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WARNEMÜNDE

Biological assessment of the Baltic Sea 2019

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Abstract

In 2019, a total of 150 <u>phytoplankton</u> species were recorded on the 5 annual monitoring cruises reported here, marking high species diversity comparable to previous years. The phytoplankton production cycle was characterized by an early onset of the spring bloom and higher phytoplankton biomass than measured in 2018, particularly in the southern Baltic Sea areas. The 2019 spring bloom was dominated by diatoms particularly in the south. Shares of dinoflagellates and *Mesodinium rubrum* increased towards the Gotland Basin. By May the 2019 the spring bloom had already declined. The summer phytoplankton community consisted mainly of dinoflagellates and diazotrophic cyanobacteria in all investigated sea areas. A bloom of toxin producing *Alexandrium pseudogonyaulax* dominated the community of the central Arkona basin in July/August with highest abundances so far reported from northern European waters. High cyanobacteria biomass shares were mainly detected in the Bornholm and Gotland basins. The phytoplankton growth period extended well into the autumn: a third biomass peak nearly equalling spring bloom biomass levels was found in October in the southern sea areas, made by diatoms of the genera *Rhizosolenia, Proboscia* and *Cerataulina*.

The 2019 phytoplankton <u>sedimentation</u> pattern reflected the growth dynamics of phytoplankton relatively well. A diatom dominated sedimentation peak in spring was followed by high shares of cyanobacteria in late summer and autumn. Data on elemental ratios and fluxes mirrored the main phytoplankton production phases and bloom events in Arkona basin: the spring bloom, a summer dinoflagellate bloom and subsequent cyanobacterial N fixation as well as the autumn diatom bloom.

A total of 50 species was identified in the <u>zooplankton</u> in 2019 and mark a medium diversity. The zooplankton was characterized by an early seasonal development and was mainly dominated by the Copepoda and the Copelata. Rotifera and Cladocera were only of minor importance 2019. They can be very abundant during spring and summer, respectively, but were restricted to the occurrence of moderate concentrations of the cladoceran *Bosmina* spp. to the eastern Arkona Basin. In spring high concentrations of the copepod *Acartia* were found in all areas. In the Kiel Bight and Bay of Mecklenburg *Acartia bifilosa* was dominating, while in the Arkona Basin, *A. longiremis* was the major species. The spring and summer concentrations of the zooplankton remained below the long term average, particularly for Rotifera and Cladocera which had a maximum stock size of 2% and 40% of the long-term average, respectively. In general, the stock size of zooplankton has remained on a very low level since 2010 compared to the preceding decade.

The 129 species found in the <u>macrozoobenthos</u> in 2019 mark a medium diversity. The species number found at the 8 monitoring stations ranged between 20 and 88. The oxygen supply in bottom waters in the current year was always higher than 2 ml/l at all stations, basically no oxygen depletion was observed. After a dramatically decrease of diversity and abundance in the Fehmarnbelt area in 2018, a complete recovering was observed in 2019. Also at the other stations the diversity was increased comparing to the last year. Depending on the region, the abundances ranged from 717 to 6.650 ind./m², and the biomass (ash free dry weight) from 0.6 g/m² to

56.7 g/m². Fourteen species of the German Red List (Categories 1, 2, 3 and G) were observed at the 8 monitoring stations. With six, the number of invasive species in 2019 was low. *Rangia cuneata,* a bivalve species originally from North America and observed at the monitoring station in the Pomeranian Bay in 2018 for the first time, was recorded again.

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. 2020). The establishment of the IOW in 1992 assured the continuance of re-unified Germany's contribution to the HELCOM Monitoring Programme. International monitoring results are collected, discussed and published by HELCOM in Periodic Assessments (HELCOM 1987, 1990, 1996, 2002) and Holistic Assessments (HELCOM, 2010 and HELCOM, 2018a). Moreover, specialized Thematic Assessments are published, for example on the influence of climatic change (HELCOM 2013a), endangered species (HELCOM 2013b) and eutrophication (HELCOM 2014, HELCOM 2018b). 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 and the federal ministries coordinate their measurements in the 'Bund/Länder-Arbeitsgemeinschaft Nord- und Ostsee' (BLANO). The collected data are transferred annually to ICES (International Council for the Exploration of the Sea, see www.ices.dk/data/Pages/default.aspx), via the national database MUDAB (https://geoportal.bafg.de/MUDABAnwendung/) One of the main tasks is the national coordination of the contributions to the EU's Marine Strategy Framework Directive (MSFD) (see www.meeresschutz.info). 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' (GES) 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 have been and still 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 HELCOM (2013c, 2020):

- Zooplankton mean size and total stock (MSTS)
- State of the soft-bottom macrofauna community (e.g. NYGÅRD et al. subm.)
- Population structure of long-lived macrozoobenthic species (Has been taken out of HELCOM list as almost no member state is able to provide data for development. No bivalves are measured in monitoring.)
- Cumulative impact on benthic habitats
- Extent, distribution and condition of benthic biotopes

- Trends in arrival of new non-indigenous species
- Chlorophyll-*a*
- Diatom/Dinoflagellate Index
- Seasonal succession of dominating phytoplankton groups
- Cyanobacterial Bloom Index (CyaBI)

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 to 15.05.2016; see WASMUND & POWILLEIT 2016) and the indicator was made applicable for the Belt Sea and the Baltic Proper (WASMUND et al. 2017a). One product is the Second Holistic Assessment of HELCOM (HELCOM 2018a). 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 2019 hydrographic-hydrochemical assessment of the Baltic Sea that has already been published (NAUMANN et al. 2020).

Dr. ANKE KREMP wrote the chapters on phytoplankton, chlorophyll and sedimentation; Dr. JÖRG DUTZ wrote the chapter on zooplankton; and Dr. MICHAEL L. ZETTLER wrote the chapter on macrozoobenthos.

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), 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. The methods to be applied are set out in the HELCOM manual (HELCOM 2017a). 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.
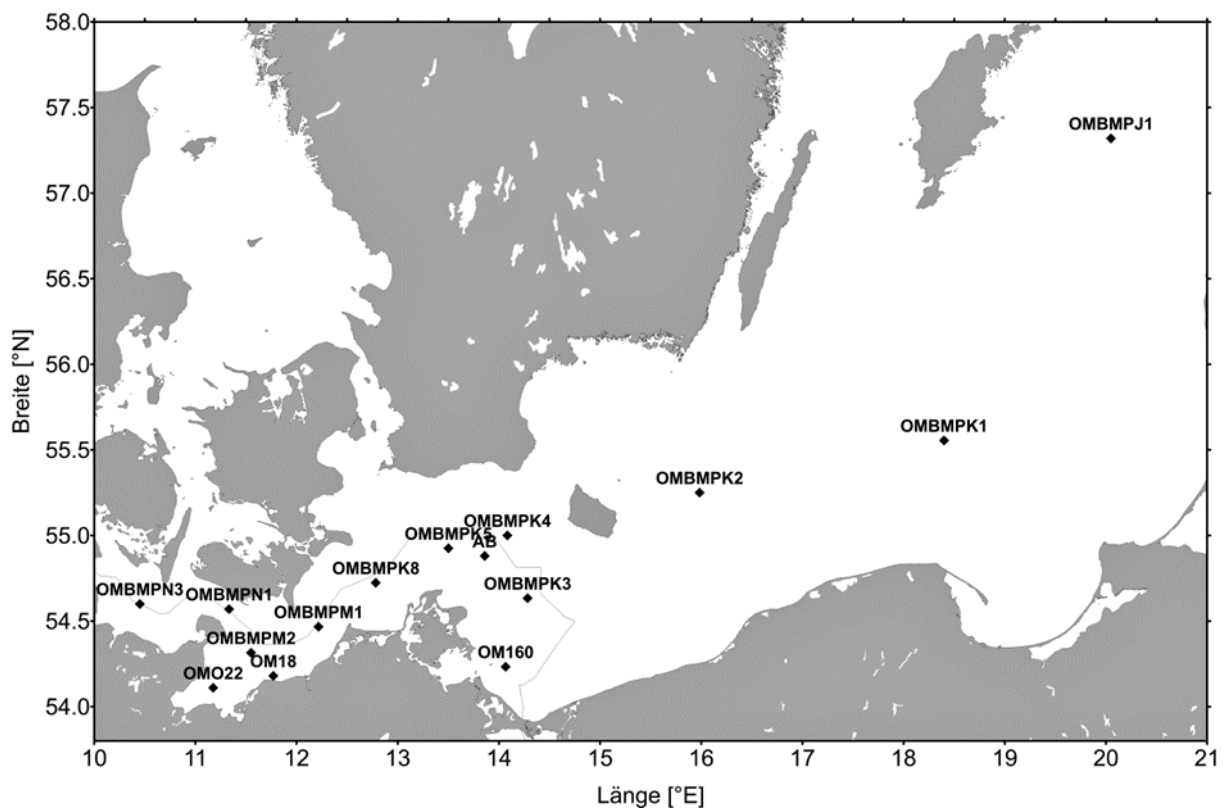
Fig. 1: Station grid for biological sampling in the Baltic Sea with depiction of the border of the exclusive economic zone of Germany. Note that Station OMO22 (Lübeck Bay) has been taken out of the monitoring program in 2019.

Within the regular monitoring program, plankton samples should, if possible, be collected on 5 annual cruises along both an outbound (from south-west to north-east) and an inbound (from north-east to south-west) station profile (below referred to as S[outh]/N[orth]- and N/S-transects resp.).

Five cruises represent different phases of the growth season and were, in 2019, conducted in February (30.01.-08.02., referred to as TF0219), March (19.03.-27.03., TF0319), May (08.05.-16.05., TF0519), August (24.707.-04.08., TF0819) and November (05.11.-14.11., TF1019). These

yield a maximum of 10 samples per station per year. Samples at stations OMBMPN3 (Kiel 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 near station OMBMPK5 (see station AB in Fig. 1).

Zooplankton samples were regularly taken at 5 stations in the German exclusive economic zone during outward and return journeys on all cruises as scheduled (Tab. 1). However, bad weather conditions prevented sampling at stations OMBMPN3 and on the OMBMPK5 (return journey) in March 2019.

Samples of macrozoobenthos are collected at 8 stations once a year in October (see Table 3).

Table 1: Sampling statistics (number of sampling events) for different parameters specified for regular monitoring stations in 2019.

Station number	IOW-station number	Sea area	Chloro-phyll	Phyto-plank-ton	Zoo-plank-ton	Zoo-benthos
Belt Sea						
OMBMPN3	TF0360	Kiel Bay	5	5	4	1
OMBMPN1	TF0010	Fehmarnbelt	-	-	-	1
OMBMPM2	TF0012	Bay of Mecklenburg	10	10	10	1
OM18	TF0018	Bay of Mecklenburg, south	-	-	-	1
OMBMPM1	TF0046	Bay of Mecklenburg, east	10	10	10	-
Arkona Basin						
OMBMPK8	TF0030	Arkona Basin, west	10	10	-	1
OMBMPK5	TF0113	Arkona Basin, central	10	10	9	-
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   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 (2017c). It is thus possible to omit homogenisation and centrifugation (WASMUND et al. 2006). Several methods are available for determining concentrations of chlorophyll *a*. They are reviewed by WASMUND et al. (2011). 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 (2017c). Between 2008 and 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). 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) 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).

2.3   Phytoplankton

Sampling and Analysis procedures follow HELCOM (2017b). 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 2017b). 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 February 2019, the species and biovolume list PEG_BVOL2019 was used. The phytoplankton samples of the March, May, July/August and November cruises were analysed with the list PEG_BVOL2020, which was confirmed by PEG during the meeting in April 2020. The latest biovolume file can be downloaded from http://ices.dk/data/Documents/ENV/PEG_BVOL.zip.

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 2019 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 preprogramed intervals.

2.5 Mesozooplankton

Sampling of zooplankton was conducted according to the recommendations by HELCOM (2018c). 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. In case a halocline or a thermocline formed through saline inflows or the seasonal warming of the surface during spring - autumn stratified hauls were taken in the respective water layers. Nets were fitted with a flow-through current meter to determine the volume of filtered water (TSK, Tsurumi-Seiko Co., Yokohama, Japan). Net angles greater than 30° were avoided during sampling. The samples were preserved in 4 % aqueous formaldehyde solution until processing in the laboratory. In total, 53 zooplankton samples were collected on 38 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 2019.

Station	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	-	19 - 0	14 - 0	14 - 0
OMBMPM2	23 - 0	19 - 0	22 - 0	20 - 10 - 0	21 - 0
	21 - 0	20 - 0	21 - 0	20 - 6 - 0	21 - 0
OMBMPM1	23 - 0	25 - 0	27 - 0	25 - 14 - 0	25 - 0
	25 - 0	25 - 0	21 - 0	25 - 0	25 - 0
OMBMPK5	44 - 37 - 0	45 - 30 - 0	43 - 17 - 0	41 - 15 - 0	44 - 30 - 0
	44 - 29 - 0	-	43 - 20 - 0	43 - 15 - 0	44 - 0
OMBMPK4	45 - 0	45 - 30 - 0	44 - 26 - 0	44 - 30 - 0	45 - 21 - 0

The sample analysis followed the established HELCOM guidelines that were revised during 2017 (HELCOM 2018c). 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}) was 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 a species list provided by the ZEN HELCOM working group. 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 October 2019, 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 2017a). 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).

Table 3: Station list of macrozoobenthic investigations in October 2019.

	date	depth	north	east	sea area
OMBMPN3	12.10.2019	18.5	54° 36.00	10° 27.00	Kiel Bay
OMBMPN1	12.10.2019	28.5	54° 33.20	11° 20.00	Fehmarnbelt
OMBMPM2	11.10.2019	25.0	54° 18.90	11° 33.00	Mecklenburg Bay
OM18	11.10.2019	20.5	54° 11.00	11° 46.00	Mecklenburg Bay, south
OMBMPK8	13.10.2019	22.8	54° 44.00	12° 47.40	Darss Sill
OMBMPK4	13.10.2019	48.3	55° 00.00	14° 05.00	Arkona Basin
OMBMPK3	14.10.2019	31.4	54° 38.00	14° 17.00	Pomeranian Bay, north
OM160	14.10.2019	14.9	54° 14.50	14° 04.00	Pomeranian Bay, central

To ensure comparability of weight determinations, HELCOM guidelines were followed (HELCOM 2017a), 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.

2.7   Quality assurance

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 QUASIMEME AQ-11 (chlorophyll in seawater). The Rounds 2019.1 and 2019.2 were passed with very good results.

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-atwork/projects/phytoplankton). Expert identification of phytoplankton species depends on a laboratory technician's level of knowledge. PEG therefore runs annual training courses and undertakes regular ring test. The PEG meeting of 2019 took place in Daugavpils (Latvia) from April 8-12 April 2019 and was attended by representatives of all Baltic Sea States except Russia. Specific training in 2019 was provided on the taxonomy of diatoms by Dr. Diana Sarno from Stazione Zoologica Napoli (Italy). Ring tests were not available nationally or internationally in 2019. Like every year, the biovolume list of species and size classes was updated during the HELCOM PEG meeting in April 2019 to assure up-to date taxonomy and biovolume information. Samples taken in January/February 2019 were counted on the basis of the previous ICES and HELCOM biovolume file PEG_BIOVOL2019, while the new list was adopted for the counting of all cruise samples collected in 2019 thereafter, i.e. following biovolume file PEG_BIOVOL2020.

Mesozooplankton

The QA followed the protocol for internal quality control concerning documentation and analyses provided by HELCOM (2018c). The duplicate analysis of every 20th zooplankton sample was done as an intra-laboratory routine to check the reliability of the zooplankton analysis. The validity of counting results and assessment of their accuracy was similarly tested. Deviations were well below the threshold value for critical errors. Data stored in databases was quality-checked and validated.

Macrozoobenthos

The IOW macrozoobenthos working group has participated in all QA measures to date. The results of the latest ring test from spring 2018, presented by the UBA in March 2019, confirmed the high quality of the macrozoobenthos analyses. Internal double checks of 4 samples of the 2019 monitoring season confirmed high accuracy.

3.   Results and discussion

3.1   Phytoplankton and Chl *a*

3.1.1 Seasonal succession of phytoplankton production and species composition

The current monitoring program, consisting of 5 annual cruises, and 9 stations, provides snapshots of the seasonal succession of phytoplankton in the southern basins of the Baltic Sea – hence, conclusions on timing of species peaks and bloom events or absolute annual parameter sizes are limited. Nevertheless, the same timing of cruises every year permits assessment of measured parameters in a longer term context and comparison to preceding years. Phytoplankton analyses focus on the 0-10m depth interval as phytoplankton mainly occurs in the mixed surface layer. Therefore, data of the deep phytoplankton samples (usually from 20 m depth) are not shown in the figures. In the following we describe the characteristic features of phytoplankton production (Chl *a* and total phytoplankton biomass) and community composition (biomass distribution across phylogenetic groups, dominant species/taxa) of the different bloom seasons of 2019, as represented by the five monitoring cruises. The spring bloom 2019 is characterized by 3 consecutive cruises in February, March and May (TF0219, TF0319 and TF0519), while the summer bloom is represented by the cruise TF0819. TF1019 provided the data to describe phytoplankton features of the autumn bloom. In the following, the three major periods of production are characterized separately.

3.1.1.1 Spring bloom

In the Belt Sea, at the southernmost station (OMBMP) N3 in Kiel Bay, the spring bloom was already fully developed in early **February** as indicated by maximum spring Chl *a* values of $> 5\mu g\ L^1$ (Fig. 2). This was different from the previous year, when the spring bloom in Kiel Bay was found to be fully developed only during the March cruise approximately 6 weeks later. The rapid decline of Chl *a* values towards the Bay of Mecklenburg and Arkona Basin nevertheless implies an isolated start of the bloom in Kiel Bay as Chl *a* was approximately 4 -fold lower at the remaining Belt Sea stations at that time and further declined towards the Bornholm and Gotland basins, reflecting the typical northward delay of the seasonal succession in the Baltic Sea. Nevertheless, approximately 8 to 10 days later when sampling southwards, Chl *a* had increased significantly at the Belt Sea Stations, indicating that the spring bloom was rapidly progressing here in February.

Spatial biomass distribution along the sampling transect (Fig. 3) generally reflected Chl *a* distribution. Total phytoplankton biomass values of >2000 µg L-1 were measured at station N3 in Kiel Bay. The community here was largely dominated by two Diatoms, *Cerataulina bergonii* and *Rhizosolenia setigera* (Fig. 4a), each contributing nearly 40% to the total biomass. Biomass at the other Belt Sea stations were dominated by the cryptophyte *Teleaulax* sp. and the ciliate *Mesodinium rubrum* (Fig. 4b), which typically co- occur as they represent a predator-prey system where *Mesodinium rubrum* utilizes (and depends on) the chloroplasts of *Teleaulax* as kleptoplasts for photosynthesis (HANSEN et al. 2013). In addition to *M. rubrum* and *Teleaulax sp.*, the diatom *Actinocyclus* sp. and gymnodinoid dinoflagelates constituted the major part of the

low biomass communities at the northern stations of the transect at this time. As indicated by increased Chl *a* levels on the way south, phytoplankton production increased rapidly at the Belt Sea stations: by that time the diatom spring bloom had apparently started in Mecklenburg Bay.

Fig. 2: Chl a concentrations (µg L⁻¹) at sampling stations along the S-N (dark green) and N-S (light green) legs of the February cruise TF0219.

Fig. 3: Total phytoplankton biomass (µg L⁻¹) and contribution of major taxa measured from samples taken during northward and southward transects of TF0219. Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Mesod = Mesodinium rubrum , Prym = Prymnesiophytes.
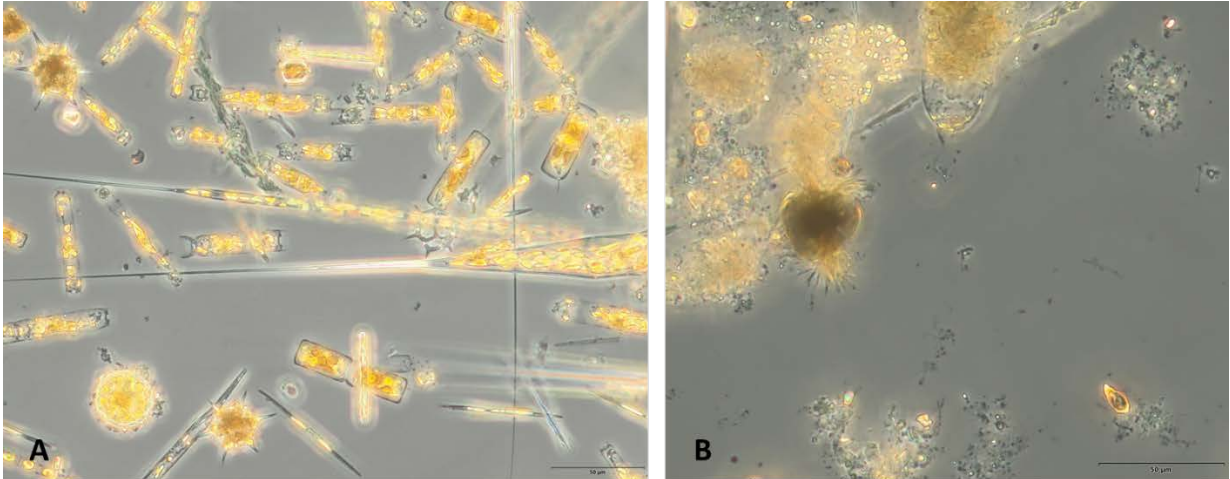
Fig. 4: Micrographs of net samples representing typical communities encountered on TF0219 at A) Station OMBMPN3 (Kiel Bay) and B) OMBMPM1, Bay of Mecklenburg from station (Basin). A) Diatom community dominated by Rhizosolenia *sp. and* Cerataulina pelagica*, B) sample containing* Mesodinium rubrum *(left) and it's prey* Teleaulax *(at the bottom right). Scale bars = 50µm.*

In **March,** high Chl *a* concentrations, ranging between 4.6 and 6.2 µg L-1, were measured at all Belt Sea Stations N3, M2, and M1 (Fig 6). Here the spring bloom that had started in January/early February was fully developed or even beginning to decline as in Kiel Bay (N3). Chl *a* concentrations had increased significantly also in Arkona Basin (Stns. K8, K5 and K4), as well as Bornholm and Gotland Basins (Stns. K2, K1 and J2) compared to February. Here the bloom was still developing, as indicated by further increased Chl *a* concentrations at station K2 when going back south. Chl *a* levels of the March cruise in the Belt Sea and in Arkona Basin were somewhat lower than in 2018 (WASMUND et al. 2019a) which might be due to the shifted timing of the bloom and a respectively earlier commencement in the western part: the peak of the spring bloom likely had already passed here by the time when March measurements were taken.
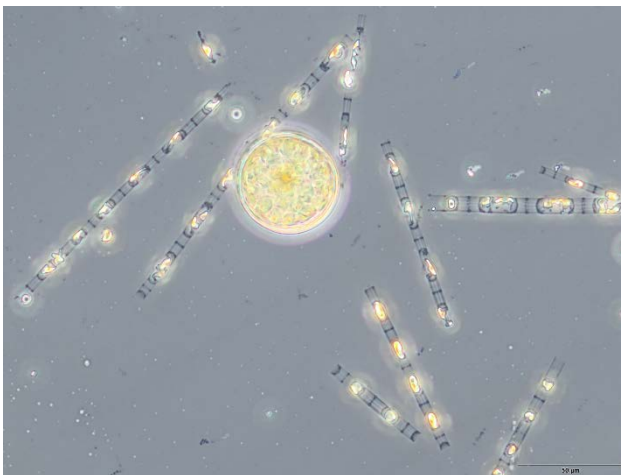
Fig 5: Light micrograph of a typical assemblage of cold-water diatoms Thalassiosira baltica *and* Skeletonema marinoi *in Bornholm basin at station OMBMPK2 in March 2019. Scale bar = 50µm.*
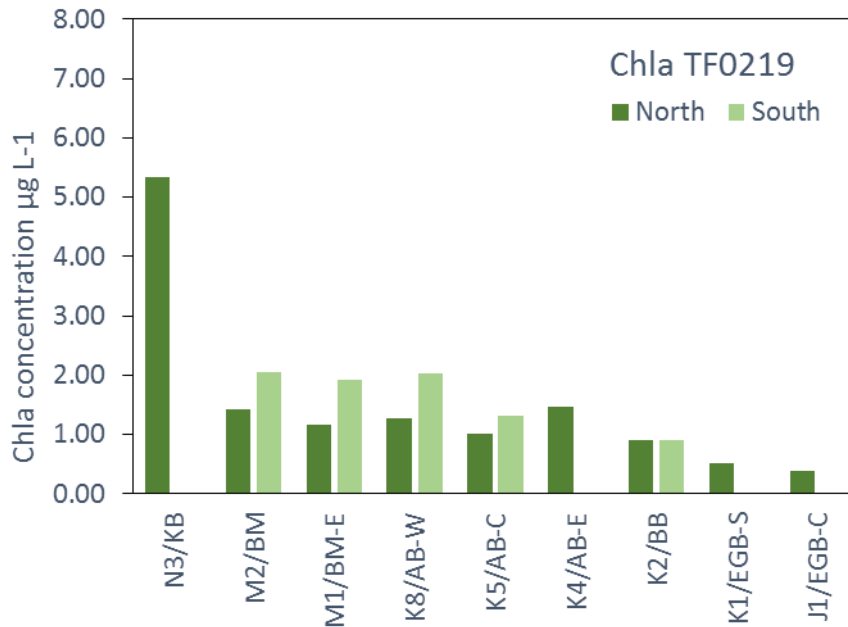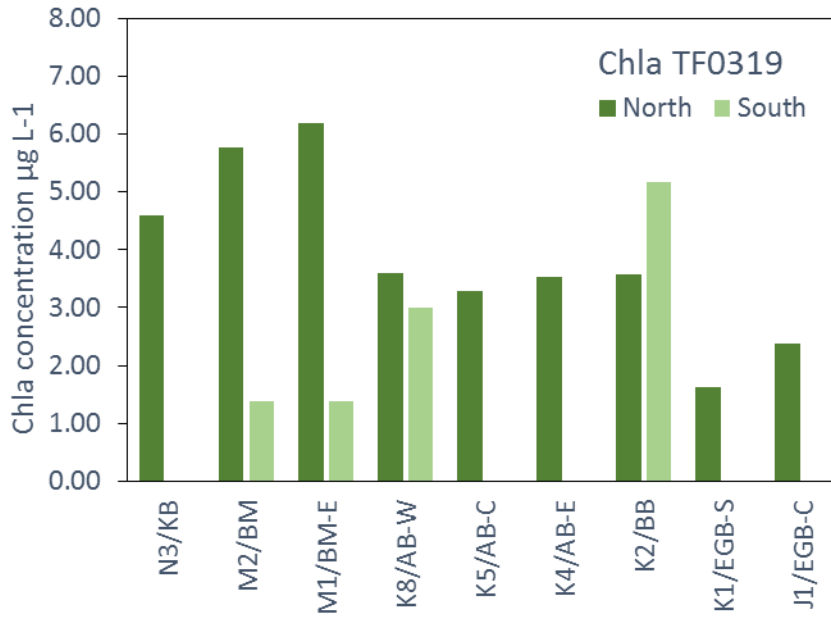
Fig. 6: Chl a concentrations (µg L⁻¹) at sampling stations along the S-N (dark green) and N-S (light green) transects of the March cruise TF0219.
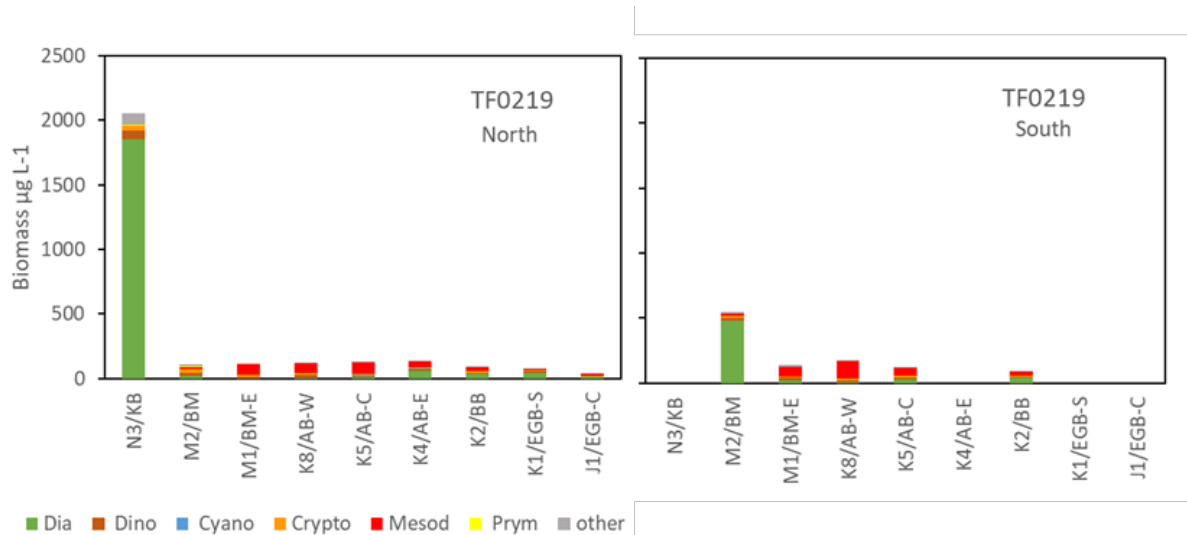

Fig. 7: Total phytoplankton biomass (µg L-1) and contribution of major taxa measured from samples taken during northward and southward transects of TF0319.

