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Biological assessment of the Baltic Sea 2021

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Kurzfassung

Im Jahr 2021 wurden auf 5 Monitoringausfahrten insgesamt 165 **Phytoplankton**arten erfasst. Die durchschnittliche jährliche Phytoplanktonbiomasse lag mit 928 µg l^{-1} etwas höher als der 20-Jahres-Mittelwert. Die Frühjahrsblüte 2021 begann Anfang Februar in der südlichen und westlichen Ostsee und entwickelte sich mit etwa 1 - 2 Wochen Verzögerung Richtung Norden. Chlorophyll-*a*-(Chl*a*)-Konzentrationen der Frühjahrsfahrten 2021 repräsentierten die ermittelte Phytoplanktonbiomasse nur bedingt, was auf einen großen Anteil von Nicht-Diatomeen oder mixotrophen Taxa, wie z.B. den fischgiftigen Raphidophyten *Heterosigma akashiwo* und den mixotrophen Ciliaten *Mesodinium rubrum* in der Kieler Bucht im Februar zurückzuführen ist. Zum Zeitpunkt der Ausfahrt im Mai war die Frühjahrsblüte in der südlichen Ostsee beendet, während Richtung Norden Chl*a*- und Biomassewerte weiterhin zunahmen. Während der Sommerfahrt 2021 war das Phytoplankton zum größten Teil von Diatomeen dominiert, die in der südlichen Ostsee bis zu 90 % der Phytoplanktonbiomasse ausmachten. Diese erreichten hier Werte von bis zu 8000 µg l^{-1}. In der zentralen Ostsee machten die zu dieser Zeit typischen fädigen und potentiell toxischen Cyanobakterien etwa die Hälfte der Gesamtphytoplanktonbiomasse aus – die hier jedoch nur etwa 5 % der im Südwesten ermittelten Werte erreichte. Auf der November-Ausfahrt 2021 war die Phytoplanktongemeinschaft im gesamten Untersuchungsgebiet von Diatomeen geprägt (80 - 90 % der Biomasse).

Maximale **Zooplankton**abundanzen erreichten 2021 8.0 x 10^4 ind. m^{-3}. Dies entspricht etwa 33 % des Langzeitmittels der Bestände seit 2000 und zeigt eine nur geringfügige Erholung der Zooplanktonbestände vom langjährigen Tiefpunkt an. Die seit 2010 bestehenden negativen Anomalien in der Langzeitserie verdeutlichen den abnehmenden Trend in der Abundanz innerhalb der letzen Dekade. Obwohl bei den Cladocera 2021 eine geringfügige Zunahme zu verzeichnen war, blieb deren Abundanz, wie auch die der Rotatorien, Copelata, cyclopoiden und calanoiden Copepoden und Polychaetenlarven erheblich unter dem Langzeitmittel. Ausschließlich Bivalven- und Gastropodenlarven erreichten Langzeitdurchschnittskonzentrationen. Cladocera dominierten die Artenzusammensetzung der Zooplanktongemeinschaften, was hauptsächlich auf eine (geringfügige) Erholung der Sommerbestände von *Bosmina* im Arkonabecken zurückzuführen war. Copepoden waren weiterhin abundant vertreten, jedoch war der Anteil des cyclopiden Copepoden *Oithona* spp. ungewöhnlich niedrig, was zur Dominanz calanoider Copepoden, insbesondere *Acartia* spp. führte. Rotatorien-Konzentrationen lagen 2021 insgesamt erheblich unter dem Langzeitdurchschnitt. Die saisonale Entwicklung begann 2021 relativ früh, so dass die Zooplanktonbestände ihr Maximum in der Beltsee bereits im Mai erreicht hatten.

Mit 124 Arten hatte das **Makrozoobenthos** 2021 eine mittlere Diversität im Vergleich zu den Vorjahren. Die Artenzahlen, die auf den 8 Monitoringstationen ermittelt wurden, lagen zwischen 20 und 67 Arten. In allen Regionen des Untersuchungsgebietes waren die Sauerstoffkonzentrationen 2021 höher als 2 ml l^{-1}, so dass die durchgängig guten Sauerstoffbedingungen am Meeresboden im Untersuchungsgebiet zu einer Erholung der Makrozoobenthosbestände führten. Außer in der Mecklenburger Bucht, wo die Artenzahl 2021 abnahm, entsprach die Diversität den Werten der Vorjahre. Je nach Region reichten die ermittelten Abundanzen von 254 bis 7687 ind. m^{-2} und die entsprechenden Biomassen

(aschefreie Trockenmasse) von 0,8 g m^{-2} bis 32 g m^{-2}. Auf den 8 Benthos-Monitoringstationen wurden 15 Arten der Roten Liste (Deutschland, Kategorien 1,2,3 und G) beobachtet. Erstmals wurden die Langzeitdaten genutzt, um den Benthic Quality Index (BQI) und damit auch den ökologischen Zustand stationsweise zu berechnen. Die Hälfte der Stationen befand sich in den Jahren 2006 - 2021 in einem "guten" Zustand. Zwei Stationen sind im Laufe der Jahre überwiegend "schlecht" geworden, zwei weitere sind häufig in "gutem" Zustand, obwohl sie entsprechend der Schwellenwerte in der Summe aller relevanten Bewertungsjahre noch unter "schlecht" fallen. Insbesondere für die südliche Mecklenburger Bucht (OM18) ist ein negativer Trend im Vergleich der drei verschiedenen Bewertungszeiträume zu erkennen. Für die anderen Stationen und Seegebiete wurde kein Trend beobachtet. Unabhängig von den Bewertungszeiträumen, die für die alle 6 Jahre stattfindende MFSD-Bewertung herangezogen wurden, blieb die Bewertung relativ unverändert. Mit 6 beobachteten Arten war die Zahl der invasiven Benthosarten 2021, wie erwartet, niedrig. Hierbei handelte es sich um bekannte Arten der Vorjahre. *Rhithropanopeus harrisii*, ursprünglich aus Nordamerika, wird seit 2006 in geringen Dichten im Gebiet der Oderbank angetroffen. In der Pommerschen Bucht erreichten die spioniden Polychaeten *Marenzelleria viridis* und *M. neglecta* nennenswerte Abundanzen. *Mya arenaria* und *Amphibalanus improvisus* sind seit über 100 Jahren in der Fauna der Ostsee etabliert. Die Ascidie *Molgula manhattensis*, ein kryptischer Neozoa, wurde 2021 in der Kieler Bucht beobachtet.

Abstract

In 2021 a total of 165 **phytoplankton** species were recorded on 5 annual monitoring cruises. Mean annual biomass of phytoplankton in the study area was, at 928 µg l^{-1}, higher than the 20-year mean. The phytoplankton spring bloom started in early February and advanced quickly in the typical manner from south to north. In spring 2021, chlorophyll-*a* (Chl*a)*-concentrations ranging from ~1 to ~10 µg l^{-1} reflected phytoplankton biomass poorly, due to high representation of non-diatom and mixotroph taxa such as *Mesodinium rubrum* or diverse flagellates. These included the ichthyotoxic invasive Raphidophyte *Heterosigma akashiwo,* blooming in Kiel Bight in February. Diatoms were abundant only locally in March, in the Arkona and Bornholm Basins. By May, Chl*a* and biomass had declined in the south, but were still increasing towards the north (~150 µg l^{-1} in the south to ~1500 µg l^{-1} wet weight in the north), reflecting the typical latitudinal delay of the spring bloom in the Baltic Sea. The summer phytoplankton composition and production was largely shaped by diatoms in the southern Baltic, which is unusual in the open sea areas. *Dactyosolen fragilissimus* constituted 80 to › 90 % of the biomass in the Bay of Mecklenburg in July. Total phytoplankton biomass of 3000 to nearly 8000 µg l^{-1} was measured in the western Baltic during the July cruise. This was contrasted by cyanobacteria dominated communities in the central Baltic, which, however, only amounted to 5 % of the biomass produced by the diatoms in the south. In November, diatoms - mostly *Coscinodiscus* spp. and *Cerataulina pelagica* - dominating the phytoplankton community throughout the study area (80 to 90 % of total biomass). In 2021 harmful *Nodularia spumigena* and *Aphanizomenon* made 10 % - 50 % of the biomass in the Arkona, Bornholm and Gotland Basins, as typical for the summer season. The 2021 diatom to dinoflagellate ratio and cyanobacteria biomass were in the same range of interannual variation as in previous years. The 2021 annual phytoplankton biomass level was slightly higher than the 20-year mean, as was the diatom to dinoflagellate ratio, reflecting the diatom dominance of summer and autumn communities.

