

Cyanobacteria biomass 1990-2014

Information from the Phytoplankton Expert Group (PEG)

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Key Message

- The different areas of the Baltic Sea are characterized by different magnitudes of biomass of the nitrogen-fixing (diazotrophic) cyanobacteria genera *Aphanizomenon*, *Nodularia* and *Dolichospermum*. The highest biomass (for the studied months June-August) occurs in the Gulf of Finland, whereas no or low biomass of nitrogen-fixing cyanobacteria appear in the Bothnian Bay and the Kattegat/Kiel Bight area.
- Biomass of nitrogen-fixing cyanobacteria may show opposing trends between different sea areas. For example some years with low biomass in the Arkona Basin and Bornholm Basin (2004, 2005) showed high biomass in the neighbouring Eastern Gotland Basin. This confirms that the sea areas have to be evaluated separately.
- The genus *Nodularia*, known for producing surface accumulations (blooms) during summer, is more common in the central and southern part of the Baltic Sea compared to the northern part where the genus *Aphanizomenon* dominates.
- The year-to-year variability in the biomass of bloom-forming cyanobacteria is high. Tendencies of decreasing cyanobacteria biomass are visible in the Gulf of Riga and the Arkona Basin for the period studied (1990-2014).

Results and Assessment

Relevance of the indicator for describing developments in the environment

Nitrogen-fixing (diazotrophic) cyanobacteria are an important component of the ecosystem. By their ability to fix molecular nitrogen, the bloom-forming cyanobacteria of the genera *Aphanizomenon*, *Nodularia* and *Dolichospermum* prevent severe nitrogen shortage and resulting starvation in all trophic levels of the ecosystem in the summer. However, human activity has imported a surplus of nutrients into the water for decades which turned the originally indispensable cyanobacteria into a nuisance because their nitrogen fixation counteracts the measures to reduce eutrophication, as specified in the following section.

According to Wasmund (1997), nitrogen-fixing cyanobacteria may be considered as “blooms” at a biomass concentration of about 200 µg/L in the mixed upper 10 m of the water. If this biomass is floating and enriched at the water surface it becomes visible and is also clearly perceived from satellites (Kahru & Elmgren 2014).

Policy relevance and policy references

The biomass of nitrogen-fixing cyanobacteria seems to have increased at least since the 1960s (Finni et al. 2001, Funkey et al. 2014). If these cyanobacteria occur in large blooms, they contribute to eutrophication, oxygen depletion in deep waters and intoxication. Already the displeasing outlook of the coloured surface scum may impair the touristic use of the coasts in summer. The changes in cyanobacteria biomass and composition represent changes in the ecosystem with far-reaching consequences. Their trends are of high relevance and interest. This Baltic Sea Environment Fact Sheet (BSEFS) “Cyanobacteria Biomass” serves for long-term documentation of the nitrogen-fixing cyanobacteria biomass development.

An Indicator Fact Sheet on a “Cyanobacteria bloom index” was presented up to the year 2007 (Kaitala and Hällfors 2008). Information about the spatial extension of the bloom based on satellite data is available during every summer (BSEFS “Cyanobacterial blooms in the Baltic Sea”, Öberg 2014). In contrast to satellite image data, our Cyanobacteria biomass fact sheet presents biomass data and gives additional information about the species composition and the actual cyanobacteria biomass in the water column. The species composition is relevant also because *Nodularia* and *Dolichospermum* are known to be toxic whereas toxicity of *Aphanizomenon* has not been confirmed in the Baltic Sea.

Cyanobacteria are consisting of three different orders (groups), where of nitrogen-fixers are one group. In this “Cyanobacteria biomass” indicator only nitrogen-fixing species of the genera *Aphanizomenon*, *Nodularia* and *Dolichospermum* are considered, since these are the main genera that form blooms in the Baltic Sea.

Owing to the high ecological importance of cyanobacterial blooms, they may serve as indicators in the sense of the EU-Marine Strategy Framework Directive (European Union 2008). A new core eutrophication indicator for cyanobacterial blooms is being developed in the frame of the HELCOM EUTRO OPER project. It is primarily based on satellite data, but combination with real biomass data is tested. These biomass data are delivered by the HELCOM-Phytoplankton Expert Group (PEG); they are identical with the data used for this Baltic Sea Environment Fact Sheet.