The March biomass distribution (Fig. 7) along the S-N transect reflected the one of Chl *a*, with highest biomass values determined for the Belt Sea stations at the beginning of the cruise on the northward transect. Generally, biomass had increased 2-fold here since February. Like in February, biomass was largely made by diatoms, with *Rhizosolenia setigera* and *R. delicatula* being the dominant species here, accompanied by *Proboscia alata* and *Cerataulina bergonii*. Compared to February, the contribution of diatoms had increased also in Arkona and Bornholm Basins. While in the western Arkona Basin *R. setigera* was the dominant diatom, typical brackish cold-water diatoms became more common towards the east/north: *Thalassiosira sp.*, specifically

T. baltica, and *Skeletonema marinoi* (Fig. 5). Samples taken here at the beginning of the March-cruise along the northward stretch still contained high amounts of *Mesodinium rubrum*. However, a week later the contribution of the ciliate to the total biomass had declined in favour of diatoms. At that time, i.e. in late March, biomass had started to increase significantly in Arkona and Bornholm basin, reflecting the northwards progression of the spring bloom.

By **May,** Chl *a* concentrations had declined at all stations, ranging between 0.9 and 1.8 μg L-1 (Fig. 8). Values were in the same range in samples collected on the northward and on the southward transect.
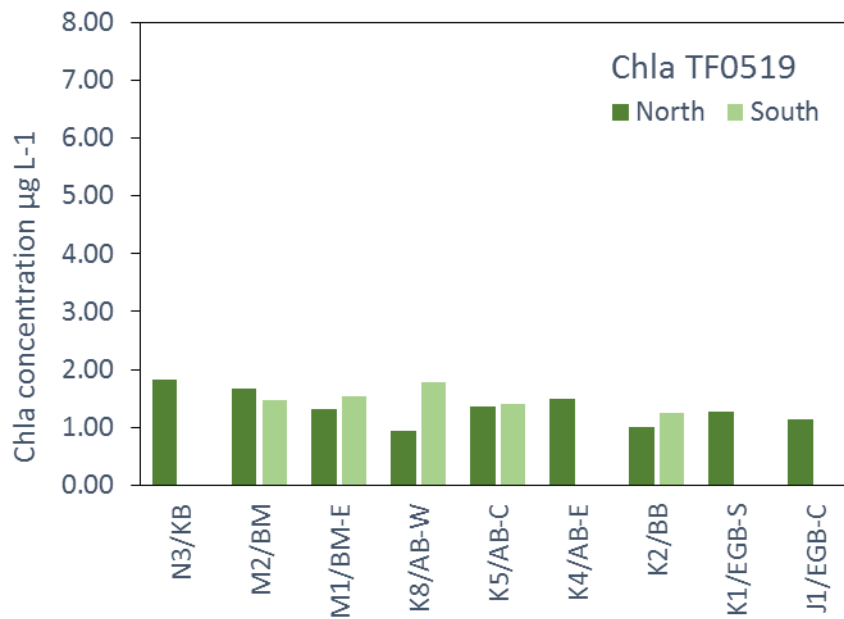
Fig. 8: Chl a concentrations (μg L^{-1}) at sampling stations along the S-N (dark green) and N-S (light green) transects of the May cruise TF0519.

The peak of the spring bloom had passed by this time. Accordingly, also total phytoplankton biomasses (Fig. 9) were much lower in May than in March. Still, highest biomasses occurred in the Belt Sea at stations N3, M2 and M1. At N3, in Kiel Bay, the community consisted almost entirely (>90%) of *Proboscia alata*, followed by the dinoflagellates of the heterotroph genus *Protoperidinium* (hetrotroph), the dinoflagellate *Ceratium tripos* and unidentified *Prymnesiales*. Further north, from the Eastern Arkona Basin to Gotland Basin, a dinoflagellate community together with *Mesodinium rubrum* contributed the major part of the phytoplankton biomass in May. Among the dinoflagellates, unidentified Gymnodiniales were abundant, likely represented by *Gymnodinium corollarium,* a recently described bloom forming cold-water dinoflagellate from the central and northern Baltic (SUNDSTRÖM et al. 2009) that had long been unrecognized. The species can only be reliably identified by specific staining or DNA based methods which are so far not implemented in the HELCOM phytoplankton monitoring program. A recent study shows that the species can dominate the central Baltic dinoflagellate community during spring (LIPSEVERS et al. 2017).
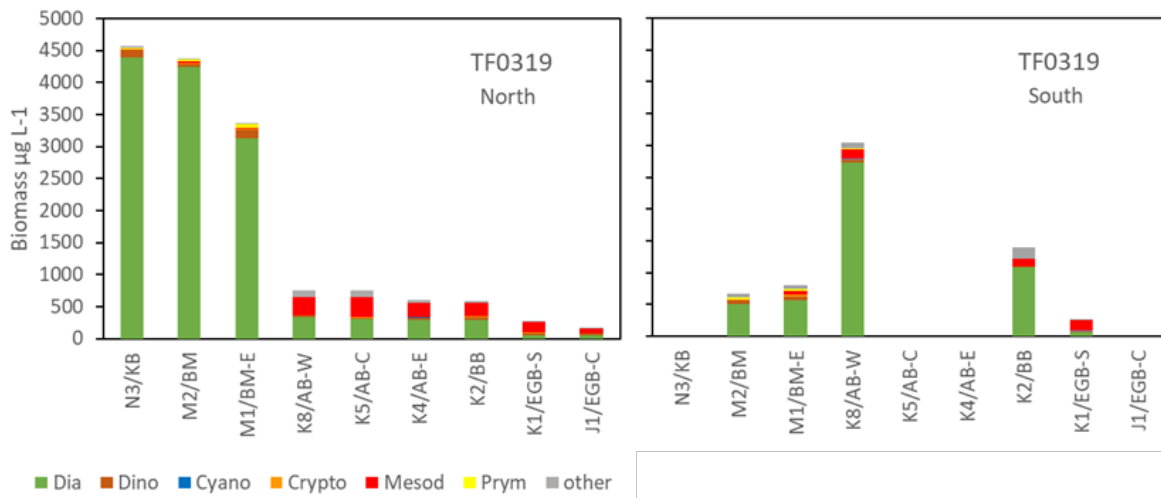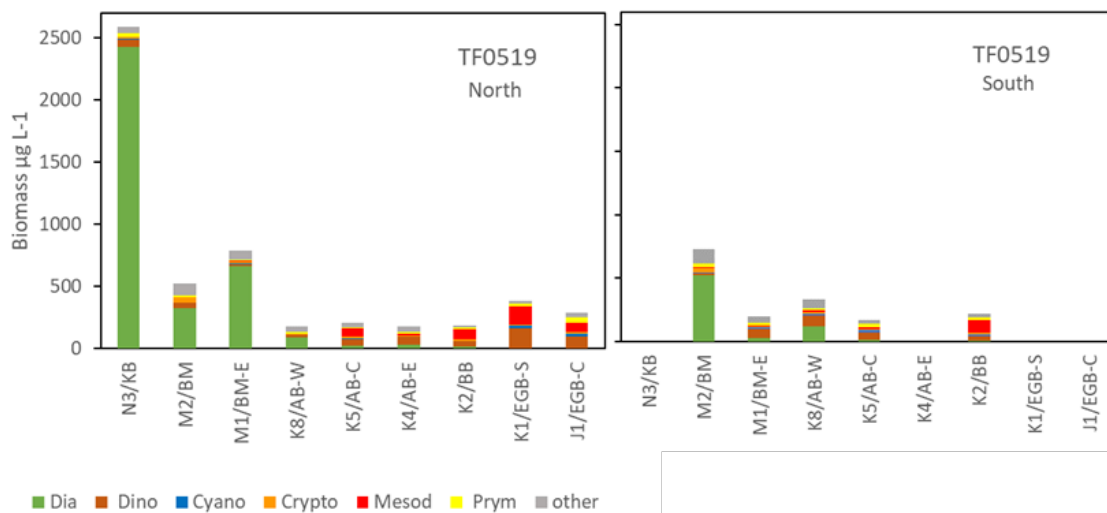
Fig. 9: Total phytoplankton biomass (µg L-1) and contribution of major taxa measured from samples taken during northward and southward transects of TF0519 in May 2019.
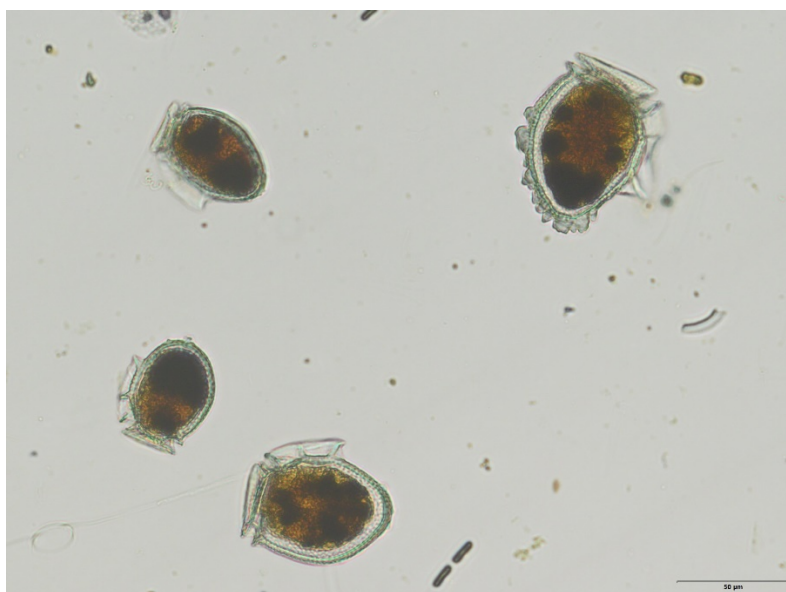
Fig. 10: Light micrograph of Dinophysis norvegica and D. acuta occurring at high cell abundance at Station OMBMPK1 in Eastern Gotland Basin during May 2019.

Furthermore, Peridiniella catenata, a chain-forming cold-water dinoflagellate and small Heterocapsa rotundata contributed significantly to the biomass produced by the spring dinoflagellate community. At the northernmost stations of the transect, in the Gotland basin, Dinophysis acuta and D. norvegica (Fig. 10) potentially toxic mixotrophic dinoflagellates, were commonly identified: Dinophysis spp. benefit from the presence of Mesodinium rubrum, which is the vector of kleptoplasts of cryptophyte origin it uses for photosynthesis (HANSEN et al. 2016). Interestingly, M. rubrum was still prominently present in the Gotland Basin during May.

Regional differences in spring bloom species composition and relative contribution to the phytoplankton biomass were detected also for the spring bloom of 2019. Table 4 shows the 10 most important phytoplankton species in terms of biomass contribution summarized for all three cruises and presented for the 4 major sea areas. The Belt Sea, had a typical marine neritic phytoplankton community consisting of large centric, diatoms such as *Rhizosolenia* spp., *Proboscia alata* and *Cerataulina bergonii* dominated the community during the entire spring season (Table 4).

Table 4: Regional differences of species composition in spring 2019. Number of stations per sea area see Table 1.

Belt Sea		Arkona Basin	
Species	% Biomass	Species	% Biomass
Rhizosolenia setigera	51.64	*Mesodinium rubrum*	35.89
Proboscia alata	21.46	*Thalassiosira sp.*	8.73
Rhizosolenia delicatula	9.68	*Thalassiosira baltica*	6.82
Cerataulina bergonii	6.68	*Skeletonema marinoi*	6.35
Coscinodiscus concinnus	0.86	*Rhizosolenia setigera*	6.26
Rhizosolenia fragilissima	0.84	*Actinocyclus*	5.80
Prymnesiales	0.81	*Eutreptiella*	4.44
Chaetoceros danicus	0.67	*Gymnodiniales*	3.81
Gymnodiniales	0.66	*Proboscia alata*	2.82
Rhizosolenia flaccida	0.55	*Heterocapsa rotundata*	2.73
Total number of taxa	**87**	**Total number of taxa**	**67**
Bornholm Basin		**Eastern Gotland Basin**	
Taxon	%Biomass	Taxon	% Biomass
Mesodinium rubrum	37.09	*Mesodinium rubrum*	33.38
Skeletonema marinoi	20.17	*Peridiniella catenata*	8.19
Thalassiosira	8.80	*Actinocyclus*	7.20
Actinocyclus	5.67	*Gymnodiniales*	7.17
Gymnodiniales	4.36	*Prymnesiales*	6.70
Thalassiosira baltica	3.95	*Heterocapsa rotundata*	4.53
Peridiniella danica	3.15	*Dinophysis acuminata*	4.32
Teleaulax	2.52	*Dinophysis norvegica*	3.73
Ebria tripartita	1.81	*Teleaulax*	3.40
Unicell spp.	1.65	*Aphanizomenon*	2.94
Total number of taxa	**48**	**Total number of taxa**	**51**

In the Arkona basin the marine community visibly changed towards more brackish species, nevertheless, marine *Rhizosolenia* spp were still abundant besides brackish Baltic cold water species. These formed the typical Baltic low salinity spring communities in Bornholm and Gotland basins – being dominated by the mixotrophic ciliate *Mesodinium rubrum*, its cryptophyte prey *Teleaulax* and typical Baltic, low salinity adapted diatoms such as *Thalassiosira*

baltica, Skeletonema marinoi, *Peridiniella catenata* and *P. danica* together with gymnodinoid dinoflagellates. The number of taxa found in the communities declined along the salinity gradient from 87 recorded in the Belt Sea to ca. 50 in Bornholm and Gotland Basins, reflecting the change from the species rich marine to the less diverse locally adapted brackish Baltic phytoplankton community.

According to the available data from the 3 cruises in February, March and May, **the spring bloom of 2019** progressed in the typical manner – starting in the southern parts of the transect and reaching the northern basins with a delay of several weeks to months. In the south, the 2019 phytoplankton spring bloom started several weeks earlier than in 2018 and reached approx. 2.5 x higher than 2018 maximum phytoplankton biomasses here already in March. Spring biomass concentrations were highest in March also in Bornholm Basin, reaching values of > 1000 µg L-1. This is different from 2018, when biomass maxima here occurred in May and reached much higher biomass concentrations than in 2019. Our interpretation is that the typical biomass peak in the North occurred earlier in 2019 than in 2018 and was not captured by the 2019 monitoring cruises: this explanation is supported by nutrient data (NAUMANN et al. 2020), revealing that inorganic nitrogen had declined to near zero here by early to mid April 2019 in the northern Basins. Accordingly, the biomass composition differed quite significantly among the two years. In 2019, diatoms where the dominant group of most bloom-like situations compared to 2018, when the ciliate *Mesodinium rubrum* and the dinoflagellate *Peridiniella catenata* were dominant and at the same time produced high biomasses. The latter made only 8% of the Gotland basin biomass peak in 2019, compared to 2018, when its biomass share was approx. 80%.

The somewhat earlier than usual timing of the spring bloom in the western parts of the Baltic may reflect a general trend of changing phenology towards an extension of the phytoplankton growth period detected by a recent time series analysis from the coastal southern Baltic. The study by WASMUND et al. (2019b) reported a recent shift to an earlier beginning and later end of the growth season and discussed it in relation to a trend of earlier warming of the surface waters.

3.1.1.2 Summer bloom
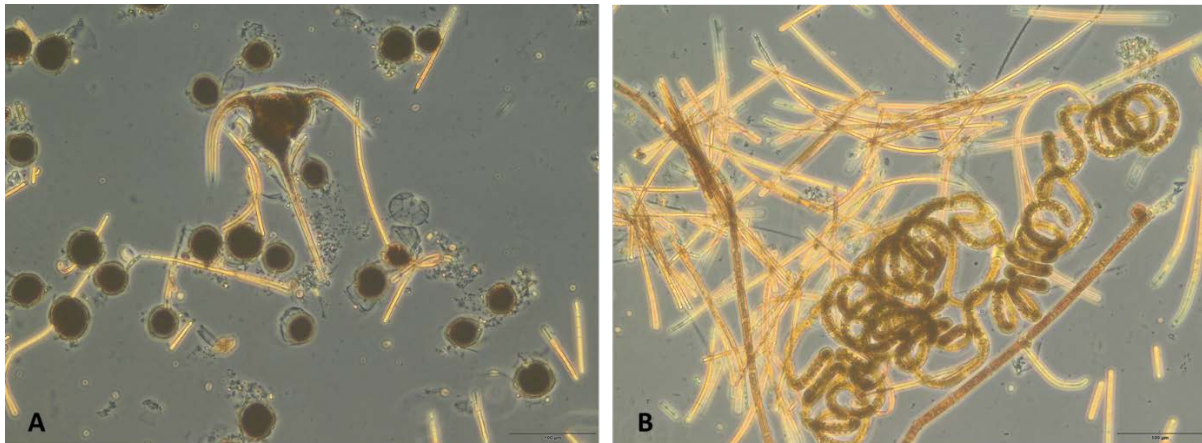
Fig. 11: Light micrographs of summer phytoplankton, observed in samples from TF0819 at Stations OMBMPK5 (A) and OMBMPJ1 (B): A) Light micrographs of the bloom of Alexandrium pseudogonyaulax *in Arkona Basin, B) of* Aphanizomenon flos-aquae *and* Nodularia spumigena *in Eastern Gotland Basin.*

In July/August 2019, at the time of the TF0819 monitoring cruise Chl *a* concentrations (Fig. 12) were relatively low (1.0 to 2.8) in the south on both, the northward and the southward transects. Low Chl *a* despite significant biomass in summer in this area has been explained by the absence of Chl *a*- rich taxa from the summer community (WASMUND et al. 2019a). From the central Arkona basin area up to the central Gotland Basin (with the exception of station OMBMPK2 sampled in Bornhom Basin) Chl *a* values ranged between 3 and 4.6 µg L-1, laying in the same range as the previous year and representing high cyanobacteria bloom biomasses The spatial Chl *a* pattern was roughly reflected by total biomasses measured on the two transects of the summer cruise. Maximum biomass of 1800 µg L-1 occurred at station OMBMPK5 in the Central Arkona Basin. At most stations total phytoplankton biomass concentrations were in the same ranges as in the previous summer, i.e. between roughly 200 and 1000µg L-1. However, diatom contributions remained lower in 2019 than in 2018, possibly as a result of low N:P ratios in the water at that time (NAUMANN et al. 2020), favouring cyanobacteria and dinoflagellates over diatoms. Diatoms, specifically *Proboscia alata*, were only abundant at the southernmost station in the Belt Sea, more or less disappearing from the community north of Mecklenburg Bay Station OMBMPM1.
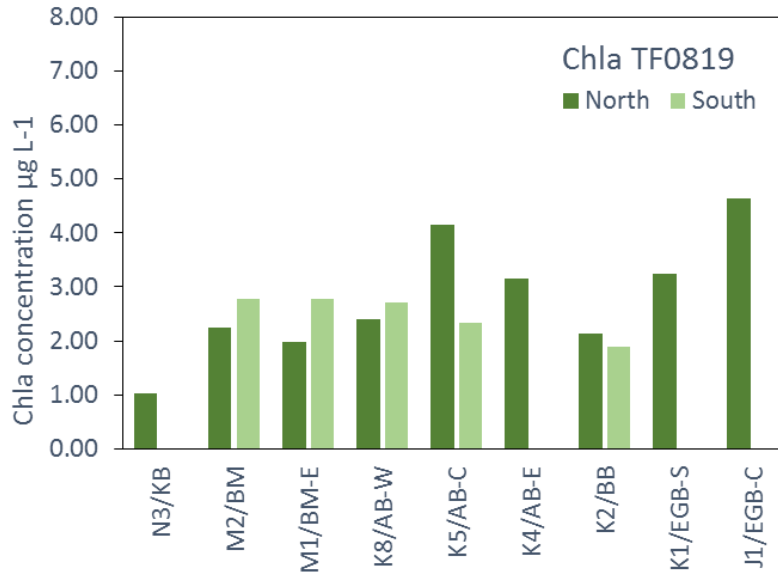
Fig. 12: Chl a concentrations (µg L⁻¹) at sampling stations along the S-N (dark green) and N-S (light green) transects of the May cruise TF0519

At most stations the bulk of the biomass consisted of a more or less diverse dinoflagellate community and cyanobacteria (Fig. 13). Notably, the dinoflagellate fraction at some Belt Sea and Arkona Basin stations was, to a large part made by the toxic dinoflagellate *Alexandrium pseudogonyaulax* – this species apparently formed a bloom at station OMBMPK5 contributing › 50% of the total biomass measured here (Table 5). Other common dinoflagellates were *Ceratium tripos*, Gymnodiniales, *Protoperidinium* sp., hetrotrophic *Polykrikos schwartzii* as well as potentially toxic and invasive, but established in the Baltic Sea, *Prorocentrum cordatum*. The cyanobacteria fraction usually consisted of *Nodularia spumigena* and *Aphanizomenon flos-aquae* (Fig. 11), species known for their potential to produce potent hepato- and neurotoxins.

Figure 13: Total phytoplankton biomass (µg L⁻¹) and contribution of major taxa measured from samples taken during northward and southward transects of TF0819 in July/August 2019.

Particularly at the Gotland Basin stations these species dominated the phytoplankton community as typical for this area in summer (Table 5). Generally, cyanobacterial summer blooms are a characteristic feature of the seasonal phytoplankton cycle in the Baltic Sea and are expected to build up high biomasses. Under the conditions of climate change their biomass has increased and the rise is expected to continue (OLOFSSON et al. 2020). In 2019, their absolute biomass and biomass contribution in the central Baltic was comparable to previous year. Surface scums occurred to some extent and were promoted by higher than usual summer surface temperatures (NAUMANN et al 2020) coinciding with phases of limited vertical water column mixing. These conditions select for species that can actively regulate their position in the water, such as motile dinoflagellates and cyanobacteria possessing gas vacuoles.

Table 5: Regional differences of species composition during summer 2019. Number of stations per sea area see Table 1.

Belt Sea		Arkona Basin	
Species	% Biomass	Species	% Biomass
Proboscia alata	20.30	*Alexandrium pseudogonyaulax*	43.86
Ceratium tripos	15.66	*Aphanizomenon*	17.25
Aphanizomenon	15.11	*Gymnodiniales*	5.82
Alexandrium pseudogonyaulax	11.58	*Prorocentrum cordatum*	4.11
Gymnodiniales	4.90	*Teleaulax*	2.69
Polykrikos schwartzii	2.99	*Ceratium tripos*	2.66
Prorocentrum cordatum	2.31	*Flagellates*	2.61
Plagioselmis prolonga	1.74	*Pyramimonas*	2.52
Protoperidinium pellucidum cf.	1.67	Unicell spp.	2.48
Prorocentrum micans	1.52	*Plagioselmis prolonga*	2.01
Total number of taxa	**83**	**Total number of taxa**	**63**

Bornholm Basin		Eastern Gotland Basin	
Taxon	%Biomass	Taxon	% Biomass
Nodularia spumigena	25.59	*Nodularia spumigena*	28.39
Unicell spp.	18.76	*Aphanizomenon*	12.88
Aphanizomenon	8.11	*Gymnodiniales*	9.75
Plagioselmis prolonga	7.60	*Unicell spp.*	7.20
Actinocyclus	5.08	*Chroococcales*	6.82
Gymnodiniales	4.46	*Mesodinium rubrum*	5.08
Prymnesiales	4.46	*Plagioselmis prolonga*	3.70
Pyramimonas	3.88	*Aphanothece paralleliformis*	3.63
Mesodinium rubrum	3.67	*Prymnesiales*	3.47
Nitzschia paleacea	3.45	*Cyanodictyon planctonicum*	1.67
Total number of taxa	**32**	**Total number of taxa**	**52**

Phytoplankton diversity of the summer community, as expressed by total number of taxa encountered at the time of sampling, was comparable to the spring community with ›80 taxa detected in the Belt Sea and approx. 50 in the Gotland Basin (Table 5). Again, the lowest number occurred in the Bornholm basin, which, however is only represented by one station, compared to the other sea areas (see Table 1).