In 2021, maximum **zooplankton** abundance achieved 8.0 x 10^4 ind. m^{-3}. This represents on average 33 % of the long-term mean of the stocks since 2000 and only a minor recovery from the long-term low of the zooplankton stocks observed in 2021. Although cladocerans showed a slight increase, their abundance together with that of rotifers, Copelata, cyclopoid and calanoid copepods, and polychaete larvae was considerably below their long-term means. Only bivalve and gastropod larvae achieved their long-term average concentrations. Cladocerans also dominated the species composition, mainly due to a small recovery of the summer peaks in the genus *Bosmina* in the Arkona Basin. Copepods were still abundant, but the contribution of the cyclopid copepod *Oithona* spp. was unusually low, so that calanoid copepods, escpecially *Acartia* spp., dominated. In addition, rotifers remained considerably below their historical concentrations. The seasonal development was early, and the zooplankton stocks achieved their maximum already in May in the Belt Sea. Except the calanoid copepod *Acartia tonsa*, no non-indigenous species were observed.

The 124 species found in the **macrozoobenthos** in 2021 mark a medium diversity. The species number found at the eight monitoring stations ranged between 20 and 67. In all regions, the oxygen supply in bottom waters in the current year was always higher than 2 ml l^{-1}. While over the last years, occasional population collapses caused by a lack of oxygen could be observed

(especially in the Fehmarnbelt and in the Mecklenburg Bay), as far as we can see from our data the consistently good oxygen conditions in 2021 led to a recovery of the stocks. Except for the southern Mecklenburg Bay with its decline, the diversity at all stations was similar or slightly increased compared to the recent years. Depending on the region, the abundances ranged from 254 to 7687 ind. m^{-2}, and the biomass (ash free dry weight) from 0.8 g m^{-2} to 32 g m^{-2}. Altogether fifteen species of the German Red List (Categories 1, 2, 3 and G) were observed at the eight monitoring stations. For the first time, the long-term data were used to calculate the Benthic Quality Index (BQI) and thus also the ecological status stationwise. Half of the stations were in "good" condition over the years 2006 - 2021. Two have become predominantly "poor" over the years, and two others are often in "good" condition, although according to the threshold rules they still fall under "poor" if you sum up all relevant assessment years. Especially for the southern Mecklenburg Bay (OM18) we see a negative trend comparing the three different evaluation periods. No trend was observed for the other stations or sea areas. With six, the number of invasive species in 2021 was low, as expected. They were all already known from previous years. *Rhithropanopeus harrisii*, originally from North America, could be observed in low densities on the Oderbank since 2006. Only the spionid polychaetes *Marenzelleria viridis* and *M. neglecta* reached noteworthy abundances in the Pomeranian Bay. *Mya arenaria* and *Amphibalanus improvisus* have been common faunal elements in the southern Baltic Sea for more than a hundred years. Finally, the ascidian *Molgula manhattensis* was observed as a cryptic neozoa species in the Bay of Kiel.

1 Introduction

This report presents the results of the biological monitoring conducted in 2021 by 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 includes an extensive programme of hydrographic and chemical investigations (NAUMANN et al. 2023). 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 Periodic Assessments (HELCOM 1987, 1990, 1996, 2002) and Holistic Assessments (HELCOM, 2010, 2018, 2023a). 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 2018). 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. 2018a).

On a national level, the German Federal Government and the coastal states 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 https://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/msrl.html). The MSFD (EUROPEAN UNION 2008; Directive 2008/56/EC) creates the regulatory framework for the necessary measures in all EU member states to achieve or maintain the 'good environmental status' in all European waters by 2020.

In order to determine the 'good environmental status', HELCOM relies on indicators (https://indicators.helcom.fi/filtering/). Members of the Biological Oceanography section of the IOW have been 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-indigenous species (D2), food web (D4) or eutrophication (D5); see see HELCOM (2013c, 2020):

- Zooplankton mean size and total stock (MSTS) (core)
- State of the soft-bottom macrofauna community (core), with Benthic Quality Index (BQI)
- Trends in arrival of new non-indigenous species (core)
- Chlorophyll-*a* (core)
- Diatom/Dinoflagellate Index (pre-core)
- Seasonal succession of dominating phytoplankton groups (pre-core)
- Cyanobacterial bloom Index (pre-core)

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. 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 2021 hydrographic-hydrochemical assessment of the Baltic Sea that has already been published (NAUMANN et al. 2023).

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

2 Material and Methods

2.1 Sampling strategy

The tasks undertaken by IOW in the monitoring programme are prescribed by the BSH (Bundesamt für Seeschifffahrt und Hydrographie), and they follow the HELCOM guidelines (https://helcom.fi/action-areas/monitoring-and-assessment/monitoring-guidelines/). Biological monitoring by IOW includes determining the qualitative and quantitative composition of phytoplankton, mesozooplankton and macrozoobenthos, and determining the chlorophyll a content of water samples. The methods are set out in the HELCOM COMBINE manual (HELCOM 2017a). Fig. 1 shows the locations of the biological monitoring stations. They are labelled 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 report. The equivalents to the internal IOW station numbers are given in Table 1.

Five cruises represent different phases of the growing season and were, in 2021, conducted in January/February (26.01. - 06.02., referred to as TF0221), March (19.03. - 31.03., TF0321), May (04.05. - 14.05., TF0521), Juli (20.07. - 30.07., TF0721) and November (04.11. - 15.11., TF1121).

Within the regular monitoring programme, plankton samples should be collected both on outbound (northward) and inbound (southward) tracks of the cruises, if possible. There is a lag of about 7 to 12 days between sampling at a given station during outbound and inbound (return) journey. Five cruises yield a maximum of 10 samples per station per year. Samples at stations N3 (Kiel Bight), K4 (Arkona Basin) and K1/OMBMPJ1 (Eastern Gotland Basin) are taken on the outward leg only.

Phytoplankton sampling was performed at 9 stations, 3 of them being located in the German Exclusive Economic Zone (EEZ), the other 6 stations in Danish, Swedish, Polish and Latvian territorial waters (Table 1). All stations were sampled according to the plan in 2021.

Zooplankton sampling is usually performed at 5 stations in the German Exclusive Economic Zone (EEZ) during outward and return journeys on the scheduled cruises (Table 1). Bad weather conditions with strong wind in gusts, however, prevented sampling on the return journeys on stations M1 and M2 in the Mecklenburg Bight during the winter cruise in January/February (TF0221) and on station M1 during the summer cruise in July (TF0721), respectively.

Samples of macrozoobenthos are usually collected at eight stations once a year. In 2021, sampling was conducted in November (Table 1 and Table 3).

