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Biological assessment of the Baltic Sea 2018

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Abstract

Dating to 1979, the HELCOM time series on species composition, biomass and abundance of phyto- and zooplankton as well as macrozoobenthos from Kiel Bay to the Eastern Gotland Basin was continued in 2018.

The phytoplankton spring bloom was well developed in the mid of March in the Belt Sea as a diatom bloom (*Skeletonema marinoi, Thalassiosira* spp.), but the importance of *Mesodinium rubrum* increased into eastern direction combined with a shift of the spring bloom peak to May. The bloom peak was primarily formed by *Mesodinium rubrum* in the Bornholm Basin, but by *Peridiniella catenata* in the Eastern Gotland Basin in the mid of May. A strong diatom (*Dactyliosolen fragilissimus*) bloom occurred in the Belt Sea and nitrogen-fixing cyanobacteria dominated in the Eastern Gotland Basin in July. The autumn bloom was composed of dinoflagellates (*Ceratium* spp.) and diatoms (*Thalassiosira* spp.) in Kiel Bay. Farther to the east, the relative importance of dinoflagellates decreased and that of diatoms (*Cerataulina pelagica*, *Coscinodiscus granii*) increased.

The chlorophyll *a* concentrations were highest (16.2 mg m^{-3}) during the spring in the southern part of the Eastern Gotland Basin.

The seasonal pattern of vertical export of particulate organic matter in the Arkona Basin in 2018 showed a spring and a summer bloom, both dominated by diverse diatoms. A cyanobacteria bloom could not be identified in the settled material. Correspondingly, the $\delta^{15}N$ signature indicates much lower nitrogen fixation rates than in the former years.

The zooplankton was characterized by a general late seasonal development. The stock size increased in May in all areas. Rotifers and cladocera increased in abundance after some years of low density and dominated not only in the Arkona Basin, but also in the Bay of Mecklenburg. The spring and summer concentrations of the zooplankton remained low below the long-term average for the period 2000-2018, but showed a considerable increase by a factor of three from the historical minimum in 2016 . The species inventory shows a decline in the number of taxa which was related to a lower number of halophilic species, larvae of benthic species and gelatinous cnidarian species compared to preceding years.

The 119 species found in the macrozoobenthos in 2018 mark a low diversity. The species number at the 8 monitoring stations ranged between 15 and 62. The oxygen supply in bottom waters was not always higher than 2 ml/l, but basically no oxygen depletion was observed with one exception. After a short recovery in 2017 we observed again a dramatically decrease (bisection) of diversity and abundance in the Fehmarnbelt area, probably because of low oxygen supply in July in this region. Depending on the region, the abundances ranged from 46 to 9.860 ind./m^2, and the biomass (ash free dry weight) from 0.4 g/m^2 to 47.5 g/m^2. Fifteen species of the German Red List (Categories 1, 2, 3 and G) were observed.

Six non-indigenous species were recorded in the macrozoobenthos in 2018, which was a relatively low number. With *Rangia cuneata* a bivalve species originating from North America was found at the monitoring stations for the first time. Regarding the zooplankton, the copepod *Acartia tonsa* and the anthomedusae *Lizzia blondina* were regularly observed.

1. Introduction

This report presents the results of the biological monitoring carried through at the Leibniz-Institute for Baltic Sea Research in Warnemünde (IOW). Within Germany's Exclusive Economic Zone (EEZ), monitoring is undertaken on behalf of the Federal Maritime and Hydrographic Agency (BSH); in the Baltic Proper (Bornholm Basin, Eastern Gotland Basin), long-term data collection is financed from the IOW's own budget.

The biological monitoring is one element of the international environmental monitoring programme of the Helsinki Commission (HELCOM) in which the IOW's predecessor institute had participated since its launch in 1979. Besides marine biology, the monitoring programme also includes an extensive programme of hydrographic and chemical investigations (NAUMANN et al. 2019). The establishment of the IOW in 1992 assured the continuance of re-unified Germany's contribution to the HELCOM Monitoring Programme. International monitoring results were collected, discussed and published by HELCOM in Periodic Assessments (HELCOM 1987, 1990, 1996, 2002). More recently, specialized Thematic Assessments are published, for example on the influence of climatic change (HELCOM 2013a), endangered species (HELCOM 2013b) and eutrophication (HELCOM 2014). In a similar manner, short reports known as the 'Baltic Sea Environment Fact Sheets' (formerly 'Indicator Fact Sheets') are published annually (e.g. ÖBERG 2017, WASMUND et al. 2018b).

On national level, the German coastal states coordinate their measurements in the 'Arbeitsgemeinschaft Bund/Länder-Messprogramm Nord- und Ostsee' (ARGE BLMP). The collected data are transferred annually to ICES (International Council for the Exploration of the Sea, see http://www.ices.dk/indexnofla.asp). One of the main tasks is the national coordination of the contributions to the EU's Marine Strategy Framework Directive (MSFD) (see http://www.blmp-online.de/Seiten/Infos.html). The MSFD (EUROPEAN UNION 2008; Directive 2008/56/EG) creates the regulatory framework for the necessary measures in all EU member states to achieve or maintain 'good environmental status' in all European waters by 2020.

In order to determine the 'good environmental status', it is necessary to elaborate indicators. Members of the Biological Oceanography section of the IOW are involved in the development or at least contributing to the following HELCOM 'Core' and 'Pre-core' indicators in connection with descriptors for biodiversity (D1), non-native species (D2), food web (D4) or eutrophication (D5); see for example HELCOM (2013c):

- Zooplankton mean size and biomass
- State of the soft-bottom macrofauna communities
- Population structure of long-lived macrozoobenthic species
- Cumulative impact on benthic habitats
- Extent, distribution and condition of benthic biotopes
- Trends in arrival of new non-indigenous species
- Chlorophyll *a* concentrations
- Diatom/Dinoflagellate Index
- Seasonal succession of dominating phytoplankton groups
- Cyanobacterial surface accumulations

These indicators are applied on the international (HELCOM) and/or national level for the evaluation of the status of the marine environment. The monitoring data collected by IOW provide a solid basis to develop some of these indicators and to assess the state of the environment in the frame of the Marine Strategy Framework Directive. Especially for the elaboration of the Diatom/Dinoflagellate Index on the national basis, a project was funded by the Bundesamt für Naturschutz (16.09.2015 – 15.05.2016; see WASMUND&POWILLEIT 2016) and the indicator was made applicable for the Belt Sea and the Baltic Proper (WASMUND 2017a; WASMUND et al. 2017a). One product is the Second Holistic Assessment of HELCOM (HELCOM 2017a).

Close cooperation between oceanographers, marine biologists and marine chemists within IOW permits the comprehensive scientific analysis of the collected biological data which are interpreted in the light of the 2018 hydrographic-hydrochemical assessment of the Baltic Sea that has already been published (NAUMANN et al. 2019).

Dr. NORBERT WASMUND wrote the chapters on phytoplankton and chlorophyll; Dr. JÖRG DUTZ wrote the chapter on zooplankton; and Dr. MICHAEL L. ZETTLER wrote the chapter on macrozoobenthos. Dr. ANKE KREMP was in charge of the sediment traps.

2. Material and Methods

2.1 Sampling Strategy

The functions undertaken by IOW in the monitoring programme are prescribed by the BSH (BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE 2017), and they follow HELCOM guidelines. Biological monitoring by IOW includes determining the qualitative and quantitative composition of phytoplankton, mesozooplankton and macrozoobenthos, determining the chlorophyll *a* content of water samples, and analysis of sediment traps. Phytoplankton growth is also tracked by means of satellite images. The methods to be applied are set out in the HELCOM manual (HELCOM 2017b).

Fig. 1 shows the locations of biological monitoring stations. They are named in accordance with the official nomenclature of the ICES Station Dictionary. If space is limited in figures and tables, the 'OMBMP' prefix is omitted in this paper. The equivalents to the internal IOW station numbers are given in Table 1.

Within the regular monitoring program, plankton samples should be collected both on outbound and inbound cruises, if possible. Five cruises yield a maximum of 10 samples per station per year. Samples at stations OMBMPN3 (Kiel Bay), OMO22 (Lübeck Bay), OMBMPK4 (Arkona Basin) and OMBMPK1/OMBMPJ1 (Eastern Gotland Basin) are taken on the outward leg only.

Sediment traps were installed in the Arkona Basin sampling area (see station AB in Fig. 1).

Zooplankton samples were regularly taken on the 6 stations in the German exclusive economic zone (Tab. 2). They were taken during outward and return journeys on all cruises as scheduled.

Samples of macrozoobenthos are collected at 8 stations once a year in November (see Table 3, page 12).

Table 1
Sampling statistics (number of sampling events) for different parameters specified for regular monitoring sampling stations in 2018.

Station number	IOW-station number	Sea area	Chloro-phyll	Phyto-plank-ton	Zoo-plank-ton	Zoo-bent-hos
Belt Sea						
OMBMPN3	TF0360	Kiel Bay	5	5	5	1
OMBMPN1	TF0010	Fehmarnbelt	-	-	-	1
OMBMPM2	TF0012	Bay of Mecklenburg	10	10	10	1
OMO22	TF0022	Lübeck Bay	5	5	-	-
OM18	TF0018	Bay of Mecklenburg, south	-	-	-	1
OMBMPM1	TF0046	Bay of Mecklenburg, east	10	10	10	-
Arkona Basin						
OMBMPK8	TF0030	Arkona Basin, west (Darss Sill)	10	10	10	1
OMBMPK5	TF0113	Arkona Basin, central	10	10	10	-
OMBMPK4	TF0109	Arkona Basin, east	5	5	5	1
Pomeranian Bay						
OMBMPK3	TF0152	Pomeranian Bay, north	-	-	-	1
OM160	TF0160	Pomeranian Bay, central	-	-	-	1
Bornholm Basin						
OMBMPK2	TF0213	Bornholm Basin	10	10	-	-
Gotland Basin						
OMBMPK1	TF0259	Eastern Gotland Basin, south	5	5	-	-
OMBMPJ1	TF0271	Eastern Gotland Basin, central	5	5	-	-

2.2 Phytoplankton

As a rule, two phytoplankton samples are taken at each station: a composite sample is mixed from equal parts of surface water from depths of 1 m, 2.5 m, 5 m, 7.5 m and 10 m; in addition, a sample is taken from below the upper pycnocline (usually from a depth of 20 m). If something of interest is present (for instance distinctive fluorescence maxima in deeper layers), additional samples are taken from that depth. Samples (200 ml) are fixed with 1 ml of acid Lugol's solution and are stored until analysis (6 months at most).

The biomass of individual phytoplankton species is analysed microscopically using the standard method according to UTERMÖHL (1958). During counting, individuals are classified not just according to taxa, but also size classes in line with HELCOM guidelines (OLENINA et al. 2006; HELCOM 2017c).

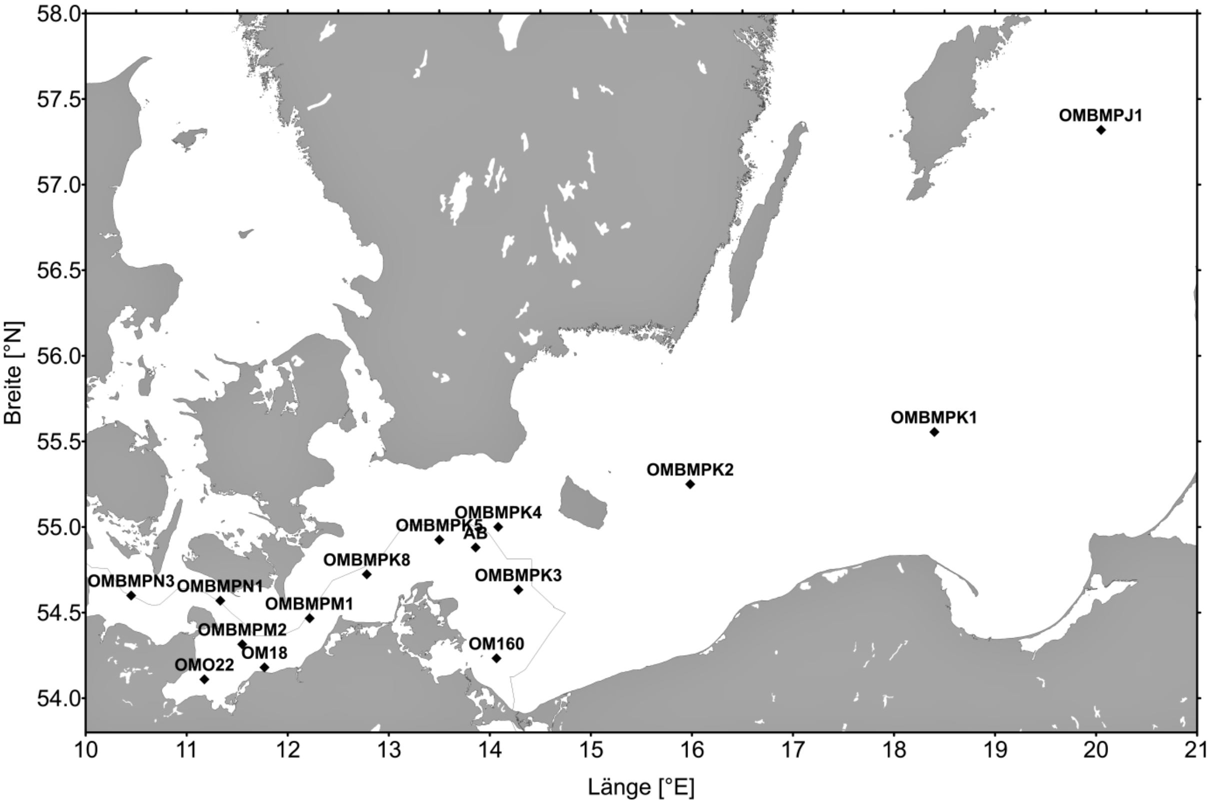

Fig. 1: The station grid for biological sampling in the Baltic Sea with depiction of the border of the exclusive economic zone of Germany.

To obtain a statistically acceptable estimate, at least 50 individuals of the most abundant species need to be counted. Thus for the most common species, a statistical counting error of around 28 % may be assumed. Generally, at least 500 individuals are counted per sample. The error in estimated total biomass is thus clearly reduced (< 10 %). Each species and size class has its own unique volume. This figure is multiplied by the number of counted individuals to obtain the biovolume of a particular species. Assuming a density of 1 g cm^{-3} the figure of biovolume equates to the biomass (wet weight).

The counting, calculation and data output were facilitated by the software "OrgaCount", delivered by AquaEcology Oldenburg. For the cruise of January/February 2018, the species and biovolume list PEG_BVOL2017 was used. The phytoplankton samples of the March, May, July/August and November cruises were analysed with the list PEG_BVOL2018, which was confirmed by PEG during the meeting in April 2018. The latest biovolume file can be downloaded from http://www.ices.dk/marine-data/Documents/ENV/PEG_BVOL.zip.

2.3 Chlorophyll

As chlorophyll *a* represents a share of the biomass of all plant cells, including phytoplankton, its concentration is indicative of the total biomass of phytoplankton. For rough estimates, 1 mg chlorophyll *a* equates to 50 mg of algal organic carbon as assumed by Eilola et al. (2009) and Hoppe et al. (2013) in the Baltic Sea. In reality, the factors are highly variable. Smetacek & Hendrikson (1979) found in Kiel Bay factors of 10-16 in winter, 22 and 69-77 during a growing and starving spring bloom, respectively, 80-110 during summer and 36-56 during the autumn bloom. Lips et al. (2014) reported on C/chl.a ratios of 12-47 in March to May in the Gulf of Finland. More detailed information on these conversion factors can be found in the papers of Spilling et al. (2014) and Paczkowska et al. (2017). Because of the variability of these factors, conversion is not usually done, and the concentration of chlorophyll *a* is taken directly as a phytoplankton parameter.

Samples for the determination of chlorophyll *a* concentrations are collected together with phytoplankton samples at standard depths of 1 m, 5 m, 10 m, 15 m and 20 m, and occasionally at other depths. 200-500 ml of water are filtered through glass-fibre filters (Whatman GF/F) that are flash-frozen in liquid nitrogen (-196°C) and stored in the institute at -80°C for a maximum of three months. 96 % ethanol is used for extraction, as specified by HELCOM (2017d). It is thus possible to omit homogenisation and centrifugation (Wasmund et al. 2006 b).

Several methods are available for determining concentrations of chlorophyll *a*. They are reviewed by Wasmund et al. (2011 a). In addition to chlorophyll *a*, it is possible using the 'acidification method' (Lorenzen 1967) to determine phaeopigment *a*, which contains various constituents (phaeophytin, phaeophorbide) that are essentially regarded as degradation products of chlorophyll *a*. The 'acidification method' is susceptible to significant inaccuracies (cf. Wasmund 1984, Stich & Brinker 2005). Unlike in shallow coastal waters, phaeopigments are not major players in the open sea, so there is no need for the 'acidification method'. This allows us to switch to a simpler and more readily reproducible method that does not involve acidification of the extracts.

In doing so, we no longer obtain a value for chlorophyll *a* that is 'corrected' for phaeopigment ('chl.*a*-cor'); instead we obtain an 'uncorrected' value that we name as 'chlorophyll *a* total' ('chl.*a*-tot'). This is the method recommended by HELCOM (2017d). Between 2008-2010, we used concurrent methods with and without acidification; in 2010 we even used a 'new' and 'old' method in parallel when determining 'chl.*a*-tot' (see Wasmund et al. 2011 a). The 'chl.*a*-cor' and 'chl.*a*-tot-OLD' values were markedly different. Our previous reports have already advised against use of the 'chl.*a*-tot-OLD' values from 2008-2010. The 'new method' used after 2010 is based on a specially configured fluorometer (TURNER-Fluorometer 10-AU-005-CE) that eliminates interference from chlorophyll *b* (procedure by Welschmeyer 1994). The 'chl.*a*-tot-NEW' values were almost identical to the 'chl.*a*-cor' values. Wasmund et al. (2011 a) therefore recommended use of the 'chl.*a*-cor' values up until 2009. After 2010, they recommended use of 'chl.*a*-tot-NEW' values. Continuity in the long-term data series is thus assured. As 'chl.*a*-tot-OLD' values are not measured anymore the nowadays measured 'chl.*a*-tot-NEW' values are simply called 'chl.*a*-tot' (since 2013).

2.4 Sedimentation

Within the IOW Arkona Basin sampling area, rates of vertical particle flux (sedimentation) were measured over the course of the year. To record the amount and quality of material sinking from the surface layer to the sea floor, we moored a programmable sediment trap (type SM 234) with a collection area of 0.5 m² that was equipped with 21 sampling bottles. The mooring was deployed at a depth of 45 m with a surface float and a recovery line, and was retrieved after 3 to 4 months. Sampling intervals ranged between 7 and 10 days. In the mooring, the trap was located below the pycnocline at a depth of 35 m. The collected material was used to perform elemental analyses, determination of the natural isotopic composition of nitrogen and carbon and microscopic taxonomic analyses. The sampling programme in 2018 worked according to the plan. Moorings could be retrieved at regular intervals without any technical or logistical problems and the collection cups turned at the preprogrammed intervals. However, during sampling intervals 21-33 (August to December) material collection was flawed: Collection vials 21 to 30 remained nearly empty, while unusually large amounts of sedimented matter were found in vials 31 to 33. Technical investigation of the problem revealed normal, though slightly loosened rotation of the sampling rosette. Dense colonization of *Balanus* was found upon retrieval of the trap on the collection funnel and screening grid, suggesting blockage of the funnel opening. When the trap was moved for the final sampling, the blockage probably dissolved and all material fell into the remaining vials. This explanation is supported by a large amount of fecal pellets and fragments of diatom frustules, indicating feeding by the respective *Balanus* population.

2.5 Mesozooplankton

Vertical net tows were collected with a WP-2 net of 100 µm mesh size. In the case of a well-mixed water column, zooplankton was sampled with a single net catch taken from a few meters above the sea floor to the surface. Stratified hauls in specific layers were taken when a halocline or a thermocline formed through saline inflows or the seasonal warming of the surface during spring - autumn. Nets were fitted with a flow metre to determine the volume of filtered water. Net angles greater than 30° were avoided during sampling. The samples were fixed in 4 % aqueous formalin solution until processing in the laboratory. In total, 57 zooplankton samples were collected on 50 stations. Table 2 provides the details about the specific depth layers sampled over the season at the monitoring stations.

Table 2
Sample statistics of zooplankton hauls on monitoring cruises between January and November 2018.

Station-label International/ IOW	Period				
	30.01. - 08.02.	19.03. - 27.03.	08.05. - 16.05.	24.07. - 04.08.	05.11. - 14.11.
	Depth from -to (m)	Depth from -to (m)	Depth from -to (m)	Depth from -to (m)	Depth from -to (m)
OMBMPN3	15 - 0	14 - 0	14 - 0	14 - 0	14 - 0
OMBMPM2	22 - 0 21 - 0	20 - 0 20 - 0	21 - 0 21 - 0	21 -0 21 - 0	21 - 0 21 - 0
OMBMPM1	23 - 0 23 - 0	25 - 0 25 - 0	25 - 0 24 - 0	25 - 15 - 0 25 - 12 - 0	22 - 0 22 - 0
OMBMPK8	19 - 0 20 - 0	19 - 0 19 - 0	19 - 0 19 - 0	19 - 0 19 - 0	20 - 0 19 - 0
OMBMPK5	44 - 0 43 - 0	42 - 0 42 - 0	43 - 30 - 0 44 - 30 - 0	43 - 15 - 0 43 - 20 - 0	46 - 0 43 - 0
OMBMPK4	44 - 0	43 - 24 - 0	44 - 0	44 - 18 - 0	46 - 0

The taxonomic analysis was conducted in the laboratory according to HELCOM guidelines that were revised during 2017 (HELCOM 2018). In short, a minimum number of individuals was identified and counted microscopically in a Bogorov chamber. Several subsamples from the total sample were counted. With the exception of nauplii and tintinnids, at least 100 individuals from three taxa were counted. The abundance (ind. m^{-3}) is then calculated from the counts and the filtered volume. The identification of the zooplankton species followed an internal species list of the long-term record of the species inventory as well as the zooplankton atlas of the Baltic Sea (TELESH et al. 2009) and the taxonomic classification of identified specimens is based on the World Register of Marine Species (WoRMS, http://www.marinespecies.org/). In the case of *Bosmina* spp. and *Synchaeta* spp., identification to the species level is unresolved; their abundances were therefore recorded on the level of the genus. In line with the standards of the Integrated Taxonomic Information System (IT IS, https://www.itis.gov/) Bryozoa were listed as Gymnolaemata and Mysidacea as Lophogastridae. The databases of the information system on Aquatic Non-Indigenous Species (AquaNIS, www.corpi.ku.lt/databases/index.php/aquanis) and of the European Network on Invasive Species (NOBANIS, http://www.nobanis.org) served as references for the classification of invasive species.

2.6 Macrozoobenthos

In November 2018, benthos investigations were undertaken at 8 stations from Kiel Bay to the Pomeranian Bay; Table 3 shows their locations. Depending on sediment type, two different Van Veen grab samplers were deployed (980 cm² and 1060 cm², weighing 38 kg - 70 kg, and 23 kg respectively). Three hauls were made at each station. Each haul was rinsed in seawater through a 1 mm mesh sieve. The sieve residue was then transferred to beakers, and fixed in 4 % formalin (HELCOM 2017 b). At all stations, a "Kieler Kinderwagen" botanical dredge with a 1 m rectangular mouth and a mesh size of 5 mm was deployed. Especially in relation to vagile and rarer species, the dredge yielded finds that would have been missed using only the grab sampler.

Further processing of samples was undertaken in the laboratory. After rinsing each haul, taxa were sorted under a binocular microscope at 10-20 x magnification and, except for a few groups (e.g., Nemertea, Halacaridae), were determined to species level. As much as possible, nomenclature complied with the 'World Register of Marine Species (WoRMS)' (http://www.marinespecies.org/index.php). Abundance and biomass were also recorded (ash free dry weight, afdw).

To ensure comparability of weight determinations, HELCOM guidelines were followed (HELCOM 2017 b), and samples were stored for three months before processing. Wet, dry, and ash-free dry weights were measured on a microbalance. The whole procedure of sorting and analysis follows the standard operating procedure (SOP) of the accredited benthos analytical laboratory of the IOW.

Table 3
Station list of macrozoobenthic investigations in November 2018.

	date	depth	north	east	sea area
OMBMPN3	06.11.2018	18.5	54° 36.00	10° 27.00	Kiel Bay
OMBMPN1	06.11.2018	28.5	54° 33.20	11° 20.00	Fehmarnbelt
OMBMPM2	05.11.2018	25.0	54° 18.90	11° 33.00	Bay of Mecklenburg
OM18	05.11.2018	20.5	54° 11.00	11° 46.00	Bay of Mecklenburg, south
OMBMPK8	07.11.2018	22.8	54° 44.00	12° 47.40	Darss Sill
OMBMPK4	07.11.2018	48.3	55° 00.00	14° 05.00	Arkona Basin
OMBMPK3	08.11.2018	31.4	54° 38.00	14° 17.00	Pomeranian Bay, north
OM160	08.11.2018	14.9	54° 14.50	14° 04.00	Pomeranian Bay, central

2.7 Quality Assurance

The main measure for quality assurance was the accreditation in line with DIN EN ISO/IEC 17025:2005 by Deutsche Akkreditierungsstelle GmbH (DAkkS) which took place on 14 and 15 May 2014. It covers the analyses of the phytoplankton, zooplankton, zoobenthos and chlorophyll and the respective documentation and reporting. Audits and re-accreditation were successfully completed in 2018.

Phytoplankton (including chlorophyll), zooplankton, and zoobenthos data are collected in line with standard operating procedures (SOP), and the required documentation is maintained. All results, quality assurance measures, and operating procedures are filed in the quality management system at IOW. QA activities for individual parameters are described here in brief:

Phytoplankton

From every tenth sample, two important species are counted a second time, and the replicate results are entered into the range control chart. This complies with the strategy agreed internationally by the HELCOM Phytoplankton Expert Group (PEG: http://helcom.fi/helcom-at-work/projects/phytoplankton).

Expert identification of phytoplankton species depends on a laboratory technician’s level of knowledge. PEG therefore runs annual training courses and undertakes a ring test. The PEG meeting of 2018 took place in Gothenburg (Sweden) from 9-13 April 2018 and was attended by 29 representatives of all riparian states of the Baltic Sea except for Russia.

Two phytoplankton experts of the IOW participated in all ring tests offered to the Baltic phytoplanktologists. A ring test prepared by the Federal Environment Agency (Umweltbundesamt, UBA) was conducted in 2016, but a first evaluation was shown as late as April 2018 during the PEG meeting. Also the evaluation of the Phytoplankton Proficiency Test (ProfTest SYKE 2017) was presented during that PEG meeting in Gothenburg (see https://helda.helsinki.fi/bitstream/handle/10138/233179/SYKEre_6_2018.pdf?sequence=4). The IOW participants passed with very good results.

As happens every year, the biovolume list of species and size classes was updated for the previous year. Samples taken in January/February 2018 are counted on the basis of the official ICES and HELCOM biovolume file PEG_BIOVOL2017 and following samples on biovolume file PEG_BIOVOL2018.

Chlorophyll

As an internal quality assurance measure, every tenth chlorophyll sample is taken twice and analysed separately to test parallel deviations. The results are entered into the range control chart. The fluorometer is calibrated every six months.

As an external quality assurance measure, IOW regularly participates in chlorophyll comparisons within the QUASIMEME AQ-11 regime (chlorophyll in seawater). The Rounds 2018.1 and 2018.2 were passed with very good results (mean z-scores of 0.25 and -0.7, respectively).

Mesozooplankton

The duplicate analysis of every 10th zooplankton sample was done as an intra laboratory routine to check the reliability of the zooplankton analysis. This was done by an independent analysis of samples by separate analysts or by the repeated analysis of the sample at times when the analysis was conducted by a single analyst. Deviations were well below the threshold value for critical errors.

Macrozoobenthos

The IOW macrozoobenthos working group has participated in all QA measures to date. The results of the latest ring test from summer 2015, presented by the UBA in November 2017, confirmed the high quality of the macrozoobenthos analyses.

3. Abiotic Conditions in 2018

The winter 2017/18 was mild. The summer 2018 was the warmest since the beginning of the record of the summer “heat sum” over the past 71 years. Also satellie-derived sea surface temperature (SST) indicates the warmest year since 1990 with 1.19 K above the long-term SST average. May to August contributed to the record by their high positive anomalies of +4 to 5 K. March and April were characterized by negative temperature anomalies.

The effects of several inflows from 2014 to 2017, which led to oxygenation of the deep water layers up to the Farö Deep in the Northern Central Basin, faded away and phosphate and ammonium concentrations were increasing again. Two weak barotropic inflows occurred during September and December 2018 transporting volumes of 233 km^3 and 215 km^3 into the Baltic Sea, showing a relatively low mean salinity of about 15 g/kg. Calm summer weather induced several phases of baroclinic inflow events, importing very warm saline surface water from the Kattegat area into the deep basins. Details of the hydrographic and hydrochemical situation in 2018 are given by NAUMANN et al. (2019).

4. Results and Discussion

4.1 Phytoplankton

4.1.1 Seasonal Variations in Species Composition and Biomass

The limited numbers of monitoring cruises, stations, and sampled depths limit comprehensive analyses of the succession or horizontal and vertical distribution of phytoplankton. In contrast to zooplankton, however, the vertical distribution of phytoplankton is of less priority as phytoplankton mainly occurs in the mixed surface layer. Therefore, we focus on mixed samples from 0-10 m depth and do not show the data of the deep phytoplankton samples (usually from 20 m depth) in the figures, even more as 9 of the deep samples could not be analyzed because of too many sediment particles disturbing microscopy. Especially in the Bay of Mecklenburg, gaps can be filled by making use of weekly data collected off Heiligendamm as part of the coastal monitoring undertaken by IOW. Information about monitoring in this coastal water is available at https://www.io-warnemuende.de/algal_blooms_at_heiligendamm_2018.html (WASMUND et. al. (2019a). Sediment traps yield samples integrated over several days (chapter 4.1.5).

The 10 most important phytoplankton taxa in terms of biomass from surface samples (0-10 m) collected on the five monitoring cruises are summarised in Table A1 (annex), arranged by their percentage share in total biomass for each station and season. The three cruises over the winter and spring are averaged. In contrast to previous reports, the completely "unidentified" cells were included in Table A1 even if their share in total phytoplankton biomass was <10 %. According to the PEG biovolume list they were named "Unicell spp.". The category of "unidentified flagellate" was also considered, but they did not belong to the 10 most abundant taxa. Also other unidentified entities, such as 'Gymnodiniales' and 'Peridiniales', are presented.

Table A2 shows the full list of phytoplankton taxa from all depths for each monitoring cruise in 2018. Taxa are arranged alphabetically. Individuals exhibiting a high degree of similarity to a species but which were not assignable to it with certainty are also considered, and are marked 'cf.'. Organisms that were classifiable only to genus level are also given, and are marked 'sp.' or 'spp.'. If species could not be identified they are assigned to a higher taxonomic level (order or class) or even to the completely unidentified "Unicell spp." or "unidentified flagellate". The biomass rank averaged over all stations and all monitoring cruises in 2018 is also given. Also taxa that did not occur in surface samples, but only in samples at 20 m depth, are recorded in Table A2 and are ranked. Note that no importance attaches to the rank order of rare species whose biomass can be determined only very imprecisely and does not permit greater differentiation. Table A2 contains also information on the taxonomic affiliation of the species. All large multi-page tables are placed in the Annex.

Related species often have similar ecological requirements and can simply be grouped together. Although class is a high taxonomic rank, one that includes ecologically disparate species, abstraction at class level is widely applied in literature and is also applied here. Seasonal variations in biomass for the most important classes of phytoplankton such as diatoms (Bacillariophyceae) and dinoflagellates (Dinophyceae) are shown for the sampled stations in Figs. 8-10 (page 22-24).

Heterotrophic species and groups such as *Peridiniella danica, Katodinium glaucum, Polykrikos schwartzii, Gyrodinium spirale, Amphidinium sphenoides, Phalacroma rotundatum, Ebria tripartita, Protoperidinium* spp., Choanoflagellatea and 'incertae sedis' are also considered. Choanoflagellatea were named "Craspedophyceae" in some previous reports. 'Incertae sedis' is a term used to refer to a taxon whose taxonomic position is unclear, such as *Katablepharis, Leucocryptos* and *Telonema*. We have included them in the species lists (Tables A1 and A2) and phytoplankton biomass data (Figs. 8-10).

Mixotrophic ciliates were also recorded. Until 2011 *Mesodinium rubrum* was the sole representative of this group in our samples. Since 2011 also the oligotrich ciliate *Laboea strobila* is considered, as it is believed to be mixotrophic (STOECKER et al. 1988; SANDERS 1995).

The *Aphanizomenon* species from the Baltic Proper was identified as *Aphanizomenon flos-aquae* until the mid-1990s. JANSON et al. (1994) noticed morphological inconsistencies of the Baltic *Aphanizomenon* species with the taxonomic description of the fresh-water *Aphanizomenon flosaquae*. Therefore, we counted the species provisionally as *Aphanizomenon* sp. According to LAAMANEN et al. (2002), the Baltic *Aphanizomenon* consists of only one genotype, with is not different from the freshwater type, despite morphological differences. Also PALIŃSKA & SUROSZ (2008) verified high overall sequence identity (97.5 – 99%) of the *Aphanizomenon* population from the Gulf of Gdańsk to freshwater isolates, but they found also significant differences in ultrastructure and morphology. Until a final solution of this problem, the HELCOM Phytoplankton Expert Group (PEG) continues to count it as *Aphanizomenon* sp.

Following the taxonomic revision of the genus *Anabaena* by WACKLIN et al. (2009), the planktonic *Anabaena* species are named as '*Dolichospermum*' (see also KOMÁREK & ZAPOMĚLOVÁ 2007, 2008). We have made use of the new name since 2014.

The taxonomic revision of the genus *Skeletonema* (SARNO et al. 2005, ZINGONE et al. 2005) necessitated a redefinition of *Skeletonema costatum*, a typical spring diatom. We undertook electron microscopic investigations, and designated the species found in our samples as *S. marinoi* (WASMUND et al. 2006a). We began to apply the new name to samples after 2012.

The species *Dictyocha speculum* occurs largely 'naked', i.e. without the typical silica skeleton (cf. JOCHEM & BABENERD 1989, HENRIKSEN et al. 1993). It is difficult to identify in such a case, and is easily mistaken for *Pseudochattonella farcimen* (also Dictyochophyceae) and *Chattonella* spp. (Raphidophyceae). As we have occasionally found both naked and skeleton-bearing stages, as well as transitional stages (WASMUND et al. 2015), we feel fairly certain that the round, naked cells are *Dictyocha speculum*. Within the HELCOM Phytoplankton Expert Group (PEG), we have agreed that elongated forms should count as *Pseudochattonella farcimen*. This uncertainty is not a problem when working at class level because both *Pseudochattonella farcimen* and *Dictyocha speculum* belong to the class of Dictyochophyceae. Up to the report of WASMUND et al. (2015), these genera were assigned to the Chrysophyceae. Now we present the Dictyochophyceae separately in Figs. 8-10 and put the few representatives of the class of Chrysophyceae (*Dinobryon, Apedinella, Pseudopedinella*) to the group of "Others".

We know from our long-term data series that three pronounced blooms occur in the study area in spring, summer, and autumn every year; they can often be further split into phases of varying species succession. We structure the following section for the seasons and within the seasons for the regions.

4.1.1.1 Spring Bloom

Belt Sea

Kiel Bay and Bay of Mecklenburg (including Lübeck Bay) belong to the German Belt Sea but were kept separate as conditions may be different. Figure 8 shows the seasonal variations in phytoplankton biomass in Kiel Bay, Lübeck Bay and Bay of Mecklenburg. At the end of January 2018, the phytoplankton biomass was still rather high, mainly based on *Ceratium tripos* (up to 258 µg/l at station OMO22; see Fig. 2 for station OMBMPM2). They seem to remain from the autumn bloom, which extends recently up to December with a trend to a prolongation of the phytoplankton growing season (cf. WASMUND et al. 2019b). Obviously, *Ceratium tripos* may stay until end of January and even longer, probably with low metabolic rates due to light limitation and low food level for mixotrophic nutrition. It almost disappeared by early February, whereas the typical mixotrophic spring species *Mesodinium rubrum* appeared (Fig. 8 b,c). *Ceratium tripos* was still found in deeper water layers (20m depth at station OMBMPM2 on 8.2.2018: 77 µg/l), and surprisingly it re-appeared in spring as shown below.

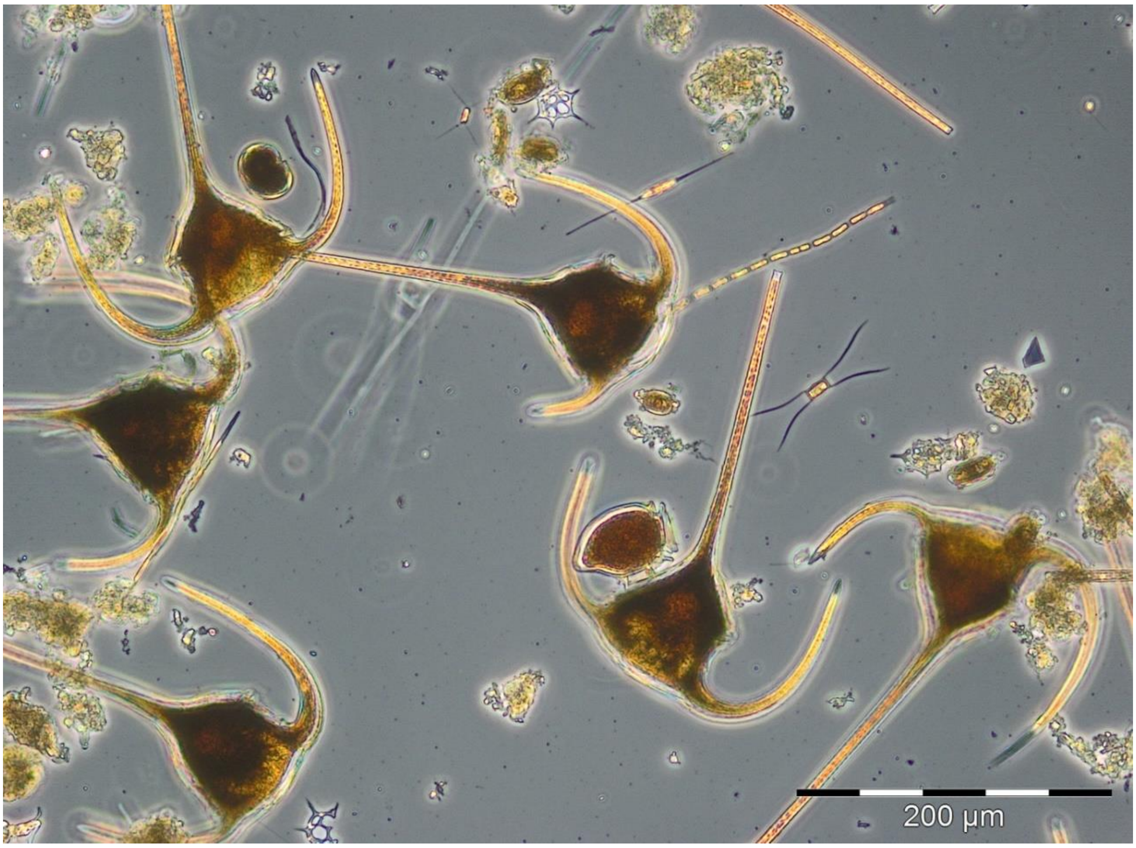

Fig. 2: Net sample from station OMBMPM2 from 30 January 2018, dominated by *Ceratium tripos*. Photo: S. Busch (IOW).

