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18–22 April 2016

Helsinki, Finland

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Executive summary

The ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) meeting was held in Helsinki (Finland), 18-22 April 2016. The meeting was attended by 26 participants from five countries and chaired by Laura Uusitalo, Finland, Saskia Otto, Germany, Martin Lindegren, Denmark, and Lena Bergström, Sweden. This was the first year of the new three-year Terms of Reference (ToR) for WGIAB. The main working activities in 2016 were to A) develop the trait-based approach of understanding the ecosystem function, and B) explore the social-ecological system, including indicator development, revising the conceptual model, and developing case studies.

As a primary outcome of the ToR A, we built on our previous work on integrated ecosystem assessments (IEAs) in the Baltic Sea, but extended it beyond considering changes in abundances of a few dominant species, to accounting for community-wide changes in a number of key traits across multiple trophic levels. These traits represent various ecosystem functions upon which we derive important ecosystem services. By investigating temporal changes in the community weighted mean traits of phytoplankton, zooplankton, zoobenthos, and fish, we demonstrated whether trait reorganizations at the level of entire communities occurred in the Central Baltic Sea as a result of the 1980s regime shift. Using in total 29 traits combined for all groups we found indications of two breakpoints across all four taxonomic groups over the last decades, i.e. one around 1990 and one around 2000. Further work will focus on exploring the nature of the changes in trait composition and on standardizing the number of traits and data types (i.e. binary, continuous or categorical) across taxonomic group.

In addition, we collected data on key functional groups and abiotic variables in all main sub-basins of the Baltic Sea, setting the stage for a cross-regional comparison of temporal patterns and trends in lower trophic level in the face of recent developments in climate-related drivers.

With reference to Tor B, to explore how social indicators could be used in parallel with biological indicators in an integrated assessment framework, we developed a conceptual model of interrelationships between ecosystem and society. We used the model as a basis for mapping factors to be accounted for in the ecosystem-based management using the Baltic salmon and clupeid species as case studies. 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) main pressures affecting the foodweb and their effects on the species, 4) key management measures, and 5) benefits that the species can produce for society.

To support the development of Ecosystem Overview the group members evaluated the probability of occurrence and the magnitude of the effect of 15 pressures occurring in the Baltic Sea. The top five pressures identified were input of nutrients, increased temperature, decreased salinity, input of hazardous substances, and input or spread of non-indigenous species.

The work will continue intersessionally and the next meeting of WGIAB is planned to be held in Lisbon, Portugal, back-to-back with WGCOMEDA and WGEAWESS.

1 Administrative details

Working Group name

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

Year of Appointment within the current cycle: 2016

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

Chair(s)

Laura Uusitalo, Finland

Saskia Otto, Germany

Martin Lindegren, Denmark

Lena Bergström, Sweden

Meeting venue

Helsinki, Finland

Meeting dates

18–22 April 2016

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.
Year 2	Annual meeting, intersessional work on research articles
Year 3	Annual meeting, intersessional work on research articles

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

Publications based on WGIAB activities, published 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

5 Progress report on ToRs and workplan

5.1 Tor 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

5.1.1 Summary of presentations relating to Tor A (see Agenda for further details)

Foodweb structure and function: examples from the Baltic Sea

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

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.

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

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.

The project FUNBAZOO is funded by the Hamburg Ministry of Science and part of the new Baltic Science Network initiative (http://www.cbss.org/baltic-science-network/). 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.

Foodweb indicators accounting for species interactions respond to multiple pressures

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*), 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.

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

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

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.

5.1.2 Data collation activities

Metadata over ongoing environmental monitoring and fish surveys in the Baltic Sea was collated in order to identify suitable focal areas for the analyses of functional traits. The central Baltic Sea was prioritized as a case study to test and further develop the proposed analytical approach.

In addition, the inventory showed that similar studies would be possible also for other Baltic subareas, and would also allow cross-system comparisons of temporal changes in functional traits in parallel with analyses of changes in the abiotic environment and in pressures.

The off shore subareas planned to be included are listed in Annex 1, together with an overview of potential variables. For each of the biotic variables (fish, zoobenthos, zooplankton, and phytoplankton), information should be included for all species that occur in the sampling/monitoring, not only the key species.

