Cyanobacteria biomass, 1990-2019

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*. During the study period 1990–2019 (June-August), the highest biomass occurred in the Gulf of Finland, whereas no or low biomass of nitrogen-fixing cyanobacteria appeared in the Bothnian Bay and the Kiel Bay/Kattegat area.
- Biomass of nitrogen-fixing cyanobacteria may show opposing trends between different sea areas. The examples below confirm that the sea areas have to be evaluated separately:
    - Simultaneous occurrence of extremely low biomass in the Arkona Basin and Bornholm Basin versus relatively high biomass in the neighbouring Eastern Gotland Basin in 2004, 2005, 2017 and 2018.
    - In 2017, cyanobacteria biomass was high in the Gulf of Finland (342 µg/L) and the Eastern Gotland Basin (283 µg/L) but very low in the southern Baltic Proper (17-79µg/L).
    - Seasonal Mann-Kendall (M-K) tests of temporal trends in time series performed for biomass of diazotrophic cyanobacteria show statistically significant increasing trends in the Bothnian Sea, Landsort Deep and the Bay of Mecklenburg but decreasing trend in the Bornholm Basin in August.
- The year-to-year variability in the biomass of bloom-forming cyanobacteria is high, however, tracking statistically significant trends with M-K tests is possible:
    - Decreasing trend for *Aphanizomenon* biomass in Arkona Basin.
    - Decreasing tendency for *Nodularia* biomass in the Eastern Gotland Basin and the Gulf of Finland.
    - Decreasing trend for sum of Nostocales biomass in the Bornholm Basin but only in August.
    - Increasing cyanobacteria biomass (sum of Nostocales, *Aphanizomenon* and *Dolichospermum*) in the Bothnian Sea since the mid of the 1990s and at the Landsort Deep station (for sum of Nostocales, *Nodularia* and *Dolichospermum* biomass) as well as to a small extent in the Bay of Mecklenburg (for sum of Nostocales, *Nodularia*, *Aphanizomenon* and *Dolichospermum*).
- The genus *Nodularia* is more common in the central and southern part of the Baltic Sea compared to the northern part – the gulfs of Bothnia, Finland and Riga, where the genus *Aphanizomenon* dominates.

Results and Assessment

Relevance of the cyanobacteria biomass 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 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), nitrogen-fixing cyanobacteria may be considered as a “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 nitrogen-fixing cyanobacteria seem to have increased at least since the 1960s (Finni et al. 2001, Funkey et al. 2014). If cyanobacteria occur in large blooms, they indicate and contribute to eutrophication, oxygen depletion in deep waters and toxic effects. The displeasing view of the coloured surface scum alone 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 the long-term documentation of the nitrogen-fixing cyanobacteria biomass development.

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 extension of the bloom during summer based on satellite data is available (BSEFS “Cyanobacterial blooms in the Baltic Sea”, Öberg 2018). In contrast to semi-quantitative rank data and satellite image data, our BSEFS presents quantitative biomass data and 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 whereas similar hepatotoxicity of *Aphanizomenon* has not been confirmed in the Baltic Sea., Though Cox et al. (2005) have reported potential for production of a neurotoxic amino acid β-N-methylamino-L-alanine (BMAA) within the strains of Baltic Sea *Aphanizomenon*.

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 HELCOM pre-core eutrophication indicator Cyanobacterial bloom index is implemented (HELCOM 2018a) and used in the Second HELCOM holistic assessment (HELCOM 2018b). It tries to combine satellite observation data with the biomass monitoring data delivered by the HELCOM Phytoplankton Expert Group (PEG). The biomass data are identical with the data used for this Baltic Sea Environment Fact Sheet, but this BSEFS gives also deeper additional information on the differences in the biomasses of genera *Nodularia*, *Aphanizomenon* and *Dolichospermum* in different Baltic Sea areas.

Assessment

The first Baltic Sea Environment Fact Sheet on the cyanobacteria biomass was published in 2011. Just like the earlier Indicator Fact Sheet "Cyanobacteria bloom index", 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). When the distances between the coastal and open sea stations were less than 70 km, the data were combined.

