A2.5
Integrated biodiversity (BEAT) and preliminary food web approach
Main report

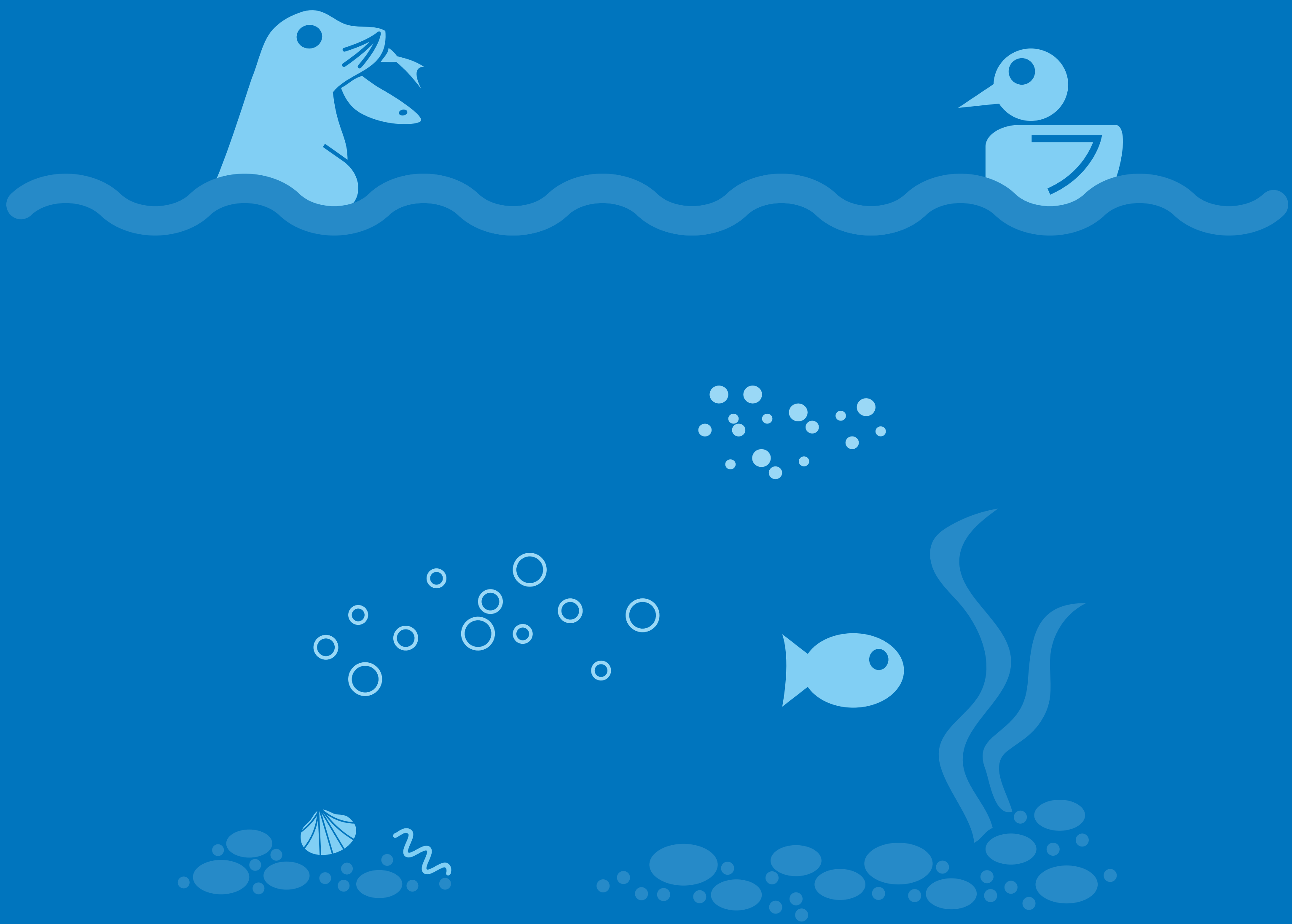
Baltic Marine Environment Protection Commission

BLUES

Co-funded by the European Union

Activity 2- Biodiversity

2023



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HELCOM BLUES – Activity 2.5 Integrated biodiversity (BEAT) and preliminary food web approach

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Summary of results

In order to achieve an Integrated biodiversity (BEAT) assessment and a preliminary food web approach (Activity 2.5) as part of the HELCOM BLUES project, two subtasks were conducted; one on the further development of the BEAT tool (A2.5.1) and another on exploratory work towards and assessment of food webs (A2.5.2). The summary results, key messages and use of results can be found in this document. The detailed document with more technical information on the work conducted is available as A2.5 Annex 1.

Subtask 2.5.1 Further development of the BEAT tool

The BEAT tool, used in HOLAS II, was reviewed and further developed to accommodate changes to existing components and include new indicators during HOLAS 3, and follow the latest guidance on indicator integration:

- Ecosystem component structure updated with new species
- Spatial structure updated according to the latest version of HELCOM spatial assessment units
- New indicators added
- Adjusted integration structure and weighting for pelagic habitats
- Integration rules modified to better align with MSFD Art. 8 guidance

Subtask 2.5.2 Exploratory work towards an assessment of food webs

A review of indicators addressing food web aspects, analysing temporal trends of food web components and make use of already developed food web models were considered to be the best options for evaluating food webs in HOLAS 3. The work was done in close cooperation between the BLUES project and a newly established correspondence group (CG FOODWEB) at HELCOM, which was recently converted to a full expert group on food webs in HELCOM (EG FOODWEB). For HOLAS 3, HELCOM BLUES A2.5.2 contributed with an analysis of indicators addressing food web aspects and compiling data on several trophic guilds for a case study in the Bothnian Sea using integrated trend analyses (ITA) to explore temporal trends within and between trophic guilds.

Key messages

Key messages for **science**

1) Further indicator development needed to cover all biodiversity aspects and increase spatial coverage
2) Specific food web indicators needed, including energy flows and transfer efficiency
3) Indicator threshold setting an important aspect of integrated assessments

Key message for **policy makers**

1) Monitoring is important as it forms the foundation of assessments
2) Streamlining assessments across policies is advantageous
3) Ecosystem-based management needs to include food web aspects more strongly

Use of results

The work of task A2.5 directly contributed to the HOLAS 3 Thematic assessment of biodiversity. The updated BEAT tool (further developed in a synergistic process by BLUES and the BDF project, publicly available on GitHub) was used in the integrated assessments of fish, marine mammals and pelagic habitats. The analyses of indicators addressing food web aspects was included in the chapter of food webs and the compiled data on trophic guilds were used in a case study on integrated trend analyses in the Bothnian Sea. Work done on food webs in the new established expert group EG FOODWEB has laid the foundation for future improvements and knowledge exchange on the topic. This will enable future advancements on the topic of food webs and developments towards a stronger assessment.

By addressing key topics in the thematic assessment of biodiversity, the work connects directly to the BSAP goal of a "Baltic Sea ecosystem ('that') is healthy and resilient". Explicitly, the work can inform the BSAP actions B33 and B34 on the need for further development of indicators to allow improved holistic assessments of the state of the Baltic Sea. Understanding food web functioning is key for implementing ecosystem-based management.

