réné Plonus, Steffen Funk, Christian Möllmann

Finding suitable state indicators is challenging and cumbersome in stochastic and complex ecological systems. Typically, a great focus is given to criteria such as data availability, scientific basis, or measurability. Features associated with the indicator's performance such as sensitivity or robustness are often neglected due to the lack of quantitative validation tools. A new R package *INDperform* has been developed, which implements a novel quantitative framework for selecting and validating the performance of state indicators. The package offers functions to identify temporal indicator changes, model relationships to pressures while taking non-linear responses and temporal autocorrelation into account, and to quantify the robustness of these models. These functions can be executed on any number of indicators and pressures and by less experienced R users. Based on these analyses and a scoring scheme for selected criteria the individual indicator's performance is quantified and visualized. An implemented cluster analysis based on indicator scores can be further used to select complementary indicators that perform well. The combination of tools described will significantly help making state indicators operational under given management schemes such as the EU Marine Strategy Framework Directive.

Retrospective integrated assessment using biodiversity indicators

by Susanna Jernberg, Henrik Nygård, Ainars Aunins, Antti Lappalainen, Anna-Stiina Heiskanen, Jens Olsson, Pirkko Kauppila, Samuli Korpinen, Kirsi Kostamo, Laura Uusitalo

Ecological indicators are essential tools when assessing the health status of the marine environment. Integrated assessment helps to summarize the information of multiple indicators and thus provide and overall view of the ecosystem. Integrated assessments have become more common during the past decades and for example in the HELCOM context, the second integrated assessment of the whole Baltic Sea was finished recently. There has been discussion how integrated assessments should be done and how the indicators should be selected for the assessments. In our study, we wanted to evaluate how different biodiversity indicators show the integrated status in different temporal and spatial scales. We used two case study areas: Gulf of Finland and the Bothnian Sea which are located in the northern Baltic Sea. They are both brackish water basins but differ in their eutrophication status: where the Gulf of Finland has suffered from eutrophication for decades, the Bothnian Sea has shown signs of eutrophication only recently. Biodiversity indicators covering different aspects of the biodiversity (e.g. birds, fish, benthic habitats etc.) and that have been developed in HELCOM or nationally in Finland were used. Long-term data of the indicators was gathered to be able to produce time-series of integrated assessment and to study the changes that might occur. The integrated assessments were performed using the same tool that has been used in the HELCOM integrated assessment of biodiversity: biodiversity assessment tool BEAT 3.0. Our results will demonstrate how the integrated status of the case study areas has developed during the past decades. The study will also discuss issues related to indicator selection and the selection of spatial and temporal scales and thus provide input for better integrated assessments in future.

Challenges and benefits of social indicators in ecosystem-based management

by Matilda Valman

There are many different social indicators. They vary both spatially and in time. It is therefore important to make your choices and selection of variables clear but also couple the selection criteria to the research questions you have. Depending on what your chosen indicators are and the aims you are contributing to you should consider whether you e.g. want to assess human behavior, the consequences of human behavior or human dependence on or interlinkage with nature. The selection of social indicators can be either qualitatively or quantitatively driven, or a combination of the two. It can also be necessary to mix not only methods but also theories for the later analyse of social indicators. Social indicators are already mentioned in existing legal marine frameworks However, these indicators have not yet been assessed or coupled to other marine indicators and/or goals. Examples of social goals and related indicators in, for the WGIAB group, relevant frameworks as the MSFD, POMs, BSAP and the CFP are human wellbeing, health and sustainable fisheries. We see a great potential in coupling and comparing different marine goals and their targets for the development of a set of indicators – both social and ecological – that can be included in our current IEAs. It has to be noted though that several marine social goals and their coupled targets and indicators are not fully developed and/or vague and these unclear goals open up for innovative interpretations and implementation strategies. We discussed that this is both positive and negative for marine management but that these “hidden” indicators need to be further explored.

5.3 Ecosystem overview: Pressures acting on the Baltic Sea

As requested by ICES, to aid the development of Ecosystem Overview for the Baltic Sea, the group members identified the main human activities as well as the main pressures in the Baltic Sea and assessed the impacts of the identified pressures on fixed biological state.

In a first part, all the participants were asked to rank a series of ecosystem pressure from 0, not an important pressure in the Baltic Sea, to 2, very important. As a result of this first round we identified four major pressures: nutrient and organic enrichment, selective extraction of species (i.e. fisheries), introduction of contaminating compound and introduction of non-indigenous species. Following a group discussion we decided to add a fifth pressure under the name seabed loss and disturbance which regrouped two pressures from the initial list. A list of human activities was selected following a group discussion and was inspired by HOLAS II report (HELCOM, 2017).

