Cyanobacteria biomass 2000–2022

Information from the Phytoplankton Expert Group (EG PHYTO)

Baltic Marine Environment Protection Commission

Eutrophication

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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) filamentous cyanobacteria (NFC) genera *Aphanizomenon, Nodularia* and *Dolichospermum*. During the study period 2000-2022 (June-August), the highest biomass occurred in the Northern Baltic Proper and the Gulf of Finland, whereas no or low biomass of NFC appeared in the Bothnian Bay, the Kiel Bay and Kattegat area.
- The genus *Nodularia* is more common in the central and southern part of the Baltic Sea compared to the northern part – i.e. in the gulfs of Bothnia, Finland and Riga, where the genus *Aphanizomenon* dominates. *Dolichospermum* is the dominant genus only in the Kiel Bay and the Bothnian Bay where the total biomass of NFC is very low.
- The biomass of NFC may show opposing trends in different sea areas, indicating that particular sub-areas of the Baltic Sea should be considered separately (examples in Wasmund et al., 2014 and next updates).
- Following update of the HELCOM Monitoring and Assessment Strategy from 25.02.2022 in this report we presented variability of the NFC biomass separately in the Gulf of Finland Eastern and the Gulf of Finland Western as well as in the Pomeranian Bay separated in the south-western part of the Bornholm Basin.

Results and Assessment

Relevance of the cyanobacteria biomass for describing developments in the environment

NFC 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* can 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 Baltic Sea 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), NFC may be considered to occur in “bloom concentration” when biomass is about 200 µg / L in the mixed upper water layer from 0 m to the depth of 10 m. 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 blooms of NFC seem to have increased at least since the 1960s (Finni et al. 2001, Funkey et al. 2014). When occurring in large blooms, cyanobacteria contribute to eutrophication, oxygen depletion in deep waters and toxic effects. The displeasing view of the discolouring surface scum alone may impair the touristic use of the coasts in summer. The changes in NFC biomass and composition represent changes in the ecosystem with far-reaching consequences. Their trends are of high relevance and interest (Funkey et al., 2014; Munkes et al., 2020). This Baltic Sea Environment Fact Sheet (BSEFS) “Cyanobacteria Biomass” serves the long-term documentation of the NFC biomass development in the different sea areas of the Baltic Sea. This Fact Sheet serves an important role since it is feeding into the Cyanobacterial bloom index pre-core indicator.

The Indicator Fact Sheet “Cyanobacteria bloom index” covering semi-quantitative rank data from year 1999 to 2007 was presented by Kaitala and Hällfors (2008). Information about the spatial extent of the blooms during summer based on satellite data was presented by Öberg (2018) in the BSEFS "Cyanobacterial blooms in the Baltic Sea". Owing to the high ecological importance of cyanobacterial blooms, they serve as indicators in the sense of the EU Marine Strategy Framework Directive (European Union 2008). The HELCOM pre-core eutrophication indicator Cyanobacterial Bloom Index (CyaBl), based on the paper by Anttila et al. (2018) has been implemented (HELCOM 2018a) and used in the Second and Third HELCOM holistic assessments (HELCOM 2018b, 2023). It combines satellite observation data with the biomass monitoring data delivered by the HELCOM Phytoplankton Expert Group (EG PHYTO). The biomass data are identical with the data used for this BSEFS, but this BSEFS gives also more comprehensive additional information on the differences in the biomasses of the genera *Nodularia*, *Aphanizomenon* and *Dolichospermum* in different Baltic Sea areas. In contrast to the satellite image data, quantitative biomass data from a greater number of sea areas gives additional information about the species composition in the water column. The species composition is relevant also because *Nodularia* and *Dolichospermum* have the potential to be hepatotoxic. Hepatotoxicity of *Aphanizomenon* has not been confirmed in the Baltic Sea, though Cox et al. (2005) have reported potential for production of the neurotoxic amino acid β-N-methylamino-L-alanine (BMAA) within the strains of Baltic Sea *Aphanizomenon* and *Nodularia*. However, BMAA levels in field samples from the Baltic Sea are low (Johansson et al., 2010; Spáčil at al. 2010).

Assessment

The first BSEFS on Cyanobacteria biomass was published in 2011. Just like the earlier Indicator Fact Sheet "Cyanobacteria bloom index" (Kaitala & Hällfors 2008), it concentrates on the open sea. However, owing to the COMBINE strategy, also coastal stations are considered. The situation near the coast may be different from that in the open sea. Therefore, clusters of coastal stations have been kept apart from open sea stations if they were separated by a long distance (> 70 km). This mainly applies to large basins such as Bornholm Basin and Eastern Gotland Basin where the distance between coastal stations and open sea stations exceeds 70 km. When the distances between the coastal and open sea stations were less than 70 km, the data were combined. In the next year BSEFS coastal and open sea stations will be presented separately for all areas.

In this BSEFS on Cyanobacteria biomass, only NFC species of the genera *Aphanizomenon*, *Nodularia* and *Dolichospermum* are considered, since these are the main genera that form blooms in the Baltic Sea. Specific information on these three cyanobacteria genera is shown in Figures 2 and 3 (see pages 13-14).

