Cyanobacteria biomass indicator

Information from the Phytoplankton Expert Group (PEG)

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Key Message

- Despite of high variability, tendencies of decreasing biomass of the nitrogen-fixing cyanobacteria (genera *Aphanizomenon, Nodularia* and *Anabaena*) are visible in the Gulf of Riga and the Arkona Sea for the period studied (1990-2012). The sometimes announced increase in cyanobacteria occurrence cannot be verified by the monitoring data.
- The Cyanobacteria biomass fact sheet confirms the patchy distribution of cyanobacteria seen in satellite images and supports the need for data from different areas of the Baltic Sea. For example some years with low cyanobacteria biomass in the Arkona Sea and Bornholm Sea (2004, 2005) showed high biomass in the Eastern Gotland Sea.
- Whereas satellite data present spatial distribution patterns of surface accumulations, the Cyanobacteria biomass fact sheet delivers real biomass data (on genus level) from representative stations of each sea area, independent of the weather situation of the summer.

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 become visible and may be considered as “blooms” at a biomass concentration of about 200 µg/L in the upper 10 m of the water. By their ability to fix molecular nitrogen they 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 serves for long-term documentation of the cyanobacteria biomass development.

The previous series of Indicator Fact Sheets (IFS) on a “Cyanobacteria bloom index” ended with 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 (Hansson and Öberg 2012). The HELCOM Phytoplankton Expert Group (PEG) was convinced, however, that information on the cyanobacteria bloom development, based on biomass measurements, is still needed. For this reason, PEG started a new “Cyanobacteria biomass” fact sheet in 2011, which is related to the earlier “Cyanobacteria bloom index” but is not its continuation for the following reasons:

- The Cyanobacteria biomass fact sheet is based on samples taken on discrete stations during monitoring cruises instead of samples taken on highly frequented routes of ships of opportunity.
- The Cyanobacteria biomass fact sheet uses biomass data instead of an index based on semi-quantitative rankings.
- The Cyanobacteria biomass fact sheet separates the different sea areas instead of pooling all data of a hydrographically and biologically highly diverse region.
- The Cyanobacteria biomass fact sheet considers all regions of the Baltic Sea and not only the area between Helsinki and Travemünde.
- The Cyanobacteria biomass fact sheet uses samples covering the upper 10 m (in the Landsort Deep 20 m) instead of a single depth of approximately 5 m.

In contrast to the Cyanobacterial bloom fact sheet (Hansson and Öberg 2012), based on satellite image data, the present Cyanobacteria biomass fact sheet gives additional information about the species composition and the actual cyanobacteria biomass in the water column.

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 (Wasmund et al. 2012). This was not possible in all regions at that time. The present Baltic Sea Environmental Fact Sheet completes the retrospective analysis for all regions considered.

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 Sea 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 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 *Anabaena* is shown in Fig. 2.

The data available from the Gulf of Bothnia was extended by acquiring data from 1991 to 1997 and from additional stations (C1 and C4; see Fig. 1). Unfortunately, in some years (1992, 1998, 2001, 2002, 2003), data from June were not available. We checked omitting the June completely from the calculation of the seasonal means in the Gulf of Bothnia, 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 Bothnian Bay, the cyanobacteria biomass was always low (< 40 µg/l). Only one exception occurred on 3.8.2005 at station RA1 (127 µg/l *Aphanizomenon*), leading to a monthly average of 50 µg/l. We neglected the Bothnian Bay and present only data of the southern part of the Gulf of Bothnia, the Bothnian Sea. The new calculations, based on the extended data set, reveal a slight change in comparison with the previous Baltic Sea Environment Fact Sheet. The increasing tendency reported for 1998 to 2011, becomes less clear and a general trend disappears completely if the years 1991-1994 were added.

It has to be mentioned that exceptionally late blooms occurred in the Gulf of Riga in September 1996, 1999 and 2011. Nevertheless, we avoided including data from September in the general calculation of seasonal averages because low September values occurring in “normal” years would generally reduce the seasonal average and makes it hardly comparable with other areas. The inclusion of the September data would change the seasonal means insignificantly to 98 µg/L in 1996 and 91 µg/L in 1999. Only the value from 2011 would increase substantially to 154 µg/L.