In a second phase we discussed the links between human activities-pressures and pressures-state. This phase raised questions and discussion, notably on whether a link has to be made as a result of direct impact or whether indirect links should also be emphasized. The problem with adding indirect links is that to a certain extant every pressure can have an indirect link to the state components, but if the indirect links are not taken into account this could also display a wrong message with a minimization of the pressures impact on the ecosystem states. A typical example that was discussed was the nutrient and organic enrichment which is a major issue in the Baltic Sea ecosystem. If only direct link were taken into account then this pressure would only be linked to few ecosystem state while it is known that nutrient and organic enrichment has had important indirect impacts on many of the biological compartments, thus using only the direct impact would understate the impact of this pressure in the Baltic Sea. As a result of the discussion, the group decided to also add important indirect links alongside direct links, while we would suggest that for future version of the Ecosystem Overview direct links could be shown using different arrows, e.g. dashed. The human activities-pressures-states diagram resulting from the group discussion is represented in Figure 5.10.

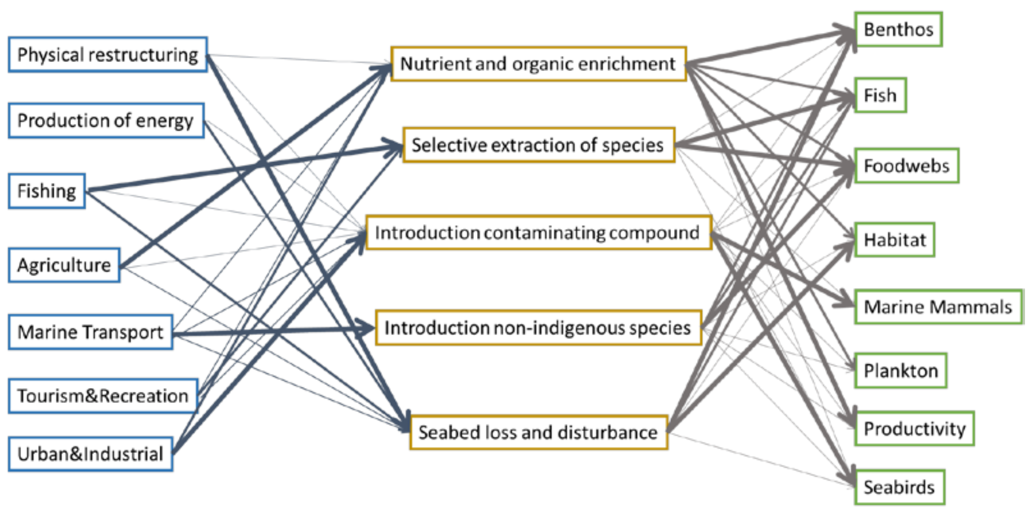

Figure 5.10. Links between the most important human activities (left) and pressures (middle) identified in the Baltic Sea and impacts of these pressures on the ecosystem states (right). The size of the arrow corresponds to the strength of the interaction.

5.4 Further steps in developing Ecosystem Overview and ICES ecosystem/integrated advice: outlining the integrated advice framework approach and scoping the possibilities for evolving the current advisory process for Baltic Sea fish stocks

The ICES Ecosystem Overviews (EOs) are created, as given by ICES website, to “provide a description of the ecosystems, identify the main human pressures, and explain how these affect key ecosystem components”. To our understanding this interpretation misses out opportunities for a better, integrated management. The current form of EOs is purely descriptive, providing a decorative padding for ICES advice on fisheries opportunities. ICES in history had a similar product by ICES WG on Regional Ecosystem Descriptions (WGRED), which annually delivered a partly updated description of major ecosystem features. Such a description was included in the advice, similar to current EOs. However, it did obviously not serve the purpose and was omitted.

Using Overviews (ecosystem and fisheries) with a graphic interface is just a first step forward. To avoid previous mistakes EOs need to be developed further, in order to become a truly integral part of the advice. At the meeting the future perspectives for developing useful EOs were discussed based on the Report of the Workshop on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (WKDEICE2) (ICES. 2017). Figure 5.11 outlines how ICES EOs could immediately be modified and used, taking in to account already existing structures, solutions and ongoing changes at ICES.

The major difference between the current and the proposed EOs is the direct use and inclusion of ecosystem information and risk assessments in the advice drafting process. This process needs to be formalized to ensure best quality scientific advice, taking into account all available sources of information (i.e. ecological, physical, and economic).