Bothnian Bay

In the Bothnian Bay, the NFC biomass is usually very low. Monthly averages do not exceed 50 µg / L. During the period 2000-2022, two maxima of NFC biomass were observed. The first maximum was caused by the high (126.81 µg / L) *Aphanizomenon* biomass at the coastal RA1 station in August 2005, and second at the same station in July 2014 (119 µg / L). *Dolichospermum* predominates in this region, with an average share of 50% in the total biomass of NFC, while the share of *Aphanizomenon* is 46% and *Nodularia* is only 3%. Long-term mean NFC biomass in the Bothnian Bay is only 7 µg / L, wherefore results are not presented in a separate diagram in Fig. 1 but only in Fig. 2b. The seasonal mean (0.3 µg / L) of the total biomass of NFC in the summer period in 2021 was the lowest in the period 2000-2022. In season 2022 only one station was sampled and through the whole season (June-October) no NFC was recorded.

Bothnian Sea

In the Bothnian Sea (including data also from stations located in the Quark), NFC are more relevant than in the Bothnian Bay. In this region there is a tendency for an earlier bloom start (cf. Kahru and Elmgren 2014), but moderate NFC biomass is also found in autumn (monthly means of 100-150 µg / L and up to 360 µg / L in the individual autumn samples). Therefore, we used the period from June to October for this area. Starting with very low NFC biomass in the mid of the 1990s, biomass has increased more or less continuously (Andersson et al. 2015, Kuosa et al. 2017). Moreover, in contrast to earlier years, NFC blooms were also observed in the northern part of the Bothnian Sea (Lehtinen et al. 2019). It should be noted that the biomass of NFC at stations located in the Quark is much lower (long-term mean is 28 µg / L, and maximum biomass 356 µg / L in August 2017 and 295 µg/L in September 2018) than at stations located in the proper of the Bothnian Sea (long-term mean 84 µg / L, maximum biomass 686 µg / L in August 2017 and 918 µg / L in August 2021). In 2022 there was nearly the same composition and biomass than in 2021.

Gulf of Finland

In the Gulf of Finland, very high NFC biomass occurred with single peak values from 2000 to 7470 µg / L in the beginning of the 2000s, in 2008 and again since 2013. The blooms have mainly been dominated by *Aphanizomenon*HELCOM Monitoring and Assessment Strategy was updated on February 25th 2022 following HOD 61-2021 meeting decision on updating HELCOM Assessment Units and as a result the Gulf of Finland was split into western (SEA-013A) and eastern (SEA-013B) parts. This new subdivision of the Gulf of Finland is included in Figures 1 and 2. From 2003 to 2007, there was a significant increase in NFC biomass in the eastern part of the Gulf of Finland with a maximum of 7467 µg/L in July 2004 at station N8. Subsequently, since 2008, there has been a decrease in the NFC biomass in the eastern part and at the same time an increase in the western part, where in July 2008 a second maximum of 7378 µg/L was recorded at station 3. Such a situation (lower NFC biomass in the east and higher in the west of the gulf) lasts until now. In 2022, the average NFC biomass in the eastern part was 321 µg/L and the western part the average was 1.4 times higher. In July 2022, there was a *Nodularia* bloom event with a biomass of 1787 µg/L at station F1 (eastern part), while in the western part the (station 3) an *Aphanizomenon* bloom with a biomass of 1789 µg/L was recorded.

Archipelago Sea and Åland Sea

The Finnish coastal station "Nau 2361 Seili intens" was the only station situated in the Archipelago Sea. Its data alone was not sufficient fulfil the requirements explained in the Metadata section **"**Methodology and frequency of data collection". Thus, data for Archipelago Sea is not presented. The same concerns data from the Åland Sea.

Northern Baltic Proper

The acquisition of data for the Northern Baltic Proper made it possible to include the area in the BSEFS 2021. The biomass of NFC is very high in this area, both in terms of monthly mean values (5-3248 µg / L), seasonal means (100-1263 µg / L, Fig. 1, Fig. 2c) and long-term mean (577 µg / L, Fig. 2c). In the taxonomic composition, *Aphanizomenon* (70%) comprises the larger share, then *Nodularia* (25%), and *Dolichospermum* (only 5%). In the Northern Baltic Proper area, the highest biomass values always occurred in July, very often exceeding 1000 µg / L. The highest biomass (2851 µg / L) in 2022 was recorded in July for *Nodularia* at the H1 station.

Gulf of Riga

In the Gulf of Riga, high seasonal average NFC biomass value in year 2015 was mainly based on peak values from 4 August (1981 µg / L). In 2017, the highest biomass was recorded on July 6th, almost exclusively based on *Aphanizomenon* (1360 µg / L at station 165). In 2018, NFC biomass was three times lower than in 2017 and by half lower than the long-term mean. In the following years, the biomass of cyanobacteria (mainly *Aphanizomenon,* which on average accounts for 93% of the total

NFC biomass) increased again. The Gulf of Riga is one of the four sub-areas of the Baltic Sea (next to the Bothnian Sea, the Arkona Basin and the Kiel Bay) where the NFC seasonal average biomass decreased in 2021 compared to 2020. In 2022 the seasonal average biomass increased compared to 2021 but was still lower than in 2020. The maximum values were recorded at station 121 in June (1061 µg/L) in in August at station K21 (1058 µg/L).