3.1.1.3 Autumn bloom

In October/November 2019 high Chl *a* values in the southern basins, ranging from 3.3 and 4.6 µg L-1, reflect an ongoing autumn phytoplankton bloom (Fig. 14). Interestingly, Chl *a* levels are in the same range as during the March cruise TF0319 capturing the fully developed diatom spring bloom in the southern basins. Values are comparable to the ones measured during the autumn cruise in 2018.
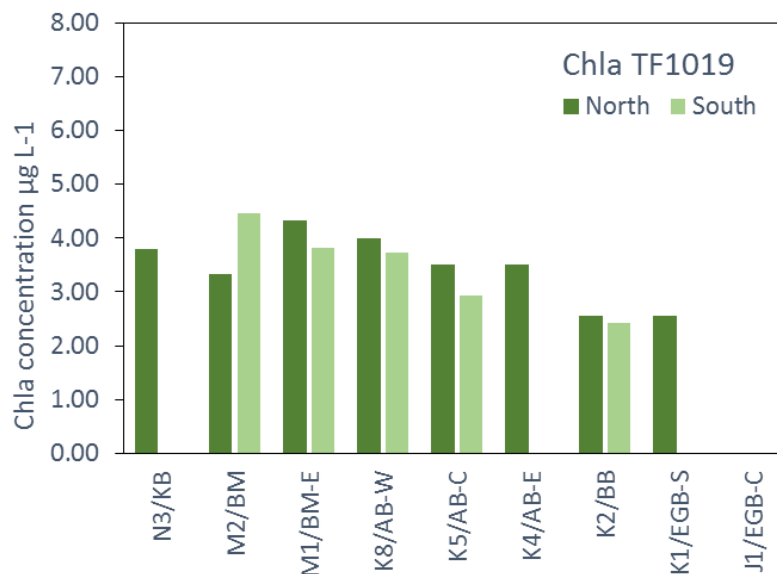
Fig. 14: Chl a concentrations (µg L⁻¹) at sampling stations along the S-N (dark green) and N-S (light green) transects of the October cruise TF0819. Measurement for OMBMPJ1 not available.
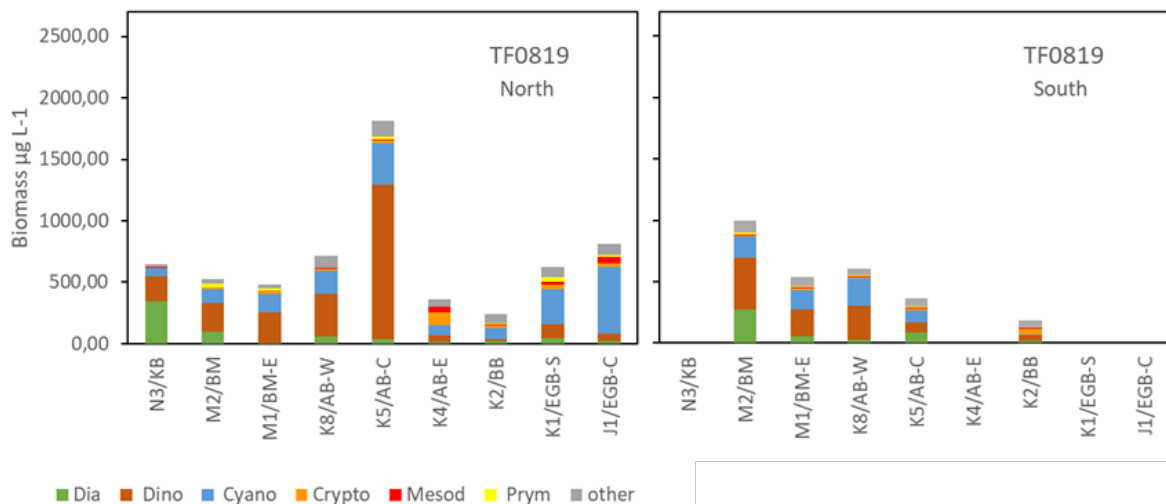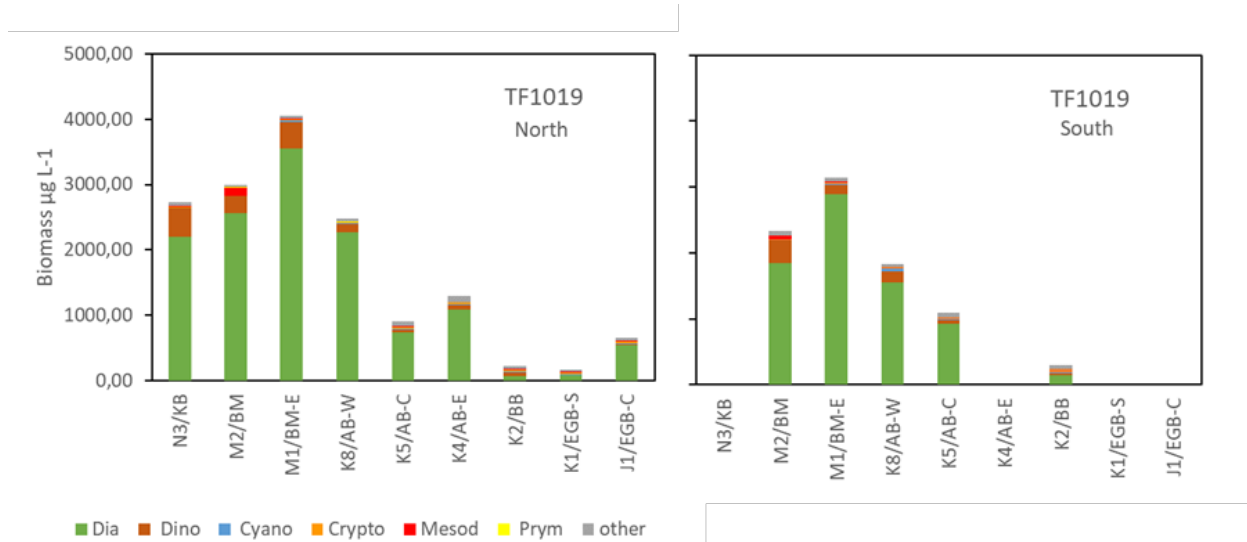
Fig. 15: Total phytoplankton biomass (µg L-1) and contribution of major taxa measured from samples taken during northward and southward transects of TF1019 in October 2019.

High Chl *a* levels corresponded to respective total phytoplankton biomasses (Fig. 15) which were nearly as high as the ones measured during the spring bloom. Like in spring, biomass was dominated by diatoms, with *Cerataulina bergonii* contributing approximately 50% of biomass at the Belt Sea and Arkona Basin stations (Table 6). In the Belt Sea *Pseudo-nitzschia* spp (Fig. 16), including domoic acid producing and toxic species, were responsible for the second largest fraction of the biomass. Dinoflagellates belonging to the genus *Ceratium* were another prominent member of the Belt-Sea autumn community.

In the Arkona Basin, *Rhizosolenia fragilissima* was the other dominant diatom besides *Cerataulina bergonii* – here 70 % of the biomass were made by two species only, leaving limited resource space for other taxa, e.g. gymnodinoid dinoflagellates and species belonging to *Ceratium* and *Prorocentrum*. The northern sea areas had different communities, both dominated by centric *Coscinodiscus* species and diverse other taxa. The Gotland basin community still contained cyanobacteria – *Nodularia spumigena* being 10th in terms of biomass contribution. Total number of taxa in the different sea areas was in the same range as during the spring and summer cruises and followed the same pattern of highest diversity in the western sea areas and significantly lower taxon numbers in the northern basins.
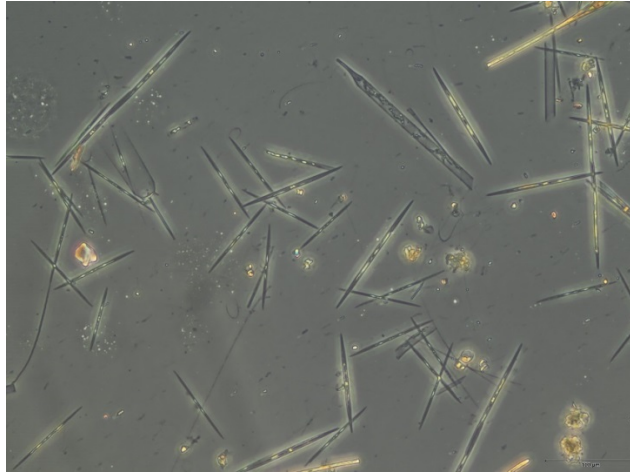
Fig. 16: Light micrograph of Pseudo-nitzschia *spp. in the sample taken at Station OMBMPN3 in Kiel Bay at the beginning of TF1019. Scale bar = 100μm*

Table 6: List of the 10 most important phytoplankton taxa and respective biomass percentages in the different Sea areas during autumn 2019. Biomasses of all stations belonging to the respective sea area were pooled. Number of stations per sea area see Table 1.

Belt Sea		**Arkona Basin**	
Species	% Biomass	Species	% Biomass
Cerataulina bergonii	46.93	*Cerataulina bergonii*	49.35
Pseudosolenia calcar-avis	12.81	*Rhizosolenia fragilissima*	30.73
Pseudo-nitzschia	8.25	*Pseudosolenia calcar-avis*	5.72
Pseudo-nitzschia seriata GRP	7.19	*Gymnodiniales*	2.41
Ceratium tripos	4.01	*Ceratium tripos*	1.56
Rhizosolenia setigera f. pungens	3.34	*Ebria tripartita*	1.45
Gymnodiniales	2.10	*Unicell spp.*	1.29
Rhizosolenia setigera	1.89	*Teleaulax*	1.12
Ceratium fusus	1.88	*Pyramimonas*	0.75
Mesodinium rubrum	1.48	*Prorocentrum micans*	0.74
Total number of taxa	**87**	**Total number of taxa**	**67**
Bornholm Basin		**Eastern Gotland Basin**	
Taxon	%Biomass	Taxon	% Biomass
Coscinodiscus granii	19.45	*Coscinodiscus concinnus*	64.64
Unicell spp.	9.11	*Coscinodiscus granii*	8.31
Gymnodiniales	8.93	*Tripos longipes*	4.68
Ebria tripartita	7.35	*Synedra nitzschioides*	2.87
Teleaulax	7.14	*Unicell spp.*	2.26
Rhizosolenia fragilissima	6.18	*Teleaulax*	2.12
Micracanthodinium claytonii	5.71	*Merismopedia punctata*	1.67
Plagioselmis prolonga	5.22	*Mesodinium rubrum*	1.58
Heterocapsa rotundata	4.69	*Flagellates*	1.40
Hemiselmis	3.09	*Nodularia spumigena*	1.04
Total number of taxa	**48**	**Total number of taxa**	**51**

3.1.2 Species diversity, non-indigenous species and harmful algal blooms

In 2019, altogether 150 phytoplankton species/taxa were recorded in monitoring samples from 0 – 10 m water depth, 11 less than in 2018. A complete list of recorded species with biomass ranks and total biomass values can be found in the appendix (Table A1). Diatoms were the most important biomass producers, specifically *Cerataulina bergonii, Rhizosolenia* spp*., Proboscia alata* in the southern sea areas and *Skeletonema marinoi* growing also in the low salinity northern parts of the monitored area. These were followed by the mixotrophic ciliate *Mesodinium rubrum* forming high biomasses across the entire monitoring area and species belonging to Gymnodiniales, forming high biomass blooms during spring in the northern basins. High biomass species dominating the productive phases were followed in ranks by toxic or potentially toxic species and genera, *Alexandrium pseudogonyaulax, Aphanizomenon flos- aquae and Pseudo-nitzschia* spp.

Table 7 shows occurrences of toxic and potentially harmful taxa at sampled stations in 2019. Under conditions of climate change, when temperatures of surface waters rise, the risk of harmful algal blooms formation is increasing (WELLS et al. 2015). Particularly warm water adapted species such as filamentous cyanobacteria and dinoflagellates should benefit from increased summer surface temperatures (OLOFSSON et al. 2020), though this relationship seems to be species and basin specific in the Baltic Sea and cannot be generalized (KAHRU et al. 2020, OLOFSSON et al. 2020). In 2019, several HAB (harmful algal bloom) taxa contributed significant biomass shares to the phytoplankton community. These include cyanobacteria, predominantly *Nodularia spumigena* and *Aphanizomenon*, which were most prominent in the summer months and in the brackish northern parts of the monitored transect. Dinoflagellates, such as *Prorocentrum cordatum*, which is - apart from being toxic - an invasive species, and toxic *Alexandrium pseudogonyaulax* formed high biomasses in the southern parts at the same time. At Station OMBMPK5 in the central Arkona Basin, peak abundances of *A. pseudogonyaulax*, being on order of magnitude higher than so far reported from northern European waters, were recorded during the summer cruise TF0819. Since the species is a large dinoflagellate, cell concentrations of 33000 cells/L resulted in a biomass proportion of ›50% here. *A. pseudogonyaulax* produces a potent toxin, Goniodomin, and is currently spreading in Northern European waters, as a consequence of an efficient nutritional strategy, rising sea surface temperatures and accumulating seed populations that anchor the species in their new habitats (KREMP et al. 2019). The ongoing establishment of a permanent population in the Baltic Sea may have negative effects on invertebrates and fish populations and potentially disturb food web transfer efficiency (BLANDA et al. 2016) here. Species of Domoic Acid producing *Pseudo-nitzschia* were most abundant during autumn, contributing significant shares of the total phytoplankton biomass. Domoic acid can be transferred through the marine food web, especially benthic compartments and cause mortalities at higher trophic levels (LUNDHOLM et al. 1994).

Table 7: Occurence of toxic/ bloom forming and invasive phytoplankton taxa in 2019. + = present, ++ = abundant (1-10% biomass share), +++ = very abundant (> 10% biomass share), ++++ = bloom (>50% biomass share). Dinpophysis *spp includes* D. acuminata, D. norvegica, D. acuta; Pseudo-nitzschia *spp.* contains records of P. pseudodelicatissima *group,* P. pungens, P. seriata *and* P. multiseries

Species	station cruise	TF0360 KB	TF0012 BM	TF0046 BM-E	TF0030 AB-W	TF0113 AB-C	TF0109 AB-E	TF0213 BB	TF0259 GB-S	0271 GB-C
Cyanophyceae										
Dolichospermum spp.	TF0819	+	++	++	++	+	+	+	+	
	TF1019					+		+		
Nodularia spumigena	TF0319								++	
	TF0519							++	++	
	TF0819	+	++	++	++	++	++	+++	+++	+++
	TF1019			+	++	+	++	++	++	
Aphanizomenon sp.	TF0219						++	+		
	TF0319						++			+
	TF0519					+		+	++	++
	TF0819	++	+++	+++	+++	+++	+++	++	++	+++
	TF1019		+	+	+	+	+	++	++	+
Dinophyceae										
Alexandrium pseudogonyaulax	TF0819	+	+++	+++	+++	++++	+		+	
Prorocentrum cordatum	TF0219		+		+	+				
	TF0319						+			
	TF0819	+	++	+++	+++	++		+		
	TF1019	+	+	+	+	+	+	+	+	
Dinophysis spp.	TF0219	+								
(D. acuminata, D. norvegica,	TF0319	+	++	++					+	
D. acuta)	TF0519	+	+					+++	+++	+++
	TF0819	+	+		+		++	++	++	++
	TF1019	++	+	+	+	+		++	+	+
Bacillariophyceae										
Pseudo-nitzschia spp.	TF0219	++	++		+			+		
	TF0319	+	+	+						
	TF1019	+++	+++	++	+	+	+			

3.1.3 Long-term trends

Average phytoplankton **biomass** values of 2020 (Fig. 17) were slightly lower than in 2019, however, well above the 20 year - mean. This is probably related to the high biomass production by diatoms in autumn that is becoming a regular feature of the seasonal cycle in the Baltic Sea, manifested by an extended production period. The ratio of diatoms and dinoflagellates in the phytoplankton community affects ecosystem functions, specifically food web transfer and biogeochemical cycles. A high proportion of diatoms compared to dinoflagellate specifically in the spring bloom is an indication for a good environmental status (WASMUND et al. 2017a, HELCOM 2020) as it supports food web transfer. On the other hand, sedimentation of large diatom blooms may enhance oxygen consumption in bottom waters leading to anoxic conditions in the sediments, which support the internal phosphorus loading (VAHTERA et al. 2007). In contrast to diatoms, dinoflagellates typically disintegrate in the water column or form resting stages that resist remineralisation in bottom sediments (SPILLING et al. 2018). Dinoflagellate dominance in summer is often related to harmful algal blooms which can disrupt trophic transfer.
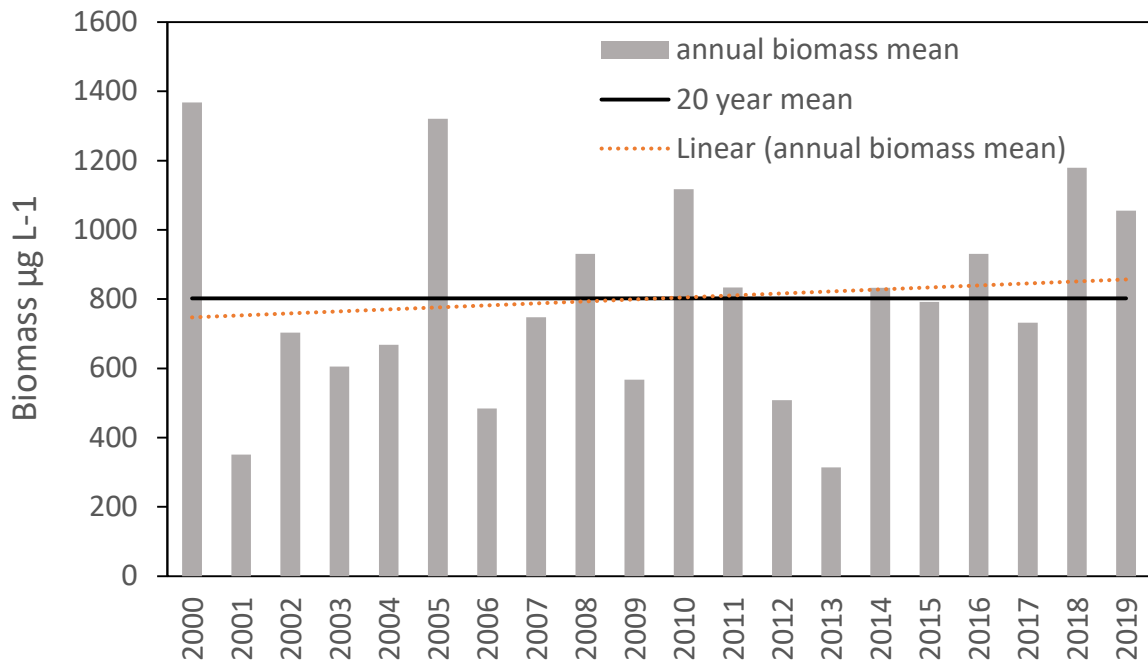
Fig. 17: Mean annual biomass values (all stations and samplings) for the period between 2000 and 2019.
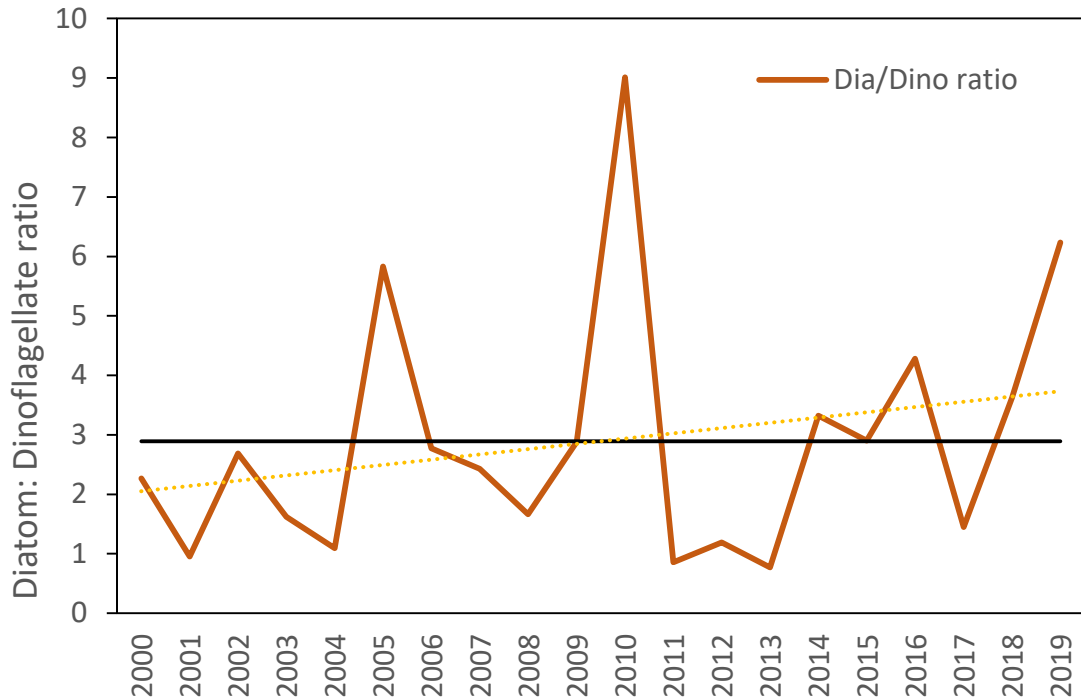
Fig. 18: Mean annual ration of diatoms to dinoflagellates. The black line marks the 20-year mean, dotted line = trendline.

The 2019 **Diatom/Dinoflagellate ratio** (Fig. 18) was much higher than during the previous years, and further corroborates the trend of an increasing importance of diatoms (in relation to dinoflagellates) in contributing to the total annual biomass production during the past decade. This trend contrasts the situation of the 1990's and early 2000's, when especially in the more northern Basins of the Baltic Sea, including Gotland Basin, dinoflagellates were on the rise and dominated specifically the Baltic spring bloom community (KLAIS et al. 2011). In 2019, monitoring data shows that diatoms have become the dominant primary producers of the spring and autumn periods again. In 2019, average **cyanobacteria biomass** measured per station and sampling (Fig. 19) was well above the long-term mean and higher than during the previous years. This is likely due to the high cyanobacteria share, particularly *Aphanizomenon* and *Nodularia,* in the summer community of the more northern basins that are typical for warm summers such as 2019.
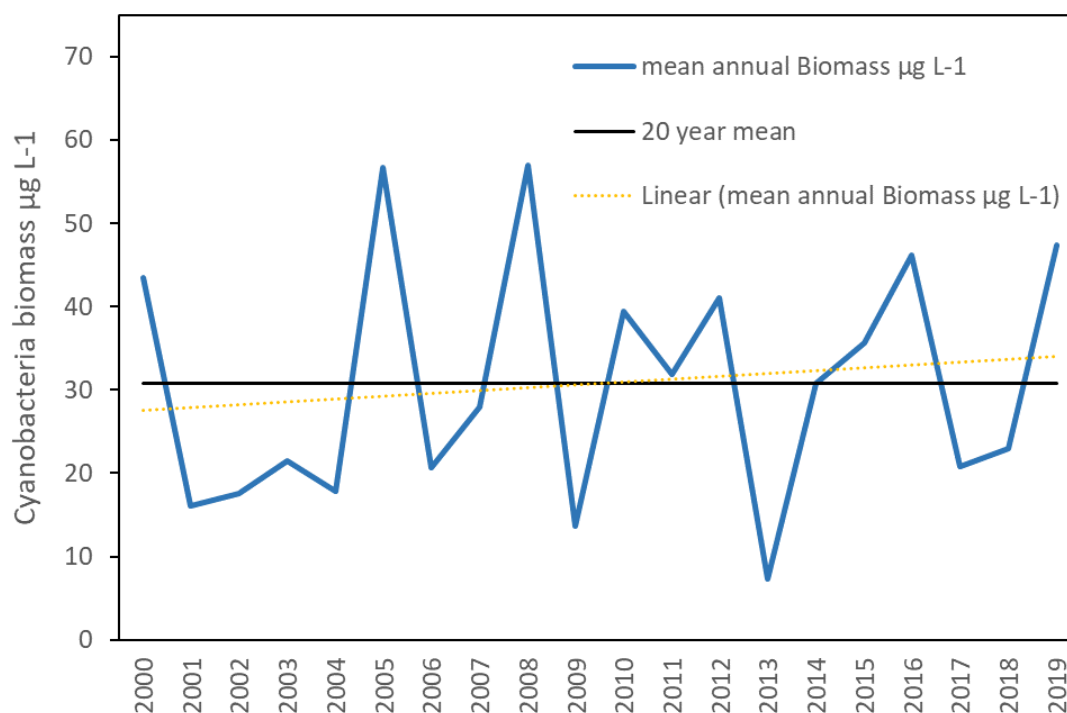
Fig. 19: Annual averages of cyanobacterial biomass for the period 2000-2020. The black line marks the 20-year mean, dotted line = trendline

3.1.4 Phytoplankton sedimentation

Microscopic analysis of phytoplankton settling out from the photic zone and being collected by the sediment trap moored in the Arkona basin throughout 2019 reflected the typical dynamics of seasonal pelagic community succession (Fig.20). Altogether 49 phytoplankton taxa were encountered in 2019 in settling material, which is slightly more than in the preceding years (40 in 2016, 45 in 2017, and 43 in 2018). Generally, the relative frequency of settled phytoplankton was higher for most taxa than in 2018.

As in previous years, diatoms were found to be the most diverse phytoplankton group in sediment trap material, comprising 27 species. This is expected, as diatoms are covered by silicified frustules which support sinking. Two distinct periods of high sedimentation occurred in 2019. The first reflected the spring bloom in the Arkona Basin from March to May – being dominated by typical cold-water species such as *Thalassiosira* spp., *Skeletonema marinoi*, *Melosira arctica* and *Chaetoceros* sp. Diatom sedimentation decreased in June to a diversity- and relative frequency minimum. Interestingly, the diatom frequency increased again and remained high during summer and early autumn, although diatoms only consisted of an insignificant proportion of the total phytoplankton biomass in the water column when sampled during the summer cruise in August. Although diatom composition in trap samples of the summer and early autumn period differs from the spring period and contained taxa only or predominantly abundant in the overlaying water column during this period (e.g. *Nitzschia paleacea, Rhizosolenia fragilissima*), it cannot be excluded that the diatom community retrieved from trap content was partly constituted from resuspended bottom sediments.

Dinoflagellates 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,* and are heavy enough to settle once the growth phase is terminated. In contrast to the previous year, highest dinoflagellate sedimentation rates were observed during the summer months and dominated by *Prorocentrum* species, notably *P. cordatum*, which was also one of the most abundant species of the plankton community at this time. In contrast to the previous year, when the summer cyanobacteria bloom was less pronounced than usual, the 2019 sedimentation pattern of cyanobacteria mirrored the typical summer cyanobacteria bloom. From July to September *Dolichospermum* spp, *Aphanizomenon flos aquae* and *Nodularia spumigena* were the dominant cyanobacteria species of the trap material.

Chlorophytes and flagellates were present in sediment trap samples in spring and summer at relatively low frequencies. In summer and autumn samples, the harmful raphidophyte *Heterosigma akashiwo* was identified. This species was not encountered in plankton samples during the respective time window and the sediment trap record is the only indication of the species being present in the phytoplankton community during 2019.
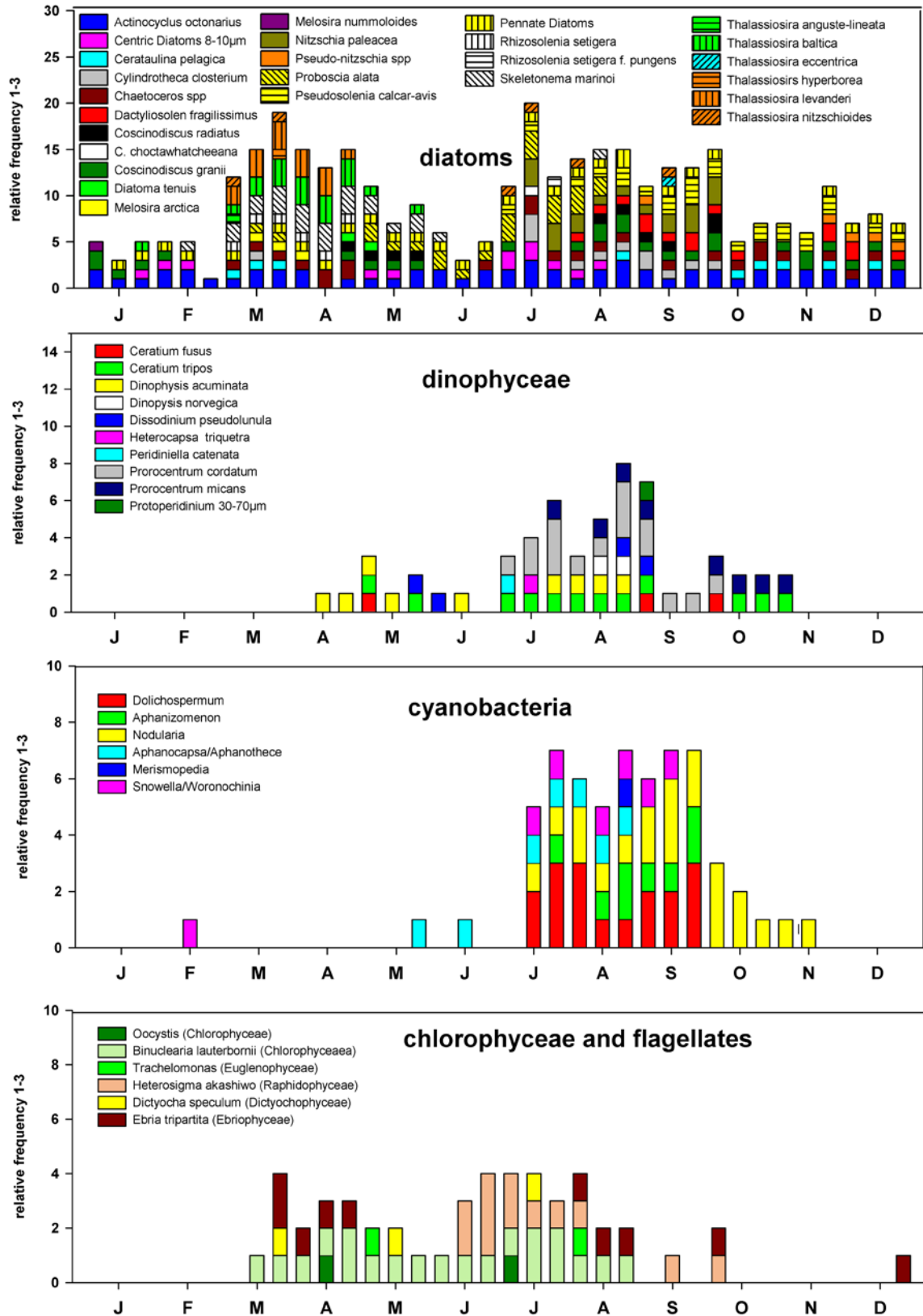
Fig. 20: Relative frequency of selected taxa of diatoms, dinoflagellates, cyanobacteria and green algae/flagellates in sinking organic material in 2019.