Further, the updated BEAT tool and identified approaches for evaluating food webs can facilitate reporting under the MSFD (Descriptor 1 and 4) for HELCOM Contracting Parties that are also EU Member States, as the assessment aimed at following the MSFD Article 8 guidance.

Baltic Marine Environment
Protection Commission

BLUES

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A2.5 Annex 1
BEAT and food web approach

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Task 2.5 Integrated biodiversity (BEAT) and preliminary food web approach

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Introduction

Assessments of the state of the environment are the back-bone in many marine policies and agreements, such as for example the EU Marine Strategy Framework Directive (MSFD; EU 2008) and the HELCOM Baltic Sea Action Plan (BSAP; HELCOM 2021). The outcome of the status assessments sets the requirements for measures to improve or maintain the environmental status. At the Baltic Sea level the assessment of biodiversity is coordinated by HELCOM and based on a set of core indicators, each representing an aspect or ecosystem element such as a species, species group or functional group and often measured using different metrics and scales. Integrating the indicator results to a single assessment of biodiversity status of an ecosystem component (fish, marine mammals, waterbirds, pelagic habitats or benthic habitats) thus requires a normalization of the indicators.

For the second holistic assessment of the Baltic Sea (HOLAS II) the integrated biodiversity assessment tool BEAT 3.0, hereafter BEAT, was developed, allowing normalization of different types of indicators (i.e., normalization of outcomes to a comparable scale) and the integration of these independent components within the HELCOM spatial assessment units (HELCOM 2018, Nygård et al. 2018). Since HOLAS II, new HELCOM indicators have been developed and the MSFD guidance for assessing and integrating ecosystem components has been updated, implying requirements to adjust BEAT.

In addition to the structural assessment of biodiversity facilitated by BEAT it is also important to understand food web functioning for a holistic evaluation of the ecosystem status. The BEAT assessment is structured according to the ecosystem components, but does not address interactions between them. It is important to understand the interactions within and between ecosystem components when evaluating food web functioning, i.e. how effectively energy is transferred between trophic levels and circulated within the ecosystem and at an even more basic level which components interact (e.g. feed on what). A food web assessment was recognized as a significant gap in HOLAS II, as food webs were only addressed in brief and qualitatively using information from single ecosystem components.

Task 2.5 of the HELCOM BLUES project had a two-fold approach aiming at 1) developing and fine-tuning the integrated biodiversity assessment tool (BEAT) to incorporate new indicators and adjusting integration methods for an improved integrated assessment of biodiversity in HOLAS 3, and 2) to explore methods and approaches for assessing food webs, in particular ones that may lay the foundations for future regional assessments in the HELCOM region.

BEAT development (HELCOM BLUES A2.5.1)

Since HOLAS II, development work on both indicators and integration rules (e.g. the MSFD Article 8 Guidance) have taken place. New indicators have been developed and many existing indicators have expanded in their geographical coverage, had new threshold values applied and/or covered more species.

For the assessment of pelagic habitats, the 'Seasonal succession of key phytoplankton groups' indicator has been operationalized and is now included in the integrated assessment and the 'Zooplankton mean size and total stock' indicator includes coverage of more spatial assessment units as compared to HOLAS II. For the assessment of coastal fish more species are evaluated in the 'Abundance of coastal key fish species' and the new indicator 'Size structure of coastal fish' is included in the integrated assessment. For the assessment of waterbirds, both the wintering waterbird indicator and the breeding waterbird indicator cover more species and the integrated assessment is done at a finer spatial scale, compared to the whole Baltic level applied in HOLAS2. For marine mammals, indicators for the abundance and distribution of harbour porpoise have been developed allowing the assessment of harbour porpoise status. The indicator 'Reproductive status of seals' now includes data for ringed seal in the Bothnian Bay management unit. Further, the indicator 'Number of drowned mammals and waterbirds in fishing gear' has been further developed, allowing the evaluation of the bycatch pressure on certain mammal and waterbird populations. Thus, the BEAT indicator catalogue has been updated to include all new indicators and species not earlier assessed in the ecosystem component structure accordingly to provide a more encompassing assessment of biodiversity.

Integration rules have been modified since HOLAS II to improve harmonization with developments under the EU MSFD Article 8 guidance (EC 2022) and to include recommendations from dedicated thematic expert workshops on towards the HOLAS 3 assessment. Compared to HOLAS II, the integration rules of all ecosystem components were modified (see below). The assessment of benthic habitats in HOLAS 3 was not considered to be practical using BEAT due to the spatial scale of pressure data underpinning it, the availability of new indicators (an impact indicator), and the more detailed spatial resolution needed to assess the requirement of broad habitat types. Consequently BEAT is used only for the integrated assessments of fish, marine mammals, waterbirds and pelagic habitats in HOLAS 3.

Other modifications to BEAT were checking and correcting the areas of the spatial assessment units according to the 2022 updated borders and including the new spatial assessment units used in the eutrophication assessment (HELCOM Monitoring and Assessment Strategy).

BEAT in HOLAS 3

Pelagic habitats

The assessment of pelagic habitats was carried out in two independent channels. Firstly, using the BEAT tool and integrating the three biological state indicators where assessment results were available (phytoplankton seasonal succession, cyanobacterial bloom index and Zooplankton mean size and total stock (MSTS)). In this channel, the phytoplankton related indicators were integrated using weighted averaging, giving more weight to the phytoplankton seasonal succession indicator (Figure 1). The phytoplankton component was then integrated with the zooplankton indicator MSTS, using the one-out-all-out (OOAO) approach. Secondly, the results from the integrated biological assessment were compared with two eutrophication state indicators, chlorophyll-a and water clarity, that were equally weighted (i.e., essentially averaged). BEAT was used to integrate the biodiversity indicators and adjusted accordingly to account for the weighting of the phytoplankton indicators and integration with zooplankton that was established by Activity 2.3 and approved via appropriate HELCOM processes for HOLAS 3.

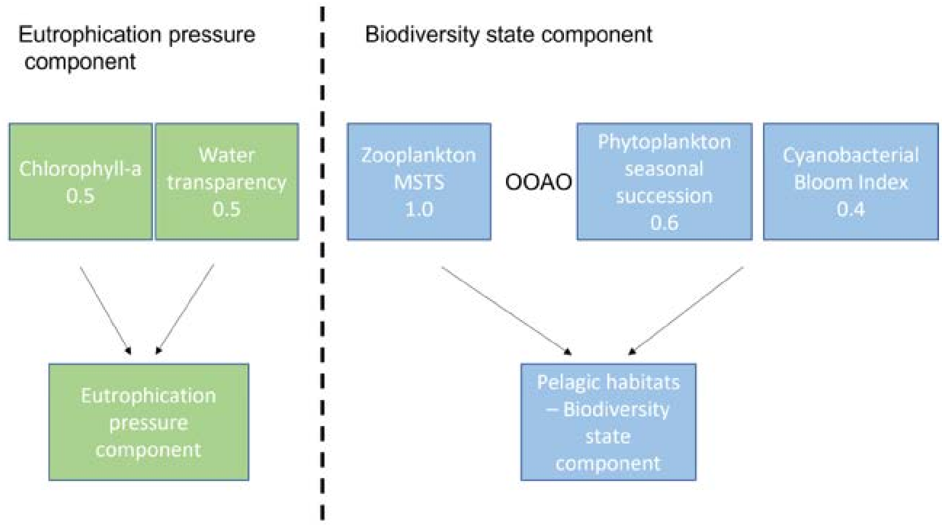

Figure 1. Schematic presentation of the assessment of pelagic habitats. Integration of the biodiversity state component (on the right) was implemented in BEAT. Numbers within the boxes of each separate HELCOM indicator present the weighting of that component in the BEAT integration process. The one-out-all-out principle (OOAO) is applied when integrating zooplankton and phytoplankton indicators.