Stations were pooled by sea areas (Fig. 1) in order to get representative data. This pooling also included 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 (June-August) are presented in Fig.1. In the Bothnian Sea, cyanobacteria blooms may extend up to October; therefore the season is defined in this area from June to October. Recently, blooms have extended to September and even later also in some other areas. In order to keep consistency with earlier reports, we still considered only the period from June to August. As shown in earlier fact sheets of the PEG, phytoplankton trends may be even opposite in the different sea areas (e.g. Jaanus et al. 2007). Therefore, separate diagrams for the most relevant sea areas were produced.

In this BSEFS on Cyanobacteria biomass, 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. Specific information on these three cyanobacteria genera is shown in Fig. 2 and 3. Statistically significant temporal trends of variability of biomass of particular genera and their sum in the separate areas are presented in Tab. 1 together with the mean biomasses for the period 1990-2019 (or the period with the longest continuous time series with gaps not longer than one year).

In the Bothnian Bay, the cyanobacteria biomass, dominated mainly by *Aphanizomenon*, is usually low (monthly average < 50 µg/L) and the results are not presented in a separate figure.

In the Bothnian Sea, nitrogen-fixing cyanobacteria are more relevant than in the Bothnian Bay. In this region there is a tendency of earlier bloom start (cf. Kahru and Elmgren 2014), but moderate (150–200 µg/L) cyanobacteria biomass is also found in autumn. Therefore we kept the period from June to October for this area. Starting with very low cyanobacteria biomass in the mid of the 1990s, biomass has increased more or less continuously (Andersson et al. 2015). Moreover, in contrast to earlier years, cyanobacterial blooms were also observed in the northern part of the Bothnian Sea (Lehtinen et al., 2019). Also the statistical analysis (see Metadata – Technical information – 6. Methodology of data manipulation) of the time series of data collected for this BSEFS indicates a significant upward trend in the biomass of diazotrophic cyanobacteria in the Bothnian Sea, which mainly concerns the genera *Aphanizomenon* and *Dolichospermum* (Tab. 1).

In the Gulf of Finland, the highest biomass of the whole Baltic Sea occurred with single peak values from 2000 to 7470 µg/L in the late 1990s and in the beginning of the 2000s, in 2009 and again since 2013. The blooms have been mainly dominated by *Aphanizomenon* with the exception of the year 1999, when *Nodularia* contributed more to the total cyanobacterial biomass. Seasonal Mann-Kendall tests of temporal trends for the Gulf of Finland data collected for this BSEFS show that there is no significant change in the biomass of diazotrophic cyanobacteria in the period 1993-2019. Only a small downward trend was observed for the genus *Nodularia*, which anyway represents only 14% of the mean biomass of cyanobacteria in this basin.

The Finnish coastal station “Nau 2361 Seili intens” was the only station situated in 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”. Thus, data for Archipelago Sea is not presented.

In the Gulf of Riga, high seasonal average 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 6 July, almost exclusively based on *Aphanizomenon* (1360 µg/L at station 165). In 2018, cyanobacteria biomass was three times lower than in 2017 and by half lower than the long-term mean. Despite the observed fluctuations of cyanobacterial biomass in the Gulf of Riga, statistical analyses of the data from 1993-2019 period do not indicate any significant change trend for the biomass of all three considered cyanobacterial genera, or for each of them individually.

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 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 31 July and it was the second highest peak from 1990. The first one (551 µg/L) was recorded on 7 July 1999. Thus, the size of the biomass of both peaks is comparable, while the quality composition of both peaks is diametrically different. In 1999 *Nodularia* constituted 2%, *Aphanizomenon* 87% and *Dolichospermum* 11% of the biomass peak of diazotrophic cyanobacteria, 20 years later the proportion looks respectively 70% : 28% : 2%. This phenomenon is also reflected in the results of statistical analyses (Tab.1), which indicate a significant upward trend for the biomass of *Nodularia.* Additionally there is a slight increase for the biomass of *Dolichospermum* at the Landsort Deep. The total biomass of diazotrophic cyanobacteria, where *Aphanizomenon* contribute on average 76% of the biomass, has statistically significant increasing trend for the period 1994-2019, probably due to the increasing trend for *Nodularia*.