The vertical fluxes of particulate carbon and nitrogen (Fig. 21) roughly reflect the semi-quantitive frequency based sedimentation patterns, with highest pulses of C and N co-occurring with highest cumulative phytoplankton frequencies (all taxa together) measured in sediment trap samples during summer. POC and PON measurements nevertheless provide a more quantitative perspective to the frequency based phytoplankton sedimentation data. The winter peak of POC and PON that was measured in January 1919 samples was not reflected by phytoplankton counts. High amounts of suspended particulate matter (SPM), however, suggest that it did not originate from settling phytoplankton.

Elemental ratios C/N and C/P should amount to 6.6 and 106 (Redfield ratio), respectively, under optimal growth conditions and balanced decomposition of the organic material. As shown in Fig. 21, the particulate C/N ratios of 2019 settling phytoplankton material were variable, ranging between approximately 5 and 10. The three peaks seem to reflect limitation situations after the major seasonal blooms: end of the spring bloom in May, end of the dinoflagellate dominated summer bloom in August and the end of the autumn diatom bloom. Possibly the dinoflagellate bloom in July/August was followed by a cyanobacteria community bringing in N into the system through nitrogen fixation. The particulate C/P ratios deviated strongly from the Redfield ratio, exceeding it significantly in most samples (Fig.22). High C/P ratios indicate strong P limitation of phytoplankton growth and/or preferred remineralization of P in comparison with C.

The vertical fluxes of particulate Silica and Phosphorus shown in Fig. 22 reflect the major sedimentation pattern seen in POC and PON. The P-Si pulse in late May was likely caused by the sedimentation of the diatom spring bloom. Similarly, settling or resuspended diatoms lead to P-Si sedimentation in July/August. Particulate P sedimentation was in phase with other elements, though the single narrow peak indicates an isolated pulse of phosphorus –rich phytoplankton – most likely dinoflagellates. In fact, an *Alexandrium pseudogonyaulax* bloom was observed during TF0819 in the Arkona basin, dominating the phytoplankton biomass. Although the species was not identified among other dinoflagellates in microscopic analyses of trap material, unrecognized encystment (resting cysts formed by dinoflagellates are hard to identify and usually not counted) and subsequent cyst sedimentation might have boosted particulate P sedimentation in late summer. Dinoflagellate resting cysts may in fact contribute a major fraction of settling particulate organic matter (HEISKANEN 1993).
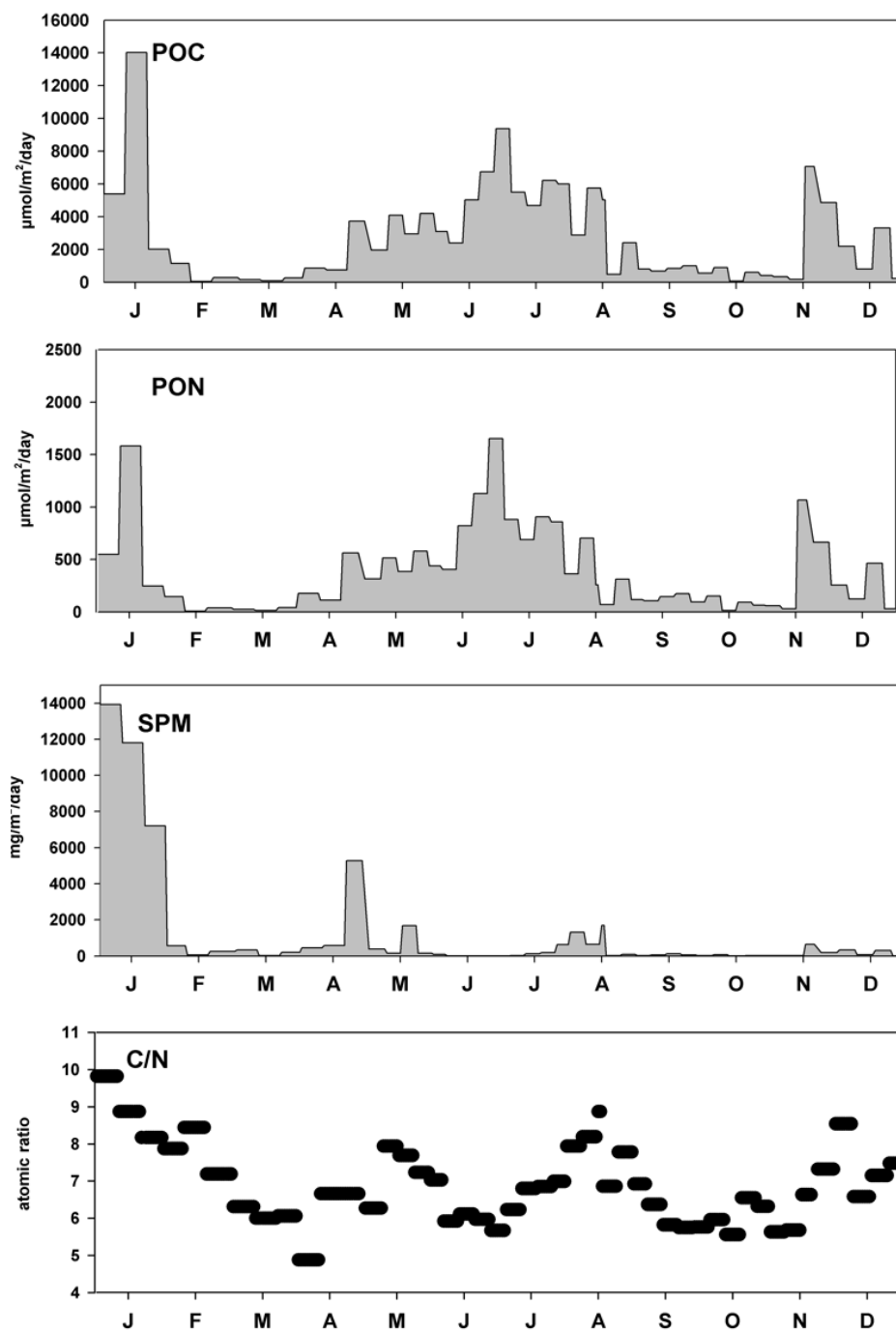
Fig. 21: Daily sedimentation rates of particulate organic carbon (POC), particulate organic nitrogen (PON) particulate suspended matter (SPM) and atomic ratio between carbon and nitrogen (C/N) in sedimenting particles at 35 m depth in the central Arkona Sea in 2019.
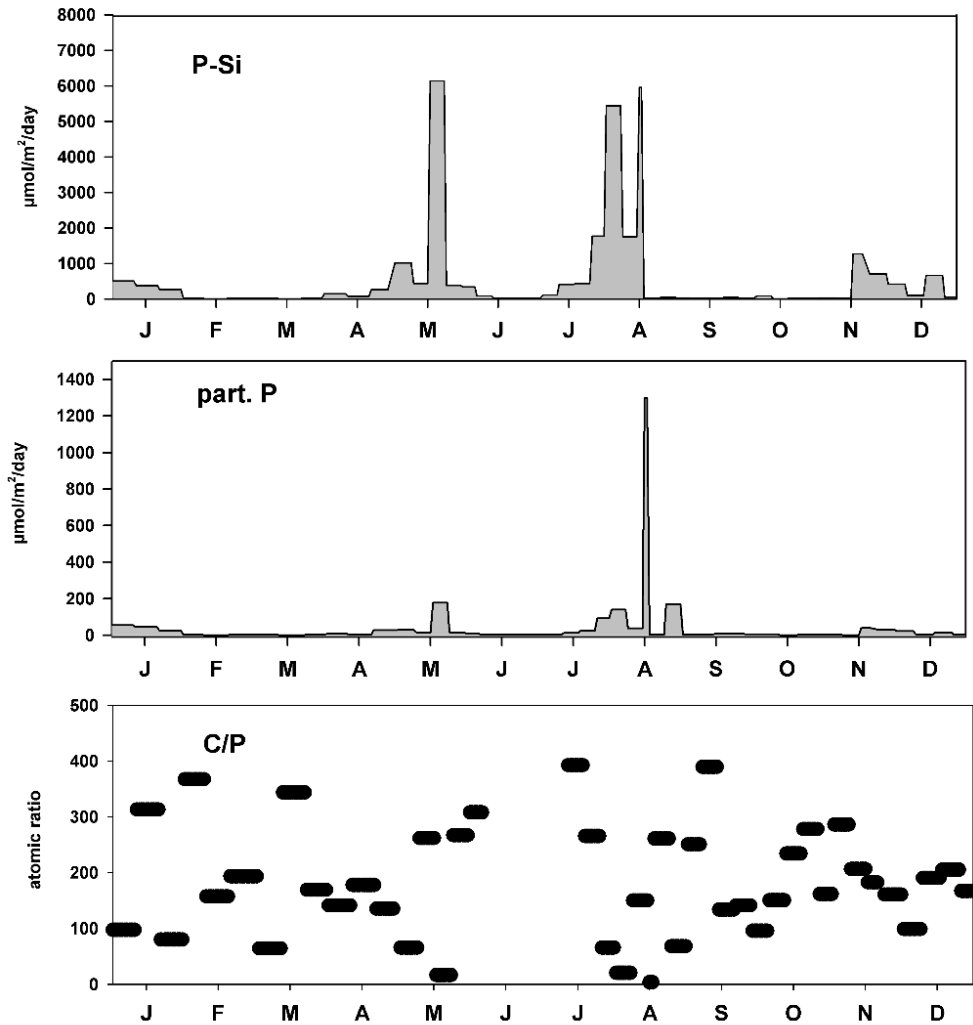
Fig. 22: Daily sedimentation rates of particulate biogenic silica (P-Si), particulate phosphorus (part.P) as well as the atomic ratio between carbon and nitrogen (C/N) in sedimenting particles at 35 m depth in the central Arkona Sea in 2018.

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). Interestingly, the particulate P pulse to the sediment in coincides with a sudden decrease of the C/P ratio, which further supports the hypothesis of an unrecognized dinoflagellate cyst sedimentation event. The $\delta_{15}N$ values were in the usual range, not exceeding 8 ‰, which is the value found in nitrate-rich deep water or winter water (Fig. 23). The slight decrease from June to August indicates a moderate nitrogen fixation, which was similar to the pattern observed in 2018, though much lower than in the previous years.
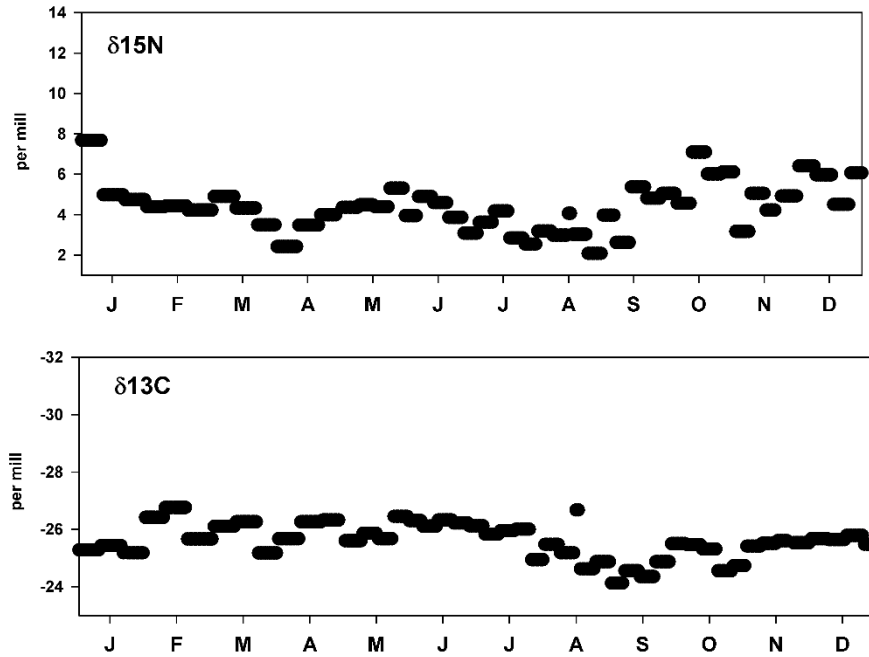
Fig. 23: Isotopic signatures of nitrogen (‰ δ15N) and carbon (‰ δ15N) at 35 m depth in the central Arkona Sea in 2019.

3.2 Mesozooplankton

3.2.1 Species composition and non-indigenous species

A total of 50 taxa were recorded in the study area during 2019 (Tab. A2). The total number recorded was slightly higher than those recorded in 2018, but remained low in in comparison to the years 2016 (73 taxa) and 2017 (63 taxa, WASMUND et al. 2017b, 2018a), in which the diversity has peaked in the recent decade. Halophilic organisms were still rarely encountered in the whole area during 2019. Only a few specimens such as the calanoid copepod *Calanus* spp., the chaetognath *Sagitta* spp. and the cladoceran *Penilia avirostris* occurred in the samples at Kiel Bight, the Bay of Mecklenburg and the Arkona Basin. In addition, fewer gelatinous taxa were found as usual and species like *Obelia geniculata* or *Aurelia aurita* that were regularly observed in previous years were absent. Thus, the species composition was largely dominated by other commonly encountered taxa in the western Baltic Sea.

Typically for the seasonal variation in the western Baltic Sea, the taxa diversity increased during the transition from winter to spring and summer to autumn (Fig. 24). This is largely owed to the occurrence of meroplanktonic larvae in spring and summer. While *Harmothoe* and other unspecified polychaete larvae primarily contributed to the meroplankton in spring, diverse decapod larvae (*Carcinus* spp., *Crangon crangon*, *Palaemon serratus*), echinoderm larvae (*Asterias* spp., *Ophiura* spp.) and polychaete larvae (*Pectinaria* spp.) frequently occurred together with unspecified bivalve and gastropod larvae in summer/autumn. These larvae were particularly common in the Bay of Mecklenburg (stations OMBMPM2 and OMBMPM1). The diversity of taxa was, therefore, higher in this area (34-39 taxa) compared to the Kiel Bight and the Arkona Basin (28-34 taxa, Fig. 24).
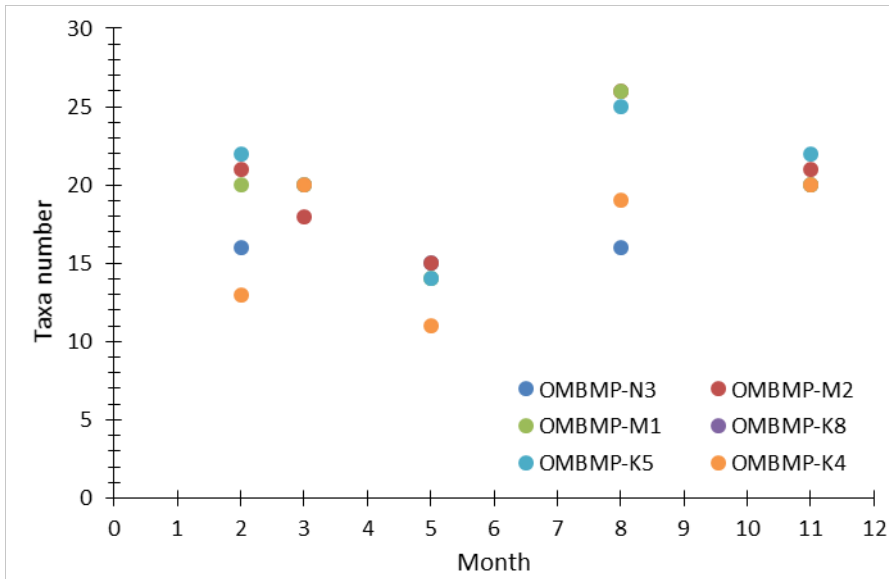
Fig. 24: Seasonal variation of the number of taxa recorded at different stations in the investigation area in 2019 (OMBMP-N3 = Kiel Bight, -M2 and -M1 = Bay of Mecklenburg, -K5 and -K4 = Arkona Basin).

Based on the maximal concentrations, the abundance of zooplankton was highest in the Kiel Bight and the Arkona Basin (8.9 and 9.1 x 10⁴ ind. m⁻³, Fig. 25 a). Copepods and Cladocera were the major groups contributing to the bulk of zooplankton and typically achieved their maximum of 6.1 and 5.2 x 10⁴ ind. m⁻³ in spring and summer, respectively (Fig. 25 b). In contrast to previous years, rotifers occurred only in small numbers ranging from 0.3 to 1.9 x 10³ ind. m⁻³ in the entire area in 2019. This group can typically build up large stocks of several thousands of individuals per m⁻³ and considerably contribute to the zooplankton in spring. Copelata primarily contributed to the zooplankton in the Kiel Bight and the Bay of Mecklenburg and were mainly observed in autumn (0.6 – 1.1 10⁴ ind. m⁻³, Fig. 25 a, b). Meroplankton was abundant in 2019. Bivalve larvae occurred in high concentrations during summer in the entire area (0.7 – 1.3 x 10⁴ ind. m⁻³, Fig. 25 a, b). Polychaete larvae were similarly abundant (0.2 – 1.1 x 10⁴ ind. m⁻³), but were restricted to the Kiel Bight and the Bay of Mecklenburg. Gastropod larvae were mainly recorded in the Kiel Bight and the Bay of Mecklenburg as well, but achieved lower concentrations than the polychaete and bivalve larvae (0.9 – 1.9 x 10³ ind. m⁻³). The meroplankton concentrations were in the range typically encountered in the area during previous years.

Peak concentrations of the cladocera were mainly restricted to the Arkona Basin (OMBMPK4, Fig. 25 a). *Bosmina* was the single most important genus contributing to the maximum (5.1 x 10⁴ ind. m⁻³). While the genus has occurred in high numbers in the Bay of Mecklenburg in the past as well, the restriction to the Arkona Basin in 2019 is not untypical for the western Baltic Sea. In the Kiel Bight and the Bay of Mecklenburg, the genus was outnumbered by *Evadne nordmanni*, *Podon intermedius* and *P. leuckartii*. *E. nordmanni* ranked second among the cladocera with concentrations ranging from 1.4 – 2.6 x 10³ ind. m⁻³. The species was found in all areas similar to *Podon intermedius* and *P. leuckartii*. While *P. intermedius* was primarily common in Kiel Bight (1.6 x 10³ ind. m⁻³), the concentrations of *P. leuckartii* increased from Kiel Bight to the
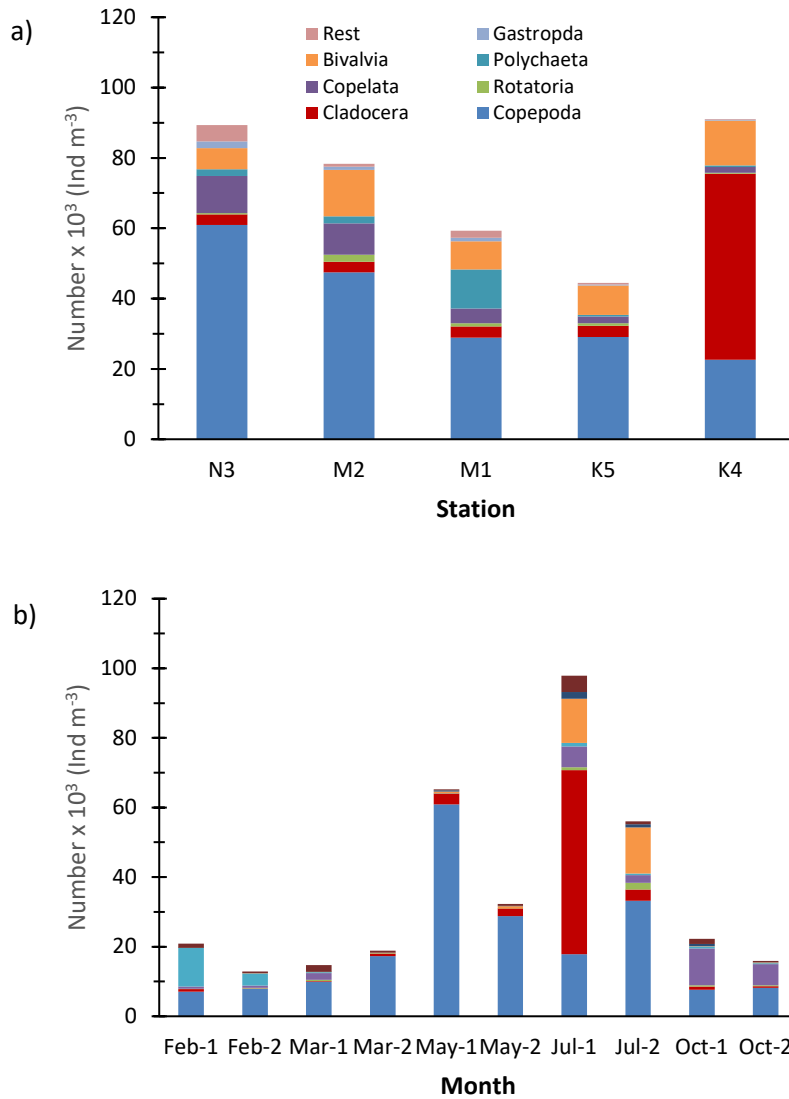
Fig. 25: Spatial and seasonal variation of the maximal abundance of the mesozooplankton groups (a, b) and of adults of calanoid and cyclopoid copepods (c, d) in the investigation area; continued on next page (N3 = Kiel Bight, M2 and M1 = Bay of Mecklenburg, K5 and K4 = Arkona Basin).

Arkona Basin (0.4 – 1.3 x 10³ ind. m⁻³). Other cladocera were generally rare. *Penilia avirostris* was regularly encountered in the Kiel Bight and the Bay of Mecklenburg during autumn (12 – 71 x ind. m⁻³). *Pleopsis polyphemoides*, in contrast, was observed in the Arkona Basin only (6 – 18 x 10³ ind. m⁻³).

Rotifers can be seasonally very abundant. In the past, peak concentrations exceeding 4.0×10^4 ind. m⁻³ were common that are based on mass occurrence of the genus *Synchaeta* in late spring. In 2019, in contrast, the abundance was low. The concentrations ranged from 0.3 to 1.9 x 10³ ind. m⁻³ and were maximal in the Bay of Mecklenburg. Unusually, the highest concentrations were recorded in summer. Specimen of the genus *Keratella* occurred at numbers of 8-22 ind. m⁻³ in all areas except the Kiel Bight.

c)

d)

Legend:
- *Oithona similis*
- *Temora longicornis*
- *Pseudocalanus spp*
- *Paracalanus parvus*
- *Eurytemora affinis*
- *Centropages typicus*
- *Centropages hamatus*
- *Acartia tonsa*
- *Acartia longiremis*
- *Acartia bifilosa*
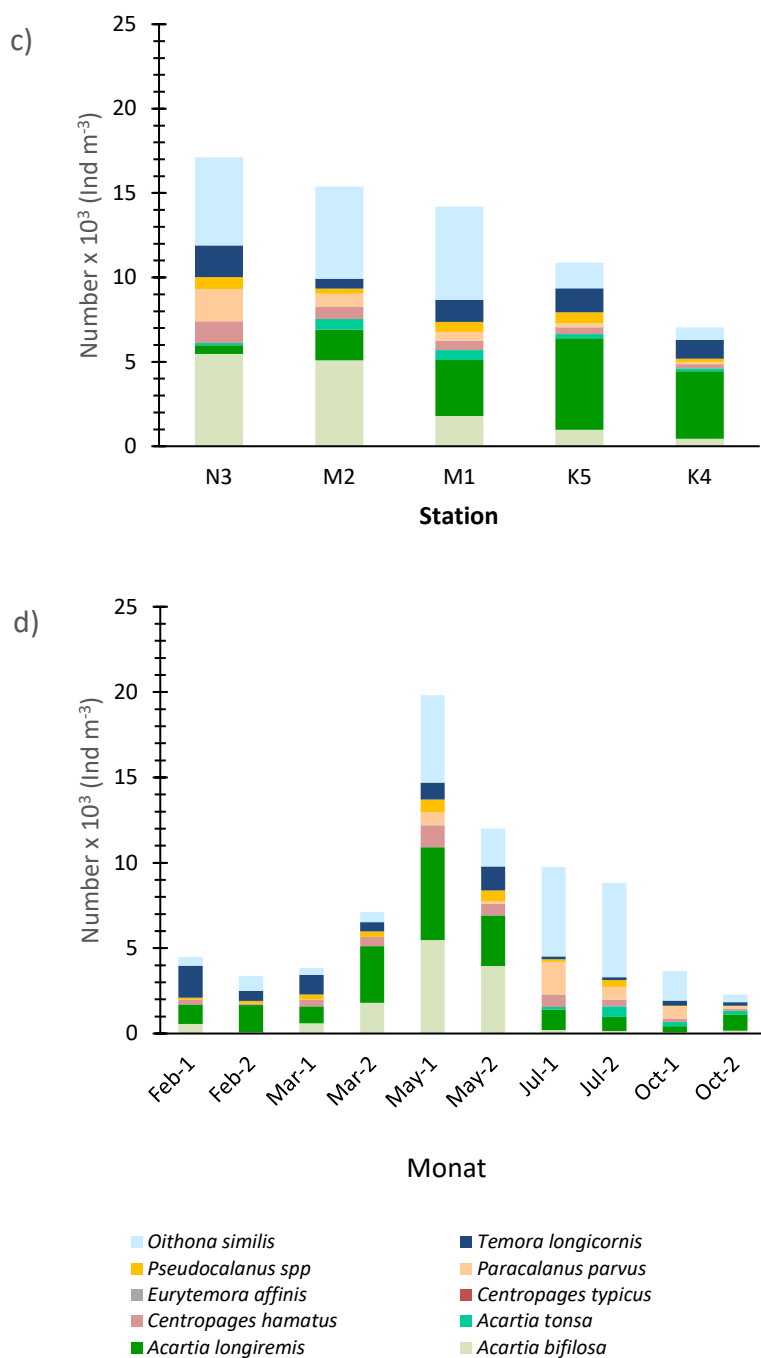
Fig. 25: continued.

