Cyanobacteria biomass

Information from the Phytoplankton Expert Group (PEG)

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Key Message

- The high temporal variability in the biomass of the nitrogen-fixing cyanobacteria (genera *Aphanizomenon, Nodularia* and *Dolichospermum*) makes trend analyses difficult. Tendencies of decreasing cyanobacteria biomass are visible in the Gulf of Riga and the Arkona Basin for the period studied (1990-2013). The sometimes announced increase in cyanobacteria occurrence cannot be clearly verified by the present open sea monitoring data.

- The different areas of the Baltic Sea are characterized by different magnitudes of the cyanobacteria biomass development. The highest biomass occurs in the Gulf of Finland, whereas no cyanobacteria blooms appear in the Bothnian Bay and the Kattegat/Belt Sea area.

- Cyanobacteria blooms may show opposing trends between different sea areas. For example some years with low cyanobacteria 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

Results and Assessment

Relevance of the indicator for describing developments in the environment

Nitrogen-fixing (diazotrophic) cyanobacteria are an important component of the ecosystem. In high abundances they can form surface accumulations that are visible even from space. According to Wasmund (1997), 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.

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.

Policy relevance and policy references

The biomass of nitrogen-fixing cyanobacteria seems to have increased at least since the 1960s (Finni et al. 2001). 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) serves for long-term documentation of the 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, with help of satellite data, is available during every summer (BSEFS "Cyanobacterial blooms in the Baltic Sea", Öberg 2013). In contrast to satellite image data, the present 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.

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 big Finnish data set was included in the present BSEFS, comprising also 5 coastal stations with slightly different sampling strategy (see section "Description of data"). This data addition led to much better data coverage in the gulfs of Bothnia and 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*.

All 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 the same figure. 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 µg/l). Only one exception occurred: Station RA1 on 3.8.2005 (127 µg/l *Aphanizomenon*), leading to a monthly average of 50 µg/l.
Because of the generally low cyanobacteria biomass, we did not present the Bothnian Bay in a figure.

In the Bothnian Sea, cyanobacteria are more relevant. Especially the inclusion of the high-frequency Finnish station "Vav-11 V-4", situated in the Quarck, changed some of the previously presented data: The cyanobacteria biomass from 1998 decreased, but that of the year 2006 increased considerably to 127 µg/l because of one extreme value from 25.7.2006 (966 µg/l *Aphanizomenon*). This single coastal value is treated as an outlier, leading to a more moderate increase of the value from 2006 in comparison to the previous BSEFS. By adding the Finnish data, gaps in the data series could be filled, but nevertheless in some years (1992, 1998, 2002, 2003), data from June were not available. We checked omitting the 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 µg/l), 2008 (194 µg/l), 2010 (104 µg/l) and 2011 (77 µg/l). Obviously, there is a tendency of earlier bloom start, 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, besides of stations LL3A and LL7, two high-frequency Finnish coastal stations were added: "Suomenl Huovari Kyvy-8A" and "UUS-23 Längden". The added Finnish stations alone comprise 247 data sets. Their inclusion led to a decrease of the previously published annual mean values of the years 1995, 1996 and especially 1999, whereas those of the years 2000, 2001, 2005 and 2006 increased. The highest blooms occurred in the Gulf of Finland with single peak values in 1998 (2900 µg/L), 1999 (3460 µg/L), 2001 (3282 µg/L), 2002 (3670 µg/L), 2004 (7470 µg/L), 2009 (4410 µg/L) and 2013 (5892 µg/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.

Data from the Kattegat and from Mecklenburg Bight are not shown because they are generally low and revealed 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. Monthly means of July 2001 and 2006 in Mecklenburg Bight reached almost 200 µg/L but were still under the cyanobacteria bloom threshold which was suggested by Wasmund (1997) at 200 µg/L. This threshold was exceeded only once (on 27.7.2006) in this area if only the open sea stations shown in Fig. 1 are considered.

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. Decreasing trends in the Bornholm Basin cannot be seen on this shorter dataset, starting only 1991. 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, also 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. 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. The comparisons above support the need to monitor actual biomass data and species composition to properly monitor the trends in cyanobacteria biomass in the Baltic Sea.

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 a north-south gradient or 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. The genus *Dolichospermum* is of less importance.

