Phytoplankton community composition in relation to the pelagic food web in the open northern Baltic Sea

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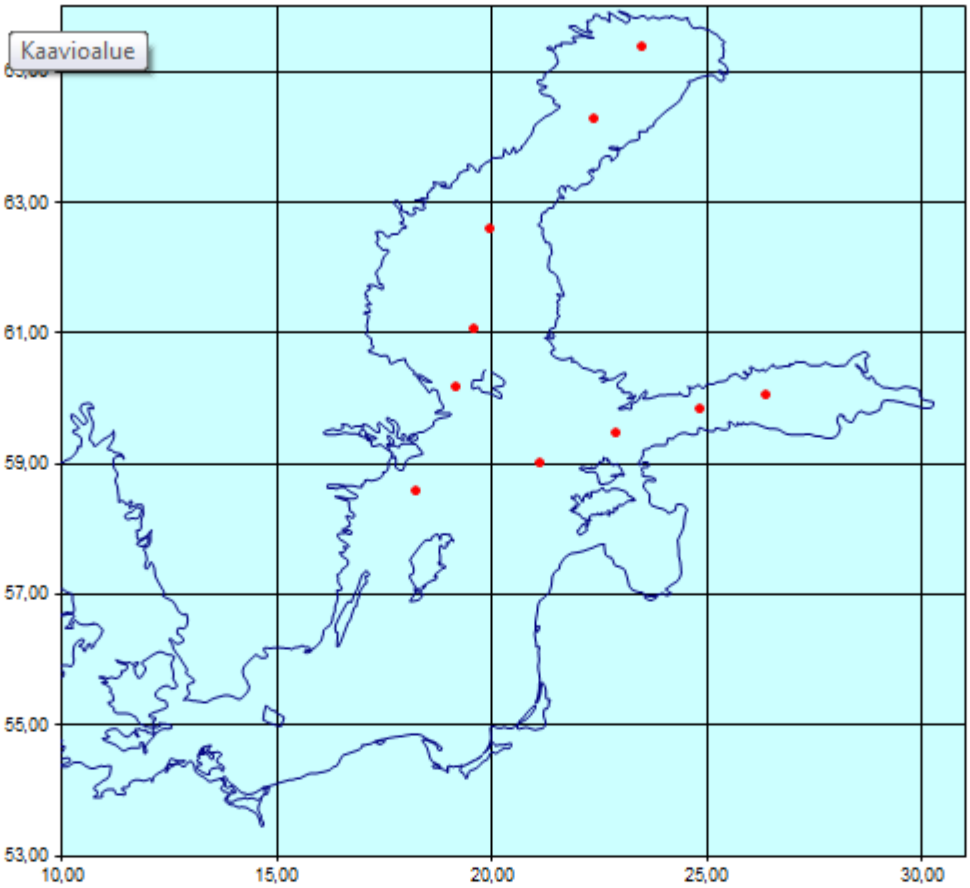

Fig. 1. The Finnish HELCOM COMBINE open sea monitoring stations (red dots). Sampling has been performed annually in late summer (late July to early September) since 1979.

Key message

- Phytoplankton primary producers constitute the base of the Baltic Sea open sea food web. Based on Suikkanen et al. (2013), in the open Gulf of Finland, the Åland Sea, and the northern Baltic proper, the late summer phytoplankton composition has changed towards a more mixotrophic and potentially low-quality food for higher trophic levels. From the food web perspective, the healthiness of the phytoplankton community has decreased also due to the increase in biomass of certain HAB species. Based on Kuosa et al. (*submitted*), there are some indications of similar phytoplankton community changes also in the Gulf of Bothnia.
- Indications of bottom-up effects of the phytoplankton community on higher trophic levels already exist, since small zooplankton such as rotifers have increased, and copepods have decreased.
- Suikkanen et al. (2013) concluded that the pressures behind plankton community changes are most probably interactions between warming, eutrophication and increased top-down pressure due to overexploitation of resources, and the resulting trophic cascades.