During the past two decades, Baltic Sea foodwebs 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. The groups decided to conduct an analysis of abiotic conditions of five main subareas of the Baltic Sea (Central Baltic Sea, Gulf of Riga, Gulf of Finland, Bothnian Sea, and Bothnian Bay) in order to identify the dominating patterns of long-term change (i.e. trends and abrupt shifts) during the past decades. Changes in the abiotic factors will then be linked to abiotic changes to bottom–up productivity dynamics, i.e. changes in regional phytoplankton and zooplankton communities, as a key to understanding changes in the capacity of the systems to support the productivity of fish (and other higher trophic level species).

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

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.

5.1.3 Functional traits analyses

The aim of this year´s work carried out under ToR A was to perform what we wish to term a "Trait-based Integrated Trend Analysis" (tITA) which will build on our previous work on Integrated Trend Analyses across Baltic Sea basin (e.g. Diekmann and Möllmann, 2010), but extend it beyond considering changes in abundances of a few dominant species, to account for community-wide changes in a number of key morphological, physiological or behavioural 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 a case study we choose to focus on the Gotland Basin (ICES Subdivision 28) for which we have a comparable set of abiotic and biotic information regarding species abundances and traits from the late 1970s onwards (Table 1 –Annex 4). The ITA is based on following working steps:

1) Collect long-term time-series of phytoplankton, zooplankton, fish, and zoobenthos (potentially also marine mammals and seabirds) 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, NAO, 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 behavioural 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 Principle Component Analysis (PCA) in accordance with our previous IEA methodology.

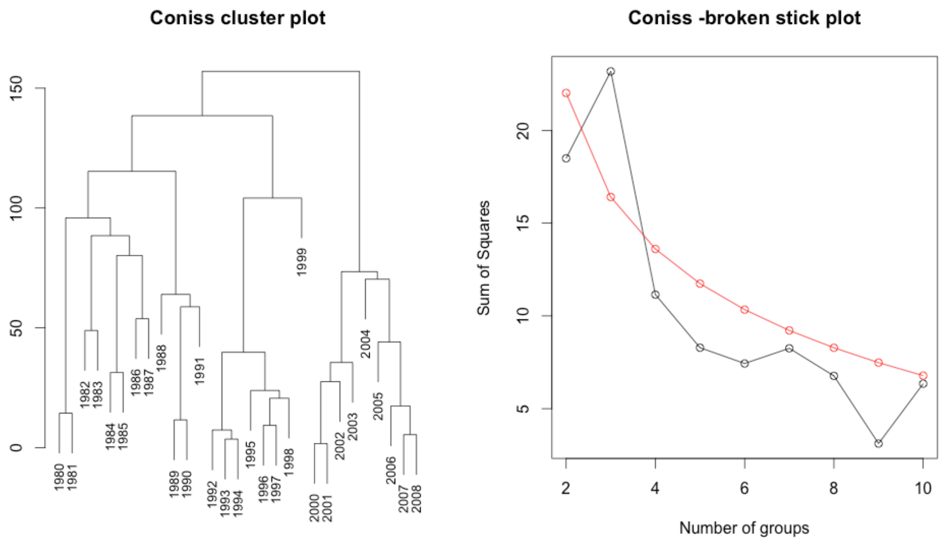

Figure 5.1.3.1. Results of a chronological clustering analysis using all CWM traits across multiple organism groups (phytoplankton, zooplankton, zoobenthos, and fish). The results suggest three distinct periods characterized by breakpoints in 1991–1992 and 1999–2000.