Marine mammals

The integrated assessment of marine mammals followed a species-based approach, providing results separately for seals and the harbour porpoise. An integration to the level of marine mammals was not done as this was considered not practical and uninformative for management. An overview of the integration is visualized in Figure 2 using harbour porpoise as an example. The BEAT assessment approach strived to be compatible with the assessment approach defined by the EU Habitats Directive (as set out in the MSFD Article 8 Guidance). However, as no HELCOM indicators address the habitat component, as defined by the Habitats Directive, the BEAT assessment was based only on the abundance, distribution and available demographic components. An additional assessment including the bycatch component was also conducted, providing the integration outcomes with and without bycatch. In practical terms, this involves applying the one-out-all-out approach for the abundance, distribution and demography components and including bycatch as one of those OOAO components. This provided two integrated assessment outcomes (a step-wise overview as components are added).

For harbour porpoise, the integrated assessment was based on the indicators 'Harbour porpoise abundance' and 'Harbour porpoise distribution' (Figure 2). The assessment was done separately for the two Baltic populations of harbour porpoise. The result for assessment units where the populations overlap was decided by the population with poorer status. In the additional integration where bycatch was addressed the indicator 'Number of drowned mammals and waterbirds in fishing gear' was included. The integration of indicators followed the one-out-all-out approach.

For seals the integrated assessment was based on the indicators 'Population trends and abundance of seals' (one indicator per seal species: Grey seal, Harbour seal, and Ringed seal), 'Distribution of Baltic seals' (one indicator per seal species: Grey seal, Harbour seal, and Ringed seal), 'Nutritional status of seals' and 'Reproductive status of seals'. Grey seal was assessed as a single management unit in the Baltic Sea (HELCOM Level 1 assessment unit, whole Baltic Sea), whereas harbour seal and ringed seal were assessed according to their defined management units (aggregated Level 2 assessment units, aggregations of the 17 sub-basins as defined in the HELCOM Seal Recommendation). For the integrated assessment of seals, the results are presented at spatial Level 2 (Baltic Sea sub-basins) using the relevant species results present within each given assessment unit. Evaluations of nutritional status were available only for grey seal. The reproductive status of ringed seal was carried out in the Bothnian Bay management unit and grey seal were evaluated (at the whole Baltic Sea level). As a first step in the integration process, the nutritional status and reproductive status indicators were integrated separately for each species using equal weighting to form the result of the demographic component that would be included in the further integration process. Subsequently, the abundance, distribution and demography component (combined integration of reproductive and nutritional status) were integrated applying the one-out-all-out approach to achieve the assessment result of the species in each management unit. The overall seal assessment was performed using the one-out-all-out approach between species. A separate assessment was performed for seals adding the results from the bycatch indicator at the management unit level for the species, and then following the same integration approach as described above.

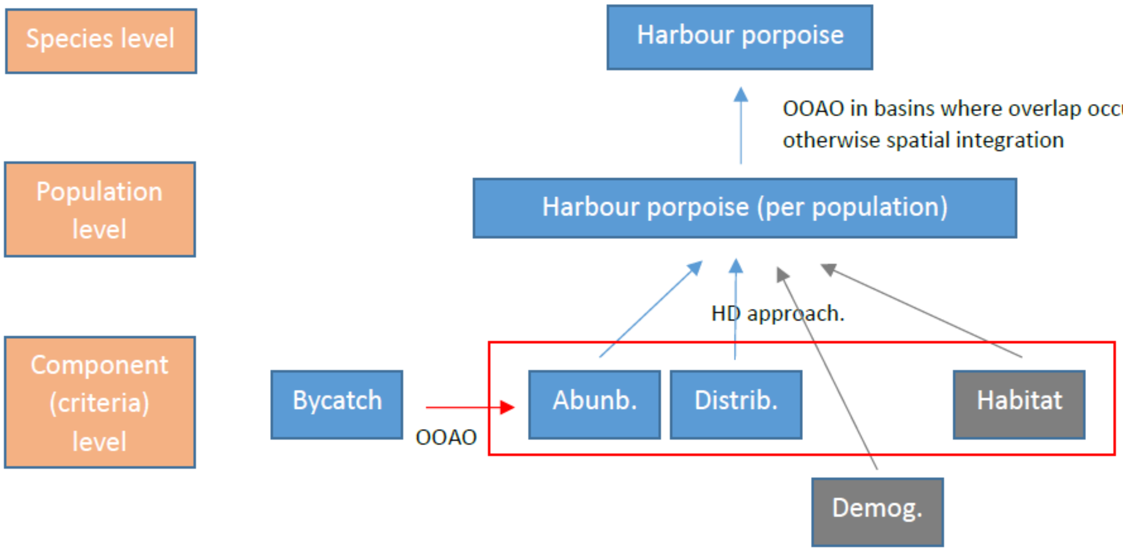

Figure 2. Schematic presentation of the assessment of harbour porpoise, following the Habitat Directive components. As no demography or habitat quality indicators are available, they are not considered. When the bycatch indicator is used, the one-out-all-out principle is applied, as the population will not meet the criteria for good status if bycatch exceeds the threshold value. The assessment of seals followed the same approach as for harbour porpoise.

Waterbirds

The integrated assessment of birds was based on the indicators 'Abundance of waterbirds in the breeding season' and 'Abundance of waterbirds in the wintering season'. Birds were assessed based on the following species groups: Surface feeders, Pelagic feeders, Benthic feeders, Wading feeders and Grazing feeders, using seven subdivisions of the Baltic Sea. The subdivisions consisted of ecologically relevant aggregated Level 2 assessment units. Both indicators provided species specific index scores to be compared to the threshold value for achieving GES. The integration of single species to species groups followed an approach that >75% of the assessed species within the species group needed to achieve GES for the species group to achieve GES. As the breeding bird indicator and the wintering bird indicator both address abundance of species, but at different periods, which reflects different factors of relevance for the population status, the species results were used as independent components in the integration process. Thus, if for example species A was assessed both in the breeding bird indicator and the wintering bird indicator, $SpA_{Breeding}$ and $SpA_{Wintering}$ were used as separate inputs in BEAT. For the overall result for birds, the one-out-all-out approach for species groups was used (Figure 3).

As for mammals, a separate assessment including the bycatch indicator 'Number of drowned mammals and waterbirds in fishing gear' was carried out. Bycatch is applied only for wintering waterbirds since it is noted in more southernly regions to be the period with the strongest impact and also since the limited amount of actual bycatch data available makes a direct assessment in the breeding season impossible at this stage. Thus, the bycatch indicator was integrated with the wintering birds indicator using the one-out-all-out approach to reflect that a species cannot be in good status if bycatch exceeds the defined threshold. The integration with the breeding bird indicator was then carried out in the same manner as described above.

