Zooplankton mean size and total abundance

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Contents

Key message

Zooplankton mean size has declined in most areas since 1980s, as a result of both the increase of the biomass of small zooplankton taxa – as a consequence of eutrophication – and decrease of the biomass of copepods – as a consequence of higher predation by zooplanktivorous fish (sprat and herring) and/or altered environmental conditions (e.g. decreased salinity, increased temperature and deep water hypoxia). The results indicate that the food web structure is not optimal in most of the studied sub-basins, whereas in the Eastern Baltic Proper and Bothnian Sea the zooplankton community indicates a better food web structure.

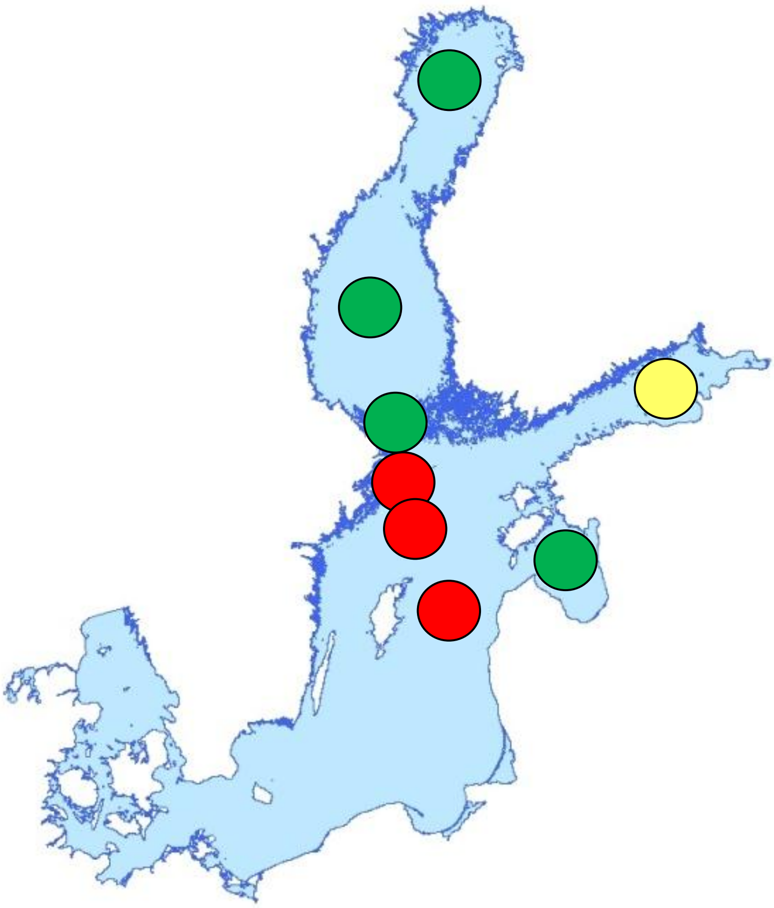

Figure 1. *The state of zooplankton community in the Baltic Sea in 2010. The green circles indicate that both the mean size and biomass meet GES. Yellow circles indicate that one of the two parameters fails to meet GES. Red circles indicate that both of the parameters fail to meet GES boundaries.*

Description of the indicator

In this proposed core indicator for food web structure, the mean zooplankter size (MeanSize) is presented as a ratio between the total zooplankton abundance (TZA) and total biomass (TZB). This metrics is complemented with an absolute measure of total zooplankton stock, TZA or TZB, to provide a two-dimensional index, MSTS (Mean Size and Total Stock). This represents a synthetic descriptor of zooplankton community structure (by MeanSize) and the stock size (by TZA or TZB). Indeed, abundant zooplankton with high mean individual size would represent both favorable fish feeding conditions and high grazing potential, whereas all other combinations of zooplankton stock and individual size would be suboptimal and imply food web limitations in terms of energy transfer from primary producers to higher trophic levels and poorer food availability for planktivorous fish.

There are a number of studies in the Baltic Sea and worldwide providing a sufficient empirical and theoretical for this rationale. For example, good fish-feeding conditions in the Baltic are characterized by high absolute or relative abundance of large-bodied copepods and/or cladocerans (Rönkkönen et al. 2004).

Determination of good environmental status

Good environmental status was based on a reference period within existing time series that defines a reference state when the food web structure was not measurably affected by eutrophication and/or representing good fish feeding conditions.