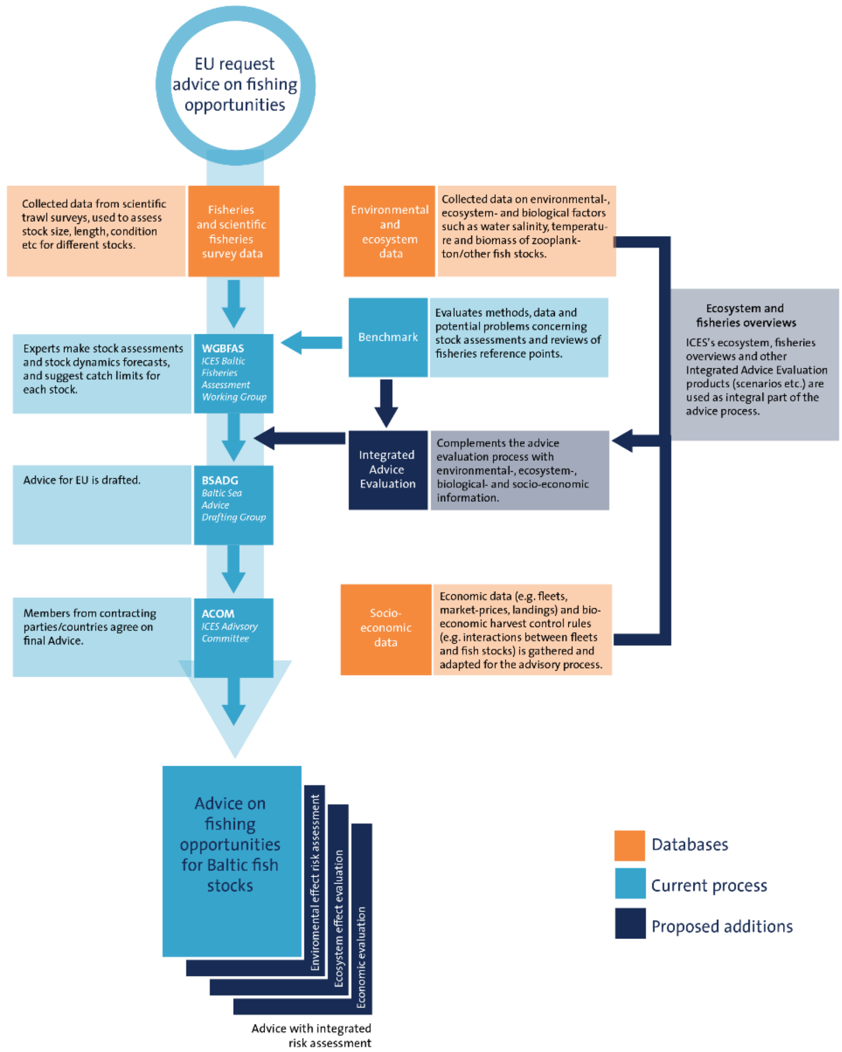

Figure 5.11. Schematic outline for Baltic fish stock with proposed including steps supporting fisheries advice at environmental/ecosystem/integrated level (right).

On top of the immediate uptake of ecosystem information as outlined above, future EOs should accomplish:

- Incorporation of environmental indices into short-term predictions, and transfer to accordingly modified catch options to support advice under environmental scenarios;
- Assessment of the risk of a stock falling below reference points under environmental scenarios;
- Evaluation of consequences of different advice options on the stock and ecosystem, also in multispecies, multifleet and spatial context;
- Usage of all available information (i.e. ecological, physical, as well as economic) in setting harvest opportunity advice;
- Development of complementary bioeconomic advice (e.g. including bioeconomic harvest control rules).

To this end, the Baltic EO should include a "New Approaches" section, where alternative assessment and advice approaches are explored to ensure better communication and exchange with stakeholders.

In the case of the Baltic Sea, where environmental conditions and trophic interactions strongly affect the state of fisheries resources (Casini et al., 2009; Möllmann et al., 2009), it is also important to evaluate both tactical and strategical advice under different environmental conditions including an assessment of risks. The Baltic EO should therefore embrace the concept developed by Punt et al. (2014) and Szuwalski and Punt (2013) to produce a risk portfolio of management consequences for stock dynamic and ecosystem dynamics.

6 Cooperation

6.1 Cooperation with other WGs

WGIAB has held its meeting back to back with other integrated assessment working groups during one of the three years. In 2017, WGIAB meeting was held in Lisbon, Portugal, back to back with its counterpart from the Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS) and the ICES Working Group on Comparative Analyses between European Atlantic and Mediterranean marine ecosystems to move towards an Ecosystem-based Approach to Fisheries (WGCOMEDA).