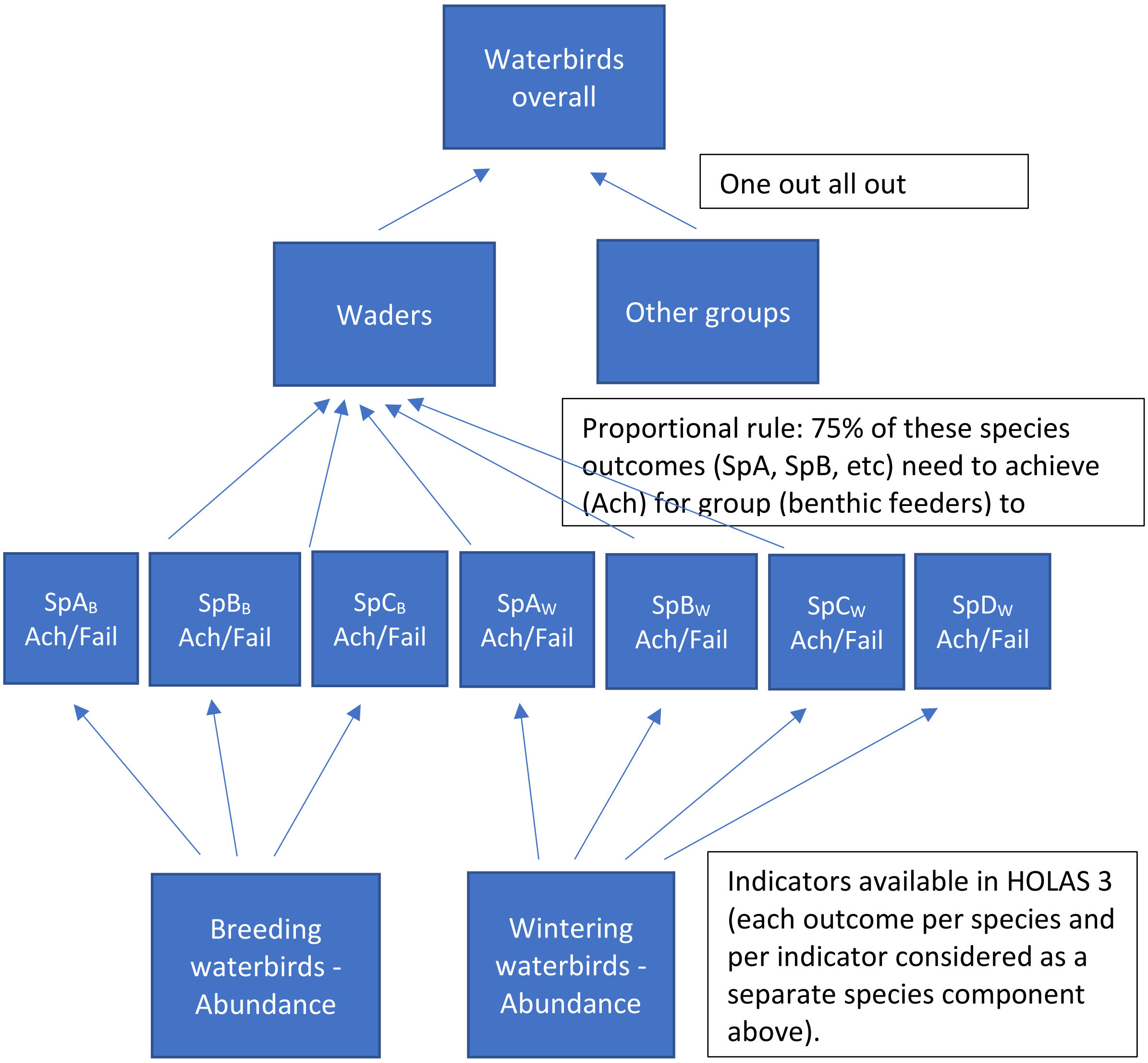

Figure 3. Schematic presentation of the assessment of waterbirds. Breeding birds and wintering birds are considered to represent different parts of the populations, thus they are treated as separate items in the integration.

Fish

The assessment of fish first integrated indicators per species and in a second step the one-out-all-out approach between species within species groups was done. In coastal areas, the assessment of fish was carried out using the indicators 'Abundance of key coastal fish species', 'Size structure of coastal fish' and 'Abundance of coastal fish key functional groups', applying spatial Level 3 assessment units. The first step of the integration was for species at the monitoring area level using equal weighting of the species abundance and size indicators (Figure 4). To apply this approach in BEAT, monitoring areas were considered to sample different populations of the same species and thus populations were added as an additional level in the ecosystem component structure, i.e. level 5 below the relevant species. The one-out-all-out approach was applied between monitoring areas to determine the species result at the spatial Level 3. The species group Coastal fish was assessed by applying the one-out-all-out approach between the species and the functional groups.