The reference period for the zooplankton indicator was selected when

1. GES for chlorophyll a concentrations and water transparency, that have been specifically defined for the sub-basins of the Baltic Sea (HELCOM 2009), were in GES , and
2. Growth zooplanktivorous fish (weight-at age. WAA) and population size were relatively high.

Recently, Ljunggren et al. (2010) have demonstrated that WAA could be used as a proxy for zooplankton food availability and related fish feeding conditions to fish recruitment in coastal areas of the northern and central Baltic Sea.

The change-point analysis of zooplankton communities in the data sets in question is also being conducted to address issues of the regime shift(s) for reference period assessment. See Table 1 and Figure 4 for the data coverage and reference periods derived using principle outlined above.

Assessment units

The assessment units for the indicator are the Baltic sub-basins.

Links to anthropogenic pressures

The proposed core indicator responds to eutrophication and pressures causing other changes in the food web, such as fishing. The regression analysis conducted during the on-going evaluation procedure, confirm that all metrics in questions (MeanSize, TZA and TZB) change significantly when both Chl-a and WAA values are outside of their reference conditions. See also details below.

Policy relevance

The proposed core indicator is among the few indicators able to assess the structure of the Baltic Sea food web with known links to lower and higher trophic levels. Assessments on the structure and functioning of the marine food web are requested by the Baltic Sea Action Plan (BSAP) and the EU Marine Strategy Framework Directive (MSFD).

The BSAP ecological objective ‘Thriving and balanced communities of plants and animals’ calls for balanced communities, which has a direct connection to the food web structure. The background document to the Biodiversity segment of the BSAP describes a target for this ecological objective as ‘By 2021 all elements of the marine food webs, to the extent that they are known, occur at natural and robust abundance and diversity’.

The EU MSFD lists a specific qualitative descriptor for the food webs: ‘All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.’

There are two associated MSFD criteria for assessing the food webs which are specifically relevant for the proposed zooplankton core indicator: the criterion 4.1, which calls for productivity of key trophic groups, and the criterion 4.2, which calls for the size and abundance of food web components.

What is the status of zooplankton in the Baltic Sea?

Current status of the Baltic Sea zooplankton

The status of the Baltic Sea pelagic food web for the data sets available is under evaluation in conjunction with indicator testing and establishing reference conditions for zooplankton, and the data compilation has not yet been finalized. Preliminary results can, however, be seen in Figures 1 and 2.

In the Bothnian Bay (Figure 2 A), the zooplankton community has not changed considerably since 1979, as seen in the overlay of z scores in the matrix. The recent years (2005–2010) do not, however, rank well in comparison to the conditions in 1980s and early 1990s. Nonetheless, the status is considered good.

In the Bothnian Sea (Figure 2 B), the zooplankton community indicates fairly good food web structure in the recent years, although the zooplankton mean size is rather small.

The zooplankton community in the Åland Sea (Figure 2 C) fails to fall within the boundaries of 'good food web structure'. The zooplankton mean size is smaller than the threshold for good fish-feeding conditions and the biomass values are too low.

In the Gulf of Finland (Figure 2 D), the zooplankton mean size is below the threshold of good fish-feeding conditions, whereas the zooplankton biomass was adequate.

In the northern Baltic Proper (Figures 2 E and F), the food web has not been in GES during the most of the recent decade (2000–2011). The mean size of the zooplankton community has decreased since 1980s but appear to recover in Askö after 2007.

In the Eastern Baltic Proper (Figure 2 G) the zooplankton mean size indicates good fish feeding conditions during most of the recent years (2004–2009), but the biomass is too low in 2004–2005 and 2010. GES was experienced in 2007–2009.

The biomass and mean size of zooplankton community in Gulf of Riga (Figure 2 H) indicate that the recent years have been optimal for food web structure.