Western Gotland Basin

The only open sea station in the Western Gotland Basin is the Landsort Deep station (BMP H3), situated in the northern part of the Western Gotland Basin. The NFC biomass at this station 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 NFC prefer the upper water layers, the inclusion of the lower layer of the euphotic zone reduces the depth-integrated average. The NFC biomass per m^3 might be up to double, especially for the strongly buoyant *Nodularia*, if only the upper 0-10 m water layer would be considered. In 2019, the peak biomass (528 µg / L) was found on July 31st and it was the highest peak for the period 2000-2022. The seasonal average has increased during the period 2000-2022 and also the composition has changed. In 2000- *Aphanizomenon* totally dominated by constituting 85% of the average total NFC biomass, and *Nodularia* 14 % and *Dolichospermum* 1 %. In the last five years (2018-2022) *Aphanizomenon* has constituted on average 70% of the NFC biomass and *Nodularia* 21% and *Dolichospermum* 9 %. The increase in the seasonal average is due to an slight increase in both *Dolichospermum* and *Nodularia*, while *Aphanizomenon* does not show an increase at the Landsort Deep.

Eastern Gotland Basin

Data from the Eastern Gotland Basin were contributed by Finland, Germany, Lithuania, Latvia, Estonia, Poland and Sweden. Nevertheless, the amount of data is rather low, although supplemented from year to year. As already mentioned above, only the open sea area of the basin is included in this BSEFS. Although coastal data is also collected, it cannot be combined with the open sea data to improve its quality because of the differences between the coastal and open sea environments are too large. The coastal data also cannot be inlcuded separately due to the too short time series (2016-2022).

The NFC biomass peak was recorded on June 28th 2018 (975 µg / L). The average biomass of cyanobacteria in 2019 (386 µg / L) decreased slightly in comparison to 2018. It should be noted that Eastern Gotland Basin was the second region of the Baltic Sea, next to the Gulf of Finland, where the biomass of NFC decreased in 2019. In 2020 the biomass of NFC decreased again to a value close to the long-term mean (220 µg / L). The highest biomass (889 µg / L) in 2020 was observed on July 15th. Along the coasts in southern part of Eastern Gotland Basin, sometimes the local standards for cyanobacterial toxin concentrations were exceeded, which resulted in the temporary closure of the bathing areas (ICES 2013, 2015, 2016, 2017, 2021). Such events occurred when sudden strong winds and water currents pushed the masses of the bloom developed in the central Baltic Sea towards the south. In 2021, NCF biomass peaks, up to a maximum of 1085 µg/L, appeared in June mainly in the northern part of the basin. In July, the amount of NFC decreased significantly, and in August, none or concentrations below 78 µg/L were found. The seasonal average biomass in 2022 was below the long-time mean.

It can be observed that among the samples in which NFC biomass was higher than 500 µg/L are collected more and more earlier in the year. In the decade 2000-2010 40% was collected in August and in the decade 2010-2020 73% was collected in July.

Gdańsk Basin

The Gdańsk Basin was added as a separate area to the BSEFS in 2018, based on the available data series from the period 2002–2018 (Fig. 1 and Fig. 2l). NFC biomass from the stations BMPL1, BMPL5 and BMPL6 (sampled within the Polish National Monitoring Programme governed by the Chief Inspectorate of Environmental Protection, footnote 11) was combined with nearby stations sampled occasionally by NMFRI (footnote 1) and the University of Gdańsk (footnote 12). Long-term mean of NFC biomass in the Gdańsk Basin is lower than for the Northern Baltic Proper and the western Gulf of Finland but higher than for the other Baltic Sea areas. The highest peak values were observed in 2009 (4693 µg / L) and 2010 (6621 µg / L). Among the genera observed in that region *Aphanizomenon* dominated (on average 64% of total cyanobacteria biomass), although in some years the contribution of *Nodularia* (2008, 2010, 2016) and *Dolichospermum* (2010, 2019) was significant. The highest biomass of NFCa (1208 µg/L) in 2021 was recorded in June. The share of the NFC genera was then as follows: 44% *Dolichospermum*, 41% *Aphanizomenon* and 15% *Nodularia*. In July, another NFC peak appeared (949 µg/L), but this time it was composed of *Aphanizomenon* (44%) and *Nodularia* (38%), whereas *Dolichospermum* accounted for only 17%. The seasonal average biomass in 2022 decreased for 44% in comparison of 2021.

As well as in the southern part of Eastern Gotland Basin, surface accumulations of NFC were also observed off the coast in the Gdańsk Basin . Therefore, the presence of cyanobacterial toxins has been regularly monitored in Polish coastal waters since 2001. Extreme concentrations (i.e. exceeding 15.00 µg / L) of nodularin (hepatotoxin produced by *Nodularia spumigena*) were determined both in 2004 (25.85 µg / L) and 2009 (42.33 µg / L) when the seasonal mean of NFC biomass was above the long-term mean, and in 2012 (45.00 µg / L), 2015 (35.28 µg / L) and 2018 (30.00 µg / L) (ICES Report: 2013, 2015, 2016, 2017, 2021; Mazur-Marzec et al. 2006) when the seasonal mean of NFC biomass was significantly below the long-term mean. This indicates that the long-term NFC biomass data collected from the central part of the Gdańsk Basin do not fully reflect the actual magnitude of NFC blooms and the risks they pose.