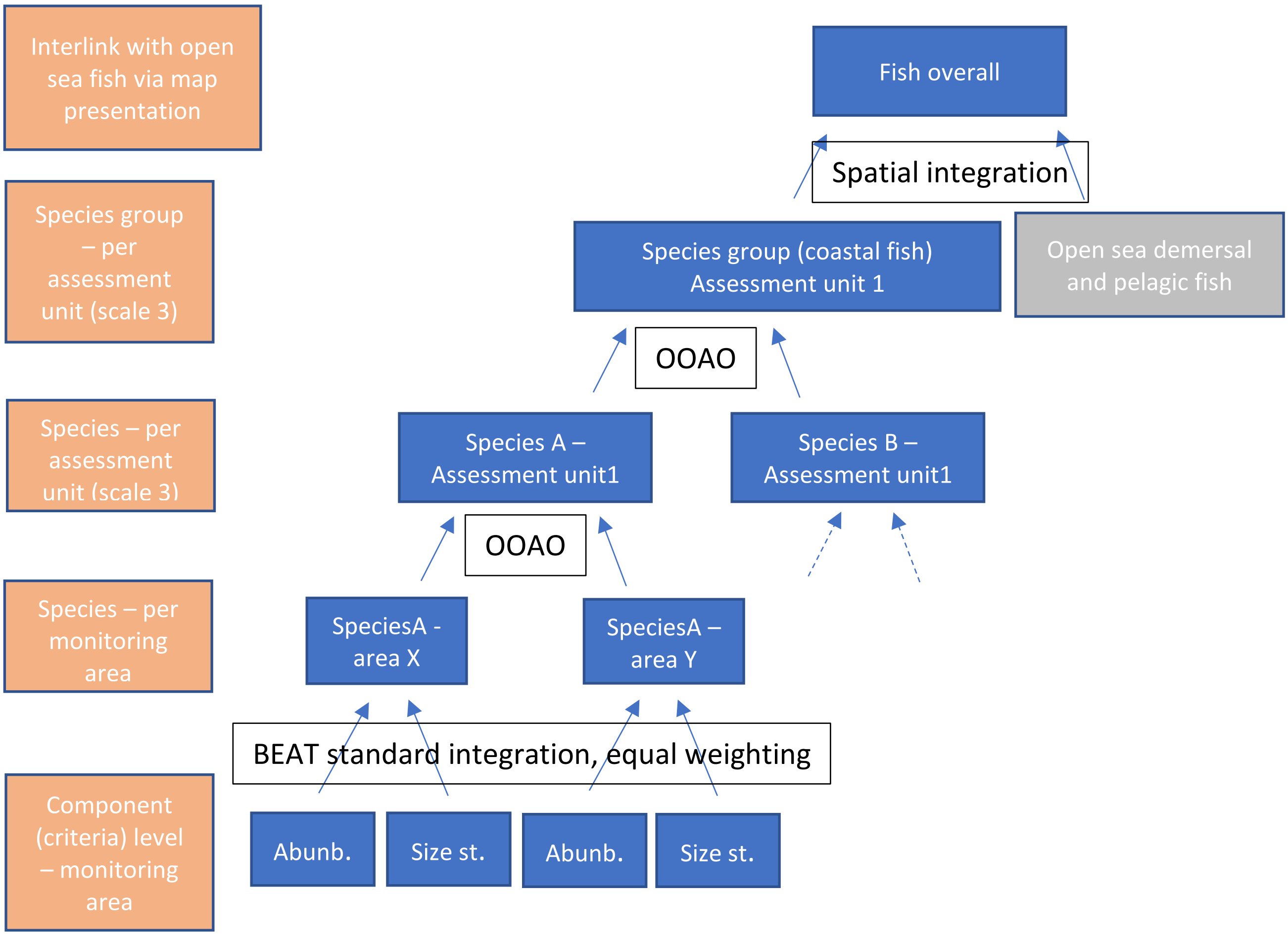

Figure 4. Schematic presentation of the assessment of coastal fish. Abund. = abundance indicator, Size st. = size structure indicator, OOAO = One out all out approach.

Integrated assessments of ecosystem components in HOLAS 3

The above presented methodology and integration rules were applied in the thematic assessment of biodiversity as part of the third holistic assessment of the Baltic Sea (HOLAS 3). Selected results of the integrated assessments are briefly presented below. A full presentation of the results is included in the HOLAS 3 thematic assessment of biodiversity (currently under review).

The biodiversity component of the pelagic habitats was assessed as not achieving good status in any of the open sea areas of the Baltic Sea (Figure 5A). Only in a few coastal areas good status was achieved. The integrated result for coastal fish was assessed as good in two out of twenty-two assessed coastal assessment units (Figure 5B). The integrated result for waterbirds did not achieve good status in any of the assessment units (Figure 5C), however, some surface-feeding birds, pelagic-feeding birds and grazing birds achieved good status in some assessment units (results not shown). For marine mammals, none of the seal species, nor any of the harbour porpoise populations, achieved good status, which is also reflected in the integrated result for seals (Figure 5D) and harbour porpoise (Figure 5E).

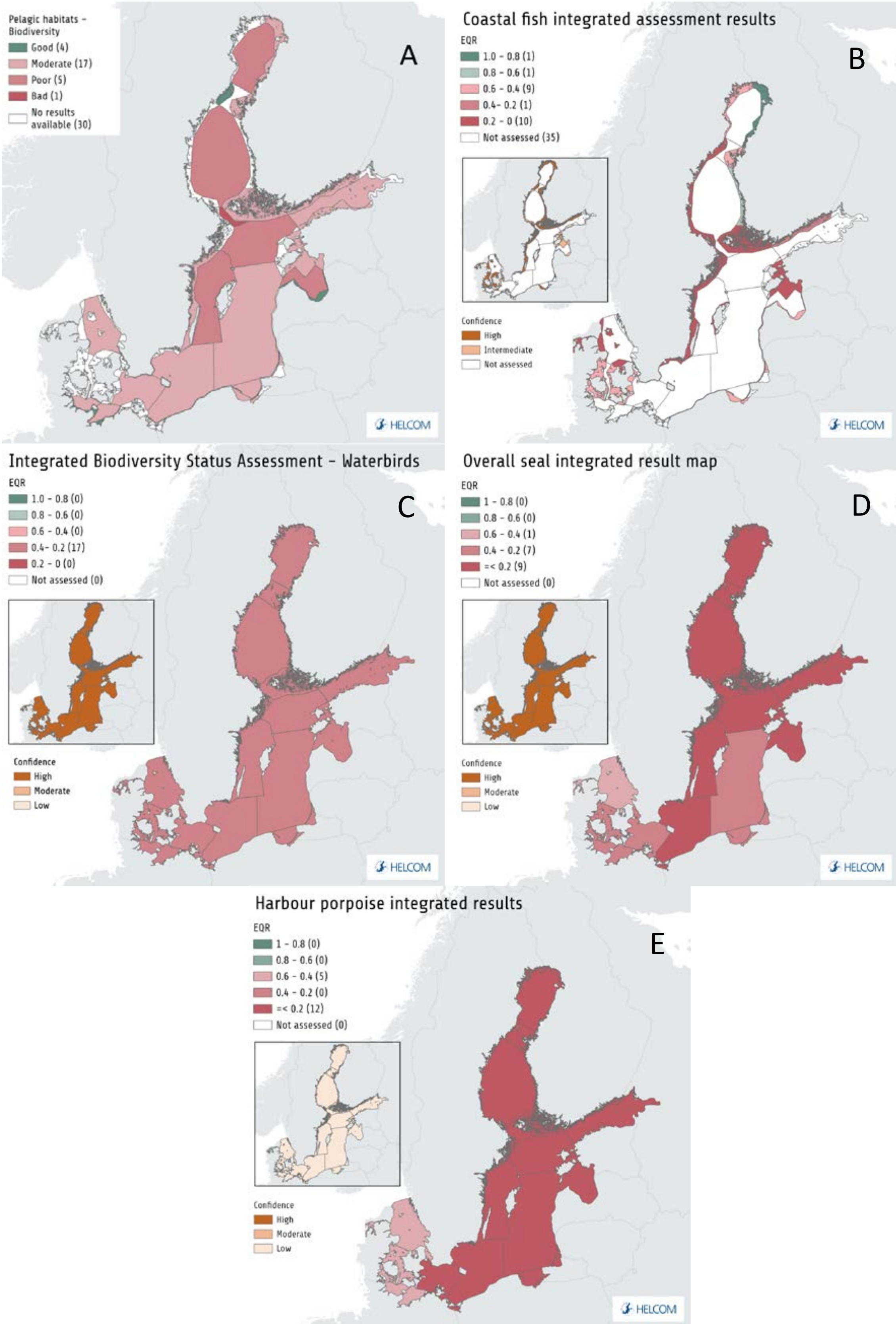

Figure 5. Results of the integrated assessments for the ecosystem components pelagic habitats (A), coastal fish (B), waterbirds (C), seals (D) and harbour porpoise (E). Please note that in the final HOLAS 3 report these maps may have been further adapted to represent regional agreements in relation to the application of management units (i.e. aggregations of individual assessment units).