- The monitoring of phytoplankton species composition in addition to monitoring chlorophyll-*a* (chl-*a*) is essential, since summarizing parameters like chl-*a*, whether measured from water samples or using satellite imagery, do not provide information on community composition, i.e. on the healthiness of the community from the food web point of view.

Results and assessment

Relevance of the parameters for describing developments in the environment

A healthy phytoplankton community forms the basis for effective micro- and mesozooplankton communities, and further for healthy fish communities. Being the primary producing component of the pelagic food webs, phytoplankton is the first trophic level responding to changes in nutrient availability. In addition to external nutrient loading, phytoplankton composition responds to internal nutrient loading, physical conditions, and food web interactions.

The monitoring of phytoplankton community composition is essential, since summarizing parameters such as chlorophyll-*a* (chl-*a*) and the occurrence of algal surface accumulations are unable to describe phytoplankton community healthiness from the food web point of view. This is because chl-*a* measurements and surface accumulation observations do not provide information on species composition, and from the food web perspective it is of significance, whether the phytoplankton community is dominated by toxic or nontoxic species, or by high or low-quality food.

Policy relevance and policy references

Phytoplankton community composition is relevant in assessing healthiness of marine food webs [Marine Strategy Framework Directive (2008/56/EC) (MSFD) Descriptor 4, i.e. food webs]. MSFD Task Group 4 has suggested including phytoplankton in assessing the status of food webs due to its fast turnover rate (Rogers et al. 2010).

Remote sensing has been suggested to be used to estimate the primary production required to sustain fishery (ICES 2014). Existing results show that even chl-*a* concentration measured from water samples is not sufficient for assessing the food web structure and healthiness, nor for the further effects of primary producers on zooplankton and fish (Suikkanen et al. 2013, Kuosa et al. *submitted*). Thus, phytoplankton community composition should be used in assessing the amount and quality of the primary producer communities required to sustain fishery.

Assessment

Statistically significant trends were used to indicate change (Table 1). The biomasses of cyanophytes, prymnesiophytes and chrysophytes have increased since 1979 in the northern Baltic proper, Gulf of Finland, Åland Sea, and the Bothnian Sea (Suikkanen et al. 2013, Kuosa et al. *submitted*). On the other hand, the biomass of cryptophytes decreased in the Gulf of Finland and in the northern Baltic proper. Even though phytoplankton composition in the Bothnian Bay is clearly different compared to that of the other basins, and it seems to be still in a less impacted stage, similar changes in the Bothnian Bay community were detected; the biomasses of prymnesiophytes and chrysophytes increased also in the Bothnian Bay (Kuosa et al. *submitted*).

The NMDS analysis visualized the phytoplankton community composition and change (Fig. 2, results for the Bothnian Sea and the Bothnian Bay are shown). Community composition was clearly different between the Bothnian Bay and the Bothnian Sea, and the composition changed simultaneously in the same direction during the study period 1979-2012 (Fig. 2, Kuosa et al. *submitted*).

The species-level examination revealed that the main taxa responsible for the changes were *Aphanizomenon flos-aquae* and *Nodularia spumigena* (Cyanophyceae), *Chrysochromulina* spp. sensu lato (Prymnesiophyceae), and *Pseudopedinella* spp. (Chrysophyceae). Both *A. flos-aquae* and *N. spumigena* are diazotrophic, which is an important function in the pelagic food web. If the increase of these species continues, it may forecast surface blooms in the future also in the Bothnian Sea. *N. spumigena* and the single-celled nano-sized (<10 µm) flagellates *Chrysochromulina* spp. sensu lato are potential HAB (Harmful Algal Bloom) species. *N. spumigena* can form hepatotoxins which accumulate in the food web and are toxic to mammals (Kozlowsky-Suzuki 2003, Haschek et al. 2013). *Chrysochromulina* spp. sensu lato can form fish-killing ichtyotoxins and allelopathic substances (Granéli & Turner 2008, Reigosa et al. 2006).