Bornholm Basin

NFC biomass in the Bornholm Basin was generally rather low (76% of considered data is below 100 µg / L) in comparison with the northern regions of the Baltic Proper. However, in 2019, the mean NFC biomass increased above the long-term mean (105 µg / L), and on July 15th, for the first time since 2015, even exceeded (337 µg / L) the bloom value established in Wasmund (1997). In this blooming event, *Nodularia* dominated (with 86% of total NFC biomass). In 2020 and 2022, all values of NFC biomass were again below the bloom value. Although in 2021 the seasonal mean also did not exceed the long-term mean, a minor bloom event took place in June when the NFC biomass reached 381 µg/L and consisted entirely of *Aphanizomenon*.

Pomeranian Bay

The same update of the HELCOM Monitoring and Assessment Strategy from February 25th 2022, which introduced splitting of the Gulf of Finland, also led to the separation of the Pomeranian Bay (SEA-007B) in the south-western part of the Bornholm Basin as an individual sub-area of the Baltic Sea. For this region, only the 2011-2022 decennial time-series is available at the moment for the NFC trend analyses (Fig. 1 and 2k). This series is the shortest time series (n=42) and additionally it was supplemented in a few seasons with data from May or September to meet the requirements of the methodology, when data from June-August were unavailable.

The Pomeranian Bay is a region with a low biomass of NFC, but with sporadic bloom events. Seasonal mean NFC biomass in this region ranges from 7 to 126 µg/L with the exception of two years: 2013 and 2021. In 2013, there were two significant peaks: in June (1014 µg/L) composed of 100% *Aphanizomenon* and in July (1656 µg/L) composed of 84% *Dolichospermum* and 16% *Aphanizomenon*. These peaks significantly increased the seasonal mean to 934 µg/L. In 2021, the maximum appeared in August (668 µg/L) and was also dominated by *Aphanizomenon* (68%) and *Dolichospermum* (31%). The long-term seasonal NFC biomass average for the Pomeranian Bay is 144 µg/L. This is higher than in the neighbouring sub-basins due to the peaks described above. In comparison to 2021 the average NFC biomass in 2022 decreased about 87% and is still half of the average NFC biomass in 2020.

Arkona Basin

In the Arkona Basin, NFC biomass seems to decrease during the investigation period. Indeed, the lowest mean NFC biomass was found in 2017 with a seasonal maximum of only 110 µg/L on August 13th. However, in the following years the NFC biomass increased again and in 2019 exceeded the long-term mean and in 2020 reached a value equal to the long-term mean. In 2021, the seasonal mean again fell between the lowest values since 1990 (38 µg/L), but in 2022 it increased nearly to the long-term mean.

Bay of Mecklenburg and Kiel Bay

In the Bay of Mecklenburg, NFC blooms are not usual, but they may reach the coasts occasionally, e.g. in 2003 and 2006, when beaches had to be closed because of nuisance cyanobacteria 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 NFC biomass exceeding 100 µg / L in the years 2006, 2010 and 2011 in the series from 2004 to 2013 presented by Schneider et al. (2015). The surface samples from coastal and open sea stations showed NFC biomass peaks in 2006, 2013 and 2016 (Fig. 2 n). In 2018, high NFC biomass of 588 µg / L was found at the Mecklenburg coast only on July 17th and was dominated by *Nodularia* (Wasmund et al. 2019), similarly to the maximum recorded on July 16th, 2019 amounting to 370 µg / L. On July 1st 2020 appeared cyanobacteria bloom with biomass of 327 µg/L at O22 station. The bloom consisted mainly of *Aphanizomenon* (53%) and *Dolichospermum (*41%). The seasonal NFC mean also the means of the three genera in 2022 are nearly the same as in 2020.

Data from the Bay of Mecklenburg and Kiel Bay were considered for the first time in the BSEFS report in 2015. Data were delivered by State Agencies (footnotes 3 and 13) and from the coastal monitoring of the IOW (station Heiligendamm = "HD"; see Wasmund et al. 2019). All these data originated from surface samples (about 1 m depth); the few samples from 0-10 m depth were excluded from the analysis to prevent mixing of different methods.

The NFC biomass in Kiel Bay, starting in 2000, was generally low (maximum summer average 140 µg / L in 2012), although the individual biomass values in July exceeded 760 µg / L at station 7. Also, in 2016 and 2020, the NFC biomass in June was 220 (at station 7) and 270 µg / L (at station 59, Fig. 1,) respectively. The NFC biomass maximum in 2022 occurred in August at station 49 (118 µg/L), but the seasonal average was lower than in 2020 and 2021.

Kattegat

As in the case of Bothnian Bay, also Kattegat data are not presented because of generally low NFC biomass, which indicates that heavy cyanobacteria blooms usually do not occur in that sea area. Only at the end of July 2008, a bloom with biomass peaks of up to 400 µg/L occurred at the two Kattegat stations, but monthly and seasonal means were much lower. However, a new data series

(2010-2020) from the southern part of the Kattegat, added in 2021, reveals that very intense NFC blooms incidentally occur in this area as well. For example, in July 2012, there was a *Dolichospermum* bloom exceeding 4300 µg / L, and in August 2015 and 2016 a mass appearance of *Nodularia* with a biomass exceeding 380 and 6000 µg / L, respectively. Apart from these exceptional years, in the remaining years the seasonal average was in the range of 0.5-30 µg/L. Similar single bloom events took place in the Little Belt in August 2012 (1448 µg/L) and 2019 (5033 µg/L) as well as in July 2020 (217 µg/L) and consisted almost only of *Nodularia*.