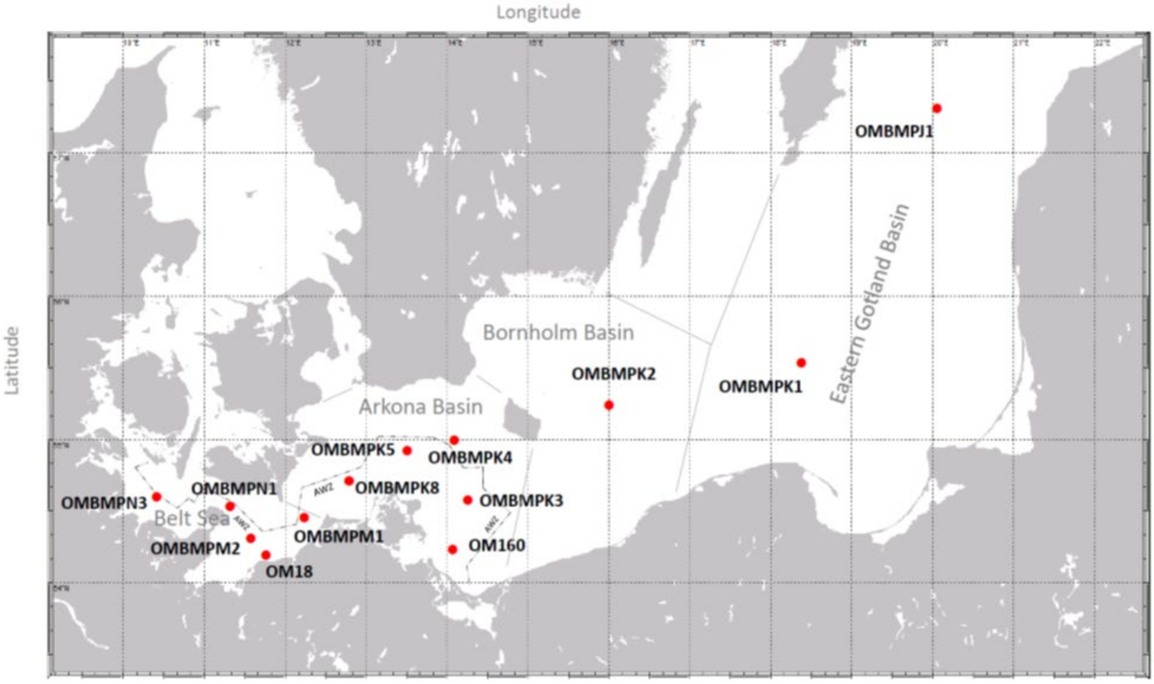

Fig. 1: Station grid for biological sampling in the Baltic Sea with depiction of the border of the Exclusive Economic Zone Germany (AWZ) and the borders between the main HELCOM basins.

Table 1: Sampling statistics (number of sampling events) for the different parameters specified for regular monitoring stations in 2021 (Chl = Chlorophyll a, PP = Phytoplankton, ZP = Zooplankton; B = Benthos)

Station number	IOW-station number	Latitude	Longitude	Sea area	Chl	PP	ZP	B
Belt Sea								
OMBMPN3 (N3)	TF0360	54°36,0'N	10°27,0'E	Kiel Bay	5	5	5	1
OMBMPN1 (N1)	TF0010	54°33,1'N	11°19,2'E	Fehmarnbelt	-	-	-	1
OMBMPM2 (M2)	TF0012	54°18,9'N	11°33,0'E	Bay of Mecklenburg	10	10	9	1
OM18	TF0018	54°11,0'N	11°46,0'E	Bay of Mecklenburg	-	-	-	1
OMBMPM1 (M1)	TF0046	54°28,0'N	12°13,0'E	Bay of Mecklenburg	10	10	8	-
Arkona Basin								
OMBMPK8 (K8)	TF0030	54°43,4'N	12°47,0'E	Arkona Basin, west	4	4	-	1
OMBMPK5 (K5)	TF0113	54°55,5'N	13°30,0'E	Arkona Basin, central	10	10	10	-
OMBMPK4 (K4)	TF0109	55°00,0'N	14°05,0'E	Arkona Basin, east	5	5	5	1
Pomeranian Bay								
OMBMPK3 (K3)	TF0152	54°38,0'N	14°17,0'E	Pomeranian Bay	-	-	-	1
OM160	TF0160	54°14,4'N	14°04,1'E	Pomeranian Bay	-	-	-	1
Bornholm Basin								
OMBMPK2(K2)	TF0213	55°15,0'N	15°59,0'E	Bornholm Basin	10	10	-	-
Gotland Basin								
OMBMPK1 (K1)	TF0259	55°33,0' N	18°24,0' E	Eastern Gotland Basin	5	5	-	-
OMBMPJ1 (J1)	TF0271	57°19.2' N	20°02.8' E	Eastern Gotland Basin	5	5	-	-

2.2 Chlorophyll *a*

As chlorophyll a (Chl*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. Nevertheless, this relationship can be highly variable depending on season, phytoplankton physiological status, bloom phase and environmental conditions (LIPS et al. 2014, SPILLING et al. 2014, PACZKOWSKA et al. 2017). Therefore, a conversion is usually not done, and the concentration of Chl*a* is used directly as parameter describing phytoplankton bulk biomass or production.

Samples for the determination of Chl*a* concentrations were collected together with phytoplankton samples at standard depths of 1, 5, 10, 15 and 20 m, and occasionally at other depths with a rosette water sampler. 200-500 ml of the seawater were filtered through glass-fibre filters (Whatman GF/F) that were flash-frozen in liquid nitrogen (-196°C) and stored at -80°C for a maximum of three months. 96 % ethanol was used for the extraction, as specified by HELCOM (2017b). Several methods are available for determining concentrations of Chl*a* as reviewed in WASMUND et al. (2011). The method to measure Chl*a* currently used by IOW does not consider phaeopigment, which contains various constituents (phaeophytin, phaeophorbide), essentially regarded as degradation products of Chl*a* and sometimes measured separately. Phaeopigments are not major players in the open sea and were thus disregarded by the current Chl*a* analyses.

2.3 Phytoplankton

Sampling and analysis procedures followed HELCOM (2023b). Generally, two phytoplankton samples were taken at each station: A composite sample was 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, one sample was taken from below the upper pycnocline (usually from a depth of 20 m). If distinctive fluorescence maxima were present in deeper layers, additional samples were taken from that depth. The water samples (200 ml) were fixed with 1 ml of acid Lugol's solution and stored until analysis (6 months at most).

The biomass of individual phytoplankton species was analysed microscopically using the standard method according to UTERMÖHL (1958). During counting, individuals were classified not just according to taxa, but also to size classes in line with HELCOM guidelines (OLENINA et al. 2006; HELCOM 2023b). To obtain a statistically acceptable estimate, at least 50 individuals of the most abundant species had to be counted. Thus for the most common species, a statistical counting error of around 28 % can be assumed. In this study, generally at least 500 individuals were counted per sample to reduce the statistical error to < 10 %. Species- and size class specific biovolumes were 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", (AquaEcology Oldenburg). For the data of the cruise in February 2020, the HELCOM species and biovolume list PEG_BVOL2019 was used. The phytoplankton samples of the March, May, July/August and November cruises were analysed according to the PEG_BVOL2021, which was confirmed by HELCOM's Phytoplankton Expert Group (PEG) during the meeting in April 2021. The latest biovolume file can be downloaded from: http://ices.dk/data/Documents/ENV/PEG_BVOL.zip.

2.4 Mesozooplankton

Zooplankton sampling followed the recommendations of the HELCOM COMBINE manual (HELCOM 2021). Vertical net tows were conducted with a Work-Party 2 net (WP-2) of 100 µm mesh size equipped with an operating/closing mechanism released by a drop messenger and a T.S.K Flowmeter (Tsurumi-Seiko Co. Ltd., Yokohama, Japan). The net was operated with a hauling speed of 0.5 m/s. 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 formed through saline inflows or a thermocline build up during seasonal warming of the surface during spring, hauls were taken in the respective water layers. Net angles greater than 30° were avoided during sampling by adding sufficient weight to the net cod end. The samples were preserved in Borax-buffered 4 % aqueous formaldehyde solution and stored at cool/dark conditions until processing in the laboratory. In total, 57 zooplankton samples were collected at 37 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 2021.