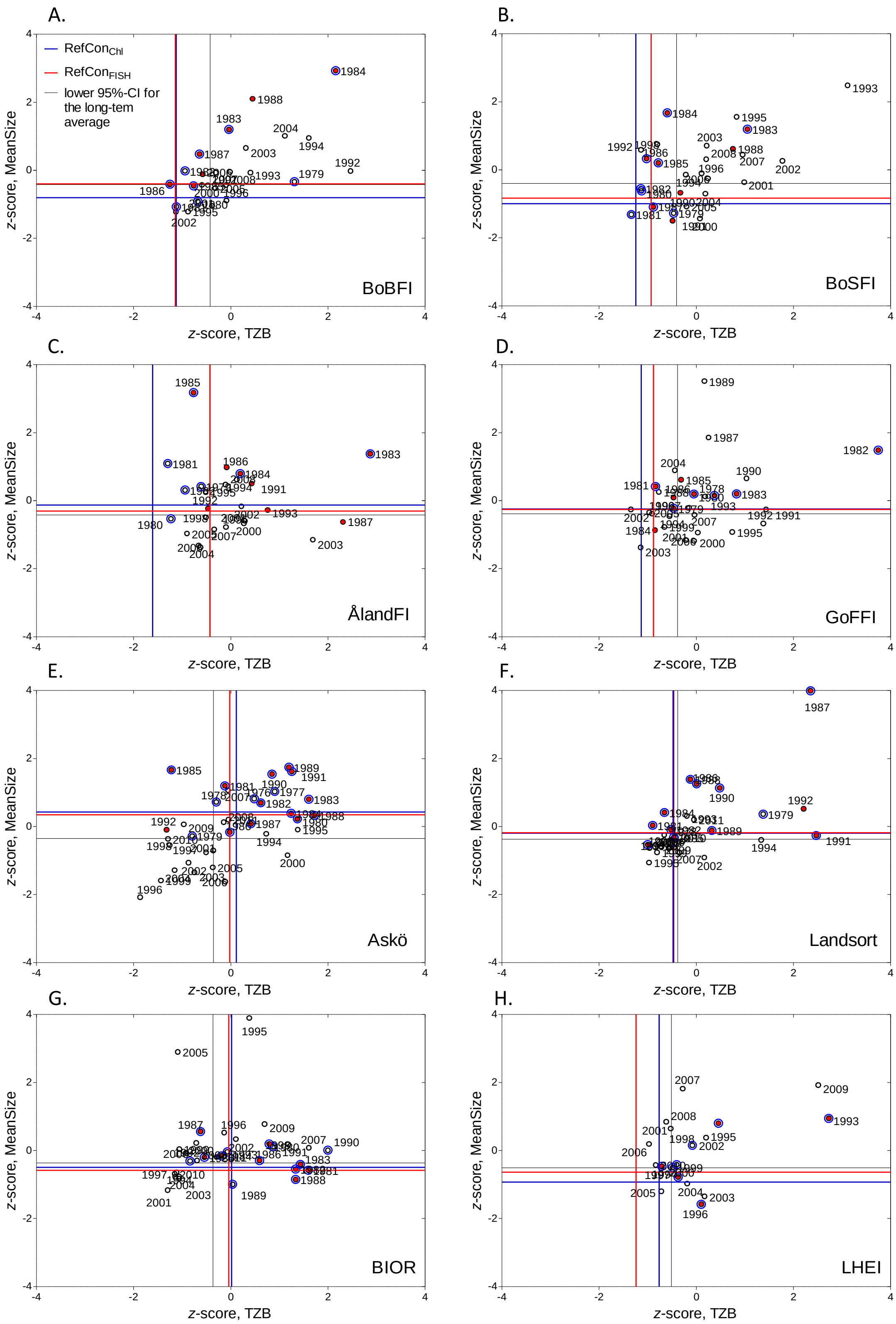

Figure 2. *Performance of MSTS index, which integrates mean size and total biomass of zooplankton (as z-scores), for datasets with >18 years of observations. Reference conditions $RefCon_{Chl}$ and $RefCon_{Fish}$ were derived based on the time periods shown in Fig. 4; see text for details. See also Table 1 for abbreviations and origin of the data sets. Blue and red symbols and lines show data and their 99 % confidence intervals for zooplankton under reference periods for non-*

eutrophied systems ($RefCon_{Chl}$) and good fish feeding conditions ($RefCon_{Fish}$), respectively. Black symbols show the same type of data outside of the reference periods.

How the zooplankton indicator describes the Baltic environment

In aquatic ecosystems, a hierarchical response across trophic levels is commonly observed; that is, higher trophic levels may show a more delayed response or a weaker response to eutrophication than lower ones (Hsieh et al. 2011). Therefore, alterations in planktonic primary producers and primary consumers have been considered among the most sensitive ecosystem responses to anthropogenic stress, including eutrophication (Schindler 1987; Stemberger and Lazorchak 1994).