General remarks for the Baltic Sea

From the above considerations it follows that due to high variability, no clear Baltic Sea -wide trends were generally detected in the NFC biomass during the period 2000-2022.

The results of testing the data series until 2020 confirm the direction of change for NFC biomass reported earlier for different parts of the Baltic Sea – Bornholm and Arkona Basin (Wasmund et al. 2011), Northern Baltic Proper (Suikkanen et al., 2013; Andersson et al., 2015), the Gulf of Finland (Suikkanen et al., 2013) and Bothnian Sea (Andersson et al. 2015; Lehtinen et al. 2016, Kuosa et al. 2017). Most of observations indicate rather fluctuations in surface blooms instead of continuous long-term trends (e.g. Kahru et al. 2018).

Large variations in NFC biomass between different areas and sub-areas of the Baltic Sea may occur (Wasmund et al., 2014, 2018; Kownacka et al., 2020 and 2021). This indicates that the sea areas must be evaluated separately. Moreover, not only the sub-areas of the Baltic Sea should be evaluated separately but even the coastal regions of some sub-areas should be considered separately from the open sea areas as they differ significantly from each other. This mainly applies to large basins such as Bornholm Basin and Eastern Gotland Basin. These observations indicate the need to analyse changes in NFC biomass in next years in accordance with the four possible hierarchical scales for sub-division suggested by HELCOM.

Although the satellite images give valuable information on the spatial differences in NFC abundances, numerous discrepancies between satellite observations and ship-based biomass data (biomass analysed from water samples) exist. For example, the high biomass in the Arkona Basin in 2008 is not reflected in the number of days with cyanobacteria observed in the satellite images (Öberg 2018). Also, at station Landsort Deep there is only little systematic correlation between the actual NFC 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 specific weather conditions (clear sky) whereas water samples taken with ship-based measurements are not so selective. If wind mixes the NFC biomass into the water, surface accumulations will not form even though NFC biomass was high. On the other hand, calm winds may enable surface blooms to become visible even though actual NFC biomass was not exceptionally high.

As shown in Fig. 2, *Aphanizomenon* is dominating in the northern regions of the Baltic Sea whereas *Nodularia* is mostly dominating in the southern Baltic Sea. This may reflect a north-south salinity gradient. *Aphanizomenon* seems to prefer lower salinity than *Nodularia* irrespective of the coasts. Lehtimäki et al. (1997) found that *Aphanizomenon* from the Baltic Sea grows best at salinities of 0 to 5 psu while the optimum salinity for *Nodularia* bloom development is 5–13 psu (Sivonen et al. 1989, Lehtimäki et al. 1994). Moreover, observations of Pliński & Jóźwiak (1999), and Mazur & Pliński (2003) showed that growth of the hepatotoxin-producing *Nodularia* is strongly temperature-dependent and is optimal at 25–28°C. Lehtimäki et al. (1997) narrows this range of optimal growth for *Nodularia* to 20-25°C, indicating that it is still higher than the temperature optimum for

Aphanizomenon (16–22 °C). *Aphanizomenon* seems to be able to utilise upwelled nutrients, while *Nodularia* seems even negatively affected by upwelling events (Munkes et al. 2020).

Dolichospermum is less important quantitatively (1-17% of mean NFC biomass, depending on area). The exceptions are the Bothnian Bay and Kiel Bay, where *Dolichospermum* biomass accounts for about 60% of the total biomass of the analysed NFC, and Kattegat, where in some events *Dolichospermum* can form almost monogenic blooms.