Although *Keratella* concentrations were generally variable in the past, the abundance was rather low in 2019. The genus was represented by *K. cruciformis* and *K. quadrata*. *K. cochlearis*, which was observed in previous years, were not encountered.The Copelata are represented by *Fritellaria borealis* and *Oikopleura dioica* in the western Baltic Sea. While *F. borealis* usually occurs in spring in the Bay of Mecklenburg and the Arkona Basin, *O. dioica* is more confined to the Kiel Bay and the Bay of Mecklenburg. Both species occur regularly at similar concentration. However, *F. borealis* was dominating in 2018. In 2019, in contrast, the dominance has shifted to *Oikopleura* due to an unusual low spring concentration of *Fritellaria* of maximal 1.9×10^3 ind. m^{-3}.

O. dioica occurred at unusual high concentrations in autumn in the Kiel Bay and the Bay of Mecklenburg (0.9 – 1.1 x 10^4 ind. m^{-3}).

The Copepoda are an ecological important group of the zooplankton as they form as fish fry a tight link between the phytoplankton and higher trophic levels. Due to the restriction in the distribution of the cladoceran *Bosmina* spp. to the Arkona Basin, they were the dominant group in the Kiel Bight and the Bay of Mecklenburg (Fig. 25 a). Maximum concentrations are usually observed in late spring and summer and the year 2019 is no exception from this general pattern (Fig. 25 b). The maximal abundance of copepods was high in 2019 compared to preceding years. Particularly in the Kiel Bight, a maximum stock of 6.1 x 10^4 ind. m^{-3} considerably exceeded the range of 1.2- 3.3 x 10^4 ind. m^{-3} observed in the years 2014-2018. In the other areas, the stock sizes were at the upper limit observed in this period.-On the long-term, however, the maximum concentrations were not exceptional (compare chapter 3.2.3).

Among the adult specimen, two calanoid species of the genus *Acartia*, *A. bifilosa* and *A. longiremis*, and the cyclopoid copepod *Oithona similis* were most abundant in 2019 (Fig. 25 c). While *Acartia* was generally most abundant during early and late spring, *Oithona* contributed primarily to the stock during late spring and summer (Fig. 25 d). There was a clear shift in the dominance of the species composition from *A. bifilosa* (5.1 - 5.5 x 10^3 ind. m^{-3}) and *O. similis* (5.2 – 5.5 x 10^3 ind. m^{-3}) in the Kiel Bight and the Bay of Mecklenburg to *A. longiremis* (4.0 - 4.5 x 10^3 ind. m^{-3}) in the Arkona Basin (Fig. 25 c). This shift is a common feature of the biographical variation in the community composition in the western Baltic Sea. In 2017-2018, however, *A. longiremis* was among the dominating species in all areas (WASMUND et al. 2018, 2019a). *A. tonsa*, contributed as usual only little to the zooplankton stock (< 0.6 x 10^3 ind. m^{-3}). *Centropages hamatus*, *Paracalanus parvus* and *Temora longicornis* ranked third among the copepods and their density ranged from 0.1 – 1.9 x 10^3 ind. m^{-3} which is in the usual range (Fig. 25 d). While *Paracalanus* is typically concentrated in the Kiel Bight, the other two species were common at all stations. *Pseudocalanus* spp. is instead more common in the Bay of Mecklenburg and the Arkona Basin. The species achieved maximum concentrations of 0.2 – 0.7 x 10^3 ind. m^{-3} only, which is a rather low stock size. Historically the species was considerably more common in the western Baltic Sea. Other copepod species were rare. Copepod species that are observed in association with inflows such *Centropages typicus* or *Acartia clausi* were not observed except a single specimen of *Calanus* spp. The typical brackish water copepod species *Eurytemora affinis* was similarly rare (0 - 5 ind. m^{-3}). The anthomedusae *Lizzia blondina* was the only exceptional species found in the zooplankton samples in 2019. The species was observed for the first time in 2017, and occurred in the Bay of the Mecklenburg. The species is of marine origin similar to the cladoceran *Penilia avirostris* (RUSSEL 1970, GIESKES 1971, GREVE et al. 2004). *Penilia*, however, was regularly found in low numbers in the Kiel Bight and the Bay of Mecklenburg during August and October ad there were no regular findings of other truly marine species. *Acartia tonsa* is a regular member of the zooplankton in the western Baltic Sea. It is considered as non-indigenous species (NIS) since its introduction during the 1920s into the Baltic Sea (OJAVEER & KOTTA 2015). It was found at all stations, but at considerably low numbers.
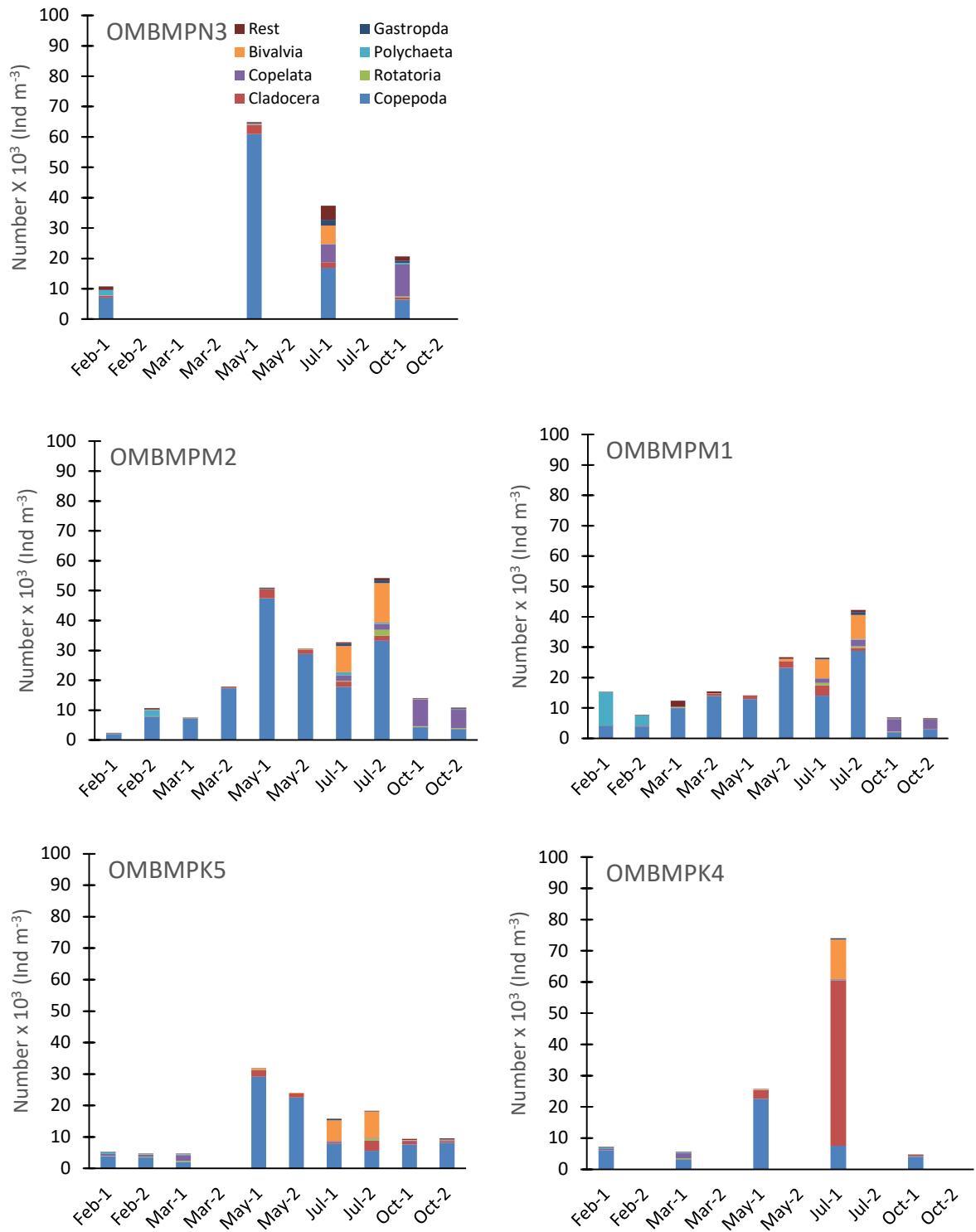
Fig. 26: Seasonal variation of the main taxonomic groups of the mesozooplankton at different stations in the investigation area in 2019 (N3 = Kiel Bight, M2 and M1 = Bay of Mecklenburg, K5 and K4 = Arkona Basin).

3.2.2 Seasonal zooplankton variation in sub-areas

Kiel Bay

The insights into the seasonal development of the zooplankton community in the Kiel Bight (OMBMP-N3) are unfortunately incomplete due to lacking spring samples in March when bad weather prevented the use of net sampling. Nevertheless, the considerable increase in zooplankton density from February to May shown in the data is rather unusual for the area and indicates a pronounced seasonal variation in 2019 (Figs. 26 and 27). In the western Baltic Sea, brackish rotifers and cladocera normally cause such a strong seasonal variation in density (see WASMUND et al. 2017b, 2018a). In contrast, fluctuations are rather uncommon in the Kiel Bight in the past because of low abundance or even absence of both groups. However, in 2019, copepoda accounted for the strong variation in 2019. In addition to this seasonality, a trend of increasing zooplankton densities in May occurring since 2015 continued also in 2019. The observed zooplankton abundance of 6.5×10^4 ind. m^{-3}, however, is unusually high because 4.0×10^4 ind. m^{-3} were barely exceeded in last decade.

The general composition of the zooplankton community resembled previous years (Fig. 26). Copepods dominated the community, but calanoid copepods were more abundant than usual (max. 4.6×10^4 ind. m^{-3}) while the cyclopoid genus *Oithona* occurred at usual densities (max. 1.5×10^4 ind. m^{-3}). Cladocera (3.0×10^3 ind. m^{-3}) and rotifers played a minor role, while the Copelata were more abundant than usual (max. 1.1×10^4 ind. m^{-3}). Meroplankton contributed primarily to the stock in winter by polychaete larvae (1.8×10^3 ind. m^{-3}) and in summer by bivalve and gastropod larvae (6.0 and 1.9×10^3 ind. m^{-3}), respectively and occurred in their usual densities. The calanoid copepods were dominated by *Acartia bifilosa* and *Oithona similis*. This reverses a trend of increasing abundance of *Pseudocalanus* spp., *Temora longicornis* and *Acartia longiremis* observed in the period 2016-2018. Particularly, *Pseudocalanus* was recorded in a considerably lower abundance in 2019 (0.7×10^3 ind. m^{-3}) than in 2018 (2.9×10^3 ind. m^{-3}). The stocks of *Acartia longiremis* were also considerably lower (0.5 vs. 1.7×10^3 ind. m^{-3}). *Temora longicornis*, *Centropages hamatus* and *Paracalanus parvus*, in contrast occurred at normal densities ($1.2 – 1.9 \times 10^3$ ind. m^{-3}).

The winter abundance of the total zooplankton was generally high (1.0×10^4 ind. m^{-3}, Fig. 26). Copepods and polychaete larvae dominated the stock (7.1 and 1.8×10^3 ind. m^{-3}). The Cladocera were represented by *Evadne nordmanni* in low numbers (658 ind. m^{-3}), while rotifers and other meroplankton was rare (<30 ind. m^{-3}). No Copelata were observed. The copepods were dominated by genus *Temora*, *Oithona* and *Acartia* ($1.5 – 2.9 \times 10^3$ ind. m^{-3}), the genera *Centropages* and *Pseudo/Paracalanus* played a minor role. Among the adults, *Temora longicornis* dominated (1.8×10^3 ind. m^{-3}) indicating the active overwintering of the species, while *Acartia bifilosa* and *Oithona similis* were less abundant ($\sim 500 \times 10^3$ ind. m^{-3}), All other species were rare.
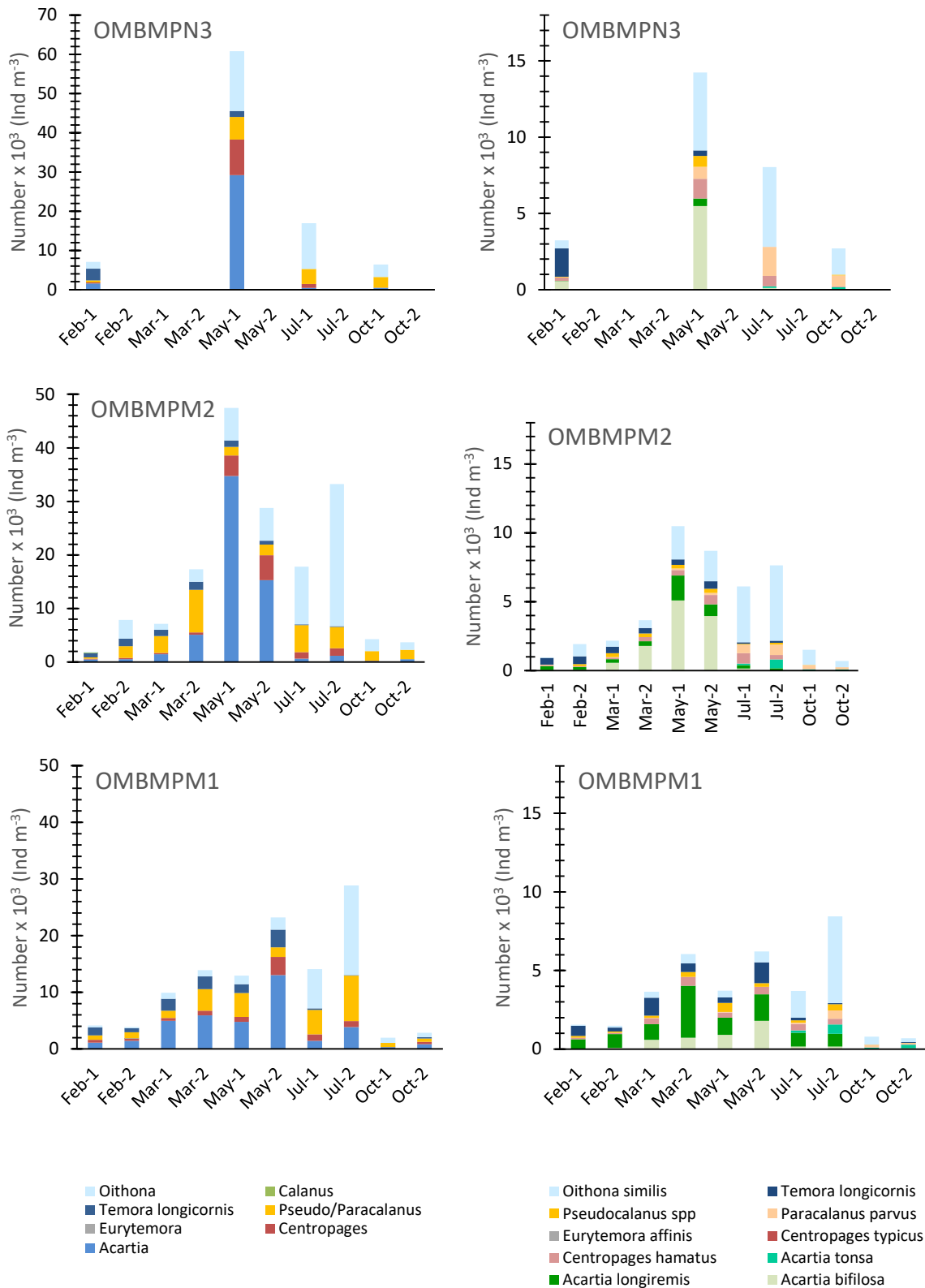
Fig. 27: Seasonal variation of the abundance and composition of juvenile (left) and adult stages of copepods (right) of different genera in 2019. Note the different scale in the abundance of juveniles and adults (continued next page) (N3 = Kiel Bight, M2 and M1 = Bay of Mecklenburg, K5 and K4 = Arkona Basin).
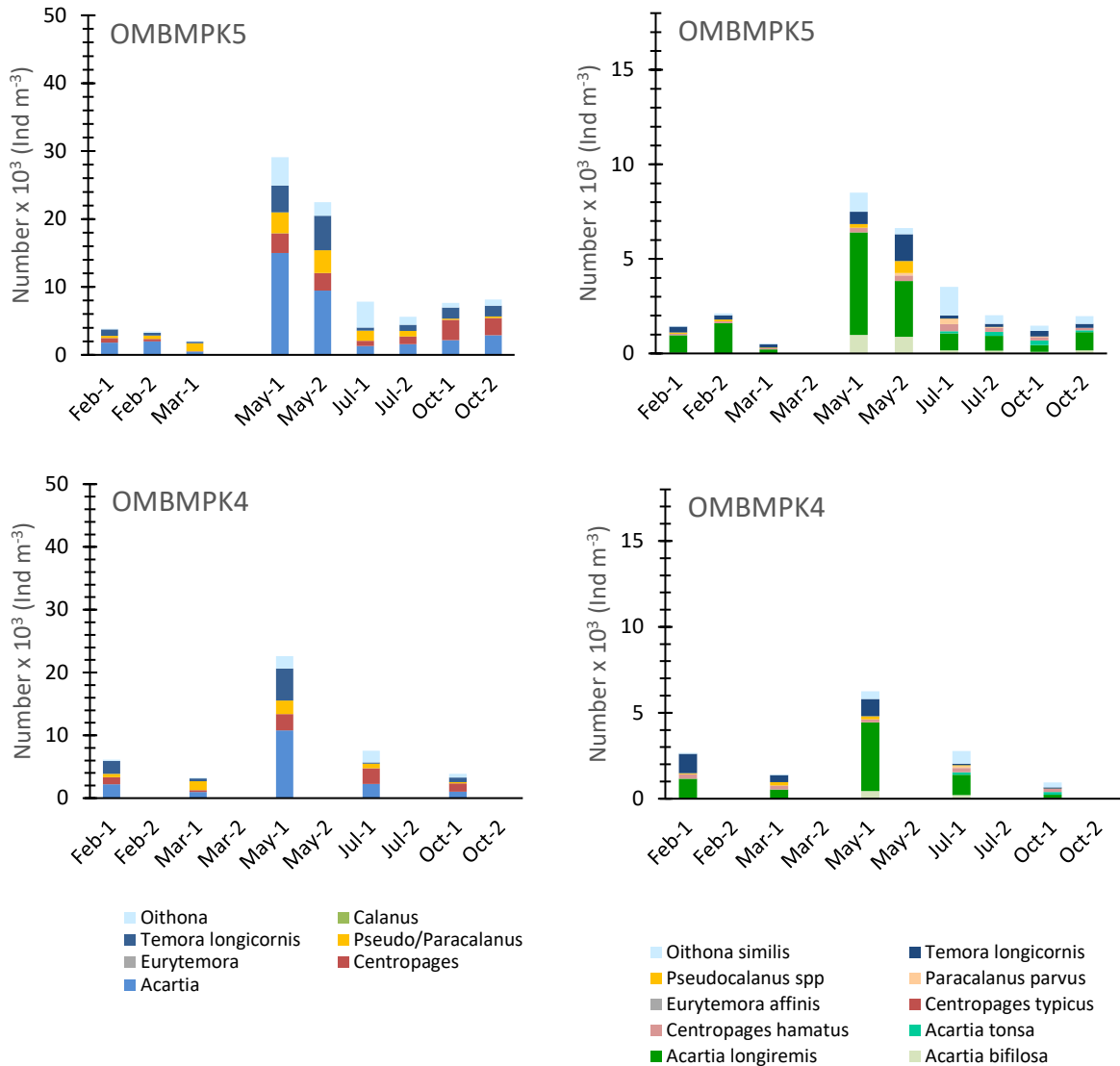
Fig. 27: continued.

In May, the considerable increase in zooplankton abundance was primarily based on the copepoda (6.1×10^3 ind. m^{-3}) and, to a lesser extent, on the cladocera (3.0×10^3 ind. m^{-3}). *Evadne nordmanni* was still the major species among the cladocera, but *Podon leuckartii* occurred at small numbers (360 ind. m^{-3}). Meroplanktonic larvae of the polychaetes nearly vanished (71 ind. m^{-3}), while bivalve and gastropod larvae remained still low (< 360 ind. m^{-3}). About 73% of the stock of copepods consisted of the genera *Acartia* and *Oithona* (2.9 and 1.5×10^4 ind. m^{-3}), *Pseudo/Paracalanus* and *Centropages* increased (5.7 and 9.1×10^3 ind. m^{-3}), while *Temora* decreased(1.5×10^3 ind. m^{-3}). Thus, it is not surprising that *Acartia bifilosa* and *Oithona similis* were also dominating the composition of the adult copepod stock (5.4 and 5.2×10^3 ind. m^{-3}). *Acartia longiremis* and *Temora longicornis* had only a minor contribution to the stock (0.5 and 0.4×10^3 ind. m^{-3}).

A strong shift in the community composition associated with a decline in abundance from late spring to summer is a typical feature of the seasonal development of the zooplankton in Kiel Bight (Figs 27 and 28). The zooplankton abundance decreased to half of the spring values (3.7×10^4 ind. m^{-3}). While copepods were still dominating, their abundance decreased considerably.

Copelata, represented by the species *Oikopleura dioica* became an important member of the community (5.9 x 10^3 ind. m^{-3}). In addition, the number of bivalve and gastropod larvae were elevated (6.0 and 1.9 x 10^3 ind. m^{-3}). The cladocera were now dominated by *Podon intermedius*, (1. 6 x 10^3 ind. m^{-3}), while *Evadne nordmanni* occurred only in small numbers. Also among the copepoda a major shift occurred. *Acartia* nearly disappeared, while *Oithona* remained as the dominant genus (1.1. x 10^4 ind. m^{-3}). *Pseudo/Paracalanus* increased in their relative contribution (3.7 x 10^3 ind. m^{-3}), while *Centropages* declined (1.1 x 10^3 ind. m^{-3}) and *Temora* disappeared. Among the adults, *Oithona similis* and *Paracalanus parvus* were abundant (5.2 and 1.9 x 10^3 ind. m^{-3}).

A further decline in the zooplankton abundance occurred towards autumn. Copepods (6.4 x 10^3 ind. m^{-3}) were replaced by Copelata - in particular *Oikopleura dioica* - as the major group (1.1 x 10^4 ind. m^{-3}). All other groups declined in abundance and had a minor contribution. Among the copepodites *Oithona* decreased (3.2 x 10^3 ind. m^{-3}), but was still the dominating genus. The abundance of *Pseudo/Paracalanus* was still high (2.7 x 10^3 ind. m^{-3}), while *Acartia* and *Centropages* had only a minor contribution (< 0.5 x 10^3 ind. m^{-3}). *Oithona similis* and *Paracalanus parvus* still dominated among the adult copepods (1.7 and 0.7 x 10^3 ind. m^{-3}).

Bay of Mecklenburg

The seasonal development of the zooplankton in the Bay of Mecklenburg (OMBMP-M2 and M1) has usually a strong similarity to the Kiel Bight and 2019 was no exception. However, some dissimilarity occurred between the two stations in the Bay with regard to stock size and species composition (Figs. 26 and 27). The western station (OMBMP-M2) displayed a strong seasonality with a considerable increase in the stock size from March to May (max. 5.1 x 10^4 ind. m^{-3}) observed in the Kiel Bight. However, the high total abundance is not unusual in the area. At station OMBMP-M1, in contrast, this increase was lacking. Copepods dominated the zooplankton community at both stations (max. 4.7 x 10^4 ind. m^{-3}). Rotifers and cladocera were minor component in the Bay of Mecklenburg (< 1.9 and 3.0 x 10^3 ind. m^{-3}, respectively). This indicates that the large contribution of both groups to the zooplankton in 2018 was an exceptional observation. The late occurrence of rotifers in summer, however, is unusual since the group has elevated levels of abundance regularly in late spring. The community composition of copepods at station OMBMP-M2 also resembled largely that in Kiel Bight. *Acartia* was the dominant genus in spring (max. 3.4 x 10^4 ind. m^{-3}) with a subsequent shift in the community composition to *Oithona* and *Pseudo/Paracalanus* (max. 1.8 and 0.9 x 10^4 ind. m^{-3}). Both *Acartia bifilosa* and *Oithona similis* were dominant species (max. 5.1 and 5.5 x 10^3 ind. m^{-3}). In contrast, at OMBMP-M1 the seasonality in copepods and the dominance of *Acartia* were less pronounced (max. 1.3 x 10^4 ind. m^{-3}), and *A. longiremis* replaced *A. bifilosa* as the major species (max. 1.7 x 10^4 ind. m^{-3}). Meroplankton achieved high concentrations and was diverse (see 3.2.1).

The overwintering stocks were as usual low (1.9 - 8.1 x 10^3 ind. m^{-3}). Similar to the Kiel Bight, copepods (1.9 – 7.9 x 10^3 ind. m^{-3}) and polychaete larvae (0.2 - 1.1 x 10^3 ind. m^{-3}) dominated, and the latter achieved high concentrations at station OMBMP-M1. All other groups were rare. Among

the copepods *Temora* (0.7 – 1.4 x 10^3 ind. m^{-3}), *Acartia* (0.5 – 1.1 x 10^3 ind. m^{-3}) and *Pseudo/Paracalanus* (0.2 – 2.1 x 10^3 ind. m^{-3}) were abundant, with *Temora longicornis* and *Acartia longiremis* were dominating the adult community (Fig. 27).

The total zooplanktons stock increased already in early spring (0.8 – 1.8 x 10^4 ind. m^{-3}) which is based on the increase in copepods (0.7 - 1.7 x 10^4 ind. m^{-3}), while the polychaetes largely disappeared (< 110 x ind. m^{-3}). The rotifer *Synchaeta* spp and the cladoceran *Podon leuckartii* had also only a small contribution to the zooplanktons (< 800 ind. m^{-3}). The genera *Temora* (1.1– 2.3 x 10^3 ind. m^{-3}), *Acartia* (1.4 – 5.9 x 10^3 ind. m^{-3}) and *Pseudo/Paracalanus* (1.2 – 7.9 x 10^3 ind. m^{-3}) were still the most abundant copepods, but also the stocks of *Oithona* started to increase (1.1 – 2.3 x 10^3 ind. m^{-3}). Among the adults, *A. bifilosa* (0.6 – 1.8 x 10^3 ind. m^{-3}) and *A. longiremis* (1.0 – 3.1 x 10^3 ind. m^{-3}) were dominating at stations OMBMP-M2 and –M1, respectively.

Copepods were primarily responsible for the increase of the zooplanktons stock in May (2.6 – 5.1 x 10^4 ind. m^{-3}, Figs. 27 and 28). The increase was more pronounced at station OMBMP-M2 than at station OMBMP-M1, but in both areas based on the genus *Acartia* (1.3 – 3.4 x 10^4 ind. m^{-3}) and - to a lesser extent on the genus *Oithona* (1..5 – 6.1 x 10^3 ind. m^{-3}). The contribution of *Temora* (0.7 – 1.3 x 10^3 ind. m^{-3}), *Centropages* (0.8 - 4.6 x 10^3 ind. m^{-3}) and *Pseudo/Paracalanus* (1.6 – 4.1 x 10^3 ind. m^{-3}) was minor. *A. bifilosa* (3.9 -5.0 x 103 ind. m^{-3}) and *A. longiremis* (1.1 – 3.3 x 10^3 ind. m^{-3}) still dominated the zooplanktons at stations OMBMP-M2 and –M1, respectively. Apart from copepods, the cladocerans *Evadne nordmanni* and *Podon intermedius* (0.2 – 2.0 x 10^3 ind. m^{-3}) contributed to the zooplanktons. All other groups were still marginally important.