Role of zooplankton in the ecosystem

Zooplankton taxa often have different preferences for trophic state and are of different value as prey for zooplanktivores, because of taxa-specific variations in size, escape response, and biochemical composition. In the Baltic Sea, alterations in fish stocks and regime shifts received a particular attention as driving forces behind changes in zooplankton (Casini et al. 2009). With the position that zooplankton has in the food web – sandwiched between phytoplankton and fish (between eutrophication and overfishing) – data and understanding of zooplankton are a prerequisite for an ecosystem approach to management.

With respect to the eutrophication-driven alterations in the food web structure, it has been suggested that with increasing nutrient enrichment of water bodies, total zooplankton abundance or biomass increases (Hanson and Peters 1984), mean size decreases (Pace 1986), and relative abundance of large-bodied zooplakters (e.g., calanoids) generally decrease, while small-bodied forms (e.g., cyclopoids, small cladocerans, rotifers, copepod nauplii, and ciliates) increase (Pace and Orcutt 1981).

Total zooplankton abundance and biomass

Herbivorous zooplankton stocks in lakes and estuaries have been reported to correlate with chlorophyll a and phytoplankton biomass (Pace 1986; Nowaczyk et al. 2011; Hsieh et al. 2011), but also with total phosphorus (Pace 1986). In general, total zooplankton stocks increase with increasing eutrophication, which is most cases is a result of increase in small herbivores (Gliwicz, 1969; Pace 1986; Hsieh et al. 2011). Both parameters have been recommended as primary 'bottom-up' indicators (Jeppesen et al. 2011).

In most areas of the Baltic Sea, copepods contribute substantially to the diet on zooplanktivorous fish, such as sprat and young herring, and fish body condition and WAA have been reported to correlate positively to abundance/biomass of copepods (Cardinale et al. 2002, Rönkkönen et al. 2004). Copepods in the study area are mostly herbivorous, therefore their biomass is indirectly impacted by eutrophication via changes in primary productivity and phytoplankton composition, whereas direct impacts are expected mostly from predation, and, to a lesser extent, from introduction of synthetic compounds (at point sources) and invasive species (via predation). Eutrophication favours, particularly, small-sized phytoplankton and detritus production, which, in turn, is particularly accessible for microphagous filtrators, rotifers, herbivorous cladocerans, and nauplial stages of copepods. These are also the conditions promoting microbial loop dominance in the energy pathways within the food web.

Zooplankton abundance and biomass are affected – both positively and negatively – by climatic changes and natural fluctuations in thermal regime and salinity.

Mean zooplankter size

During the past decades, it has become widely accepted that a shift in zooplankton body size can dramatically affect water clarity, rates of nutrient regeneration and fish abundances (Moore and Folt 1993). Although these shifts can be caused by a variety of factors, such as increased temperatures (Moore and Folt 1993; Brucet et al. 2010), eutrophication (Yan et al. 2008, Jeppesen et al. 2000), fish predation (Mills et al. 1987; Yan et al. 2008, Brucet et al. 2010), and pollution (Moore and Folt 1993), the resulting change implies a community that is well adapted to eutrophic conditions and provides a poor food base for fish. It has been recommended to use zooplankton size as an index of predator-prey balance, with mean zooplankton size decreasing as the abundance of zooplanktivorous fish increased and increasing when the abundance of piscivores increased (Mills et al. 1987).

Figure 2 shows how the mean size of the zooplankton community has negative correlation with the abundance of cyanobacteria, showing the relationship between eutrophication and the proposed zooplankton core indicator.