WGIAB has taken active part in the development of ecosystem based approaches to management within ICES, for example in the Workshop on Exchange of Knowledge for Integrated Ecosystem Assessment (ICES Science Fund funded project "IEA-Exchange") 1–2 February 2016, the Workshop on Integrated Ecosystem Assessment methods (WKIDEA) 11–12 October 2016, Copenhagen, and the Strategic Initiative on the Human Dimension (SIHD) Workshop on Balancing Economic, Social, and Institutional Objectives in Integrated Assessments (WKSIHD-BESIO) 29 November – 1 December 2017, the Hague.

6.2 Cooperation with Advisory structures

WGIAB members take an active part and as member and chairs at series of ICES Workshop under umbrella of DEMO - Demonstration exercise for integrated ecosystem assessment and advice of Baltic Sea fish stocks by Stockholm University and ICES Workshop on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (ICES WKDEICE. 2016, and ICES WKDEICE2. 2017) looking to design a concept of operationalized Integrated Advice Evaluation (IAE) and ways to include environmental and economic considerations into ICES advice on Baltic Sea fish stocks from operational and structural perspectives.

7 Summary of Working Group self-evaluation and conclusions

The conclusions below and the suggested terms of reference for WGIAB 2019–2021 (Annex 4) are based on the discussions at WGIAB 2018. The suggested terms of reference are in the core of the ICES strategic plan for 2014–2018 (ICES, 2013), with respect to the goals: ”Develop an integrated, interdisciplinary understanding of the structure, dynamics, and the resilience and response of marine ecosystems to change” and “Understand the relationship between human activities and marine ecosystems, estimate pressures and impacts, and develop science-based, sustainable pathways”. During the past three years, WGIAB has developed further the understanding of patterns and processes in the Baltic Sea foodweb, and the results have been presented in the working group reports, in >5 peer reviewed papers stemming from work of the group, and with several conference contributions. The group has taken part in workshops of relevance as arranged at ICES, and contributed to the further development of methods to integrate environmental information in fish stock assessments. The planned future work seeks the active participation of experts in socio-economy, fisheries biology, marine biology, oceanography and foodweb modelling.

The work on the so-called human dimension in the WGIAB started during the 2016-2018 ToR period. We see a need for more expertise on judicial as well as socio-economic aspects in the WG. Continued expertise in fisheries biology, marine biology, oceanography and foodweb modelling is still fundamental. We believe that information of environmental as well as societal indicators is important for the support of the ecosystem and fisheries assessments within ICES.

References

Cardinale, B. J. et al. 2012. Biodiversity loss and its impact on humanity. Nature. 486, 59-67.

Casini, M., Rouyer, T., Bartolino, V., Larson, N., Grygiel, W. 2014. Density- dependence in space and time: opposite synchronous variations in population distribution and body condition in the Baltic Sea sprat (Sprattus sprattus) over three decades. PLOS One, 9(4):e92278.

Díaz, S., Lavorel, S., de Bello, F., Quétier, F., Grigulis, K., and Robson, T. M. 2007. Incorporating plant functional diversity effects in ecosystem service assessments. Proceedings of the National Academy of Sciences, 104: 20684–20689.

Diekmann, R., and Möllmann, C. (Eds). 2010. Integrated ecosystem assessments of seven Baltic Sea areas covering the last three decades. ICES Cooperative Research Report No. 302. 90 pp.

Frelat, R., Lindegren, M., Denker, T.S., Floeter, J., Fock, H.O., Sguotti, C., Stäbler, M., Otto, S.A. and Möllmann, C., 2017. Community ecology in 3D: Tensor decomposition reveals spatio-temporal dynamics of large ecological communities. PloS one, 12(11), p.e0188205.

Frelat, R., Orio, A., Casini, M., Lehmann, A., Mérigot, B., Otto, S. A., Sguotti, C., Möllmann, C. 2018. A three-dimensional view on biodiversity changes: spatial, temporal, and functional perspectives on fish communities in the Baltic Sea. ICES Journal of Marine Science.

HELCOM (2017): First version of the 'State of the Baltic Sea' report – June 2017 – to be updated in 2018. Available at: http://stateofthebalticsea.helcom.fi

ICES. 2013. ICES Strategic Plan 2014–2018. 19 pp.

ICES. 2017. Report of the Workshop on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (WKDEICE2) . ICES WKDEICE2 REPORT 2017 19–21 June 2017. Gdynia, Poland. ICES CM 2017/IEASG:14. 23 pp.

Lavorel, S., Grigulis, K., McIntyre, S., Williams, N. S. G., Garden, D., Dorrough, J., Berman, S., et al. 2008. Assessing functional diversity in the field – methodology matters! Functional Ecology, 0: 071124124908001

Leibovici, D. G. (2010) Spatio-temporal multiway decompositions using principal tensor analysis on k-modes: The R package PTAk. Journal of Statistical Software, 34, 1-34.