In contrast to Kiel Bight, zooplanktons stocks remained high in summer (2.6 – 5.4 x 10^4 ind. m^{-3}) and copepods did not show the considerable decline (Figs. 26 and 27). In addition, meroplankton contributed considerably to the community. While bivalve larvae dominated this group (0.6 – 1.3 x 10^4 ind. m^{-3}), polychaete, gastropod and crustacean larvae were an important component as well. In addition, the *Oikopleura dioica* (1.8 – 4.1 x 10^3 ind. m^{-3}) and *Synchaeta* spp. (0.5- 1.9 x 10^3 ind. m^{-3}) got abundant as well. The copepod community displayed a major shift due to the decline in *Acartia* (0.6 -3.8 x 10^3 ind. m^{-3}) and a simultaneous increase in *Oithona* (0.9 - 1.1 x 10^4 ind. m^{-3}) and *Pseudo/Paracalanus* (4.0 - 8.0 x 10^3 ind. m^{-3}). *Oithona similis* was the most important single species (1.6 – 5.5 x 10^3 ind. m^{-3}), followed by *Paracalanus parvus* (max. 625 ind. m^{-3}) and *Centropages hamatus* (max. 740 ind. m^{-3}).

The zooplankton abundance declined in autumn. Similar to Kiel Bight, copepods (1.9 – 4.3 x 10^3 ind. m^{-3}) were replaced by *Oikopleura dioica* (3.1 – 8.8 x 10^3 ind. m^{-3}). All other groups declined in abundance and had a minor contribution.

Arkona Basin

The zooplankton abundance in the Arkona Basin was low. With the exception of station OMBMP-K4 (7.9 x 10^4 ind. m^{-3}) during summer, the concentration did not exceed 3.2 x 10^4 ind. m^{-3} (Fig. 26). This is primarily attributed to the lack of high densities of rotifers in spring and the restriction of high densities of the cladoceran *Bosmina* spp. to the eastern part of the basin. This is not

uncommon for the area and has been observed in the years 2012 and 2016 as well. However, peak concentrations of these groups might have been missed due to infrequent sampling because their occurrence can be short-lived. Due to the lack of these important brackish-water zooplankters, copepods were the dominating group during most of the seasons (2.2 - 2.9 x 10^4 ind. m^{-3}). In autumn, bivalve larvae achieved high concentrations as well (max. 1.3 x 10^4 ind. m^{-3}).

Winter stocks were typically low (4.6 – 6.7 x 10^3 ind. m^{-3}) and dominated by the copepods (3.4 – 5.9 x 10^3 ind. m^{-3}). In contrast to the Kiel Bight and the Bay of Mecklenburg, polychaete larvae had a minor contribution only (200 – 500 ind. m^{-3}) and were replaced by *Fritellaria borealis* (Copelata, 513- 660 ind. m^{-3}) as second most important group (Fig 26). All other tax were rare. The copepods mainly consisted of the genera *Acartia*, *Temora* and *Centropages* (0.9 – 2.1 x 10^3 ind. m^{-3}), and among the adults *Acartia longiremis* (0.9 – 1.2 x 10^3 ind. m^{-3}) and *Temora longicornis* (0.3 – 1.1 x 10^3 ind. m^{-3}) dominated (Fig. 27).

The stocks remained low in March (4.6 – 5.6 x 10^3 ind. m^{-3}). While the copepoda had similar concentrations than in winter (2.0 – 3.1 x 10^3 ind. m^{-3}), *Fritellaria borealis* increased (1.6 – 1.9 x 10^3 ind. m^{-3}) similar to the rotifer Synchaeta (230 - 322 ind. m^{-3}). Polychaetes larvae were still present (253 - 295 ind. m^{-3}). The contribution of genera *Acartia* and *Temora* declined among the copepodites (249 - 986 ind. m^{-3}), *Pseudo/Paracalanus* increased (1.2 – 1.5 x 10^3 ind. m^{-3}). *Acartia longiremis* (0.9 – 1.2 x 10^3 ind. m^{-3}) and *Temora longicornis* (0.3 – 1.1 x 10^3 ind. m^{-3}) still dominated the adult copepod community.

The major increase in zooplankton stocks (2.4 – 3.1 x 10^4 ind. m^{-3}) occurred from March to May and was - as usual - delayed in comparison to contrast to the Kiel Bight and the Bay of Mecklenburg (Figs 26 and 27). The calanoid and cyclopoid copepods primarily accounted for this increase (2.2 – 2.9 x 10^4 ind. m^{-3}), but the cladocerans *Evadne nordmanni* and *Podon leuckartii* got also abundant (0.9 - 1.5 x 10^3 ind. m^{-3}). Maxima of the in previous years dominant *Synchaeta* spp. were lacking in 2019. In addition, *Fritellaria borealis* had vanished from the plankton. The copepod stock was dominated by *Acartia* (0.9 – 1.4 x 10^4 ind. m^{-3}) which is typical for the area. *Oithona*, *Pseudo/Paracalanus*, *Temora* and *Centropages* all increased in abundance (range 1.5 – 5.1 x 10^3 ind. m^{-3}). *Acartia longiremis* was the single most important species (2.9 – 5.4 x 10^3 ind. m^{-3}), followed by *Oithona similis* (0.3 – 1.1 x 10^3 ind. m^{-3}) and *Temora longicornis* (0.6 – 1.4 x 10^3 ind. m^{-3}). *Pseudocalanus* spp. and *Paracalanus parvus* were rare as in previous years.

The zooplankton already decreased during summer (1.5 -1.8 x 10^4 ind. m^{-3}), with the exception of the high concentration of the cladoceran *Bosmina* spp. at station OMBMP-K4 (total 7.3 x 10^4 ind. m^{-3}, Bosmina 5.1 x 10^4 ind. m^{-3}). Copepods were not the dominant group anymore, and were regularly outnumbered by high concentrations of planktonic larvae of the Bivalvia (0.6 – 1.3 x 10^4 ind. m^{-3}). The cladocerans *Evadne nordmanni* and *Podon intermedius* (0.1 – 1.1 x 10^3 ind. m^{-3}) occurred regularly as well as the larvae of gastropods (160 - 315 ind. m^{-3}). Copelata appeared again, but *Fritellaria borealis* was replaced by *Oikopleura dioica* (220 – 412 ind. m^{-3}). The genus *Acartia* declined considerably, and contributed equally to *Centropages* and *Oithona* to the copepod stock (1.2 – 1.8 x 10^3 ind. m^{-3}). *Acartia longiremis* (0.8 – 1.2 x 10^3 ind. m^{-3}) and *Oithona similis* (0.3 – 1.5 x 10^3 ind. m^{-3}) were the dominant species followed by and *Centropages hamatus*

(0.2 – 0.4 x 10^3 ind. m^{-3}). *Pseudocalanus* spp. and *Paracalanus parvus* were still rare, and *Acartia tonsa* appeared at low densities.

Autumn stocks were again low (4.7 – 9.8 x 10^3 ind. m^{-3}) and were dominated by copepods (3.9 - 8.1 x 10^3 ind. m^{-3}). The cladocerans *Evadne nordmanni* and *Podon leuckartii* (44 – 790 ind. m^{-3}) and *Oikopleura dioica* (231 – 300 ind. m^{-3}) were other groups of importance. *Acartia*, *Centropages*, *Temora* and *Oithona* equally contributed to the copepods (0.6 - 2.9 x 10^3 ind. m^{-3}) and no single species dominated.

3.2.3 Long-term trends

Since 2010, the stock size of zooplankton has remained on a very low level compared to the preceding decade (Fig. 28 a). This is clearly depicted by the annual anomalies in the maximum abundance of the zooplankton, which shows strongly negative values for the period 2012-2019 (Fig. 28 b). A minimum was achieved in 2016, but since then no clear recovery occurred. The total abundance of 1.1 x 10^5 ind. m^{-3} in 2019 was the second lowest value recorded and accounted only for one third of the long-term average of 3.2 x 10^5 ind. m^{-3}. The decline is most pertinent for the groups of rotifers and cladocera which are distinguished from the copepoda by their ephemeral peak concentrations. Thus, caution needs to be taken in the interpretation of the changes, because shifts in timing and in abundance cannot be fully assessed with the current sampling frequency. Nevertheless, in 2019 the maximum stock of rotifers achieved 2% of the long-term average only. The stock size of Cladocera accounted for 40% of the long-term average. Copelata and the diverse groups of meroplankton, on the other hand, show some strong fluctuations in the past, but no clear long-term trend.

The long-term variation in the species abundance and composition of adult calanoid copepods displays a similar decline since 2010 (Fig. 28 c). Apart from *A. longiremis* and *A. bifilosa*, nearly all copepod species display a decline, but *Pseudocalanus* spp, *Temora longicornis* and *Centropages hamatus* appear to be affected most.
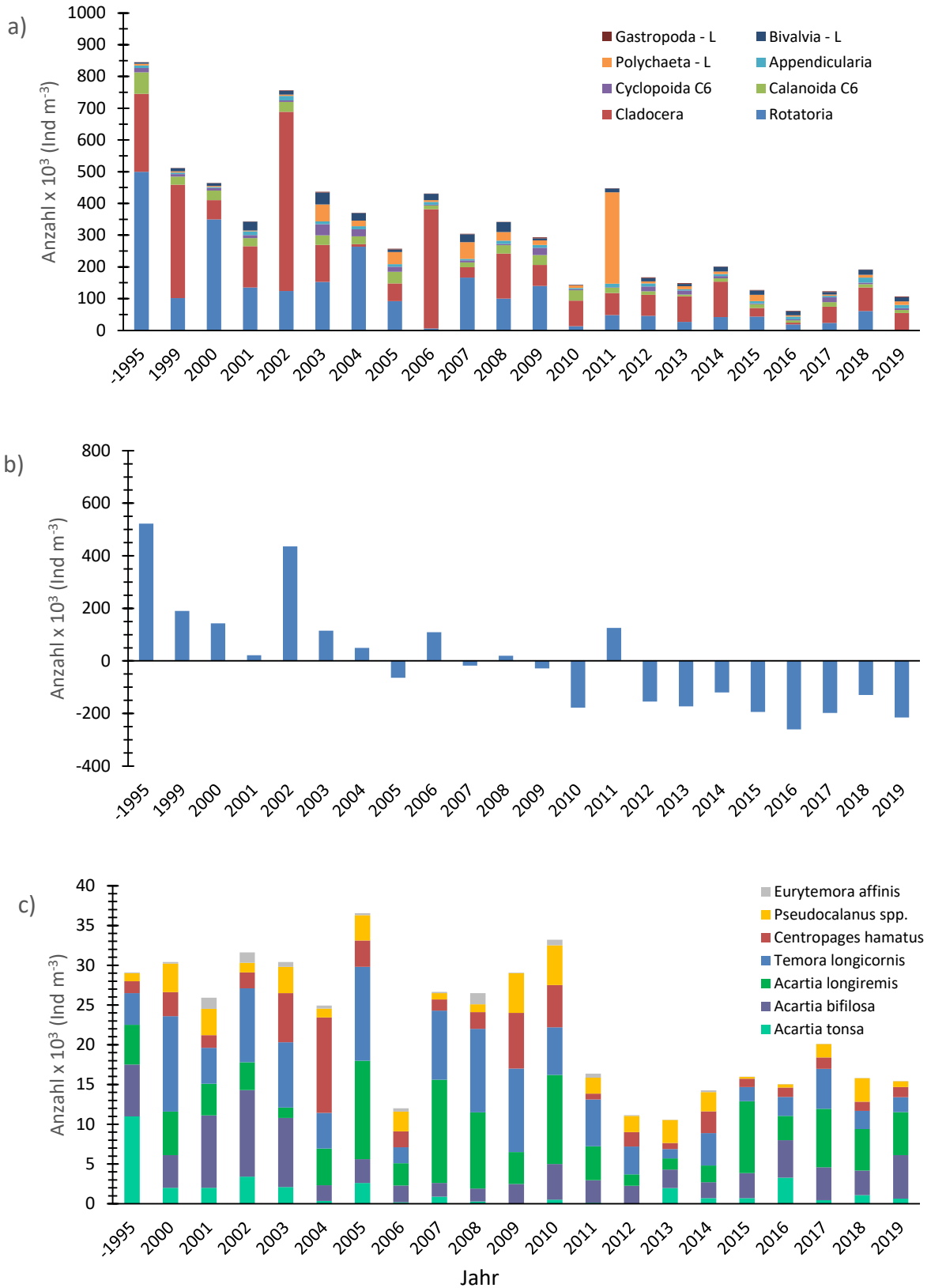
Fig. 28: Long-term trends in the maximal abundance of a) holoplanktonic taxa (Rotatoria, Cladocera, Cyclopoida, Calanoida, Copelata) and meroplanktonic taxa (Polychaeta, Bivalvia, Gastropoda), b) in the anomalies of the total zooplankton abundance and c) of seven calanoid copepod species in the years 1995 to 2019.

3.3   Macrozoobenthos

3.3.1 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 8). At all station almost the whole year a good oxygen supply was observed. Only in the in the Mecklenburg Bight the oxygen content was lower than 1 ml/l in October.

Table 8: Abiotic parameters at 8 monitoring stations in autumn 2019 (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	1.28	228	6.1	19.8	fine to middle sand
OMBMPN1	2.73	284	1.93	24.3	muddy sand
OMBMPM2	8.40	28	0.89	24.2	mud
OM18	2.27	126	6.28	16.1	muddy sand
OMBMPK8	0.38	217	5.12	15.2	fine sand
OMBMPK4	13.35	31	2.85	17.8	mud
OMBMPK3	0.56	217	4.24	11.7	fine sand
OM160	0.24	187	10.81	8.2	fine sand

For almost all stations the salinity ranged in an average value. The autumn bottom water salinity ranged from west to east between 24.3 and 8.2 psu (Table 8).

3.3.2 Macrozoobenthos at the stations

In October 2019, 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 medium to high at 129 (Table A3, Fig. 29 and 32). At four stations (N3, N1, M2, K8) we observed higher diversity as the median. Only at station 018 the diversity was lower as the mean, at the other stations the diversity was comparable to the long term average (Fig. 29). As in the years before the ocean quahog *Arctica islandica* reached high abundances and biomasses, especially at the western stations (Fig. 30)

Fig. 29: Number of species (columns) of macrozoobenthos at 8 monitoring stations in October 2019. The median values of the years 1991 to 2019 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).

Fig. 30: The dredge sample of the Mecklenburg Bay (OMBMPM2) was dominated by Arctica islandica.

Contrary to the previous year a general recovery of the benthic stock was observed. Additionally, for almost all stations new species (never observed during the last 20 years at these stations) were found. These species are listed below:

=›OMBMPN3: *Thracia phaseolina*, *Phyllodoce groenlandica*, *Spirorbis corallinae*, *Carcinus maenas*, *Mesopodopsis slabberi*, *Pontoporeia femorata*, *Ophiura ophiura*
=›OMBMPN1: *Alvania punctura* (Fig. 31), *Echinocyamus pusillus*, *Ophiura ophiura*
=›OMBMPM2: *Onchidoris muricata*, *Laonome kroyeri*
=›OM18: *Tritia reticulata*
=›OMBMPK8: *Nereimyra punctata*
=›OMBMPK4: *Balanus crenatus*
=›OMBMPK3: *Nephtys caeca*, *Nephtys hombergii*, *Spio goniocephala*
=›OM160: none
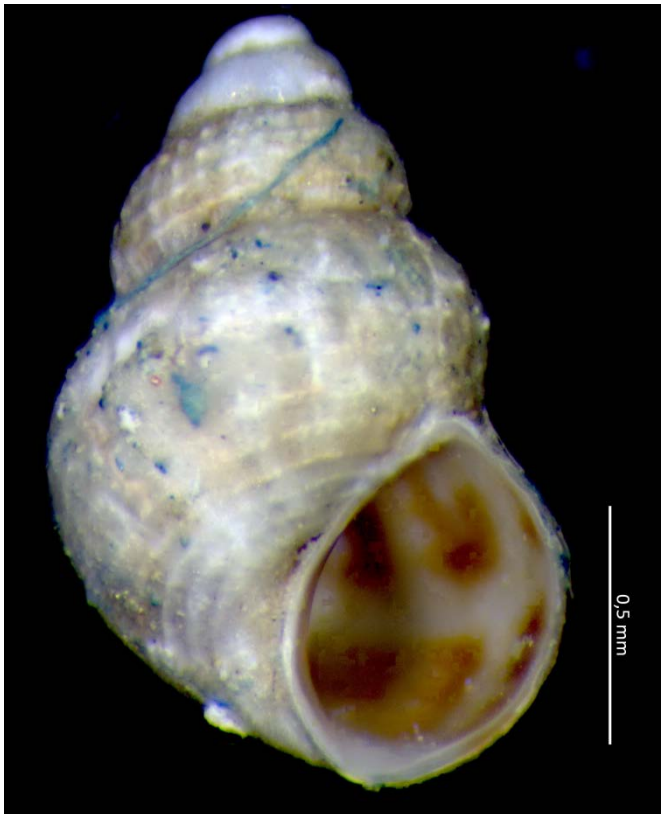
Fig. 31: Alvania punctura *was observed the first time in the monitoring program (here Fehmarnbelt) and probably also the entire Baltic Sea (see ZETTLER et al. 2018).* A. punctura *has a wide distribution including the western part of the Mediterranean Sea, the Atlantic coast of Spain, and the English and Scandinavian coasts up to the Barents Sea (NEKHAEV 2013 and references therein).*
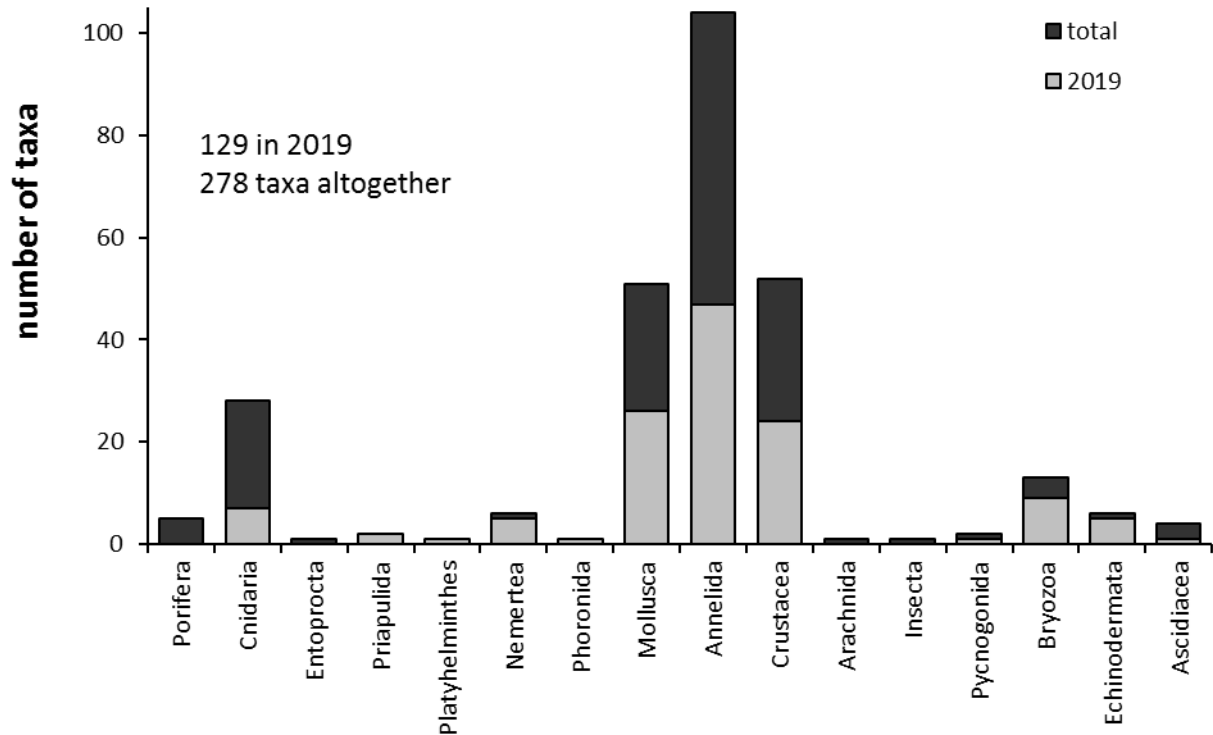
Fig. 32: Taxonomical classification of macrozoobenthos at 8 monitoring stations in October 2019. The species number of the entire monitoring from 1991 to 2019 is also indicated.

Figure 32 gives the taxa found at our 8 monitoring stations in 2019 as well as the total number of species found in measurements since 1991. Not just in 2019 (see ZETTLER et al. 2014, 2018), the Annelida (Polychaeta and Oligochaeta) emerged as the group that is richest in species, numbering 104; in 2019, 47 species were identified. Other species-rich groups in 2019 were Mollusca (26), Crustacea (24), Cnidaria (7) and Bryozoa (9).

Depending on the sea area, abundances varied between 717 (Arkona Basin) and 6.650 ind./m² (Kiel Bay) (Fig. 33, Table A3). Only in the Pomeranian Bay (OMBMP160) the abundance was decreased compared with previous years (Fig. 33). At all other stations (except Fehmarnbelt OMBMPN1) the abundance remained similar or is something higher to the median values of the last decades. In the Fehmarnbelt the abundance was significantly higher as the long term median.

Which species was dominant in a given sea area varied greatly; it depended essentially on salinity and substrate. While the polychaetes *Dipolydora quadrilobata*, *Lagis koreni* and *Scalibregma inflatum* accounted for over 50 % of density in Kiel Bay (OMBMPN3), *Ampharete baltica* and *Diastylis rathkei* dominated the abundance in the southern Mecklenburg Bight (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) the mud snail *Peringia ulvae*, the bivalve *Limecola balthica* and the polychaete *Ampharete baltica* were most frequent. In the Pomeranian Bay (OM160) *Pygospio elegans*, the bivalves *Mya arenaria* and *Mytilus edulis* and the mud snail *Peringia ulvae* accounted for high abundance. At the central Mecklenburg Bay (OMBMPM2) bivalves *Corbula gibba* and *Kurtiella bidentata* dominated the

community. The polychaete *Scalibregma inflatum* reached more than 76% of the abundance of the station in the Fehmarnbelt area (OMBMPN1). In the northern Pomeranian Bay (OMBMPK3) the spionid *Pygospio elegans* (64%) dominated the community.
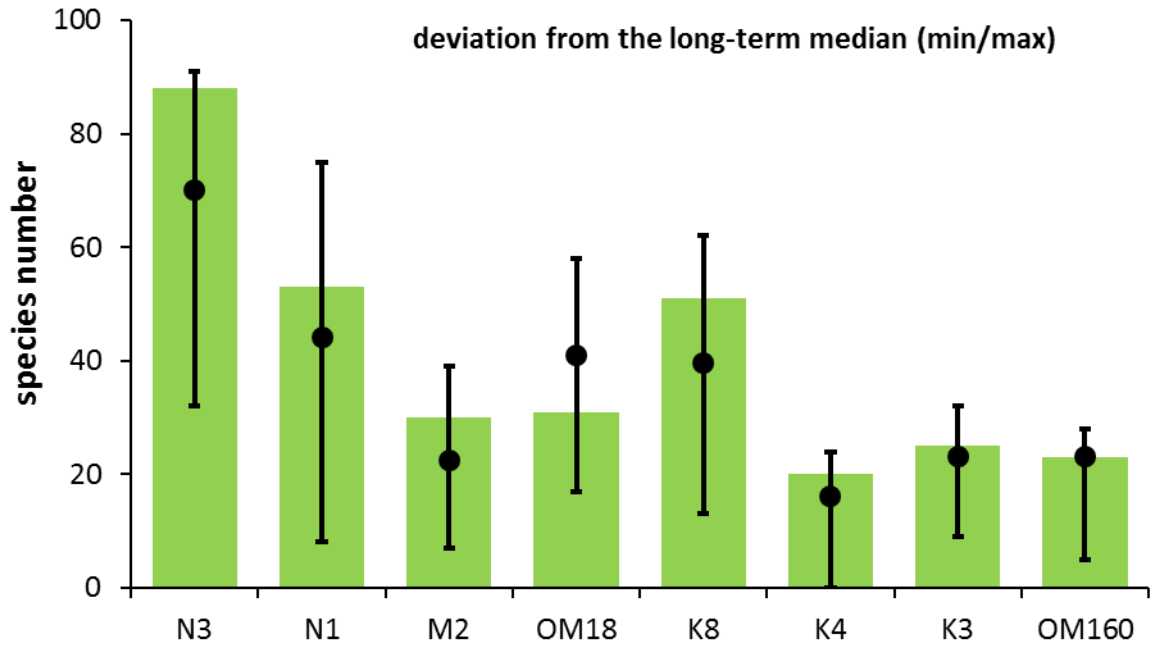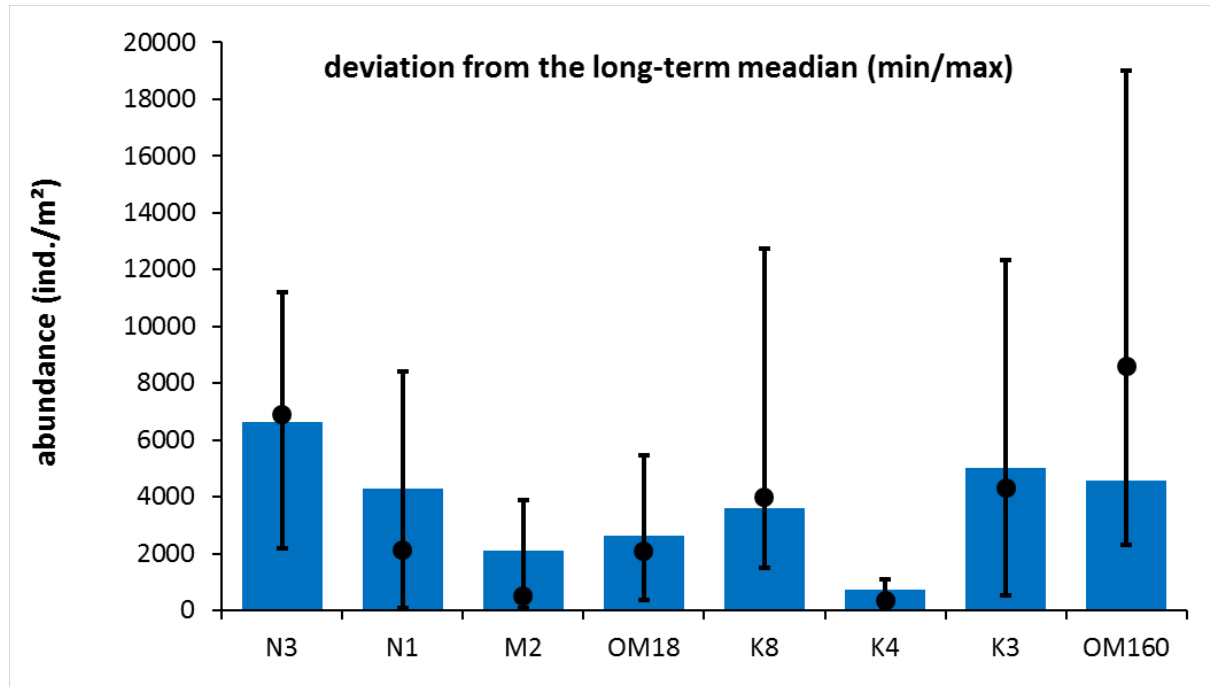

Fig. 33: Total abundances (columns) of macrozoobenthos at 8 monitoring stations in October 2019. The median values of the years 1991 to 2019 are shown as dots; the minimum and maximum values are indicated as interval.