Approaches for food web assessment (HELCOM BLUES A2.5.2)

The initial idea for an approach to assess food webs was to restructure BEAT and utilize the existing HELCOM indicators to assess trophic guilds. The approach was presented to the HELCOM Correspondence Group on Food webs (CG FOODWEB) meeting 15-16.4.2021 (CG FOODWEB 1-2021), but the meeting considered the approach may be weakly informative and could even lead to misinterpretation. In such an assessment, BEAT could produce estimates of the status of the trophic guilds, but as the food web assessment rather should consider the diversity within trophic guilds and balance between trophic guilds, this approach was not considered viable. Additionally, the limited number of indicators directly reflecting food web aspects restricted the use of this approach as despite there being data and information on a large number of food web components each indicator utilises that data in a specific manner. BEAT requires indicators with defined threshold values for good status. Using the biodiversity indicators, with thresholds set to define biodiversity status, the assessment would in practice only repeat the biodiversity assessment from a trophic guild perspective without providing information on food web functioning. It was also discussed that instead of aiming to describe the integrated status of food web components it is more informative to document changes in food web structure and functioning. Further, the definition of good food web status is not trivial, as food webs can be very dynamic and adapt to prevailing conditions. Thus, the approach to utilize BEAT as a food web assessment was abandoned and the effort of HELCOM BLUES 2.5.2 was instead directed to assisting the work considered most regionally useful under CG FOODWEB.

HELCOM BLUES Task 2.5.2 continued the work to develop the food web evaluation approach for HOLAS 3 in close collaboration with CG FOODWEB. In a series of meetings different methods and food web models were evaluated (CG FOODWEB 1-2021, CG FOODWEB 2-2021, CG FOODWEB 3-2021, CG FOODWEB 4-2021, CG FOODWEB 5-2022). CG FOODWEB considered integrated trend analysis (ITA), to evaluate how the different food web components have changed over time, and the Ecosim with Ecopath (EwE) model, for which food web models are already developed for parts of the Baltic Sea, to be the most promising methods feasible of providing input to HOLAS 3. Both methods were included in the work of CG FOODWEB and contributed to the food web evaluation in HOLAS 3. However, aiming for an evaluation of the whole Baltic Sea was not seen as realistic as these methods are very data demanding. Further, due to the many environmental gradients in the Baltic Sea affecting e.g. species composition and distribution, only case studies in selected basins were considered feasible when taking into account the time frame of HOLAS 3. HELCOM BLUES 2.5.2 contributed to the work of CG FOODWEB by providing a review of the relevance of HELCOM indicators in evaluating food webs and gathering data for a case study in the Bothnian Sea on integrated trend analyses, entering a cooperation with SLU Aqua (Swedish Agricultural University). The cooperation was focussed on approaches that hoped to be the foundations for future regional HELCOM assessments on food webs. This work also contributed to HOLAS 3, more specifically to the chapter on food web evaluation in the thematic assessment of biodiversity. The results of the contributions are briefly presented below.

Review of HELCOM indicators

In the review of indicators the focus was to identify state indicators representing trophic guilds that cover aspects directly related to food web functioning. Thus, abundance indicators for a single species or species groups were not considered if not fully representing the trophic guild. Eight indicators were found to directly address food web aspects (Table 1). An additional eleven indicators included data relevant for food web analyses, e.g. abundance of single species or species groups, but not adequately representing the trophic guild. Combining the species indicators to trophic guilds could be informative, but as the indicators' threshold values are only reflecting the concerned species, an evaluation of the status of the trophic guild would not be meaningful. In order not to repeat the biodiversity assessment, emphasis was put on the indicators covering food web aspects. Nevertheless, it is highly recommendable that the data and information used in the excluded indicators should be developed in future work into dedicated food web indicators, where the focus could be on trophic guilds rather than on species or species groups.

Table 1. Operational HELCOM state indicators and their relevance for food web assessments. Indicators marked with green background colour were included in the food web evaluation for HOLAS 3. Note that for hazardous substances and eutrophication indicators only those considered having relevance are listed.

Indicator name	Includes data relevant for assessing trophic guilds	Directly addressing food web aspects
Biodiversity indicators		
Marine mammals		
Distribution of Baltic seals	No	No
Population trends and abundance of seals	Yes	No
Nutritional status of marine mammals	Yes	Yes
Reproductive status of marine mammals	Yes	Yes
Harbour porpoise distribution	No	No
Harbour porpoise abundance	Yes	No
Waterbirds		
Abundance of waterbirds in the breeding season	Yes	No
Abundance of waterbirds in the wintering season	Yes	No
Fish		
Abundance of coastal fish key functional groups	Yes	Yes
Abundance of key coastal fish species	Yes	No
Size structure of coastal fish	Yes	No
Abundance of salmon spawners and smolt	Yes	No
Abundance of sea trout spawners and parr	Yes	No
Stock size (commercial fish)	Yes	No
Pelagic habitats		
Zooplankton mean size and total stock	Yes	Yes
Seasonal succession of dominating phytoplankton groups	Yes	Yes
Diatom/Dinoflagellate index (pre-core indicator)	Yes	Yes
Benthic habitats		
State of the soft-bottom macrofauna community	Yes	No
Eutrophication indicators		
Cyanobacterial bloom index	Yes	Yes
Hazardous substances indicators		
White-tailed sea eagle productivity	Yes	Yes
Reproductive disorders: Malformed amphipod embryos (supplementary, only FI&SE)	Yes	No

Phytoplankton are the main primary producers in marine ecosystems and constitute the foundation of marine food webs. Phytoplankton are only assessed for a part of the HELCOM region. The core indicator 'Seasonal succession of dominating phytoplankton groups' evaluates changes in the biomass of dominating phytoplankton groups during the seasonal cycle. Since the amounts and ratios of available nutrients change with alterations in species composition, the indicator may provide insight on quality of food for higher trophic levels. The pre-core (i.e. evaluation being tested) indicator 'Diatom/Dinoflagellate index' can give insights on energy pathways, with dinoflagellates mainly fuelling the pelagic system while the larger-sized diatoms enhance energy transport to the benthic system through higher sedimentation. The core indicator 'Cyanobacterial bloom index' reflects symptoms of eutrophication and potential changes in the phytoplankton community, as cyanobacteria commonly dominate during blooms. Extensive cyanobacterial blooms have negative impacts on the biodiversity and functioning of marine ecosystems (Suikkanen *et al.* 2005, Vahtera *et al.* 2007).

Zooplankton function as important mediators of energy in the food web, as they are a link between pelagic primary producers and larger species (e.g. fish and beyond). The core indicator 'Zooplankton mean size and total stock' can give information about the functioning of the link between phytoplankton and fish. Higher abundances of large sized individuals indicate good food web functioning, as this provides high grazing potential on phytoplankton and offers favourable fish feeding conditions (Gorokhova *et al.* 2016). Zooplankton status is evaluated for the central and northern Baltic Sea. In the areas where the zooplankton indicator did not achieve good status, it was the size component that failed, indicating adverse bottom-up conditions in the food web (with the exception of the Bothnian Bay).

Fish are central components of many food webs, where different fish species and trophic guilds contribute to different functions and ecosystem services. Fish is an important food resource for humans but also for other species in the ecosystem. Many species also have important regulatory functions through their feeding. Viable populations of top piscivores (fish that mainly feed on other fish) generally indicate a balanced food web structure, whereas increases in mesopredatory fish (carnivorous mid trophic-level species that hold the dual role of being both prey and predator) could reflect more deteriorated conditions. The abundances of key predator species such as pike (*Esox lucius*) and perch (*Perca fluviatilis*) were assessed in the core indicator 'Abundance of key coastal fish species' whereas the core indicator 'Abundance of coastal fish key functional groups' in the current assessment addressed cyprinids and mesopredatory fish. Fish are affected by a variety of pressures, such as fishing, eutrophication, and habitat deterioration. In addition, climate changes influence for example their reproduction and growth rates.