Assessment

The first Baltic Sea Environment Fact Sheet on the cyanobacteria biomass appeared in 2011 and covered a period from the years 2000 to 2010. The version from the year 2012 tried to trace data back to the year 1990, which was not possible for all regions at that time but was completed in 2013 (Wasmund et al. 2013). Moreover, the northern and southern parts of the Eastern Gotland Basin were joined since 2013. In contrast to 2013, a large Finnish data set was included in the present BSEFS, comprising also five coastal stations with slightly different sampling strategy (see section “Description of data”). This data addition led to much better data coverage in the Gulf of Bothnia and Gulf of Finland, but also to retrospective changes in the data presented in the previous BSEFS for the Bothnian Sea, Gulf of Finland and to a minor degree in the Eastern Gotland Basin. According to a taxonomic revision of the genus *Anabaena* (Wacklin et al., 2009), we changed the old name *Anabaena* to *Dolichospermum*.

In the recent BSEFS, large data sets from the Bay of Mecklenburg and Kiel Bight were considered for the first time; for details see section “Metadata”.

Quantitative phytoplankton monitoring data, available to PEG members, were included in the analysis. Stations were pooled for sea areas (Fig. 1) in order to get representative data and fulfil the minimum requirement of at least one sampling per month during summer. This pooling included also stations which are rarely sampled (in the Bornholm Basin and the southern parts of the Eastern Gotland Basin), but which are not specified in Fig.1. The data were treated as explained in the technical information below. The seasonal means of the total biomass of the nitrogen-fixing filamentous cyanobacteria in the summer period (mainly June-August, in the Bothnian Sea June-October) are presented in Fig.1. It has to be noted that the peak values are generally higher than the

seasonal means presented here. As shown in an earlier Indicator Fact Sheet of PEG, phytoplankton trends may be even opposite in the different sea areas (Jaanus et al. 2007). Therefore, separate diagrams for the most relevant sea areas were produced. Specific information on the three bloom-forming cyanobacteria genera *Aphanizomenon*, *Nodularia* and *Dolichospermum* is shown in Fig. 2.

In the Bothnian Bay, the cyanobacteria biomass was always low ($< 40 \mu\text{g/L}$). Only two exceptions occurred: Station RA1 on 3.8.2005 ($127 \mu\text{g/L}$ *Aphanizomenon*), leading to a monthly average of $50 \mu\text{g/L}$, and Station RA1 on 30.7.2014 ($106 \mu\text{g/L}$ *Aphanizomenon*), leading to a monthly average of $25 \mu\text{g/L}$. Because of the generally low cyanobacteria biomass, we did not present the results from the Bothnian Bay in a figure.

In the Bothnian Sea, nitrogen-fixing cyanobacteria are more relevant than in the Bothnian Bay. One extreme value from 25.7.2006 ($966 \mu\text{g/L}$ *Aphanizomenon*) is treated as an outlier. In some years (1992, 1998, 2002, 2003), data from June were not available. We checked omitting June completely from the calculation of the seasonal means in the Bothnian Sea, because cyanobacteria biomass data in June were generally low in the first years considered. However, in recent years we got samples of rather high cyanobacteria biomass already in June, i.e. in 2007 ($83 \mu\text{g/L}$), 2008 ($194 \mu\text{g/L}$), 2010 ($104 \mu\text{g/L}$), 2011 ($77 \mu\text{g/L}$) and 2014 ($77 \mu\text{g/L}$). Obviously, there is a tendency of earlier bloom start (cf. Kahru and Elmgren 2014), but high cyanobacteria biomass was still found in autumn. Therefore we kept the period from June to October as before. Despite of some missing monthly data, we included also these years in the diagram.

In the Gulf of Finland, the highest biomass of the whole Baltic Sea occurred with single peak values in 1998 ($2900 \mu\text{g/L}$), 1999 ($3460 \mu\text{g/L}$), 2001 ($3282 \mu\text{g/L}$), 2002 ($3670 \mu\text{g/L}$), 2004 ($7470 \mu\text{g/L}$), 2009 ($4410 \mu\text{g/L}$), 2013 ($5892 \mu\text{g/L}$) and 2014 ($2244 \mu\text{g/L}$). The Finnish coastal station "Nau 2361 Seili intens" was the only station belonging to the Archipelago Sea. As it could not be combined with other stations, its data gaps could not be filled and the data could not fulfil the requirements explained in the Metadata section "Methodology and frequency of data collection".

In the Gulf of Riga, high cyanobacteria biomass values occurred occasionally even in September (in 1996, 1999 and 2011). Nevertheless, we restricted the period considered to the summer season from June to August in order to keep the comparability to the neighbouring areas, as in the other regions blooms are noticed only from June to August (cf. seasonal pattern presented by Kaitala and Hällfors 2008).

