BONUS XWEBS – Taking stock of Baltic Sea food webs: synthesis for sustainable use of ecosystem goods and services

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BONUS XWEBS overview

Food webs are essential for ecosystem functioning, yet resource management rarely incorporates food web knowledge, in part due to the complexity of food webs and the heterogeneous knowledge base. The overarching aims of BONUS XWEBS are to synthesize available knowledge on food webs in the Baltic Sea, to assess how food web knowledge is used in management, and to outline a future vision for this field. At the core of the XWEBS approach is a series of writing workshops, in which we link the expertise from our core consortium (four partner institutes from four Baltic nations, coordinated by the GEOMAR Helmholtz Centre for Ocean Research Kiel) with that of experts as well as stakeholders from around the Baltic Sea.

Why are food webs important?

Food webs are the backbones of healthy ecosystems providing sustainable goods and services to humans. Their function is essential for energy and matter cycling and for healthy populations and interactions of fish, seabirds and marine mammals. Food webs also play an important role in the buffering of global and regional anthropogenic impacts resulting from e.g., human exploitation, eutrophication, hypoxia, climate change, and the introduction of non-indigenous species. Understanding of the complex food web processes in the Baltic Sea will therefore be key to predict futures states of Baltic ecosystems and to manage resources sustainably, now and in the future.

The problem

While information about Baltic Sea food webs has grown strongly over the past decade, the synthesis of this knowledge and its transfer and integration into management strategies is lagging. Also, a number of crucial knowledge gaps remain, including insufficient abilities to forecast future states of food webs. Baltic food web science thus stands at a crossroad: synthesis is needed, and decisions need to be taken on where to direct future research efforts and on how to best apply the new wealth of information in practical management to benefit society.

XWEBS and Baltic Sea food webs

BONUS XWEBS has the objective to address these pressing needs, by

- Synthesizing what we know and need to know about Baltic food webs, their temporal and spatial dynamics, the impacts of bottom-up (e.g., nutrient availability) and top-down (i.e., grazing, predation, harvesting) forces under changing anthropogenic drivers, and their past, present and future states. In these efforts, we are taking stock and synthesizing the wealth of new information available from completed and running BONUS food web projects as well as from outside BONUS.
- Assessing the bottlenecks in the application of this knowledge in assessment and management.
- Providing a future vision for Baltic food web science, including the identification of the methods, tools and concepts required for the incorporation of knowledge into management.

The ultimate goal of these efforts is to guide Baltic food web science in the direction needed to support the sustainable use of ecosystem goods and services in the future.

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Executive Summary

Food webs are an essential part of marine ecosystems, and reflect many aspects of ecosystem dynamics. Ecological indicators, which serve as proxies for multiple ecological processes and represent ecosystem states, are increasingly used to better inform management decisions. Of particular interest are food-web indicators, which are becoming increasingly important as they represent ecosystem services that concern stakeholders and are relevant for regulators. The global uses of these indicators are increasing over time. The current study provides a review of the food web indicators available in the Baltic Sea, and assesses to which extent they meet the requirements stated in the EU Marine Strategy Framework Directive.

Based on the published evidences from multiple sources, we have identified a total of 27 food-web related indicators. A key overarching conclusion is that the number of indicators varies greatly between the food web components. As an example, while for fish twelve indicators have been proposed, for zoobenthos, which is very important in energy flows in the coastal areas, only one indicator is available. Very importantly, several proposed indicators are not primary food web indicators (incl. all for benthos, seals and seabirds).

Regarding trophic guilds, there is at least one (but mostly more than one) primary food-web indicator available for primary and secondary producers, planktivores, sub-apex predators and sub-apex demersal predators, with the latter having the higher number of indicators (9). In contrast, no primary food-web indicators were developed so far for filter feeders, deposit feeders and apex predators. Similarly, for planktonic and benthic planktivores (jellies and mysids, respectively), there are no food-web indicators.

Out of the six taxonomic groups, at least one primary food-web indicator is available for three taxonomic groups (phytoplankton, zooplankton and fish) to cover both MSFD D4 primary criteria (i.e. D4C1 and D4C2), while no primary food-web indicators are available for benthos, seabirds and marine mammals.

From guilds, at least one primary food-web indicator is available for primary and secondary producers, planktovores and sub-apex predators under both criteria (i.e. D4C1 and D4C2). While several of them might not explicitly address the criteria, it can be fixed through developmental work, as the required data should be available.