Marine mammals are top predators in the marine ecosystem and are exposed to changes in the environment and variations in the food web. For grey seal (*Halichoerus grypus*), the core indicators 'Nutritional status of seals' and 'Reproductive status of seals' both signal changes in food supply. The reproduction rate of grey seal has been shown to indicate changes in the Baltic Sea food web spanning over three trophic levels (zooplankton biomass, clupeid fish quality and grey seal reproduction rate, Kauhala *et al.* 2017). Both indicators are assessed at the scale of the whole Baltic Sea, and none of them achieved their threshold value for GES. Long-term trends show improved reproduction rates, whereas nutritional status is decreasing.

Table 1 does not include indicators on benthic habitats or waterbirds (except the 'White-tailed sea eagle productivity'), as it is limited to indicators that can be directly linked to changes in food web processes, or to a clear food-web related mechanism. For the indicator 'White-tailed sea eagle productivity' no data was available for HOLAS 3 at the stage of drafting this report. The HELCOM indicators that reflect food web aspects do not provide a complete picture, however, and do not cover several aspects requested for MSFD assessment (EC 2022). For a more representative evaluation of Baltic Sea food web status, including trophic cascade effects, it is necessary to cover a range of trophic guilds as well as sub-guilds to resolve food web functioning.

Evaluation of HELCOM indicators

Most existing HELCOM biodiversity indicators reflect the status of structural components of the food web. There is a gap in indicators reflecting changes in food web functions and processes, such as productivity and energy transfer, or changes in diversity within trophic guilds or in the balance between trophic guilds, as requested in the MSFD. However, several HELCOM biodiversity core indicators have been suggested to infer information on the status of food webs (Korpinen *et al.* 2022). Existing HELCOM indicators that at least partly address key food web aspects (Tam *et al.* 2017, ICES 2021) are mainly related to pelagic habitats, fish and marine mammals, whereas there is a lack of benthic and water bird indicators relevant for food web assessment. Fish indicators are restricted to coastal areas, leaving out important food web components in open sea areas of the Baltic Sea such as herring, sprat and cod, for which information is obtained from ICES. In the current evaluation, HELCOM indicators reflecting changes in biomass or abundance of species groups were not included as they do not represent full trophic guilds in an adequate way, as requested in the MSFD. Nevertheless, the abundance and biomass of species groups supporting those indicators provide valuable information for future work to develop quantitative food web indicators, which could be used in future assessments.

Table 2 summarizes the evaluation results for selected HELCOM indicators developed under other assessment grounds that are also potentially relevant for indicating food web status. The selection identifies indicators that could directly reflect changes in food web functions or a clear food-web related mechanism. The overall results imply a degraded food web status in the Baltic Sea, based on biodiversity core indicators for primary producers, zooplankton, coastal fish and grey seal during the current assessment period. However, the evaluation results vary to some extent across the Baltic Sea. Improvements since the previous assessment have occurred in a few assessment units. Even within this limited selection, indicator evaluations are lacking for several sub-basins, further emphasizing the need to develop HELCOM indicators, and to extend methods and monitoring to currently unassessed sub-basins.

Table 2. Evaluation results for HELCOM biodiversity indicators that address food web aspects, by HELCOM sub-basins. Green cells indicate that the indicator achieves its threshold value, red cells that the threshold value is not achieved. Yellow cells indicate that the threshold value is achieved partly, either in coastal or open sea area, but not in the assessment unit as a whole).

Indicator	Trophic guild	Criterion	Kattegat	Great Belt	The Sound	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Gdansk Basin	Eastern Gotland Basin	Western Gotland Basin	Gulf of Riga	Northern Baltic Proper	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Seasonal succession of functional phytoplankton groups	Primary producers - phytoplankton	D4C1, D4C2	**	NA	NA			** +	**		-	NA	+			*	**	*	
Diatom/Dinoflagellate index (test indicator)	Primary producers - phytoplankton	D4C2	NA	NA	NA	**	**	NA	NA	NA	** +	NA	NA	NA	NA	NA	NA	NA	NA
Cyanobacterial bloom index	Primary producers - phytoplankton	D4C4	NA	NA	NA	NA	**	**	**	**	**	**	**	**	**	**	**	NA	NA
Zooplankton Mean Size and Total Stock	Secondary producers - Zooplankton	D4C1, D4C2, D4C3	NA	NA	NA	NA	NA	NA	**	**	**	**	**	**	**	** +	**		** -
Abundance of coastal fish key functional groups	Planktivores/Sub-apex predators - Fish	D4C2	NA	NA	NA	NA	NA	NA	*	*	*	* -	*	*	*	*	* +	*	*
Nutritional status of seals	Apex predators - Mammals	D4C4	NA																
Reproduction status of seals	Apex predators - Mammals	D4C4																	
			* = coastal areas only, ** = open sea areas only, +/- = improved/worsened from HOLASII																

Although HELCOM data and indicators exist for most trophic guilds, few explicitly address food web-relevant aspects. For example, the EU MSFD requests that the status of food webs is assessed through a comparison of changes in biomasses between and across guilds (EC 2022). One existing gap is that most HELCOM indicators focus on certain species or taxonomic groups, but do not cover diversity, size distribution or production at the level of the whole trophic guild. However, existing HELCOM monitoring data could support the dedicated development of food web indicators in line with EC (2022), as many trophic guilds are included in the monitoring programs. A potential limitation is that monitoring programs are typically designed by taxonomic groups, whereas food web indicators would need to combine data from several programs, which are not necessarily spatially or temporally compatible. Enhancing the use of existing monitoring data to support food web assessments may require further harmonization of monitoring programs to ensure their spatial and temporal relevance for this purpose.

Case study in the Bothnian Sea on integrated trend analyses for food webs

Integrated trend analyses (ITA) can be used as a way to summarize changes in the ecosystem and to highlight the possible connections between biological ecosystem components, environmental drivers and human-induced pressures. ITA combines several multivariate methods to identify shifts in temporal trends and can support assessments of food webs by addressing changes in the relative abundances within and between trophic guilds as required for the MSFD assessment. A summary of multivariate tools commonly used for ITA was compiled by the ICES WKINTRA workshop (ICES 2018).