Mouillot, D., Villéger, S., Scherer-Lorenzen, M., and Mason, N. W. H. 2011. Functional structure of biological communities predicts ecosystem multifunctionality. PLoS ONE, 6.

Möllmann, C., Diekmann, R., Müller-karulis, B., Kornilovs, G., Plikshs, M., and Axe, P. 2009. Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: A discontinuous regime shift in the Central Baltic Sea. Global Change Biology, 15: 1377–1393.

Mohrholz, V., Naumann, M., Nausch, G., Krüger, S. and Gräwe, U., 2015. Fresh oxygen for the Baltic Sea—An exceptional saline inflow after a decade of stagnation. Journal of Marine Systems, 148, pp.152-166.

Mørup, M. (2011) Applications of tensor (multiway array) factorizations and decompositions in data mining. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 1, 24-40.

Pécuchet, L., Törnroos, A., and Lindegren, M. 2016. Patterns and drivers of fish community assembly in a large marine ecosystem. Marine Ecology-Progress Series, 546: 239–248

Planque, Benjamin, Per Arneberg, and Handling editor: James Watson. Principal component analyses for integrated ecosystem assessments may primarily reflect methodological artefacts. 2017. ICES Journal of Marine Science 75.3 (2017): 1021-1028.

Scheffer, M., Carpenter, S., J. A. Foley, C. Folke, B. Walker. 2001. Catastrophic shifts in ecosystems. Nature. 413, 591-596.

Törnroos, A., Bonsdorff, E., Bremner, J., Blomqvist, M., Josefson, A. B., Garcia, C., and Warzocha, J. 2015. Marine benthic ecological functioning over decreasing taxonomic richness. Journal of Sea Research, 98: 49–56. Elsevier B.V.

Violle, C., Navas, M. L., Vile, D., Kazakou, E., Fortunel, C., Hummel, I., and Garnier, E. 2007. Let the concept of trait be functional! Oikos, 116: 882–892.

Zuur, Alain F., et al. Estimating common trends in multivariate time series using dynamic factor analysis. 2003. Environmetrics 14.7:665-685.

ICES. 2016. Report of the Workshop on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (WKDEICE), 18-21 April 2016, Helsinki, Fin-land. ICES CM 2016/SSGIEA:13. 41 pp.

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Annex 2: Recommendations

Recommendation	Adressed to
2. WGIAB recommends a coordinated effort from WGSOCIAL carried out together with all IEA WGs to identify and report on social indicators that are relevant across all the IEA areas.	WGSOCIAL
3. WGIAB recommends that ICES/ACOM/secretariat take the recommendation from WKDEICE2 further to improve the Ecosystem overviews to be serve the purpose of operational Ecosystem based advice.	Secretariat

Annex 3: DRAFT WGIAB Resolution 2018

The **ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB)**, chaired by Saskia Otto, Germany, Martin Lindegren, Denmark, Lauréne Pécuchet, Finland, and Matilda Valman, Sweden, will generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2019	April	Palma de Mallorca, Spain	Interim report by 30 May 2019 to IEASG	
Year 2020	TBD	Copenha-genm Den-mark	Interim report by TBD 2020 to IEASG	
Year 2021	TBD	TBD	Final report by TBD 2021 to IEASG	

ToR descriptors

ToR	Description	Background	Science Plan codes	Duration	Expected Deliverables
a	Conduct an ecosystem indicator analysis (combining natural and social sciences) across a number of Baltic Sea sub-systems including (i) robustness testing with respect to confounding multiple stressor effects and management suitability, (ii) threshold determination, and (iii) ecosystem trend and state evaluations.	This ToR will provide sub-system-specific suites of ecosystem indicators and respective thresholds to support the development of Integrated Ecosystem Assessments and Ecosystem-based Fisheries Management.	Code 2: Understanding Ecosystems Develop an integrated, interdisciplinary understanding of the structure, dynamics, and the resilience and response of marine ecosystems to change	1 year	-Research article(s) on ecosystem indicator testing and ecosystem state assessments - Report cards displaying the state of Baltic Sea sub-systems using selected indicator suites - Intermediate results reported in interim reports 2019 and 2020 as well as the final report.
b	Conduct vulnerability analyses for the combined social – ecological system of Baltic Sea sub-systems to the cumulative effects of climate change, fisheries and eutrophication using an exposure – sensitivity approach.	This ToR will investigate the consequences of cumulative external threats on the Baltic Sea ecosystems identifying vulnerable components of both the social and ecological sub-systems as a basis for model-based management strategy evaluation exercises.	Code 2: Understanding Ecosystems Code 6: Conservation and Management Understand the relationship between human activities and marine ecosystems, estimate pressures and impacts, and	2 years	- Research article(s) on the vulnerability of Baltic Sea subs-systems to cumulative drivers - Intermediate results reported in interim reports 2019 and 2020 as well as the final report.