Most food-web specific indicators are well-supplied with past and ongoing data and have sufficient temporal coverage, and are technically rigorous with generally estimable management threshold targets. However, most of them only partly reflect changes that are caused exclusively by manageable pressures. Furthermore, indicators for plankton are not relevant for management. The latter is primarily due to the peculiar natural geography of the Baltic Sea, that is a semi-enclosed system with biota mostly under abiotic control and strong climatic influence upon the system.

Although the available suite of food web indicators for the Baltic Sea generally and formally allows the assessment of the MSFD requirements re. D4C1, “the diversity (species composition and their relative abundance) of trophic guilds is not adversely affected due to anthropogenic pressures”, and D4C2, “the balance of total abundance between the trophic guilds, is not adversely affected due to anthropogenic pressures”, there are major deficiencies for key trophic groups which play essential roles in the local food webs. The other major

limitation is lack of primary food-web indicators for upper trophic levels. Thus, any model-based approaches should essentially target these major limitations.

Progress and deviations from the original workplan

No deviations from the workplan.

Introduction

The objectives of the workpackage 3 on 'Integration and transformation' are to: 1) contribute to meeting the objectives of the EU Marine Strategy Framework Directive (MSFD) (essentially Descriptor 4), and implementation of the EU Common Fisheris Policy (CFP), and 2) evaluate the applicability of existing food web models in GES-assessments.

This workpackage provides review of the food web indicators proposed under the MSFD (essentially under Descriptor 4 (food webs), but also other Descriptors) and their suggested threshold values, together with associated uncertainties and gaps (Deliverable 3.1 submitted here). Second, it provides a comprehensive review of existing food web models in the Baltic Sea, and select those potentially suited for testing indicators and their threshold values (Deliverable 3.2 submitted at same time as D3.1). Third, we will work further with the sub-set of the selected models and assess their applicability to D4 and the implementation of the EU CFP (Deliverable 3.3 due end of July 2020).

Task 3.1 on 'Review of food web indicators' provides synthesis of the proposed indicators related to food webs, and evaluation of the associated uncertainty and assessment of gaps in relation to MSFD. The review includes the suggested indicators of lower, intermediate and upper trophic levels. This allowed us to obtain a comprehensive picture of the need under MSFD, and to better investigate the applicability of various model approaches to contribute to achieving MSFD objectives. The work will feed into Task 3.3 on ' Evaluation of the model application potential'.

The situation regarding MSFD D4 indicators is made more complex and difficut to analyse by the fact that the Commission Decision 2017 changed the definition of some of the descriptors, including D4, considerably. A lot of indicator development took place in the years following the Commission Decision 2010, and the indicators were developed to fit those requirements, namely, indicators for ' Performance of key predator species using their production per unit biomass (productivity)', 'Large fish (by weight)', and 'Abundance trends of functionally important selected groups/species'. As the Commission Decision 2017 defines Descriptor 4 assessment criteria to be the diversity within and balance between trophic guilds, some of the D4 indicators developed earlier do not fit into this directly.

Methods

This is a desk study, based on the published evidences from multiple sources including research papers in scientific journals, project reports and online publications. The consulted sources include those created only by international organisations, EU-funded projects and international research groups.

The collected information was interpreted in the context of EU Marine Strategy Framework Directive (EC 2007) and the Commission Decision 2017/848 (EU 2017; see Box 1 below), considering also ICES advice on this matter (ICES 2015). The trophic guild /taxonomic group matrix (ICES 2015) was used for mapping the availability of indicators by trophic guilds, with the first activity being allocating specific/example species and/or taxonomic groups by the requested fields (Table 1, white cells).

Final evaluation of the primary food-web indicators for meeting the selected data and management-related criteria (Tam et al. 2017, adjusted) was performed at the three-rank scale (meet criteria fully, partly, or fail to meet).

Box 1. Information on D4 criteria, and associated detailed information for assessment (EU 2017)

COMMISSION DECISION (EU) 2017/848:

D4C1 — Primary: The diversity (species composition and their relative abundance) of the trophic guild is not adversely affected due to anthropogenic pressures.

D4C2 — Primary: The balance of total abundance between the trophic guilds is not adversely affected due to anthropogenic pressures.

D4C3 — Secondary: The size distribution of individuals across the trophic guild is not adversely affected due to anthropogenic pressures.

D4C4 — Secondary (to be used in support of criterion D4C2, where necessary): Productivity of the trophic guild is not adversely affected due to anthropogenic pressures.