Data from the Eastern Gotland Basin were contributed by Finland, Germany, Lithuania, Poland and Sweden. Nevertheless, the data basis is rather poor. The biomass peak of the genera considered was recorded on 28 June 2018 (975 µg/L). Mean cyanobacteria biomass increased compared to 2017 and significantly exceeded the long-term mean (197 µg / L). The increase in biomass occurred both in the open sea and the coastal area, where it was necessary to close the beaches even for two weeks in July. (For exemplar along the Polish coast of the

Eastern Gotland Basin it was recorded around 30 such events according to the announcements of the State Sanitary Inspection https://sk.gis.gov.pl/index.php/kapielisko/112). Although the average biomass of cyanobacteria in 2019 (196 µg/L) decreased to a value close to the long-term mean, a peak of 793 µg/L was recorded on 14 July at BMP J1 station. 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 diazotrophic cyanobacteria decreased in 2019. However, statistical analyses do not indicate any trends in total filamentous cyanobacteria biomass. On the other hand, there is detected a slight downward trend of *Nodularia* biomass and a slight upward trend of *Dolichospermum* biomass (Table 1).

In the BSEFS Cyanobacteria biomass from previous years, data from the Gdańsk Basin were not considered separately due to the lack of data from the 1990s meeting the criteria of the methodology (averages of at least three months June-August), and some of them were combined with the Eastern Gotland Basin data. For the first time the Gdańsk Basin was considered in 2018 BSEFS based on the available data series from the period 2004–2018 and single years: 2000 and 2002 (Fig. 1 and Fig. 2h). Data from stations previously included in the Eastern Gotland Basin analysis have now been transferred to the Gdańsk Basin database. Cyanobacteria 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). Long-term mean of cyanobacteria biomass in the Gdańsk Basin is lower than for the Gulf of Finland and higher than for the other Baltic Sea areas. The single peak values were observed in 2004 (1335 µg/L), 2008 (2408 µg/L), 2009 (4693 µg/L), 2010 (6621 µg/L), 2013 (2989 µg/L), 2015 (1090 µg/L) and 2019 (1171 µg/L). Among the genera observed in that region *Aphanizomenon* dominated although in some years the contribution of *Nodularia* (2008, 2010, 2016) and *Dolichospermum* (2010, 2019) was significant. As in the case of the Gulf of Riga, no trends in the biomass of diazotrophic cyanobacteria were found in the Gdańsk Basin (Table 1). This may be related to a short time series of data (18 years) and a small number of data (n=175) for the Gdansk Basin.

Cyanobacteria 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 biomass of cyanobacteria increased above the long-term mean (105 µg/L), and on 15 July, for the first time since 2015, even exceeded (337 µg/L) the bloom value established in Wasmund (1997). In this blooming event *Nodularia* had 86% share. When the continuous data series for the period 1997-2019 is taken into account, there is no statistically significant trend for the Bornholm Basin except for the downward trend of the Nostocales sum in single month August.

In the Arkona Basin, cyanobacteria biomass seems to decrease during the investigation period. Indeed, the lowest mean biomass was found in 2017 with a seasonal maximum of only 110 µg/L on 13 August. However, statistical analysis of data from the Arkona Basin does not show significant trend for cyanobacteria biomass but only decreasing trend for genus *Aphanizomenon* (forming 57% of the biomass of cyanobacteria on average).

In the Bay of Mecklenburg, 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 cyanobacterial 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 biomass peaks in 1993, 1994, 2006, 2013 and 2016 (Fig. 2 b). In 2018, high cyanobacteria biomass of 588 µg/L was found at the Mecklenburg coast only on 17 July and was dominated by *Nodularia* (Wasmund et al. 2019), similarly to the maximum recorded on July 16, 2019 amounting to 370 µg/L. The Seasonal Mann-Kendall test carried out for the Bay of Mecklenburg showed statistically significant upward trends in the biomass of all diazotrophic cyanobacteria under consideration (Tab. 1).

Data from the Bay of Mecklenburg and Kiel Bight 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 in order to prevent mixing of different methods.

The cyanobacterial biomass in Kiel Bight, starting in 2000, was generally low (maximum summer average 167 µg/L in 2012) and is thus not presented in a figure. The biomass peak samples were almost exclusively dominated by *Dolichospermum*.

Also Kattegat data are not presented because of generally low cyanobacteria biomass, which indicates that heavy cyanobacteria blooms 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.