In the other regions, blooms are noticed only from June to August (cf. seasonal pattern presented by Kaitala and Hällfors 2008). The highest blooms occurred in the Gulf of Finland with single peak values in 1998 (2900 µg/L), 1999 (3460 µg/L), 2002 (3670 µg/L), 2004 (7470 µg/L) and 2009 (4410 µg/L).

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 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 might be more than double, especially for *Nodularia*, in the 0-10 m water layer.

In the previous Baltic Sea Environmental Fact Sheets on the Cyanobacteria biomass, the Eastern Gotland Basis was divided into a northern and a southern part as they differed in their bloom intensities in some years. This was in agreement with some older HELCOM Baltic Sea sub-divisions, where the southern part of the Eastern Gotland Basin was joined with the Bornholm Sea and the Arkona Sea to the “Southern Baltic Proper”. Nowadays, HELCOM considers the Eastern Gotland Basin as one large unitary sea area. For this reason, we joined the data sets from the northern and southern parts of the Eastern Gotland Basin and recalculated the seasonal averages. Due to the extended data set, the requirements of data coverage are now fulfilled for many additional years, especially from the 1990s. Only the years 1994 and 1996 had to be excluded because they contained only data from August. Data from 1993, 1995 and 1997 are shown despite lacking July data. The data basis used for the figures increased strongly to n = 234. The general tendencies after the recalculation remained similar to those shown before for the northern part of the Eastern Gotland Basin, except an increase of the seasonal averages from 1999 and 2006.

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.

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 Sea. Trend analyses by Wasmund et al. (2011) with data from 1979 to 2005 revealed decreasing trends in summer cyanobacteria in the Bornholm Sea and Arkona Sea but not in the Eastern Gotland Basin. Decreasing trends in the Bornholm Sea cannot be seen on this shorter dataset, starting only 1991. The basin-wide differences in bloom distribution are also known from satellite images (Hansson and Öberg 2011). This stresses the importance to divide the Baltic Sea into sub-regions and to treat them separately.

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. *Anabaena* spp. are of less importance.

The comparison with the “Cyanobacteria bloom index” (Kaitala and Hällfors 2008) for the overlapping period from 1997 to 2007 shows only little correspondence. For example, the Cyanobacteria bloom index was especially high in 2007 when the cyanobacteria biomass presented in this fact sheet was rather low in the areas passed by the ship of opportunity (Gulf of Finland, Eastern Gotland Basin, Bornholm Sea, Arkona Sea). On the other hand, the Cyanobacteria bloom index was rather low in 2004 and 2005, when also the cyanobacteria biomass was low in the Arkona Sea and Bornholm Sea. It is interesting that the cyanobacteria biomass was high in the Eastern Gotland Basin at the same time. Integration over all these areas, as done by the former Cyanobacteria bloom index, would widely level out these differences. The Cyanobacteria biomass fact sheet wants to retain these naturally occurring differences, which make them better comparable with satellite images.

Although the satellite images from Hansson and Öberg (2012) and the here presented data support the spatial differences in cyanobacteria abundances there are also numerous discrepancies between these two data sets. For example, the high biomass in the Arkona Sea 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 recorded by satellites. Satellites may detect the blooms only under rather specific weather conditions (clear sky) whereas ship-base 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.