Data

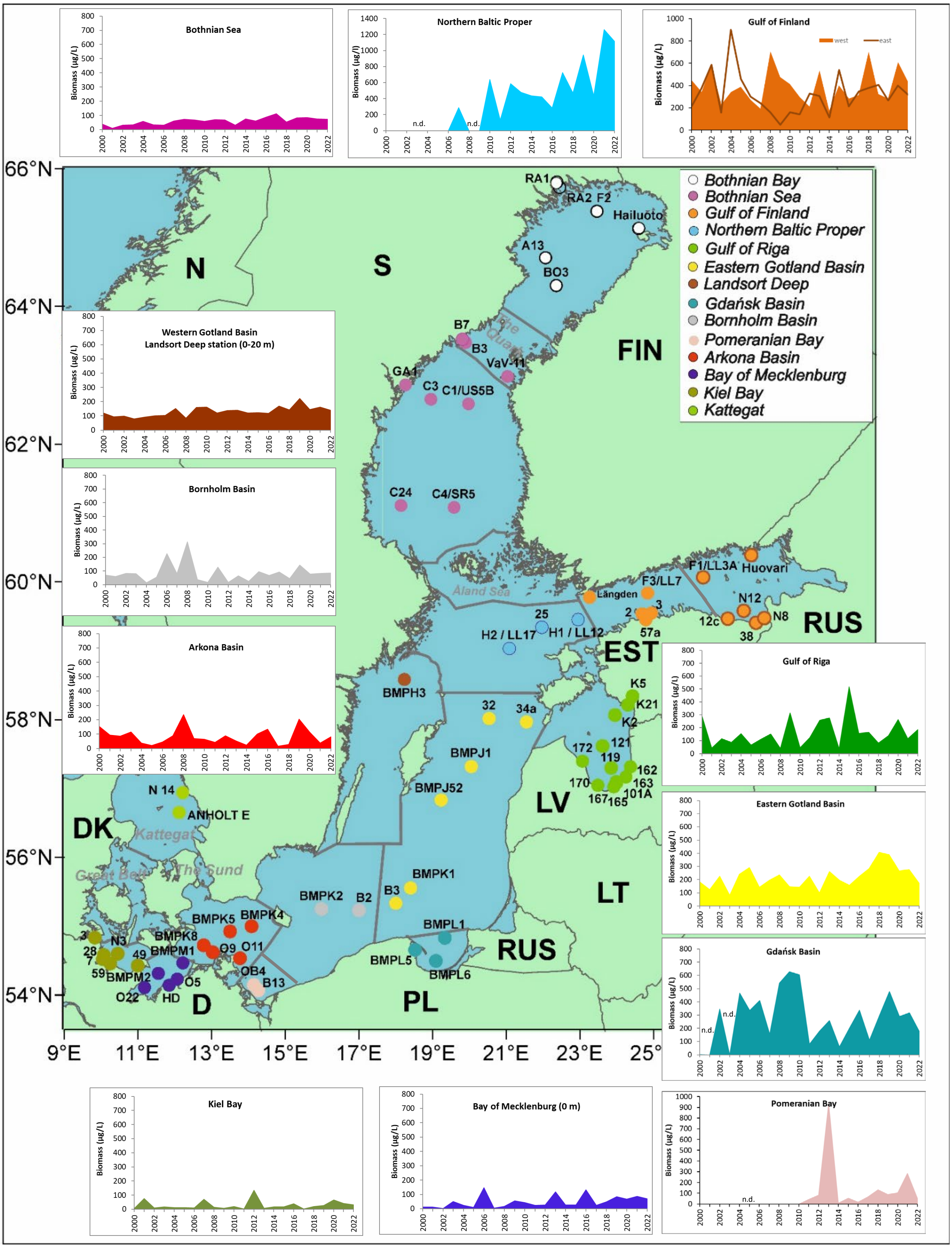
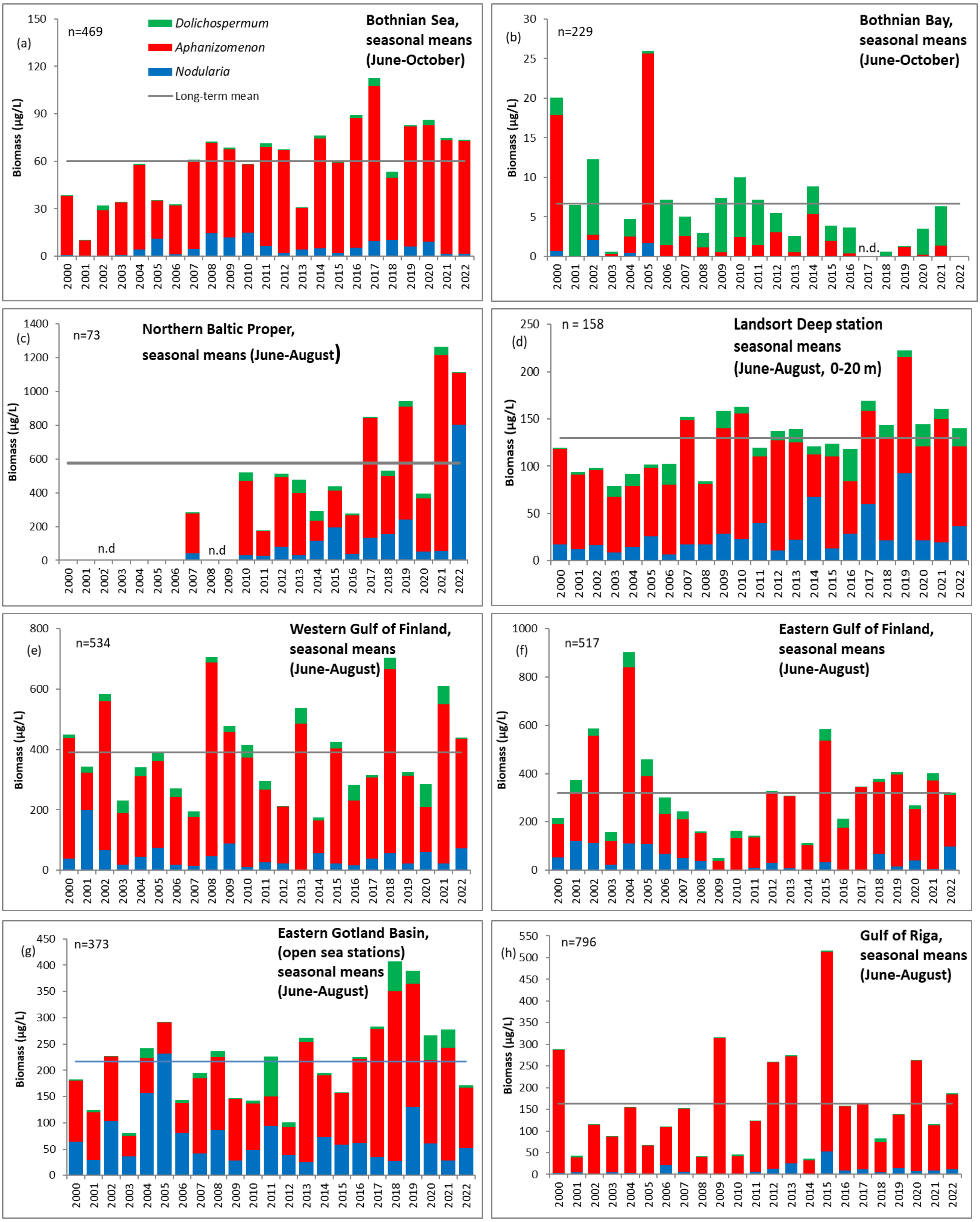


Fig. 1: Map of the regularly sampled stations, containing one graph on nitrogen-fixing (diazotrophic) cyanobacteria biomass per area (seasonal mean biomass in µg / L); Stations in Bothnian Bay and Kattegat tested but results not presented. "n.d." = no sufficient data. Please note that the Pomeranian Bay graph has a different scale in the x axis compared to others.