In addition to the increasing risk of potential HAB effects on the food web, these phytoplankton community changes can have direct food-web effects through the changes in the food quality of micro- and mesozooplanktonic grazers. Cyanophytes and prymnesiophytes have been shown to be low-quality food for herbivorous zooplankton (de Bernardi & Giussiani 1990, Sopanen et al. 2008), while cryptophytes are high-quality food (Lehman & Sandgren 1985). On the other hand, *N. spumigena* is known to be a good thiamine source for zooplankton (Sylvander et al 2013), and thus optimal food may contain a small share of this species. Since *Chrysochromulina* spp. sensu lato and *Pseudopedinella* spp. are mixotrophic species, their increase indicates a shift towards a more mixotrophic community of less efficient food web functioning.

In the Gulf of Finland, the Åland Sea, and the northern Baltic proper, results show that the changes in the phytoplankton composition are accompanied by further effects on the higher levels of the food web, i.e. by an increase in rotifers and a decrease in total zooplankton, cladoceran, and copepod abundances (Suikkanen et al. 2013).

The conclusion based on the results of Suikkanen et al. (2013) is that the open sea late summer communities in the Gulf of Finland, the Åland Sea, and the northern Baltic proper have shifted towards more microbial, less energy-efficient food webs consisting of more mixotrophic and lower food-quality phytoplankton, which may lead to a decreased availability of energy for herbivorous zooplankton and planktivorous fish, despite the observed increase in chl-*a* and phytoplankton biodiversity. Based on Kuosa et al. (*submitted*), there are some indications of similar phytoplankton community changes also in the Gulf of Bothnia.

Table 1. Combined results of the Mann-Kendall trend test for detection of monotonous long-term trends, based on Suikkanen et al. (2013) and Kuosa et al. (*submitted*). Direction of the trend and p-value are shown. n = number of samples, * indicates number of samples for *Mesodinium rubrum*. Samples were collected from the Finnish HELCOM COMBINE open sea monitoring stations once a year during late July to early September in 1979-2012 (Bothnian Bay and Bothnian Sea) or 1979-2008 (Gulf of Finland, Åland Sea, and northern Baltic proper). *Mesodinium rubrum* trends have been calculated only for the Bothnian Bay and the Bothnian Sea, and only since the 1980's since this species was not included in calculations during the early years. NA = Results not available.

	Bothnian Bay n=47, *34	**Bothnian Sea n=52, *39**	**Åland Sea n=22**	**Gulf of Finland n=45**	**Northern Baltic proper n=52**
Cyanophyceae	0.869	**Inreasing + 0.001**	**Inreasing + 0.004**	**Inreasing + 0.032**	**Inreasing + 0.020**
Cryptophyceae	0.075	0.058	**Decreasing - <0.001**	**Decreasing - <0.001**	**Decreasing - <0.001**
Dinophyceae	0.377	0.335	0.652	0.512	**Inreasing + 0.002**
Prymnesiophyceae	**Inreasing + <0.001**	**Inreasing + 0.006**	**Inreasing + <0.001**	**Inreasing + <0.001**	**Inreasing + <0.001**
Chrysophyceae	**Inreasing + 0.018**	**Inreasing + 0.047**	**Inreasing + 0.002**	**Inreasing + <0.001**	**Inreasing + <0.001**
Diatomophyceae	0.468	0.069	**Decreasing - 0.006**	0.072	0.575
Euglenophyceae	0.637	0.517	0.061	0.857	0.271
Prasinophyceae	0.219	0.543	0.735	0.395	**Inreasing + 0.018**
Chlorophyceae	0.441	0.434	0.693	0.092	0.390
Mesodinium rubrum*	0.051	**Inreasing + <0.001**	NA	NA	NA