HELCOM BLUES 2.5.2 contributed to a case study on food webs using ITA in the Bothnian Sea open sea area by collating data sets on different species or trophic guilds, whereas the analyses were performed by SLU Aqua (Swedish University of Agricultural Sciences). The Bothnian Sea (a Level 2 sub-basin assessment unit) was chosen, as long-term data is available for many biological and environmental components. The results are included as a section of the food web assessment chapter in the HOLAS 3 thematic assessment of biodiversity (to be published and openly accessible after March 2023). Data on phytoplankton, zooplankton, zoobenthos and grey seal abundance were compiled by HELCOM BLUES 2.5.2, whereas herring biomass, environmental data and fish mortality data were compiled by SLU. The biological data was combined into the trophic guilds primary producers (phytoplankton), secondary producers (zooplankton), benthic filterers and benthic predators, planktivores (herring) and apex predators (grey seal) according to ICES guidelines. In this case study constrained principal component analyses (PCO) were combined with chronological clustering and minimum-maximum factor (MAFA) analysis to identify shifts in community composition over time and the underlying common patterns in the data. The explanatory variables used as drivers of change on the ecosystem were nutrient enrichment, climate change and fishing mortality. These methods only consider linear relationships, which gives rise to some uncertainties in interpretations. Below, examples of the results from the case study are presented. Further results and careful interpretations of the results are included in the HOLAS 3 thematic assessment of biodiversity. Furthermore, it is hoped that such approaches could form the basis of future work on food webs in the Baltic Sea region – this case study being the springboard from which discussion on future development and improved data collection can occur.

The case study in the Bothnian Sea identified two overarching changes in the food web configuration when comparing the relative abundances of the trophic guilds over the past 30 years (Figure 6). A shift towards lower biomass of herring, increased abundance of seals and higher benthic biomass occurred in 2005. Increasing biomasses of zooplankton levelled off at the same point in time. Concurrent to the shift in food web structure, fishing pressure on herring and phosphorus levels increased. In 2016, a second shift occurred with further declines in herring biomass and a decline in seal abundance. It needs to be noted that the explanatory variables only account for part of the total variation in the analyses. Further analyses to account for non-linear relationships are ongoing and may reveal additional patterns in the data. The explanatory variables are of differing importance for the trophic guilds, complicating the interpretation.

The analyses also identified shifts within the trophic guilds. For example, in phytoplankton a shift towards higher relative biomass of cyanobacteria and diatoms at the expense of dinophytes and euglenoids took place in 1999. These changes coincided with decreasing salinity and an increase in phosphorus concentrations (Figure 7).

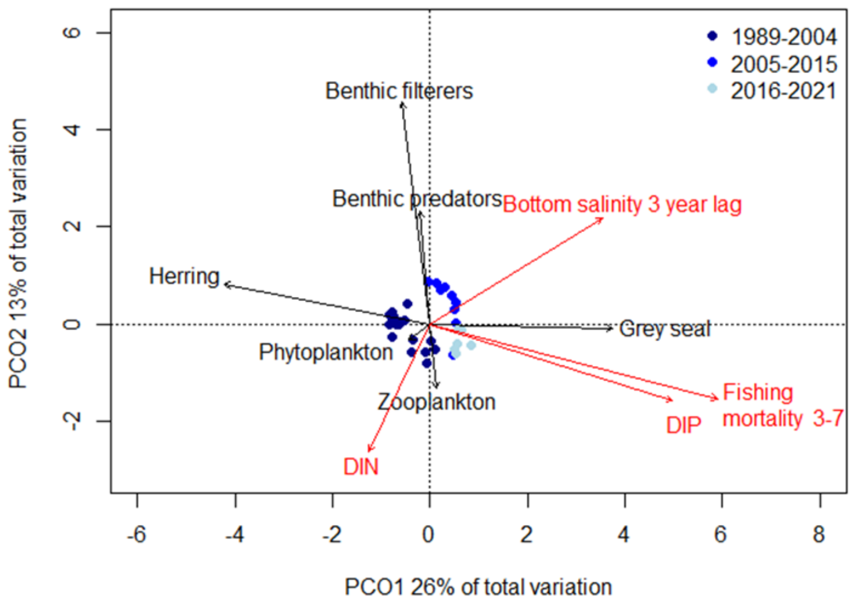

Figure 6. Overarching results from the integrated trend analyses for the Bothnian Sea, using a constrained principal components ordination (PCO) with ln+1 and normalized data. Chronological clusters of years are represented by points of different colours with the year periods shown in the legend, with shifts present at 2004-2005 and 2015-2016. The biplot for first two PCO axes is shown, with the direction of the arrows representing linear relationships between the variables and the length of arrows representing the strength of the relationship. Only explanatory variables remaining after model simplification are shown, dissolved inorganic phosphorus (DIP) and nitrogen (DIN), bottom salinity with a 3-year lag and herring fishing mortality. For example, fishing mortality on 3 to 7 year-old herring is negatively correlated with herring along PCO axis 1, which explains 26% of the variation of all the variables. Along PCO axis 2 benthic filterers and benthic predators show a negative relationship with dissolved inorganic nitrogen (DIN), although only 13% of the variation is explained by this axis.

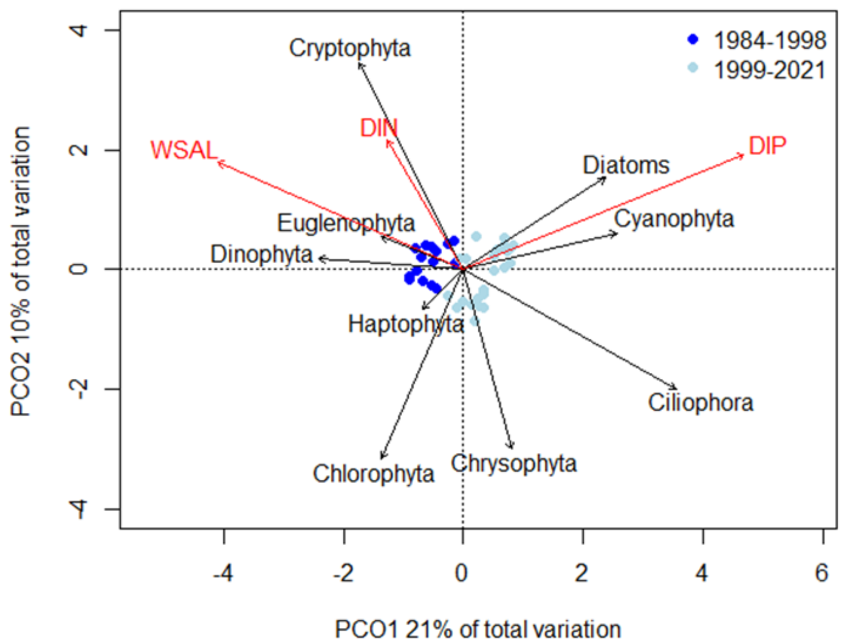

Figure 7. Constrained PCO showing variation over time in the primary producer guild. Chronological clusters of years are represented by points of different colours with the year periods shown in the legend, with a shift at 1998-1999. The biplot for first two PCO axes is shown, with the direction of the arrows representing linear relationships between the variables and the length of arrows representing the strength of the relationship. Only significant explanatory variables are shown, with dissolved inorganic nitrogen (DIN) and phosphorus (DIP), and winter salinity (WSAL) explaining 33% of the variation

in the diagram. Diatoms and Cyanophytes are correlated with DIP and have increased over time, being close to the samples from later years (1999-2021).

As shown above the case study in the Bothnian Sea proved ITA to be suitable for the evaluation of temporal shifts both between and within trophic guilds. To fully take advantage of ITA, long-term data series are needed for a wide range of taxonomic groups, environmental variables and human pressures, which may restrict its usefulness in some areas. In the Baltic Sea, monitoring efforts over the last decades have produced suitable data to cover if not all, at least many of the trophic guilds, further strengthening its potential to inform future food web evaluations.

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