Compared with their long-term averages six stations show similar or even higher total biomass than in the years before (Fig. 34). Significant lower than the long term mean were the values in the Kiel Bay (OMBMPN3) and the northern Pomeranian Bay (OMBMPK3). Obviously due to higher productivity of *Mya arenaria* during the last year the biomass value increased rapidly in the Pomeranian Bay (OMBMP160).

The highest biomass was observed at the Kiel Bay station (OMBMPN3) although much lower as the mean (Fig. 34). 56.7 g afdw/m² was measured, consisting of 65.5 % *Astarte borealis* (37.1 g afdw/m²) and 26.6 % *Arctica islandica* (15.1 g afdw/m²). At stations in the Fehmarnbelt and Mecklenburg Bay 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 Mecklenburg Bay (OMBMPM2), *Arctica islandica* contributed as much as 88 % and 66 % to the biomass respectively; total values between 33.8 and 7.2 g afdw/m² were obtained there, respectively. At Darss Sill (OMBMPK8), biomass (17.1 g afdw/m²) was dominated by the bivalve *Astarte borealis* (53.8 %) and the bivalve *Limecola balthica* (11.8 %). In the Arkona Basin, (OMBMPK4), *Limecola balthica* accounted for 32.3 % of the total biomass (0.6 g afdw/²). In the dredge hol also large *Arctica islandica* were found (Fig. 35) however not in the grab samples, where this species only contributed 1 % to the biomass. In the north of the Pomeranian Bay

(OMBMPK3), 2.1 g of total biomass was measured, made up of 35.4 % *Limecola balthica* and 29 % *Scoloplos armiger*. Further east in the central Pomeranian Bay (OM160; 24.6 g afdw/m²) *Mya arenaria* (85.8 %) was prominent.
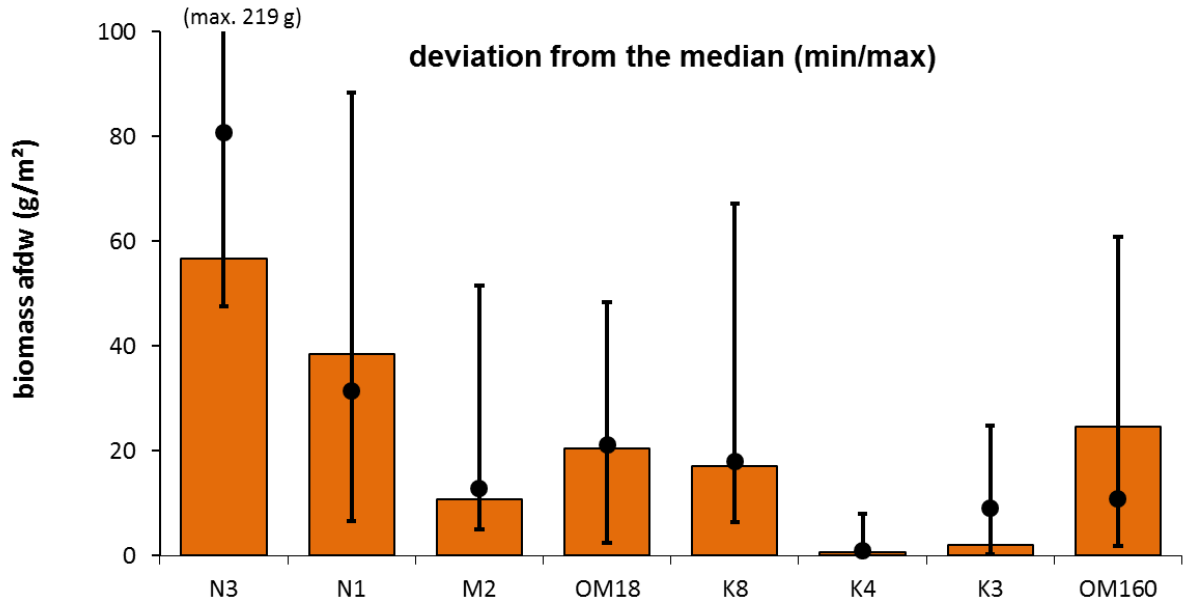
Fig. 34: *Total biomasses (columns) of macrozoobenthos at 8 monitoring stations in October 2019. The median values of the years 1991 to 2019 are shown as dot and the minimum and maximum values are indicated as interval.*

Fig. 35: In 2019 the dominant species of the dredge sample in the Arkona Basin (OMBMPK4) was Limecola balthica *and regarding to biomass also* Arctica islandica.

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. 33 and 34. Basically fluctuations relate to the population dynamics of long-living species (molluscs mostly). Another general 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 were not evidently visible in the analysis of the data. Nevertheless, impacts or effects on the benthic community of for example bottom trawling cannot be excluded, although and because it was not an object of the present study.

3.3.3 Long-term trends

The Figs. 36 to 38 present a follow-up to the corresponding presentations of the monitoring report from 2018 and earlier (WASMUND et al. 2019a) of long-term trends of species number, abundance and biomass of macrozoobenthos at the 8 monitoring stations.

Figure 36 shows the relative **number of species** (see also previous reports). As expected, species diversity falls from west to east (Kiel Bay OMBMPN3 to Pomeranian Bay OM160). During the considered period of the last 14 years, 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 dramatic 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. In the last year (2019) the overall diversity was medium to high (see also chapter 3.2.2). The sum of the species number at all stations reached the fifth highest value within the last 14 years (Fig. 36).
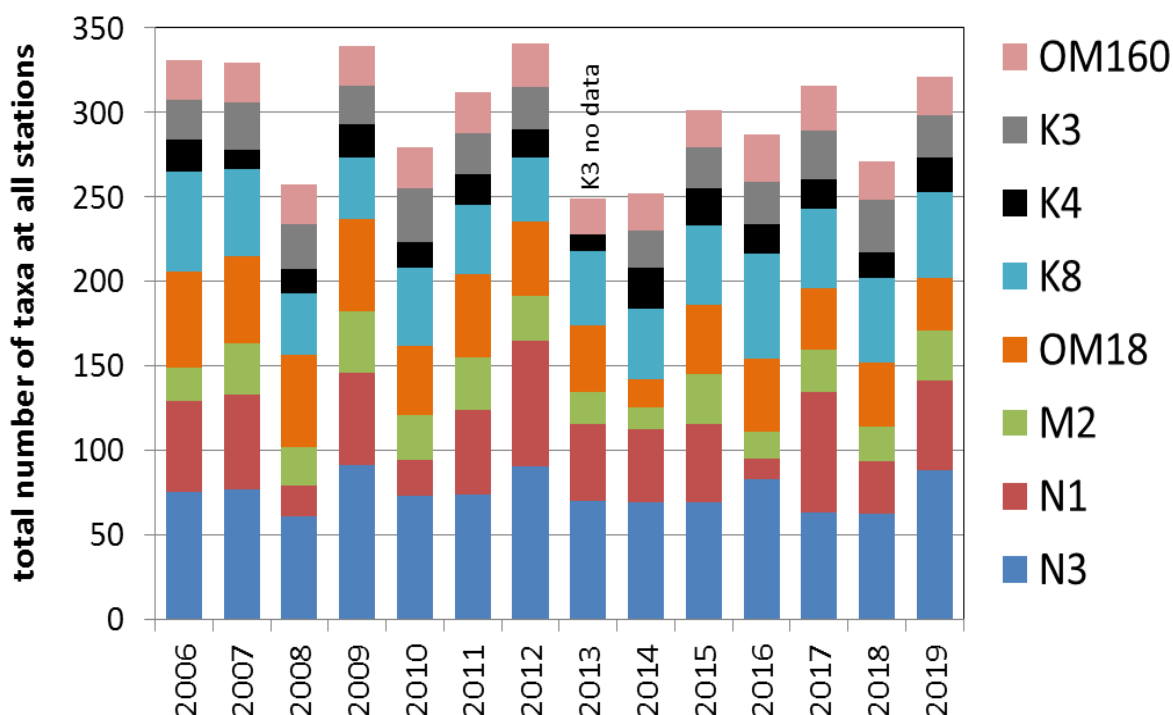
Fig. 36: Cumulative number of taxa of macrozoobenthos at 8 monitoring stations from 2006 to 2019. The stations are arranged within the columns from west to east (Kiel Bay = OMBMPN3 to Pomeranian Bay = OM160).

In terms of **abundance**, the situation is similar (Fig. 37). 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. Although also very variable interannually, the stations in the Pomeranian Bay (OM160, OMBMPK3) are least affected by lack of oxygen during the years. In 2019 the overall abundance of all stations was of mediocre value (Fig. 37).
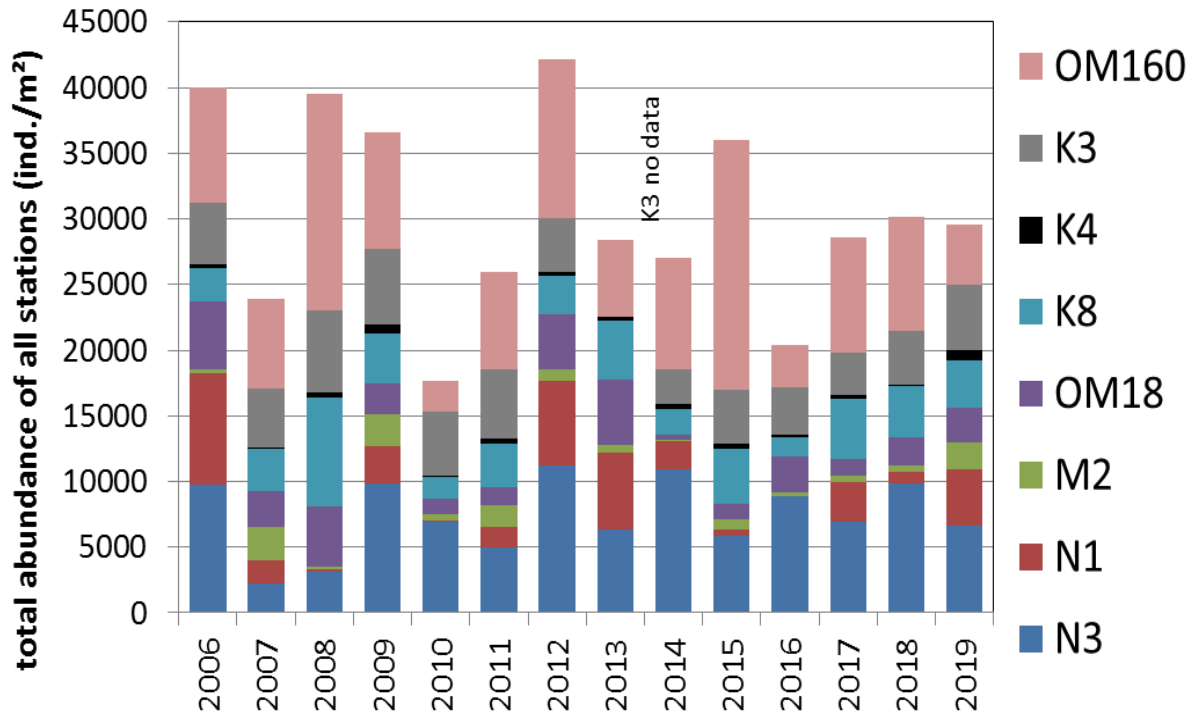
Fig. 37: Cumulative abundance of macrozoobenthos at 8 monitoring stations from 2006 to 2019. The stations are arranged within the columns from west to east (Kiel Bay = OMBMPN3 to Pomeranian Bay = OM160).

Figure 38 illustrates the long-term trend in **biomass**. Firstly, it is obvious that 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 2014-2019). 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 a 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 2019 was relatively low and in the range of the last 5 years.
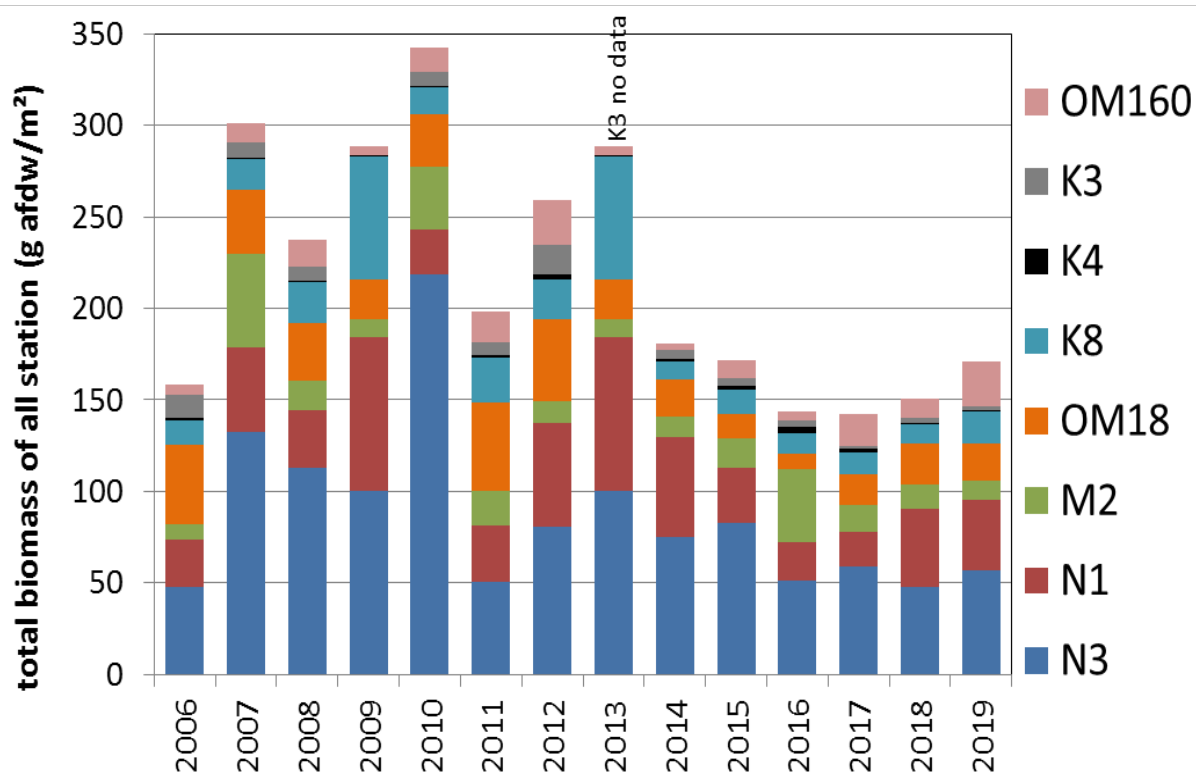
Fig. 38: Cumulative biomass of macrozoobenthos at 8 monitoring stations from 2006 to 2019. The stations are arranged within the columns from west to east (Kiel Bay = OMBMPN3 to Pomeranian Bay = OM160).

For a detailed assessment of long-term trends since 1980 we refer to our study on variation in benthic long-term data of transitional waters (ZETTLER et al. 2017) and to last year's monitoring report (WASMUND et al. 2019a). In these studies, 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).

3.3.4 Red list

This section refers to the Red List of bottom-dwelling invertebrates by RACHOR et al. (2013). Of a total of 129 species, 14 are classed as threatened (1, 2, 3, G) (Fig. 39, Table A3). Four species are classed as being near threatened. Three species are categorised as extremely rare. Currently, 75 species are classed as being of least concern. Data are deficient for 14 species, and 19 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. 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 2019 were distributed across almost all sea areas: 9 species in Kiel Bay (OMBMPN3), 5 at the Fehmarnbelt (OMBMPN1), 1 at the Mecklenburg Bay (OMBMPM2), 5 at southern Mecklenburg Bay (OM18), 3 at the Darss Sill (OMBMPK8), 1 in Arkona Basin (OMBMPK4) and 1 in northern Pomeranian Bay (OMBMPK3). The polychaete *Travisia forbesii* (Fig. 40) belongs to this category G and was found at the Darss Sill (OMBMPK8) and in the 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 2019.
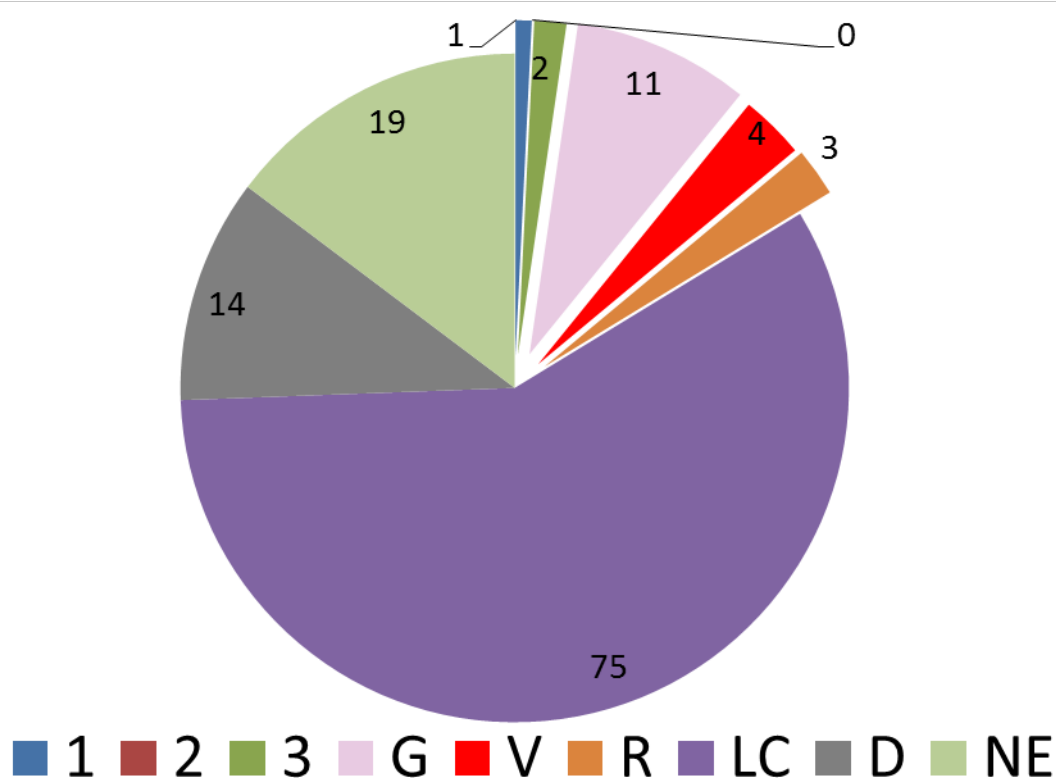
Fig. 39: Percentage of red list categories (RACHOR et al. 2013) in relation to macrozoobenthos in autumn 2019 (1=critically endangered, 2=endangered, 3=vulnerable, G=probably vulnerable, V=near threatened, R=extremely rare, LC=least concern, D=data deficient, NE=not evaluated).

Fig. 40: The small polychaete Travisia forbesii, *a red listed species of the category G (probably vulnerable).*
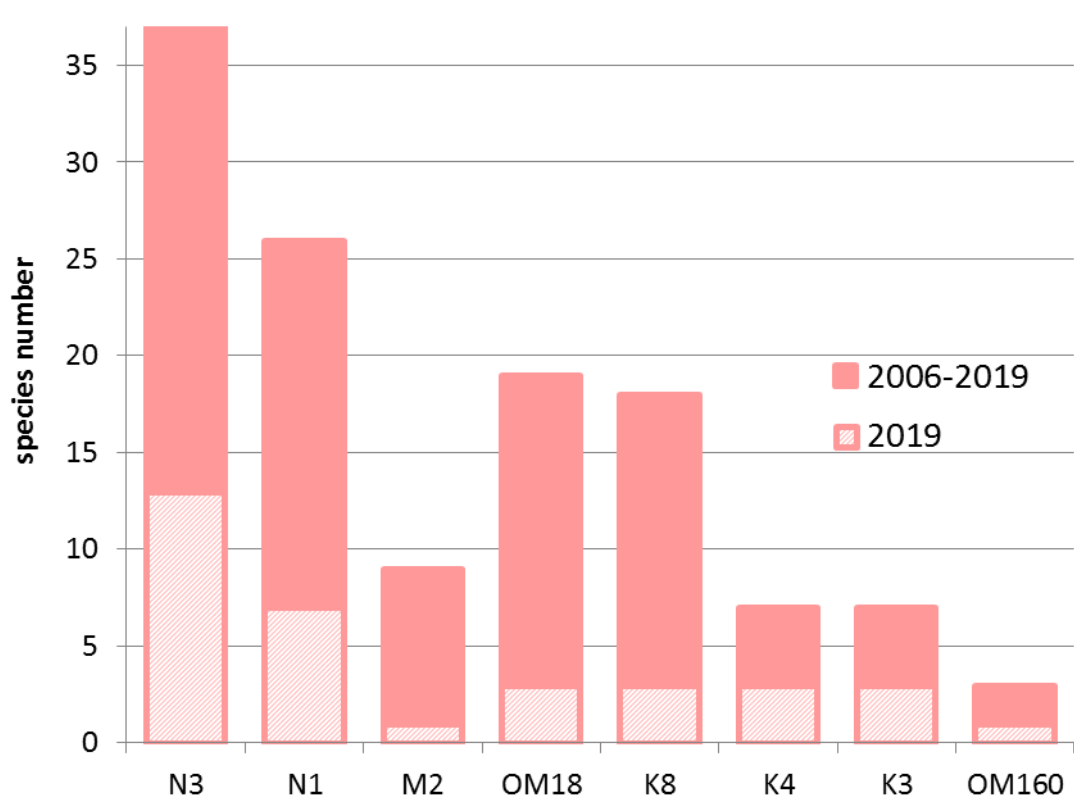
Fig. 41: Number of red listed species (categories 1, 2, 3, G, V and R) (RACHOR et al. 2013) at the 8 monitoring stations in 2019 and in total (2006-2019).
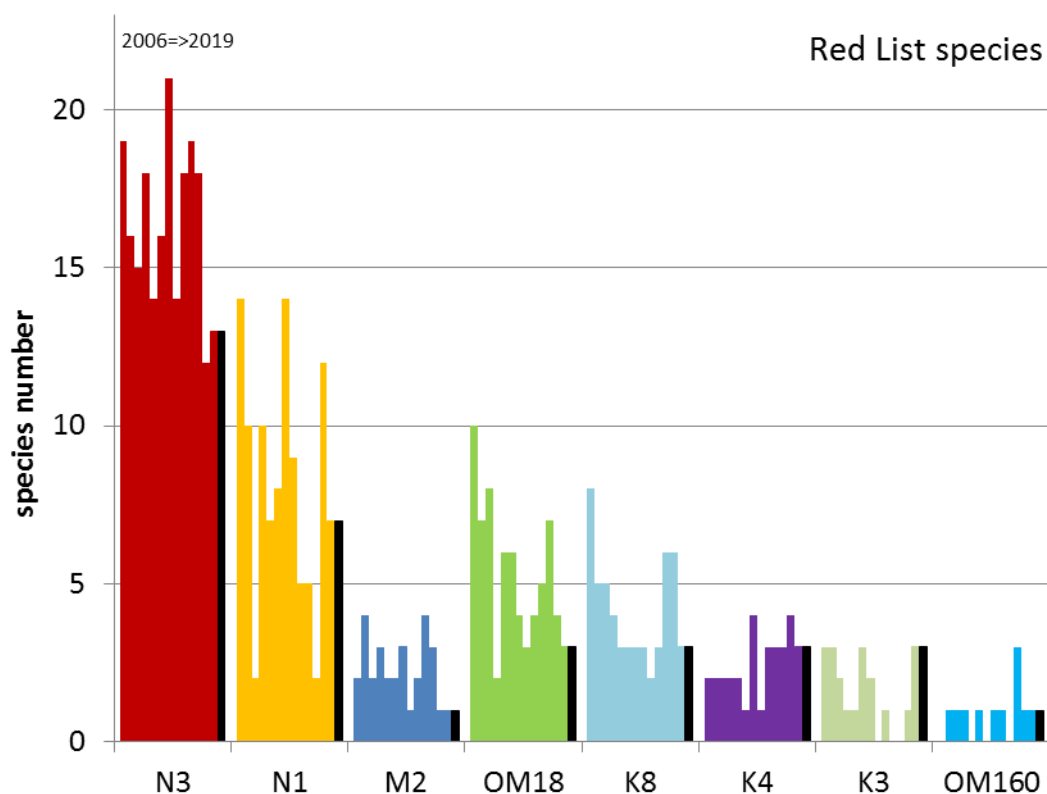
Fig. 42: Development of the number of red listed species (categories 1, 2, 3, G, V and R) (RACHOR et al. 2013) at the 8 monitoring stations from 2006 to 2019. The values of 2019 are highlighted in black colour.

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. 41 and 42). The percentage of red listed species in 2019 in comparison to observations in the whole investigation time (2006 to 2019) ranges between 11 and 43 % (Fig. 41). At all stations the number of red listed species was comparable to the previous years (Fig. 42). 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.

3.3.5 Nonindigeneous species (NIS)

The role of NIS in the open Baltic Sea is negligible (ZETTLER et al. 2014, 2018). Only six species were observed at our 8 monitoring stations in 2019. *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 2019 we observed the following abundances of *M. viridis*: 7 ind./m² in the northern Pomeranian Bay (OMBMPK3) and 49 ind./m² in the central Pomeranian Bay (OM160). In 2019 we were able to confirm the occurrence of *Rangia cuneata* at the central Pomeranian Bay (OM160) (Fig. 43). 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; WASMUND et al., 2019a; present study). Additionally, the decapod crab *Rhithropanopeus harrisii* was found at the Oderbank (OM160). Finally the natantian shrimp *Palaemon elegans* (Fig. 44) should be mentioned. It is not clear if it is a neozoan species or a cryptic indigenous species. We have it observed at the Darss Sill (OMBMPK8) and in the Pomeranian Bay (OM160).