The cyanobacteria biomass at the Landsort Deep station (BMP H3) appears relatively low for methodological reasons: This was the only station where the upper 20 m were sampled in contrast to 10 m in the other open sea regions. As cyanobacteria prefer the upper water layers, the inclusion of the lower layer of the euphotic zone reduces the depth-integrated average. The cyanobacteria biomass per m^3 might be more than double, especially for *Nodularia*, if only the upper 0-10 m water layer would be considered.

Data for the Eastern Gotland Basin were contributed from Finland, Germany, Lithuania, Poland and Sweden. Nevertheless, the data basis is rather poor because these open sea samples have to be taken at costly cruises. The years 1994 and 1996 had to be excluded because they contained only data from August. However, data from 1993, 1995 and 1997 were included despite lacking July data. The data from the Bornholm Basin had a gap for similar reasons (1994 and 1995 only August data; 1996 no data)

In 2015, we considered coastal data from Kiel Bight and the Bay of Mecklenburg for the first time. Data were delivered by State Agencies (Footnote 2 and 12) and from the coastal monitoring of the IOW (Footnote 1; station Heiligendamm = "HD"; <http://www.io-warnemuende.de/algenblueten-vor-heiligendamm-2014.html>). All these data originated from surface samples (about 1 m depth); the few samples from 0-10 m depth were excluded from the analysis in order to prevent mixing of different methods. The data from Kiel Bight, starting in 2000, were generally low; there was no use to show them in a figure. Monthly means exceeding $100 \mu\text{g/L}$

occurred only in June 2012 (172 µg/L) and July 2012 (326 µg/L), leading to a summer average of 167 µg/L in 2012. They were almost exclusively made by *Dolichospermum*.

The Bay of Mecklenburg needs more attention because big blooms reach the coasts occasionally, e.g. in 2003 and 2006, when even beaches had to be closed because of nuisance cyanobacterial blooms. Differences occurred between samplings from 0-10 m depth and samplings from the surface only. Samplings of the upper 10 m in the open sea revealed cyanobacterial biomass exceeding 100 µg/L in the years 2006, 2011 and 2010 in the series from 2004 to 2013 presented by Schneider et al. (2015). The surface samples from coastal and open sea stations showed biomass peaks in 1993, 1994, 2006 and 2013 (Fig. 2 g).

Kattegat data are not presented because they are generally low and indicated that heavy cyanobacteria blooms did not occur. Only at the end of July 2008, a bloom with peaks of up to 400 µg/L occurred at the two Kattegat stations, but monthly and seasonal means were of course much lower.

Because of the high variability, no clear trend is visible in most areas. A decrease in cyanobacteria biomass can be noticed in the Gulf of Riga and Arkona Basin. Trend analyses by Wasmund et al. (2011) with data from 1979 to 2005 revealed decreasing trends in summer cyanobacteria in the Bornholm Basin and Arkona Basin but not in the Eastern Gotland Basin. However, on this shorter dataset, starting only 1991, no trend can be found in the Bornholm Basin, as the single high value from 1991 should not be overrated (Fig. 2h).

Big differences between different areas may occur. For example, the cyanobacteria biomass was low in the Arkona Basin and Bornholm Basin in 2004 and 2005, but high in the Eastern Gotland Basin at the same time. Integration over all these areas would widely level out these differences. The basin-wide differences in bloom distribution are also known from satellite images (Öberg 2013). This stresses the importance to divide the Baltic Sea into sub-regions and to treat them separately.

Although the satellite images give valuable information on the spatial differences in cyanobacteria abundances, numerous discrepancies between satellite images and ship-based biomass data exist. For example, the high biomass in the Arkona Basin in 1998 and 2008 is not reflected in the number of days with cyanobacteria observed in the satellite images (Öberg 2014). Also at station Landsort Deep there is little systematic correlation between actual cyanobacteria biomass and satellite surface data, probably because of deep maxima of *Aphanizomenon* which cannot be adequately recorded by satellites. Satellites may detect the blooms only under rather specific weather conditions (clear sky) whereas ship-based measurements are not so selective.

As shown in Fig. 2, *Aphanizomenon* sp. is dominating in the northern regions of the Baltic Sea whereas *Nodularia spumigena* is mostly dominating in the southern Baltic Sea. The question is whether this reflects (1) a north-south salinity gradient or (2) a coastal versus open sea gradient as most stations in the north are situated near the coast whereas those in the south are mainly remote of the coast. *Aphanizomenon* sp. seems to prefer lower salinity than *Nodularia spumigena* irrespective of the coasts. *Dolichospermum* is of less importance.