			develop science-based, sustainable pathways		
c	Conduct a multi-model exercise exploring management strategies that best adapt vulnerable social – ecological system components of Baltic Sea sub-systems to the cumulative effects of multiple external drivers.	This ToR will provide important context to management and decision making processes within the Baltic Sea ecosystem-based management landscape.	Code 6: Conservation and Management Understand the relationship between human activities and marine ecosystems, estimate pressures and impacts, and develop science-based, sustainable pathways	2 years	-Research article(s) on management strategy evaluations of social – ecological systems components to multiple external drivers, - Intermediate results reported in the final report.

Summary of the Work Plan

Year 1	Annual meeting, intersessional work on social- ecological indicator suites development.
Year 2	Annual meeting, intersessional work on vulnerability analyses to multiple external drivers.
Year 3	Annual meeting, intersessional work on management strategy evaluations of vulnerable social- ecological system components.

Supporting information

Priority	WGIAB aims to conduct and further develop Integrated Ecosystem Assessments for the different subsystems of the Baltic Sea, in support of implementing the ecosystem approach in the Baltic Sea.
Resource requirements	Assistance of the Secretariat in maintaining and exchanging information and requirements data to potential participants. Assistance of especially the ICES Data Centre to collect and store relevant dataseries.
Participants	The Group is normally attended by some 20 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	WGBFAS
Linkages to other committees or groups	WGINOSE, WGNARS, WGEAWESS, WGINOR, WGIBAR, WGCOMEDA, WGSOCIAL, WGMARS
Linkages to other organizations	HELCOM

Annex 4: Copy of Working Group self-evaluation

1) **Working group name:** ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB)

2) **Year of appointment:** 2008 (2016 within the current 3-yr-cycle)

3) **Current chairs:** Saskia Otto, Germany; Martin Lindegren, Denmark; Laurène Pécuchet, Finland; Matilda Valman, Sweden

4) **Venues, dates and number of participants per meeting:** Helsinki, Finland, 18-22 April, 26 participants; Lisbon, Portugal, 24-28 April, 31 participants; Tartu, Estonia, 16-20 April 2018, 25 participants

WG Evaluation

5) **If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution**.

Develop an integrated, interdisciplinary understanding of the structure, dynamics, and the resilience and response of marine ecosystems to change; Understand the relationship between human activities and marine ecosystems, estimate pressures and impacts, and develop science-based, sustainable pathways and indicator tools for management

6) **In bullet form, highlight the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc**:

Peer reviewed papers published based on data and findings from the group; integrated trend analyses of functional changes over time in the foodwebs of the main sub-basins of the Baltic Sea; contribution on indicators for MSFD

7) **Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice**.

WGIAB has drafted a first EO that will serve as input to advice. WGIAB has also provided information of environmental indicators (relating to cod recruitment) to WGBFAS.

8) **Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities**.

The BONUS project BLUEWEBS partly developed based on ideas discussed in WGIAB. WGIAB members are taking active part in a European Training Network "MARine MAnagement and Ecosystem Dynamics under climate change" (MARmaED) which aims to build a greater knowledge base and train the next generation of scientists in cross-disciplinary work relating among others to ecosystem-based management.

9) **Please indicate what difficulties, if any, have been encountered in achieving the workplan**.

Collection of a dataset with such high taxonomic resolution as needed for tbITA was more time consuming as expected. This explains why we did not achieve a full system comparison for the entire Baltic Sea within the 3 years cycle.

Future plans

10) **Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)**.

Yes. There is a continued need for developing the understanding of the Baltic Sea ecosystems and its traits. The work on including the human dimension in the IEA has only started, why the work and results from this are foreseen to contribute to the development of integrated marine management.

11) **If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG**.

NA

12) **What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR**?

Expertise on judicial as well as socio-economic aspects in order to include and account for the so called human dimension in the IA-group(s). Continued expertise in fisheries biology, marine biology, oceanography and food-web modelling is still fundamental.

13) **Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used**?

The long-term ambition of WGIAB is to develop an IEA for the Baltic Sea which can serve as a tool to inform and advice ecosystem-based management. Although we have not yet accomplished this aim we have provided information of environmental indicators in support of fisheries assessments and advice.