Specifications and standardised methods for monitoring and assessment

1. Species composition shall be understood to refer to the lowest taxonomic level appropriate for the assessment.

2. The trophic guilds selected under criteria elements shall take into account the ICES list of trophic guilds and shall meet the following conditions:
(a) include at least three trophic guilds;
(b) two shall be non-fish trophic guilds;
(c) at least one shall be a primary producer trophic guild;
(d) preferably represent at least the top, middle and bottom of the food chain.

Units of measurement: — D4C2: total abundance (number of individuals or biomass in tonnes (t)) across all species within the trophic guild.

Table 1. Trophic guilds exemplified/specified with indicative species or higher taxonomic units contributing significantly to each guild (ICES 2015, amended and adopted).

Guild\taxonomic group	**Phytoplankton**	**Zooplankton**	**Benthos**	**Nekton (excl. warm-blooded)**	**Seabirds**	**Marine mammals**
Primary producers	several groups: diatoms, dinoflagellates, cyanobacteria, chlorophytes, chrysophytes					
Secondary producers		several groups: ciliates, rotifers, cladocerans, copepods				
Filter feeders			e.g. bivalves (*Mytilus edulis*, *Mya arenaria*), cirriped *Amphibalanus improvisus*			
Deposit feeders			e.g. amphipods (*Pontoporeia femorata*, *Monoporeia affinis*), *Macoma balthica*			
Planktivores		*Aurelia aurita*, *Mnemiopsis leidyi*	mysids (*Neomysis integer*, *Mysis* spp.)	sprat, herring	N/A	N/A
Sub-apex pelagic predators				Salmon, perch, pike, pikeperch	e.g. common guillemot, razorbill, great cormorant	N/A
Sub-apex demersal predators			e.g. *Saduria entomon*	cod, turbot	e.g. terns, common eider, velvet scoter	N/A
Apex predators				N/A	white-tailed eagle	grey seal, ringed seal, harbour porpoise

Results

In total we have identified 27 food-web related indicators (Table 2). While for fish (mostly internationally assessed and managed) 12 indicators have been found, the zoobenthos, which is very important in energy flows not only in the coastal areas but also in the open sea (Kiljunen et al. 2020), only one indicator is available. Several indicators are not primary food-web indicators (incl. all for benthos, seals and seabirds; see column labelled 'Comments' in Table 2).

Table 2. List of food-web related indicators developed for and/or applied in the Baltic Sea aggregated by different categories.

No.	Indicator name	Ecosystem attribute	Source	Comments
	PLANKTON (6)			
1	Seasonal succession of dominating phytoplankton groups	Structural	HELCOM 2018a	HELCOM - Primary link to D4
2	Diatom to dinoflagellate ratio	Structural	HELCOM 2018b	HELCOM - Primary link to D4
3	Ratio of total zooplankton biomass to total phytoplankton biomass	Structural/functional	Otto et al. 2018	
4	Ratio of cladocerans to copepods	Structural	Otto et al. 2018	
5	Microphagous mesozooplankton biomass	Structural	Otto et al. 2018	
6	Zooplankton mean size and total stock	Structural	HELCOM 2018c; Gorokhova et al. 2016.	HELCOM - Primary link to D4
	BENTHOS (1)			
7	State of the soft-bottom macrofauna community		HELCOM 2018d	HELCOM - Secondary link to D4
	FISH (12)			
8	Abundance of key fish species *[separate indicator for 1) cod, 2) herring, 3) sprat, and 4) sticklebacks]*	Structural	Torres et al. 2017; Otto et al. 2018	
9	Abundance of coastal fish key functional groups *[separate indicator for 1) piscivores and 2) cyprinids or mesopredators]*	Structural	HELCOM 2018e	HELCOM - Primary link to D4
10	Abundance of salmon spawners and smolt	Structural	HELCOM 2018f	HELCOM - Secondary link to D4
11	Abundance of seatrout spawners and parr	Structural	HELCOM 2018g	HELCOM - Secondary link to D4
12	Proportion of predatory fish	Structural/functional	Coll et al. 2016	IndiSeas programme
13	Biomass of large predatory fish	Structural/functional	Torres et al. 2017; Otto et al. 2018	
14	Biomass of small prey fish	Structural/functional	Torres et al. 2017; Otto et al. 2018	The value of the indicator remains questionable as guild level biomass could include small pelagic and small demersal biomass indicators (ICES 2019)