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Data

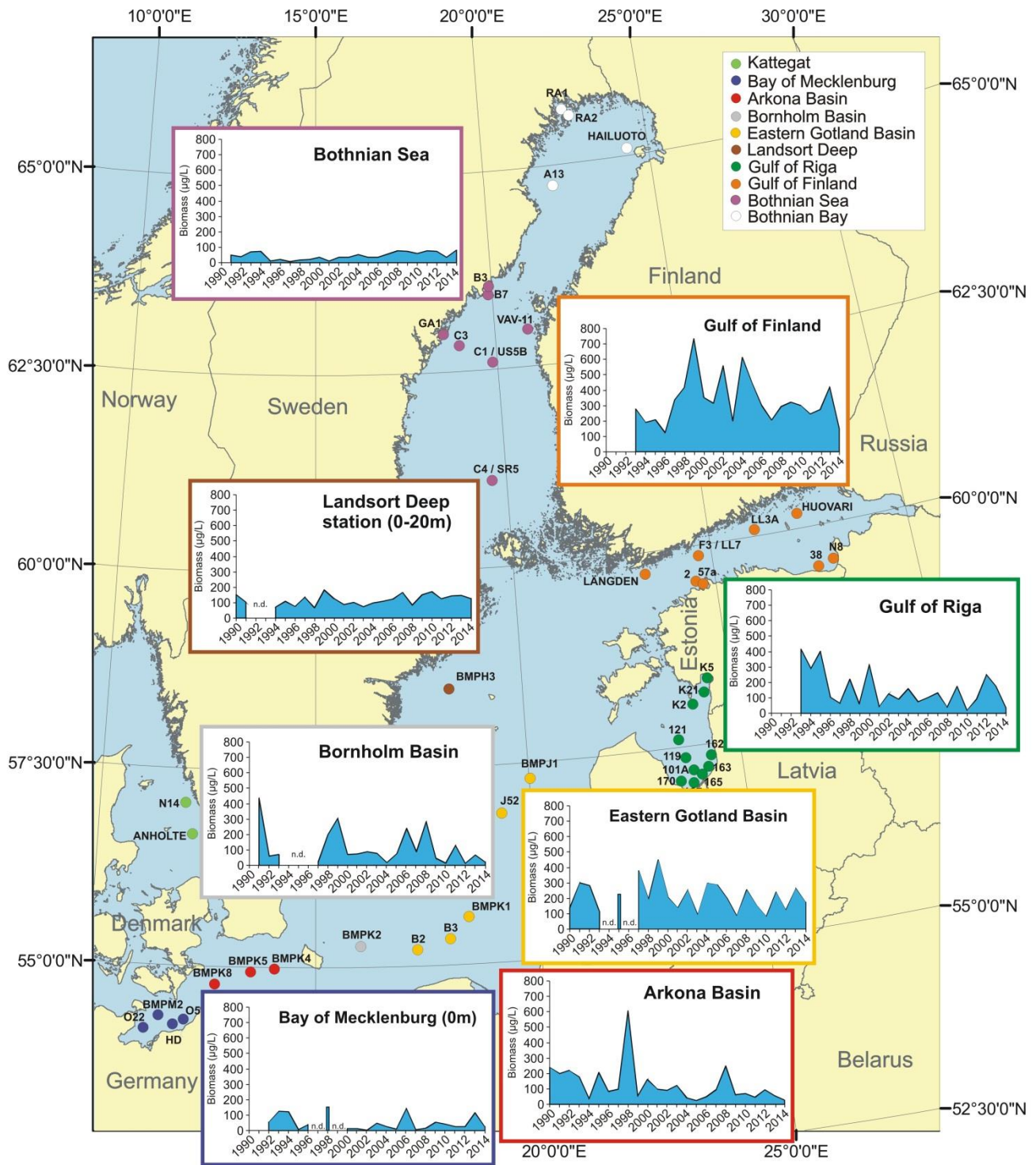


Fig. 1: Map of the regularly sampled stations, containing one graph on diazotrophic cyanobacteria biomass per area (seasonal mean biomass µg/L); details see in Fig.2. Names of some Finnish coastal stations abbreviated. Stations in Bothnian Bay and Kattegat tested but results not presented.



Fig. 2: Mean biomass (wet weight, µg/L) of the three bloom-forming cyanobacteria genera in the different Baltic Sea areas (a-h) during their blooming period (note the different scales). The long-term average per area (all species together) is indicated by a horizontal line. “n” is total number of samples analysed for this region, “n.d.” = not sufficient data.