	Period				
	TF-02-2021 26.01. - 05.02.	TF-03-2021 19.03. - 30.03.	TF-05-2021 04.05. - 13.05.	TF-07-2021 20.07. - 29.07.	TF-11-2021 04.11. - 14.11.
Station OMPK-	Depth from -to (m)	Depth from -to (m)	Depth from -to (m)	Depth from -to (m)	Depth from -to (m)
N3	18 - 0	14 - 0	14 - 0	15 - 0	18 - 0
M2	21 - 0	21 - 9 - 0-	21 - 8 - 0	21 - 14 - 0	22 - 0
	-	21 - 0	21 - 0	21 - 8 - 0	22 - 0
M1	26 - 10 - 0	24 - 0	26 - 0	25 - 13 - 0	25 - 0
	-	25 - 0	25 - 0	-	25 - 0
K5	45 - 20 - 0	44 - 20 - 0	44 - 33 - 0	43 - 32 - 12 - 0	44 - 28 - 0
	45 - 0	45 - 15 - 0	42 - 30 - 0	44 - 10 - 0	44 - 33 - 0
K4	45 - 0	43 - 15 - 0	4 - 29 - 0	45 - 12 - 0	45 - 31 - 0

The analysis of samples followed the established HELCOM guidelines (HELCOM 2021). In short, a minimum number of individuals was identified and counted microscopically in a Bogorov chamber. Several subsamples from the total sample were analysed. 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 volume of seawater filtered by the net. The identification of the zooplankton species followed an internal IOW species list summarizing the long-term record of species as well as the zooplankton atlas of the Baltic Sea (Telesh et al. 2009) and the internal species list of the ZEN HELCOM working group. The taxonomic classification of identified specimens is based on the World Register of Marine Species (WoRMS 2022). In the case of *Bosmina* spp. and *Synchaeta* spp., identification to the species level is unresolved; their abundances were recorded and reported on the level of the genus. In line with the standards of the Integrated Taxonomic Information System (ITIS 2022), Bryozoa were listed as Gymnolaemata and Mysidacea as Lophogastridae. The databases of the information system on Aquatic Non-Indigenous Species (AquaNIS 2022) and of the European Network on Invasive Species (NOBANIS 2022) served as references for the classification of invasive species.

2.5 Macrozoobenthos

In November 2021, benthos investigations were undertaken at eight stations from Kiel Bay to the Pomeranian Bay (Table 3 and Fig. 1). 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 taken at each station. Each haul was rinsed in seawater through a 1 mm mesh sieve. The sieve residue was transferred to beakers and fixed in 4 % buffered formalin (HELCOM 2017a). Additionally, at all stations, a “Kieler Kinderwagen” botanical dredge with a 1 m rectangular mouth and a mesh size of 5 mm was deployed. The speed was less than 1 knot. Especially in relation to vagile and rarer species, the dredge yields finds that would be missed with the grab alone.

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)’. Abundance and biomass were also recorded (ash free dry weight, afdw). 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.

Table 3: Station list of macrozoobenthic investigations in November 2021.

HELCOM-ID	IOW-ID	date	depth	north	east	sea area
N3	360	04.11.2021	18.5	54° 36.00	10° 27.00	Kiel Bay
N1	010	04.11.2021	28.5	54° 33.20	11° 20.00	Fehmarnbelt
M2	012	05.11.2021	25.0	54° 18.90	11° 33.00	Mecklenburg Bay
OM18	018	04.11.2021	20.5	54° 11.00	11° 46.00	Mecklenburg Bay, south
K8	030	05.11.2021	22.8	54° 44.00	12° 47.40	Darss Sill
K4	109	08.11.2021	48.3	55° 00.00	14° 05.00	Arkona Basin
K3	152	06.11.2021	31.4	54° 38.00	14° 17.00	Pomeranian Bay, north
OM160	160	06.11.2021	14.9	54° 14.50	14° 04.00	Pomeranian Bay, central

2.6 Quality Assurance (QA)

Chlorophyll *a*

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 2021.1 and 2021.2 were passed with good results.

Phytoplankton

From every tenth sample, two abundant 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) (HELCOM 2023b). Expert identification of phytoplankton species depends on the analyst's level of knowledge. PEG therefore runs annual training courses and undertakes regular ring test. Two annual PEG meetings took place online in 2021 and were attended by representatives of all Baltic Sea States. The spring meeting addressed the implementation of molecular methods in phytoplankton monitoring and respective future activities in this regard of PEG. During the autumn online meeting technical procedures of data transfer were discussed specifically. Like every year, the biovolume list of species and size classes was updated during the HELCOM PEG meeting in April 2021 to assure up-to date taxonomy and biovolume information. Samples taken in January/February 2021 were counted based on the previous ICES and HELCOM biovolume file PEG_BIOVOL2020, while the new list was adopted for the counting of all cruise samples collected in 2021 thereafter, i.e. following biovolume file PEG_BIOVOL2021.

Mesozooplankton

The quality assurance followed the protocol for internal quality control concerning documentation and analyses provided by HELCOM (2021). 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 Umweltbundesamt (UBA) in March 2019, confirmed the high quality of the macrozoobenthos analyses. Internal double checks of four samples of the 2021 monitoring season confirmed high accuracy. In addition, internal and external audits of our analysis groups were successfully passed in 2021.

3 Results and Discussion

3.1 Phytoplankton and Chl*a*

3.1.1 Seasonal succession of phytoplankton production and species composition

The current monitoring programme, consisting of 5 annual cruises and nine 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 – 10 m 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 2021, as represented by five monitoring cruises (Table 4). The spring bloom 2021 was characterized by three cruises that took place in January/ February, March and May (TF0221, TF0321 and TF0521), while the summer bloom was represented by the cruise TF0721 in July. TF1121 in November provided the data to examine phytoplankton features of the autumn season. In the following, data of these cruises are presented and discussed to characterize the 2021 seasonal phytoplankton succession.

Table 4: Phytoplankton data representation in 2021 for different cruises and sampling stations. (X: sample only taken on northward journey, XX sample taken on northward and southward transect), geographical locations see Table 1.

Station number	IOW-station number	**Cruise in Jan/Feb. TF0221** Phyto	Chla	**Cruise in March TF0321** Phyto	Chla	**Cruise in May TF0521** Phyto	Chla	**Cruise in July TF0721** Phyto	Chla	**Cruise in Nov. TF1121** Phyto	Chla
Belt Sea											
OMBMP-N3	TF0360	X	X	X	X	X	X	X	X	X	X
OMBMP-M2	TF0012	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
OMBMP-M1	TF0046	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
Arkona Basin											
OMBMP-K8	TF0030	XX	XX	XX	XX	XX	XX			XX	XX
OMBMP-K5	TF0113	XX	XX	XX	XX	XX	XX	XX	XX	X	X
OMBMP-K4	TF0109	X	X	X	X	X	X	X	X	X	X
Bornholm Basin	TF0213	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX
OMBMP-K2											
Gotland Basin	TF0259	X	X	X	X	X	X	X	X		
OMBMP-K1	TF0271	X	X	X	X	X	X	X	X	X	X
OMBMP-J1											

3.1.1.1 Spring bloom

Chl*a* and biomass data (Fig. 2, Fig. 3) suggest that phytoplankton production had just started in the westernmost part of the southern Baltic Sea at the time of the first cruise, TF0221. In Kiel Bight, the spring phytoplankton community was already well developed at the end of January.

With the exception of Station K8 in the western Arkona Basin, Chl*a* values and biomass had increased on the inbound return journey, indicating rapid onset of the spring bloom in Arkona Basin and the Bay of Mecklenburg at that time.