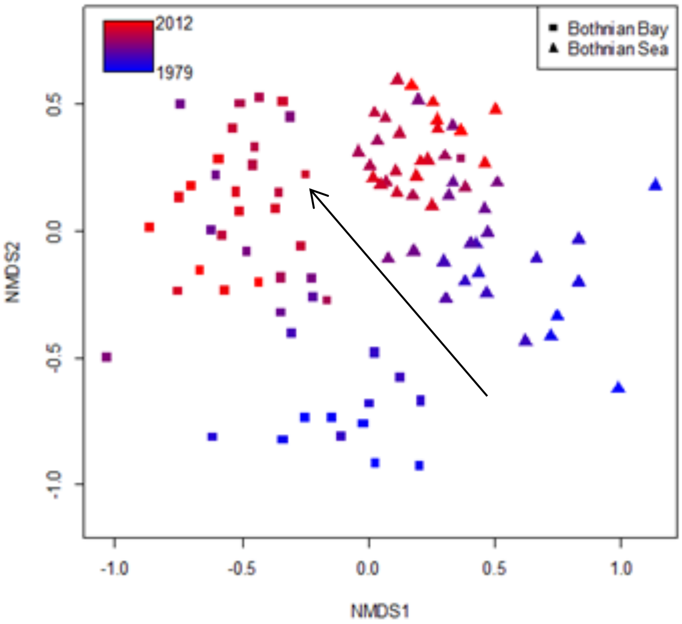

Fig. 2. An example of the non-metric multidimensional scaling (NMDS) results (modified from Kuosa et al. *submitted*). The NMDS analysis clusters samples based on genus-level biomass composition. The color scale represents years from 1979 (blue) to 2012 (red). Samples were taken from the Finnish HELCOM COMBINE open sea stations once a year during late July to early September.

Metadata

Technical information

1. Data source

Finnish national HELCOM COMBINE monitoring data collected and stored by the Marine Research Centre of the Finnish Environment Institute (SYKE), earlier by the Finnish Institute of Marine Research.

2. Description of data

Samples were collected from the Finnish HELCOM COMBINE open sea stations during late July to early September in 1979-2012. Quantitative species-specific phytoplankton biomass data was used (wet weight in µg/l).

The results are stored in the Finnish national data base (www.ymparisto.fi/oiva). Results are also sent yearly to the ICES data base (http://ecosystemdata.ices.dk/inventory/index.aspx).

3. Geographical coverage

The sampling locations in the open sea areas of the Bothnian Bay, Bothnian Sea, Åland Sea, Gulf of Finland, and the northern Baltic proper are presented in Fig. 1.

4. Temporal coverage

Samples were taken during late July to early September once a year in 1979-2012 (Bothnian Bay and Bothnian Sea) or 1979-2008 (Gulf of Finland, Åland Sea, and northern Baltic proper).

5. Methodology and frequency of data collection

Sampling frequency was once a year during late July to early September. The methodology follows the HELCOM COMBINE Manual (HELCOM 2015): Samples were taken as integrated water samples from the surface layer (0-10 m) by mixing equal amounts of water from the depths 1, 2.5, 5, 7.5, and 10 m. Samples were preserved with acidic Lugol's solution (1 ml Lugol's per 300 ml sample), and kept refrigerated (+4 - +10ºC) and in the dark before the microscopic analysis within a year of sampling. Microscopy was performed with an inverted light microscope using the Utermöhl method. A volume of 50 ml (25 ml) of sample was settled into the settling chamber. A magnification of 125x was used to count the >30 µm –sized and sparse species, as well as Nostocales. A magnification of 250x was used to count the 20-30µm –sized species, Chroococcales colonies with a cell size of >2 µm, as well as Oscillatoriales. A magnification of 500x was used to count <20 µm –sized species and

Chroococcales colonies with a cell size of <2µm. 60 ocular squares were analyzed with each of the three magnifications, aiming to count at least 400 counting units with each magnification. Before the 2000s, only two magnifications were used. The counting units and size classes of the HELCOM PEG taxa and biovolume list were used to convert the results into biomasses µg/l (Olenina et al 2006, a link to the annually updated *Biovolume file* is available on the HELCOM PEG www-page http://helcom.fi/helcom-at-work/projects/phytoplankton).