The spring bloom developed by 19 March in Kiel Bay and Lübeck Bay, as also suggested by a strong decrease in nitrate+nitrite and phosphate concentrations in the water (Table 4). In the central and eastern Bay of Mecklenburg, nutrients were still available at that time and were further reduced, indicating a further growth of the bloom. That means the real peak of the bloom will be higher and later than indicated in the figures. Only by the 9 May, the nutrients were almost completely exhausted. The retardation of the spring bloom into eastern direction is a well-known phenomenon reported in earlier reports (cf. also WASMUND et al. 1998). The spring bloom of the Belt Sea was primarily formed by diatoms (*Skeletonema marinoi, Thalassiosira* spp., Fig. 3). To a minor extent also *Rhizosolenia setigera*, *Ebria tripartita* and *Ceratium tripos* contributed to the bloom in Kiel Bay, primarily found in the deeper water layer (17 m depth). Farther east, the importance of *Mesodinium rubrum* increased (Fig. 4).

A bloom of *Dictyocha speculum*, as found in some previous years (2008, 2011, 2014, 2015, 2017), was completely absent. Therefore, there was no need to specify the Dictyochophyceae in Figs. 8-10, in contrast to earlier reports. Instead, we present the Cryptophyceae separately in the figures, but they are generally of low importace concerning biomass.

The spring bloom disappeared by 8 May 2018 at station OMBMPN3, when *Ceratium tripos* was still present, and became dominant after the decline of the diatoms whereas *Dinophysis norvegica* dominated in Kiel Bay at 18 m depth with 77 µg/l (Fig. 5).

Fig. 3: *Skeletonema marinoi* and *Thalassiosira anguste-lineata* in the net sample from station OMBMPM2 from 27 March 2018. Photo: S. Busch (IOW).

Fig. 4: Net sample from station OMBMPM1 from 27 March 2018, primarily composed of *Skeletonema marinoi, Mesodinium rubrum, Chaetoceros* spp. and *Rhizosolenia setigera*. Photo: S. Busch (IOW).

Fig. 5: Net sample from station OMBMPN3 from 8 May 2018, showing *Ceratium tripos, Dinophysis norvegica* and *Protoperidimium pellucidum*. Photo: S. Busch (IOW).

Surprisingly, *Ceratium tripos* seems to become a perennial species in that area. Also at station OMO22, biomass was reduced in May, now dominated by *Rhizosolenia setigera* and unidentified Gymnodiniales and Prymnesiales. In contrast to the other stations of the Belt Sea, the high phytoplankton biomass stayed until 9 May 2018 at station OMBMPM2, dominated by *Rhizosolenia setigera* (679 µg/l), which followed the earlier *Skeletonema marinoi*. Finally, biomass reduced strongly by 16 May 2018. At station OMBMPM1, biomass was low both on 9 and 16 May, represented mainly by *Mesodinium rubrum* and unidentified Gymnodiniales, on 9 May also *Rhizosolenia setigera,* but on 16 May also *Chaetoceros similis, Peridiniella danica* and *Snowella* sp.

The timing of the spring bloom cannot be determined on the basis of the sketchy routine monitoring alone. According to weekly data from the coastal station Heiligendamm, the spring bloom started in week 10 (6.3.2018) and reached its maximum on 20 March 2018 with a much higher chlorophyll *a* concentration (19.74 mg/m^3) than observed in the open Bay of Mecklenburg (Table 5). Also here, *Skeletonema marinoi* and *Thalassiosira* spp. were the bloom-forming species, followed by *Rhizosolenia setigera*, Gymnodiniales and *Mesodinium rubrum*. The 24 April 2018 may mark the end of the spring bloom (WASMUND et al 2019a).

The nutrient data comipiled in Table 4 verify the known phenomenon of nitrate limitation if compared with the Redfield ratio of N:P=16 mol/mol. Despite a surplus in phosphate, it was completely consumed in spring. Its transfer to the cyanobacteria of the summer is still not fully resolved (WASMUND et al. 2005, NAUSCH et al. 2012, 2018). Silicate is needed by the diatoms but it is not completely used up and seems not to be the limiting nutrient.

Arkona Basin

The phytoplankton biomass in the Arkona Basin was much lower in comparison with the Belt Sea at the end of January because *Ceratium tripos* did not occur in the surface water (Fig. 9). However, *Mesodinium rubrum* was present so early with a biomass of 91 µg/l on 8 February 2018 at station OMBMPK8. The timing of the spring bloom in the Arkona Basin was similar to that of the Belt Sea, with biomass › 1000 µg/l after 19 March at most stations. The development started with *Mesodinium rubrum*, but in the western Arkona Basin (OMBMPK8) diatoms were forming the spring bloom with similar specis as in the Bay of Mecklenburg: *Thalassiosira* spp. (652 µg/l) and *Skeletonema marinoi* (271 µg/l). The same diatom species but with lower biomass occurred in the central and eastern Arkona Basin (Fig. 6).

Also in this region, just like in the Bay of Mecklenburg, further decreasing nutrient concentrations after the 20/21 March 2018 indicate that the spring bloom continues and may reach its maximum later (Table 4). Ideed, the chlorophyll *a* concentrations further increased by the 27 March 2018 (Table 5).

Table 4
Concentrations of nitrate+nitrite, phosphate, and silicate (µmol/L) from 1-3 m water depth at the biological stations in 2018. Data extracted from the IOW database.

Station	Date	Nitrate+Nitrite	Phosphate	Silicate
OMBMPN3	30.01.2018	4.23	0.67	20.35
OMBMPN3	19.03.2018	0.61	0.21	7.30
OMBMPN3	08.05.2018	0.10	0.00	2.60
OMBMPN3	24.07.2018	0.04	0.00	1.00
OMBMPN3	06.11.2018	0.13	0.41	12.00
OMO22	31.01.2018	6.76	0.69	22.45
OMO22	19.03.2018	0.10	0.09	6.90
OMO22	08.05.2018	0.11	0.00	3.80
OMO22	25.07.2018	0.20	0.00	4.45
OMO22	05.11.2018	0.17	0.71	16.70
OMBMPM2	30.01.2018	5.47	0.71	21.50
OMBMPM2	20.03.2018	1.19	0.36	12.75
OMBMPM2	09.05.2018	0.07	0.00	4.40
OMBMPM2	25.07.2018	0.08	0.00	3.90
OMBMPM2	05.11.2018	0.09	0.31	14.25
OMBMPM1	31.01.2018	5.10	0.72	20.75
OMBMPM1	20.03.2018	2.11	0.41	15.35
OMBMPM1	09.05.2018	0.05	0.09	9.70
OMBMPM1	25.07.2018	0.01	0.01	8.30
OMBMPM1	06.11.2018	0.85	0.45	16.20
OMBMPK8	31.01.2018	3.66	0.69	19.35
OMBMPK8	20.03.2018	2.86	0.46	16.05
OMBMPK8	09.05.2018	0.05	0.20	11.55
OMBMPK8	25.07.2018	0.02	0.03	11.10
OMBMPK8	07.11.2018	0.46	0.34	17.30
OMBMPK5	31.01.2018	2.95	0.67	19.10
OMBMPK5	20.03.2018	3.50	0.46	16.85
OMBMPK5	09.05.2018	0.12	0.09	10.20
OMBMPK5	25.07.2018	0.06	0.01	9.90
OMBMPK5	07.11.2018	0.53	0.42	15.75
OMBMPK4	01.02.2018	3.01	0.68	19.10
OMBMPK4	21.03.2018	4.64	0.56	20.00
OMBMPK4	10.05.2018	0.07	0.23	13.70
OMBMPK4	26.07.2018	0.04	0.00	10.30
OMBMPK4	07.11.2018	0.40	0.29	12.00
OMBMPK2	02.02.2018	2.63	0.66	18.05
OMBMPK2	21.03.2018	2.56	0.63	20.10
OMBMPK2	26.03.2018	1.86	0.68	19.45
OMBMPK2	10.05.2018	0.03	0.17	13.35
OMBMPK2	15.05.2018	0.10	0.08	13.50
OMBMPK2	27.07.2018	0.01	0.01	10.40
OMBMPK2	03.08.2018	0.06	0.02	10.40
OMBMPK2	09.11.2018	0.08	0.27	11.40
OMBMPK1	03.02.2018	3.20	0.70	20.55
OMBMPK1	22.03.2018	3.70	0.67	18.55
OMBMPK1	11.05.2018	0.05	0.03	18.05
OMBMPK1	27.07.2018	0.10	0.02	13.65
OMBMPK1	10.11.2018	0.16	0.13	10.60
OMBMPJ1	05.02.2018	3.54	0.68	18.40
OMBMPJ1	23.03.2018	4.33	0.66	16.75
OMBMPJ1	12.05.2018	0.01	0.05	12.70
OMBMPJ1	29.07.2018	0.03	0.01	11.65
OMBMPJ1	11.11.2018	0.24	0.24	12.25

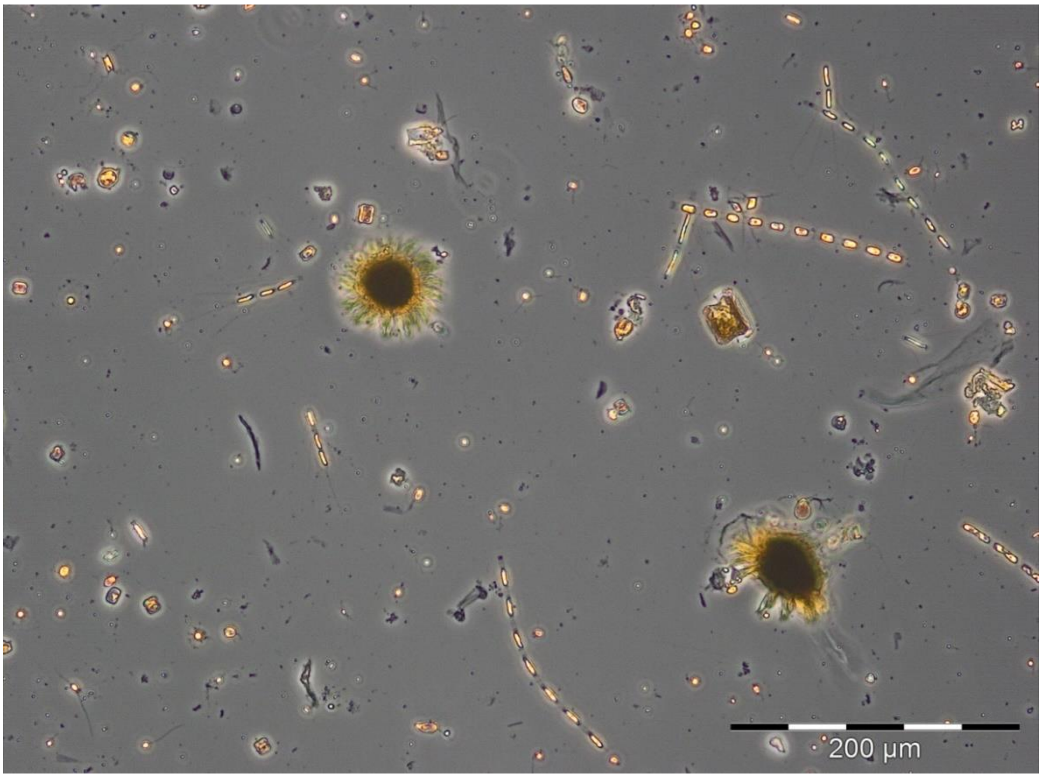

Fig. 6: *Skeletonema marinoi*, *Mesodinum rubrum* and *Thalassiosira* spp. in the mixed sample (0-10m) from station OMBMPK5 from 27 March 2018. Photo: S. Busch (IOW).

Fig. 7: Net sample from station OMBMPK2 from 7 February 2018, composed of *Mesodinium rubrum, Aphanizomenon* sp. and *Actinocyclus* sp. Photo: S. Busch (IOW).

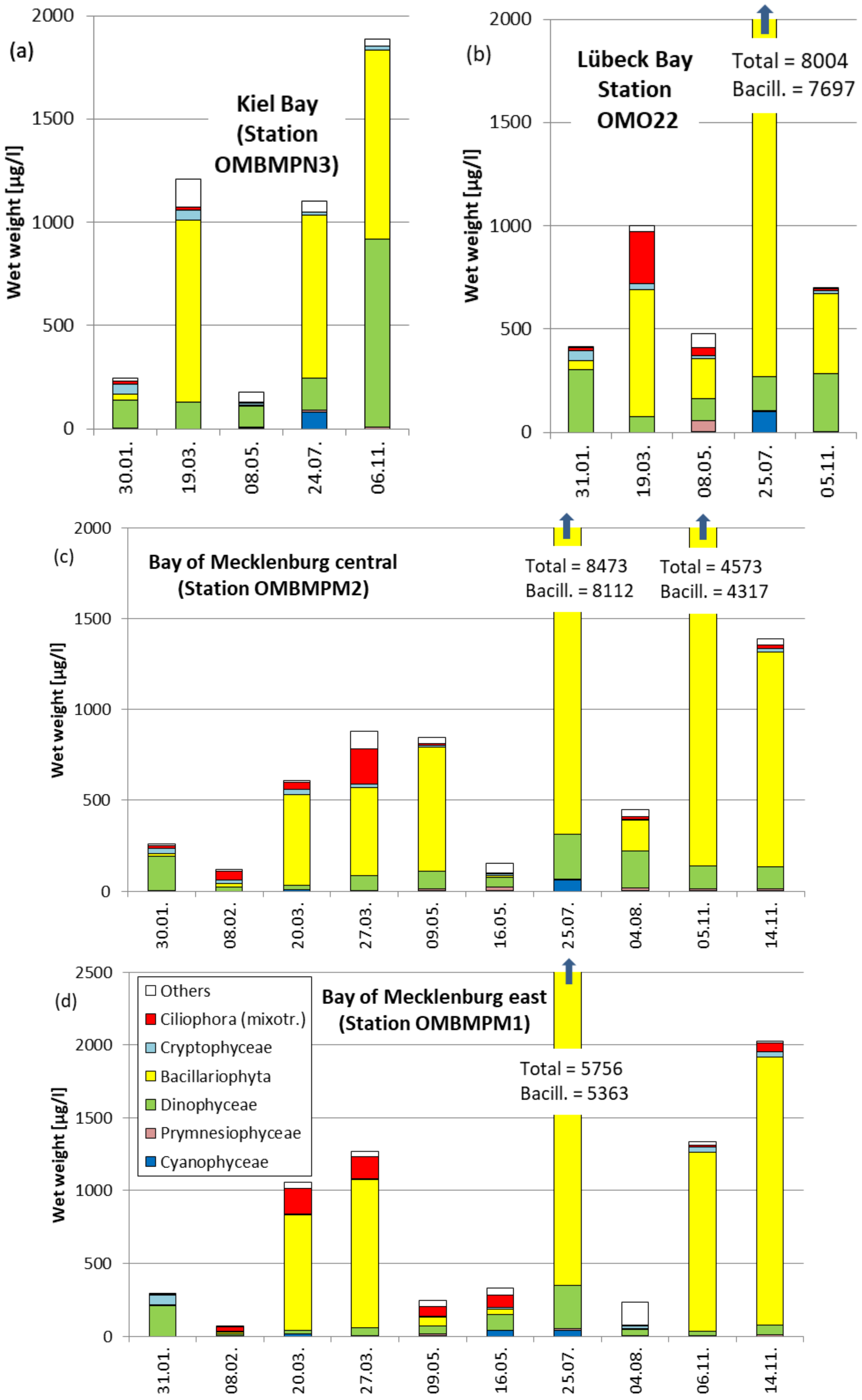

Fig. 8: Seasonal variation of phytoplankton wet weight of the main taxonomic groups in Kiel Bay (a), Lübeck Bay (b), and Bay of Mecklenburg (c, d) in 2018.

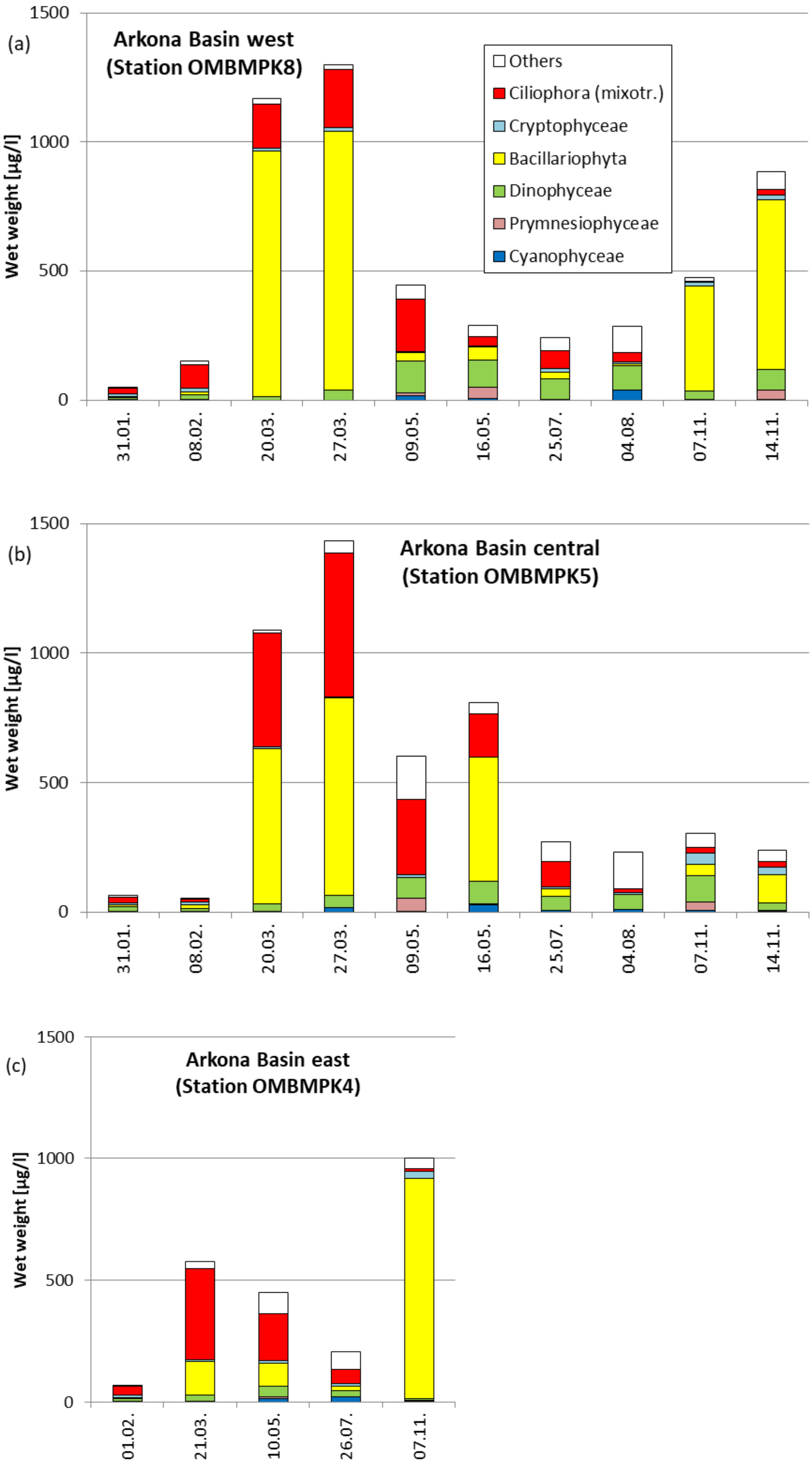

Fig. 9: Seasonal variation of phytoplankton wet weight of the main taxonomic groups in the Arkona Basin (a-c) in 2018.

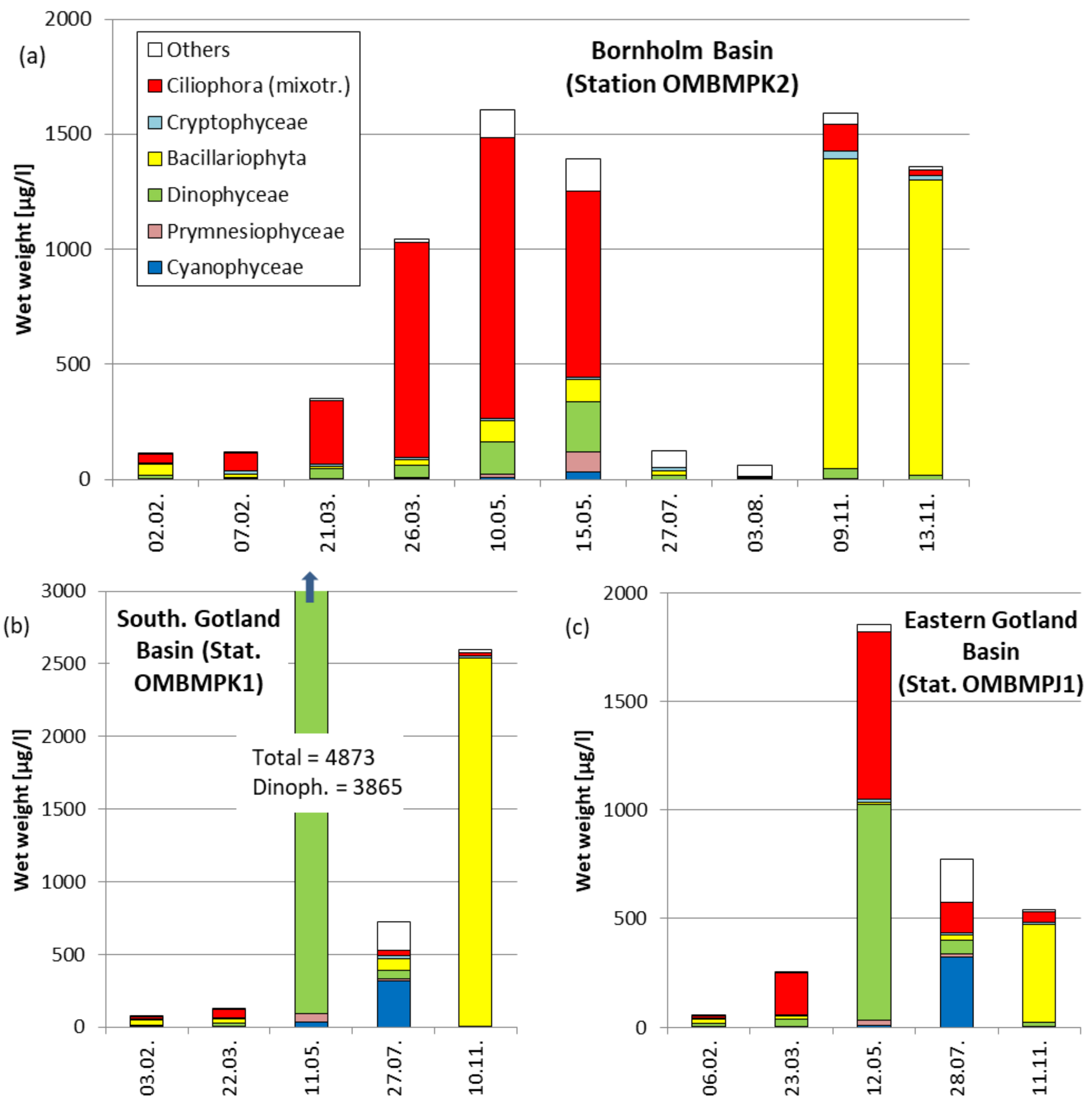

Fig. 10: Seasonal variation of phytoplankton wet weight of the main taxonomic groups in the Bornholm Basin (a) and Eastern Gotland Basin, southern part (b) and central part (c), in 2018.

The diatoms decreased by 9 May 2018 in the western and central Arkona Basin whereas dinoflagellates, prymnesiophyceae and *Ebria tripartita* (shown as "Others") increased. Also cyanobacteria (*Aphanizomenon* sp.) were present. The sudden strong appearance of *Chaetoceros similis* at station OMBMPK5 on 16 May 2018 was surprising; it may be connected with its occurrence on 10 May 2018 in the eastern Arkona Basin and on 10/15/16 May 2018 in the Bornholm Basin and western Arkona Basin.

In early studies, the spring bloom in the Baltic Proper occurred in the period from March to May, leading to the strategy of HELCOM to define the spring by these months, as for example applied by HELCOM (1996), CARSTENSEN et al. (2004) and WASMUND et al. (2011b). However, the spring blooms seem to shift to earlier dates of the year (Wasmund et al. (2019b). If the spring blooms in the Baltic Proper start already in February, as suggested by the nutrient consumption (Table 4) and biomass data (Fig. 9a) as well as in previous reports (Wasmund et al. 2017b, 2018a), the common strategy of assuming March-May as "spring" has to be revised.

Bornholm Basin

The Bornholm Basin is represented by only one station (OMBMPK2). The low biomass in February 2018 is dominated by *Mesodinium rubrum* and diatoms (Fig. 7). *Mesodinium rubrum* inceased strongly in March. As in 2017, the spring bloom appeared as a long-lasting phenomenon extending from March to May. This unusually long duration may be caused by the dominating mixotrophic ciliate *Mesodinium rubrum*, which may survive much longer than the diatoms. In 2016, a probably short diatom bloom was followed by long-lasting ciliate and flagellate occurrence (Wasmund et al. 2017b). Mentionable biomass of diatoms (*Chaetoceros similis*) occurred only in May and not in March 2018 (Fig. 11). Also *Pyramimonas* spp. and *Ebria tripartita* (both shown under "Others" in Figs. 8-10), *Peridiniella* spp., *Amylax triacantha, Aphanizomenon* sp., Gymnodiniales and Prymnesiales are worth mentioning.

The peak of the bloom in our data shows up on 10 May 2018, which is confirmed by the minimum in the dissolved inorganic nitrogen concentration (Table 4) and the maximum chlorophyll *a* concentration (Table 5).

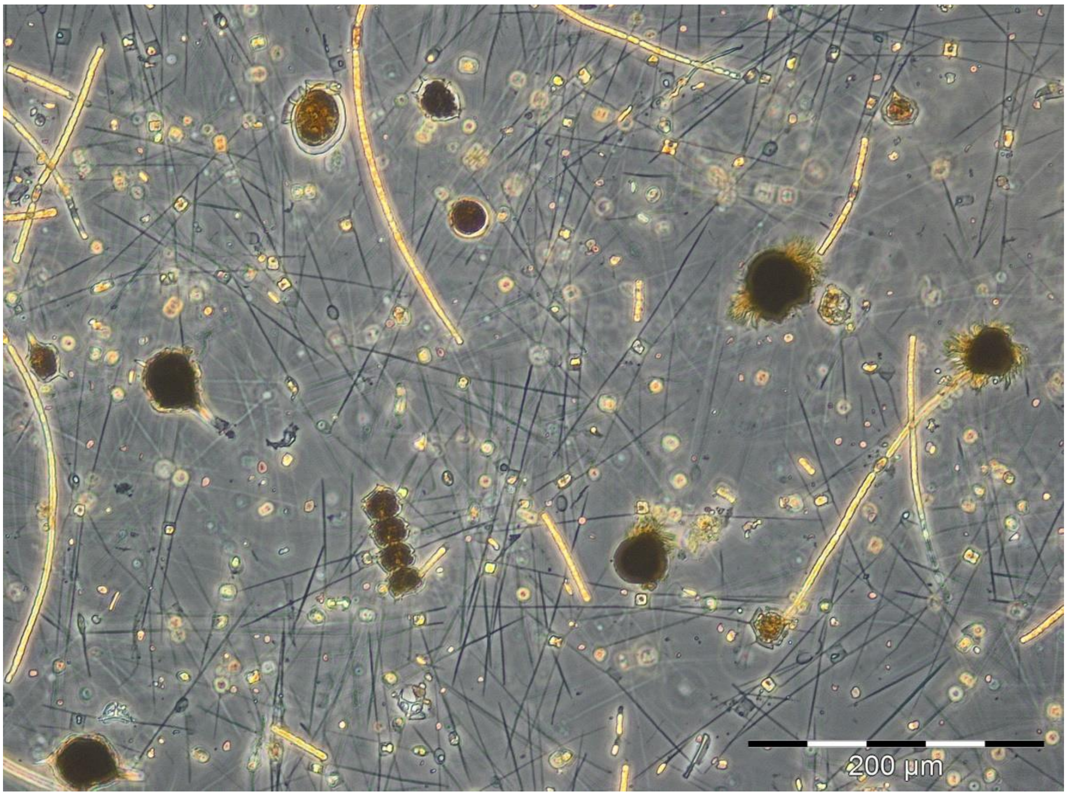

Fig. 11: Net sample from station OMBMPK2 from 15 May 2018, primarily composed of *Chaetoceros similis, Mesodinium rubrum, Aphanizomenon* sp., *Amylax triacantha* and *Dinophysis* sp. Photo: S. Busch (IOW).

Eastern Gotland Basin

The Eastern Gotland Basin is represented by the central station OMBMPJ1 (Fig. 10 c) and a more southern station OMBMPK1 (Fig. 10 b), which is called “Southern Gotland Basin” in our case. In some years, they were rather similar in their phytoplankton characteristics. It is worth mentioning that the cyanobacterium *Aphanizomenon* sp., which is typical for the summer blooms, occurs already in February in the water (Fig. 12). It may be abundant recently even under the ice, as found on the southern Finnish coast on 7 January 2019 [http://www.syke.fi/fi-FI/Ajankohtaista/Tiedotteet/Viileassakin_vedessa_viihtyvaa_sinilevaa(48957); pers. comm. by Sirpa Lehtinen]. The overwintering of *Aphanizomenon* sp. was investigated by WASMUND 2017b.

On 22 March 2018, *Mesodinium rubrum* was less developed at station OMBMPK1(61 µg/l) than at the neighbouring stations (e.g. 276 µg/l at station OMBMPK2). However, an extreme growth of *Peridiniella catenata* to 3508 µg/l occurred by 11 May 2018 at station OMBMPK1, which is also reflected in the extremely high chlorophyll *a* concentration. This species was also dominant at station OMBMPJ1, but it was accompanied by high biomass of *Mesodinium rubrum* there (Fig. 13). *Peridiniella catenata* was the dominating dinoflagellate in the Eastern Gotland Basin in the 1990s, but decreased strongly after the mid-1990s. It showed a strong decreasing overall trend in the Bornholm Basin and Arkona Basin (WASMUND et al. 2011b). The sudden re-appearance of this species breaks these trends at least in the Eastern Gotland Basin.

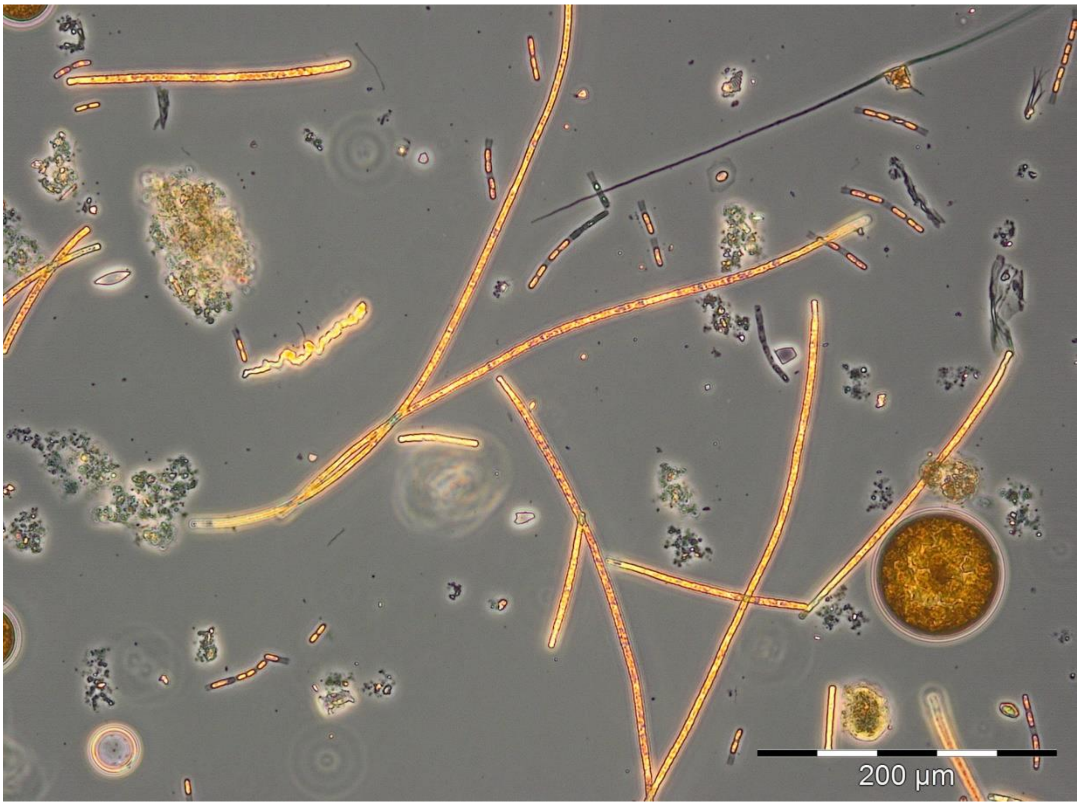

Fig. 12: *Aphanizomenon* sp., *Actinocyclus* sp. and *Binuclearia lauterbornii* in a net sample from 3 February 2018, Station OMBMPK1. Photo: S. Busch (IOW).

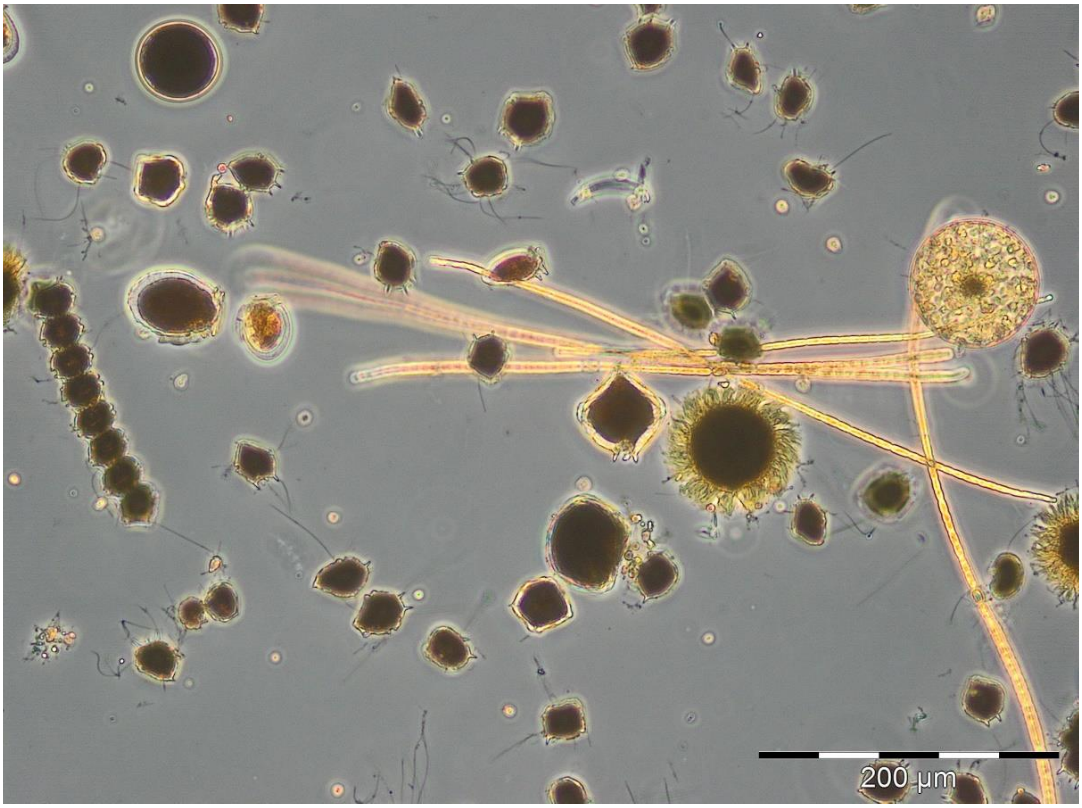

Fig. 13: *Peridiniella catenata* (in chains and single cells), *Mesodinium rubrum, Aphanizomenon* sp., *Thalassiosira baltica* and *Dinophysis* spp. in a net sample from 12 May 2018, Station OMBMPJ1. Photo: S. Busch (IOW).

Summary on the spring bloom 2018:

1.) The dinoflagellate *Ceratium tripos* was still present in the Belt Sea in January, probably because its autumn bloom extends increasingly into the winter. Surprisingly, this species occurs also in spring. Moreover, a cyanobacterium of the summer bloom, *Aphanizomenon* sp., was found already in winter.

2.) The first samples containing the spring bloom originated from 19/20 March 2018 in the Belt Sea and the western and central Arkona Basin, dominated by diatoms (*Skeletonema marinoi, Thalassiosira* spp., later also at some stations *Rhizosolenia setigera* and *Chaetoceros similis*). However, enhanced biomass was already identified on 8 February in the western Arkona Basin. Into eastern direction, the importance of *Mesodinium rubrum* is strongly increasing with spring maxima in the Bornholm Basin. In the Eastern Gotland Basin, extremely high biomass of *Peridiniella catenata* was found on 11/12 May 2018. In contrast to the previous year, *Dictyocha speculum* did not occur in the spring bloom of the western Baltic Sea.

3.) Nutrient consumption data may give further information on spring bloom dynamics. Nutrients (N, P) were strongly reduced by mid of March 2018 in Kiel Bay and Lübeck Bay, but were still available in the Bay of Mecklenburg and remained at winter concentrations in the Baltic Proper at that time. It reflects the typical retard of the spring bloom into eastern direction. Only in May, the nutrients were almost exhausted. However, silicate was not used up and seems not to limit diatom growth.

4.) If the enhanced biomass values in February 2018 in the western Arkona Basin are assumed as the start of the spring bloom, the month of February can no longer be considered as “winter” concerning the phytoplankton development in this area. The tendency to earlier spring blooms was described by WASMUND et al. (2019b).