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Data

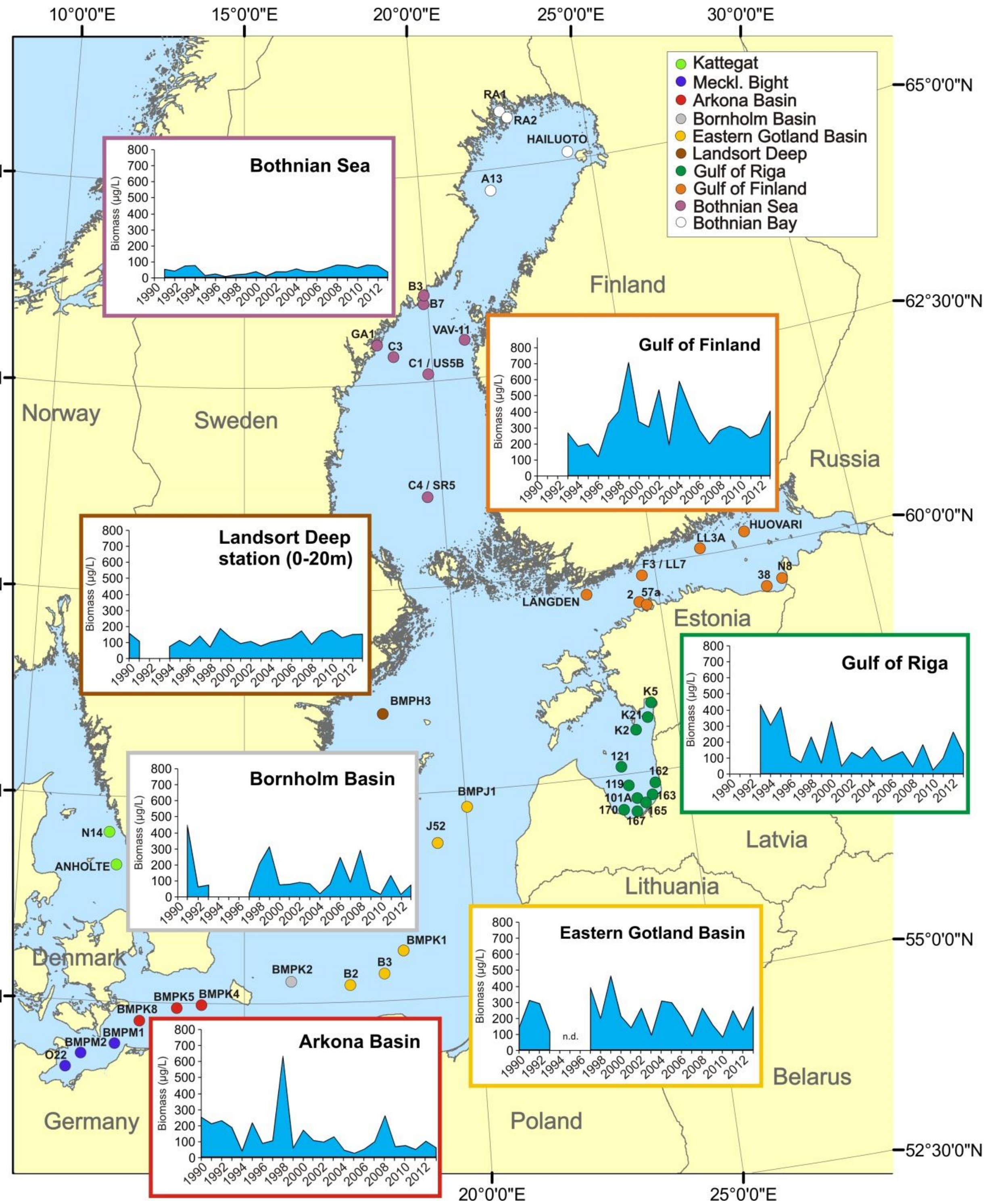

Fig. 1: Map of the regularly sampled stations, containing one graph on diazotrophic cyanobacteria biomass per area (seasonal mean biomass µg L^{-1} $year^{-1}$); details see in Fig.2. Names of some Finnish coastal stations abbreviated.