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Data

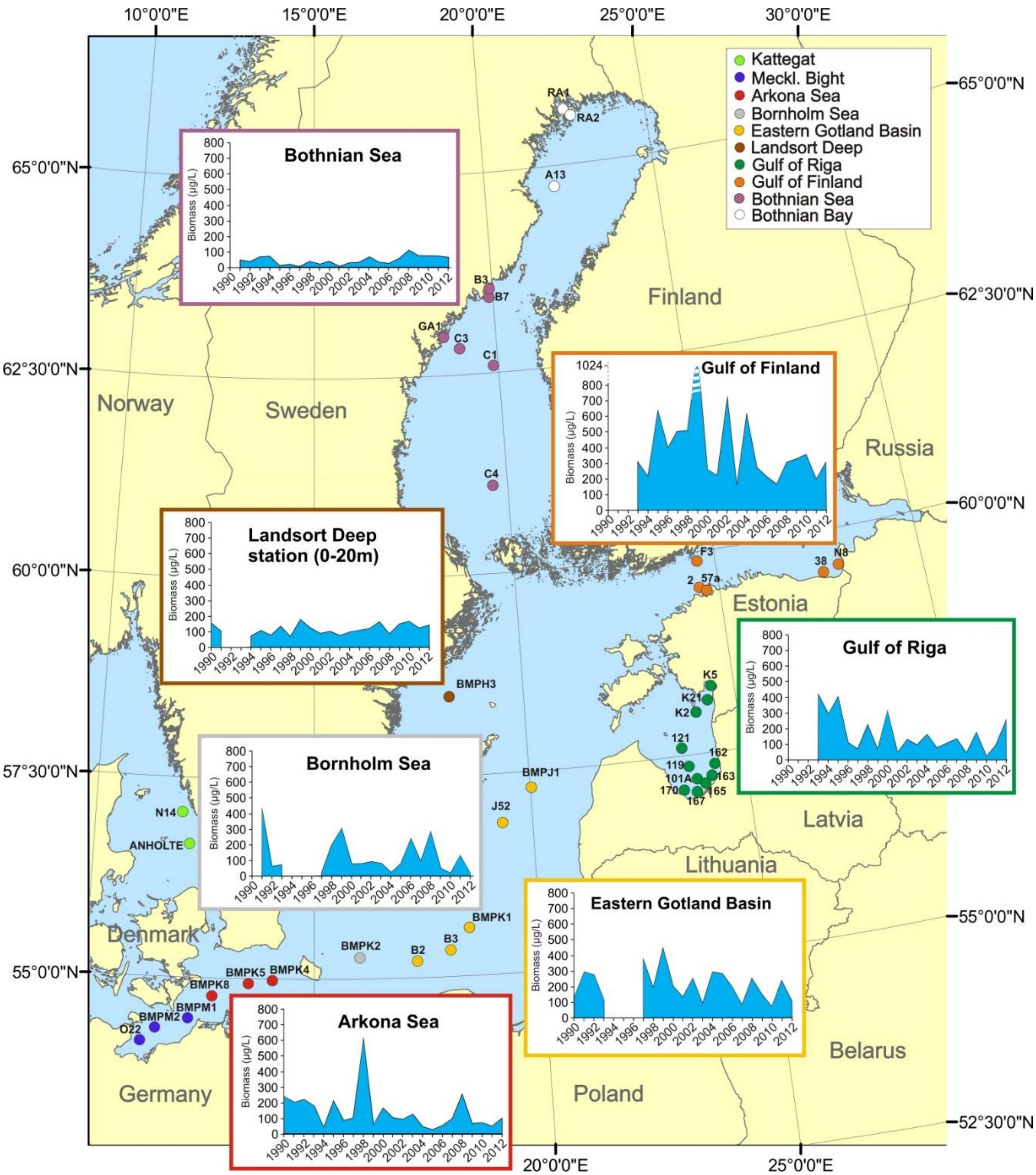

Fig. 1: Map of the regularly sampled stations, containing one graph on diazotrophic cyanobacteria biomass per area; details see in Fig.2.