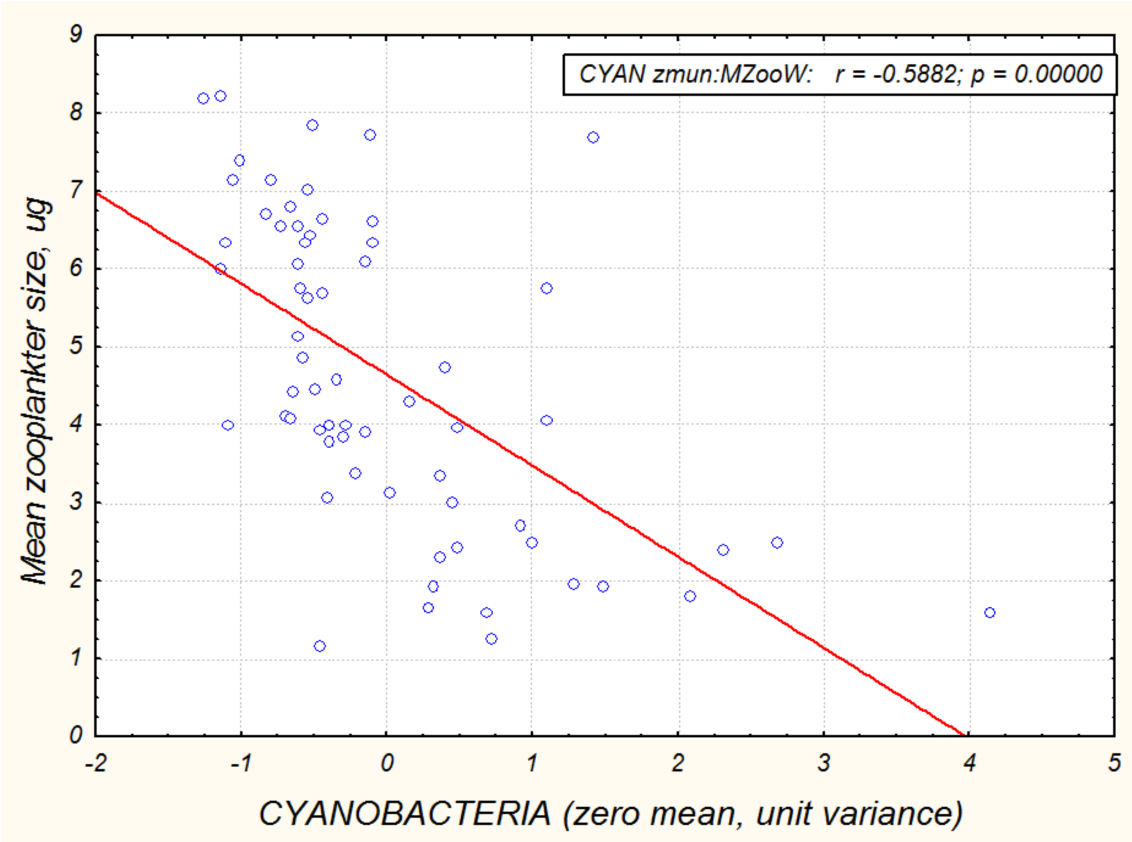

Figure 2. *Relationship of the mean zooplankter size and the abundance of cyanobacteria (Laura Uusitalo, unpublished).*

Metadata

Data source

National monitoring programmes with HELCOM COMBINE parameters and methods.

Description of data

Due to considerable variations in sampling frequency between the monitoring programmes and datasets, the data are restricted to the summer period (June-September) as the most representative in the datasets. This is also the period of the highest plankton productivity as well as predation pressure on zooplankton (Johansson et al. 1993; Adrian et al. 1999).

Assessment units

19 Baltic Sea sub-basins.

Geographic coverage

Zooplankton monitoring stations are generally found from every Baltic Sea sub-basin. Most of the stations are offshore but also coastal stations have been included.