From the above considerations it follows that due to high variability, no clear trends were generally detected in the biomass of diazotrophic cyanobacteria during the period 1990–2019. However, a non-parametric Seasonal Mann-Kendall test (Hirsch and Slack, 1984) revealed some statistically significant temporal trends both in the total biomass of N_2-fixing filamentous cyanobacteria and in the biomasses of individual genera (Table 1). An increase in total biomass of diazotrophs was confirmed in the Bothnian Sea, in the Bay of Mecklenburg and Landsort Deep. For *Dolichospermum* only increasing trends were found (Eastern Gotland Basin, Bay of Mecklenburg, Bothnian Sea and Landsort Deep), while for *Nodularia* the analysis revealed both increase (Bay of Mecklenburg, Landsort Deep) and decrease (Eastern Gothland Basin, Gulf of Finland) in biomass values.

The results of testing the data series until 2019 confirm the direction of change for cyanobacterial 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; Huseby et al., 2019), the Gulf of Finland (Suikkanen et al., 2013) and Bothnian Sea (Andersson et al., 2015; Lehtinen et al., 2016). Most of observations indicate rather fluctuations in surface blooms instead of continuous long-term trends (e.g. Kahru et al. 2018).

Large variations between different areas may occur. For example, cyanobacterial biomass was exceptionally low in the Arkona Basin and Bornholm Basin in 2004, 2005, 2017 and 2018 but high in the Eastern Gotland Basin at the same time. The basin-wide differences in bloom distribution are also known from satellite images (Kahru and Elmgren 2014, Kahru et al. 2018, Öberg 2018). This stresses the importance of dividing the Baltic Sea into sub-regions and treating them separately.

Although the satellite images give valuable information on the spatial differences in cyanobacteria abundances, numerous discrepancies between satellite observations 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 2018). Also at station Landsort Deep there is only little systematic correlation between the 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 specific weather conditions (clear sky) whereas ship-based measurements are not so selective. If wind mixes the cyanobacterial biomass into the water, surface accumulations will not form even though cyanobacterial biomass was high. On the other hand, calm winds may enable surface blooms to become visible even though actual cyanobacteria biomass was not exceptionally high.

As shown in Fig. 2 and Tab. 1, *Aphanizomenon* is dominating in the northern regions of the Baltic Sea whereas *Nodularia* is mostly dominating in the southern Baltic Sea. This may reflect: (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* 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. Moreover, *Nodularia* has a higher temperature optimum (20–25 °C) than *Aphanizomenon* (16–22 °C) according to Lehtimäki et al. (1997). *Aphanizomenon* seems to be able to utilise upwelled nutrients, while *Nodularia* seems even negatively affected by upwelling events (Munkes et al., 2020).

Dolichospermum is of less quantitative importance (2-15% of mean cyanobacteria biomass, depending on area).