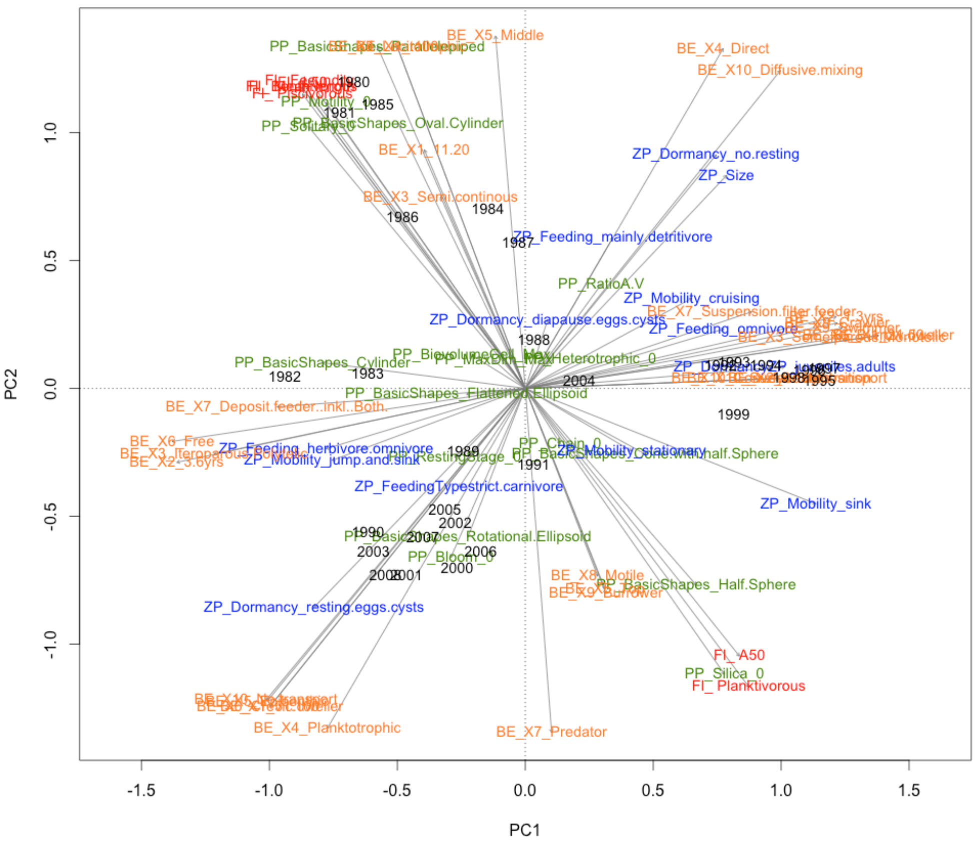

Figure 5.1.3.2. Results of a principal component analysis using all CWM traits across multiple organism groups (phytoplankton, zooplankton, zoobenthos, and fish). The biplot shows the corresponding variable loadings on PC1 and PC2. (For variable abbreviations please see Table 1 in annex 4). The following time clusters were identified (1980–1991, 1992–1999, 2000–2008). The variables, i.e. trait categories, are colored depending on their taxonomic group (green = phytoplankton, blue = zooplankton, red = fish, orange = zoobenthos).

Our preliminary integrated analysis illustrates the degree of correlations (positive, negative or no correlation) among traits of different organism groups (Figures 5.1.3.2 and 5.1.3.3) and demonstrates significant temporal changes in CWM traits across organisms groups in the early 1990s and early 2000s (Figure 5.1.3.1). The first breakpoint follows the previously described regime shift in the Baltic Sea during the late 1980s/early 1990s (Möllmann *et al.*, 2009). However, the second breakpoint has not been observed in the species composition in previous analyses. One reason could be the inclusion of zoobenthos in our analysis. On the other hand, we also found changes in trait composition of phytoplankton, zooplankton, and fish, which rather support the hypothesis of changes in trait composition of the entire foodweb. Some issues in balancing trait numbers and the trait type (i.e. binary, categorical or continuous) across taxonomic groups or the identification of most representative traits have not been resolved yet. Hence, analyses results represent a first snapshot and need further refinements.

5.2 Tor 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

5.2.1 Summary of presentations relating to Tor B (see Agenda for further details)

Foodweb indicators accounting for species interactions respond to multiple pressures

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.

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

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.

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

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.

5.2.2 The human dimension in integrated ecosystem analyses

What is covered by human dimension in relation to marine ecosystems?

The term ”human dimension” comes up increasingly often in the context of integrated assessment of the seas. It covers a wide range of issues related to the society’s and individuals’ relationship with the sea. Below, we outline various aspects that can be included under the “human dimension” umbrella.

In the Table 5.2.2.1, we also outline the WGIAB work relevant to human dimensions, and how that links to the identified aspects.

Table 5.2.2.1: 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 ecological-social system
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 ES 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	
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	

Conceptual model of social-ecological system

Ecosystem-based management requires an understanding of 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 to be developed. In the presentations, two conceptual models were presented (DPSIR and another model for looking at how to link ecosystem function and human dimension), but both were also criticized.

The group decided to try to think up a better conceptual model that could be used to understand and talk about the system. It should be noted that the group does not commit itself to working exclusively with any one conceptual model of framework.