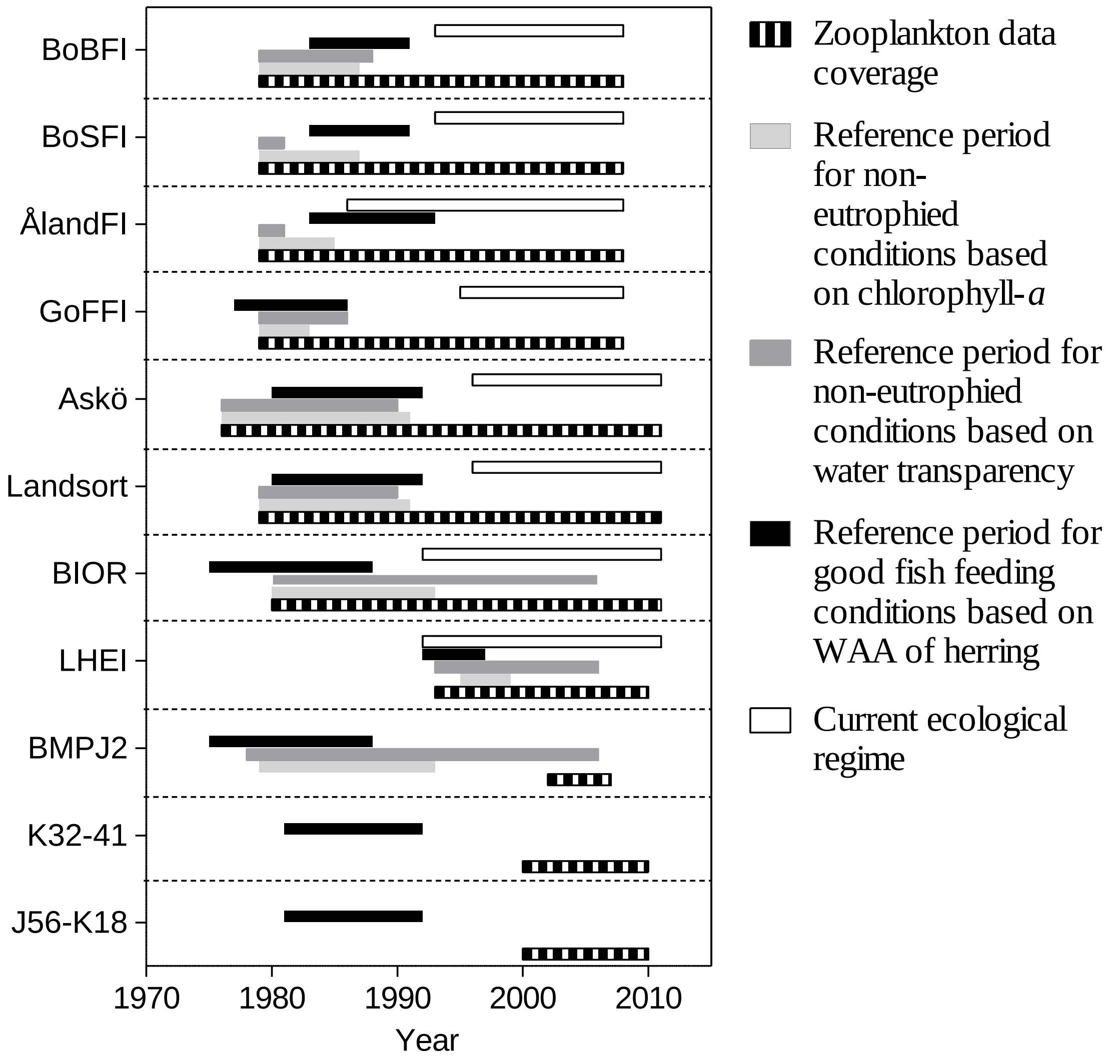

Figure 3. *Time periods for zooplankton data coverage and reference conditions for ecosystem not affected by eutrophication according to HELCOM (2009) and providing adequate environment for fish feeding and growth (Rahikainen and Stephenson 2004; Rönkkönen et al. 2004). As eutrophication criteria, chlorophyll-a temporal development in the Baltic Sea open sub-basins (Fig. 2.13 in HELCOM 2009) and water transparency (Fig. 2.20 in HELCOM 2009) were used. Current ecological regime for each particular dataset was determined by change-point-analysis, see text for details. See also Table 1 for abbreviations and origin of the data sets.*

Recommendations for monitoring

Zooplankton should be monitored in all the sub-basins of the Baltic Sea in order to assess the 19 assessment units. As the core indicator assesses particularly offshore food web, the stations should situate in the offshore.

Temporal coverage

Time series of zooplankton are of different lengths. Table 1 shows the time series used for this indicator.

Methodology and frequency of data collection

According to HELCOM guidelines for biological monitoring (HELCOM 1988), zooplankton were collected by vertical tows from either ~5 m above the bottom to the surface (shallow stations, ≤ 30 m) or in depth layers (deep stations, ≥ 30 m) as designed and specified by regional monitoring programmes. Most commonly, a 100 µm WP2 net (diameter 57 cm) equipped with a flow meter was used; see, however, Table 1 for details on deviations in sampling methods in different laboratories.

Methodology and data analyses

Samples were preserved upon collection in formalin and analyzed within the respective monitoring programmes (Table 2). In most laboratories, copepods were classified according to species, developmental stage (copepodites CI-III and CIV-V classified as younger and older copepodites, respectively), and sex (adults); naupliar stages were not separated. Rotifers and cladocerans were identified to the lowest possible taxonomic level; moreover, the latter were classified according to sex, and females as ovigerous or non-ovigerous. Biomass was estimated using individual wet weights recommended by Hernroth (1985); for species not included in this list, either measured or calculated individual weights based on length measurements were used.