4.1.1.2 Summer Bloom

Belt Sea

The summer situation is represented by one cruise. Therefore, the information is fragmentary. A summer diatom bloom, as found in previous years, was extremely strong on 25 July 2018 in the Bay of Mecklenburg including Lübeck Bay and to less extend in Kiel Bay. It was mainly formed by *Proboscia alata* and *Dactyliosolen fragilissimus* in Kiel Bay, but almost exclusively by *Dactyliosolen fragilissimus* in Lübeck Bay (7689 µg/l) and Bay of Mecklenburg (e.g. 8102 µg/l at station OMBMPM2; Fig. 14). This high biomass is not reflected in the chlorophyll *a* concentrations because these large diatoms are very poor in chlorophyll. The summer bloom contains also relatively high biomass of *Ceratium tripos*, cyanobacteria (*Nodularia spumigena, Aphanizomenon* sp.) and unidentified Gymnodiniales. The *Nodularia* filaments looked rather pale and “dying”. Indeed, the cyanobacteria have already disappeared by 4 August 2018 and also the diatoms were strongly reduced. At station OMBMPM1, *Dactyliosolen fragilissimus* was almost absent, but small single cells (2-5 µm) appeared, counted as “Others”.

According to the coastal data of Heiligendamm, the bloom of *Dactyliosolen fragilissimus* lasted from 3 July to 31 July 2018. High biomass of the nitrogen-fixing cyanobacterium *Nodularia spumigena* (567 µg/l) was found on 17 July 2018 at that coastal station where it was accumulated by drifting water masses. The visual survey confirms the transience of cyanobacterial accumulations. For example, they appeared in the evening of the 24 and 25 July 2018 in front of Warnemünde at calm conditions, but in the morning of 26 July 2018, the have disappeared by offshore wind.

Arkona Basin

In contrast to the Belt Sea, a diatom summer bloom could not be identified in the Arkona Basin in 2018. As already in 2017, the summer biomass was low (< 350 µg/l) at all Arkona Basin stations. The three stations were characterized by *Mesodinium rubrum*, *Ceratium tripos* and small unidentified cells (2-5 µm). The occurrence of *Ceratium tripos* in summer is usual in the Belt Sea, but unusual in the Arkona Basin.

Cyanobacteria blooms occurred in some areas of the Arkona Basin as observed during a surveying flight organized by “Greenpeace” (Fig. 15), but bloom concentrations were not found in our samples. The highest biomass of *Aphanizomenon* sp. and *Nodularia spumigena* occurred at station OMBMPK8 with 35 µg/l which is far below the threshold for bloom concentrations of 200 µg/L (according to WASMUND 1997).

In contrast to our single samplings or surface water, the data from the sediment trap indicate a diatom summer bloom, but they confirm that a cyanobacteria bloom did not occur in the central area of the Arkona Basin (cf. chapter 4.1.5).

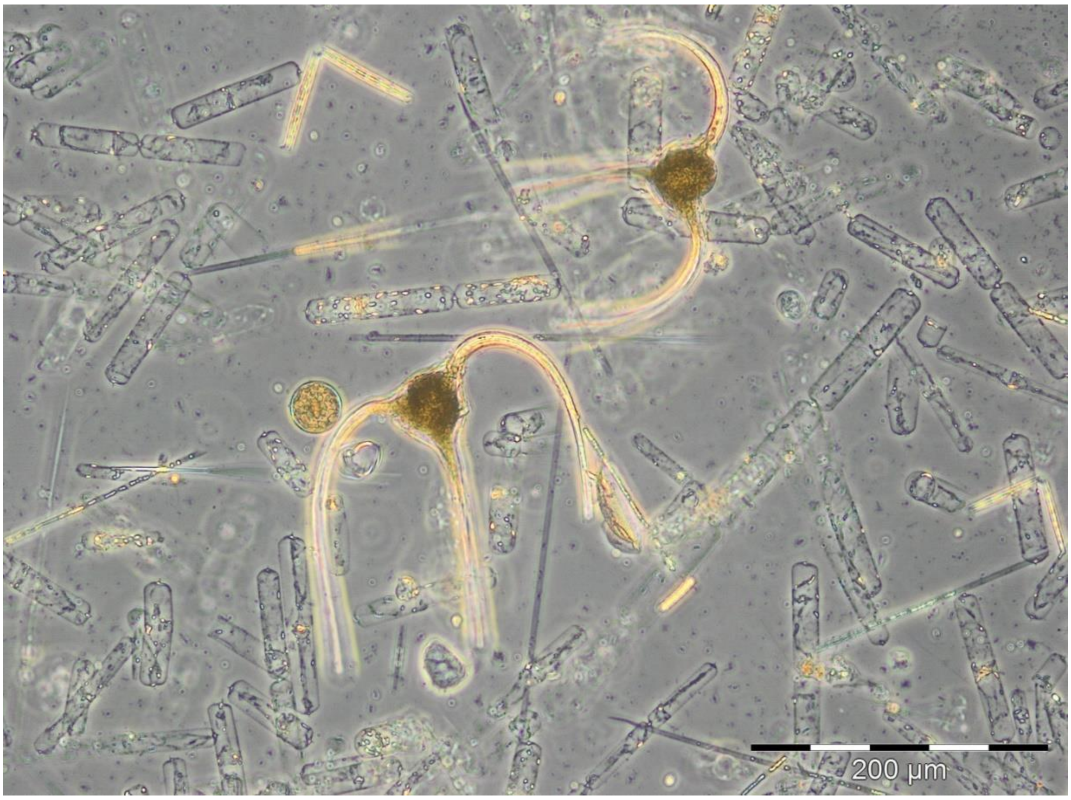

Fig. 14: *Dactyliosolen fragilissimus*, *Ceratium tripos*, *Proboscia alata* and *Thalassionema nitzschioides* in a net sample from 25 July 2018, Station OMBMPM2. Photo: S. Busch (IOW).

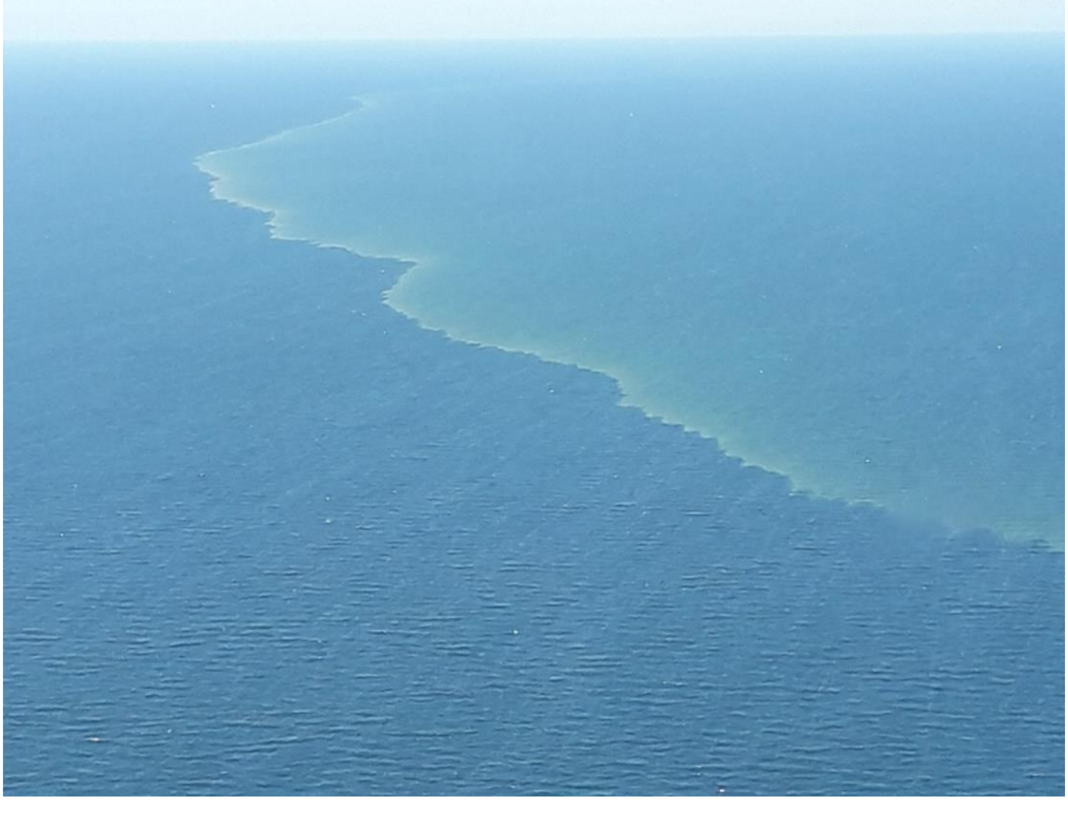

Fig. 15: Cyanobacteria bloom in a ocenographical front west of Bornholm. Surveying flight by “Greenpeace” from 4 August 2018. Photo: N.Wasmund (IOW).

Bornholm Basin

In the Bornholm Basin, phytoplankton biomass was very low in summer. The species composition was similar on the two sampling days, characterized by *Pyramimonas* sp. (shown in the category of "Others" in Fig. 10 a), *Plagioselmis prolonga, Chaetoceros castracanei, Actinocyclus* sp., unidentified Gymnodiniales and small cells of 2-5 µm size. The nitrogen-fixing cyanobacteria *Aphanizomenon* sp., *Nodularia spumigena* and *Dolichospermum* spp. were not found.

Eastern Gotland Basin

The summer was represented by only one sampling event in the Eastern Gotland Basin, which cannot be representative for the whole season. The biomass was mainly composed of *Aphanizomenon* sp., *Nodularia spumigena, Mesodinium rubrum, Aphanothece* spp., *Aphanocapsa* spp., *Pseudanabaena limnetica*, *Cyanonethron styloides, Cyclotella* spp., *Coelosphaerium minutissimum, Dinophysis norvegica, Nitzschia paleacea,* unidentified Gymnodiniales and small cells of 2-5 µm size. The nitrogen-fixing cyanobacteria contributed 134 µg/l and 140 µg/l to the phytoplankton biomass at stations OMBMPK1 and OMBMPJ1, respectively, and did not reach bloom concentrations.

However, strong cyanobacteria blooms occurred at the Polish coast where many bathing sites were closed for swimmers because of measured toxicity (Kobos et al. 2019). Also in the Gulf of Finland, the exceptionally warm summer 2018 caused the strongest cyanobacteria bloom of the 2010's, dominated by *Aphanizomenon* spp. [https://www.syke.fi/en-US/Current/Algal_reviews/Summary_reviews/Summary_of_algal_bloom_monitoring_2018_S(47752); pers. comm. by Sirpa Lehtinen].

Summary on the summer bloom 2018:

1.) A strong diatom (*Dactyliosolen fragilissimus*) summer bloom occurred in the Belt Sea in July 2018. No summer bloom was found in the Arkona Basin and Bornholm Basin. Nitrogen-fixing cyanobacteria dominated in the Eastern Gotland Basin.

2.) The "excess" phosphorus remaining after the spring bloom is widely consumed between May and July from Kiel Bay to the Eastern Gotland Basin, which indicates a non-Redfied uptake during and/or after the spring bloom. The silicate consumption in the Belt Sea confirms the diatom summer bloom. In contrast, silicate consumption and the related diatom development were low in summer in the Baltic Proper.

4.1.1.3 Autumn Bloom

Belt Sea

The typical autumn bloom in the Belt Sea should be composed of dinoflagellates (*Ceratium*) and diatoms, sometimes as a mixture, but frequently as a succession of these two groups. As our autumn data are generally based on only one monitoring cruise, they may miss the blooms or some phases of the blooms. Therefore, we have no complete and sometimes even misleading information. The weekly samplings from the coastal station Heiligendamm enabled a more complete image and are consulted in addition.

The autumn bloom was well developed at most stations during the time of our autumn cruise. Typically, *Ceratium* spp. start development already in summer and reach bloom concentrations in autumn in the Belt Sea. Surprisingly, *Ceratium* spp. were present from winter through autumn in 2018, as mentioned above. Strong growth occured in Kiel Bay by 6 November 2018 when *Ceratium lineatum* reached 284 µg/l and *C. tripos* accounted for 98 µg/l besides of other dinoflagellates (*Polykrikos schwartzii* 66 µg/l, *Gyrodinium spirale* 40 µg/l, unidentified Gymnodiniales 339 µg/l). The other important group was the diatoms with *Thalassiosira gravida* (135 µg/l), unidentified *Thalassiosira* spp. (326 µg/l), *Rhizosolenia setigera* (139 µg/l), *Rh. setigera* f. *pungens* (42 µg/l), *Cerataulina pelagica* (68 µg/l) and *Pseudo-nitzschia* spp. (59 µg/l).

Farther to the east, the relative importance of diatoms increased and that of dinoflagellates decreased. *Ceratium* spp. accounted for only 59 µg/l at station OMO22 and 58 µg/l at station OMBMPM2 on 5 November 2018 besides of unidentified Gymnodiniales. Diatoms were mainly represented by *Rhizosolenia calcar-avis* (75 µg/l), *Thalassiosira* spp. (70 µg/l), the *Pseudo-nitzschia delicatissima* group (64 µg/l), *Ditylum brightwellii* (18 µg/l), *Guinardia flaccida* (17 µg/l) and *Proboscia alata* (17 µg/l) at station OMO22. However, at stations OMBMPM2 and OMBMPM1, strong blooms of *Cerataulina pelagica* (4121 µg/l and 1151 µg/l, respectively), accompanied by *Dactyliosolen fragilissimus* (72 µg/l and 31 µg/l, respectively), occurred at the same time. This bloom decreased by the 14 November 2018 at station OMBMPM2: *Cerataulina pelagica* (798 µg/l), *Pseudo-nitzschia* spp. (112 µg/l), *Rhizosolenia setigera* (52 µg/l), *Dactyliosolen fragilissimus* (26 µg/l), but it still increased at station OMBMPM1: *Cerataulina pelagica* (1802 µg/l). Surprisingly, *Dictyocha speculum* appeared in its naked form at station OMBMPM2 on 5 November 2018 with 14 µg/l; it was expected in spring, but was almost lacking at that time.

The weekly coastal data from Heiligendamm revealed a long diatom dominance extending from beginning of September to end of December 2018. In fact, it seems to be a succession of different blooms, dominated or sub-dominated by *Pseudosolenia calcar-avis, Dactyliosolen fragilissimus, Coscinodiscus granii, Cerataulina pelagica, Thalassiosira* spp. and *Pseudo-nitzschia* spp. in the different months (WASMUND et al. 2019a).

Arkona Basin

An autumn bloom was found in the Arkona Basin only at stations OMBMPK8 and OMBMPK4 during the time of the cruise. It was dominated by *Cerataulina pelagica* (342 µg/l) at station OMBMPK8 and by *Coscinodiscus granii* (640 µg/l) and *Actinocyclus* spp. (174 µg/l) at station OMBMPK4. The diatom biomass increased further by the 14 November at station OMBMPK8 (*Cerataulina pelagica* 489 µg/l, *Dactyliosolen fragilissimus* 109 mg/l), but also *Ceratium tripos, Mesodinium rubrum* and Prymnesiales were noteworthy. Surprisingly, the biomass was low at station OMBMPK5, dominated by unidentified Gymnodiniales (57 µg/l) on 7 November and by *Actinocyclus* spp. (68 µg/l) on 14 November 2018.

Bornholm Basin

A bloom of the typical diatom *Coscinodiscus granii* was recorded in the Bornholm Basin with biomasses of 1222 µg/l and 1052 mg/l on 9 and 13 November 2018, respectively. It was accompanied by *Actinocyclus* spp. (e.g. 177 mg/l on 13 November 2018). The diatom species of the western Baltic, such as *Pseudosolenia calcar-avis, Dactyliosolen fragilissimus, Pseudo-nitzschia* spp. and *Cerataulina pelagica* were completely lacking.

Eastern Gotland Basin

The species composition in the southern part of the Eastern Gotland Basin (station OMBMPK1) was similar to that of the Bornholm Basin, with dominating *Coscinodiscus granii* (2460 µg/l) and *Actinocyclus* spp. (69 mg/l) on 10 November 2018. In the central part of the Eastern Gotland Basin (station OMBMPJ1), *Coscinodiscus* spp. (69 mg/l) and *Actinocyclus* spp. (16 µg/l) were less developed.

Summary on the autumn bloom 2018:

1.) The autumn bloom was well developed at most stations in the Baltic Sea. It was composed of dinoflagellates (*Ceratium* spp.) and diatoms (*Thalassiosira* spp.) in Kiel Bay. Farther to the east, the relative importance of dinoflagellates decreased and that of diatoms increased.

2.) The bloom-forming diatom was *Cerataulina pelagica* in the Bay of Mecklenburg and the western Arkona Basin, but *Coscinodiscus granii* in the eastern Arkona Basin, Bornholm Basin and Eastern Gotland Basin.

4.1.2 Regional Differences in Species Composition

Sampling locations are chosen so that they form a transect through the Baltic Sea from Kiel Bay to the Eastern Gotland Basin. The composition of phytoplankton species along this transect changes markedly corresponding to the salinity gradient. While this has already been explained in the previous chapter, it is reiterated here in Figs. 16-18 using the most important species as examples. Sampling points with size corresponding to the mean seasonal biomass of the selected species are inserted into the maps.

Mesodinium rubrum (Fig. 16 a) is the typical representative of the spring bloom in the Baltic Proper with decreasing tendency to the west whereas *Thalassiosira* was the dominating spring species in the western Baltic in 2018 (Fig. 16 b). *Skeletonema marinoi* usually forms the spring blooms in the Bay and Mecklenburg and the Arkona Basin, but its biomass was relatively low in 2018. *Dictyocha speculum,* which forms late spring blooms in the Belt Sea in some years, was nearly lacking in spring 2018, as discussed in chapter 4.1.3. *Peridiniella catenata* is typical for the Baltic Proper, but was almost absent for many years and re-appeared in 2018 (Fig. 16 c).

A strong summer bloom of the large diatom *Dactyliosolen fragilissimus* occurred in the Bay of Mecklenburg (Fig. 17 a). *Proboscia alata* was the dominating diatom in Kiel Bay, but not shown here. The nitrogen-fixing cyanobacteria, represented as a sum of *Nodularia spumigena* and *Aphanizomenon* sp. in Fig. 17 b, form usually blooms in the Baltic Proper. Exceptionally they were not present in our samples from the Bornholm Basin, but they should be there also in 2018. They invaded even the Belt Sea. *Ceratium tripos* is a typical autumn species of the Belt Sea. In order to express their unusually strong appearance in summer, we present their distribution pattern in summer (Fig. 17 c), which is similar to the autumn pattern (not shown).

Cerataulina pelagica formed a strong autumn bloom in the Bay of Mecklenburg (Fig. 18 a). On the other hand, *Coscinodiscus granii* was the typical bloom-forming species in the Baltic Proper (Fig. 18 b). It is usually accompanied by *Actinocyclus* spp., which was shifted more to the Bornholm Basin and eastern Arkona Basin in 2018 (Fig. 18 c). In addition, *Rhizosolenia setigera*, *Pseudosolenia calcar-avis* and *Ceratium lineatum* were part of the autumn bloom in the western Baltic Sea, but they are not shown here because of their lower biomass.

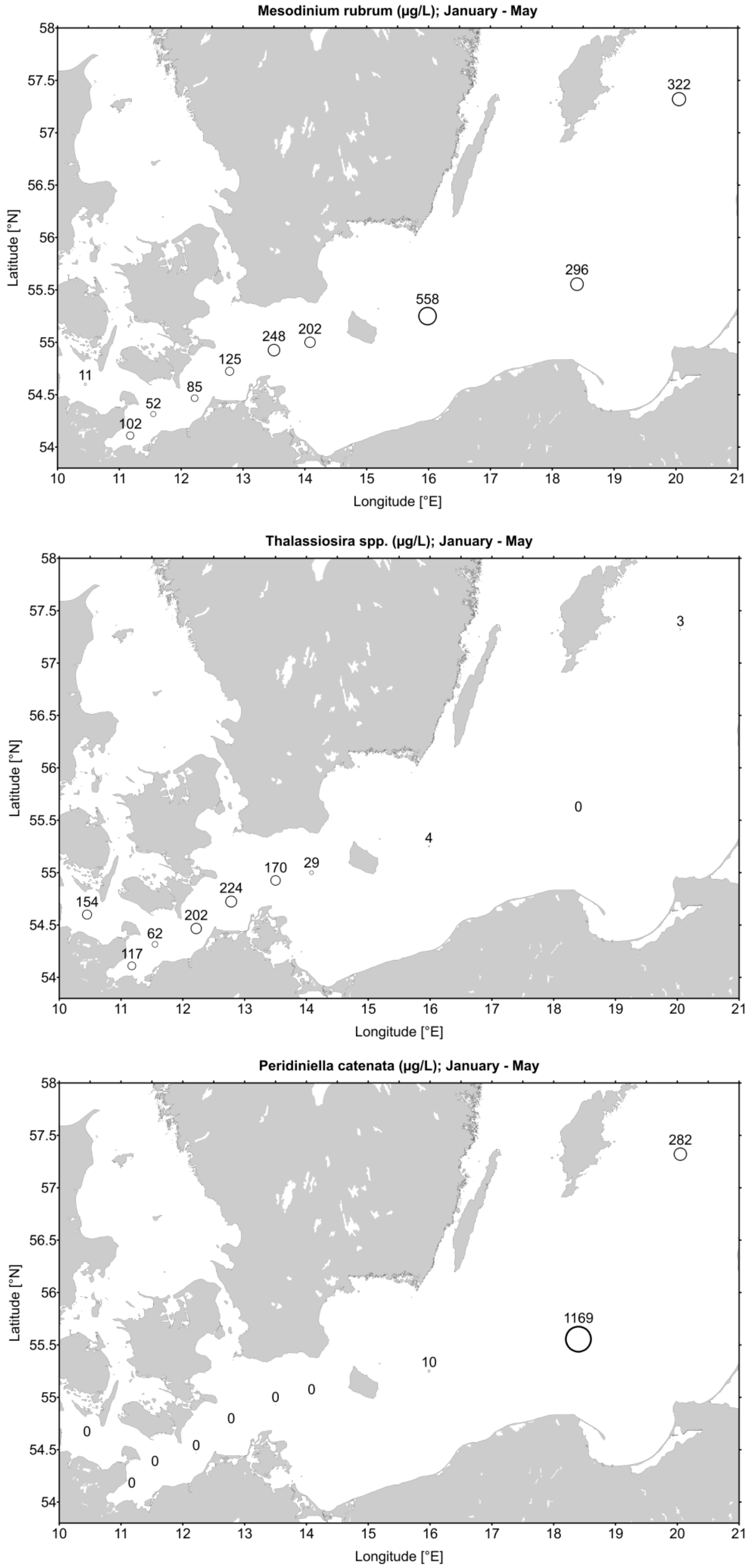

Fig. 16: Distribution of the main spring taxa, *Mesodinium rubrum* (a), *Thalassiosira* spp. (b) and *Peridiniella catenata* (c) in spring 2018 (mean values of three cruises).

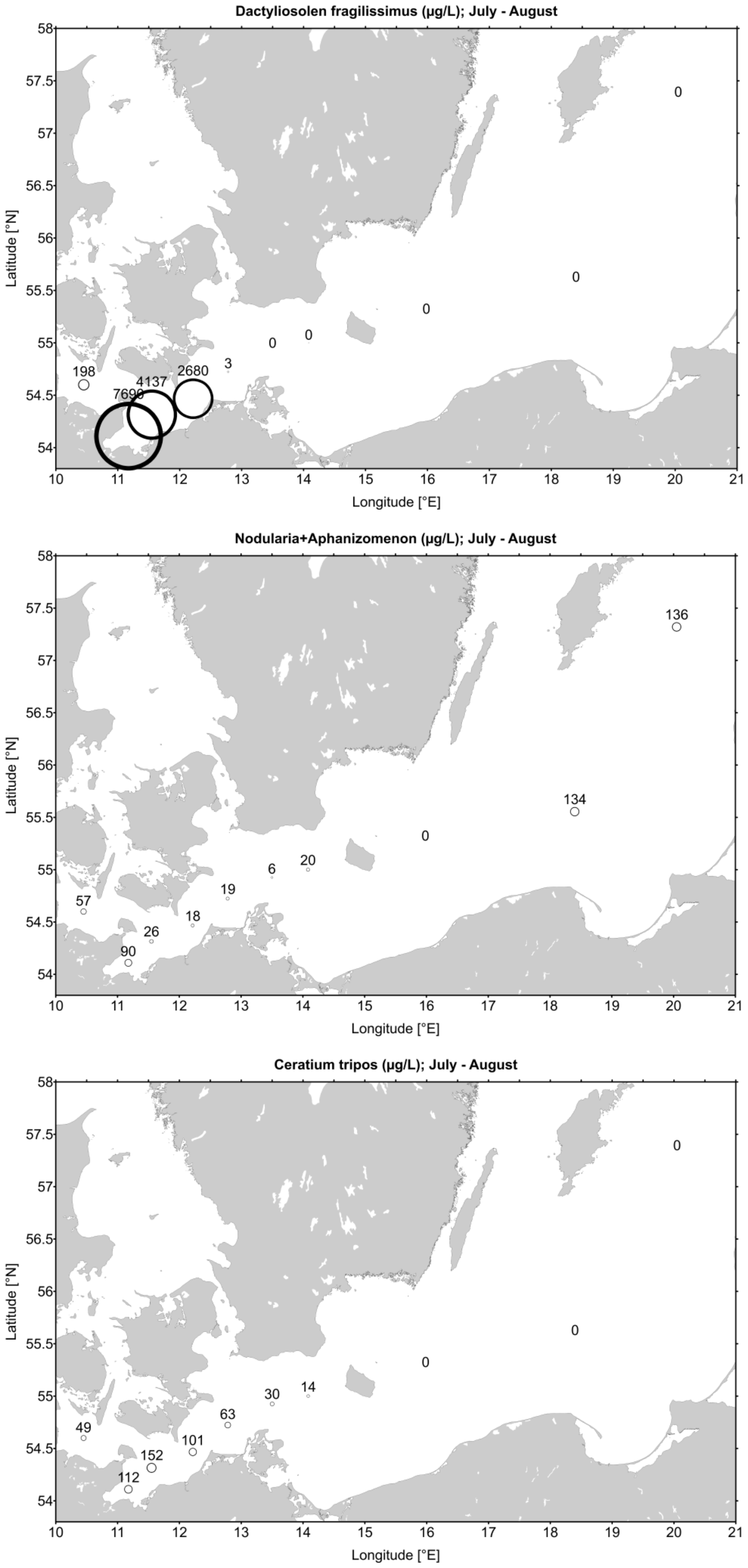

Fig. 17: Distribution of the main summer Taxa, *Dactyliosolen fragilissimus* (a), *Nodularia+Aphanizomenon* (b) and *Ceratium tripos* (c) in July-August 2018.

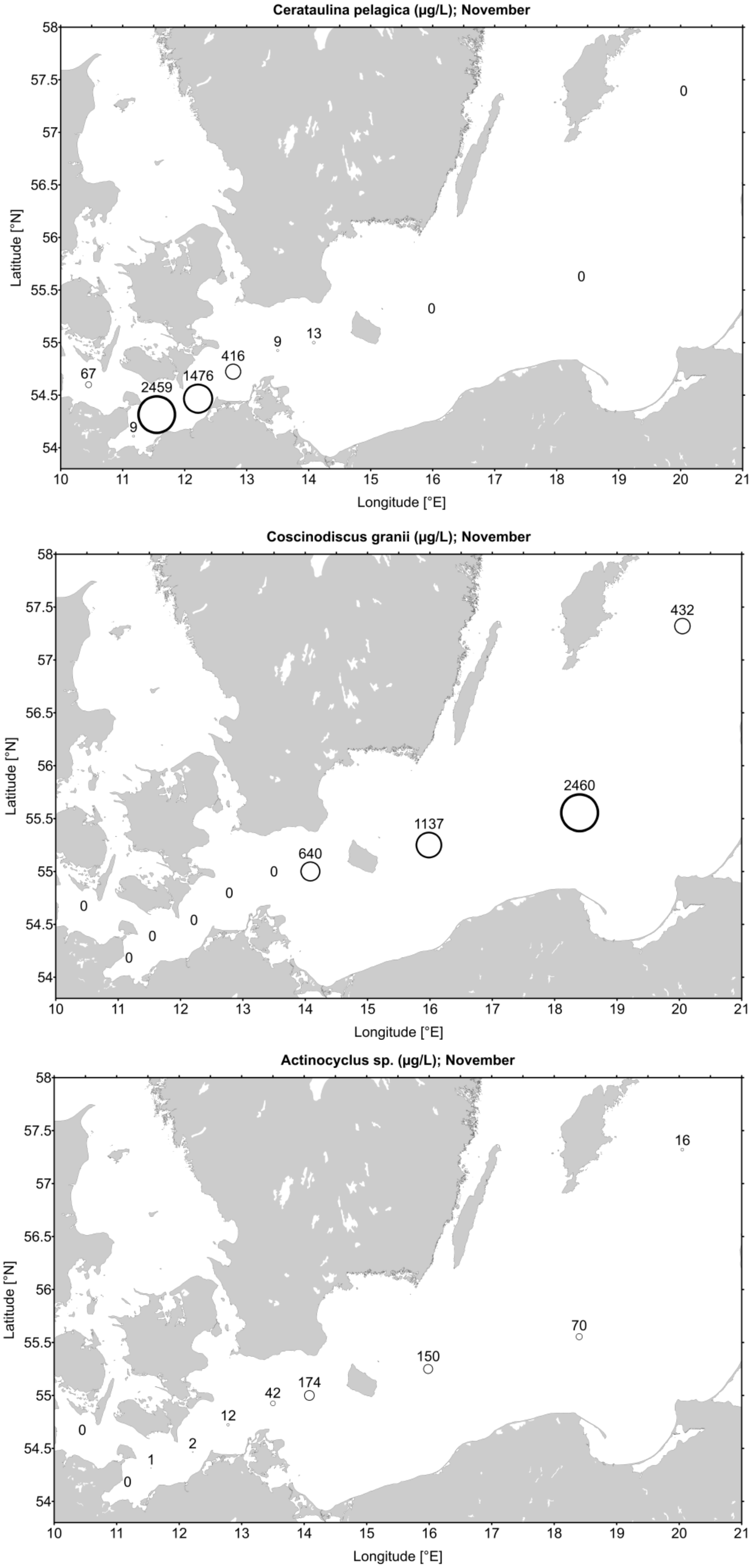

Fig. 18: Distribution of the autumn species *Cerataulina pelagica* (a), *Coscinodiscus granii* (b), and *Actinocyclus* spp. (c) in November 2018.

4.1.3 Changes in species composition and non-indigenous species

The protection of the marine environment not only means achieving and maintaining good water quality and the natural productivity of a waterbody, but also means preserving its natural diversity. The immigration and establishment of new species may be associated with the displacement of native species. While this might temporarily increase biodiversity locally (α-diversity), it causes typical biocoenotic structures to disappear, and leads to a reduction in global biodiversity (β-diversity).

This is why efforts are made to prevent the introduction of new species. In the case of phytoplankton, this is difficult as it has a great variety of entry routes that cannot be blocked. *Prorocentrum cordatum* (old synonym: *Prorocentrum minimum*) serves as an example of an invasive phytoplankton species that has probably entered the Baltic naturally via the Kattegat. HAJDU et al. (2000), OLENINA et al. (2010), and TELESH et al. (2016) have impressively traced the advance of this species, which has occasionally become dominant. In contrast, *Prorocentrum balticum* has vanished (WASMUND et al. 2008).

The species *Prorocentrum compressum* was first found during our long-term monitoring program at station OMBMPN3 in surface and deep (15 m) samples on 6 November and at station OMO22 in the deep (20 m) sample on 5 November 2018 (Fig. 19). It was a new species not only in our samples but also in the species list of PEG, suggested as a new species by Swedish colleagues working at the Swedish west coast. However, it was already mentioned in the species list of HÄLLFORS (2004) for the Kattegat/Belt Sea area. Obviously it was transported with inflowing water into the Baltic Sea.

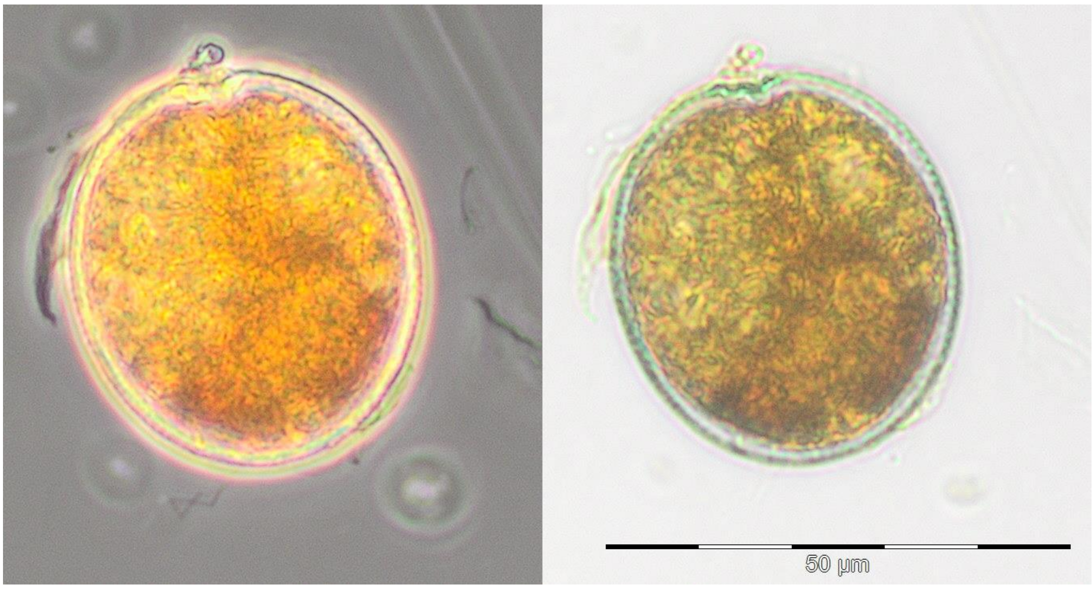

Fig. 19: *Prorocentrum compressum* from station OMO22, 20 m depth, 5 November 2018.

It is known that marine species such as *Cerataulina pelagica, Chaetoceros brevis,* and *Dactyliosolen fragilissimus* are sometimes carried into the Baltic Sea even to the Lithuanian coast. In this sense these species are indicators of inflows not only of deep water but also of surface water from the North Sea. Some of the intruded marine species have established, while others had disappeared (OLENINA & KOWNACKA, 2010).

The past series of inflow events, e.g. the Major Baltic Inflow of December 2014 (MOHRHOLZ et al. 2015), should have transported marine species into the Baltic Sea which should appear in our samples from 2015. Only *Coscinodiscus* cf. *centralis, Roperia tesselata, Karenia mikimotoi* and *Nematopsides vigilans* were new for us in 2015, but their identification was not proved. They were not found in 2016, 2017 and 2018 anymore except the uncertain *Coscinodiscus* cf. *centralis*.

Lennoxia faveolata was new to us in 2009, was still found in 2010 but not in 2011-2013, probably because of its generally low abundance. From 2014 to 2018 it was present in our samples in very low biomass (Table A2). The presence or absence of those species that are generally rare has no meaning because they may be accidentially found or not found in our small sample volumes. This applies to *Spatulodinium pseudonoctiluca*, *Chaetoceros lorenzianus* or *Phaeodactylum tricornutum*, which were sometimes present in samples in previous years but not found in 2018 because their generally low abundance may fall below the detection limit. *Polykrikos schwartzii* and *Alexandrium pseudogonyaulax* were more regularly found and have now become established. The diatom *Pseudosolenia calcar-avis*, which occurred in large numbers in autumn 2010, has not been observed in 2013 and 2014. However, it reappeared in 2015, held the high biomass rank of 18 in 2017 (see also KAISER et al. 2016) and covers rank 21 in 2018 (Table A2). High biomass levels of *Peridiniella danica* first occurred in 2011 (rank 5). This dinoflagellate has declined in the following years but has re-established and held the ranks 12 and 36 in 2017 and 2018, respectively.

Thalassionema frauenfeldii was new for us in 2017. It was identified in samples from Kiel Bay and Bay of Mecklenburg from November 2017. However, this species was already known from the Kattegat/Belt Sea area according to the checklist of HÄLLFORS (2004). In 2018, it occurred sporadically in March in Kiel Bay and in July in the Bay of Mecklenburg.

Statements on species that are generally abundant are more reliable. The difficulties involved in identifying naked Dictyochophyceae have been discussed in chapter 4.1.1. Since 2009 we have attempted to distinguish *Pseudochattonella farcimen* (old synonym: *Verrucophora farcimen*) from the naked form of *Dictyocha speculum*, and have included it in our lists. The spring species *Dictyocha speculum* occurred vigorously in 2007 and 2008, but was relatively insignificant in 2010. In 2011, Dictyochophyceae were highly abundant, dominated by *Pseudochattonella farcimen* (named *Verrucophora* cf. *farcimen* at that time). However, *Pseudochattonella farcimen* did not appear in samples in 2012, 2014 and 2016. In 2012 and 2013, biomass of *Dictyocha speculum* was low, but a strong spring bloom of *Dictyocha speculum* recurred in 2014. In 2015 the two species occured together and formed a spring bloom in the Belt Sea. The appearance of *Dictyocha speculum* was weak in 2016. Already in 2013 its presence was stronger in autumn than in spring. Also in 2016 and 2017, this species occurred both in spring and in autumn mainly in Kiel Bay and Lübeck Bay. In 2018, it was almost absent in spring but appeared in autumn.

Coscinodiscus concinnus formed a spring bloom in Kiel Bay and in the Bay of Mecklenburg in 2016, but not at all in 2017 and 2018.

The cold-water diatom *Achnanthes taeniata* formed blooms in the Baltic Proper in the 1980s, but has sharply declined (HELCOM 1996; WASMUND et al. 2011 b). The mild winters of the 1990s seem to have harmed it. Exceptionally it was dominant in 2011 after a strong winter. From 2012 to 2015 it was hardly represented at all, and it was completely absent in 2016, 2017 and 2018. The dinoflagellate *Peridiniella catenata* was the dominating spring species in the Eastern Gotland Basin in the mid of the 1990s (WASMUND et al. 2011b). Surprisingly, it appeared in extremely high biomass during our cruise in May 2018 in the Eastern Gotland Basin (Figs. 13, 16c).

4.1.4 Chlorophyll *a*

Table 5 shows the chlorophyll *a* data of the monitoring cruises. Mean values for the uppermost 10 m, averaged from samples of 1 m, 5 m and 10 m depth, are shown for each date and station. As explained in chapter 2.3, we determine 'total chlorophyll *a*' values ('chl.a-tot'), which are uncorrected for phaeopigments.