15	Trophic level of landings	Structural	Coll et al. 2016	IndiSeas programme
16	Catch based Marine Trophic Index	Structural	Coll et al. 2016	IndiSeas programme
17	Mean fish length	Structural	Coll et al. 2016	IndiSeas programme
18	Large fish indicator	Structural	Otto et al. 2018; Zaiko et al. 2017 (BONUS BIO-C3)	
19	Body condition of fish	Functional	Ojaveer et al. 2017 (BONUS INSPIRE); Zaiko et al. 2017 (BONUS BIO-C3)	Can be considered as indicators of the availability of food (ICES 2019)
	SEALS (4)			
20	Distribution of Baltic seals *[separate indicator for 1) grey seal, 2) ringed seal, and 3) harbour seal]*	Structural	HELCOM 2018h	HELCOM - Secondary link to D4
21	Population trends and abundance of seals *[separate indicator for 1) grey seal, 2) ringed seal, and 3) harbour seal]*	Structural	HELCOM 2018i	HELCOM - Secondary link to D4
22	Reproductive status of seals	Functional	HELCOM 2018j	HELCOM - Secondary link to D4
23	Nutritional status of seals	Functional	HELCOM 2018k	HELCOM - Secondary link to D4
	BIRDS (3)			
24	Abundance of wintering waterbirds *[separate indicator for 1) surface, 2) pelagic, 3) benthic, 4) wading and 5) grazing feeders]*	Structural	HELCOM 2018l	HELCOM - Secondary link to D4
25	Abundance of breeding waterbirds *[separate indicator for 1) surface, 2) pelagic, 3) benthic, 4) wading and 5) grazing feeders]*	Structural	HELCOM 2018m	HELCOM - Secondary link to D4
26	White-tailed eagle productivity	Functional	HELCOM 2018n	Can be considered as indicators of the availability of food (ICES 2019); HELCOM - Secondary link to D4
	VARIA (1)			
27	Number of drowned mammals and waterbirds in fishing gear	Structural	HELCOM 2018o	HELCOM - Secondary link to D4

There is at least one (but mostly more than one) primary food-web indicator available for primary and secondary producers, planktivores, sub-apex predators and sub-apex demersal predators, with the latter having the higher number of indicators (9). No primary food-web indicators were developed so far for filter feeders, deposit feeders and apex predators (Table 3; orange text). For planktonic and benthic planktivores (jellies and mysids, respectively), there are no food-web indicators.

Table 3. Availability of indicators by guilds and taxonomic groups. Numbering and naming of indicators as in Table 2. Grey cells - indicator not required.

Guild\Taxonomic group	Phytoplankton	Zooplankton	Benthos	Nekton (excl. warm-blooded)	Seabirds	Marine mammals
Primary producers	1.Seasonal succession of dominating phytoplankton groups; 2.Diatom to dinoflagellate ratio					
Secondary producers		3.Ratio of total zooplankton biomass to total phytoplankton biomass; 4.Ratio of cladocerans to copepods; 5.Microphagous mesozooplankton biomass; 6.Zooplankton mean size and total stock				
Filter feeders			7.State of the soft-bottom macrofauna community			
Deposit feeders			As above			
Planktivores		none	none	8.Abundance of key fish species; 14.Biomass of small prey fish; 15.Trophic level of landings: 16.Catch based Marine Trophic Index; 17.Mean fish length	N/A	N/A
Sub-apex pelagic predators				9.Abundance of coastal fish key functional groups 10.Abundance of salmon spawners and smolt; 11.Abundance of seatrout spawners and parr	24.Abundance of wintering waterbirds 25.Abundance of breeding waterbirds 27.Number of	N/A

					drowned waterbirds in fishing gear	
Sub-apex demersal predators			7.State of the soft-bottom macrofauna community	8.Abundance of key fish species ; 9.Abundance of coastal fish key functional groups; 12.Proportion of predatory fish; 13.Biomass of large predatory fish; 15.Trophic level of landings; 16.Catch based Marine Trophic Index; 17.Mean fish length; 18.Large fish indicator; 19.Body condition of fish	24.Abundance of wintering waterbirds; 25.Abundance of breeding waterbirds; 27.Number of drowned waterbirds in fishing gear	N/A
Apex predators				N/A	26.White-tailed eagle productivity	20.Distribution of Baltic seals; 21.Population trends and abundance of seals; 22.Reproductive status of seals; 23.Nutritional status of seals; 27.Number of drowned mammals in fishing gear

* Not a primary food-web indicator. Those cells are colored in red in the D4C1 and D4C2 spreadsheets (see tables below).