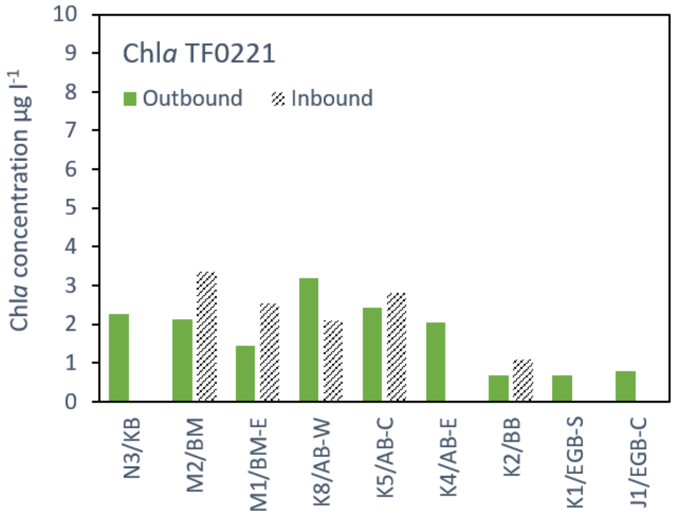

Fig. 2: Chla concentrations ($\mu g\ l^{-1}$) at sampling stations along the outbound (dark green) and inbound (grey bars) journeys of the January/February cruise TF0221 in 2021.

Biomass and Chl*a* concentrations decreased northward with increasing latitude, towards Bornholm and Gotland Basins, reflecting the typical latitudinal delay of the spring bloom commencement. More obviously than Chl*a*, biomass build-up (Fig. 2) followed the typical spatial pattern of the spring bloom succession in the Baltic Sea, where phytoplankton development progresses from the southwest to the northeast over a period of several weeks.

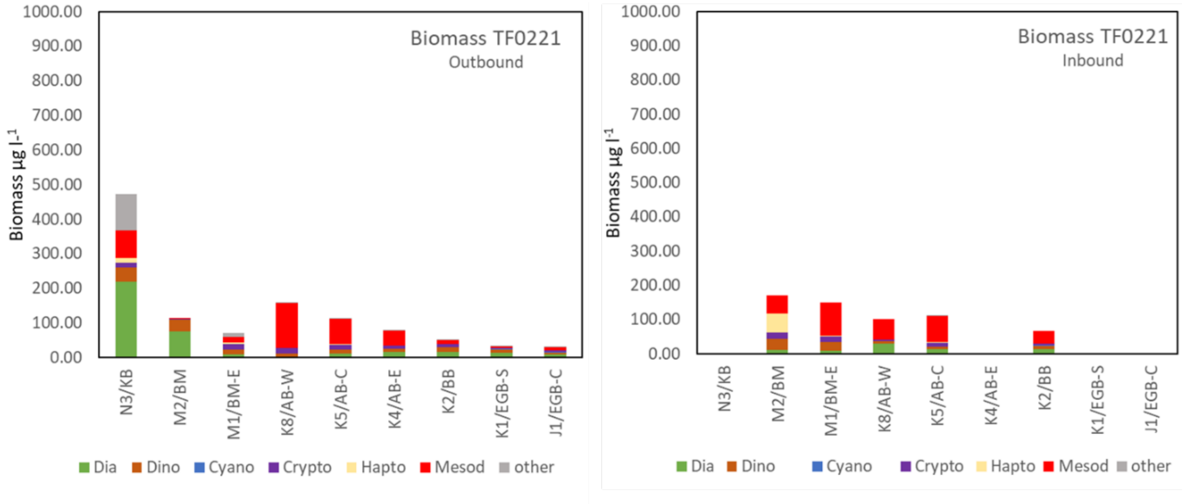

Fig. 3: Total phytoplankton biomass ($\mu g\ l^{-1}$) and contribution of major taxa measured from samples taken during northward and southward transects of TF0221 in January/February 2021. Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Hapto = Haptophytes, Mesod = Mesodinium rubrum.

At the end of January 2021, total phytoplankton biomass in Kiel Bight amounted to 470 $\mu g\ l^{-1}$ and was significantly higher than at all other stations of the transect (Fig. 3). Nevertheless, compared to the previous year, 2020, biomass in the southern Baltic, specifically Kiel Bight, was significantly lower. This likely reflects the somewhat earlier than usual timing of the winter monitoring cruise. Interestingly, the relatively high phytoplankton biomass here was not reflected by Chl*a* concentrations, which were comparably low in all three southern basins (Kiel Bight, Bay of Mecklenburg and Arkona Basin). The apparent mismatch between Chl*a* dynamics and biomass distribution, particularly during the outbound journey, is somewhat striking. It might reflect the high representation of non-diatom taxa, with prominent accessory pigments besides Chl*a*, such as the ichthyotoxic raphidophyte *Heterosigma akashiwo* (Fig. 4a), which made ~15 % of phytoplankton biomass in January/February 2021 in Kiel Bight and contains the accessory pigments beta-carotene and diadinoxanthin (MOSTAERT et al. 1998). Furthermore, the ciliate *Mesodinium rubrum* (Fig. 4b) with (klepto)plastids acquired from mixotrophic cryptophytes, as well as mixotrophic dinoflagellates with prominent accessory pigments (xantophylls) or kleptoplastids masking Chl*a* (HONGO et al. 2019), were abundant taxa of the community in the southern Basins. Their high contribution to the biomass here might explain the mismatch between biomass and Chl*a* representation.

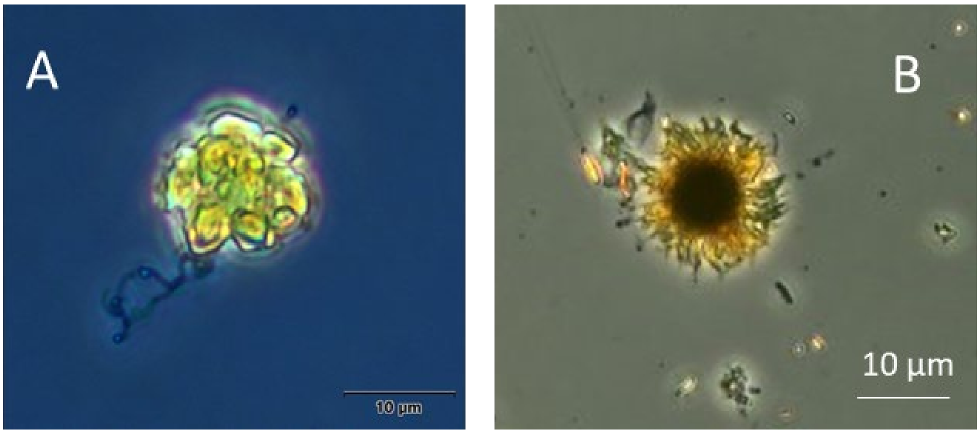

Fig. 4: Heterosigma akashiwo (A), Mesodinium rubrum (B), at the time of the February cruise in Kiel Bight and Belt Sea in 2021 (Photos: IOW).

Compared to the previous year, 2020, biomass in Kiel Bight as measured during the first cruise in January/February 2021 was approximately four-fold lower in 2021. The ciliate *Mesodinium rubrum* together with the diatom *Actinocyclus octonarius* contributed more than 50 % of the biomass in Arkona, Bornholm and Eastern Gotland Basins. The dominance of these species here is a typical feature of the early stages of seasonal phytoplankton succession (e.g. DUTZ et al. 2022) and therefore expected. Nevertheless, dominance of *Mesodinium rubrum* and flagellates represented by Prymnesiales and Gymnodiniales was somewhat unusual for the western Baltic where diatoms typically dominate at this time. This suggests that the brackish influence was high at the time of sampling. Phytoplankton communities of Bay of Mecklenburg, Arkona Basin and Baltic Proper were structured as expected – with taxa like *Mesodinium rubrum*, cryptophytes, brackish diatoms and cold water dinoflagellates, e.g. *Peridiniella catenata*, dominating. With a total of 64 taxa in the Belt Sea, 46 in Arkona Basin, 35 in Bornholm Basin and 42 in Eastern Gotland Basin (Table 5), the January/February cruise 2021 was slightly less diverse than the year before, possibly as a result of the strong influence of brackish water being transported to the south at that time.

Table 5: The 10 most abundant phytoplankton taxa (percentage of total phytoplankton biomass) and total number of taxa recorded in different sea areas (upper 10 m, data from individual stations pooled) for the January/February cruise TF0221.