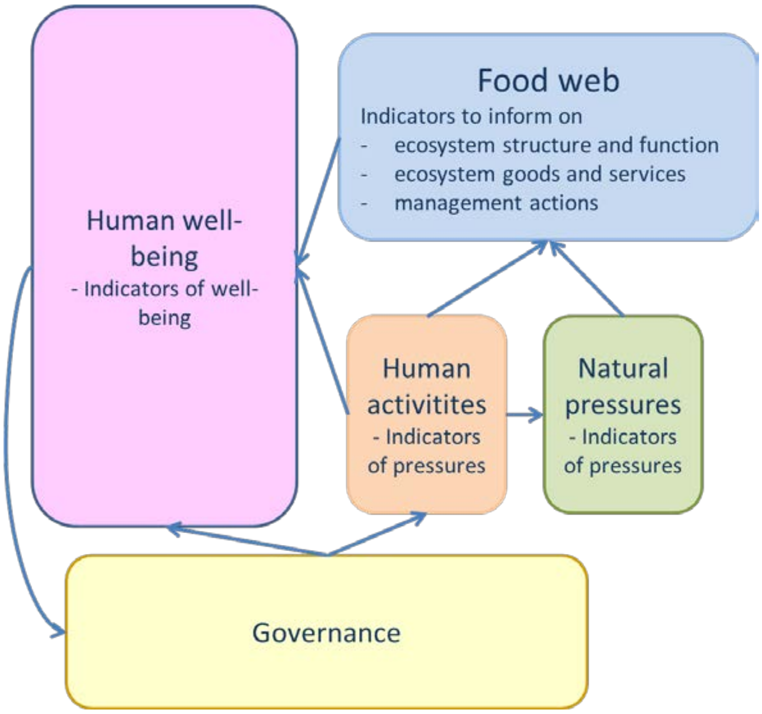

Figure 5.2.2.1. Conceptual model to facilitate understanding and discussion on the Baltic Sea social-ecological system.

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) main pressures affecting the foodweb and their effects on the species, 4) key management measures, and 5) 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.

5.3 Ecosystem overviews: Pressures acting on the Baltic Sea

As requested by ICES, to aid the development of Ecosystem Overview for the Baltic Sea, the group members were asked to evaluate the probability of occurrence and the magnitude of the effect of 15 pressures within five categories (Figure 5.3.1). Both scores ranged from 1 to 3. 18 responses were obtained.

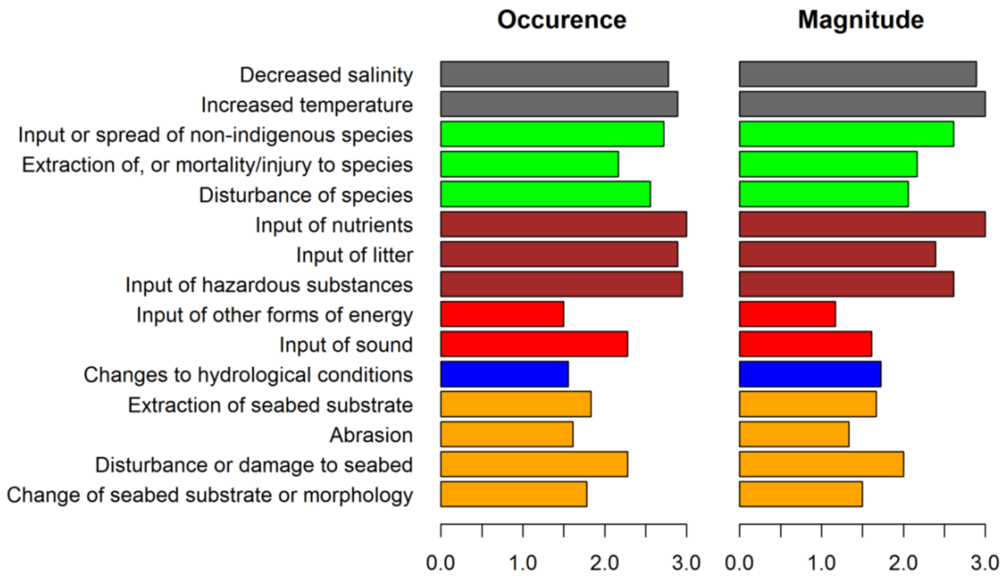

Figure 5.3.1. Mean ranks of probability of occurrence and magnitude of effect from 18 respondents.