The seasonal variations of the chlorophyll data corresponds to those given for biomass in Figs. 8-10. The highest concentrations of chlorophyll *a* coincided with the spring and autumn blooms. The maximum of the chlorophyll concentrations appears during the extreme spring bloom on 11 May 2018 in the southern part of the Eastern Gotland Basin.

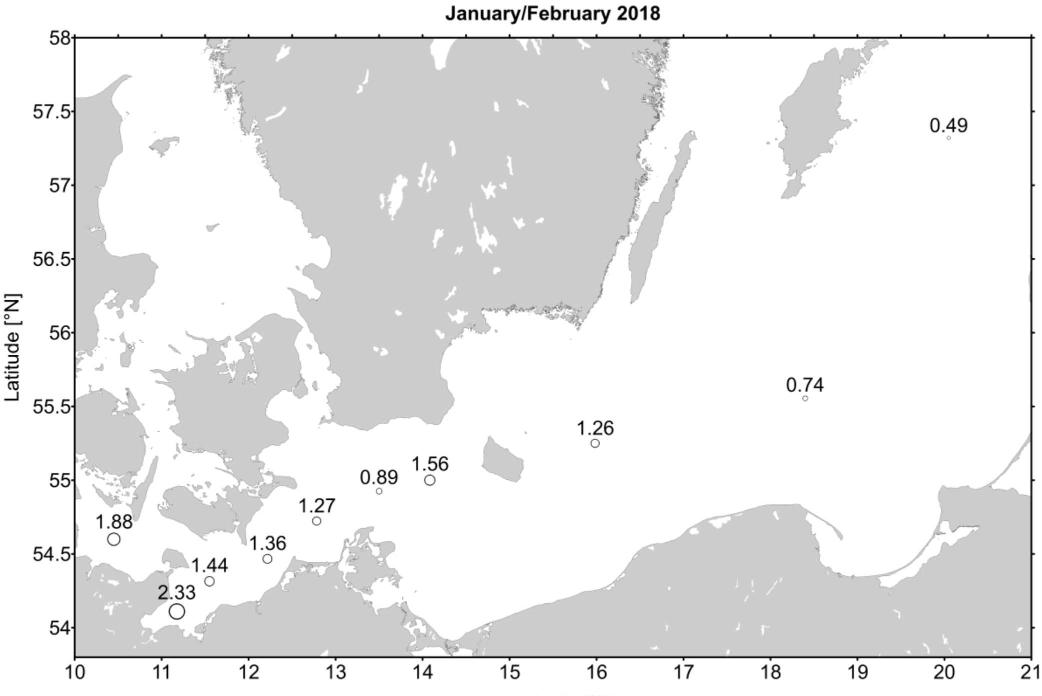

Fig. 20: Horizontal distribution of chlorophyll *a* concentrations (µg/L) at sampling locations during the monitoring cruise of January/February 2018.

Figs. 20-22 present the horizontal distribution of chlorophyll *a* values determined during the 5 monitoring cruises in 2018. They visualise the progression of the spring bloom from the western Baltic Sea in March to the Eastern Gotland Basin in May (Fig. 21). Most values indicated in the figures are lower than the peak values given in Table 5 because mean values from the outward and return leg of each cruise are depicted in Figs. 20-22 in contrast to single values in Table 5.

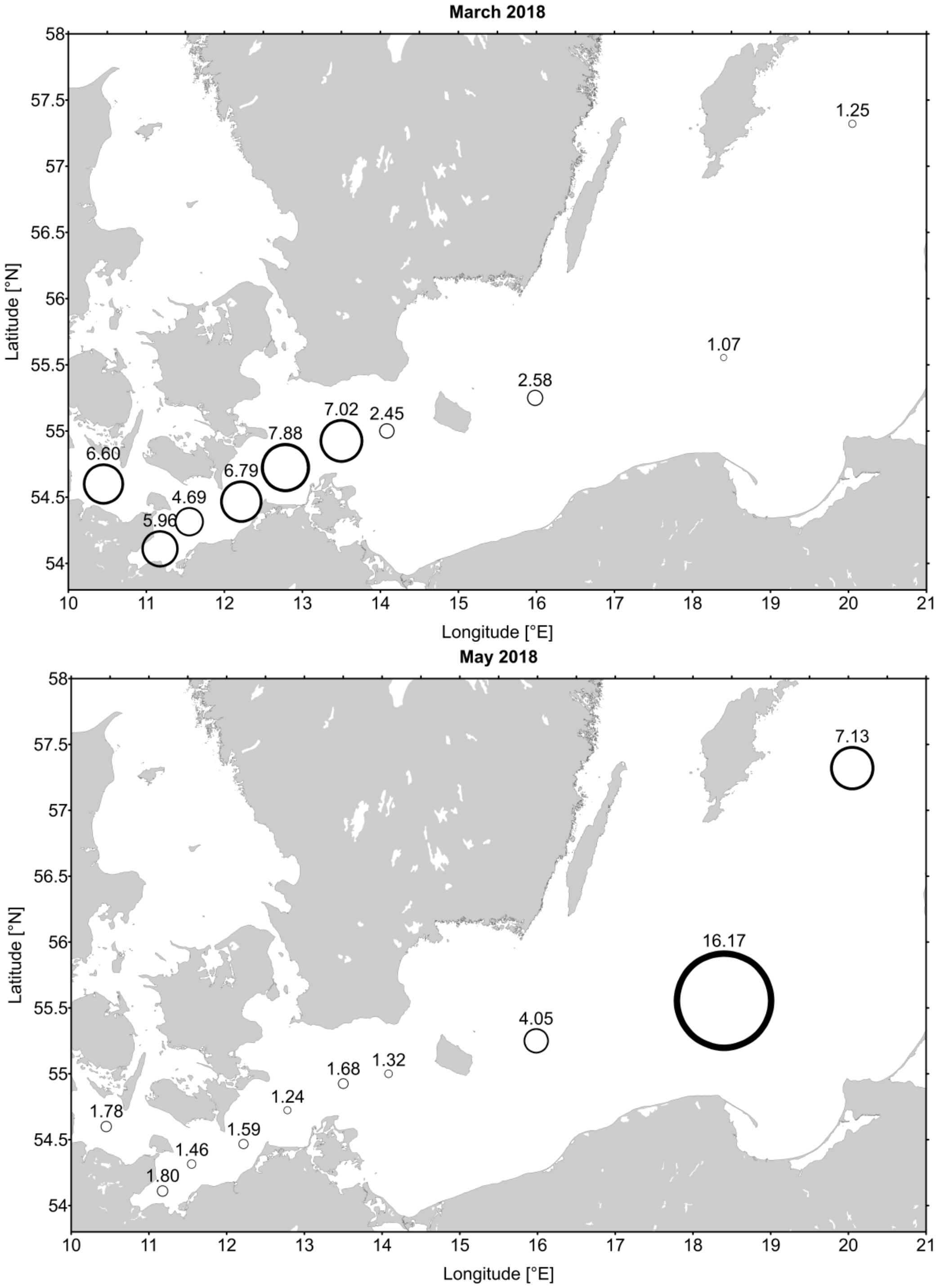

Fig. 21: Horizontal distribution of chlorophyll *a* concentrations (µg/L) at sampling locations during monitoring cruises in March and May 2018.

A summer bloom was not represented in chlorophyll values because the summer diatoms are poor in chlorophyll (Fig. 22a). Only the higher cyanobacteria biomasses in the Eastern Gotland Basin are reflected in the chlorophyll *a* concentrations. The raised chlorophyll a concentrations in autumn indicate the autumn bloom throughout the whole Baltic Sea (Fig. 22b).

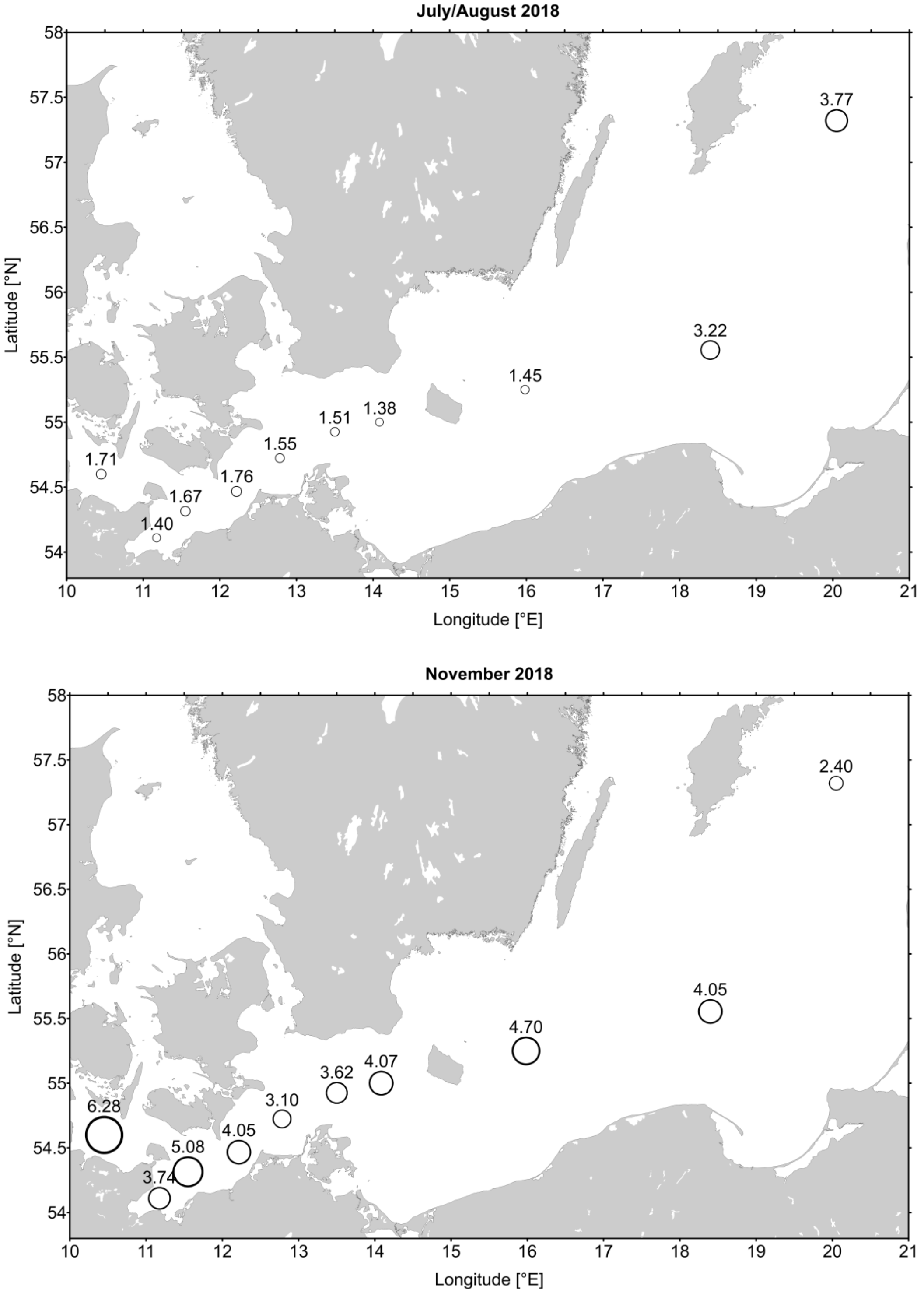

Fig. 22: Horizontal distribution of chlorophyll *a* concentrations (µg/L) at sampling locations during the monitoring cruise in November 2018.

Table 5
Mean concentrations of total chlorophyll *a* from 0 – 10 m depth during the sampling occasions in 2018.

Station	Date	Chl.a-tot (mg m^{-3})
OMBMPN3	30.01.2018	1.88
OMBMPN3	19.03.2018	6.60
OMBMPN3	08.05.2018	1.78
OMBMPN3	24.07.2018	1.71
OMBMPN3	06.11.2018	6.28
OMO22	30.01.2018	2.33
OMO22	19.03.2018	5.96
OMO22	08.05.2018	1.80
OMO22	25.07.2018	1.40
OMO22	05.11.2018	3.74
OMBMPM2	30.01.2018	1.61
OMBMPM2	08.02.2018	1.27
OMBMPM2	20.03.2018	5.92
OMBMPM2	27.03.2018	3.45
OMBMPM2	09.05.2018	1.78
OMBMPM2	16.05.2018	1.14
OMBMPM2	25.07.2018	2.12
OMBMPM2	04.08.2018	1.23
OMBMPM2	05.11.2018	5.48
OMBMPM2	14.11.2018	4.69
OMBMPM1	31.01.2018	1.53
OMBMPM1	08.02.2018	1.20
OMBMPM1	20.03.2018	6.12
OMBMPM1	27.03.2018	7.46
OMBMPM1	09.05.2018	1.38
OMBMPM1	16.05.2018	1.80
OMBMPM1	25.07.2018	1.70
OMBMPM1	04.08.2018	1.82
OMBMPM1	06.11.2018	3.85
OMBMPM1	14.11.2018	4.25
OMBMPK8	31.01.2018	1.31
OMBMPK8	08.02.2018	1.22
OMBMPK8	20.03.2018	7.82
OMBMPK8	27.03.2018	7.95
OMBMPK8	09.05.2018	1.01
OMBMPK8	16.05.2018	1.46
OMBMPK8	25.07.2018	1.52
OMBMPK8	04.08.2018	1.58
OMBMPK8	07.11.2018	1.95
OMBMPK8	14.11.2018	4.24
OMBMPK5	31.01.2018	0.99
OMBMPK5	08.02.2018	0.80
OMBMPK5	20.03.2018	6.81
OMBMPK5	27.03.2018	7.22
OMBMPK5	09.05.2018	2.04
OMBMPK5	16.05.2018	1.32
OMBMPK5	25.07.2018	1.54
OMBMPK5	04.08.2018	1.48
OMBMPK5	07.11.2018	3.83
OMBMPK5	14.11.2018	3.40
OMBMPK4	01.02.2018	1.56
OMBMPK4	21.03.2018	2.45
OMBMPK4	10.05.2018	1.32
OMBMPK4	26.07.2018	1.38
OMBMPK4	07.11.2018	4.07
OMBMPK2	02.02.2018	0.96
OMBMPK2	07.02.2018	1.56
OMBMPK2	21.03.2018	2.04
OMBMPK2	26.03.2018	3.11
OMBMPK2	10.05.2018	4.57
OMBMPK2	15.05.2018	3.54
OMBMPK2	27.07.2018	1.61
OMBMPK2	03.08.2018	1.29
OMBMPK2	09.11.2018	4.61
OMBMPK2	13.11.2018	4.79
OMBMPK1	03.02.2018	0.74
OMBMPK1	22.03.2018	1.07
OMBMPK1	11.05.2018	16.17
OMBMPK1	27.07.2018	3.22
OMBMPK1	10.11.2018	4.05
OMBMPJ1	06.02.2018	0.49
OMBMPJ1	23.03.2018	1.25
OMBMPJ1	12.05.2018	7.13
OMBMPJ1	28.07.2018	3.77
OMBMPJ1	11.11.2018	2.40

4.1.5 Sedimentation

Microscopic examination of settled material collected by a sediment trap in Arkona Basin in 2018 revealed a sedimentation pattern that reflected the typical growth dynamics of phytoplankton in the western Baltic Sea from January to August 2018. Due to flawed trap functioning during the third collection period (intervals 21-33), no conclusive data on sedimentation dynamics is available for August through December. Integration of the material however provides information on mean relative frequencies and taxonomic distribution of settled phytoplankton for this period. Alltogether 43 phytoplankton taxa were encountered in 2018 in sediment trap material, which is comparable to taxonomic diversity of the preceeding years (45 in 2017 and 40 in 2016).

Diatoms were the most diverse group of phytoplankton found in settled material with 23 taxa recorded throughout the year (Fig. 23 a). Diatoms were present and abundant during winter with pennate species as well as cold water adapted *Thalassiosira levanderi*, *Coscinodscus granii*, *Melosira arctica* and *Cyclotella choctawhatcheeana* constituting the settling community. Settling diatom material increased in spring samples, their abundance pattern closely following the dynamics of the spring bloom in the upper water column. Particularly high abundances and species diversity (8-9 major taxa) were recorded from sediment trap samples in March and April simultaneously with the spring bloom. Dominant species in these samples were typical cold-water adapted diatoms such as *Thalassiosia levanderi, Skeletonema marinoi* and *Thalassiosira baltica*, which formed the spring bloom as reported in chapter 4.1.1.1. Diatom abundances and diversity decreased in sediment traps in May, slightly earlier than during the previous year. After a month of low representation and diversity, diatoms increased again in June and remained abundant throughout the summer in trap material. *Actinocyclus octonarius* and small centric diatoms were most abundant together with pennates and *Dactyliosolen fragilissimus*. In the intergrated trap material collected between August and December a number of diatom species not present in the previous months was recorded, among them species belonging to the toxic genus *Pseudo-nitzschia* as well as *Cerataulina pelagica*.

Dinoflagellates (Fig. 23 b) were found in settled material during and after the diatom spring bloom. Most of the taxa encountered were thecate dinoflagellates belonging to the genera *Ceratium, Dinophysis*, *Protoperidinium*, *Peridiniella* and *Prorocentrum* that do not disintegrate in the water column and are heavy enough to settle once the growth phase is terminated. Highest sedimentation records were observed after the spring bloom. These represented the typical spring bloom species *Dinophysis* spp., *Gymnodinium corollarium* and *Peridiniella catenata*. *Ceratium tripos*, which was highly abundant in the summer phytoplankton was found in summer and autumn trap samples. Other taxa representing the summer and autumn phytoplankton community in the water such as *Prorocentrum micans*, *Phalachroma rotundata* and *Protoperidinium spp*. were found in the integrated autumn sample.

Small colonial cyanobacteria of the genera *Snowella/Woronochinia* and *Merismopedia* were present occasionally in winter, summer and/or autumn samples together with *Nodularia spumigena* (Fig. 23 c). Indications of a cyanobacteria summer bloom were not found in the sedimentation data confirming the lack of a bloom in the water column as reported in chapter 4.1.1.2. The low representation of diazotrophic cyanobacteria in settling material was different from the previous year, when all three major genera, *Dolichospermum*, *Nodularia* and *Aphanizomenon* constituted a large part of settling material during summer and autumn.

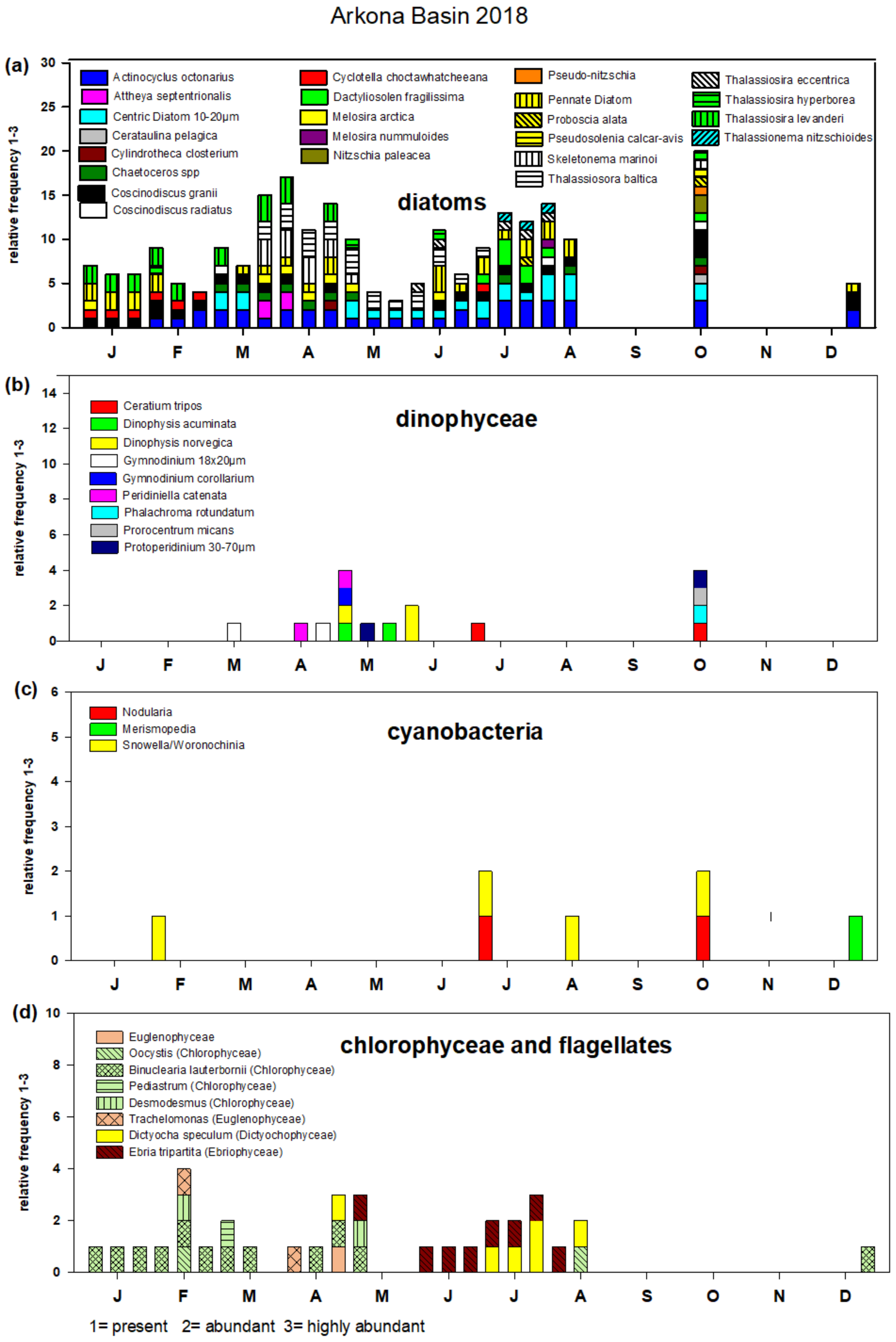

Fig. 23 a-d: Relative frequency of selected taxa of diatoms, dinoflagellates, cyanobacteria and green algae/flagellates in sinking organic material in 2018. Columns for October represent cumulative frequencies and distributions of settled phytoplankton taxa for the period August through December 2018 when all sinking material was collected in the last 3 vials.

Diverse chlorophytes and flagellates were present in sediment trap material in winter, spring and summer at relatively low abundances. While Chlorophytes were mainly found in settled winter/spring material, represented by *Binuclearia lauterbornii*, *Pediastrum* sp. and *Desmodesmus* sp., Dictyochophyceae and Ebriophyceae occurred in summer samples (Fig. 23 d).

The vertical fuxes of particulate carbon (Fig. 24), nitrogen (Fig. 25), suspended particulate matter (Fig. 26), phosphorus (Fig. 27) and silica (Fig. 28) roughly reflect the sedimentation dynamics of phytoplankton and the major bloom phases in 2018, with co-occurring peaks of all elements in March, June and August. This differs from the previous year, 2017, when sediment resuspension seemed to mask the sedimentation pulses and sedimentation during winter appeared to be higher than during the spring bloom. Although the bloom dynamics, especially the spring bloom, was reflected by the sedimentation pulses, elemental peaks did not match abundance peaks quantitatively, which is most likely a result of the different quatification approaches. While elemental data represent analytical measurements, phytoplankton estimates are based on semiquantitative categories ("relative frequency"). Concentrations of particulate organic nutrients and suspended particulate matter in sediment traps were much higher than in 2017 and sedimentation occurred in pulses during or after major bloom phases.

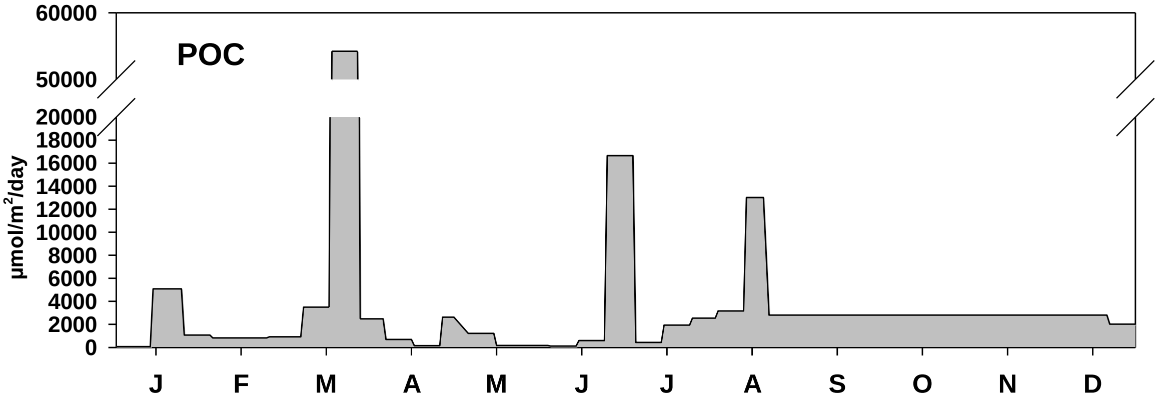

Fig. 24: Daily sedimentation rates of particulate organic carbon (POC) at 35 m depth in the central Arkona Sea in 2018.

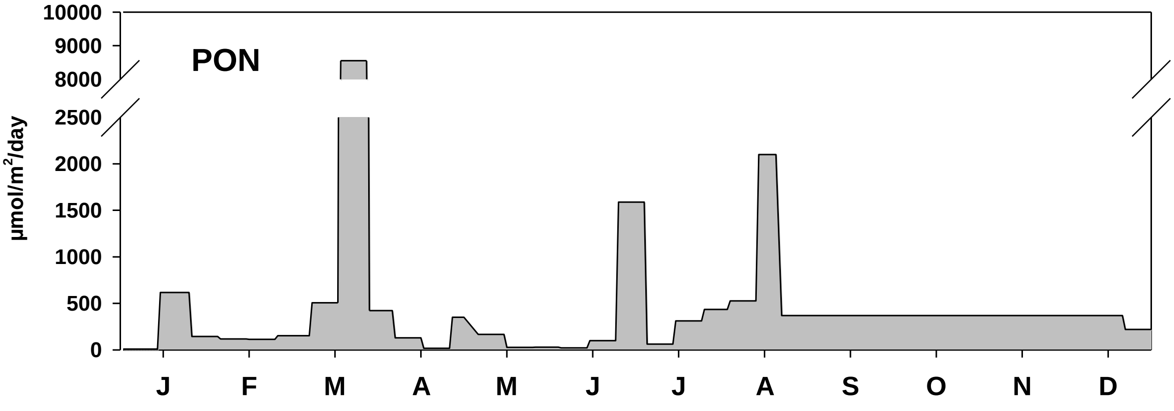

Fig. 25: Daily sedimentation rates of particulate organic Nitrogen (PON) at 35 m depth in the central Arkona Sea in 2018.

It seems that in 2018 measured fluxes were not critically influenced by resuspension of bottom sediments as proposed for 2017. Interestingly, integrated particulate silica data of the August to December period were high compared to other particulate nutrient values, indicating the diatom autumn bloom.

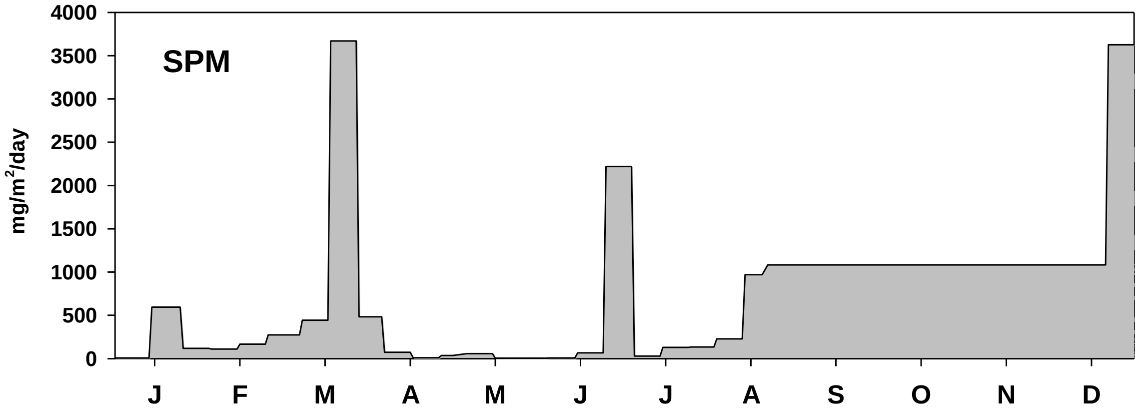

Fig. 26: Daily sedimentation rates of particulate suspended matter (SPM) at 35 m depth in the central Arkona Sea in 2018.

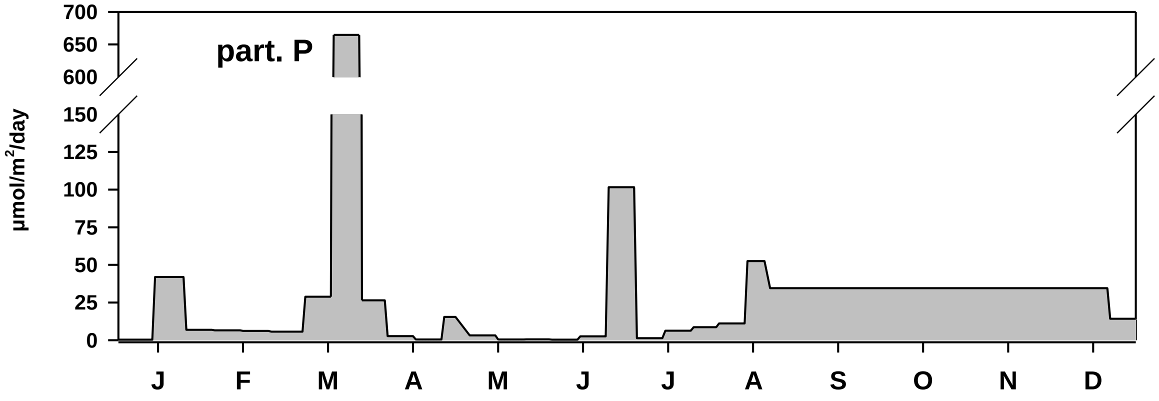

Fig. 27: Daily sedimentation rates of particulate phosphorus (part.P) at 35 m depth in the central Arkona Sea in 2018.

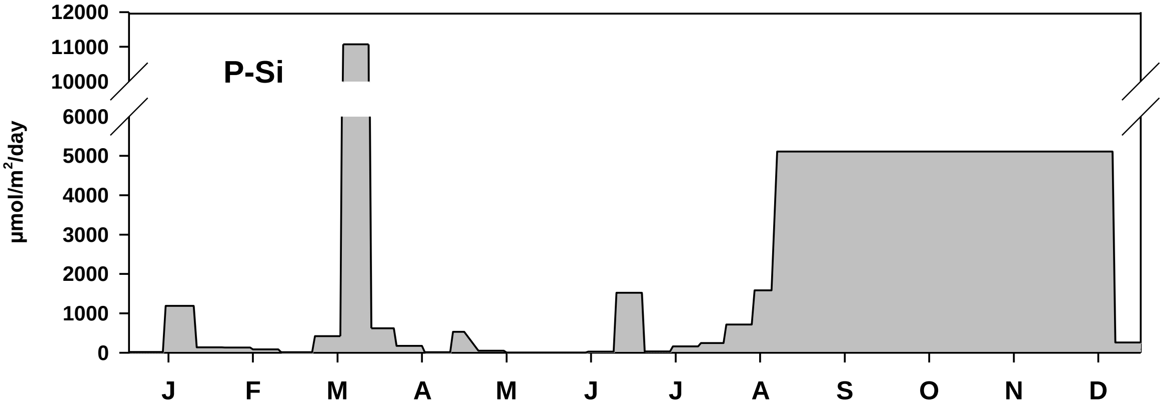

Fig. 28: Daily sedimentation rates of particulate biogenic silica (P-Si) at 35 m depth in the central Arkona Sea in 2018.

In fact, large amounts of fragmented diatom frustules were present in sample vials 31-33, containing the material shaken loose from the overgrown (*Balanus*) metal sceen covering the trap opening during the third seasonal sampling period. Obviously, these frustules were already degraded by filter-feeding balanids and depleted in C, N and P whereas Si was the remaining texture.

Elemental ratios C/N and C/P should amount to 6.6 and 106, respectively, under optimal growth conditions and balanced decomposition of the organic material. As shown in Fig. 29, the particulate C/N ratios are variable but close to 6.6 on average. The highest value occurred at the end of June, when nitrogen limitation seems to be most severe. Even though not in bloom concentrations, nitrogen-fixing cyanobacteria add nitrogen to the ecosystem, which leads to decreasing C/N ratios in July and August. The particulate C/P ratios are strongly deviating from the Redfield ratio (Fig. 30). They indicate strong P limitation of phytoplankton growth and/or preferred remineralization of P in comparison with C. Cyanobacteria may accumulate N and C whereas the P quota is decreasing. Therefore, the particulate C/P ratio in isolated cyanobacteria may increase to peak values of 930 (NAUSCH et al. 2012). Surprisingly, the peak in the C/P ratio appeared much earlier then in some previous years.

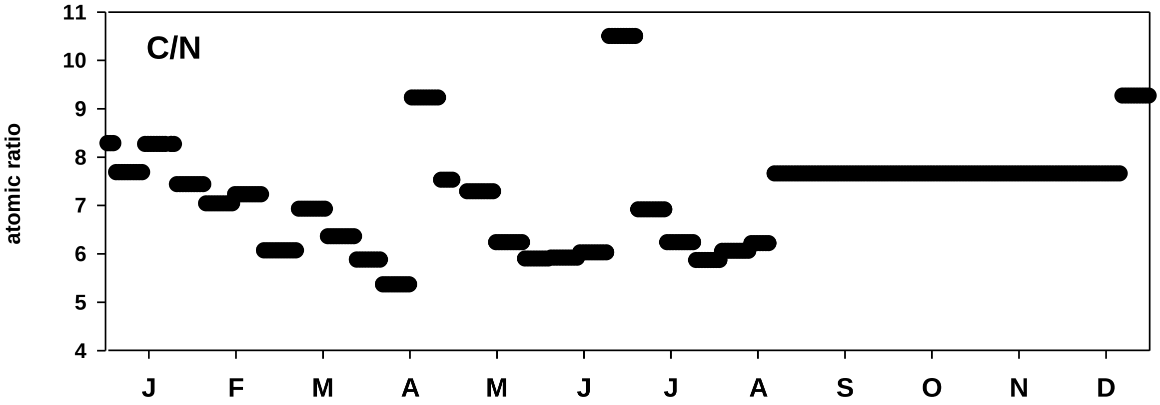

Fig. 29. Atomic ratio between carbon and nitrogen (C/N) in sedimenting particles at 35 m depth in the central Arkona Sea in 2018.

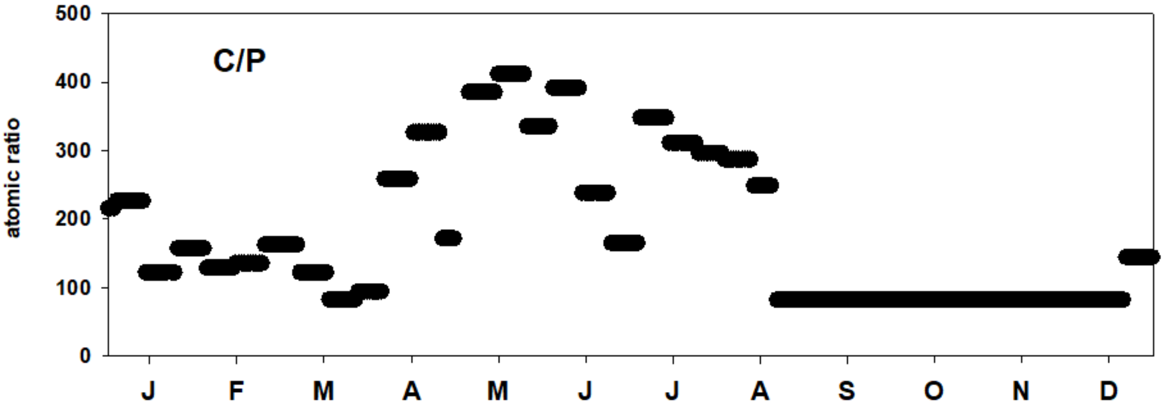

Fig. 30: Atomic ratio between carbon and phosphorus (C/P) in sedimenting particles at 35 m depth in the central Arkona Sea in 2018.

The δ¹⁵N values were in the usual range, nor exceeding 8 ‰, which is the value found in nitrate-rich deep water or winter water (Fig. 31). The slight decrease from June to August indicates a moderate nitrogen fixation, which was much lower than in the previous years, but the season of nitrogen fixation may have started earlier than usual.

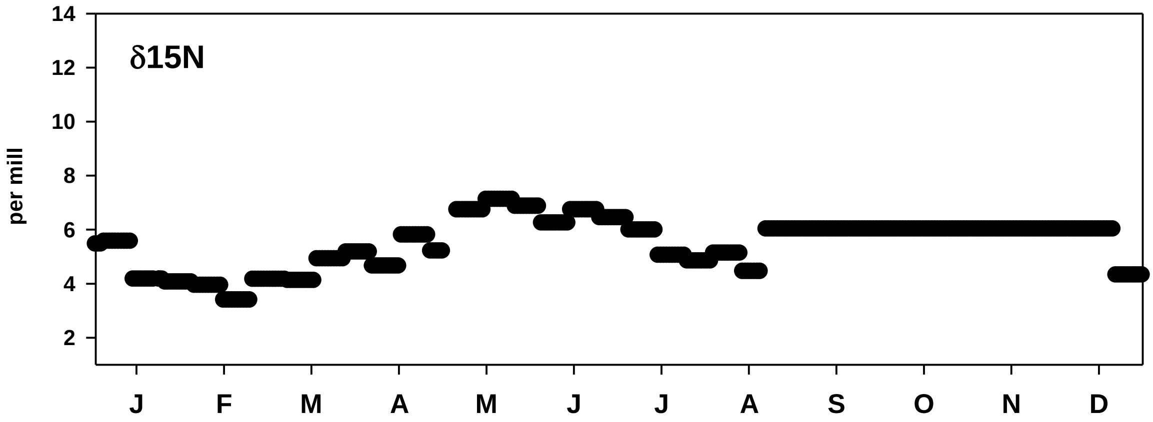

Fig. 31: Isotopic signature of nitrogen (‰ δ15N) at 35 m depth in the central Arkona Sea in 2018.

4.2 Mesozooplankton

4.2.1 Species composition and non-indigenous species

A total of 44 taxa were recorded in the study area during 2018 (Tab. A3). The total number recorded decreased considerably in comparison to the preceding years (2016: 73 taxa, 2017: 63 taxa; WASMUND et al. 2017b, 2018a), in which the diversity of the zooplankton has peaked in the recent decade.