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Data

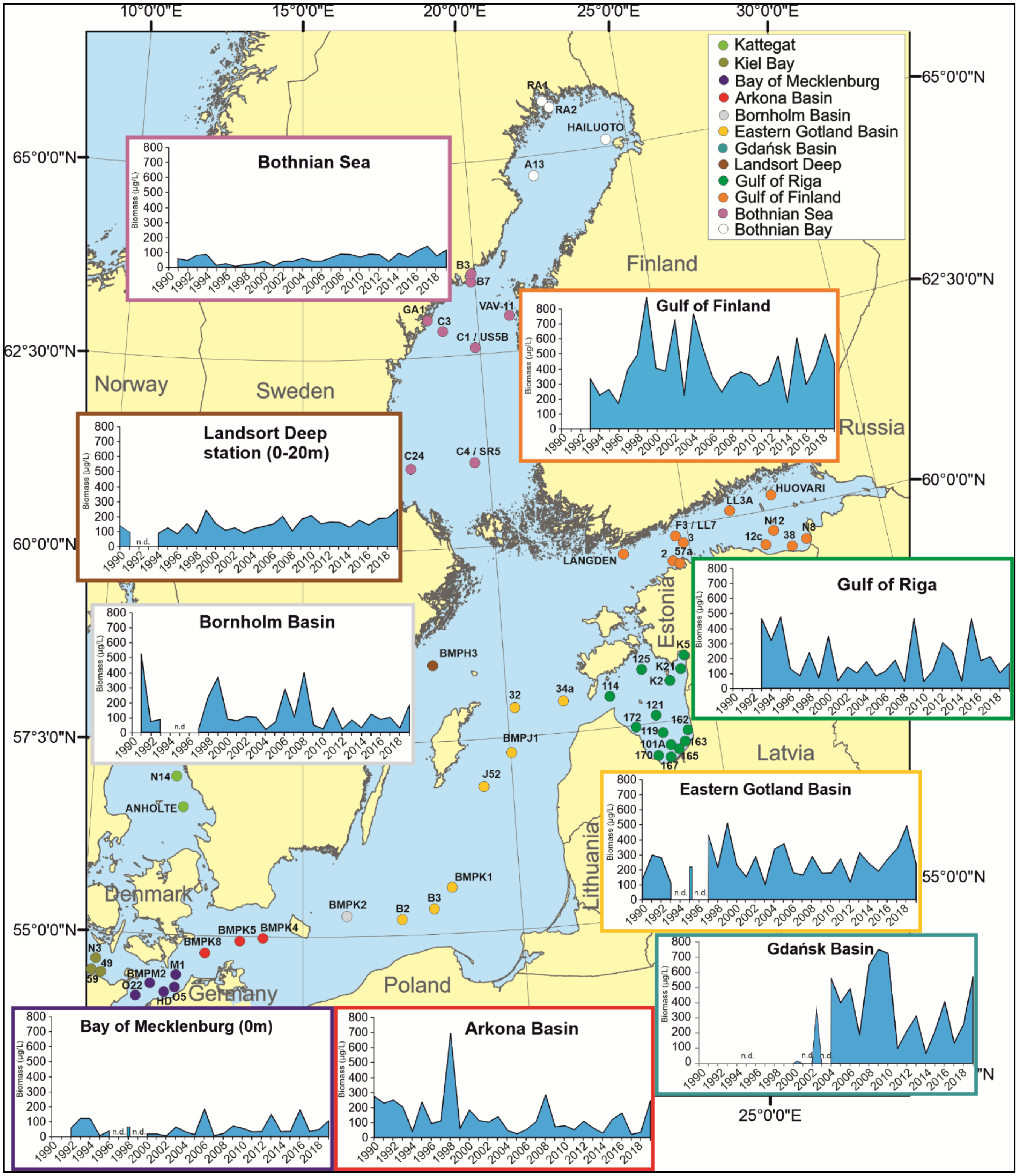
Kattegat
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Eastern Gotland Basin
Gdańsk Basin
Landsort Deep
Gulf of Riga
Gulf of Finland
Bothnian Sea
Bothnian Bay
Bothnian Sea
Gulf of Finland
Landsort Deep station (0-20m)
Bornholm Basin
Gulf of Riga
Eastern Gotland Basin
Gdańsk Basin
Bay of Mecklenburg (0m)
Arkona Basin
Biomass (µg/L)
Norway
Sweden
Finland
Russia
Estonia
Latvia
Lithuania
Denmark
Germany
Poland
10°0'0"E
15°0'0"E
20°0'0"E
25°0'0"E
30°0'0"E
65°0'0"N
62°30'0"N
60°0'0"N
57°3'0"N
55°0'0"N

Fig. 1: Map of the regularly sampled stations, containing one graph on diazotrophic cyanobacteria biomass per area (seasonal mean biomass in µg/L); details see in Fig.2. Stations in Bothnian Bay, Kiel Bay and Kattegat tested but results not presented. “n.d.” = no sufficient data.