Metadata

Technical information

1. Data source: Estonian, Finnish, German, Latvian, Lithuanian, Polish and Swedish national monitoring data (see list of authors and Footnotes). Main sampling locations are presented in Fig. 1. Original purpose of the data: Phytoplankton monitoring programs in the frame of HELCOM COMBINE.

2. Description of data: Biomass data (wet weight in $\mu\text{g/L}$) in integrated samples (0-10 m, less at some shallower coastal stations; 0-20 m at the Landsort Deep; surface = 0-1 m in Bay of Mecklenburg). Sampling at the Finnish high-frequency coastal stations “Hailuodon ed int. asema”, “Suomenl Huovari Kyvy-8A”, “UUS-23 Längden” and “Vav-11 V-4” reached from surface to the depth of 2x Secchi depth (usually 0-8m); they could be integrated into the existing data series without problems. Genera included in index: *Nodularia*, *Aphanizomenon* and *Dolichospermum* (previously *Anabaena*).

3. Geographical coverage: Entire Baltic Sea (see Fig. 1).

4. Temporal coverage: Summer 1990-2014 (June-August, in the Bothnian Sea June-October). Note that the years 1992-1993 are missing from the Landsort Deep station, 1994 and 1996 from the Eastern Gotland Basin, 1994-1996 from the Bornholm Basin and 1997 and 1999 from the Bay of Mecklenburg. Even if data from one month were available, they were excluded because only one month was not representative for the investigation period. Some time series started later, e.g. from Gulfs of Finland and Riga in 1993.

5. Methodology and frequency of data collection: Information based on national monitoring samples analysed and identified by phytoplankton experts, using the mandatory HELCOM methods (HELCOM 2014). Additional explanation on the counting procedure in size classes was given by Olenina et al. (2006). Sampling frequency was variable in dependency of the national monitoring cruises. At least one sample per month has to be available to allow the calculation of the seasonal average. This precondition could also be fulfilled by pooling nearby stations. Only in a few exceptions, mentioned in the Assessment section, data are presented despite missing data from one month out of three. The total number of samples is indicated in each diagram in Fig. 2.

6. Methodology of data manipulation: The precondition of at least one sample per month could be fulfilled in the representative open sea stations by combining the different national monitoring data. In coastal areas under the responsibility of only one country, many data (from Lithuania and Poland) had to be rejected because of too low sampling frequency. Other coastal data (from Gulfs of Bothnia, Finland and Riga, see Fig. 1) are included, leading to a high number of data (Fig. 2).

From the single data, monthly means were calculated, which served as basis for calculation of seasonal mean values.

Quality information

1. Strength and weakness (at data level): The main problem is the sampling. Samples are taken only at few stations and with a low seasonal coverage. This undersampling problem, occurring generally at ship-based sampling, is dramatic if high patchiness occurs. Especially the buoyant cyanobacteria are inhomogeneous in their horizontal and vertical distribution. The vertical inhomogeneity is tackled by the integrated sampling down to 10 or at some stations specified above down to 20 m depth (Landsort Deep) or 2 times Secchi depth (Finnish coastal stations). The equipment is however not designed for representative sampling of surface scums. Monitoring cruises into the open Baltic Sea are expensive and can be conducted only a few times per year by the countries involved. The combining of the different national data taken at the central HELCOM stations improves the total sampling frequency to reach the minimum requirements.

2. Reliability, accuracy, robustness, uncertainty (at data level): Data on the reliability and precision are not available. A current ring test of HELCOM-PEG, conducted in 2012, gave information on the precision of *Nodularia* countings in dependence of the counting procedure (Griniene et al. 2013). The sampling problems are discussed above; they have natural reasons. The microscopical counting is a robust method of high accuracy. In contrast to indirect methods (satellites, pigments etc.), the objects can directly be recognized, counted and measured. Moreover, the contribution of the different species can be evaluated. The calculation of biomass from the counting results is highly reliable since common biovolume formulas (Olenina et al. 2006) and a regularly updated biovolume file (http://www.ices.dk/marine-data/Documents/ENV/PEG_BVOL.zip) are used.

3. Further work required (for data level and indicator level): In order to assure a sufficient sampling frequency, the combined efforts of different countries to sample at least the central key station in each sea area have to be maintained or better to be extended. This is especially important when these data will be used to follow up the Baltic Sea Action Plan, the Marine Strategic Framework Directive and the Water Framework Directive. We think that the basic data for this Environment Fact Sheet have to be integrated into a combined Cyanobacteria indicator in the sense of the Marine Strategic Framework Directive.

FOOTNOTES

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