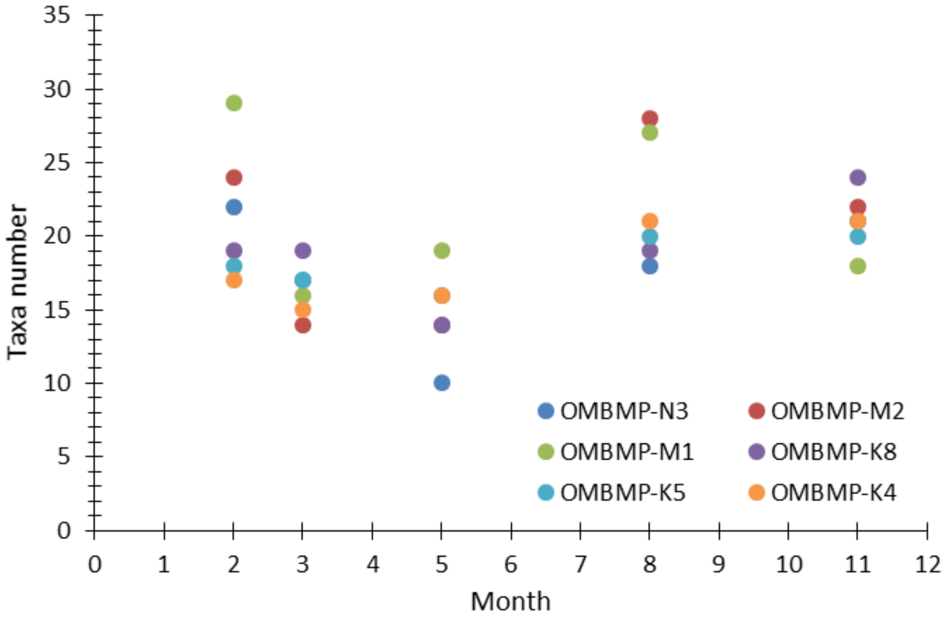

Fig. 32: Seasonal variation of the number of taxa recorded at different stations in the investigation area in 2018.

This is likely due to the disappearance of halophilic organisms, such as the calanoid copepod *Calanus* spp., *Acartia clausi* or *Centropages typicus,* in the Kiel Bay and the Bay of Mecklenburg occurring during recent inflows and due to the absence of several gelatinous Cnidaria such as *Obelia geniculata*, *Aurelia aurita* or *Rathkea octopunctata*. In addition, larvae of benthic crustaceans were generally rare in 2018. Nevertheless, the taxa number was not lower than in those years preceding the diversity peak in 2016-2017. Due to the lack of halophilic species, no pronounced differences in the species number occurred at different stations in western Baltic Sea (Fig. 32). About 36-39 species were recorded in the Bay of Mecklenburg, in which species occurring in the Kiel Bay (e.g., *Euphysa aurata* or *Asterias* spp.) or the Arkona Basin (e.g., *Bosmina* spp.) mixed. In the Kiel Bay and the Arkona Basin fewer species (30-33) were observed, respectively. Similar to preceding years, the number of species increased during the transition from winter to spring and summer to autumn (Fig. 32).

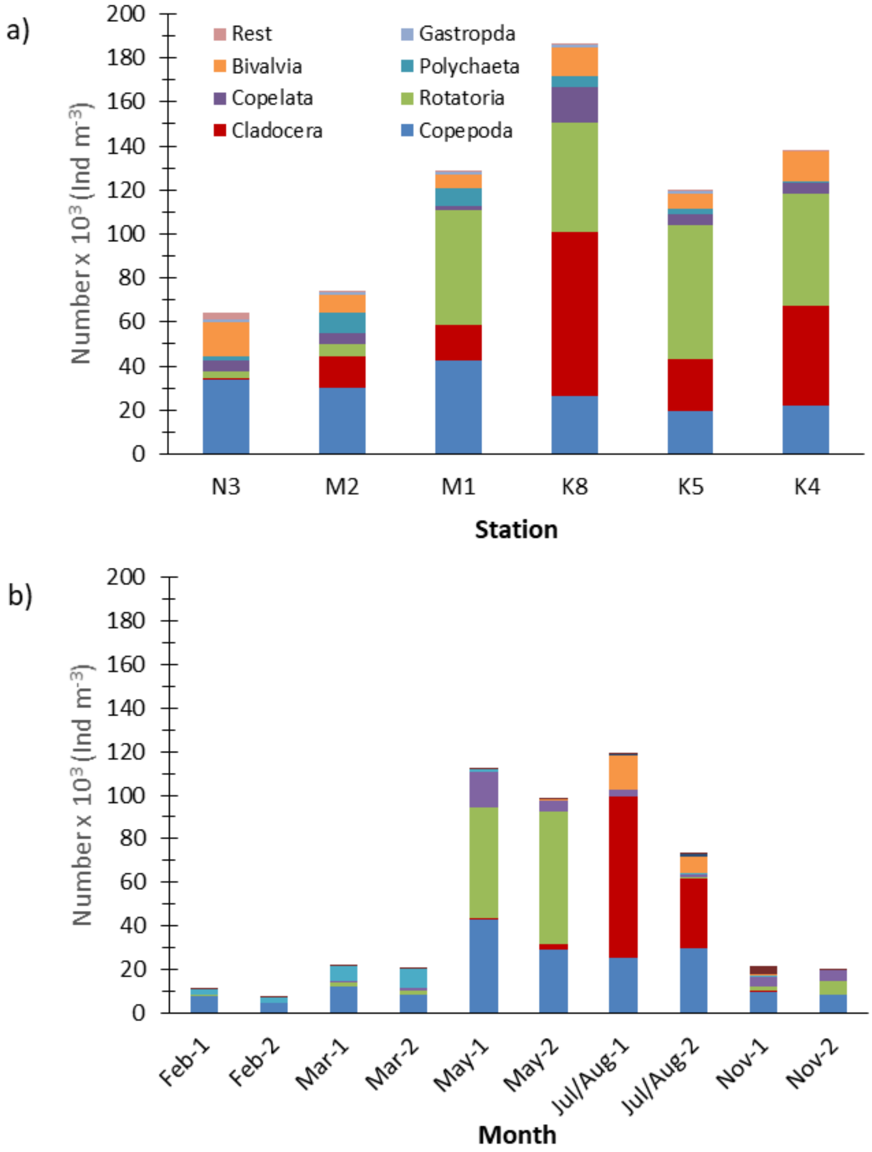

Fig. 33: Spatial and seasonal variation of the maximal abundance of the mesozooplankton groups (a, b) and of adults of calanoid and cyclopoid copepods (c, d) in the investigation area; continued on page 49.

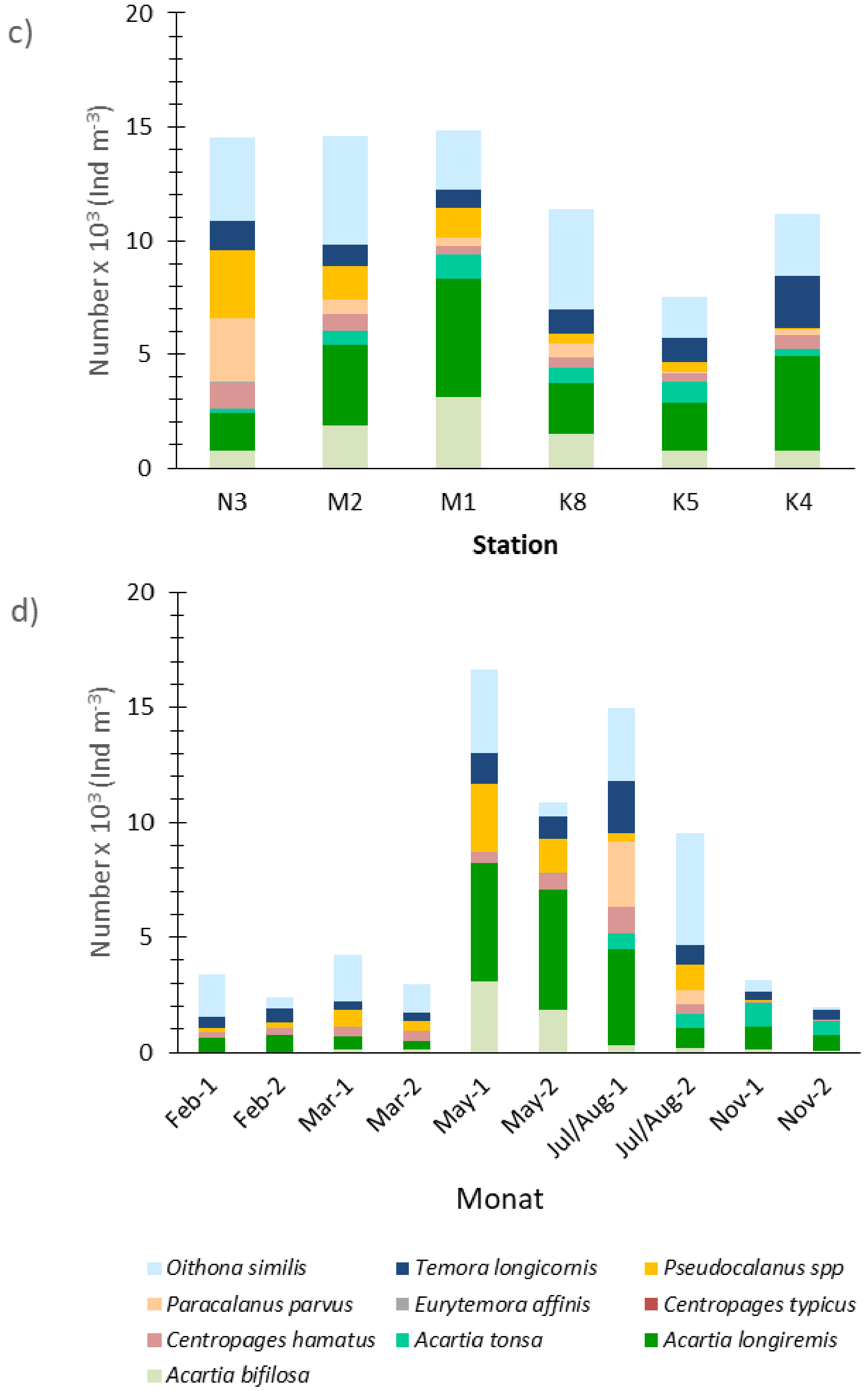

Fig. 33, continued.

The concentrations of zooplankton were again low in 2018, but a reversal of the general decline in stock size since the 2000s already observed in 2017 continued (compare Fig. 36a,b). This is mainly caused by a considerable increase in the abundance of rotifers by a factor of 2-10, particularly in the in the Bay of Mecklenburg and Arkona Basin (Fig. 33a, b). The stocks of cladocera showed a continued recovery in all areas as well, while calanoid and cyclopoid copepods remain on a similar level compared to 2017. Cladocera were the single most important group in the area, with maximum concentrations of 7.4 x 10^4 ind. m^{-3} (Fig. 33a). While their abundance was similar to 2017 in the Kiel Bay and Arkona Basin, the stock size of up to 1.5 x 10^4 ind. m^{-3} in the Bay of Mecklenburg was enhanced by a factor of 3-6. Rotifers were the second most important group with maximum concentrations of 6.1 x 10^4 ind. m^{-3}, followed by calanoid copepods (4.7 x 10^4 ind. m^{-3}) and cyclopoid copepods (2.1 x 10^4 ind. m^{-3}, Fig. 33a-d).

The population size of appendicularians (Copelata) has also increased (max. 1.6 x 10^4 ind. m^{-3}) in comparison to 2017 (0.5 x 10^4 ind. m^{-3}), while the meroplankton has generally slightly increased, particularly among polychaete and bivalve larvae.

Among the cladocera, *Bosmina* is usually the most important genus. The stocks varied between 1.2 and 6.9 x 10^4 ind. m^{-3} and showed a recovery from the very low concentrations observed in 2016 (< 0.6 x 10^4 ind. m^{-3}). In contrast to the preceding years 2015-2017, in which the occurrence of *Bosmina* spp. was largely restricted to the Arkona Basin, it was also abundant in the Bay of Mecklenburg. The genus is usually not found in the Kiel Bay and is outnumbered by *Evadne nordmanni*, *Podon intermedius* and *P. leuckartii*. The stocks of these species displayed, in contrast to *Bosmina* spp., no substantial changes to the preceding years. *E. nordmanni* ranked second with concentrations ranging from 1.3 – 4.6 x 10^3 ind. m^{-3}. It occurred in the entire area, but highest concentrations were observed in the Bay of Mecklenburg. *Podon leuckartii* and *P. intermedius* were also observed in the entire area, their stocks size achieved 0.2 - 1.2 x 10^3 and 0.2 – 1.1 x 10^3 ind. m^{-3}, respectively. Other species were rare. *Pleopsis polyphemoides* occurred at low concentrations of 18-396 ind. m^{-3} in Kiel Bay, Bay of Mecklenburg and Arkona Basin, whereas few individuals of *Penilia avirostris* were restricted to Kiel Bay only.

Rotifers were seasonally very abundant in 2018 and replaced the copepods as second most important group in terms of abundance (0.3 – 6.1 x 10^4 ind. m^{-3}). The group is usually restricted to the Arkona Basin mainly, but had a wide distribution in 2018 ranging from Kiel Bay to Arkona Basin. The genus *Synchaeta* is typically the dominant group. Highest concentrations were observed in the Arkona Basin and the eastern Bay of Mecklenburg (5.0 – 6.1 x 10^4 ind. m^{-3}), whereas concentrations in the Kiel Bay were one order of magnitude lower (0.3 – 0.6 x 10^4 ind. m^{-3}). The genus *Keratella* was not observed during 2017, but represented by two species, *K. cochlearis* and *K. quadrata*, in 2018. They achieved low concentrations in the Bay of Mecklenburg and Arkona Basin mainly (104 – 546 ind. m^{-3}).

Only small differences in the stock sizes of the ecological important group of the copepoda in comparison to the preceding year were observed. A general recovery from low stocks during 2015-2016 were observed in 2017 (total stock: 2.4– 4.9 x 10^4 ind. m^{-3}), and this trend continued in 2018 (total stock: 1.9 – 4.2 x 10^4 ind. m^{-3}). The genus *Acartia* replaced *Temora* as the most abundant genus among the calanoid copepods (0.6 – 2.5 x 10^4 ind. m^{-3}). While its density remained similar in the Kiel Bay and the Arkona Basin in comparison to the previous years, the stock size was considerably enhanced in the Bay of Mecklenburg (Fig. 33c). Only small changes were observed in the density of the genera *Para/Pseudocalanus* and *Centropages*. *Para/Pseudocalanus* ranked second among the calanoid copepods. The stock size showed a continuous recovery from 0.05 – 0.45 x 10^4 ind. m^{-3} and 0.13 – 1.3 x 10^4 ind. m^{-3} in in the years 2016 and 2017, respectively, to 0.28 – 1.4 x 10^4 ind. m^{-3} in 2018. *Para/Pseudocalanus* were most abundant in the Kiel Bay and Bay of Mecklenburg (Fig. 33c). In contrast, *Temora* decreased in stock size (0.2 – 1.1 x 10^4 ind. m^{-3}) and ranked only third. This is owed to a considerable reduction of the genus in the Arkona Basin. The fourth raking genus *Centropages* was generally less abundant (0.9 – 4.0 x 10^3 ind. m^{-3}) and was more common in the Kiel Bay and Bay of Mecklenburg. Other genera such as *Eurytemora* were rare with maximal densities below 50 ind. m^{-3}. In the western Baltic Sea, cyclopoid copepods are represented by a single genus *Oithona*. It is generally very abundant, particularly in the Kiel Bay. In 2018, the maximal abundance ranged from 0.7 – 2.1 x 10^4 ind. m^{-3}) and the highest densities were observed in the Bay of Mecklenburg (1.9 – 2.1 x 10^4 ind. m^{-3}).

Among the adult copepods, two *Acartia* species and *Oithona similis* were most abundant (Fig. 33d). As in previous years, *Acartia longiremis* (1.7 – 5.2 x 10^3 ind. m^{-3}) dominated over *A. bifilosa* (0.7 – 3.1 x 10^3 ind. m^{-3}) in all areas. This is untypical because in Kiel Bay *A. bifilosa* is normally more common. *A. tonsa*, in contrast, contributed only a little to the zooplankton stock (‹ 1.0 x 10^3 ind. m^{-3}). *Oithona similis* was abundant in the entire area with densities ranging from 1.8 – 4.8 x 10^3 ind. m^{-3}. *Pseudocalanus* spp. and *Paracalanus parvus* were more common than in the period 2015-2016 and their stock size recovered (0.1 – 2.9 x 10^3 ind. m^{-3}). *Temora longicornis* occurred in similar densities (0.7 – 2.3 x 10^3 ind. m^{-3}), but was less common than in 2018. The stock size of *Centropages hamatus* did not display major changes compared to previous years (0.3 – 1.2 x 10^3 ind. m^{-3}).

The appendicularians (Copelata, Chordata) were restricted to the Bay of Mecklenburg and Arkona Basin and as usual represented by two species (Fig. 33 a,b). *Fritellaria borealis* achieved maximum concentrations in May ranging from 0.4 – 1.6 x 10^4 ind. m^{-3}. These concentrations are considerably higher than those observed in preceding years (0.2 – 0.7 x 10^4 ind. m^{-3}). *Oikopleura dioica*, an autumn species, occurred in the Bay of Mecklenburg at concentrations of 2.2 – 4.9 x 10^3 ind. m^{-3}, mainly. It was rare in the Kiel Bay (6 – 15 ind. m^{-3}) and the Arkona Basin (15 – 383 ind. m^{-3}).

Apart from these holoplankton groups, meroplankton regularly contributes to the stock of zooplankton (Fig. 33). As in previous years, polychaete and bivalve larvae dominated the meroplankton. The maximal abundance of bivalve larvae (5.7 – 15.4 x 10^3 ind. m^{-3}) in 2018 exceeded those from 2017. However, this concentrations are not uncommon in the Kiel Bay, Bay of Mecklenburg and Arkona Basin. Polychaeta larvae were also abundant (1.6 - 9.0 x 10^3 ind. m^{-3}), but occurred mainly in the Kiel Bay and Bay of Mecklenburg. This was also the case in gastropod larvae, which were less common (0.3 -1.3 x 10^3 ind. m^{-3}).

Exceptional species were not observed in the zooplankton in 2018. The calanoid copepod *Acartia tonsa*, which was already introduced during the 1920s, is a well-established calanoid copepod in Baltic Sea (OJAVEER & KOTTA 2015).The species is confined to the coastal areas of the southern Baltic Sea (CHOJNACKI 1991, HEERKLOSS et al. 1991), but occurs frequently at low numbers in the offshore water. After some years of low abundance or absence, the stocks are presently increasing. The anthomedusae *Lizzia blondina* was observed for the first time in 2017, and occurred regularly in the Bay of Mecklenburg. The species is of marine origin similar to *Penilia avirostris* (RUSSEL 1970, GIESKES 1971, GREVE et al. 2004). Other species that are related to water that is more saline were, however, not recorded during 2018.

4.2.2 Seasonal zooplankton variation in sub-areas

Kiel Bay

The zooplankton in Kiel Bay (OMBMP-N3) displayed a typical variation in the seasonal development in the stock and its composition (Figs. 34 and 35). Copepods generally dominated the community, while other holoplankton such as cladocera, rotifers or appendicularia played a minor role. The meroplankton contributed primarily to the stock in winter by polychaete larvae and in summer by high numbers of bivalve larvae (Fig. 2), respectively. Timing and composition of the zooplankton in 2018 resembled strongly the previous year and, thus, continued a shift in the composition of the zooplankton since 2016, particularly among the copepods. While *Acartia bifilosa* and the cyclopoid copepod *Oithona similis* dominated the community until

2016, *Pseudocalanus* spp., *Temora longicornis* and *Acartia longiremis* got increasingly more abundant.

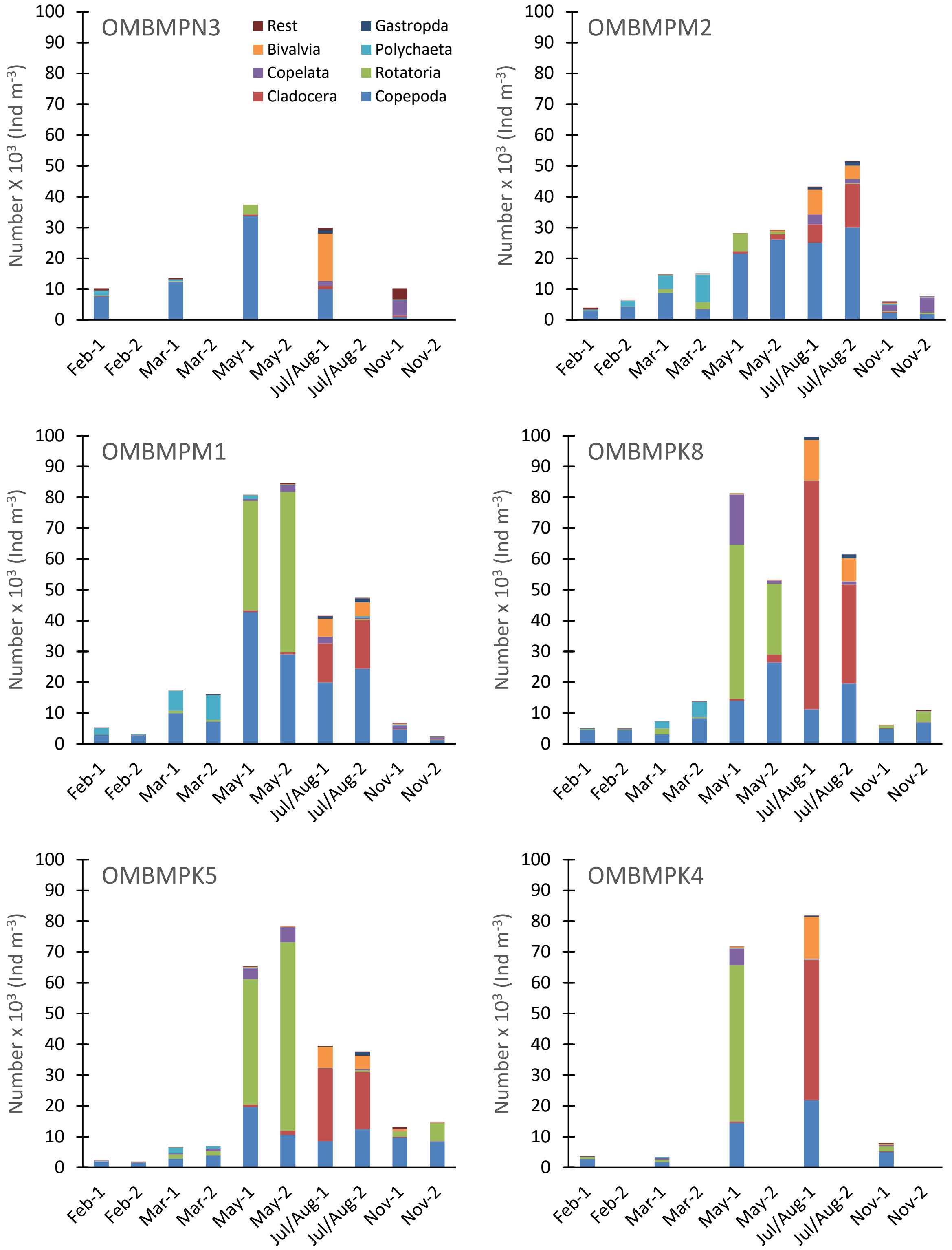

Fig. 34: Seasonal variation of the main taxonomic groups of the mesozooplankton at different stations in the investigation area in 2018

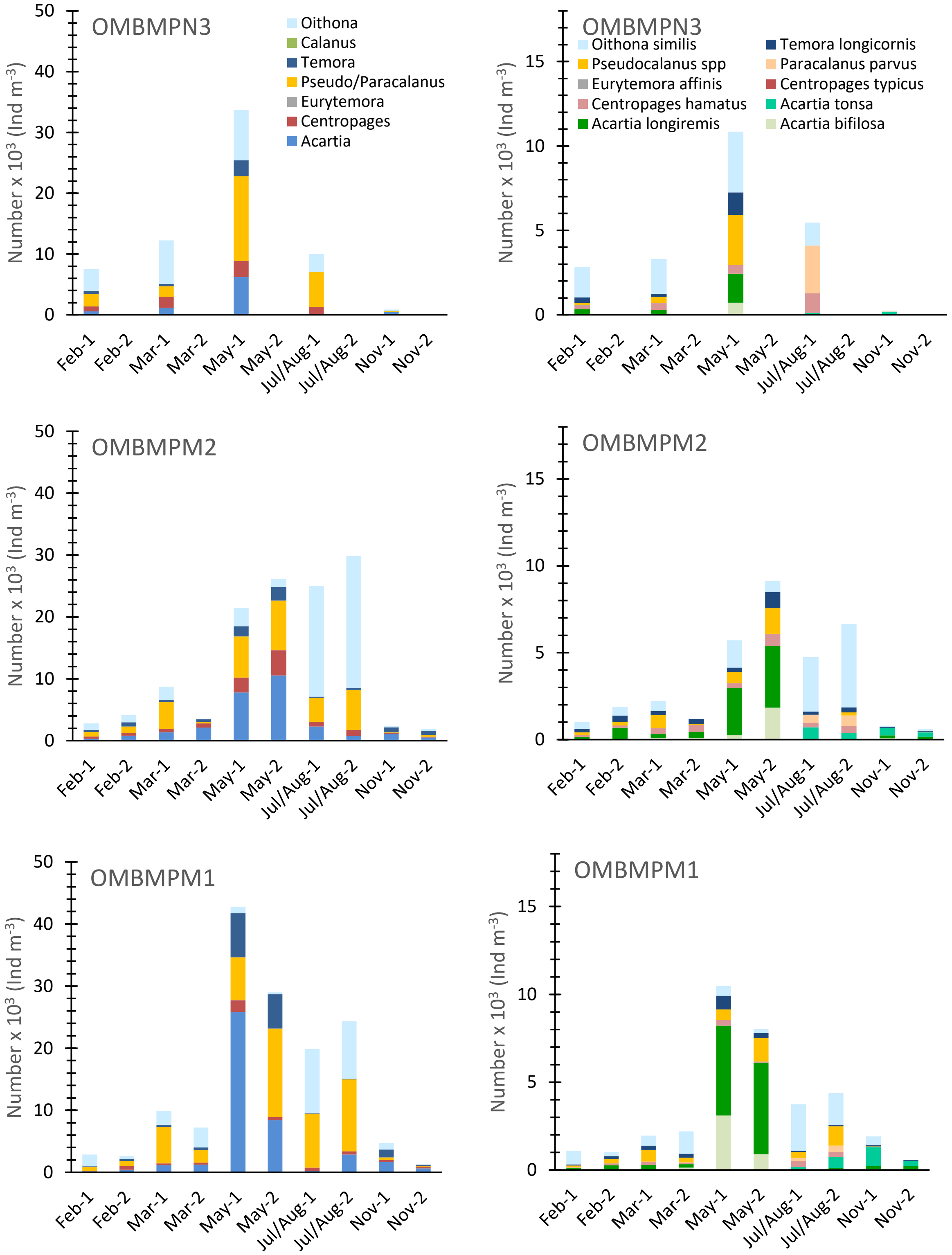

Fig. 35: Seasonal variation of the abundance and composition of juvenile (left) and adult stages of copepods (right) of different genera in 2016. Note the different scale in the abundance of juveniles and adults (continued on page 54).

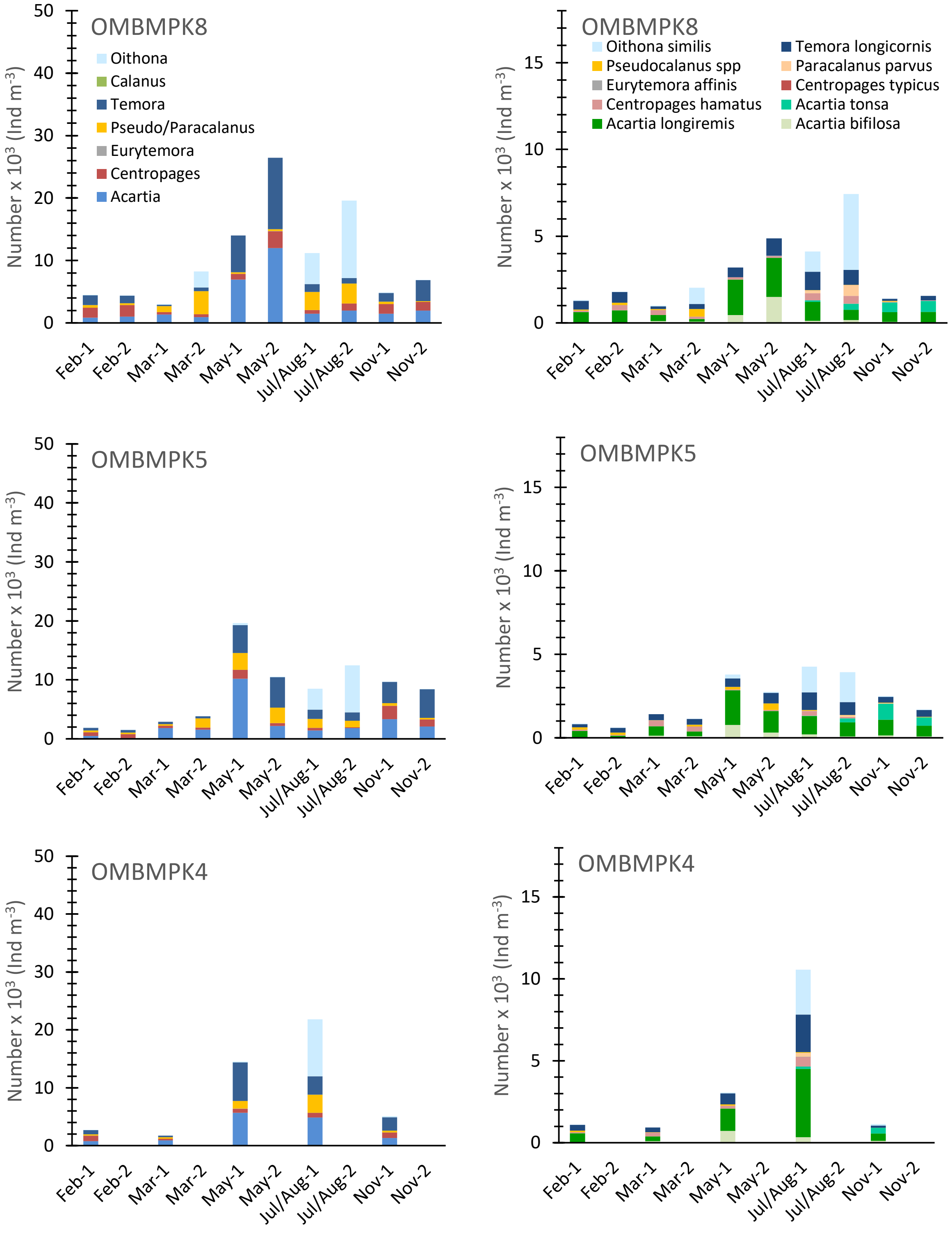

Fig. 35, continued.

Similar to 2017, the winter abundance of the total zooplankton was high (1.1 x 10^4 ind. m^{-3}, Fig. 34). Copepods dominated the stock (>70%), to which calanoid and cyclopoid copepods contributed equally with 3.9 and 3.5 x 10^3 ind. m^{-3}, respectively. Polychaete larvae were already abundant (1.6 x 10^3 ind. m^{-3}), while other taxa such as *Evadne nordmanni*, larvae of *Balanus* spp. or Tintinnids were generally rare. There was only a small increase in the stock in March (1.4 x 10^4 ind. m^{-3}, Fig. 34), which was mainly based on the increase in the abundance of copepods, in particular that of *Oithona* spp. to 7.1 x 10^3 ind. m^{-3}. The density of polychaete larvae decreased in turn. The stock increased further to the annual maximum of 3.7 x 10^4 ind. m^{-3} in May. Calanoid copepods dominated now the community (2.5 x 10^4 ind. m^{-3}), while the density of the cyclopoid copepod *Oithona* spp. remained at 8.2 x 10^3 ind. m^{-3}. Apart from the copepods, rotifers contributed with (3.1 x 10^3 ind. m^{-3}) to the zooplankton stock, while all other groups were rare. The stock remained high until the end of July (3.0 x 10^4 ind. m^{-3}). The bulk of the zooplankton was formed by the bivalve larvae (1.5 x 10^4 ind. m^{-3}), while the contribution of the copepods decreased to 34% of the stock (1.0 x 10^4 ind. m^{-3}). The appendicularian *Oikopleura dioica* (1.6 x 10^3 ind. m^{-3}), gastropod larvae (1.1 x 10^3 ind. m^{-3}) and the cladoceran *Podon intermedius* (0.8 x 10^3 ind. m^{-3}) had a minor contribution. All other taxa were rare. In autumn, the dominating taxa had largely disappeared and the stock decreased to winter concentrations of 1.0 x 10^4 ind. m^{-3}. *Oikopleura dioica* (4.4 x 10^3 ind. m^{-3}) and bryozoan larvae (2.4 x 10^3 ind. m^{-3}) dominated (Fig. 34). The remainder included *Evadne nordmanni* (458 ind. m^{-3}), *Fritellaria borealis* (501 ind. m^{-3}) and tintinnids (551 ind. m^{-3}) mainly.

Among the copepods, *Pseudocalanus* spp. replaced *Acartia bifilosa* as the dominant species on an annual basis (Figs. 33c and 35). This tendency was already apparent in 2017. The cyclopoid *Oithona similis*, however, remained an important species. The winter stocks of the copepods were already high in 2018 (7.5 x 10^3 ind. m^{-3}). *Oithona similis* was the dominant taxon, particularly among the copepodite stages (7.5 x 10^3 ind. m^{-3}). *Pseudo/Paracalanus* spp. contributed with (2.0 x 10^3 ind. m^{-3}), while the rest of the copepods consisted of *Temora longicornis*, *Acartia longiremis* and *Centropages hamatus* mainly ($<$1.0 x 10^3 ind. m^{-3}). Only little changes were observed until March. The stock increased to 1.2 x 10^4 ind. m^{-3}, mainly due to an increase in the number of copepodites of *Oithona similis*. The strong increase in abundance in May (3.4 x 10^4 ind. m^{-3}), in contrast, was based on the calanoid copepods, mainly *Pseudo/Paracalanus* (1.4 x 10^4 ind. m^{-3}), *Acartia* spp. (6.2 x 10^3 ind. m^{-3}), *Temora longicornis* (2.6 x 10^3 ind. m^{-3}) and *Centropages hamatus* (2.6 x 10^3 ind. m^{-3}). *Oithona similis*, *Pseudocalanus* spp, and *Acartia longiremis* dominated the stock of adult copepods (1.3 – 3.6 x 10^3 ind. m^{-3}). A major shift in composition was observed towards the summer. While *Pseudo/Paracalanus* (2.6 x 10^3 ind. m^{-3}) and *Oithona* spp. (2.6 x 10^3 ind. m^{-3}) still were the major taxa, *Paracalanus parvus*, *Oithona similis* and *Centropages hamatus* were dominant among the adults. In autumn, the stock size decreased considerably to less than 1.0 x 10^4 ind. m^{-3}. *Acartia* spp, with *A. tonsa* as the main species, *Oithona similis* and *Pseudo/Paracalanus* consisting of *P. parvus* were the main contributors.

Bay of Mecklenburg

The zooplankton in the Bay of Mecklenburg (OMBMPM2-M1) was characterized by a relatively late development and a pronounced seasonality with high stocks during spring and summer (4.3 – 8.4 x 10^4 ind. m^{-3}, Fig. 34). Comparable to Kiel Bay, this is a continuation of a major change started in 2017 and owed to the strong development of the copepod stock and relatively high densities of rotifers and cladocera, which are usually not observed in high numbers such as the rotifers at station OMBMPM1. Among the copepods, changes in the composition were, however, not as pronounced as in Kiel Bay. While *Pseudocalanus* spp. became more abundant, *Acartia* spp. remained the dominant genus (Fig. 33c, 35). Meroplankton was negligible.

The overwintering stock was low (3.1 – 6.5 x 10^3 ind. m^{-3}) and consisted mainly of copepods (max. 2.8 x 10^3 ind. m^{-3}) and meroplanktonic polychaetes (max. 2.1 x 10^3 ind. m^{-3}), similar to 2017 (Fig. 34). Other taxa, such as cladocera, rotifers or appendicularia were generally rare.

There was a moderate increase in the total abundance to 1.5 – 1.7 x 10^4 ind. m^{-3}. This was mainly based on the copepods (3.5 – 9.8 x 10^3 ind. m^{-3}) and polychaete larvae (4.5 – 9.0 x 10^3 ind. m^{-3}), but rotifers occurred in substantial numbers as well (0.5 - 2.1 x 10^3 ind. m^{-3}). A substantial increase in the abundance of the zooplankton occurred in May. Copepods and rotifers contributed mainly. Their numbers varied, however, considerably between stations (Fig. 34) and amounted to 2.1 – 2.6 and 2.9 – 4.2 x 10^4 ind. m^{-3} for copepods and 0.1 – 0.6 and 3.6 – 5.2 x 10^4 ind. m^{-3} for rotifers at station OMBMPM1 and OMBMPM2, respectively. Apart from these taxa, the cladocerans *Evadne nordmanni* and *Podon intermedius* (0.6 – 1.6 x 10^3 ind. m^{-3}) and the appendicularian *Fritellaria borealis* (0.6 – 2.1 x 10^3 ind. m^{-3}) occurred in low numbers. Copepod numbers remained high in summer (1.9 – 2.9 x 10^4 ind. m^{-3}), while cladocerans replaced the rotifers, which occurred in low numbers only. *Bosmina* spp was the major cladoceran species (0.5- 1.3 x 10^4 ind. m^{-3}), *E. nordmanni* (0.8 – 2.3 x 10^3 ind. m^{-3}) and *P. intermedius* (224 - 297 ind. m^{-3}) were less abundant. The appendicularian *Oikopleura dioica* replaced *F. borealis* (1.4 – 3.2 x 10^3 ind. m^{-3}), and bivalve and gastropod larvae occurred in substantial numbers with 4.3 -8.1 and 0.7 – 1.2 x 10^3 ind. m^{-3}, respectively. The autumn stocks were again very low, copepods and *O. dioica* were the only taxa occurring in substantial numbers (> 1.0 x 10^3 ind. m^{-3}).