The pressures were then ranked according to occurrence x magnitude (Figure 5.3.2). The top 5 pressures were input of nutrients, increased temperature, decreased salinity, input of hazardous substances, and input or spread of non-indigenous species. If the climate-related variables (temperature and salinity) are not considered, the top 5 pressures list will include input of nutrients, input of hazardous substances, input or spread of non-indigenous species, input of litter, and disturbance of species (Figure 5.3.2).

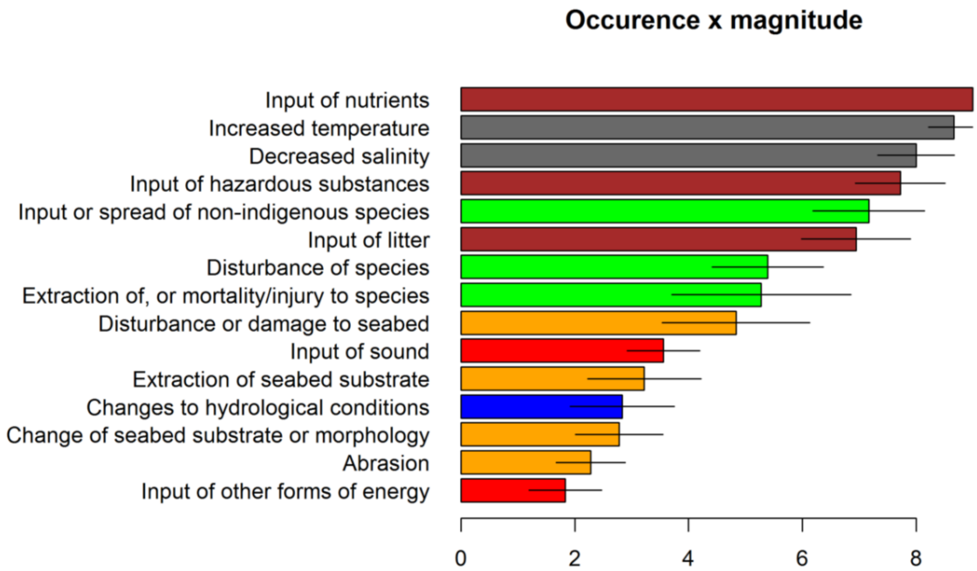

Figure 5.3.2. Ranking of the severity of the pressures.

6 Next meetings

The next WGIAB meeting will be arranged as a joint back-to-back meeting with WGCOMEDA and WGEAWESS at the Instituto Português do Mar e da Atmosfera (IPMA) in Lisbon, Portugal (tentatively in spring 2017, date to be decided).

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Annex 2. Agenda

Monday 18/04/16

1200 – 1300	Arrival of participants
1300 – 1330	Word of welcome by Paula Kankaanpää, Director of the Marine Research Centre of the Finnish Environment Institute
	Practical information, tour de table and discussion of the agenda
1330 – 1430	WGIAB and its work over the years, Goals of the 2016 meeting
	Introduction to the topics of the meeting
1430 – 1500	Coffee and Tea
1500 – 1700	Specification of tasks, startup of work
	Presentations by participants on:
	Datasets: key variables, temporal and spatial range
	Available information on traits of the biotic components
	Links between biota, ecosystem function, indicators, and ecosystem services
1700 – 1800	Short summary and preparation of next day

Tuesday 19/04/16

0900 – 1100 Presentations in relation (10-15 min each)

- Marie Nordström. Foodweb structure and function: examples from the Baltic Sea
- Spatio-temporal patterns in species and functional diversity of phytoplankton. Zuzanna Zagrodska
- Summary of the first FUNBAZOO (FUNctional diversity of Baltic ZOOplankton) workshop held in Hamburg 2015. Saskia Otto
- Spatial and temporal patterns in zoobenthic functional diversity. Benjamin Weigel
- Lauréne Pécuchet. Assembly rules shaping the composition of demersal fish communities in the Baltic Sea

1100 – 1200 Continued work

1200 – 1300 Lunch

1300 – 1430 Presentations

- The 2014 saltwater inflow. Karin Wesslander
- Long-term changes in salmon post-smolt survival and possible drivers behind the changes. Atso Romakkaniem
- Long-term trends in the Gulf of Bothnia. Sanna Suikkanen
- Information on the ICES regional Ecosystem overviews