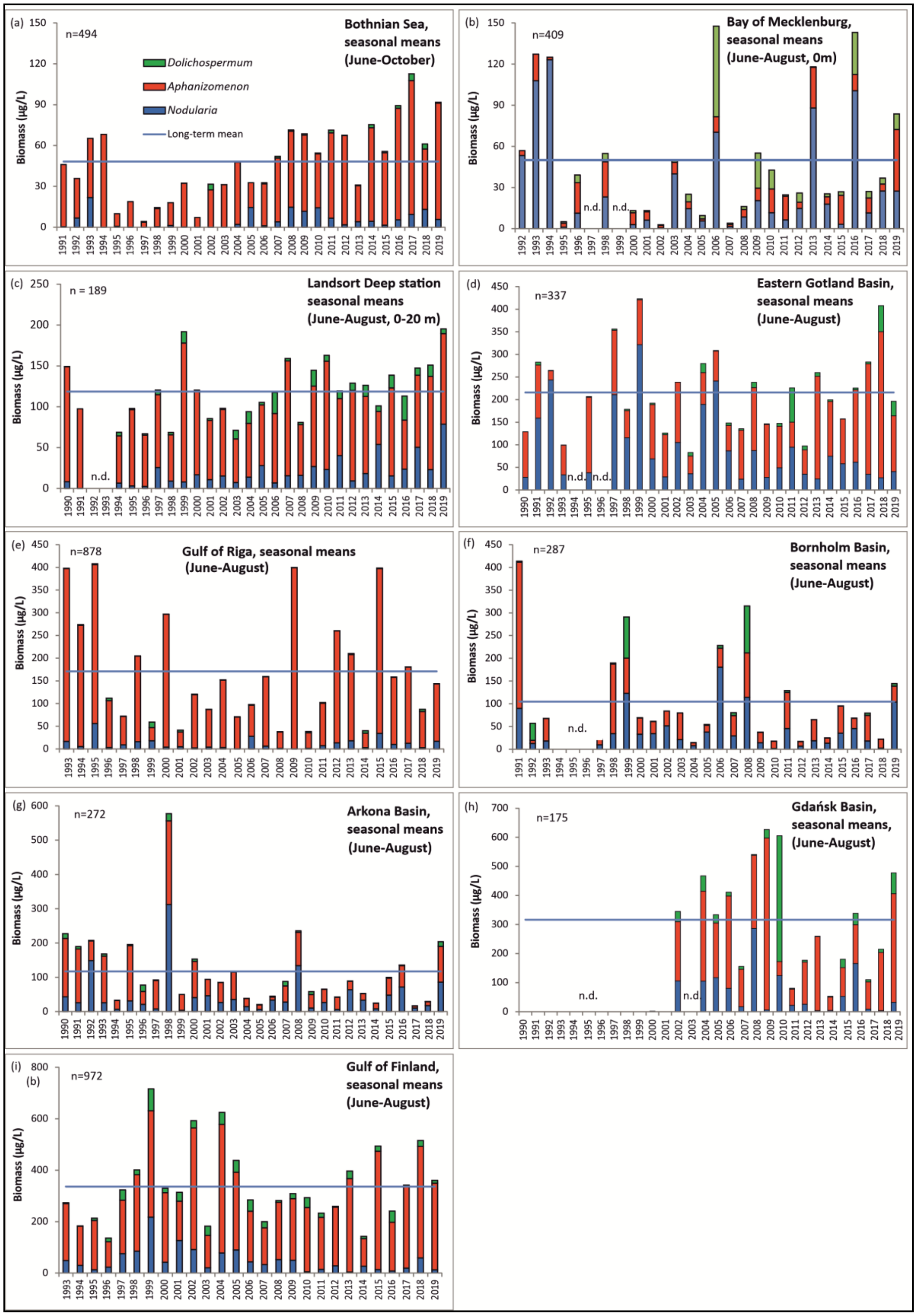

Fig. 2: Mean biomass (wet weight, µg/L) of the three bloom-forming cyanobacteria genera in the different Baltic Sea areas (a-i) during their blooming period (note the different scales). The long-term mean per area (all species

together) is indicated by a horizontal line. “n” is total number of samples analysed for this region, “n.d.” = no sufficient data.

Tab. 1: Results of Mann-Kendall tests of temporal trends in time series of Nostocales,* Nodularia, Aphanizomenon *and* Dolichospermum *biomass and mean values for them during particular testing periods