The low stock of copepods in February and March consisted of *Pseudocalanus* spp. and *Oithona similis* mainly (max. 5.8 and 3.2 x 10^3 ind. m^{-3}, respectively), while *Acartia* spp. (2.1 x 10^3 ind. m^{-3}), in particular overwintering *A. longiremis* contributed less (Fig. 35). *Temora longicornis* and *Centropages hamatus* occurred regularly, but at low numbers. Nearly all taxa contributed to the spring increase. *Acartia* spp., *Pseudo/Paracalanus* and – at station OMBMPM2 –, *Temora* spp. were the major genera among the calanoid copepods, with maximal concentrations of 2.5, 1.4 and 0.7 x 10^4 ind. m^{-3} respectively. Among the adults copepods, *A. bifilosa* and *A. longiremis* were dominating (max. 3.1 and 5.1 x 10^3 ind. m^{-3}). *Pseudocalanus* spp. and *Oithona similis* were abundant as well. The community composition changed substantially in summer. The cyclopoid copepod *Oithona* dominated (0.9 – 2.1 x 10^4 ind. m^{-3}), while *Pseudo/Paracalanus* remained high (0.4 – 1.1 x 10^4 ind. m^{-3}). Other taxa declined substantially. Thus, *Oithona similis*, *Pseudocalanus* spp. and - to a lesser extent - *Paracalanus parvus* dominated among the adults copepods. In autumn, copepod densities declined strongly. *Acartia tonsa* and *Temora longicornis* were the major taxa (max. < 1.0 x 10^3 ind. m^{-3}).

Arkona Basin

Comparable to the zooplankton stocks in the Kiel Bay and Bay of Mecklenburg, low winter stocks and a substantial increase of the abundance in spring and summer characterized dynamics of the zooplankton in the Arkona Basin (OMBMPK8-OMBMPK4, Figs. 33, 34, 35). Also here, the zooplankton stock size was high (max. 6.5 – 9.9 x 10^4 ind. m^{-3}) and exceeded the increase observed in 2017. Although copepods were abundant, the increase was primarily caused by rotifers in spring and cladocerans in summer, which both occurred at low densities in the period 2015-2017. Except for the occurrence of polychaete larvae in winter, the abundance of meroplankton was low. While the zooplankton composition at station OMBMP-K8 usually reflected the transition between the Bay of Mecklenburg and the Arkona Basin, the composition with the dominance of rotifers and cladocera together with the of the copepod community dominated by *Temora* and *Acartia* strongly resembled stations OMBMPK5-OMBMPK4 in 2018 (Figs. 34, 35).

The low overwintering stock was dominated by copepods (1.5 – 4.3 x 10^3 ind. m^{-3}), but the appendicularian *Fritellaria borealis* and the rotifer *Synchaeta* spp. occurred at low numbers of 115-584 ind. m^{-3}) and 44 – 545 ind. m^{-3}, respectively. In March copepod densities remained low (1.7 – 8.2 x 10^3 ind. m^{-3}), while polychaete larvae (0.2 – 4.9 x 10^3 ind. m^{-3}) and rotifers (0.7 – 1.9 x 10^3 ind. m^{-3}) increased. Similar to the Bay of Mecklenburg, the spring increase in the zooplankton occurred rather late in May but was substantial (5.3 – 8.1 x 10^4 ind. m^{-3}, Figs. 34, 35). This was largely related to the increase of *Synchaeta* spp. to 2.3 -6.1 x 10^4 ind. m^{-3}. *Fritellaria borealis* and the copepods displayed a moderate increase to maximum concentrations of 1.6 and 2.6 x 10^4 ind. m^{-3}, respectively. The cladocerans *Evadne nordmanni* and *Podon leuckartii* had a low contribution (0.5 – 2.5 x 10^3 ind. m^{-3}). In summer, the zooplankton stocks remained high (3.7 – 9.9 x 10^4 ind. m^{-3}) and were dominated by cladocerans. *Bosmina* spp. was the most abundant species (1.7 – 4.2 x 10^4 ind. m^{-3}). *E. nordmanni* showed a lower abundance (max. 4.6 x 10^3 ind. m^{-3}) and *P. leuckartii* was replaced by P*. intermedius* (max. 1.1 x 10^3 ind. m^{-3}). The copepod concentration remained high (0.8 -2.1 x 10^4 ind. m^{-3}) and bivalve larvae were abundant as well (0.4 -1.4 x 10^4 ind. m^{-3}). The zooplankton stocks decreased considerably until autumn. They were dominated by copepods (4.9 – 9.7 x 10^3 ind. m^{-3}), but the rotifer *Synchaeta* spp. contributed as well (0.5 – 5.7 x 10^3 ind. m^{-3}). The abundance of the appendicularian *Oikopleura dioica* was, in contrast, unusual low (max. 426 ind. m^{-3}).

Similar to 2017, *Acartia* and *Temora* dominated the copepods on an annual basis, while *Oithona* was particularly important during summer (Fig. 33d, 35). The overwintering stocks were low; *Temora*, *Centropages* and *Acartia* were the main taxa occurring at densities of 0.1 – 2.3 x 10^3 ind. m^{-3}. The increase in May was caused by increasing numbers of *Temora longicornis* (0.5 – 1.1 x 10^4 ind. m^{-3}), *Acartia* spp. (0.2 – 1.2 x 10^4 ind. m^{-3}), and to a lesser extend of *Pseudo/Paracalanus* (1.3 – 2.8 x 10^3 ind. m^{-3}). *Acartia longiremis* was the major species among the adults of the genus *Acartia*. In summer, *Oithona similis* was the dominating copepod (0.4 – 1.2 x 10^4 ind. m^{-3}), while *T. longicornis* (0.8 – 3.1 x 10^3 ind. m^{-3}), *Acartia* spp. and *A. longiremis* (1.4 – 4.8 x 10^3 ind. m^{-3}) as well as *Pseudocalanus* spp./*Paracalanus parvus* (1.1 – 3.2 x 10^3 ind. m^{-3}) occurred at low numbers. In autumn, *Oithona similis* occurred at very low numbers (< 100 ind. m^{-3}). The low stock (4.8 – 9.7 x 10^3 ind. m^{-3}) consisted of *Acartia* spp., *Temora longicornis* and *Centropages hamatus*. *Acartia tonsa* was the dominant species in the genus *Acartia*.

4.2.3 Long-term trends

The stock size of zooplankton is still low (Fig. 36a). Despite a reversal tendency in the last 2 years, the total abundance of 1.9 x 10^5 ind. m^{-3} remained below the long-term average of 3.3 x 10^5 ind. m^{-3} for the period 2000-2018. Nevertheless, the maximal seasonal abundance has tripled from 1.8 and 0.6 x 10^4 ind. m^{-3} in 2016 to 6.1 and 7.4 x 10^4 ind. m^{-3} in 2018, respectively (Fig. 36a). The density of rotifers and cladocera, however, are still considerably below their long-term mean. An increase by a factor of 1.5 to 2.1 was also observed for all other holoplanktonic (calanoid and cyclopoid copepods, appendicularia) and meroplanktonic taxa (bivalve and polychaete larvae) except gastropods. Nevertheless, caution needs to be taken in the interpretation of the changes, because changes in timing and in abundance cannot be fully assed with the frequency in sampling.

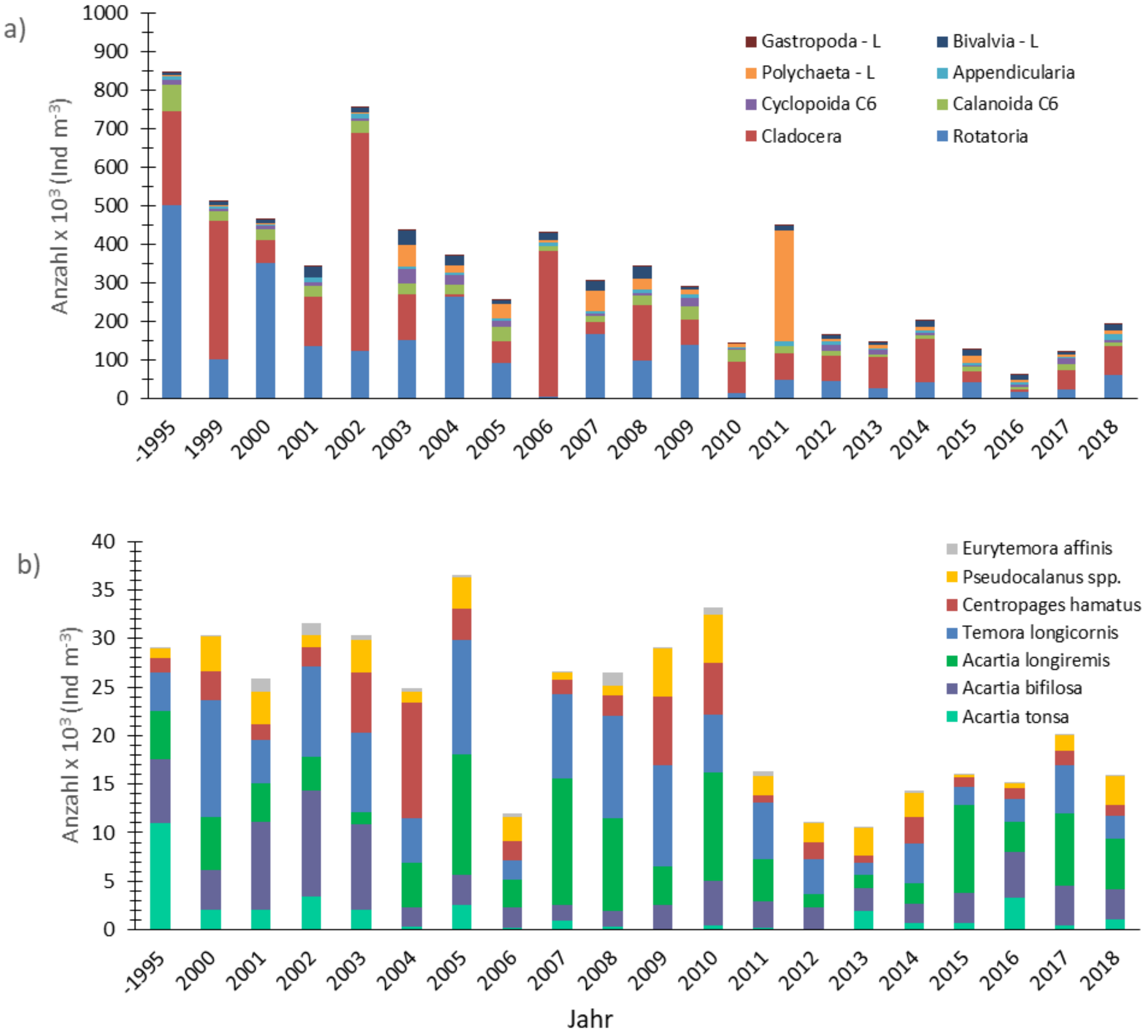

Fig. 36: Long-term trends in the maximal abundance of a) holoplanktonic taxa (Rotatoria, Cladocera, Cyclopoida, Calanoida, Copelata) and meroplanktonic taxa (Polychaeta, Bivalvia, Gastropoda) and b) of seven calanoid copepod species in the years 1995 to 2018.

As indicated by the long-term variation in the species abundance and composition of adult calanoid copepods, there were only small changes in the composition in the present decade with *Acartia longiremis*, *A. bifilosa* and *Temora longicornis* being the major species (Fig. 36b). The abundance of *Pseudocalanus* spp. has apparently recovered since its minimum in the period 2015-2016. However, the stocks of all species are considerably diminished in comparison to the beginning of the century.

4.3 Macrozoobenthos

4.3.1 Sediments and Oxygen

At each of the eight monitoring stations, samples were taken using separate Van Veen grabs for analysis of the particle size and organic content of sediment. In addition, CTD dips were made to determine associated parameters such as oxygen concentrations and near-bottom salinity (Table 6). At all station almost the whole year a good oxygen supply was observed. Only in the Fehmarnbelt and in the Bay of Mecklenburg the oxygen content was lower than 1 and 2 ml/l during few July weeks, respectively.

Table 6
Abiotic parameters at 8 monitoring stations in autumn 2018 (org=organic content of sediment in %, GS=mean grain size in µm, O2=oxygen content of near bottom water in ml/l, S=salinity at near bottom water in psu).

Station	**Org %**	**GS (µm)**	**O_2 (ml/l)**	**S (psu)**	**Sediment characteristics**
OMBMPN3	1.21	236	6.01	21.0	fine to middle sand
OMBMPN1	3.25	193	6.33	19.6	muddy sand
OMBMPM2	7.46	31	6.11	19.2	mud
OM18	1.88	104	5.97	19.2	muddy sand
OMBMPK8	0.21	234	6.66	9.8	fine sand
OMBMPK4	10.83	22	2.22	19.1	mud
OMBMPK3	1.01	213	3.62	12.5	fine sand
OM160	0.39	185	6.77	9.7	fine sand

For almost all stations the salinity ranged in an average value. The autumn bottom water salinity ranged from west to east between 21 and 9.7 psu (Table 6). The long-term development of the minimum and maximum salinity in near bottom waters at the deepest station OMBMPK4 in the Arkona Basin is shown in Figure 37. The maximum value of 2018 is higher than the median (see blue line).

Regarding the oxygen content only in the Fehmarnbelt and Bay of Mecklenburg the values dropped down below 1 and 2 ml/l along the year (summer), respectively (Fig. 38 for Fehmarnbelt). With 0.93 ml/l the lowest value were observed in July.

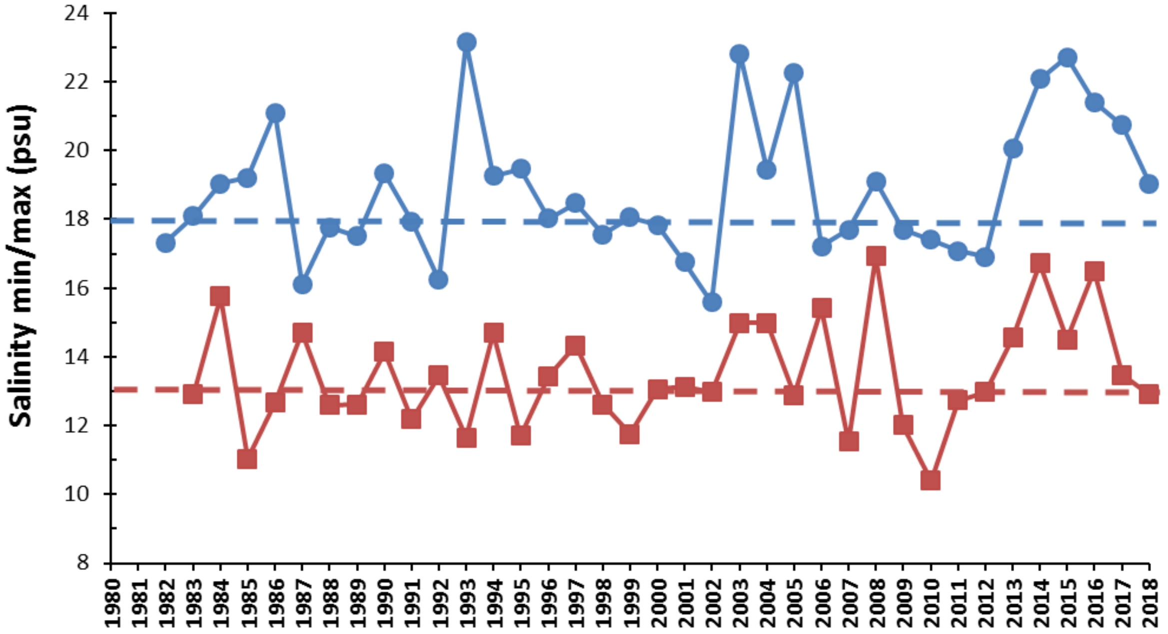

Fig. 37: Long-term development of the bottom water salinity in the Arkona Basin (OMBMPK4) from 1982 to 2018 (5-10 measurements per year). The red line indicates the lowest and the blue line the highest value per year, respectively. The dashed lines show the long-term median of the lowest and highest values.

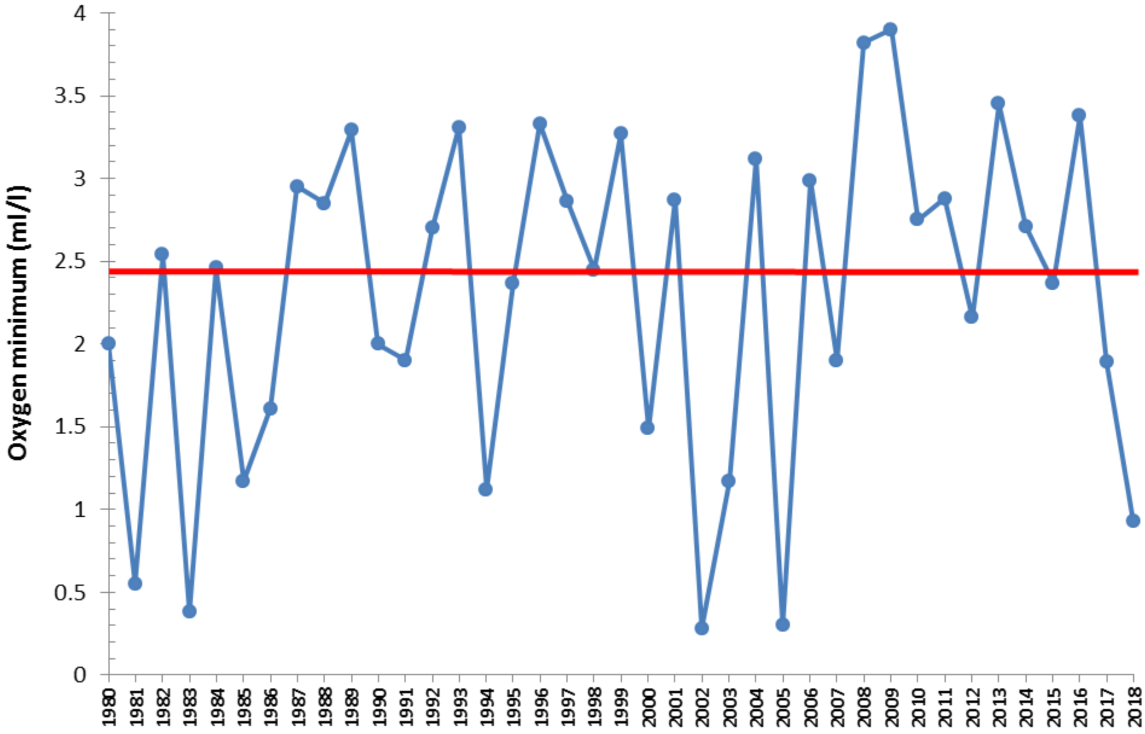

Fig. 38: Long-term development of the bottom water oxygen content in the Fehmarnbelt (OMBMPN1) from 1980 to 2018 (5-10 measurements per year). The blue line indicates the lowest value per year and the red line the median value of the lowest oxygen content in all years, respectively.

4.3.2 Macrozoobenthos at the Stations

In November 2018, we deployed a Van Veen grab sampler to collect 3 samples from each of the 8 stations for macrozoobenthic analysis. In addition, a dredge was deployed at all stations to record rarer and vagile species. Our monitoring stations belong to four or five different macrozoobenthic communities along the salinity and depth gradient (see GOGINA et al. 2016).

Compared with the period 1991 to 2018, the number of species was low at 119 (Table A4, Figs. 39 and 42). Whereas the species number in the Kiel Bay (OMBMPN3) was almost stable clearly within one year, the number at station Fehmarnbelt (OMBMPN1) decreased significantly from 71 to 31. Thereby the species diversity in the Fehmarnbelt area was much lower as the long-term median value. Compared with their long-term averages five stations show similar or even higher species richness than in the years before (Fig. 39).

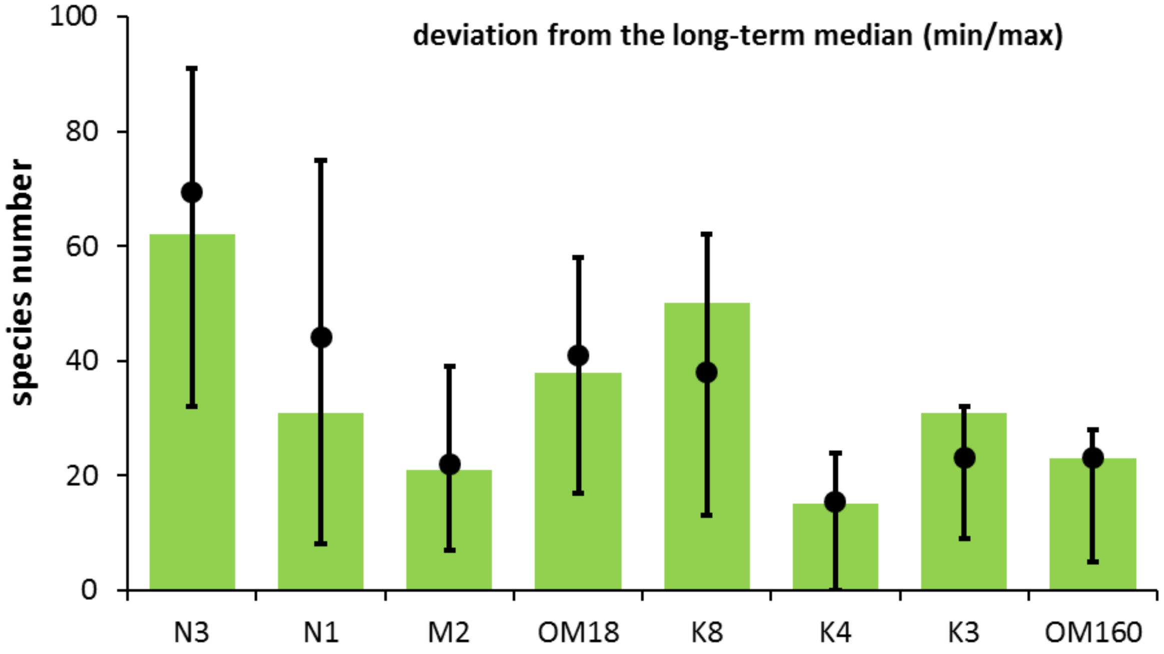

Fig. 39: Number of species (columns) of macrozoobenthos at 8 monitoring stations in November 2018. The median values of the years 1991 to 2018 are shown as dots; the minimum and maximum values are indicated as interval. The stations are plotted from west to east (Kiel Bay = OMBMPN3 to Pomeranian Bay = OM160).

In the Kiel Bay (OMBMPN3) the biodiversity situation was similar in comparison with the previous year. With *Hydractinia echinata* (Hydrozoa), *Fabriciola baltica* (Polychaeta) and *Escharella immersa* (Bryozoa) three new species were found for the first time at this station. Especially echinoderms as *Ophiura albida* and *Asterias rubens* were dominant community members (Fig. 40).

At station OMBMN1 in the Fehmarnbelt the decrease in the number of species was obvious: 31 taxa were identified there, lesser the long-term median. Nevertheless, with the spionid polychaete *Polydora cornuta* one species was noticed for the first time within the last 13 years (and longer) at this station. *Arctica islandica* is still very dominant in both abundance and biomass (Fig. 41).

Fig. 40: The dredge sample of the Kiel Bay (OMBMPN3) was dominated by *Asterias rubens*, *Ophiura albida* and *Arctica islandica*.

Fig. 41: *Arctica islandica* were typical in the grab samples in the Fehmarn Belt area.

At the Darss Sill (OMBMPK8) with 50 species the diversity was higher than the mean in comparison to the last 20 years. No new species were recorded here in 2018.

In the Arkona Basin and the Pomeranian Bay the species number was similar or slightly increased to the long-term mean.

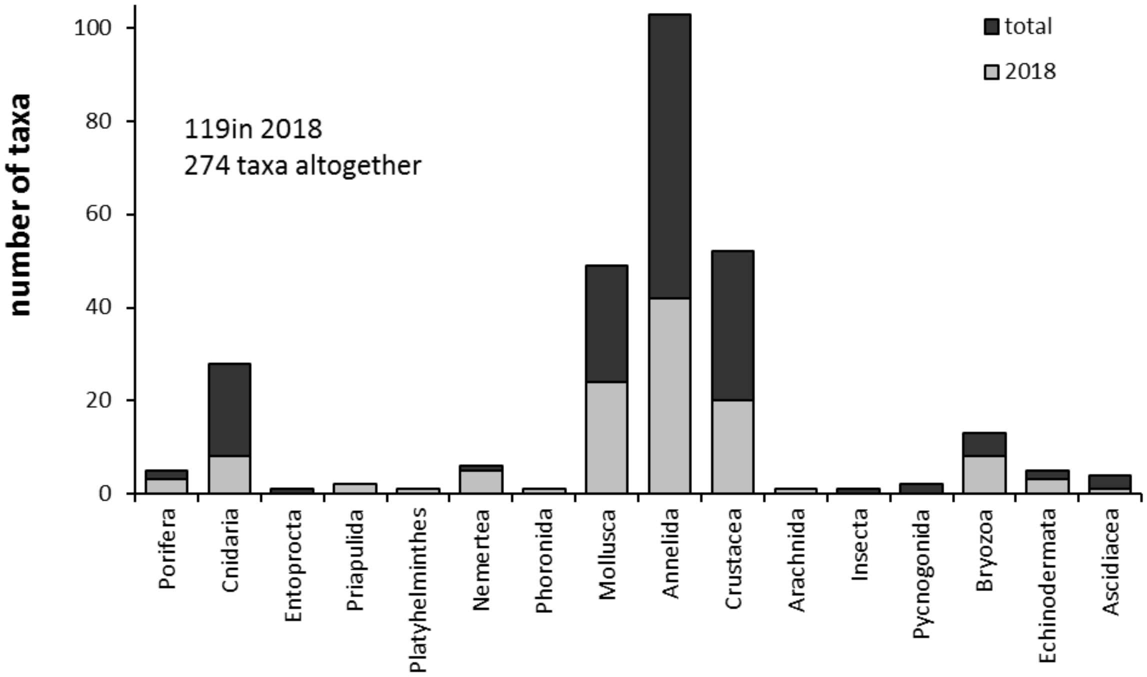

Fig. 42: Taxonomical classification of macrozoobenthos at 8 monitoring stations in November 2018. The species number of the entire monitoring from 1991 to 2018 is also indicated.

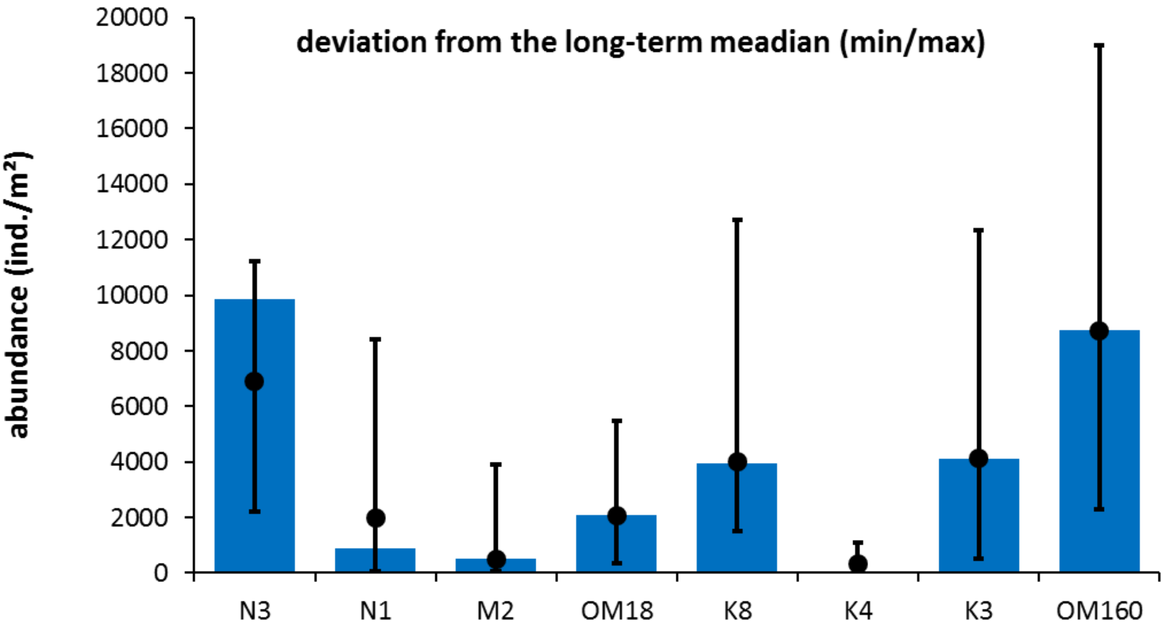

Fig. 43: Total abundances (columns) of macrozoobenthos at 8 monitoring stations in November 2018. The median values of the years 1991 to 2018 are shown as dots; the minimum and maximum values are indicated as interval.

Figure 42 gives the taxa found at our 8 monitoring stations in 2018 as well as the total number of species found in measurements since 1991. Not just in 2018 (see Zettler et al. 2014, 2018), the Annelida (Polychaeta and Oligochaeta) emerged as the group that is richest in species, numbering 103; in 2018, 42 species were identified. Other species-rich groups in 2018 were Mollusca (24), Crustacea (20), Cnidaria (8) and Bryozoa (8).

Depending on the sea area, abundances varied between 46 (Arkona Basin) and 9.860 ind./m² (Kiel Bay) (Fig. 43, Table A4). Only in the Fehmarnbelt (OMBMPN1) and in the Arkona Basin (OMBMPK4) the abundance was increased compared with previous years (Fig. 43). At all other stations (except Kiel Bay) the abundance remained similar to the median values of the last decades. In the Kiel Bay (OMBMPN3) the abundance was significantly higher than the long-term median.

Which species was dominant in a given sea area varied greatly; it depended essentially on salinity and substrate. While the molluscs *Corbula gibba* and *Kurtiella bidentata* assisted by the polychaete *Pygospio elegans* accounted for over 60 % of density in Kiel Bay (OMBMPN3), *Abra alba*, *Mytilus edulis* and *Lagis koreni* dominated the abundance in the southern Bay of Mecklenburg (OM018). The Darss Sill (OMBMPK8) was dominated by the spionid *Pygospio elegans* and the mud snail *Peringia ulvae*. Although in low abundances at all in the Arkona Basin (OMBMPK4) three bivalve species (*Arctica islandica*, *Astarte borealis* and *Limecola balthica*) were most frequent. In the Pomeranian Bay (OM160) the mud snail *Peringia ulvae* accounted for high abundance. However, epibenthic structures sampled by the dredge were mainly consisting of blue mussels (*Mytilus* sp.) (Fig. 44). At the central Bay of Mecklenburg (OMBMPM2) bivalves *Corbula gibba* and *Kurtiella bidentata* dominated the community. The polychaete *Lagis koreni,* the bivalve *K. bidentata* and juveniles of *Mytilus edulis* reached more than 60% of the abundance of the station in the Fehmarnbelt area (OMBMPN1). In the northern Pomeranian Bay (OMBMPK3) the spionid *Pygospio elegans* (65%) dominated the community.

Compared with their long-term averages, four stations show similar or even higher total biomass than in the years before (Fig. 45). The values in the Kiel Bay (OMBMPN3), the Arkona Basin (OMBMPK4) and the northern Pomeranian Bay (OMBMPK3) were significantly lower than the long-term means. Contrary to our expectation, the biomass was higher in the Fehmarnbelt (OMBMPN1) which was caused by the survival of large individuals of *Arctica islandica*. The biomass at all other stations were in the range of the long-term means.

The highest biomass was observed at the Kiel Bay station (OMBMPN3) although much lower as the mean (Fig. 45). 47.5 g afdw/m² was measured, consisting of 42.5 % *Astarte borealis* (20.2 g afdw/m²) and 49.2 % *Arctica islandica* (23.4 g afdw/m²). In addition, dredge catches yielded echinoderms (*Asterias rubens, Ophiura albida*) and shrimps (*Crangon crangon*) that were certainly under-represented in the quantitative grab samples (Fig. 40). At stations in the Fehmarnbelt and Bay of Mecklenburg the biomass was rather high; this is almost explainable with the dominance and patchy distribution of heavy adults of the ocean quahog. At Fehmarnbelt (OMBMPN1) and in Bay of Mecklenburg (OMBMPM2), *Arctica islandica* contributed as much as 95 % to biomass (Fig. 46); total values between 43 and 12 g AFDM/m² were obtained there, respectively. At Darss Sill (OMBMPK8), biomass (10.3 g AFDM/m²) was dominated by the bivalve *Astarte borealis* (40 %) and the bivalve *Limecola balthica* (46 %). In the Arkona Basin, (OMBMPK4), *Limecola balthica* accounted for 59 % of the total biomass (0.4

g afdw/²). In the north of the Pomeranian Bay (OMBMPK3), 3.4 g of total biomass was measured, made up of 68 % *Limecola balthica* and 11 % *Scoloplos armiger*. Further east in the central Pomeranian Bay (OM160; 10.3 g afdw/m²) *Cerastoderma glaucum* (15 %), *Limecola balthica* (30 %) and *Peringia ulvae* (17 %) were prominent.

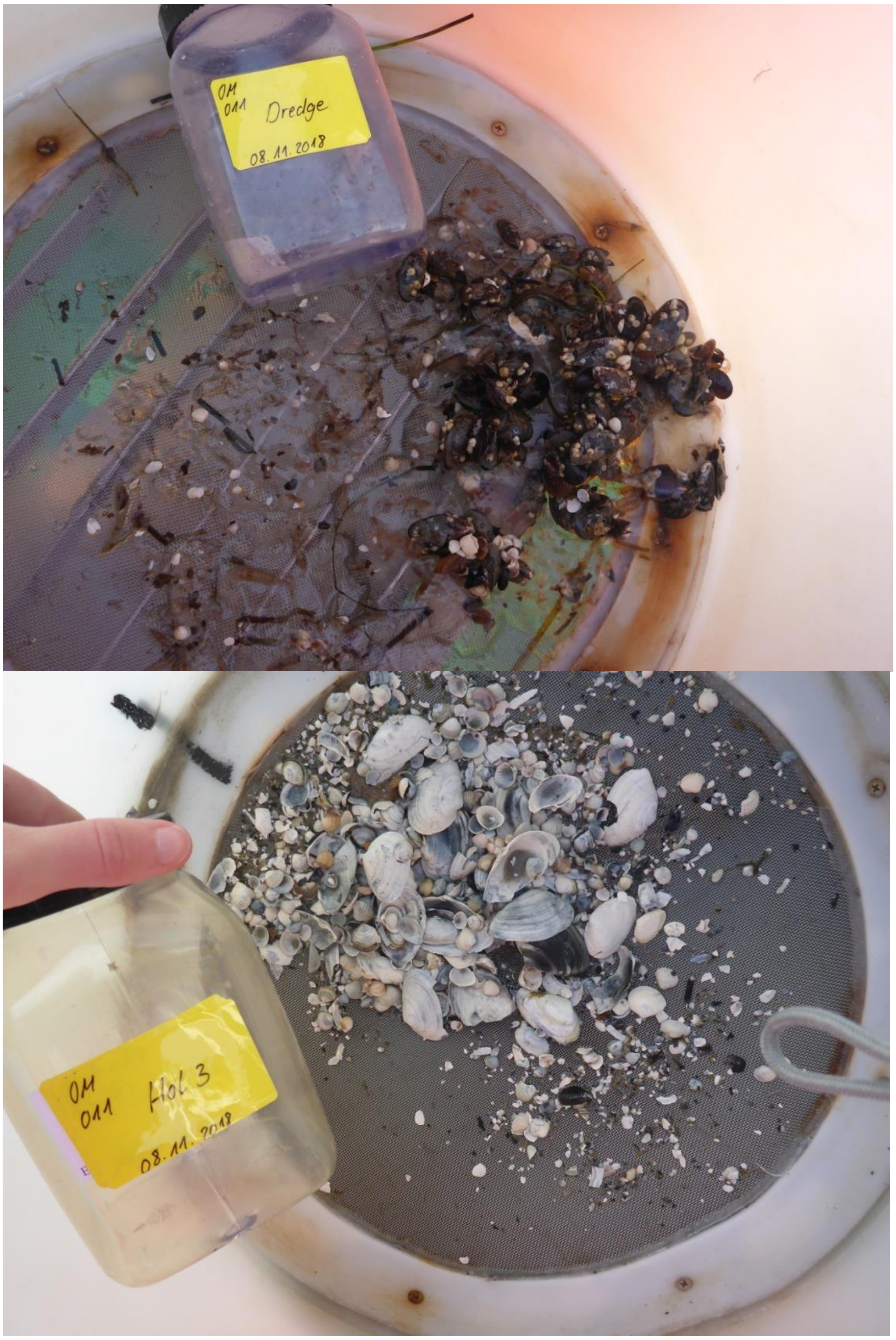

Fig. 44: In 2018 dominant epibenthic species in the Pomeranian Bay (OM160) were *Mytilus edulis* and *Crangon crangon* (above), whereas the endobenthic samples consisted mainly of *Peringia ulvae* and *Pygospio elegans* added by plenty of empty shells of *Mya arenaria*, *Cerastoderma glaucum* and *Limecola balthica* (below).

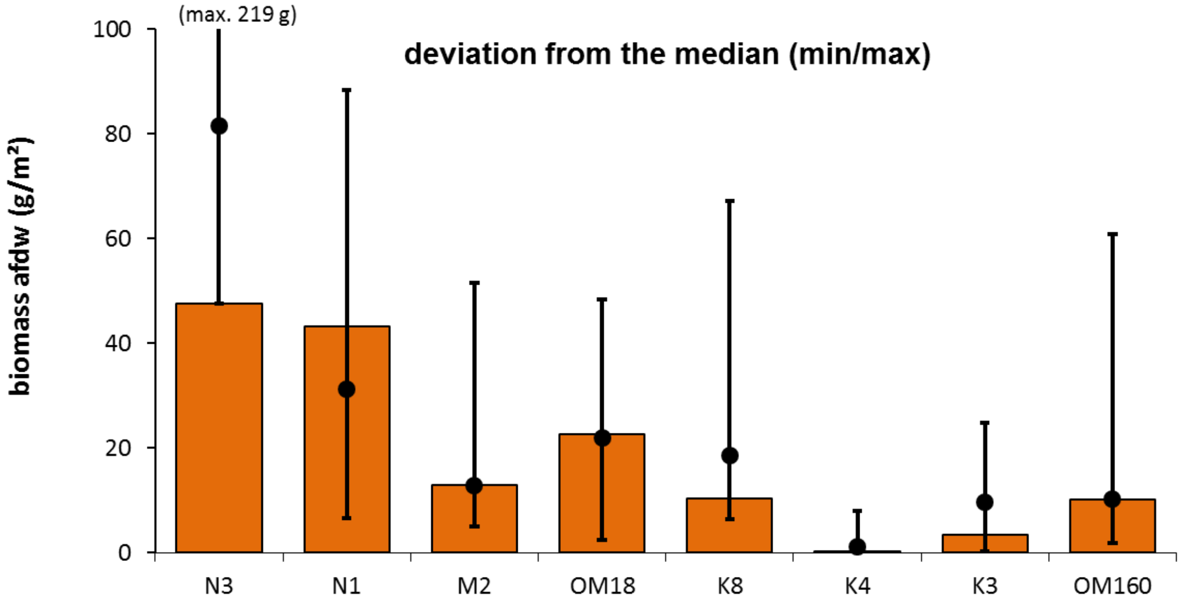

Fig. 45: Total biomasses (columns) of macrozoobenthos at 8 monitoring stations in November 2018. The median values of the years 1991 to 2018 are shown as dot and the minimum and maximum values are indicated as interval.