(a) n=469
Dolichospermum
Aphanizomenon
Nodularia
Long-term mean
Bothnian Sea, seasonal means (June-October)
Biomass (µg/L)
(b) n=229
Bothnian Bay, seasonal means (June-October)
n.d.
(c) n=73
Northern Baltic Proper, seasonal means (June-August)
n.d
(d) n = 158
Landsort Deep station seasonal means (June-August, 0-20 m)
(e) n=534
Western Gulf of Finland, seasonal means (June-August)
(f) n=517
Eastern Gulf of Finland, seasonal means (June-August)
(g) n=373
Eastern Gotland Basin, (open sea stations) seasonal means (June-August)
(h) n=796
Gulf of Riga, seasonal means (June-August)

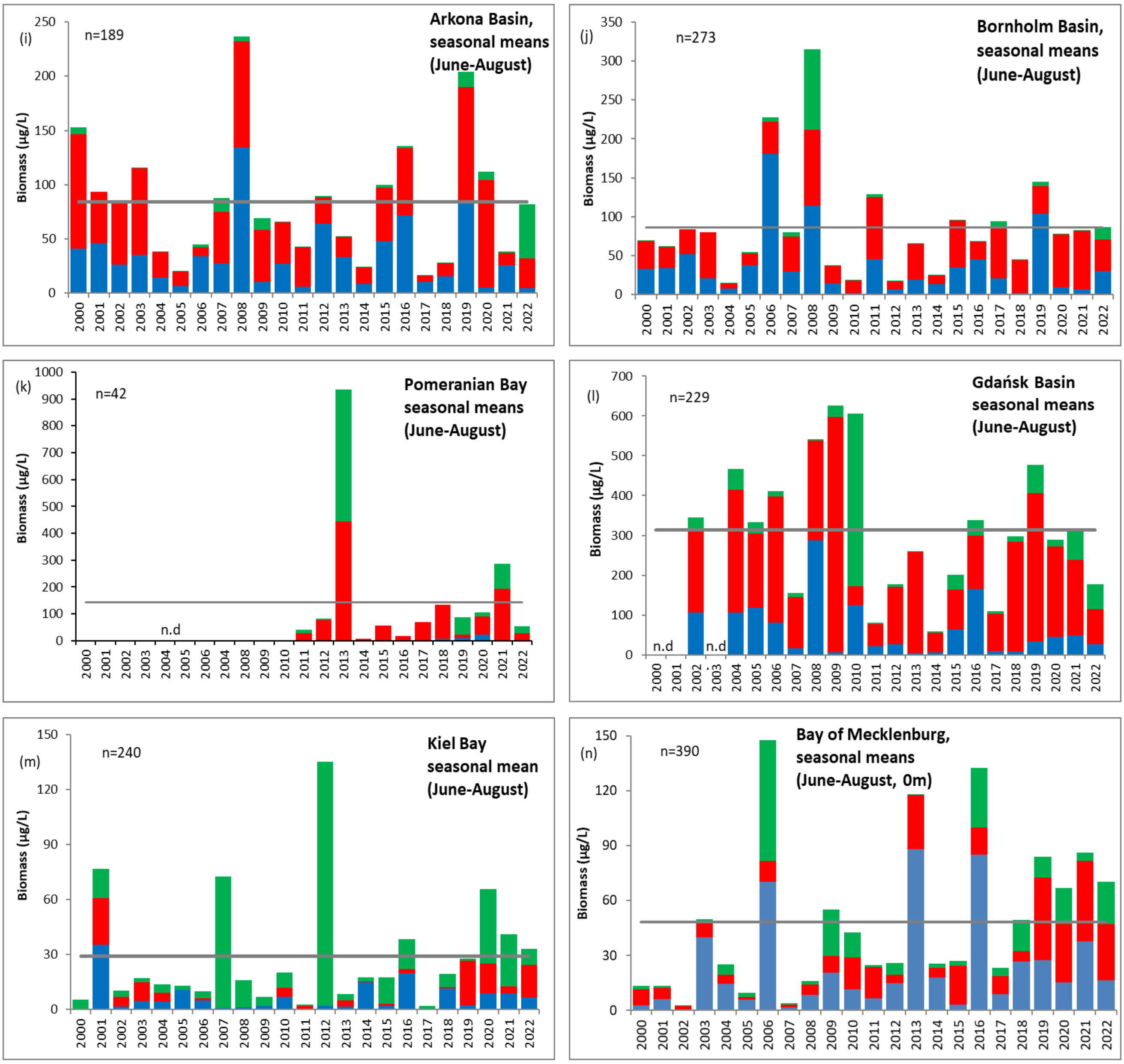


Fig. 2: Mean biomass (wet weight, µg/L) of the three bloom-forming nitrogen-fixing cyanobacteria genera in the different Baltic Sea areas (a-n) during their blooming period (note the different scales for the separate diagrams). The long-term mean per area (all species together) is indicated by a horizontal line. “n” is total number of samples analysed for this region, “n.d.” = no sufficient data or no data at all.