1430 – 1500 Coffee and Tea

Afternoon: Excursion to Suomenlinna fortress

Wednesday 20/04/16

0900 – 1100 Presentations

- Evaluating the suitability of foodweb indicators under environmental gradients and non-linear interactions - is there a universal indicator? Saskia Otto
- Foodweb indicators accounting for species interactions respond to multiple pressures. Maria A. Torres
- Nash equilibrium to understand productivity in a multispecies system during environmental change. Niclas Norrström
- Changes in four societal drivers and their potential to reduce Swedish nutrient inputs to the sea. Anders Grimwall
- Bayesian machine learning approach for analysing dependencies between coastal fish indicators and environmental pressures. Annukka Lehikoinen (presented by L.Uusitalo)

1100 – 1630 Continued work including lunch break

1630 – 1800 Mental model and fisheries game. Christian Möllman and Phil Levin

Pressure exercise

Thursday 21/04/16

0900 – 1000

- HELCOM project to develop a holistic assessment of ecosystem health in the Baltic Sea (HOLAS II) Lena Bergström
- Presentation of results from the Pressure exercise

1000 – 1730 Continued work, including lunch break

1730 – 1800 Closure and summary of the day

Friday 22/04/16

0900 – 1030 Final plenary session

- Final conclusions from the group work
- Date and venue for the next meeting
- Planning of the report and report writing

1030 – 1100 Coffee and Tea

1100 – 1300 Wrap up and planning of continued work

1300 Closure of the meeting

Annex 3. Functional Trait Analysis

Table 1: Overview of traits used in the analysis that are specific to each taxonomic group.

Taxonomic Group	Trait	Data Type	Trait Category	Label
phytoplankton	maximum dimension	continuous		PP_MaxDim_Max
	biovolume	continuous		PP_BiovolumeCell_Max
	area to volume ratio	continuous		PP_RatioA.V
	basic shapes	categorical	cone with half sphere	PP_BasicShapes_Cone.with.half.Sphere
			cylinder	PP_BasicShapes_Cylinder
			flattened ellipsoid	PP_BasicShapes_Flattened.Ellipsoid
			half sphere	PP_BasicShapes_Half.Sphere
			oval cylinder	PP_BasicShapes_Oval.Cylinder
			parallelepiped	PP_BasicShapes_Parallelepiped
			rotational ellipsoid	PP_BasicShapes_Rotational.Ellipsoid
	chain building	binary		PP_Chain_0
	solitary	binary		PP_Solitary_0
	resting stages	binary		PP_RestingStage_0
	heterotrophic	binary		PP_Heterotrophic_0
	silica	binary		PP_Silica_0
	bloom forming	binary		PP_Bloom_0
	motility	binary		PP_Motility_0
zooplankton	body weight	continuous		ZP_Size
	feeding type	categorical	herbivorous / omnivorous	ZP_Feeding_herbivore.omnivore
			mainly detritivorous	ZP_Feeding_mainly.detritivore
			strict omnivorous	ZP_Feeding_omnivore
			strict carnivorous	ZP_FeedingTypestrict.carnivore
	dormancy	categorical	diapause eggs/cysts	ZP_Dormancy_diapause.eggs.cysts
			no resting stage	ZP_Dormancy_no.resting
			resting eggs/cysts	ZP_Dormancy_resting.eggs.cysts
			juveniles,adults	ZP_DormancyZP_juveniles.adults
	mobility	categorical	cruising	ZP_Mobility_cruising
			jump and sink	ZP_Mobility_jump.and.sink
			sink	ZP_Mobility_sink
			stationary	ZP_Mobility_stationary
fish	feeding type	categorical	benthivorous	FI_ Benthivorous
			planktivorous	FI_ Planktivorous
			piscivorous	FI_ Piscivorous
	mean length	continuous		FI_ Mean.length
	L50	continuous		FI_ L50
	A50	continuous		FI_ A50
	fecundity	continuous		FI_ Fecundity
zoobenthos	maximum size	categorical	11-20	BE_X1_11.20
			21-50	BE_X1_21.50
			50-100	BE_X1_51.100
			>100	BE_X1_.100
	longevity	categorical	1-3yrs	BE_X2_1.3yrs
			3-6yrs	BE_X2_3.6yrs
			6-10yrs	BE_X2_6.10yrs
	reproductive frequency	categorical	semelparous monotelic	BE_X3_Semelparous.Monotelic