Annex 5: Overview of data collection

Table A5.1. Metadata of the surveys collected

Taxa	Survey.id	Area (SD)	Years	Bio-mass	Abun-dance	All species	Provider and Contact
Fish	NS-IBTS	Kattegat (21)	1971–2017	Y	Y	Y	ICES/DATRAS; Laurene Pecuchet
	BITS	The Sound (22) to Gotland Basin (29)	1991–2017	Y	Y	Y	ICES/DATRAS; Laurene Pecuchet
	GoR	Gulf of Riga (28b)	1973–2016	Y	Y	Y	BIOR; Ivars Putnis
	Gillnet	Swedish coast	2009–2014	N	Y	Y	SLU; Jens Olsson
	SMS model	Arkona Basin (24) to Gotland Basin (29)	1974–2011	Y	Y	N	DTU Aqua; Stefan Neuenfeldt
Benthos	ODA	Danish straits (21-23)	1971–2013	N	Y	Y	DHI/EUROBIS; Laurene Pecuchet
	GoR	Gulf of Riga (28b)	1979–2016	Y	Y	Y	LHEI; Ivars Putnis
	SYKE	Eastern Baltic Sea (26-32)	1964–2016	Y	Y	Y	SYKE; Henrik Nygård
Zooplankton	ODA	Kattegat (21)	1982–2016	N	Y	Y	DHI; Laurene Pecuchet
	SYKE	Eastern Baltic Sea (28-32)	1979–2014	N	Y	Y	SYKE; Saskia Otto
	P40	Borhnolm Basin (25)	1979–2015	Y	Y	Y	NMFRI; Piotr Margonski
	GoR	Gulf of Riga (28b)	1958–2015	Y	Y	Y	BIOR; Ivars Putnis
Phytoplankton	ODA	Kattegat (21)	1981–2014	Y	Y	Y	DHI; Laurene Pecuchet
	GoR	Gulf of Riga (28b)	1976–2015	Y	Y	Y	BIOR; Ivars Putnis