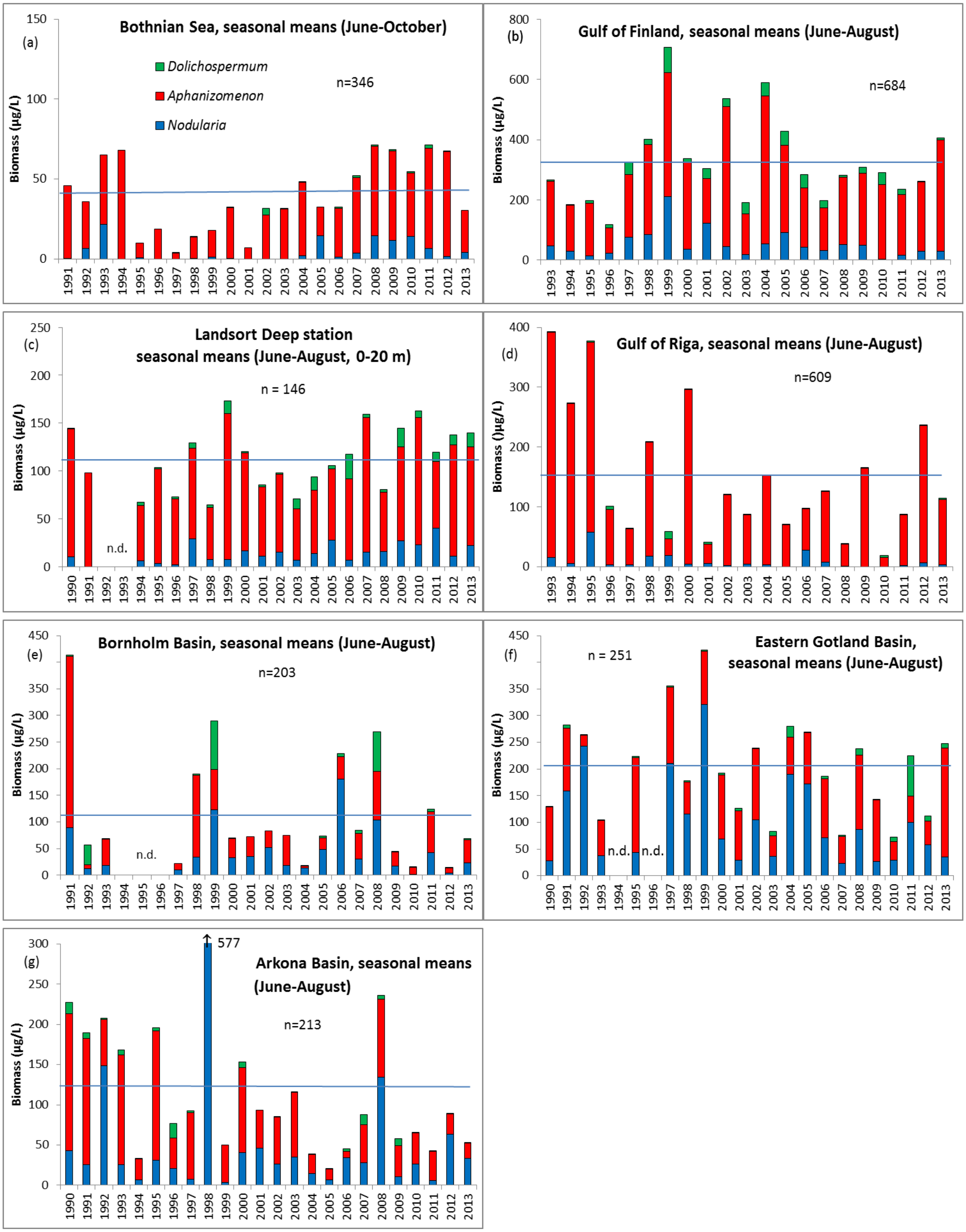

Fig. 2: Mean biomass (wet weight, µg/L) of the three bloom-forming cyanobacteria genera in the different Baltic Sea areas (a-g) during their blooming period (Note the different scales). The long-term average (all species together) is indicated by a horizontal line. "n" is total number of samples analysed 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). 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 µg/L) in integrated samples (0-10 m, less at some shallower coastal stations; 0-20 m at the Landsort Deep). We integrated the Finnish high-frequency coastal stations “Hailuodon ed int.asema”, “Suomenl Huovari Kyvy-8A”, “UUS-23 Längden” and “Vav-11 V-4” for the first time. Despite differing sampling, reaching 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 1990-2013 (June-August, in the Bothnian Sea June-October). Note that the years 1992-1993 are missing from the Landsort Deep station, 1994-1996 from the Bornholm Basin area and 1994 and 1996 from the Eastern Gotland Basin. 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
http://www.helcom.fi/Documents/Action%20areas/Monitoring%20and%20assessment/Manuals%20and%20Guidelines/Manual%20for%20Marine%20Monitoring%20in%20the%20COMBINE%20Programme%20of%20HELCOM_PartC_AnnexC6.pdf
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 complete monthly data. 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. The low sampling frequency by the few national monitoring cruises is improved by combining the different national data taken at the central HELCOM stations.

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, with different environmental requirements, 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 this Environmental Fact Sheet can be easily enhanced to an indicator in the sense of the Marine Strategic Framework Directive.

FOOTNOTES

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