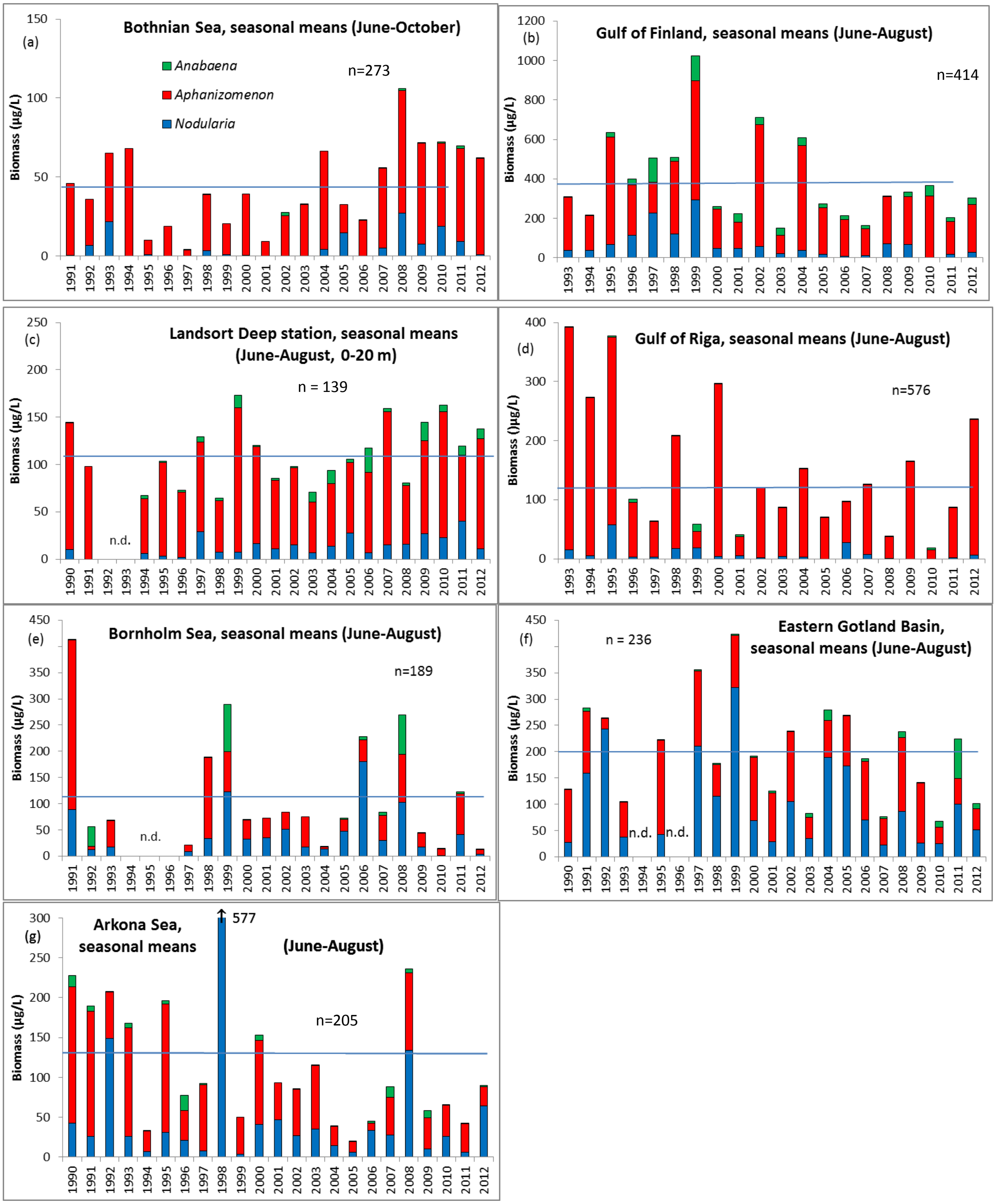

Fig. 2: Mean biomass (wet weight) of the three bloom-forming cyanobacteria genera in the different Baltic Sea areas during their blooming period (Note the different scales). "n" is total number of samples analysed for this region, "n.d." = no data

Metadata

Technical information

1. Data source: Estonian, 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). Genera included in index: *Nodularia*, *Aphanizomenon* and *Anabaena*.

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

4. Temporal coverage: Summer 1990-2012 (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 Sea area and 1994 and 1996 from the Eastern Gotland Basin.

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/groups/monas/CombineManual/AnnexesC/en_GB/annex6/, specified 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 (fromGulfs 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 even 20 m depth. 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 and Daunys 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 recognized and evaluated. The calculation of biomass from the counting results is highly reliable since common biovolume formulas are used (Olenina et al 2007 and its updated biovolume file:http://www.ices.dk/marine-data/vocabularies/Documents/PEG_BVOL.zip.).

3. Further work required (for data level and indicator level): The national monitoring programmes must not be shortened. 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 even extended. This is especially important now when these data need to be used to follow up the Baltic Sea Action Plan, the Marine Strategic Framework Directive and the Water Framework Directive.

FOOTNOTES

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