Annex 6: Spatio-temporal pattern in environmental summer conditions

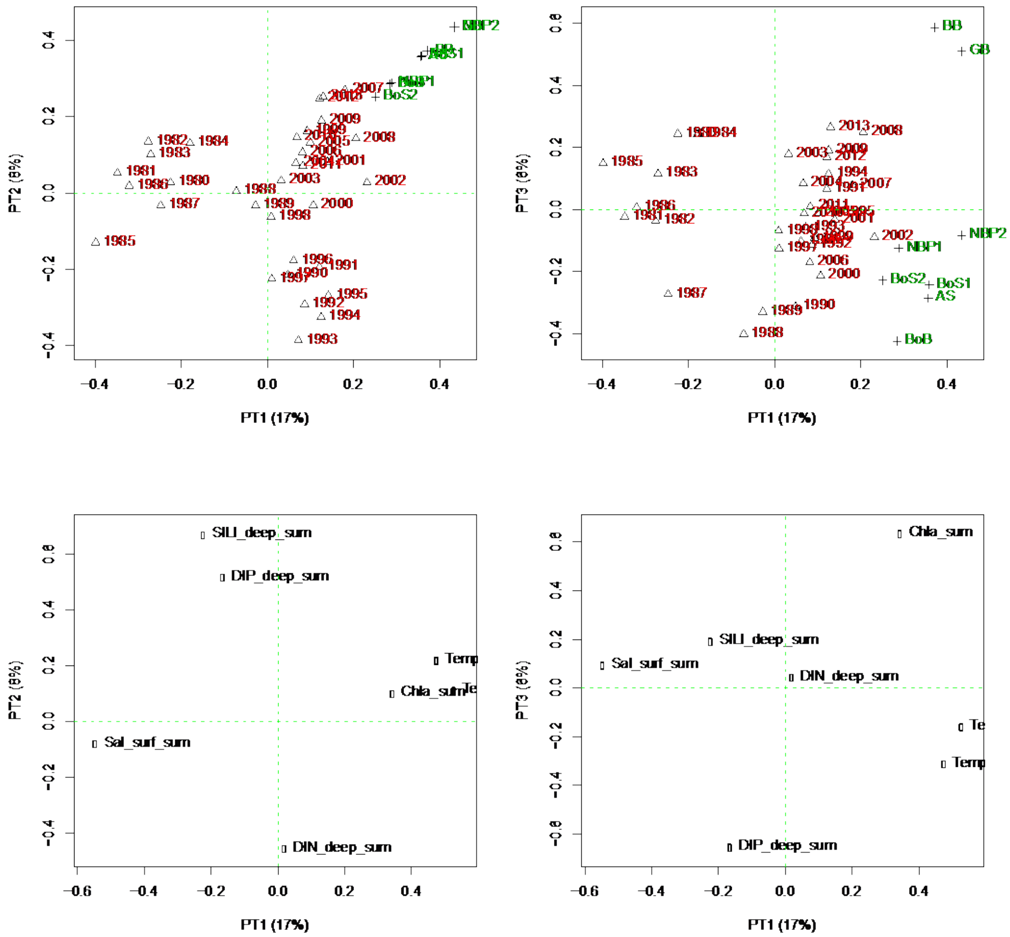

Figure A6.1. Results of the Principal Tensor Analysis with three principal tensors (PT) explaining together 31% of the total variability of environmental conditions. The upper panels show the time and space component projected on PT1 vs. PT2 (left) and PT1 vs. PT3 (right). The lower panels show the environmental variables in these PT domains. While PT1 and 2 show greater differences in the time component, PT3 features greatest variability of the spatial component reflected by differences in *Chl a* and phosphate concentrations.

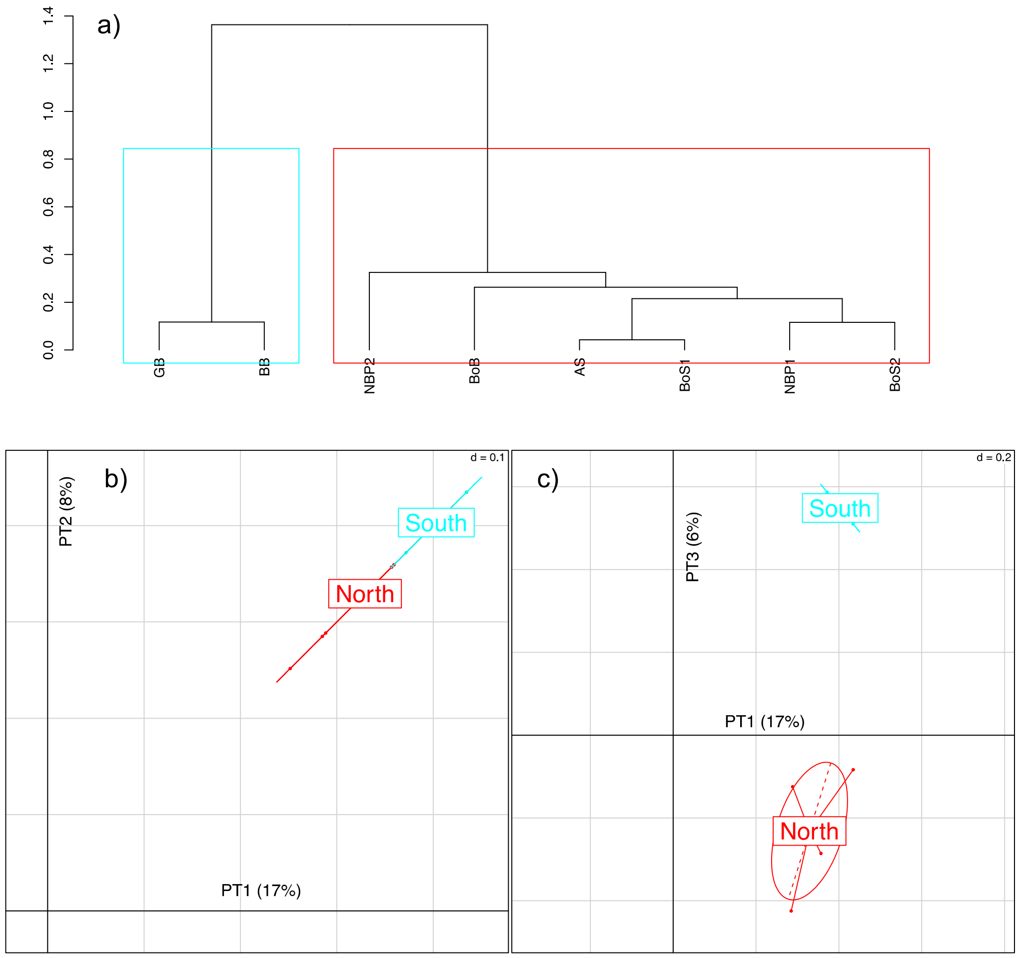

Figure A6.2. Classification of stations based on their environmental dynamics over time showing a strong North–south division. (a) Dendogram of the Hierarchical Agglomerative Clustering and the cutting at 2 clusters. (b) The clusters represented on the principal tensors PT1 and PT 2 and (c) on PT1 and PT3. (AS = Archipelago Sea, BB = Bornholm Basin, BoB = Bothnian Sea, BoS = Bothnian Sea, GB = Gotland Basin, NBP = Northern Baltic Proper)