Out of the six taxonomic groups, at least one primary food-web indicator is available for three taxonomic groups (phytoplankton, zooplankton and fish) to cover both MSFD D4 primary criteria (i.e. D4C1 and D4C2), while no primary food-web indicators are available for benthos, seabirds and marine mammals. From guilds, at least one primary food-web indicator is available for primary and secondary producers, planktovores and sub-apex predators under both criteria (i.e. D4C1 and D4C2; Tables 4 and 5). While several of them might not explicitly address the criteria, it can be fixed through developmental work, as the required data should be available.

Table 4. Availability of indicators for MSFD D4C1 [The diversity (species composition and their relative abundance) of the trophic guild is not adversely affected due to anthropogenic pressures]. Green: at least one primary food-web indicator available per guild. Red: no primary food-web indicator available. Indicator in grey: example/potential indicator, requires further developmental work to address D4C1.

Guild\Taxonomic group	Phytoplankton	Zooplankton	Benthos	Nekton (excl. warm-blooded)	Seabirds	Marine mammals
Primary producers	1.Seasonal succession of dominating phytoplankton groups 2.Diatom to dinoflagellate ratio					
Secondary producers		4.Ratio of cladocerans to copepods 5. Microphagous mesozooplankton biomass				
Filter feeders						
Deposit feeders						
Planktivores				8.Abundance of key fish species	N/A	N/A
Sub-apex pelagic predators				9.Abundance of coastal fish key functional groups		N/A
Sub-apex demersal predators				8.Abundance of key fish species 9.Abundance of coastal fish key functional groups 13.Biomass of large predatory fish		N/A
Apex predators				N/A		

Table 5. Availability of indicators for MSFD D4C2 [The balance of total abundance between the trophic guilds is not adversely affected due to anthropogenic pressures]. For details and legend, see Table 4.

Guild\Taxonomic group	Phytoplankton	Zooplankton	Benthos	Nekton (excl. warm-blooded)	Seabirds	Marine mammals
Primary producers	3.Ratio of total zooplankton biomass to total phytoplankton biomass					
Secondary producers		3.Ratio of total zooplankton biomass to total phytoplankton biomass 6. Zooplantkon mean size and total stock				
Filter feeders						
Deposit feeders						
Planktivores				8.Abundance of key fish species 14. Biomass of small prey fish	N/A	N/A
Sub-apex pelagic predators				12.Proportion of predatory fish		N/A
Sub-apex demersal predators				12.Proportion of predatory fish		N/A
Apex predators				N/A		

Most food-web specific indicators are well-supplied with past/ongoing data and have sufficient temporal coverage, are technically rigorous with generally estimable management threshold targets. However, most/all only partly reflect changes that are only caused by manageable pressures and indicators for plankton are not relevant for management (Table 6). The latter is primarily due to a peculiar natural geography of the Baltic Sea (semi-enclosed system with biota mostly under abiotic control) and strong climatic influence upon the system.

Table 6. Rank-based evaluation of primary food-web indicators for meeting the selected data and management-related criteria (Tam et al. 2017, adjusted). Green: generally meets criteria; orange – meets criteria only partly, red – fails to meet criteria).

Indicator no. and name	**Availability of underlying data**			**Quality of underlying data**		**Management**	
	Existing and ongoing data	Relevant spatial coverage	Relevant temporal coverage	Indicators technically rigorous	Reflects changes in ecosystem component that are caused by manageable pressures	Relevant to management	Management thresholds targets are estimable
PLANKTON							
1. Seasonal succession of dominating phytoplankton groups							
2. Diatom to dinoflagellate ratio							
3. Ratio of total zooplankton biomass to total phytoplankton biomass							
4. Ratio of cladocerans to copepods							
5. Microphagous mesozooplankton biomass							
6. Zooplankton mean size and total stock							
FISH							
8. Abundance of key fish species							
9. Abundance of coastal fish key functional groups							
12. Proportion of predatory fish							
13. Biomass of large predatory fish							
14. Biomass of small prey fish							

Recommendations

Although the available suite of food web indicators for the Baltic Sea generally and formally allows the assessment of the MSFD requirements re. D4C1 – "The diversity (species composition and their relative abundance) of the trophic guild is not adversely affected due to anthropogenic pressures", and D4C2 – "The balance of total abundance between the trophic guilds is not adversely affected due to anthropogenic pressures", there are major deficiencies for key trophic groups which play essential roles in the local food webs. This is essentially valid for macrozoobenthos, which is the driving force for food web interactions in both the shallow coastal areas and open sea. The other major limitation is lack of primary food-web indicators for upper trophic levels. Thus, the model-based approaches should essentially target these major limitations. Further work is needed to harmonize the indicator work done since 2010 to fit with the Commission Decision 2017 criteria regarding food webs.

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