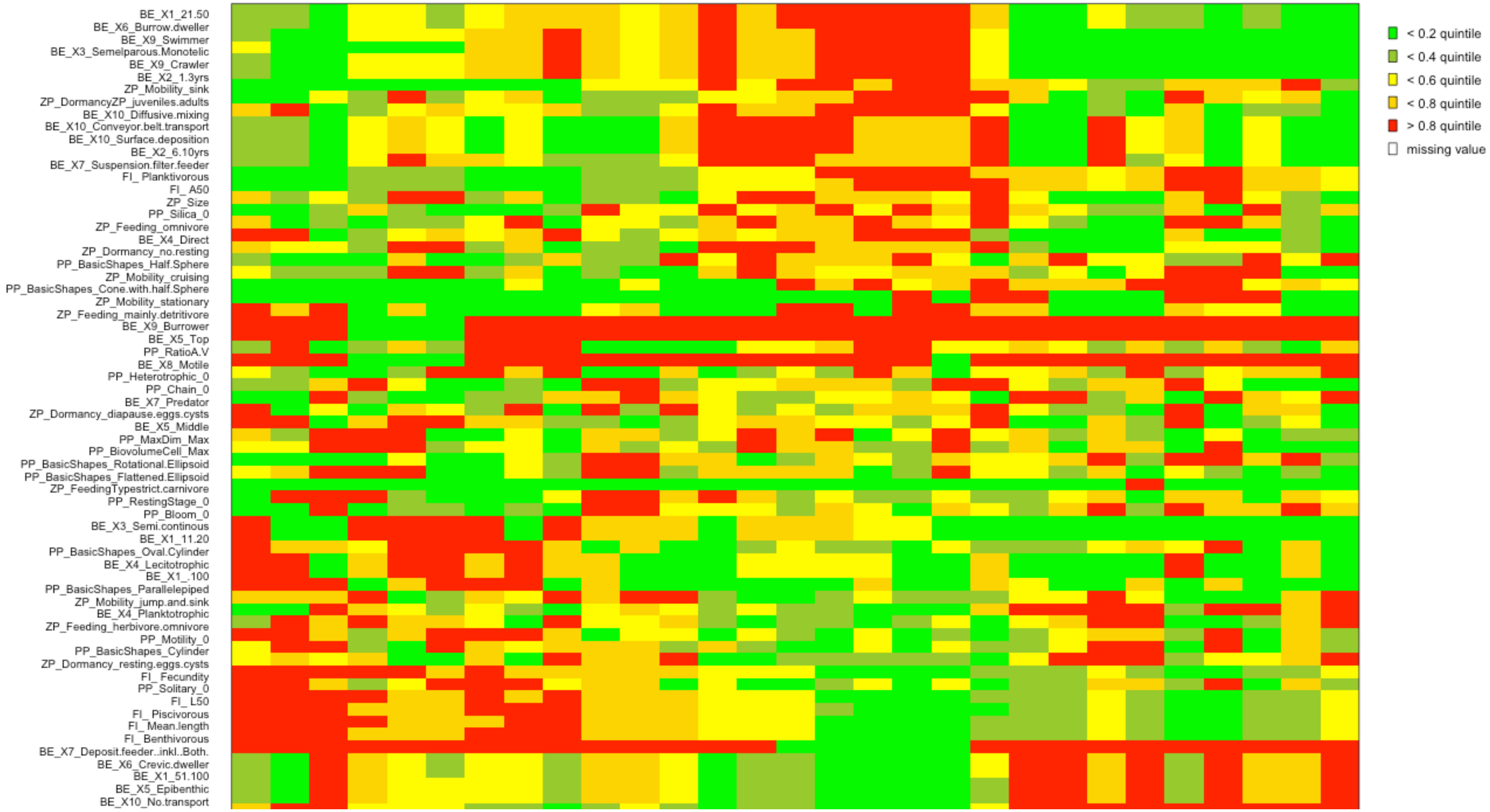

Figure A.3.1: Traffic-light plot representing the development of functional traits in the Gotland Basin across all trophic levels (i.e. phytoplankton, zooplankton, fish, and zoobenthos); time-series of CWM traits transformed into quintiles and sorted according to PC1 of the PCA; red represents high values while green represents low values of the respective variable.