6. Methodology of data manipulation

Taxonomic nomenclature and biomass results were harmonized with the latest version of the HELCOM PEG taxa and biovolume list. A link to the annually updated *Biovolume file* is available at http://helcom.fi/helcom-at-work/projects/phytoplankton.

All statistical analyses were performed using R software (www.r-project.org). The statistically significant p-value < 0.05 was the reference value for significant change. The non-parametric Mann-Kendall test for monotonic trends (*MannKendall*, R package 'Kendall', McLeod, 2011) was used to detect significant monotonic trends in the time series of class-level phytoplankton biomasses. Biomasses of phytoplankton classes with significant trends were plotted with LOESS smoothing, and non-monotonic, non-linear trends can be further evaluated with generalized additive models (GAM, results not shown) (*gam*, R package 'mgcv', Wood, 2014). The phototrophic ciliate *Mesodinium rubrum* was only included in the phytoplankton counts since the late 1980's, and thus its trend was analyzed only since that time (results for the Bothnian Bay and the Bothnian Sea are shown only). Classes with <10 observations per sub-basin (Pedinophyceae, Charophyceae) were excluded.

The non-metric multidimensional scaling (NMDS) (*metaMDS*, R package 'vegan', Oksanen et al. 2015) was used to make a visual ordination of samples based on the similarities and dissimilarities in the genus-level phytoplankton community composition. Results show the ordination of samples based on genus-level biomasses (Fig. 2, results for the Bothnian Bay and the Bothnian Sea are shown).. Data was organized into a cross table, in which each row is a separate sample and sample-specific genus biomasses are in columns. Genus-level biomasses were square root -transformed to stabilize variance and reduce the influence of dominant taxa on the ordination. Bray dissimilarity was used as the distance metric in the NMDS. Genera with <5 observations were excluded, as well as *M. rubrum* and unidentified heterotrophic nanoflagellates. Cyanobacterial colonies with cells smaller than 2 µm were grouped into Chroococcales. Species from the genera *Teleaulax*, *Plagioselmis*, *Rhodomonas*, *Cryptomonas*, and *Hemiselmis* were grouped into Cryptomonadales.

Species-level biomass was examined from the original full data (all taxa included) with simple trend analyses (with year as the explanatory variable and species-specific biomasses as the dependent variable) in order to detect which taxa were the most important for the community composition and possible changes.

Quality information

1. Strength and weakness (at data level)

The main strengths are the robust harmonized methods for sampling, microscopy, and biomass calculations.

Due to the natural patchiness and dynamic fluctuations typical for the fast growing phytoplankton, low sampling frequency is a weakness. A higher sampling frequency would make it possible to detect possible changes already within a shorter monitoring period. Thus, the sampling frequency should be increased to at least once a month, preferably two samplings per month during the whole year. For example, phytoplankton community composition during the spring bloom is a very important factor affecting the bio-geochemical cycles of the Baltic Sea (Spilling & Lindström 2008, Klais et al. 2011). Currently only the late summer phytoplankton community can be assessed in the area.

2. Reliability, accuracy, robustness, uncertainty (at data level)

All the methodology relating to sampling, preservation, storing, microscopy, and biomass calculation is reliable since the common HELCOM COMBINE Manual and the updated HELCOM PEG taxa and biovolume list are used (HELCOM 2015; a link to the annually updated *Biovolume file* is available at http://helcom.fi/helcom-at-work/projects/phytoplankton).

Microscopists are trained annually in the HELCOM PEG workshops, and they participate in proficiency tests for species identification and counting (e.g. Vuorio et al. 2015). The problem of low sampling frequency was discussed above: sampling frequency should be preferably once or twice a month.

3. Further work required

The sampling of the existing long-term monitoring stations should be continued with the existing robust methods, and the sampling frequency should be increased preferably to twice a month during the whole year. In addition to phytoplankton community composition, also other trophic levels should be monitored (sampling frequency varies for different parameters) to be able to perform a holistic assessment of food web functioning and healthiness, and to follow changes in these.

The authors are currently developing a food web indicator "Phytoplankton Community Composition as a food web indicator".

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