Area	MK statistic	p-value	Significance code	Slope (change/ unit)	Median	Mean biomass [µg/L]
Mann-Kendall tests of temporal trends in time series of sum of Nostocales						
Bothnian Sea (1991-2019)	489	0,0003	+++	1,08	19,50	48
Gulf of Finland (1993-2019)	77	0,3636		1,14	173,65	336
Landsort Deep (1994-2019)	189	0,0169	+	1,93	95,51	119
Bornholm Basin (1997-2019)	-81	0,1367		-0,57	32,76	95
Gulf of Riga (1993-2019)	-15	0,8919		-0,17	115,50	171
Eastern Gotland Basin (1990-2019)	34	0,6875		0,35	122,88	216
Gdańsk Basin (2002-2019)	-16	0,6793		-3,25	172,94	316
Arkona Basin (1990-2019)	-165	0,0787		-0,98	51,35	117
Bay of Mecklenburg (1992-2019)	325	0,0022	++	0,16	6,20	50
Mann-Kendall tests of temporal trends in time series of Nodularia						
Bothnian Sea (1991-2019)	72	0,3729		0,00	0,00	5
Gulf of Finland (1993-2019)	-129	0,0240	-	0,00	0,00	48
Landsort Deep (1994-2019)	314	0,0001	+++	0,47	8,99	21
Bornholm Basin (1997-2019)	-74	0,1240		-0,14	6,60	43
Gulf of Riga (1993-2019)	-78	0,3936		0,00	2,49	11
Eastern Gotland Basin (1990-2019)	-166	0,0258	-	-0,13	10,38	91
Gdańsk Basin (2002-2019)	-84	0,0708		-1,84	17,82	68
Arkona Basin (1990-2019)	15	0,8667		0,00	11,27	46
Bay of Mecklenburg (1992-2019)	160	0,0318	+	0,00	0,12	31
Mann-Kendall tests of temporal trends in time series of Aphanizomenon						
Bothnian Sea (1991-2019)	477	0,0003	+++	0,87	17,41	42
Gulf of Finland (1993-2019)	107	0,2232		1,48	136,21	263

Landsort Deep (1994-2019)	47	0,5692		0,39	66,22	88
Bornholm Basin (1997-2019)	-56	0,3361		-0,41	18,91	43
Gulf of Riga (1993-2019)	-1	0,9929		-0,10	104,53	158
Eastern Gotland Basin (1990-2019)	118	0,1748		0,83	59,33	115
Gdańsk Basin (2002-2019)	-6	0,8783		-0,36	97,00	202
Arkona Basin (1990-2019)	-263	0,0110	-	-1,15	27,82	67
Bay of Mecklenburg (1992-2019)	269	0,0077	++	0,05	0,91	12
Mann-Kendall tests of temporal trends in time series of Dolichospermum						
Bothnian Sea (1991-2019)	342	0,0002	+++	0,00	0,00	1
Gulf of Finland (1993-2019)	-44	0,6124		0,00	1,84	25
Landsort Deep (1994-2019)	242	0,0094	++	0,04	2,77	9
Bornholm Basin (1997-2019)	-19	0,6976		0,00	0,00	10
Gulf of Riga (1993-2019)	-119	0,2031		0,00	0,17	2
Eastern Gotland Basin (1990-2019)	231	0,0177	+	0,02	1,33	10
Gdańsk Basin (2002-2019)	17	0,6405		0,05	3,64	46
Arkona Basin (1990-2019)	-22	0,8164		0,00	0,04	4
Bay of Mecklenburg (1992-2019)	221	0,0068	++	0,00	0,07	8

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; 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 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 the left: *Nodularia*, *Aphanizomenon* and *Dolichospermum* (previously *Anabaena*).

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 1990-2019 (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, 1997 and 1999 from the Bay of Mecklenburg and 2001 and 2003 from the Gdańsk Basin. 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 and Gdańsk Basin in 2000.

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 2017).

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 coastal data (from Gulfs of Bothnia, Finland and Riga, see Fig. 1) are included, as they were close to the open sea stations and their sampling frequency was high (Fig. 2).

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

The temporal trends for the investigated groups of filamentous cyanobacteria (*Nodularia*, *Aphanizomenon*, *Dolichospermum* and the sum of all Nostocales) were tested with a non-parametric Seasonal Mann-Kendall test

(Hirsch and Slack, 1984) with autocorrelation set to one and using month as a class variable. All data series collected until 2019 were used to test each of the Baltic Sea regions separately (Table 1).

Analysis was performed using the software Multitest (http://www.miljostatistik.se/mannkendall.html , Linköping University). We have used following the M-K tests offered by this software:

- Ordinary M-K tests for monotone trends in univariate time series (for separate month or station etc.)
- Multivariate M-K (Hirsch and Slack, 1984) tests for common monotone trends in multiple time series (for all months or for all stations).

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. 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 (http://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 Environment Fact Sheet are integrated into a Cyanobacteria indicator, called “CyaBl”, 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 (since year 1990). At the moment, data for this BSEFS has been collected yearly from the national PEG representatives.

FOOTNOTES

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http://www.helcom.fi/baltic-sea-trends/environment-fact-sheets/eutrophication/cyanobacteria-biomass/