Belt Sea		***Arkona Basin***	
Taxon	% Biomass	Taxon	% Biomass
Mesodinium rubrum	23.21	*Mesodinium rubrum*	59.41
Heterosigma akashiwo cf.	15.10	*Actinocyclus octonarius*	11.47
Guinardia flaccida	13.41	*Teleaulax*	7.64
Prymnesiales	7.12	*Gymnodiniales*	6.09
Gymnodiniales	5.87	*Eutreptiella*	3.65
Guinardia delicatula	5.27	*Prymnesiales*	1.63
Teleaulax	3.67	*Plagioselmis prolonga*	1.57
Rhizosolenia setigera	2.71	*Peridiniella danica*	1.08
Proboscia alata	1.97	*Octactis speculum NK*	0.89
Hemiselmis	1.60	*Ebria tripartita*	0.84
Total number of taxa	64	Total number of taxa	41

Bornholm Basin		***Eastern Gotland Basin***	
Taxon	%Biomass	Taxon	% Biomass
Mesodinium rubrum	39.27	*Actinocyclus octonarius*	37.13
Actinocyclus octonarius	23.54	*Mesodinium rubrum*	21.04
Gymnodiniales	14.63	*Gymnodiniales*	14.89
Teleaulax	10.42	*Teleaulax*	7.89
Gymnodinium verruculosum	2.46	*Snowella*	5.12
Peridiniella catenata	2.00	*Protoperidinium*	2.82
Woronichinia	1.78	*Gymnodinium verruculosum*	1.92
Prymnesiales	0.62	*Dinophysis acuminata*	1.87
Plagioselmis prolonga	0.59	*Flagellates*	1.29
Phalachroma rotundata	0.35	*Peridiniella catenata*	0.73
Total number of taxa	33	Total number of taxa	34

In March 2021, Chl*a* concentrations (Fig. 5) varied by an order of magnitude between the southernmost station in Kiel Bight (N3) and Bornholm Basin (K2), where Chl*a* concentrations reached maximum values of 9.8 µg l^{-1}, declining towards the north. Apparently, the spring bloom was well developed in Arkona and Bornholm Basins at the time of the March cruise, while the peak of the spring bloom was likely not yet reached in the Eastern Gotland Basin.

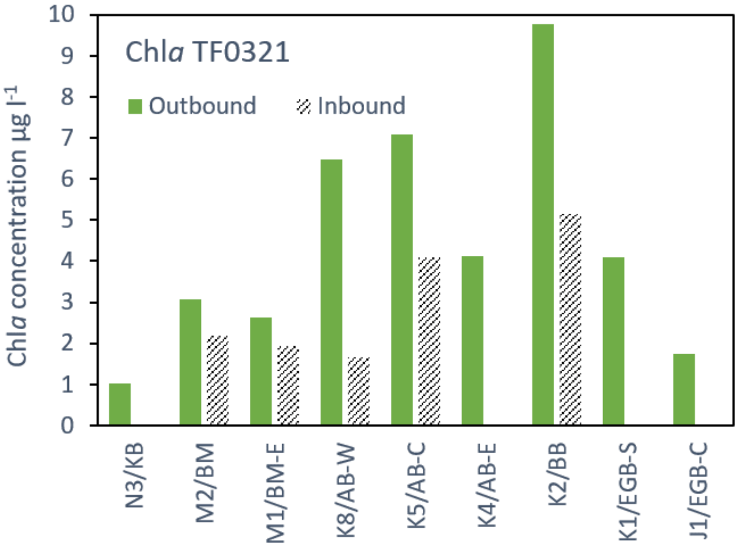

Fig. 5: Chl a concentrations (µg l-1) at sampling stations along the S-N, outbound (green) and N-S inbound (grey) legs of the March cruise TF0321 in 2021.

Like in January/February, Chl*a* dynamics were poorly reflected by total phytoplankton biomass measurements. While Chl*a* data suggested peak phytoplankton production in Bornholm Basin, total phytoplankton biomass values were highest in the Bay of Mecklenburg. However, here biomass was almost entirely dominated by the ciliate Mesodinium rubrum, haptophytes and dinoflagellates (Fig. 6), which do not precisely reflect Chl*a* dynamics (see above). In Arkona and Bornholm Basins, on the other hand, diatoms were abundant and their spatial biomass distribution was well aligned with Chl*a* patterns here. Phytoplankton Chl*a* and biomass data suggest that the bloom had started to decline on the inbound journey south in late March. The decline was sudden – in Bornholm Basin phytoplankton biomass had decreased by half, within the few days since sampling on the outbound journey. This development likely reflects changed water transport processes rather than a rapid decline of the spring bloom.

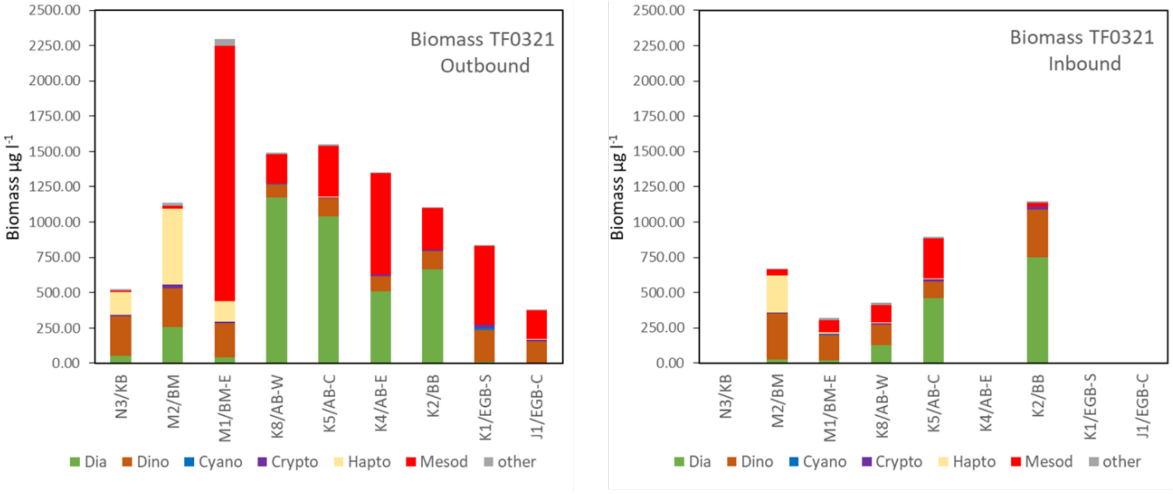

Fig. 6: Total phytoplankton biomass (µg l-1) and contribution of major taxa measured from samples taken during northward/outbound and southward/inbound transects of TF0321 in March 2021. Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Mesod = Mesodinium rubrum, Prym = Prymnesiophytes.

Table 6: The 10 most abundant phytoplankton taxa (percentage of total phytoplankton biomass) and total number of taxa recorded in different sea areas (upper 10 m, data from individual stations pooled) for the March cruise TF0321.