Determination of GES boundaries

GES is met when

- there is a high contribution of large-sized individuals (mostly copepods) in the zooplankton community that efficiently graze on phytoplankton and provide good-quality food for zooplanktivorous fish, and
- the abundance of zooplankton is at the level adequate to support fish growth and exert control over phytoplankton production.
- The GES will be determined for two parameters: the zooplankter mean size and the total abundance or biomass of the zooplankton community.
- The reference period for the mean size: the GES boundary is at lower 95 % CI of the mean during a time period when zooplankton is adequate to support high growth of zooplanktivorous fish (measured as weight at age [WAA] and high stock size). The high WAA values in combination with relatively high stock abundance (to avoid density-dependent WAA) indicate good growth of the herring stock because of high abundance of high-quality food (usually large amount of copepods) and, thus, a good reference period with regard to the fish-feeding conditions.
- The reference period for the total zooplankton abundance (or biomass) reflects a time period when effects of eutrophication are low, defined as ‘acceptable’ chlorophyll a concentration (i.e. EQR > 1) and hence eutrophication-related food web changes are negligible.

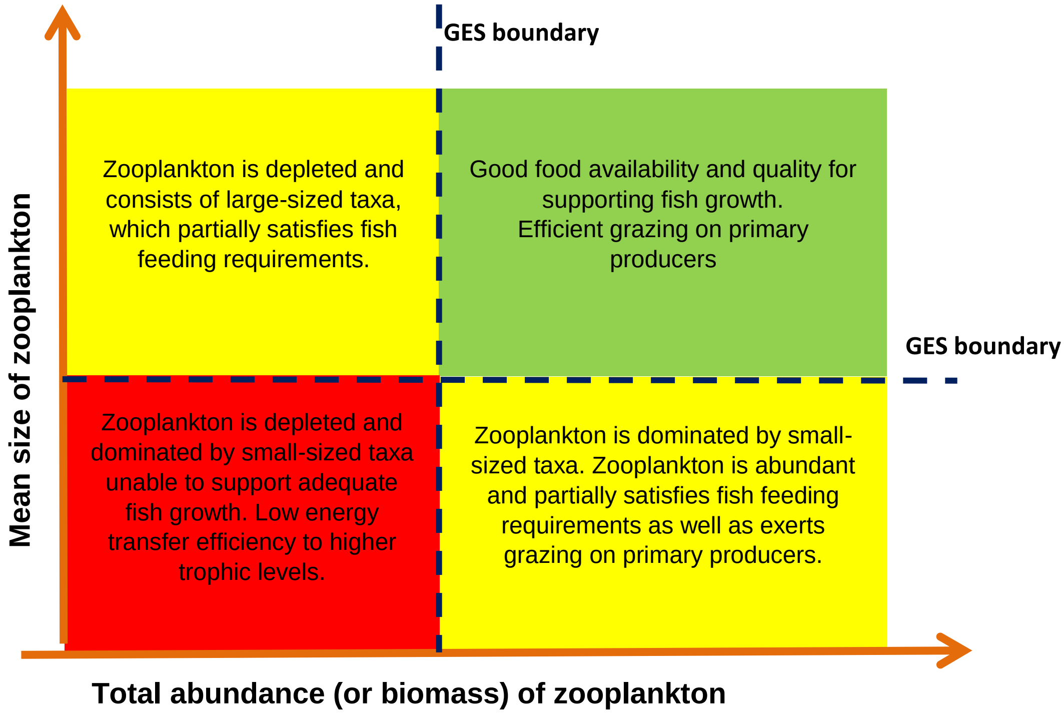

Figure 4 *A schematic diagram of the use of the indicator. The green area represents GES condition, yellow areas represent sub-GES conditions where only one of the two parameters is adequate and the red area represents sub-GES conditions where both parameters fail.*

Strengths and weaknesses of data

Strengths

Scientific evidence of the role of zooplankton in the middle of primary production and zooplanktivorous fish.

Weaknesses

GES boundaries may require re-iteration. Zooplankter size is in most cases calculated based on default constants. Direct measurements by size scanners would be needed.

Further work required

Evaluation of the monitoring programme: to provide geographically and temporally adequate data.

Shift to automatic zooplankton size scanners.

Testing of the GES boundaries in all Baltic Sea areas.

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View data

Data table 1. *Details for data sets used for indicator testing and calculating GES values; deviations from sampling methods outlined in the HELCOM guidelines are provided*.