Fig. 46: In the Bay of Mecklenburg (OMBMPM2), the ocean quahog (*Arctica islandica*) dominated the dredge sample.

Both for abundance and biomass, analysis of long-term data in part revealed considerable fluctuations that are illustrated as error bars (min/max) in Figs. 43 and 45. Basically, fluctuations relate to the population dynamics of long-living species (molluscs mostly). Another influence is population collapse following a phase of oxygen deficiency. Not least, however, the randomness of sampling and the clustered distribution of organisms are responsible for these fluctuations. Human induced direct effects (exclusive the eutrophication) were not evidently visible in the analysis of the data. Nevertheless, impacts or effects of for example bottom trawling on the benthic community are not to be excluded, although and because it was not an objectivity of the present study.

4.3.3 Long-term Trends

For an assessment of long-term trends since 1980 refer to our recently published study (ZETTLER et al. 2017). The development of major macrozoobenthic parameters (abundance, biomass, species number) has been successfully interpreted relying on the modelling of the long-term fluctuations of salinity and oxygen, incorporation of the North Atlantic Oscillation index (NAOI) for winter, and the alliance of modelled and measured data along the 35 years of observation. The effects of oxygen deficiency on ecosystem functions, as well as temporal and spatial variations at selected monitoring stations, were published also in GOGINA et al. (2014).

To ensure maximum comparability in our analysis of long-term trends, we referred to the last 13 years only (2006 to 2018). Eight stations were sampled every autumn using three grab samples and one dredge. Stations are thus assessed on an identical basis. Figure 47 shows the relative number of species (see previous reports, e.g. WASMUND et al. 2018a, and Table A4, Appendix for absolute numbers). As expected, species diversity falls from west to east (Kiel Bay OMBMPN3 to Pomeranian Bay OM160). During this period, the station OMBMPN1 (Fehmarnbelt) was characterised by a severe loss of species due to oxygen deficiency. In 2008 and 2010, up to 50 % fewer species were found there than in the previous or subsequent year. In 2016 again a dramatically loss in species number occurred and also in the Bay of Mecklenburg (OMBMPM2). The reasons for this decline are not well recognized yet. The oxygen conditions around the year 2016 cannot be used as explanation, because no oxygen depletion was observed at all (at least during the sampling campaigns). All other stations had diversity rates that were relatively stable; no further significant changes were observed. After a short recovery in 2017 the diversity (species number) was even at the station in the Fehmarnbelt area in a range of the "normal condition" and showed with 71 species the second highest diversity during the last 13 years. In the Kiel Bay (OMBMPN3) the species number (63) was as low as in 2008 and indicated a clear decrease in comparison to the previous years. In the last year (2018) again the species number bisected in the Fehmarnbelt, which was probably cause by low oxygen supply in July. The other stations were not affected by oxygen demand and the diversity is comparable to the previous years.

In terms of abundance, the situation is similar (Fig. 48). Only the western and eastern most stations (Kiel Bay, OMBMPN3 and Pomeranian Bay, OM160) were characterised by high abundances. In some years, values fell below those of other years by more than 50 % - 2007 and 2008 at station OMBMPN3, and 2010 and 2016 at station OM160, and 2015, 2016 and 2018 at station OMBMPN1 in Fehmarnbelt for instance. Some significant variations also occurred at other stations, but they were based on substantially lower absolute values. At Fehmarnbelt (OMBMPN1) and in the Bay of Mecklenburg (OMBMPM2), oxygen deficiency in e.g. 2008 and

2010 caused a serious decline in abundance rates. A similar loss of abundance was observed for 2018 as well. At least at some other stations no significant decline was observed.

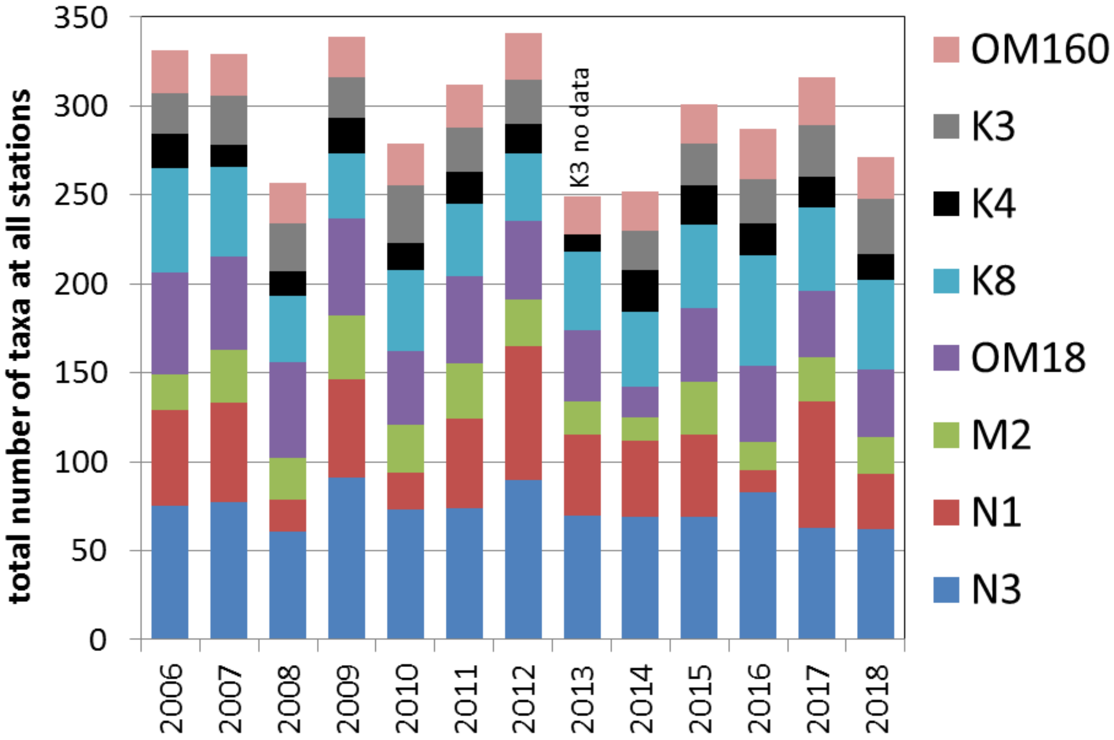

Fig. 47: Cumulative number of taxa of macrozoobenthos at 8 monitoring stations from 2006 to 2018. The stations are arranged within the columns from west to east (Kiel Bay = OMBMPN3 to Pomeranian Bay = OM160).

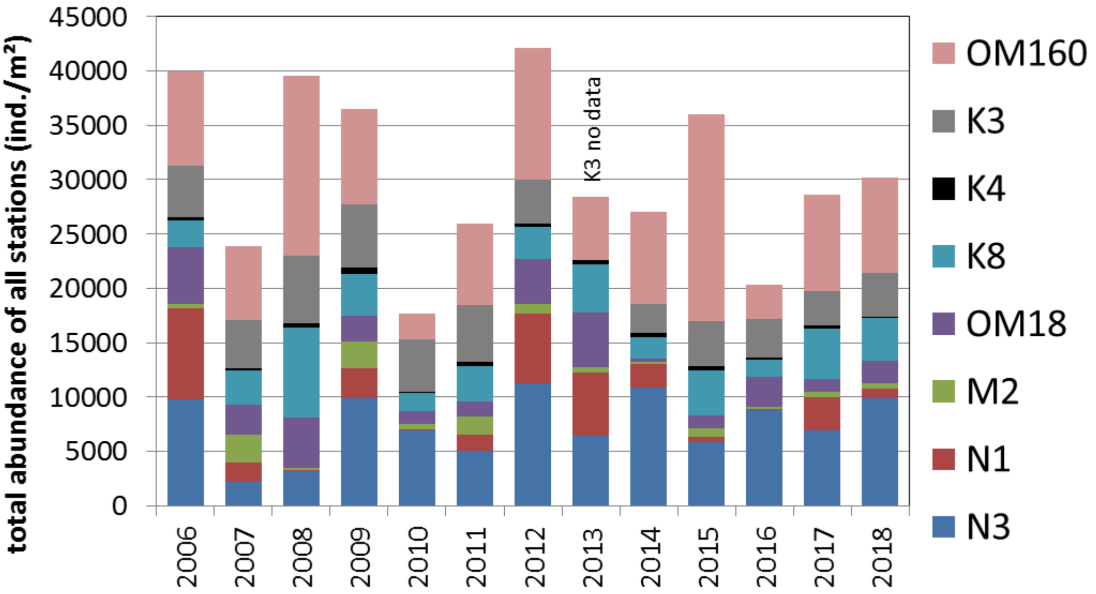

Fig. 48: Cumulative abundance of macrozoobenthos at 8 monitoring stations from 2006 to 2018. The stations are arranged within the columns from west to east (Kiel Bay = OMBMPN3 to Pomeranian Bay = OM160).

Figure 49 illustrates the long-term trend in biomass. Firstly, it is obvious the greatest values were observed in the west (Kiel Bay = OMBMPN3) followed by the Bay of Mecklenburg (OMBMPM2, OM018)) and Fehmarnbelt (OMBMPN1) and secondly it is obvious that biomass is not as strongly influenced as species numbers or abundance. Nevertheless, we can observe a clear decline during the last few years (compare 2007-2013 with 2014-2018). If this trend is significant cannot be answered so far. Also the reasons for this decrease can only be speculated. For any reason the large bivalves seem to be reduced in abundances (and therefore biomass) since few years. Similarly, variations can be significant, although at no point did we observe the sharp decline in biomass that we saw in species numbers and abundance due to oxygen deficiency at Fehmarnbelt (OMBMPN1) in 2008 and 2010, and in Bay of Mecklenburg (OMBMPM2, OM18) in 2014. The dominating species (bivalves of the genera *Arctica* and *Astarte*) with high individual weights buffer the loss of species and their weights for the total biomass. Overall, the total biomass observed in 2018 was relatively low and in the range of the last 5 years.

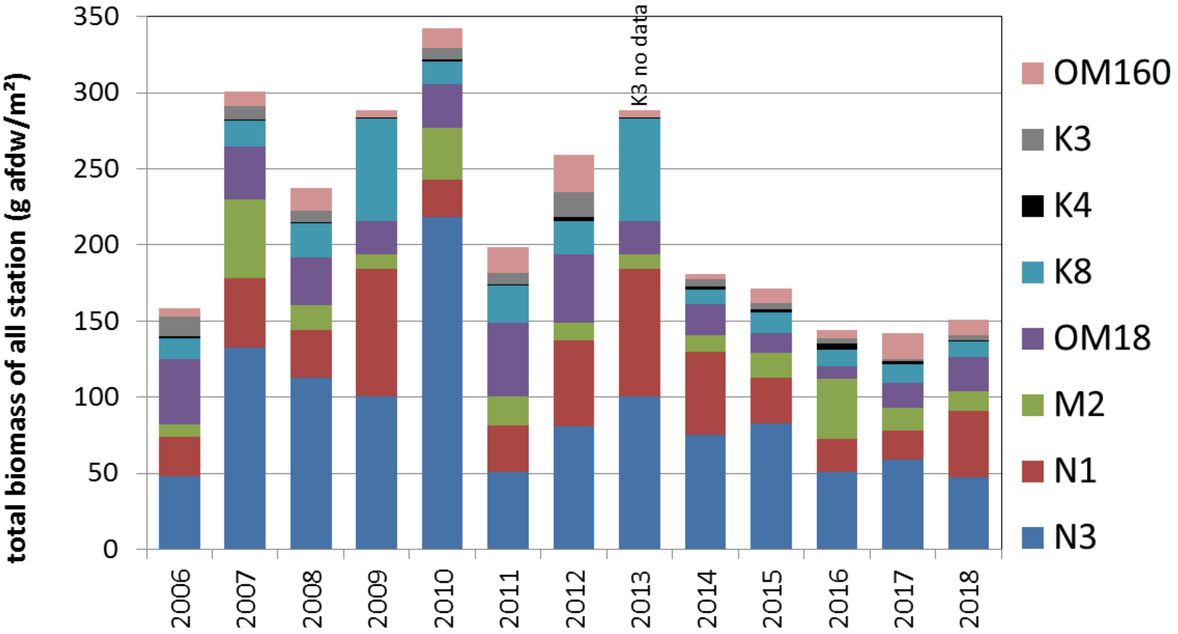

Fig. 49: Cumulative biomass of macrozoobenthos at 8 monitoring stations from 2006 to 2018. The stations are arranged within the columns from west to east (Kiel Bay = OMBMPN3 to Pomeranian Bay = OM160).

The increase of biomass in the Fehmarnbelt is mainly caused by the effect of patchily distributed larger bivalves as *Arctica islandica*. Whereas between 2012 and 2014 the biomass of the ocean quahog reached values between 50 and 80 g/m² afdw, the values in 2016 and 2017 ranged between 16 and 20 g/m². In 2018 again this species reached 43 g/m² afdw. About the reasons we can only speculate, maybe fishery pressure or an unknown shellfish disease are responsible. And as mentioned above, the patchy distribution of these large bivalves impacts the variation as well.

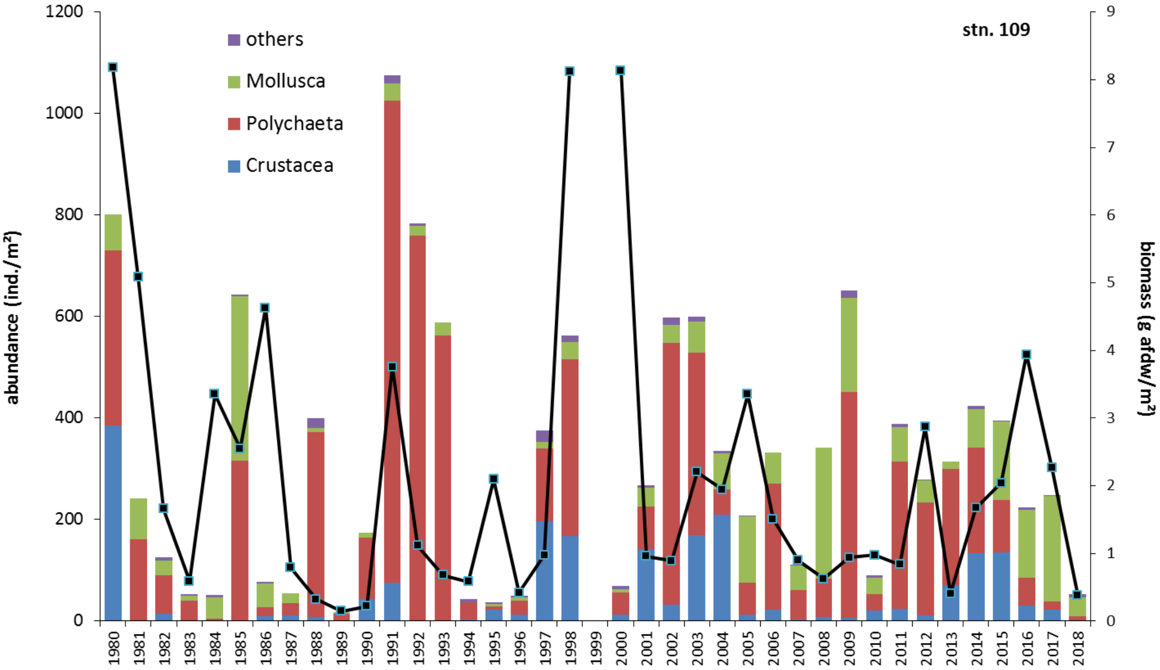

Fig. 50: The development of the abundance, biomass and species number at the monitoring station in Arkona Basin (OMBMPK4) from 2006 to 2018

As example for the long-term variation of the macrozoobenthos the development of population parameters at station OMBMPK4 are presented in Figure 50. Within the time span of the last 39 years several main collapses and recovery phases are obvious. In some years the crustaceans (blue colour) contribute a significant amount of abundance to the total values. These peaks are caused by the presence of the amphipod *Pontoporeia femorata* (Fig. 51). As in 2018 this species could not be found in several years. Within the polychaete abundance *Bylgides sarsi* and *Scoloplos armiger* are most responsible for high fluctuations.

Fig. 51: The amphipod *Pontoporeia femorata* contribute up to 40 % of the total abundance in the central Arkona Basin (OMPMBK4) in some years.

4.3.4 Red List

This section refers to the recently published Red List of bottom-dwelling invertebrates by RACHOR et al. (2013). Of a total of 119 species, 15 are classed as threatened (1, 2, 3, G) (Fig. 52, Tab. A4). Four species are still classed as being near threatened. One species is categorised as extremely rare. Currently, 64 species are classed as being of least concern. Data are deficient for 15 species, and 20 taxa on the Red List were not evaluated. The anthozoan *Halcampa duodecimcirrata* are critically endangered. It was detected in the Arkona Basin (OMBMPK4) in very low densities. Species that are classed as endangered (category 2) were not found. Specimens of *Arctica islandica* (ocean quahog; category 3, vulnerable) were observed at all western stations (OMBMPN3, OMBMPN1, OMBMPM2, and OM18) and in the deeper Arkona Basin (OMBMPK4) at various levels of abundance. Montagu's Astarte (*Astarte montagui*) occurred in the Kiel Bay only (Fig. 53). The hydrozoan species *Halitholus yoldiaearcticae* were observed in the Fehmarnbelt (OMBMPN1). Category G (probably vulnerable) includes species that cannot be assigned to category 1, 2 or 3 above, but which - based on current knowledge - are assumed to be endangered. They are declared to be at risk (uncategorized). The 11 species observed in 2018 were distributed across almost all sea areas: 9 species in Kiel Bay (OMBMPN3), 3 at the Fehmarnbelt (OMBMPN1), 1 at southern Bay of Mecklenburg (OM18), 3 at the Darss Sill (OMBMPK8), 1 in Arkona Basin (OMBMPK4) and 2 in northern Pomeranian Bay (OMBMPK3). Since 2013 there has also been a Red List for the entire Baltic Sea as compiled by a HELCOM group of experts (KONTULA et al. 2013). No species of this list could be observed in 2018.

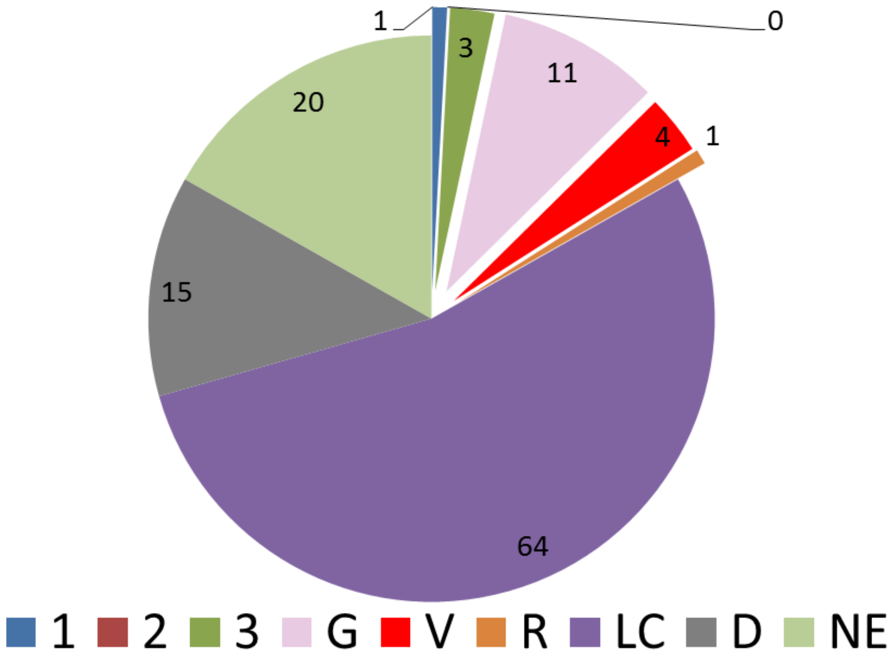

Fig. 52: Percentage of red list categories (RACHOR et al. 2013) in relation to macrozoobenthos in autumn 2018 (1=critically endangered, 2=endangered, 3=vulnerable, G=probably vulnerable, V=near threatened, R=extremely rare, LC=least concern, D=data deficient, NE=not evaluated).

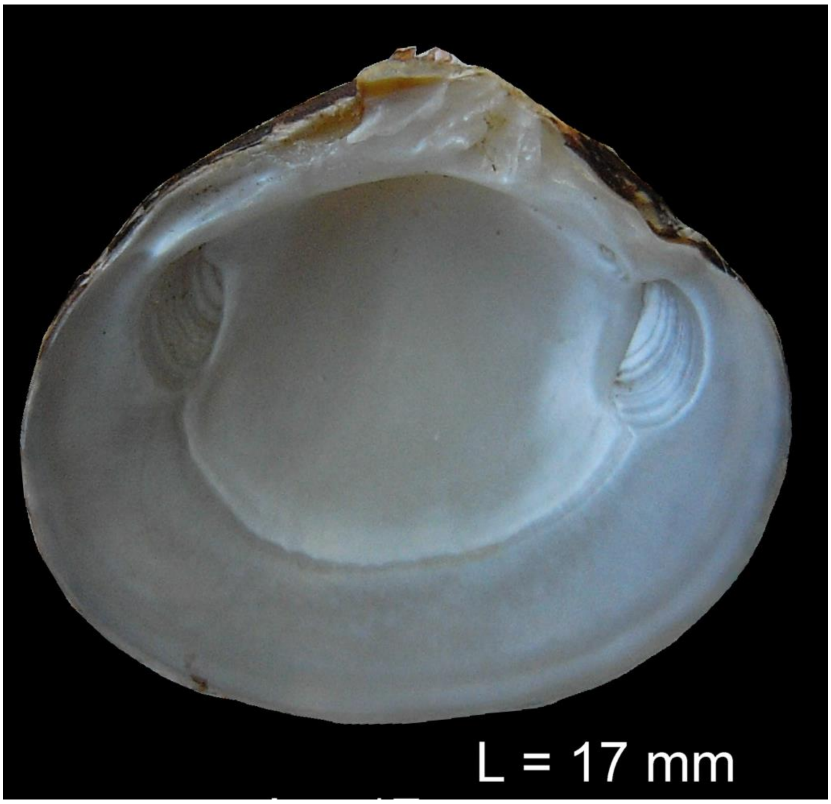

Fig. 53: The small bivalve *Astarte montagui*, a red listed species of the category 3 (vulnerable).

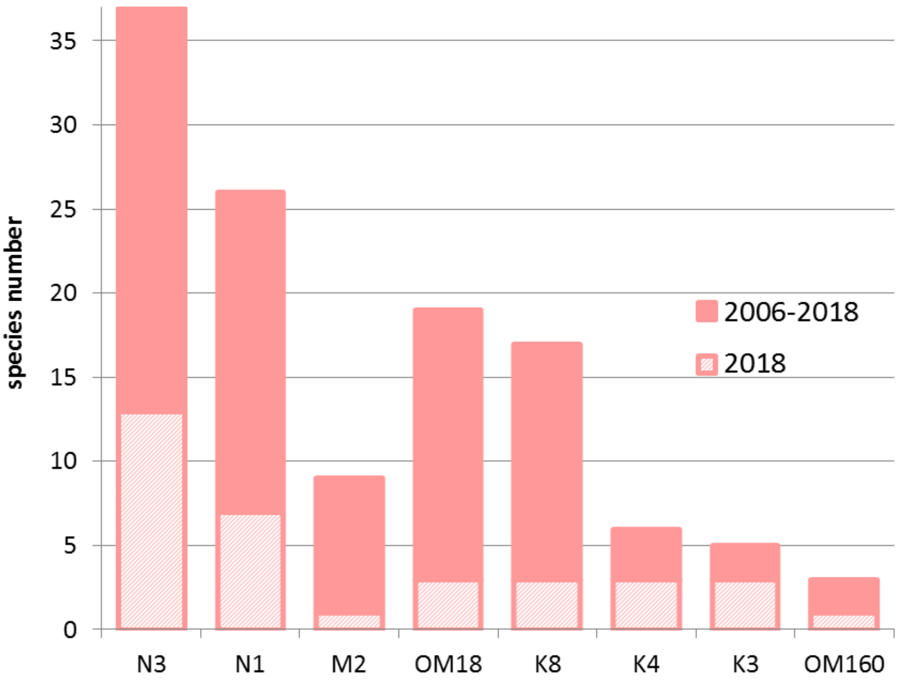

Fig. 54: Number of red listed species (categories 1, 2, 3, G, V and R) (Rachor et al. 2013) at the 8 monitoring stations in 2018 and in total (2006-2018).

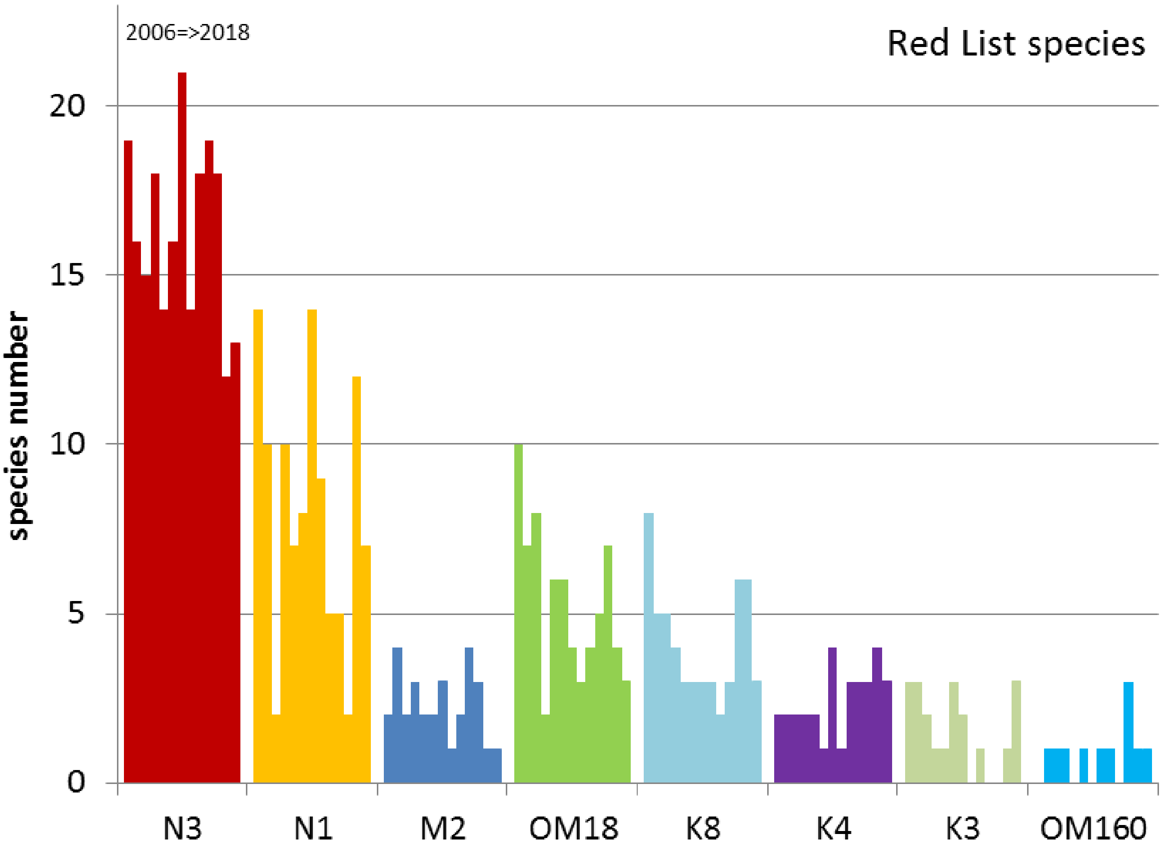

Fig. 55: Development of the number of red listed species (categories 1, 2, 3, G, V and R) (Rachor et al. 2013) at the 8 monitoring stations from 2006 to 2018

In general the number of potentially occurring red listed species at the monitoring stations is decreasing systematically with the salinity gradient from the West to the East (Fig. 54 and 55). The percentage of red listed species in 2018 in comparison to observations in the whole investigation time (2006 to 2018) ranges between 11 and 60 % (Fig. 54). At all stations, except Kiel Bay (OMBMPN3) and northern Pomeranian Bay (OMBMPK3), the number of red listed species was significantly lower than in the previous years (Fig. 55). The strong salinity gradient and its effect on the distribution of red listed marine species are clearly visible. Both the number of records and the species number decrease with decreasing salinities from west to east.

4.3.5 Invasive Species

The role of invasive species in the open Baltic Sea is negligible (Zettler et al. 2014, 2018). Only six species were observed at our 8 monitoring stations in 2018. *Amphibalanus improvisus* (bay barnacle) and *Mya arenaria* (soft-shell clam) have been present in the Baltic region for so long now that they barely still qualify as invasive species. Two species of polychaete from North America have been present in the Baltic since the 1980s and 1990s: while *Marenzelleria neglecta* mainly occurs in inshore waters where it can achieve significant abundances, *Marenzelleria viridis* finds suitable habitat conditions in offshore waters. In 2018 we observed the following abundances of *M. neglecta*: 117 ind./m² in the central Pomeranian Bay (OM160). In 2018 *M. viridis* was observed at the same station with 124 ind./m² and at the northern Pomeranian Bay (OMBMPK3) with 29 ind./m². In 2018 we found a non-indigenous bivalve species for the first time during our monitoring program. *Rangia cuneata* was observed at the central Pomeranian Bay (OM160) (Fig. 56). Only juvenile individuals could be detected. *R. cuneata* was reported from German waters in 2013 (Kiel Canal, Brunsbüttel, North Sea, BOCK et al. 2015) and in 2015 (near Lübeck, Baltic Sea; WIESE et al. 2016). In 2018 it was observed from several places along the Kiel Canal (WIESE 2018) and in the Pomeranian Bay (WIESE & ENGELHARDT, 2019; present study). Additionally, the decapod crab *Rhithropanopeus harrisii* was found at the Oderbank (OM160).

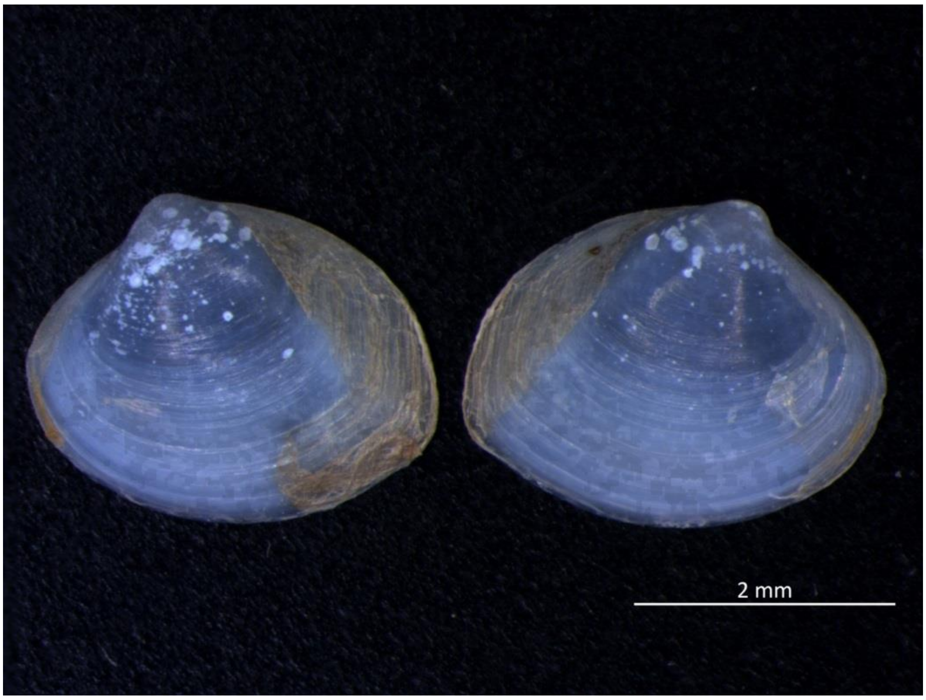

Fig. 56: The North American bivalve species *Rangia cuneata* was recorded for the first time during our monitoring program in 2018. The given image comes from material of the Oderbank (OM160).

Summary

As part of the German contribution to the HELCOM monitoring, data on species composition and biomass or abundance of phyto- and zooplankton as well as macrozoobenthos from Kiel Bay, Bay of Mecklenburg, Arkona Basin, Bornholm Basin and Eastern Gotland Basin (Fig. 1) were gathered in 2018 in order to continue the time series which exists since 1979. A general sample statistics is shown in Table 1 and special statistics of the zooplankton and zoobenthos samplings are presented in Tables 2 and 3. Data from sediment traps deployed in the Arkona Basin give information on particle dynamics.

Phytoplankton

Quantitative information on the species composition and succession of the phytoplankton was gathered from water samples, taken during the cruises and analysed microscopically in the lab. In this report, we concentrated mainly on mixed samples from 0-10 m depth. Gaps owing to the low sampling frequency in routine monitoring could be partly closed by information from the coastal monitoring of the IOW in front of Heiligendamm, to be found on https://www.io-warnemuende.de/algal_blooms_at_heiligendamm_2018.html.

The 10 most important phytoplankton taxa of each season in each sea area are compiled in Table A1 (Annex), sorted by their percentage in total phytoplankton biomass. A complete species list of the year 2018, including a seasonal indicator, is shown in Table A2 (Annex). The ranking according to their biomass in 2018 is also given.

Spring bloom:

The dinoflagellate *Ceratium tripos* was still present in the Belt Sea in January, probably because its autumn bloom extends increasingly into the winter. Surprisingly, this species occurs also in spring. Moreover, a cyanobacterium of the summer bloom, *Aphanizomenon* sp., was found already in winter.

The first samples containing the spring bloom originated from 19/20 March 2018 in the Belt Sea and the western and central Arkona Basin, dominated by diatoms (*Skeletonema marinoi, Thalassiosira* spp., later also at some stations *Rhizosolenia setigera* and *Chaetoceros similis*). However, enhanced biomass was already identified on 8 February in the western Arkona Basin. Into eastern direction, the importance of *Mesodinium rubrum* is strongly increasing with spring maxima in the Bornholm Basin. In the Eastern Gotland Basin, extremely high biomass of *Peridiniella catenata* was found on 11/12 May 2018. In contrast to the previous year, *Dictyocha speculum* did not occur in the spring bloom of the western Baltic Sea.

Nutrient consumption data may give further information on spring bloom dynamics. Nutrients (N, P) were strongly reduced by mid of March 2018 in Kiel Bay and Lübeck Bay, but were still available in the Bay of Mecklenburg and remained at winter concentrations in the Baltic Proper at that time. It reflects the typical retard of the spring bloom into eastern direction. Only in May, the nutrients were almost exhausted. However, silicate was not used up and seems not to limit diatom growth.

If the enhanced biomass values in February 2018 in the western Arkona Basin are assumed as the start of the spring bloom, the month of February can no longer be considered as “winter” concerning the phytoplankton development in this area.

Summer bloom:

A strong diatom (*Dactyliosolen fragilissimus*) summer bloom occurred in the Belt Sea in July 2018. No summer bloom was found in the Arkona Basin and Bornholm Basin. Nitrogen-fixing cyanobacteria dominated in the Eastern Gotland Basin.

The “excess” phosphorus remaining after the spring bloom is widely consumed between May and July from Kiel Bay to the Eastern Gotland Basin, which indicates a non-Redfied uptake during and/or after the spring bloom. The silicate consumption in the Belt Sea confirms the diatom summer bloom. In contrast, silicate consumption and the related diatom development were low in summer in the Baltic Proper.

Autumn bloom:

The autumn bloom was well developed at most stations in the Baltic Sea. It was composed of dinoflagellates (*Ceratium* spp.) and diatoms (*Thalassiosira* spp.) in Kiel Bay. Farther to the east, the relative importance of dinoflagellates decreased and that of diatoms increased.

The bloom-forming diatom was *Cerataulina pelagica* in the Bay of Mecklenburg and the western Arkona Basin, but *Coscinodiscus granii* in the eastern Arkona Basin, Bornholm Basin and Eastern Gotland Basin.

Invading phytoplankton species:
The dinoflagellate *Prorocentrum compressum* was found for the first time in 2018 during our long-term monitoring program in the Belt Sea on 5 November 2018 (Fig. 19). Obviously it was transported with inflowing water into the Baltic Sea. The Major Baltic Inflow from December 2014 introduced only few marine species in low abundances into the Baltic Sea, such as *Roperia tesselata, Karenia mikimotoi* and *Nematopsides vigilans,* but they did not stay there in the following years. However, some species which were new for us in previous years (*Pseudosolenia calcar-avis, Peridiniella danica, Polykrikos schwartzii, Alexandrium pseudogonyaulax*) have established.

Chlorophyll: The concentrations of chlorophyll *a* are compiled in Table 5. They were highest (16.2 mg m^{-3}) during the spring bloom in the Eastern Gotland Basin, but also the autumn bloom was well reflected in the chlorophyll a data throughout the Baltic Sea.

Sedimentation: In 2018, the seasonal phytoplankton sedimentation pattern reflected the growth dynamics of phytoplankton in the Arkona Basin with diatoms being the dominant group in the settling spring bloom, followed by a peak in dinoflagellate sedimentation. Interestingly, a second diatom peak, consisting of different species, was recorded in summer. Contrary to the typical pattern, filamentous cyanobacteria were not abundant in the settling material collected during summer, which was consistent with low biomass of these taxa in the summer phytoplankton community. The relatively high The $\delta^{15}N$ values in summer indicate low rates in nitrogen fixation, which is consistent with the low cyanobacteria biomass found in summer 2018. The diversity of taxa in sedimented material was comparable to 2017, except for cyanobacteria, which only consisted of 3 taxa compared to 6 in 2017 and Chlorophyceae/flagellates of which 8 were detected in 2018 in contrast to 4 in 2017. Due to excessive growth of *Balanus* on the funnel and screen of the trap during the third deployment period, no conclusive data could be generated from the retrieved material. Due to this malfunctioning of the trap during the third deployment phase, meaningful annual sedimentation rates and mass fluxes of elements could not be calculated for comparison with previous years.