Belt Sea		***Arkona Basin***	
Species	% Biomass	Species	% Biomass
Mesodinium rubrum	39.54	*Mesodinium rubrum*	43.49
Prymnesiales	22.22	*Skeletonema marinoi*	37.15
Peridiniella danica	8.46	*Peridiniella catenata*	3.12
Gymnodiniales	7.35	*Gymnodiniales*	2.83
Skeletonema marinoi	5.46	*Heterocapsa rotundata*	2.28
Gymnodinium cf.	2.74	*Thalassiosira baltica*	1.70
Protoperidinium depressum	1.84	*Chaetoceros septendrionales*	1.51
Heterocapsa rotundata	1.63	*Ebria tripartita*	1.29
Pyramimonas	1.29	*Thalassiosira*	0.99
Rhizosolenia setigera	0.98	*Pyramimonas*	0.54
Total number of recorded taxa	**64**	**Total number of recorded taxa**	**46**

Bornholm Basin		***Eastern Gotland Basin***	
Taxon	%Biomass	Taxon	% Biomass
Skeletonema marinoi	58.67	*Mesodinium rubrum*	62.74
Mesodinium rubrum	13.88	*Peridiniella catenata*	21.37
Peridiniella catenata	12.78	*Gymnodiniales*	5.04
Gymnodiniales	2.90	*Teleaulax*	2.30
Apocalathium CPX	2.73	*Gymnodinium spirale*	1.64
Thalassiosira	1.87	*Aphanizomenon*	1.18
Teleaulax	0.93	*Dinophysis acuminata*	0.85
Heterocapsa rotundata	0.73	*Actinocyclus octonarius*	0.72
Peridiniella danica	0.62	*Heterocapsa rotundata*	0.48
Pyramimonas	0.53	*Protoperidinium*	0.40
Total number of taxa	**40**	**Total number of taxa**	**43**

Biomass composition of cruise TF0321 differed largely between the basins (Fig. 6, Table 6). In Kiel Bight and the western parts of the Bay of Mecklenburg, *Mesodinium rubrum* and Prymnesiales (haptophytes) dominated the biomass (Stations N3 and M2). Diatoms were almost entirely absent at the time of the March cruise here, and like in January/February, the community showed a strong brackish influence. In Arkona and Bornholm Basins, the spring diatom *Skeletonema marinoi* constituted ~40 to 60 % of the biomass in March in Bornholm and Arkona Basins, which is a typical situation at that time of the year here. Besides diatoms, typical cold-water dinoflagellates were present, including *Peridiniella catenata* (Fig. 7) and *Gymnodinium corollarium*. The latter is difficult to identify based on morphological features, and can easily be confused with other spring dinoflagellates. The species is known to grow to high biomass in the large central basins of the Baltic Sea. Identification is difficult and requires in-depth knowledge of dinoflagellate taxonomy (SUNDSTRÖM et al. 2009). Total number of taxa was highest in the Belt Sea (64). Arkona (46), Bornholm (40) and Gotland (43) Basins were comparable in terms of species diversity. Here taxa representation was typical for the season (DUTZ et al. 2022).

Fig. 7: The cold water dinoflagellate Peridiniella catenata (up right), a Cryptophyte (below), and chains of Skeletonema marinoi*, representing typical spring taxa of the southern and central Baltic Basins in March 2021 (Photo: IOW).*

In May 2021, the phytoplankton spring bloom was still ongoing throughout the study area as indicated by Chl*a* levels ranging from 1.3 µg l^{-1} at the southernmost station N3 in Kiel Bight to 3.36 µg l^{-1} in the Bay of Mecklenburg (Station M1). Chl*a* concentrations differed only slightly on the southward (inbound) journey, being insignificantly higher or even lower at most stations than on the outbound journey. Generally, low (compared to the March cruise) Chl*a* values throughout the study area suggest that the bloom was already declining at the time of the May cruise. This was somewhat expected, as the peak of the phytoplankton spring bloom cascades temporally from south to north and has usually passed the southern and central Basins by May (e.g. DUTZ et al. 2022). In May 2021, the Chl*a* concentrations were in the same range as the year before.

Similar to the February and March cruises, Chl*a* patterns in May were inconsistent with spatial biomass dynamics (Fig. 8 and Fig. 9). Biomass was dominated by phytoplankton groups other than diatoms, the latter contributing ~5 % at most (K2 and K1 in Bornholm- and southern Gotland Basins), and even less than 1 % at most other stations. May biomass was dominated by dinoflagellates and haptophytes (Prymnesiales) in the south and by *Mesodinium rubrum* and dinoflagellates in the north.

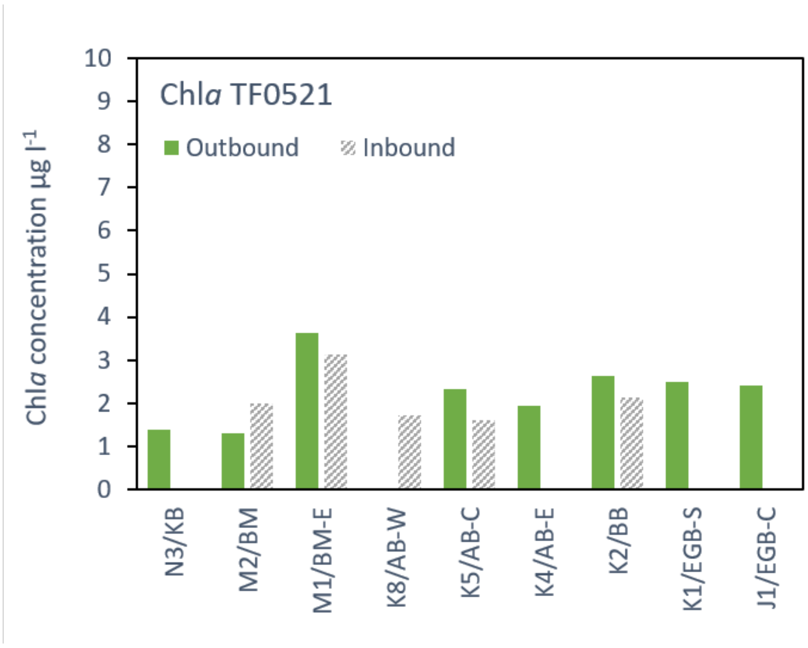

*Fig. 8: Chl*a *concentrations (µg l^{-1}) at sampling stations along the outbound (northward, green) and inbound (southward, hatched grey) legs of the March cruise TF0321 in 2021.*

The highest total biomass measured in May was ~1000 and ~1400 µg l^{-1}, respectively, and occurred at the northernmost stations K1 and J1 in the Eastern Gotland Basin. The respective spatial biomass distribution reflects, on one hand, the northward delay of the spring bloom peak, and at the same time regional bloom dynamics of dinoflagellate dominated communities that are a typical feature of the central and northern Baltic spring bloom (Sundström et al. 2009, Klais et al. 2011a, Klais et al. 2011b). Compared to the previous year, total biomass was generally twice as high as in 2020, when *Mesodinium rubrum* was absent from the community. It remains difficult to explain this specific pattern. The late phases of the Baltic spring bloom are generally very dynamic and typical features might be missed by the specific time window of annual spring monitoring cruises.

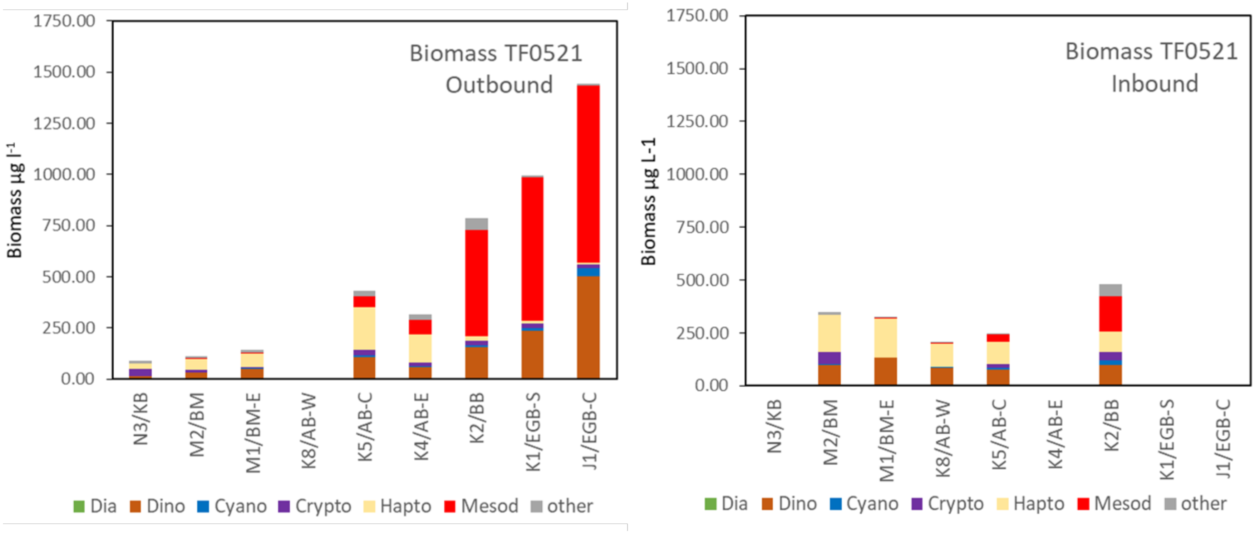

Fig. 9: Total phytoplankton biomass (µg l^{-1}) and contribution of major taxa measured from samples taken during northward/outbound and southward/inbound transects of TF0521 in May 2021. Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Mesod = Mesodinium rubrum, Prym = Prymnesiophytes.