Fig. 43: The North American bivalve species Rangia cuneata *was recorded for the first time during our monitoring program in 2018 und could be observed this year again. The given image comes from material of the Oderbank (OM160).*
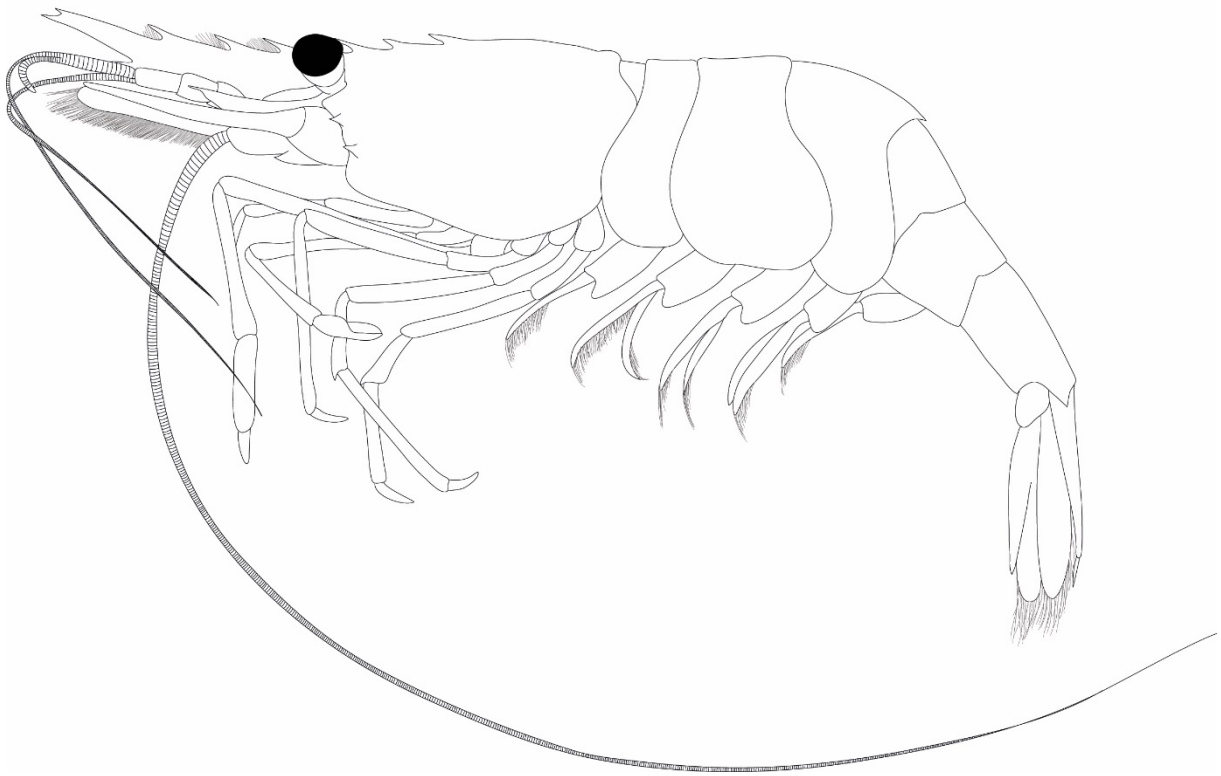
Fig. 44: Palaemon elegans *from Kalmarsund (Sweden)*, *leg. Zettler in 2007 (drawn by A. Degen-Smyrek)*

Summary

In 2019, the phytoplankton growth period started in early February with a diatom bloom dominated by *Rhizosolenia* spp. and *Cerataulina pelagica* developing in the western Belt Sea. By March the spring bloom was well in progress in most basins, reaching Chl *a* concentrations between approx. 4.6 – 6.2 µg L^{-1} in the Belt Sea, approx. 3.0 -5.2 µg L^{-1} in Arkona and Bornholm Basins and 1.6 – 2.4 µg L^{-1} at the northernmost stations. Diatoms continued to be the dominant phytoplankton group in March and were, at the northern stations, represented by *Skeletonema marinoi* and brackish *Thalassiosira baltica*. Besides diatoms, the mixotrophic ciliate Mesodinium rubrum contributed significant shares to the spring bloom biomass throughout the spring. After an early beginning, the 2019 spring bloom had already declined by May in most parts of the monitoring area. At that time diatoms were still prevalent at the southern stations, however in the North, dinoflagellates (*Peridiniella catenata* and *Dinophysis* spp.) together with M. rubrum dominated the community. Generally, spring biomass values recorded in the south, where significantly higher in 2019 than in 2018, reaching maximum biomass values of › 4500 µg L-1. The summer community encountered during the July/August cruise was largely composed of dinoflagellates and cyanobacteria, the biomass shares of the latter increasing towards the North. In the Gotland basin, *Nodularia spumigena* together with *Aphanizomenon* contributed ~40% to the biomass in Gotland basin. A noteworthy bloom of the toxin producing dinoflagellate *Alexandrium pseudogonyaulax* occurred in Arkona basin during the July/August monitoring cruise. Cell concentrations of › 30000 cells L-1 are among the highest reported for this species so far in northern European waters. An autumn bloom of diatoms belonging to *Cerataulina*, *Rhizosolenia* and *Proboscia*, which was particularly pronounced in the Belt Sea, resulted in autumn Chl *a* levels and biomasses comparable to the spring bloom. In 2019, 150 phytoplankton species were identified, which is in the range of previous years. Among them were several harmful algal bloom taxa and invasive species, most noticeable *A. pseudogonyaulax* detected at high cell concentrations in July in Arkona Basin.

In 2019 altogether 49 phytoplankton taxa were recorded in samples retrieved from **sedimentation** traps. The seasonal sedimentation pattern of phytoplankton reflected the growth dynamics of phytoplankton in the Arkona Basin with diatoms being the dominant group of the settling spring bloom, followed by a peak in dinoflagellate sedimentation. The summer sedimentation pattern of cyanobacteria mirrored the typical summer cyanobacteria bloom The seasonal dynamics of elemental rations revealed the typical limitation patterns of the annual phytoplankton production cycle, where particularly N limitation at the end of spring bloom was well reflected, but also the summer bloom of dinoflagellates, subsequent N fixation by summer cyanobacterial assemblages and another limitation situation after the diatom dominated autumn bloom. The single narrow peak of particulate P in summer indicates an isolated pulse of phosphorus –rich phytoplankton and most likely reflects the sedimentation of the *A. pseudogonyaulax* bloom. It was noted that species forming heavily silicified resting stages, such as *Chaetoceros* spp. and *Melosira arctica* were more prominent in sedimentation traps than in phytoplankton samples.

A total of 53 __zooplankton__ samples were collected on 38 stations. The species inventory showed a lower number of taxa than those recorded in the years 2016-2017, in in which the diversity has peaked in the recent decade. Halophilic organisms and gelatinous taxa were rare. Commonly encountered brackish taxa dominated the species composition. The anthomedusae *Lizzia blondina* was the only exceptional species found in the zooplankton samples in 2019. Copepods and Cladocera were the major groups contributing to the bulk of zooplankton. However, cladocerans were largely restricted to the eastern Arkona Basin. In addition, rotifers occurred only in small numbers which is rather unusual. Meroplankton was abundant and diverse. Bivalve larvae regularly occurred in high concentrations during summer and meroplankton was frequently observed (*Carcinus* spp., *Crangon crangon*, *Palaemon serratus*, *Asterias* spp., *Ophiura* spp., *Pectinaria* spp.).

The seasonal development of the zooplankton community in the __Kiel Bight__ (OMBMP-N3) was characterized by a considerable increase in zooplankton density from February to May caused by the genus *Acartia*. Nevertheless, the general composition of the zooplankton community strongly resembled previous years with rotifers and cladocerans playing only a minor role. The calanoid copepods were dominated by *Acartia bifilosa* and *Oithona similis*. This reverses a trend of increasing abundance of *Pseudocalanus* spp., *Temora longicornis* and *Acartia longiremis* which was observed in the period 2016-2018. Winter concentrations were low, and following the late spring maximum caused by copepods, decreased again during summer associated with a strong shift in the community composition. Copepods declined and Copelata were an important member of the community. The latter dominated the autumn community.

In the __Bay of Mecklenburg__, seasonal development was similar to the Kiel Bight with a dominance of copepods and a strong seasonality with a considerable increase in the stock size in the western station of Mecklenburg Bay from March to May (OMBMP-M2). At the eastern station (OMBMP-M1) however, a low seasonality was observed. Rotifers and cladocera were generally minor components. Differences were observed also in the zooplankton composition of both Mecklenburg Bay stations. At the western station, *Acartia* was the major copepod genus and both *Acartia bifilosa* and *Oithona similis* were dominant species, while *A. longiremis* replaced *A. bifilosa* at the eastern station. After the spring increase, the zooplankton abundance remained high during summer and meroplankton contributed considerably to the community. Similar to Kiel Bight, stocks declined in autumn and were dominated by *Oikopleura dioica*, Copelata, as major group.

The zooplankton abundance in the __Arkona Basin__ was generally low in 2019. With the exception of station OMBMP K4 during summer, the concentration did not exceed 3.2×10^4 ind. m^{-3} due to the lack of high densities of rotifers in spring and the restriction of high densities of the cladoceran *Bosmina* spp. to the eastern part of the basin, which is not uncommon for the area. Copepods and Copelata, therefore, were the major groups, others were generally rare. The major increase in zooplankton stocks occurred from March to May and was delayed in comparison to contrast to the Kiel Bight and the Bay of Mecklenburg. Copepods and Copelata dominated the plankton in winter and early spring, and replaced by copepods and cladocera in late spring. The genus *Acartia, with Acartia longiremis* was the single most important group, dominated the

plankton. The abundance of zooplankton already decreased during summer. Bivalve larvae were most abundant.

On the long-term, the stock size of zooplankton remained on a low level since 2010. The decline is most pertinent for the groups of rotifers and cladocera. In 2019 the maximum stock of rotifers achieved 2% of the long-term average only. The stock size of Cladocera accounted for 40% of the long-term average. Copelata and the diverse groups of meroplankton show some strong fluctuations in the past, but no clear long-term trend. The long-term variation in the species abundance and composition of adult calanoid copepods displays a similar decline since 2010. Apart from *Acartia longiremis* and *A. bifilosa*, nearly all copepod species display a decline, but *Pseudocalanus* spp, *Temora longicornis* and *Centropages hamatus* appear to be affected most.

This study presents the results of **macrozoobenthos** monitoring in the southern Baltic Sea in October 2019. The following parameters were measured: species richness, and the abundance and biomass of organisms per station. Compared to previous years, the 129 species recorded at the 8 monitoring stations were considered to be a medium number. No long-lasting oxygen deficiency was observed in 2019. Depending on the region, abundances varied between 717 and 6.650 ind./m². In terms of biomass, similarly high variations were observed (0.6 g in the Arkona Basin to 56.7 g afdw/m² in the Kiel Bay).

Fourteen 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 nonindigeneous species found during the 2019 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) *Marenzelleria viridis* (Polychaeta) is locally important in the Pomeranian Bay. Additionally, with *Rangia cuneata*, an originally North American bivalve species was recorded for the first time during the last year and was confirmed this year in off-shore waters on the Oderbank (Pomeranian Bay). The shrimp *Palaemon elegans* is still established since some decades and it is not clear if it is a real neozoan species. Last but not least the decapod crab *Rhithropanopeus harrisii* were recorded on the Oderbank.

Acknowledgements

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Appendix

Appendix Table A1. List of phytoplankton species recorded in phytoplankton samples from 0 – 10 m
water depth of monitoring cruises TF0219-TF1019 (e.g. TF0219 means Terminfahrt February 2019)

	TF0219	TF0319	TF0519	TF0819	TF1019	Biomass	Rank
Actinocyclus	X	X	X	X	X	646,33	20
Alexandrium pseudogonyaulax				X		1663,75	11
Amphidinium crassum	X				X	0,38	136
Amphidinium sphenoides		X	X		X	2,65	122
Amylax triacantha		X				1,79	126
Apedinella radians	X	X	X		X	40,69	68
Aphanizomenon	X	X		X	X	1536,76	12
Aphanocapsa	X					0,01	150
Aphanothece paralleliformis		X	X	X	X	63,70	56
Asterionella frauenfeldii		X				2,72	120
Asterionella frauenfeldii cf.		X				3,33	118
Binuclearia lauterbornii	X	X	X	X	X	9,48	98
Botryococcus				X		1,54	127
Centrales	X	X		X	X	114,81	44
Cerataulina bergonii	**X**	**X**	**X**	**X**	**X**	**12820,34**	**1**
Ceratium fusus	X	X	X	X	X	331,08	29
Ceratium tripos	X	X	X	X	X	1329,34	13
Chaetoceros	X	X			X	53,21	64
Chaetoceros affinis					X	5,74	109
Chaetoceros brevis		X				9,97	96
Chaetoceros castracanei	X	X	X	X	X	51,70	65
Chaetoceros contortus				X	X	14,79	87
Chaetoceros convolutus		X		X	X	43,83	66
Chaetoceros curvisetus		X			X	117,26	42
Chaetoceros curvisetus cf.		X				6,66	105
Chaetoceros danicus	X	X	X	X	X	150,07	37
Chaetoceros septentrionalis		X		X	X	5,03	113
Chaetoceros similis	X	X	X			5,21	111
Chaetoceros socialis					X	21,41	78
Chaetoceros subtilis		X		X		8,87	100
Chaetoceros wighamii		X				0,73	132
Choanoflagellatea	X	X	X	X	X	53,40	62
Chroococcales	X	X	X	X	X	256,32	33
Coelosphaerium minutissimum	X	X	X	X		13,55	88
Coscinodiscus concinnus			X			175,30	34
Coscinodiscus granii				X	X	767,89	16
Coscinodiscus radiatus	X		X		X	26,20	75
Cyanodictyon				X		0,84	129
Cyanodictyon planctonicum	X	X	X	X	X	53,99	61
Cyanonephron styloides	X		X	X	X	15,33	86

Appendix Table A1 continued.

Cyclotella			X	X	X	8,17	104
Cylindrotheca closterium	X	X	X	X	X	22,16	77
Cymbomonas tetramitiformis				X	X	83,43	52
Dictyocha speculum	X	X	X	X	X	298,55	32
Dictyocha speculum NK cf.			X	X		75,12	54
Dinobryon			X	X	X	2,17	124
Dinobryon balticum			X	X		4,68	115
Dinobryon faculiferum		X	X	X	X	18,23	81
Dinophysis	X					0,52	135
Dinophysis acuminata		X	X	X	x	95,42	50
Dinophysis acuta			X			2,69	121
Dinophysis norvegica		X	X	X	x	127,14	41
Ditylum brightwellii					x	105,54	48
Dolichospermum				X	x	60,58	58
Ebria tripartita	X	X	X	X	x	402,50	26
Ebria tripartita cf.				X		29,44	72
Ethmodiscus punctiger					X	10,25	94
Eutreptiella	X	X	X	X	X	300,64	31
Flagellates	X	X	X	X	X	142,94	39
Gymnodiniales	**X**	**X**	**X**	**X**	**X**	**1934,90**	**7**
Gyrodinium spirale	X	X			X	72,24	55
Hemiselmis	X	X	X	X	X	113,96	46
Heterocapsa		X	X			0,35	139
Heterocapsa rotundata	X	X	X	X	X	438,20	24
Heterosigma cf.	X					53,23	63
Katablepharis				X		6,44	106
Katablepharis remigera	X	X	X	X	X	170,35	35
Katodinium glaucum	X	X	X	X	X	18,71	80
Koliella	X					0,01	151
Kryptoperidinium triquetrum	X	X		X	x	26,09	76
Laboea strobila		X			x	9,20	99
Laboea strobila cf.			X			1,36	128
Lemmermanniella pallida			X			3,31	119
Lemmermanniella parva	X	X	X	X	X	9,82	97
Lennoxia faveolata	X	X				0,30	140
Leptocylindrus danicus				X	X	6,04	107
Leptocylindrus minimus	X	X			X	15,79	84
Leucocryptos marina	X	X	X	X	X	114,68	45
Licmophora			X			0,07	145
Melosira arctica		X				3,75	117
Mesodinium rubrum	**X**	**X**	**X**	**X**	**X**	**3273,16**	**6**
Micracanthodinium claytonii	X	X	X	X	X	33,33	70
Miraltia throndsenii			X	X		4,10	116

Appendix Table A1 continued.

Monoraphidium					X	0,03	148
Monoraphidium contortum				X		0,12	143
Monoraphidium minutum	X		X			0,05	147
Nitzschia longissima	X	X			X	8,74	102
Nitzschia paleacea				X		40,23	69
Nitzschia paleacea cf.				X		0,73	133
Nodularia spumigena		X	X	X	X	761,11	17
Oocystis	X	X	X	X	X	11,07	92
Pennales	X	X	X	X		8,80	101
Peridiniales	X	X	X	X	X	139,70	40
Peridiniella catenata	X	X	X	X		115,09	43
Peridiniella danica		X	X			97,43	49
Phalacroma rotundatum	X			X	X	8,51	103
Plagioselmis prolonga	X	X	X	X	X	485,49	23
Planktolyngbya		X				0,07	146
Polykrikos schwartzii					X	41,95	67
Proboscia alata	**X**	**X**	**X**	**X**	**X**	**5565,93**	**3**
Prorocentrum cordatum		X		X	X	305,82	30
Prorocentrum micans				X	X	336,67	28
Protoperidinium	X	X		X	X	106,83	47
Protoperidinium bipes			X		X	9,99	95
Protoperidinium brevipes cf.			X			19,92	79
Protoperidinium depressum		X	X			75,27	53
Protoperidinium depressum cf.		X				58,55	60
Protoperidinium divergens					X	4,84	114
Protoperidinium oblongum				X		5,04	112
Protoperidinium pallidum					X	10,72	93
Protoperidinium pellucidum		X			X	30,91	71
Protoperidinium pellucidum cf.					X	2,40	123
Prymnesiales	X	X	X	X	X	668,56	19
Pseudanabaena	X					0,02	149
Pseudanabaena cf.				X		0,25	141
Pseudanabaena limnetica	X	X	X	X	X	17,93	82
Pseudanabaena limnetica cf.				X		13,24	90
Pseudochattonella					X	2,13	125
Pseudo-nitzschia	**X**	**X**			**X**	**1721,99**	**10**
Pseudo-nitzschia delicatissima		X				0,37	138
Pseudo-nitzschia delicatissima GRP	X	X				12,17	91
Pseudo-nitzschia seriata	X					0,84	130
Pseudo-nitzschia seriata GRP					X	967,03	15
Pseudopedinella	X	X	X	X	X	63,48	57
Pseudosolenia calcar-avis	**X**	**X**		**X**	**X**	**1911,21**	**9**

Appendix Table A1 continued.

Pterosperma			X	X	X	5,42	110
Pterosperma cf.		X				5,91	108
Pyramimonas	X	X	X	X	X	339,05	27
Rhizosolenia delicatula	**X**	**X**	**X**		**X**	**1914,18**	**8**
Rhizosolenia flaccida	X	X	X		X	148,32	38
Rhizosolenia fragilissima	**X**	**X**		**X**	**X**	**3586,61**	**5**
Rhizosolenia minima				X		0,37	137
Rhizosolenia minima cf.			X	X		0,11	144
Rhizosolenia setigera	**X**	**X**			**X**	**9680,48**	**2**
Rhizosolenia setigera f. pungens	X	X		X	X	428,43	25
Rhodomonas cf.		X				0,63	134
Romeria			X	X		0,19	142
Skeletonema marinoi	**X**	**X**		**X**	**X**	**3967,83**	**4**
Snowella	X	X	X	X	X	28,98	73
Synedra nitzschioides f. nitzschioides	X	X	X	X		84,63	51
Teleaulax	X	X	X	X	X	699,34	18
Telonema	X	X	X	X	X	157,99	36
Thalassiosira	X	X	X	X	X	619,80	21
Thalassiosira baltica		X				496,63	22
Thalassiosira eccentrica	X		X		X	26,25	74
Thalassiosira gravida	X					0,75	131
Trachelomonas		X		X		13,51	89
Tripos lineatus				X	X	60,56	59
Tripos longipes	X		X			15,56	85
Unicell spp.	X	X	X	X	X	967,69	14
Woronichinia	X	X	X	X	X	17,39	83

Appendix Table A2: Seasonal occurrence of taxa found in the investigation area in 2019 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
Annelida							
Polychaeta - Trochophora	Subphylum		o	o		o	
Polychaeta - others	Subphylum	883	o	o	o	o	o
Harmothoe spp. Kinberg, 1856	Genus	129491	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
Calanus spp. Leach, 1816	Genus	104152	o				
Centropages hamatus Lilljeborg, 1853	Species	104496	o	o	o	o	o
Cyclopoida Burmeister, 1834	Order	1101	o		o		
Eurytemora affinis Poppe, 1880	Species	104872	o	o	o	o	
Euterpina acutifrons Dana, 1847	Species	116162	o	o			
Harpacticoida G. O. Sars, 1903	Order	1102	o	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	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		
Pleopsis polyphemoides (Leuckart,1859)	Species	247981					o
Penilia avirostris Dana, 1849	Species	106272				o	o
other Crustacea							
Balanus spp. Costa, 1778	Genus	106122	o	o	o	o	o
Carcinus maenas (Linnaeus, 1758)	Species	107381				o	
Crangon crangon Linnaeus, 1758	Species	107552				o	
Palaemon spp.	Species	107616				o	
Ostracoda Latreille, 1802	Class	1078		o			
Bryozoa							
Gymnolaemata Allman, 1856	Class	1795	o	o	o	o	o

Appendix Table A2 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			
Oikopleura dioica Fol 1872	Species	103407	o			o	o
Teleostei	Infraclass	293496	o	o	o		
Echinodermata							
Asterias spp. Linnaeus, 1758	Genus	123219				o	
Ophiura spp. Lamarck, 1801	Genus	123574				o	
Cnidaria & Ctenophora							
Antothecatae Cornelius, 1992	Order	13551			o		
Leptothecata Cornelius, 1992	Order	13552		o			
Ctenophora Eschscholtz, 1829	Phylum	1248	o	o			o
Euphysa aurata Forbes, 1848	Species	117561				o	
Lizzia blondina Forbes, 1848	Species	117345				o	
Phoronida							
Phoronis muelleri Selys-Longchamps, 1903	Species	206663					o
Platyhelminthes							
Alaurina spp. Metschnikoff, 1861	Genus	142785	o	o	o	o	o
Leptoplanidae Stimpson, 1857	Family	142062	o				
Mollusca							
Bivalvia Linnaeus, 1758	Class	105	o	o	o	o	o
Gastropoda Cuvier, 1797	Class	101	o	o	o	o	o
Rotifera							
Synchaeta spp. Ehrenberg, 1832	Genus	134958	0	o	o	o	o
Keratella cruciformis Thompson, 1892	Species	134991				o	o
Keratella quadrata O. F. Muller, 1786	Species	134992				o	o

Appendix Table A3: Distribution of macrozoobenthos at 8 stations in October 2019. 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									
Bathyporeia pilosa							1		*
Crassicorophium crassicorne					1				*
Gammarus oceanicus					1				*
Gammarus salinus					1		1	1	*
Gammarus zaddachi							1		*
Melita palmata					1				V
Microdeutopus gryllotalpa	1	1			1			1	*
Monocorophium insidiosum	1								*
Phtisica marina	1								*
Pontoporeia femorata	1	1							V
Protomedeia fasciata	1								R
Anthozoa									
Edwardsia danica				1					D
Halcampa duodecimcirrata						1			1
Sagartia sp.		1							ne
Ascidiacea									
Dendrodoa grossularia	1	1							V
Bivalvia									
Abra alba	1	1		1					*
Arctica islandica	1	1	1	1		1			3
Astarte borealis	1			1	1				G
Astarte elliptica	1			1		1			G
Astarte montagui	1								3
Cerastoderma glaucum					1			1	*
Corbula gibba	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		1	1	*
Mytilus edulis	1	1	1	1	1		1	1	*
Parvicardium pinnulatum	1	1							D
Phaxas pellucidus	1	1	1	1					*
Rangia cuneata								1	ne
Thracia phaseolina	1								*
Bryozoa									
Alcyonidium diaphanum	1								*
Callopora lineata	1				1				*
Cribrilina punctata	1								*
Einhornia crustulenta	1			1	1		1	1	*

Appendix Table A3 continued.

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Electra pilosa	1			1					*
Escharella immersa	1								*
Eucratea loricata		1							V
Farrella repens	1								D
Flustra foliacea	1								*
Cirripedia									
Amphibalanus improvisus								1	ne
Balanus crenatus					1	1			*
Cumacea									
Diastylis rathkei	1	1	1	1	1	1	1		*
Decapoda									
Carcinus maenas	1	1			1				*
Crangon crangon	1	1		1	1	1	1	1	*
Palaemon elegans					1			1	*
Rhithropanopeus harrisii								1	ne
Echinodermata									
Asterias rubens	1	1		1	1	1			*
Echinocyamus pusillus	1	1							G
Ophiura albida	1	1	1		1				*
Ophiura ophiura	1	1							*
Psammechinus miliaris	1								*
Gastropoda									
Alvania punctura		1							ne
Aporrhais pespelecani	1								G
Brachystomia scalaris					1				*
Facelina bostoniensis	1	1			1				*
Onchidoris muricata			1		1				*
Peringia ulvae			1	1	1	1	1	1	*
Philine aperta	1		1						*
Retusa obtusa		1	1		1				*
Tritia reticulata	1			1					G
Hydrozoa									
Dynamena pumila		1							D
Hartlaubella gelatinosa							1		D
Hydractinia echinata	1								*
Sertularia cupressina		1							G
Isopoda									
Cyathura carinata								1	D
Idotea chelipes								1	D
Jaera albifrons					1		1		*
Mysida									
Gastrosaccus spinifer	1	1			1				ne
Mesopodopsis slabberi	1								ne
Neomysis integer					1	1	1	1	ne

Appendix Table A3 continued.

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Nemertea									
Cyanophthalma obscura					1				ne
Lineus ruber	1				1	1			ne
Malacobdella grossa	1	1	1	1					ne
Nemertea	1					1			ne
Tubulanus polymorphus	1		1		1				ne
Oligochaeta									
Tubificinae		1	1		1		1	1	ne
Tubificoides benedii					1		1	1	*
Phoronida									
Phoronis sp.	1	1		1					ne
Plathelminthes									
Turbellaria	1							1	ne
Polychaeta									
Alitta succinea	1	1						1	D
Ampharete acutifrons	1		1	1		1			*
Ampharete baltica	1	1		1	1	1	1		*
Arenicola marina	1				1				*
Aricidea suecica	1				1				*
Bylgides sarsi	1	1	1		1				*
Capitella capitata		1			1				*
Dipolydora quadrilobata	1	1	1	1	1	1			*
Eteone longa					1				*
Eumida sanguinea	1								*
Flabelligera affinis	1								D
Harmothoe imbricata	1	1			1				D
Harmothoe impar	1	1	1		1				*
Hediste diversicolor	1	1	1				1	1	*
Heteromastus filiformis	1		1			1			*
Lagis koreni	1	1	1	1	1	1			*
Lanice conchilega	1								*
Laonome kroyeri			1						D
Levinsenia gracilis	1		1						*
Lysilla loveni	1								R
Marenzelleria viridis							1	1	ne
Neoamphitrite figulus	1								*
Nephtys caeca	1	1					1		*
Nephtys ciliata	1	1							*
Nephtys hombergii	1	1	1	1		1	1		*
Nereimyra punctata	1	1		1	1				G
Nicolea zostericola	1								*
Paradoneis eliasoni	1								*
Paraonis fulgens	1								*
Pherusa plumosa	1	1							D
Pholoe assimilis	1								D

Appendix Table A3 continued.

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Phyllodoce groenlandica	1								*
Phyllodoce mucosa	1	1	1	1	1				*
Polydora cornuta	1	1							*
Pseudopolydora pulchra	1	1	1						*
Pygospio elegans	1	1		1	1		1	1	*
Scalibregma inflatum	1	1	1	1					G
Scolelepis foliosa					1				*
Scoloplos armiger	1	1	1	1	1	1	1		*
Sphaerodoropsis baltica	1								D
Spio arndti	1								*
Spio goniocephala					1		1		*
Spirorbis corallinae	1								R
Terebellides stroemii	1	1	1	1		1			*
Travisia forbesii					1		1		G
Priapulida									
Halicryptus spinulosus		1	1		1		1		ne
Priapulus caudatus		1							ne
Pycnogonida									
Nymphon brevirostre	1	1							*
species number 129	**88**	**53**	**30**	**31**	**51**	**20**	**25**	**23**	
abundance (ind m^{-2})	**6650**	**4268**	**2105**	**2633**	**3610**	**717**	**5008**	**4588**	
biomass (afdw g m^{-2})	**56.7**	**38.4**	**10.8**	**20.5**	**17.1**	**0.6**	**2.1**	**24.6**	

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