Zooplankton

The long-term variation in abundance and community composition of Baltic Sea zooplankton in 2018 was assessed from 57 samples taken at 50 sampling events in the western Baltic Sea. A considerably lower number of taxa was recorded in comparison to the preceding years. While in 2016 and 2017 about 73 and 63 taxa were observed, the number decreased to 44 taxa. This is mainly due to the disappearance of halophilic crustaceans, gelatinous cnidarians or meroplanktonic larvae in the Kiel Bay and the Bay of Mecklenburg. Similar to preceding years, the number of taxa increased from winter to spring and summer to autumn. Exceptional species were not observed in 2018.

The concentrations of zooplankton were again low in 2018, but an upward tendency observed in 2017 continued. This was caused by an increase in the abundance of rotifers by a factor of 2-

10, particularly in the Bay of Mecklenburg and Arkona Basin. The stocks of cladocera showed a continued recovery in all areas as well, while calanoid and cyclopoid copepods remained on a similar level compared to 2017. Cladocera were the single most important group, with a maximum concentration of 7.4 x 10^4 ind. m^{-3}. *Bosmina* spp. was as usual the most important genus. The stock showed a recovery from the very low concentrations observed in 2016. While highest densities occur usually in the Arkona Basin, the genus was also abundant in the Bay of Mecklenburg. Apart from this taxon, *Evadne nordmanni*, *Podon intermedius* and *P. leuckartii* were common. The rotifer *Synchaeta* spp. was seasonally very abundant and replaced the copepods as second most important group in terms of abundance (up to 6.1 x 10^4 ind. m^{-3}). Again, this taxon had a wide distribution ranging from Kiel Bight to Arkona Basin in 2018. A general recovery from low stocks during 2015-2016 were observed among the copepods (up to 4.2 x 10^4 ind. m^{-3}). The genus *Acartia* replaced *Temora* as the most abundant genus among the calanoid copepods. While its density remained similar in the Kiel Bight and the Arkona Basin in comparison to the previous years, the stock size was considerably enhanced in the Bay of Mecklenburg. Only small changes were observed in the density of the genera *Para/Pseudocalanus* and *Centropages*. *Para/Pseudocalanus* ranked second among the calanoid copepods. In contrast, *Temora* decreased in stock size. The cyclopoid copepod *Oithona* is usually very abundant in the Kiel Bight. In 2018, the maximal abundance was 2.1 x 10^4 ind. m^{-3} and the highest densities were observed in the Bay of Mecklenburg.

The zooplankton in Kiel Bay (OMBMPN3) displayed a typical variation in the seasonal development in the stock and its composition. Copepods generally dominated the community, while other holoplankton such as cladocera, rotifers or appendicularia play a minor role. Timing and composition of the zooplankton in 2018 resembled strongly the previous year. A shift in the composition of the zooplankton observed since 2016 continued, particularly among the copepods from *Acartia/Oithona* to *Pseudocalanus/Temora/Acartia longiremis*. The zooplankton in the Bay of Mecklenburg (OMBMPM2, OMBMPM1) was characterized by a relatively late development and a pronounced seasonality with high stocks during spring and summer. Comparable to Kiel Bight, this is a continuation of a major change started in 2017 and owed to the strong development of the copepod stock and relatively high densities of rotifers and cladocera, which are usually not observed in high numbers. In the Arkona Basin (OMBMPK8 – OMBMPK4), zooplankton stocks were also high. Although copepods were abundant, the increase was primarily caused by rotifers in spring and cladocerans in summer, which both occurred at low densities in the period 2015-2017.

The stock size of zooplankton remained still low in 2018. Despite a reversal tendency in the last 2 years with a tripling of the abundance in comparison to the historical low in 2016, the total abundance of 1.9 x 10^5 ind. m^{-3} remained below the long-term average of 3.3 x 10^5 ind. m^{-3} for the period 2000-2018.

Macrozoobenthos

This study presents the results of macrozoobenthos monitoring in the southern Baltic Sea in November 2018. The following parameters were measured: species richness, and the abundance and biomass of organisms per station. Compared to previous years, the 119 species recorded at the 8 monitoring stations were considered to be a low number. No long-lasting oxygen deficiency was observed in 2018; however in the Fehmarnbelt we recorded a short term oxygen demand in July (values below 1 ml/l). Depending on the region, abundances varied between 46 and 9.860 ind./m². In terms of biomass, similarly high variations were observed (0.4 g in the Arkona Basin to 47.6 g afdw/m² in the Kiel Bay).

Fifteen species of the German Red List (Categories 1, 2, 3 and G) were observed at the 8 monitoring stations. The anthozoan *Halcampa duodecimcirrata*, very rarely observed and critically endangered in German waters, was found in the Arkona Basin, for instance. In line with expectations, the number of invasive species found during the 2018 sampling campaign was low: six species were identified, among them long-established species like *Amphibalanus improvisus* (Cirripedia) and *Mya arenaria* (Bivalvia). Recently introduced species (since the 1980s and 1990s) of the genus *Marenzelleria* (Polychaeta) are locally important, whereof *Marenzelleria viridis* and M. neglecta colonised the Pomeranian Bay in densities of around 100 to 200 ind./m². Additionally, with *Rangia cuneata*, an originally North American bivalve species was recorded for the first time during the monitoring program in off-shore waters on the Oderbank (Pomeranian Bay). Last but not least the decapod crab *Rhithropanopeus harrisii* were recorded on the Oderbank.

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ANNEX (for multi-page tables)

Table A1

The 10 most abundant phytoplankton taxa (percentage of total phytoplankton biomass) in the different sea areas (upper 10 m): averages from the three cruises January-May as well as cruises from July/August and November 2018. The mean phytoplankton biomass (in µg/l) is given on the top of each station block. Continued on page 88-89 !

January-May	(%)	July-August	(%)	November	(%)
Kiel Bay (Stat. OMBMPN3)					
Phytopl. biomass in µg/L	543	Phytopl. biomass in µg/L	1102	Phytopl. biomass in µg/L	1888
Thalassiosira	28.42	Proboscia alata	50.18	Gymnodiniales	17.99
Skeletonema marinoi	19.68	Dactyliosolen fragilissimus	17.97	Thalassiosira	17.27
Ceratium tripos	11.04	Gymnodiniales	8.34	Ceratium lineatum	15.05
Ebria tripartita	7.97	Nodularia spumigena	5.17	Rhizosolenia setigera	7.35
Teleaulax	5.68	Ceratium tripos	4.43	Thalassiosira gravida	7.16
Dinophysis norvegica	4.55	Unicell spp.	2.87	Ceratium tripos	5.17
Gymnodiniales	4.25	Rhizosolenia setigera f. pungens	2.87	Cerataulina pelagica	3.56
Rhizosolenia setigera	3.41	Dolichospermum spp.	2.10	Polykrikos schwartzii	3.46
Mesodinium rubrum	2.03	Cymbomonas tetramitiformis	1.21	Pseudo-nitzschia	2.53
Heterocapsa rotundata	1.71	Prymnesiales	1.04	Rhizosolenia setigera f. pungens	2.21
Lübeck Bay (Stat. OMO22)					
Phytopl. biomass in µg/L	630	Phytopl. biomass in µg/L	8004	Phytopl. biomass in µg/L	699
Thalassiosira	18.49	Dactyliosolen fragilissimus	96.09	Gymnodiniales	16.14
Mesodinium rubrum	16.21	Ceratium tripos	1.39	Pseudosolenia calcar-avis	10.72
Ceratium tripos	15.09	Aphanizomenon	0.73	Pseudo-nitzschia	9.17
Skeletonema marinoi	12.65	Gymnodiniales	0.49	Rhizosolenia setigera	6.69
Rhizosolenia setigera	10.44	Nodularia spumigena	0.40	Gyrodinium spirale	6.65
Gymnodiniales	6.44	Unicell spp.	0.35	Ceratium lineatum	6.42
Teleaulax	4.08	Prymnesiales	0.08	Thalassiosira	4.53
Prymnesiales	2.77	Pseudanabaena limnetica	0.07	Protoperidinium	3.09
Chaetoceros	1.72	Alexandrium pseudogonyaulax	0.06	Ditylum brightwellii	2.52
Heterocapsa rotundata	1.34	Plagioselmis prolonga	0.05	Thalassiosira gravida	2.51
Central Mecklenburg Bay (Stat. OMBMPM2)					
Phytopl. biomass in µg/L	478	Phytopl. biomass in µg/L	4460	Phytopl. biomass in µg/L	2980
Rhizosolenia setigera	24.93	Dactyliosolen fragilissimus	92.77	Cerataulina pelagica	82.53
Skeletonema marinoi	14.60	Ceratium tripos	3.40	Pseudo-nitzschia	2.23
Thalassiosira	12.97	Gymnodiniales	1.52	Dactyliosolen fragilissimus	1.64
Mesodinium rubrum	10.88	Nodularia spumigena	0.39	Gymnodiniales	1.32
Gymnodiniales	6.56	Unicell spp.	0.38	Pseudosolenia calcar-avis	1.09
Ceratium tripos	6.32	Aphanizomenon	0.20	Teleaulax	0.94
Chaetoceros	3.27	Katablepharis remigera	0.18	Ceratium tripos	0.94
Ebria tripartita	3.00	Prymnesiales	0.17	Rhizosolenia setigera	0.88
Teleaulax	2.39	Cymbomonas tetramitiformis	0.15	Mesodinium rubrum	0.86
Heterocapsa rotundata	2.15	Mesodinium rubrum	0.14	Ceratium lineatum	0.67
Eastern Mecklenburg Bay (Stat. OMBMPM1)					
Phytopl. biomass in µg/L	544	Phytopl. biomass in µg/L	2995	Phytopl. biomass in µg/L	1680
Thalassiosira	37.04	Dactyliosolen fragilissimus	89.48	Cerataulina pelagica	87.86
Mesodinium rubrum	15.61	Ceratium tripos	3.38	Mesodinium rubrum	1.84
Skeletonema marinoi	11.01	Gymnodiniales	2.21	Teleaulax	1.42
Ceratium tripos	5.86	Unicell spp.	2.13	Gymnodiniales	1.14
Gymnodiniales	5.30	Pyramimonas	0.82	Ceratium tripos	1.13
Rhizosolenia setigera	3.04	Aphanizomenon	0.31	Dactyliosolen fragilissimus	1.05
Ebria tripartita	2.57	Nodularia spumigena	0.28	Pseudosolenia calcar-avis	0.80
Teleaulax	2.52	Mesodinium rubrum	0.24	Ditylum brightwellii	0.46
Chaetoceros	2.31	Plagioselmis prolonga	0.21	Pseudo-nitzschia	0.41
Chaetoceros similis	1.39	Pseudanabaena limnetica	0.16	Pyramimonas	0.40

Western Arkona Basin (Stat. OMBMPK8)					
Phytopl. biomass in µg/L	567	Phytopl. biomass in µg/L	263	Phytopl. biomass in µg/L	679
Thalassiosira	39.48	Ceratium tripos	23.85	Cerataulina pelagica	61.22
Mesodinium rubrum	22.10	Unicell spp.	23.54	Dactyliosolen fragilissimus	10.34
Skeletonema marinoi	14.04	Mesodinium rubrum	20.24	Unicell spp.	4.21
Gymnodiniales	6.10	Gymnodiniales	8.72	Gymnodiniales	3.75
Chaetoceros similis	1.80	Pyramimonas	4.47	Ceratium tripos	3.49
Thalassiosira baltica	1.64	Actinocyclus	4.14	Pseudosolenia calcar-avis	3.29
Prymnesiales	1.56	Aphanizomenon	3.84	Prymnesiales	2.95
Ebria tripartita	1.56	Nodularia spumigena	3.32	Mesodinium rubrum	1.71
Rhizosolenia setigera	1.30	Plagioselmis prolonga	1.86	Actinocyclus	1.70
Teleaulax	1.25	Teleaulax	1.81	Teleaulax	1.54
Central Arkona Basin (Stat. OMBMPK5)					
Phytopl. biomass in µg/L	675	Phytopl. biomass in µg/L	251	Phytopl. biomass in µg/L	272
Mesodinium rubrum	36.69	Unicell spp.	41.66	Actinocyclus	15.31
Thalassiosira	25.13	Mesodinium rubrum	22.42	Gymnodiniales	12.03
Chaetoceros similis	12.04	Ceratium tripos	11.78	Teleaulax	9.60
Gymnodiniales	5.01	Gymnodiniales	10.70	Ceratium tripos	8.98
Skeletonema marinoi	4.15	Actinocyclus	5.04	Mesodinium rubrum	8.17
Ebria tripartita	3.66	Pyramimonas	1.67	Unicell spp.	7.97
Chaetoceros	1.85	Teleaulax	1.58	Prymnesiales	6.73
Unicell spp.	1.33	Nodularia spumigena	1.28	Pyramimonas	6.47
Prymnesiales	1.32	Aphanizomenon	1.09	Dactyliosolen fragilissimus	5.01
Actinocyclus	1.13	Chaetoceros castracanei	0.83	Cerataulina pelagica	3.16
Eastern Arkona Basin (Stat. OMBMPK4)					
Phytopl. biomass in µg/L	365	Phytopl. biomass in µg/L	207	Phytopl. biomass in µg/L	1001
Mesodinium rubrum	55.48	Mesodinium rubrum	28.46	Coscinodiscus granii	63.95
Chaetoceros similis	8.60	Unicell spp.	27.48	Actinocyclus	17.42
Thalassiosira	8.08	Pyramimonas	8.56	Coscinodiscus	5.10
Ebria tripartita	5.94	Actinocyclus	7.97	Unicell spp.	3.75
Gymnodiniales	5.44	Nodularia spumigena	6.79	Dactyliosolen fragilissimus	1.64
Skeletonema marinoi	3.14	Ceratium tripos	6.73	Teleaulax	1.51
Teleaulax	1.96	Gymnodiniales	3.82	Cerataulina pelagica	1.33
Pyramimonas	1.92	Aphanizomenon	3.06	Mesodinium rubrum	1.12
Heterocapsa rotundata	1.54	Teleaulax	2.92	Gymnodiniales	0.75
Unicell spp.	1.16	Plagioselmis prolonga	0.84	Plagioselmis prolonga	0.60
Bornholm Basin (Stat. OMBMPK2)					
Phytopl. biomass in µg/L	772	Phytopl. biomass in µg/L	92	Phytopl. biomass in µg/L	1475
Mesodinium rubrum	72.36	Unicell spp.	42.06	Coscinodiscus granii	77.08
Chaetoceros similis	4.11	Pyramimonas	21.20	Actinocyclus	10.15
Gymnodiniales	4.01	Gymnodiniales	10.01	Mesodinium rubrum	4.63
Pyramimonas	2.70	Actinocyclus	9.34	Coscinodiscus centralis cf.	1.71
Prymnesiales	2.29	Plagioselmis prolonga	6.76	Unicell spp.	1.50
Ebria tripartita	1.94	Teleaulax	4.02	Teleaulax	1.24
Actinocyclus	1.28	Chaetoceros castracanei	3.17	Gymnodiniales	1.07
Peridiniella catenata	1.27	Mesodinium rubrum	1.79	Pyramimonas	0.58
Amylax triacantha	1.25	Prymnesiales	0.82	Plagioselmis prolonga	0.31
Peridiniales	0.95	Pseudopedinella	0.37	Ceratium tripos	0.24
Southern Gotland Basin (Stat. OMBMPK1)					
Phytopl. biomass in µg/L	1690	Phytopl. biomass in µg/L	724	Phytopl. biomass in µg/L	2597
Peridiniella catenata	69.17	Unicell spp.	25.25	Coscinodiscus granii	94.75
Mesodinium rubrum	17.53	Nodularia spumigena	12.13	Actinocyclus	2.69
Gymnodiniales	3.00	Cyclotella	10.72	Mesodinium rubrum	0.85
Prymnesiales	1.26	Cyanonephron styloides	6.45	Unicell spp.	0.76
Actinocyclus	1.22	Aphanizomenon	6.41	Teleaulax	0.26
Peridiniella danica	1.15	Aphanothece	5.96	Chaetoceros castracanei	0.21
Heterocapsa rotundata	1.06	Mesodinium rubrum	5.35	Gymnodiniales	0.16
Amylax triacantha	0.97	Aphanocapsa	4.85	Gyrodinium spirale	0.05
Unicell spp.	0.93	Gymnodiniales	4.18	Eutreptiella	0.05
Dinophysis acuminata	0.72	Gonyaulax spinifera	2.47	Hemiselmis	0.04

Eastern Gotland Basin (Stat. OMBMPJ1)					
Phytopl. biomass in µg/L	719	Phytopl. biomass in µg/L	773	Phytopl. biomass in µg/L	542
Mesodinium rubrum	44.75	Unicell spp.	22.25	Coscinodiscus granii	79.66
Peridiniella catenata	39.24	Mesodinium rubrum	17.79	Mesodinium rubrum	8.45
Gymnodiniales	2.97	Nodularia spumigena	13.26	Actinocyclus	2.92
Heterocapsa rotundata	1.34	Aphanocapsa	6.89	Teleaulax	1.68
Prymnesiales	1.29	Pseudanabaena limnetica	5.05	Gymnodiniales	1.43
Peridiniella danica	1.27	Dinophysis norvegica	4.57	Unicell spp.	1.12
Actinocyclus	1.25	Aphanizomenon	4.33	Protoperidinium pellucidum	0.79
Dinophysis acuminata	1.20	Aphanothece	3.95	Dinophysis norvegica	0.72
Teleaulax	0.87	Cyanonephron styloides	3.17	Chaetoceros castracanei	0.57
Gyrodinium spirale	0.82	Coelosphaerium minutissimum	2.99	Eutreptiella	0.38

Table A2
Phytoplankton taxa list of 2018, with class affiliation, biomass rank (for all stations, all depths) and seasonal occurrence from the five monitoring cruises.

Continued on page 91-93.

Taxon	Class	Rank	Jan/Feb	March	May	Jul/Aug	Nov
Actinocyclus	Bacillarioph.	11	X	X	X	X	X
Actinoptychus senarius	Bacillarioph.	95				X	X
Akashiwo sanguinea	Dinophyceae	119				X	
Alexandrium pseudogonyaulax	Dinophyceae	103				X	X
Amphidinium crassum	Dinophyceae	105	X	X	X		X
Amphidinium sphenoides	Dinophyceae	97	X	X	X	X	X
Amylax triacantha	Dinophyceae	39		X	X	X	
Anabaenopsis	Cyanobact.	161				X	
Apedinella radians	Chrysophyc.	99	X	X	X	X	X
Aphanizomenon sp.	Cyanobact.	26	X	X	X	X	X
Aphanocapsa spp.	Cyanobact.	45	X	X	X	X	X
Aphanothece spp. +*Anathece* spp.	Cyanobact.	55	X	X	X	X	X
Aphanothece paralleliformis	Cyanobact.	84	X	X	X	X	
Attheya longicornis	Bacillarioph.	134					X
Attheya septentrionalis	Bacillarioph.	78	X	X	X	X	X
Binuclearia lauterbornii	Ulvophyceae	110	X	X	X	X	X
Botryococcus spp.	Trebouxioph.	136			X		X
Centrales	Bacillarioph.	51	X	X	X	X	X
Cerataulina pelagica	Bacillarioph.	3	X				X
Ceratium fusus	Dinophyceae	81	X	X		X	X
Ceratium lineatum	Dinophyceae	25				X	X
Ceratium longipes	Dinophyceae	32			X	X	X
Ceratium tripos	Dinophyceae	8	X	X	X	X	X
Chaetoceros spp.	Bacillarioph.	28	X	X	X	X	X
Chaetoceros affinis (incl. cf.)	Bacillarioph.	94			X	X	X
Chaetoceros brevis	Bacillarioph.	117	X	X		X	
Chaetoceros castracanei	Bacillarioph.	47	X	X		X	X
Chaetoceros circinalis	Bacillarioph.	120				X	X
Chaetoceros contortus	Bacillarioph.	75				X	X
Chaetoceros convolutus	Bacillarioph.	73					X
Chaetoceros curvisetus	Bacillarioph.	91	X	X		X	X
Chaetoceros danicus	Bacillarioph.	80	X	X		X	X
Chaetoceros debilis	Bacillarioph.	149				X	
Chaetoceros decipiens (incl. cf.)	Bacillarioph.	82		X	X	X	
Chaetoceros didymus	Bacillarioph.	157				X	
Chaetoceros laciniosus	Bacillarioph.	152				X	
Chaetoceros minimus	Bacillarioph.	154	X	X			X
Chaetoceros similis	Bacillarioph.	13	X	X	X		X
Chaetoceros socialis	Bacillarioph.	89		X			X
Chaetoceros subtilis	Bacillarioph.	40	X	X	X	X	
Chaetoceros throndsenii	Bacillarioph.	139		X	X		
Chaetoceros wighamii (incl. cf.)	Bacillarioph.	93		X			
Choanoflagellatea	Choanoflag.	70	X	X	X	X	X
Chroococcales	Cyanobact.	124	X	X			X

Coelosphaerium minutissimum	Cyanobact.	66	X	X	X	X	X
Coscinodiscus spp.	Bacillarioph.	69					X
Coscinodiscus cf. *centralis*	Bacillarioph.	71					X
Coscinodiscus granii	Bacillarioph.	4				X	X
Coscinodiscus radiatus	Bacillarioph.	65	X	X	X	X	X
Coscinodiscus wailesii	Bacillarioph.	20					X
Cryptomonas cf.	Cryptoph.	132		X			
Cyanodictyon spp.	Cyanobact.	135	X	X	X		
Cyanodictyon planctonicum	Cyanobact.	77	X	X	X	X	X
Cyanonephron styloides	Cyanobact.	59	X	X	X	X	X
Cyclotella spp.	Bacillarioph.	54	X	X	X	X	X
Cylindrotheca closterium	Bacillarioph.	128	X	X	X	X	X
Cymbomonas tetramitiformis	Prasinophyc.	68			X	X	X
Dactyliosolen fragilissimus	Bacillarioph.	1	X		X	X	X
Detonula pumila	Bacillarioph.	138					X
Diatoma tenuis	Bacillarioph.	148		X			
Dictyocha speculum (incl. cf.)	Dictyochoph.	56	X	X	X	X	X
Dinobryon spp.	Chrysophyc.	133			X	X	
Dinobryon balticum	Chrysophyc.	88			X		
Dinobryon faculiferum	Chrysophyc.	126		X	X	X	X
Dinophysis acuminata	Dinophyceae	49	X	X	X	X	X
Dinophysis acuta	Dinophyceae	72			X		X
Dinophysis norvegica	Dinophyceae	29	X	X	X	X	X
Dissodinium pseudolunula	Dinophyceae	118					X
Ditylum brightwellii	Bacillarioph.	38					X
Dolichospermum spp.	Cyanobact.	79		X		X	
Ebria tripartita	Ebriophyc.	16	X	X	X	X	X
Eutreptiella spp.	Euglenoph.	53	X	X	X	X	X
Eutreptiella braarudii	Euglenoph.	160	X				
Gonyaulax spinifera	Dinophyceae	96				X	
Guinardia delicatula	Bacillarioph.	52	X			X	X
Guinardia flaccida	Bacillarioph.	43	X			X	X
Gymnodiniales	Dinophyceae	7	X	X	X	X	X
Gyrodinium spirale	Dinophyceae	33	X	X	X	X	X
Hemiselmis spp.	Dinophyceae	57	X	X	X	X	X
Heterocapsa rotundata	Dinophyceae	19	X	X	X	X	X
Heterocapsa triquetra	Dinophyceae	123			X	X	X
Katablepharis spp.	Incertae sedis	143	X				
Katablepharis remigera	Incertae sedis	46	X	X	X	X	X
Katodinium glaucum	Dinophyceae	44	X	X	X	X	X
Kirchneriella spp.	Chlorophyc.	140			X		
Koliella spp.	Trebouxioph.	146		X	X	X	X
Laboea strobila (incl. cf.)	Oligotrichea	98	X		X		X
Lemmermanniella pallida	Cyanobact.	102	X		X	X	
Lemmermanniella parva	Cyanobact.	112	X	X	X	X	X
Lennoxia faveolata	Bacillarioph.	129	X				X
Leptocylindrus danicus	Bacillarioph.	158					X
Leptocylindrus minimus	Bacillarioph.	100	X				X
Leucocryptos marina	Incertae sedis	50	X	X	X	X	X
Melosira arctica	Bacillarioph.	63		X			
Merismopedia spp.	Cyanobact.	131			X	X	

Merismopedia punctata	Cyanobact.	153		X			X
Mesodinium rubrum	Litostomatea	2	X	X	X	X	X
Micracanthodinium claytonii	Dinophyceae	108	X	X	X		X
Monoraphidium cf.	Chlorophyc.	144			X		
Monoraphidium contortum	Chlorophyc.	137			X		
Monoraphidium minutum	Chlorophyc.	156	X		X		X
Nitzschia spp.	Bacillarioph.	125					X
Nitzschia longissima	Bacillarioph.	76	X	X			X
Nitzschia paleacea	Bacillarioph.	90				X	
Nodularia spumigena	Cyanobact.	23			X	X	X
Oocystis spp.	Trebouxioph.	101	X	X	X	X	X
Pauliella taeniata	Bacillarioph.	113		X	X		
Pennales	Bacillarioph.	67	X	X	X	X	X
Peridiniales	Dinophyceae	30	X	X	X	X	X
Peridiniella catenata	Dinophyceae	6	X	X	X		
Peridiniella danica	Dinophyceae	36	X	X	X		
Phalacroma rotundatum	Dinophyceae	115				X	X
Plagioselmis prolonga	Cryptophyc.	22	X	X	X	X	X
Planktolyngbya spp.	Cyanobact.	130	X		X		
Planktolyngbya contorta	Cyanobact.	151			X		
Polykrikos schwartzii	Dinophyceae	42					X
Porosira glacialis	Bacillarioph.	116		X			
Proboscia alata	Bacillarioph.	15	X			X	X
Prorocentrum compressum	Dinophyceae	121					X
Prorocentrum cordatum	Dinophyceae	107		X		X	X
Prorocentrum micans	Dinophyceae	64	X			X	X
Prorocentrum triestinum	Dinophyceae	141					X
Protoperidinium spp.	Dinophyceae	37	X	X	X	X	X
Protoperidinium bipes	Dinophyceae	104			X	X	X
Protoperidinium cf. *brevipes*	Dinophyceae	127			X		
Protoperidinium depressum	Dinophyceae	86	X			X	
Protoperidinium pallidum	Dinophyceae	111					X
Protoperidinium pellucidum	Dinophyceae	85	X		X		X
Prymnesiales	Prymnesioph.	18	X	X	X	X	X
Pseudanabaena limnetica (incl. cf.)	Cyanobact.	60	X	X	X	X	X
Pseudo-nitzschia spp.	Bacillarioph.	27	X			X	X
Pseudo-nitzschia delicatissima group	Bacillarioph.	145					X
Pseudo-nitzschia seriata group	Bacillarioph.	74					X
Pseudopedinella sp.	Chrysophyc.	62	X	X	X	X	X
Pseudosolenia calcar-avis	Bacillarioph.	21					X
Pterosperma spp.	Prasinophyc.	122	X	X		X	X
Pyramimonas spp.	Prasinophyc.	17	X	X	X	X	X
Pyramimonas longicauda	Prasinophyc.	159					X
Rhizosolenia hebetata f. *semispina*	Bacillarioph.	147			X		
Rhizosolenia setigera	Bacillarioph.	10	X	X	X		X
Rhizosolenia setigera f. *pungens*	Bacillarioph.	41				X	X
Romeria spp.	Cyanobact.	150		X	X	X	
Scenedesmus spp.	Chlorophyc.	142			X		
Scrippsiella COMPLEX	Dinophyceae	114					X
Skeletonema marinoi	Bacillarioph.	9	X	X	X	X	X
Snowella spp.	Cyanobact.	58	X	X	X	X	X

Teleaulax spp.	Cryptophyc.	14	X	X	X	X	X
Telonema spp.	Incertae sedis	48	X	X	X	X	X
Telonema subtile	Incertae sedis	155		X			
Tetrastrum staurogeniaeforme	Chlorophyc.	162					X
Thalassionema frauenfeldii (incl. cf.)	Bacillarioph.	109	X	X	X	X	
Thalassionema nitzschioides	Bacillarioph.	83	X	X	X	X	X
Thalassiosira spp.	Bacillarioph.	5	X	X	X	X	X
Thalassiosira anguste-lineata	Bacillarioph.	35	X	X	X		X
Thalassiosira baltica	Bacillarioph.	24	X	X	X	X	X
Thalassiosira eccentrica (incl. cf.)	Bacillarioph.	34	X		X	X	X
Thalassiosira gravida	Bacillarioph.	31		X			X
Thalassiosira punctigera	Bacillarioph.	92					X
Trachelomonas	Euglenoph.	106	X	X		X	X
Unicell spp.		12	X	X	X	X	X
Unidentified flagellata		61	X	X	X	X	X
Woronichinia spp.	Cyanobact.	87	X	X	X	X	X
Number of taxa: total 162	**Number of taxa per cruise:**		**90**	**90**	**94**	**100**	**121**

Table A3: Seasonal occurrence of taxa found in the investigation area in 2018 with information on original description, taxonomic rank and taxonomic life science identifier according to the Aphia Database (AphiaID) of the world register of marine species (WoRMS).

	rank	AphiaID	Feb	March	May	Aug	Nov
Protozoa							
Tintinnidae Claparède & Lachmann, 1858	Family	183533	o	o	o	o	o
Noctiluca scintillans (Macartney) Kofoid and Swezy, 1921	Species	109921					o
Annelida							
Polychaeta - Trochophora	Subphylum		o				
Polychaeta - others	Subphylum	883	o	o	o	o	o
Harmothoe spp. Kinberg, 1856	Genus	129491	o	o	o		
Pectinaria spp. Savigny in Lamarck, 1818	Genus	129437				o	o
Arthropoda - Crustacea							
Copepoda							
Acartia bifilosa Giesbrecht, 1881	Species	345919	o	o	o	o	o
Acartia longiremis Lilljeborg, 1853	Species	346037	o	o	o	o	o
Acartia tonsa Dana, 1849	Species	345943				o	o
Centropages hamatus Lilljeborg, 1853	Species	104496	o	o	o	o	o
Eurytemora affinis Poppe, 1880	Species	104872	o	o	o	o	o
Euterpina acutifrons Dana, 1847	Species	116162	o	o	o	o	o
Harpacticoida G. O. Sars, 1903	Ordnung	1102	o	o			
Microsetella spp. Brady & Robertson, 1873	Genus	115341	o	o	o	o	
Oithona similis Claus, 1866	Species	106656	o	o	o	o	o
Paracalanus parvus Claus, 1863	Species	104685	o	o		o	o
Pseudocalanus spp. Boeck, 1872	Genus	104165	o	o	o	o	o
Temora longicornis O.F.Müller, 1785	Species	104878	o	o	o	o	o
Phyllopoda							
Bosmina spp. Baird, 1845	Genus	106265			o	o	o
Evadne nordmanni Lovén, 1836	Species	106273	o	o	o	o	o
Podon intermedius Lilljeborg, 1853	Species	106276	o			o	o
Podon leuckartii G. O. Sars, 1862	Species	106277	o	o	o	o	
Pleopsis polyphemoides (Leuckart,1859)	Species	247981				o	o
Penilia avirostris Dana, 1849	Species	106272				o	
other Crustacea							
Balanus spp. Costa, 1778	Genus	106122	o	o	o	o	o
Crangon crangon Linnaeus, 1758	Species	107552				o	
Lophogastrida G. O. Sars, 1870	Order	119821	o				
Ostracoda Latreille, 1802	Class	1078		o			
Bryozoa							
Gymnolaemata Allman, 1856	Class	1795	o	o		o	o

Table A3 continued.

	Rang	TSN	Feb	März	Mai	Aug	Nov
Chaetognatha							
Sagittidae Claus and Grobben, 1905	Family	5953	o				o
Chordata							
Fritellaria borealis Lohmann, 1896	Species	103375	o	o	o		o
Oikopleura dioica Fol 1872	Species	103407	o			o	o
Teleostei	Infraclass	293496	o		o	o	
Echinodermata							
Asterias spp. Linnaeus, 1758	Genus	123219				o	
Cnidaria & Ctenophora							
Antothecatae Cornelius, 1992	Order	13551				o	
Ctenophora Eschscholtz, 1829	Phylum	1248	o	o	o		o
Euphysa aurata Forbes, 1848	Species	117561				o	
Lizzia blondina Forbes, 1848	Species	117345				o	
Nematoda							
Nematoda	Phylum	799	o				
Platyhelminthes							
Alaurina spp. Metschnikoff, 1861	Genus	142785	o	o		o	o
Leptoplanidae Stimpson, 1857	Family	142062	o				o
Mollusca							
Bivalvia Linnaeus, 1758	Class	105	o	o	o	o	o
Gastropoda Cuvier, 1797	Class	101	o	o	o	o	o
Rotifera							
Keratella spp. Bory de St. Vincent, 1822	Genus	134941			o		
Keratella cochlearis Gosse, 1851	Species	134990		o		o	
Keratella quadrata O. F. Muller, 1786	Species	134992				o	o

Table A4: Distribution of macrozoobenthos at 8 stations in November 2018. In the right column the red list (Rachor et al. 2013) species are indicated (1=critically endangered, 2=endangered, 3=vulnerable, G=probably vulnerable, V=near threatened, R=extremely rare, D=data deficient, *=least concern, ne=not evaluated).

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Amphipoda									
Corophium volutator							1	1	*
Crassicorophium crassicorne					1				*
Gammarus oceanicus					1		1		*
Gammarus salinus					1		1		*
Gammarus zaddachi					1		1		*
Microdeutopus gryllotalpa	1			1	1				*
Monocorophium insidiosum	1								*
Protomedeia fasciata	1								R
Anthozoa									
Anthozoa						1			ne
Edwardsia danica	1			1					D
Halcampa duodecimcirrata						1			1
Arachnida									
Halacaridae							1		ne
Ascidiacea									
Dendrodoa grossularia	1	1							V
Bivalvia									
Abra alba			1	1					*
Arctica islandica	1	1	1	1		1			3
Astarte borealis	1				1				G
Astarte elliptica	1				1	1			G
Astarte montagui	1								3
Cerastoderma glaucum								1	*
Corbula gibba	1	1	1	1	1	1			*
Kurtiella bidentata	1	1	1	1					*
Limecola balthica				1	1	1	1	1	*
Musculus niger	1								G
Musculus subpictus	1	1							G
Mya arenaria					1		1	1	*
Mytilus edulis	1	1	1	1	1	1	1	1	*
Parvicardium pinnulatum					1				D
Rangia cuneata								1	ne
Bryozoa									
Alcyonidium polyoum							1		D
Callopora lineata	1	1		1					*
Einhornia crustulenta		1	1	1			1	1	*
Electra pilosa	1	1		1	1				*
Escharella immersa	1	1							*
Eucratea loricata		1		1					V
Farrella repens	1			1					D
Flustra foliacea	1	1							*

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Cirripedia									
Amphibalanus improvisus			1				1	1	ne
Balanus crenatus	1		1		1				*
Cumacea									
Diastylis rathkei	1	1	1	1	1		1		*
Decapoda									
Carcinus maenas			1		1				*
Crangon crangon	1			1	1		1	1	*
Palaemon adspersus							1		V
Palaemon elegans					1				*
Rhithropanopeus harrisii								1	ne
Echinodermata									
Asterias rubens	1	1		1	1	1	1		*
Echinocyamus pusillus	1								G
Ophiura albida	1	1							*
Gastropoda									
Ancula gibbosa	1								*
Brachystomia scalaris	1				1				*
Facelina bostoniensis	1	1			1				*
Onchidoris muricata					1				*
Peringia ulvae				1	1	1	1	1	*
Philine aperta	1								*
Pusillina inconspicua				1					*
Retusa truncatula	1			1	1				*
Tritia reticulata	1								G
Hydrozoa									
Dynamena pumila				1					D
Halitholus yoldiaearcticae		1							3
Hartlaubella gelatinosa	1	1			1		1		D
Hydractinia echinata	1								*
Sertularia cupressina		1		1					G
Isopoda									
Jaera albifrons					1		1	1	*
Mysida									
Mysis mixta							1		ne
Neomysis integer					1		1	1	ne
Praunus flexuosus								1	ne
Nemertea									
Cyanophthalma obscura					1				ne
Lineus ruber			1		1	1			ne
Malacobdella grossa	1	1		1					ne
Nemertea	1								ne
Tubulanus polymorphus	1		1	1	1				ne
Oligochaeta									
Nais elinguis							1		*
Tubificinae		1		1	1		1	1	ne
Tubificoides benedii					1		1	1	*
Phoronida									

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Phoronis sp.	1	1							ne
Plathelminthes									
Turbellaria					1			1	ne
Polychaeta									
Alitta succinea	1			1	1			1	D
Ampharete acutifrons						1			*
Ampharete baltica				1	1		1		*
Arenicola marina				1	1				*
Aricidea suecica	1				1				*
Bylgides sarsi	1	1	1	1	1		1		*
Capitella capitata		1			1				*
Dipolydora quadrilobata	1		1	1		1			*
Eteone longa					1				*
Eumida sanguinea				1					*
Fabriciola baltica	1						1		G
Flabelligera affinis	1								D
Harmothoe imbricata	1				1				D
Harmothoe impar					1	1			*
Hediste diversicolor								1	*
Heteromastus filiformis	1		1						*
Lagis koreni	1	1	1	1	1				*
Marenzelleria neglecta								1	ne
Marenzelleria viridis							1	1	ne
Neoamphitrite figulus	1								*
Nephtys caeca	1				1				*
Nephtys hombergii	1	1	1	1		1			*
Nereimyra punctata	1								G
Paradoneis eliasoni			1						*
Paraonis fulgens	1	1							*
Pherusa plumosa	1								D
Pholoe assimilis	1								D
Pholoe baltica	1								*
Phyllodoce mucosa	1				1				*
Polydora ciliata	1								*
Polydora cornuta	1	1	1						*
Pygospio elegans	1			1	1		1	1	*
Scalibregma inflatum	1	1							G
Scoloplos armiger	1			1	1		1		*
Spio goniocephala					1				*
Streblospio shrubsolii								1	V
Terebellides stroemii	1			1					*
Travisia forbesii					1		1		G
Trochochaeta multisetosa				1		1			D
Porifera									
Chalinula limbata		1							D
Haliclona oculata	1	1		1					D
Halisarca dujardinii				1					D
Priapulida									

Taxa	**N3**	**N1**	**M2**	**018**	**K8**	**K4**	**K3**	**160**	**RL**
Halicryptus spinulosus			1		1		1		ne
Priapulus caudatus			1						ne
species number 119	**62**	**31**	**21**	**38**	**50**	**15**	**31**	**23**	
abundance (ind m^{-2})	**9860**	**877**	**505**	**2082**	**3965**	**46**	**4109**	**8723**	
biomass (afdw g m^{-2})	**47.5**	**43.3**	**12.9**	**22.6**	**10.3**	**0.4**	**3.4**	**10.3**	

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CONTENT

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