Dataset code	Area	Monitoring station(s), geographic coordinates, maximal sampling depth (m)	Time period (gaps)	Sampling frequency[a]	Deviations in sampling methods from HELCOM guidelines
ASKÖ	Northern Baltic proper	B1 (N 58° 48' 19, E 17° 37' 52), 40 m	1976-2010 (1990, 1993)	8-10	Water bottle[b] (1983-1988), otherwiseWP2 with 90-µm mesh size [c]
GoF FI	Gulf of Finland	LL7 (N 59.5101, E 24.4981), 95 m	1979-2010 (1999, 2009)	1[d]	none
GoF FI	Gulf of Finland	LL3A (N 60.0403, E 26.8020), 60 m	1979-2010 (1989,1990,1999, 2000, 2009)	1[d]	none
Åland FI	Åland Sea	F64 (N 59.5101, E 24.4981), 280 m	1979-2010 (1988-1990,1997, 1999, 2009)	1[d]	none
BoS FI	Bothnian Sea	SR5 (N 61.0500, E 19.3478), 125 m	1979-2010 (1989,1997, 1999, 2009)	1[d]	none
BoS FI	Bothnian Sea	US5B (N 62.3517, E 19.5813),116 m	1980-2010 (1989,1997, 1999, 2009)	1[d]	none
BoB FI	Bay of Bothnia	BO3[e] (N 64.1812, E 22.2059), 100 m	1979-2010 (1989, 1990,1997-1999, 2009)	1[d]	none
BoB FI	Bay of Bothnia	F2[f] (N 65.2302, E 23.2776), 90 m	1979-2010 (1983, 1989, 1990,1997-2000, 2009)	1[d]	none
LHEI	Gulf of Riga	24 stations: N 56° 58,8', E 23° 44,6' to N 57° 44,8', E 24° 18,9'; 7 to 55 m	1993-2010	10-39 [g]	WP2 net is not equipped with a flowmeter. Filtered volume is calculated without adjusting for net filtration efficiency.
K32/41	Southeastern Baltic proper, shallow coastal area	4 stations: N 55° 18.7' E 20° 57.4' to N 56° 01.7' E 21° 01.0'; 12 to 15 m	2000-2010	2-4[d,g]	WP-2 with 108 µm mesh size (1998-2005) and Apstein net with 100 µm mesh size (2009-2011)

J56/K18	Southeastern Baltic proper, deep coastal area	6 stations: N 55° 31.2' E 20° 33.8' to N 56° 01.7' E 20° 50.0'; 25 to 62 m	2000-2010	3-6 [d,g]	Same as above
BMPJ2	Southeastern Baltic proper, open sea	46 (N 56° 01. 2' E 19° 08. 8'), 120 m	2000-2007	1[d]	Same as above

a) if not specified otherwise, this frequency is a number of samples collected during June-September;
b) 23-L water bottle was used to sample water column every 5 m (bottom to surface) and pooled for counting using 90- µm sieve;
c) WP2 nets with mesh size of 90 and 100 µm were compared in 2003 and found to provide statistically similar sampling efficiencies towards all relevant taxa (Gorokhova, pers. observations); d) August; e) or stations BO3N and/or BO3S located in a very close proximity; f) or station F2A located in a very close proximity; g) total for all stations

Data table 2. *Details for zooplankton analysis methods employed in different laboratories.*

Dataset code	Institute, country	Preservation	Sub-sampling equipment	Magnification, number of specimens counted	Biomass assessment
ASKÖ	Systems Ecology, Stockholm University, Sweden	Buffered (di-sodium tetraborate) formalin, 4 %	Kott splitter [a]	×80, ≥500	Standard stage-and taxon-specific individual weights [b,c]
GoF FI Åland FI BoS FI BoB FI	Finnish Institute of Marine Research/Finnish Environment Institute, Finland	Buffered (hexamine) formalin, 4 %	Folsom splitter	×80, ≥500	Standard stage-and taxon-specific individual weights [b,c]
LHEI	Latvian Institute of Aquatic Ecology	Buffered (di-sodium tetraborate) formalin, 4 %	Stempel-pipette (2 mL)	×32-128, ≥300	Standard stage-and taxon-specific individual weights [c, d]
K32/41 J56/K18 BMPJ2	Environmental Protection Agency, Marine Research Department, Lithuania	Unbuffered formalin, 4 %	Plunger Sampling Pipette (0.5 mL)	×70, ≥500	Standard stage-and taxon-specific individual weights [b]

a) Kott (1953) Modified whirling apparatus for the subsampling of plankton. Aust J Mar Freshw Res 4:387–393;
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