Metadata

Technical information

1. Data source: Danish, 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 µg / L) in integrated samples (0-10 m; 0-20 m at the Landsort Deep station; surface = 0-1 m in Bay of Mecklenburg; 0-5 m at the Polish high-frequency coastal station BMPL5). 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 ca. 2x Secchi depth (usually 0-8 m, maximum depth is 10 m); they could be integrated into the existing data series without problems. Genera included in index: *Nodularia*, *Aphanizomenon* and *Dolichospermum* (previously *Anabaena*) (see Fig. 3).

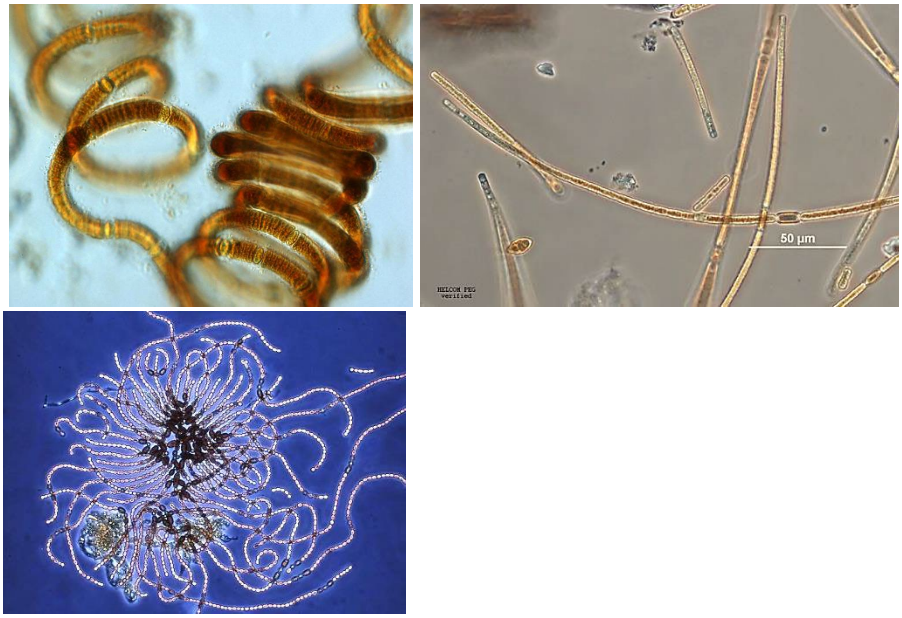


Fig. 3: Genera included in index, from left: *Nodularia* (taken by Irina Olenina), *Aphanizomenon* (taken by Susanne Busch) and *Dolichospermum* (previously *Anabaena*, taken by Helena Höglander).

http://nordicmicroalgae.org/taxon/Nodularia%20spumigena?media_id=Nodularia%20spumigena_8.JPG&page=2

http://nordicmicroalgae.org/taxon/Aphanizomenon?media_id=Aphanizomenon_5.jpg

http://nordicmicroalgae.org/taxon/Dolichospermum%20lemmermannii?media_id=Dolichospermum%20lemmermannii_2.jpg&page=2

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

4. Temporal coverage: Summer 2000-2022 (June-August, in the Bothnian Sea June-October). Note that the year 2003 is missing from the Gdańsk Basin, 2008 and 2009 from the Northern Baltic Proper. 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 Gdańsk Basin in 2002 and Kiel Bay in 2000, from Northern Baltic Proper 2007, from Pomeranian Bay 2011 (Figs.1 and 2).

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 2021).

Additional explanation on the counting procedure using size classes was given by Olenina et al. (2006). Sampling frequency varies 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, Poland and Finland) had to be rejected because of too low sampling frequency. Other more coastal data (from Gulfs of Bothnia, Finland, Riga and the Gdańsk Basin, see Fig. 1) are included, as they were close to the open sea stations and their sampling frequency was high (Fig. 1).

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 strength is the availability of comparable multi-decadal genus-specific biomass data. The main weaknesses are the low number of sampling stations and the low seasonal coverage in the sampling frequency. Monitoring cruises into the open Baltic Sea are expensive and can be conducted only a few times per year by the countries involved. 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 m, or at specific stations 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 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 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 phytoplankton proficiency test (Vuorio et al. 2015), which was participated by many HELCOM PEG members, included identification test for *Aphanizomenon flosaquae* and *Nodularia spumigena*, and counting test for *Aphanizomenon* sp. Similar phytoplankton proficiency test provided in 2020 included test for *Dolichospermum lemmermannii* identification. The uncertainties concerning sampling 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 (https://www.ices.dk/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. The basic data for this BSEFS are integrated into a Cyanobacteria Bloom indicator, called "CyaBl Index", for the implementation of the Marine Strategic Framework Directive. In order to be able to utilize the ICES database for the long-term trend analyses, the database should be updated annually, and kept harmonized concerning taxonomy and biovolume calculation formulae since the beginning of the study period. At the moment, data for this BSEFS has been collected yearly from the national EG PHYTO representatives.

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