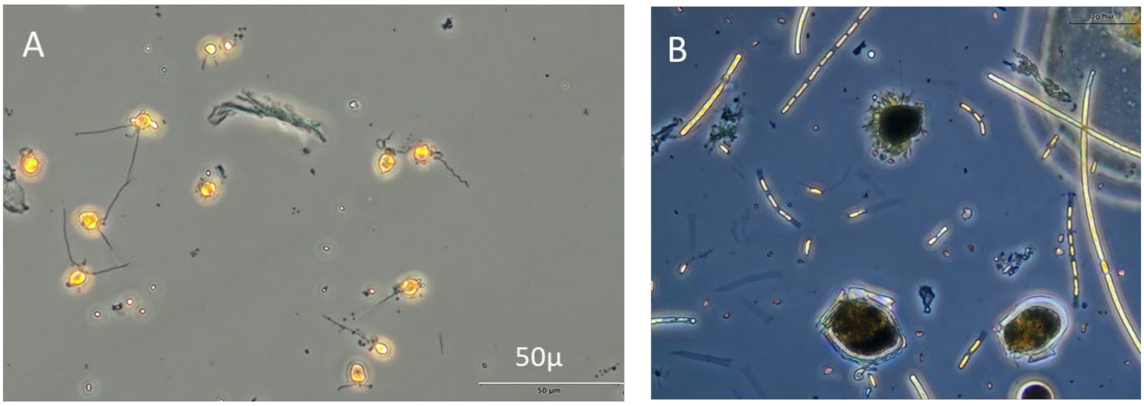

Fig. 10: Light micrographs of (A) prymnesiophyte dominated community as found in Belt Sea at TF012, and B) dinoflagellates (Dinophysis spp.) and filamentous cyanobacteria in Arkona Basin (TF113) in May 2021 (Photos: IOW).

Table 7: The 10 most abundant phytoplankton taxa (percentage of total phytoplankton biomass) and total number of taxa recorded in different sea areas (upper 10 m, data from individual stations pooled) for the May cruise TF0521 in 2021.

Belt Sea		***Arkona Basin***	
Species	% Biomass	Species	% Biomass
Prymnesiales	44.80	*Prymnesiales*	44.48
Gymnodiniales	10.39	*Mesodinium rubrum*	16.05
Peridiniella danica	8.42	*Gymnodiniales*	9.63
Heterocapsa rotundata	6.21	*Peridiniella danica*	8.68
Telonema	6.05	*Heterocapsa rotundata*	3.83
Peridiniales	2.47	*Pyramimonas*	3.69
Pyramimonas	2.39	*Telonema*	3.59
Plagioselmis prolonga	1.84	*Teleaulax*	1.51
Pseudopedinella	1.73	*Peridiniales*	1.26
Mesodinium rubrum	1.28	*Pseudopedinella*	1.03
Total number of recorded taxa	40	Total number of recorded taxa	36

Bornholm Basin		***Eastern Gotland Basin***	
Taxon	% Biomass	Taxon	% Biomass
Mesodinium rubrum	53.63	*Mesodinium rubrum*	63.88
Prymnesiales	8.90	*Dinophysis acuminata*	7.84
Pyramimonas	7.60	*Dinophysis norvegica*	5.30
Heterocapsa rotundata	6.49	*Apocalathium CPX*	3.16
Peridiniella danica	4.09	*Gymnodiniales*	2.82
Gymnodiniales	3.60	*Aphanizomenon*	2.06
Telonema	2.03	*Protoperidinium brevipes*	2.04
Dinophysis norvegica	1.79	*Peridiniella catenata*	2.00
Katablepharis remigera	1.09	*Amylax triacantha*	1.36
Teleaulax	1.08	*Heterocapsa rotundata*	1.00
Total number of taxa	40	Total number of taxa	40

Prymnesiales (Fig. 10a) constituted approximately half of the biomass in the southern basins (Table 7). Their blooms are a common feature in the Baltic Sea in spring. Sometimes, they can grow to high biomass and cover large areas, as in 2008, when an extensive bloom covered large parts of the Baltic proper (MAJANEVA et al. 2012). Dinoflagellates of Gymnodiniales, *Peridiniella danica* and *Heterocapsa rotundata* were the next abundant group of phytoplankton here, contributing ~25 % to total biomass in the south. Besides *Mesodinium rubrum*, dinoflagellates, particularly the different species of *Dinophysis* (Fig. 10b) were highly abundant in the northern basins, with similar biomass shares. Unlike in previous years, diatoms played a minor role in the May phytoplankton community. The number of species was comparable to the previous cruise in March, except for the Belt Sea, where only 40 taxa were documented. These consisted mainly of brackish taxa, suggesting strong influence of the Baltic Proper here.

3.1.1.2 Summer bloom

In July 2021, at the time of the TF0721 monitoring cruise, Chl*a* levels were similar along the cruise track transect. Concentrations (Fig. 11) ranged between 1.3 and 2.4 µg l^{-1} on the outbound journey, but had increased slightly on the return journey with maximum concentrations of 3.2 µg l^{-1}, indicating that the summer bloom was still developing in late July. Highest Chl*a* values were measured in Arkona Basin and the Bay of Mecklenburg at stations M1 and K8 respectively.

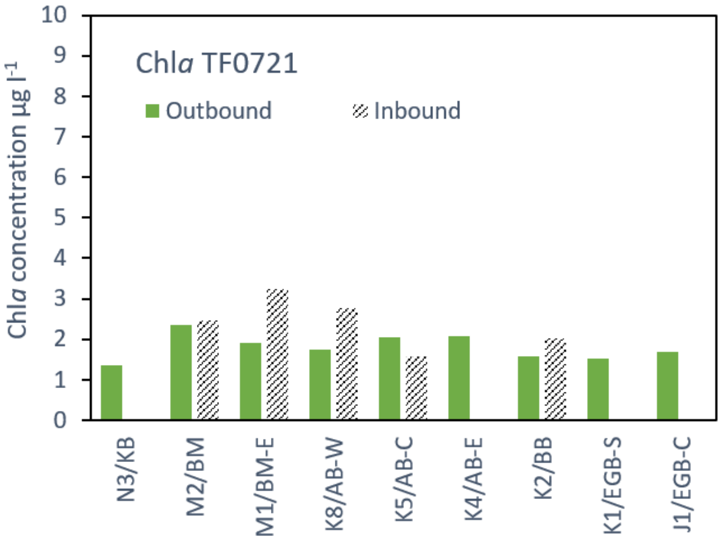

Fig. 11: Chla concentrations (µg l^{-1}) at sampling stations along the S-N (green) and N-S (hatched grey) transects of cruise TF0721 in July 2021.

Chl*a* dynamics were not well reflected by biomass dynamics (Fig. 12), particularly in the south at the Belt Sea and Arkona Basin stations. As in the previous year (Dutz et al. 2022), diatoms dominated the summer phytoplankton community here, specifically *Dactyosolen fragilissimus*, which constituted 80 and >90 % of the biomass in the Bay of Mecklenburg during TF0721 (Table 8). It has been proposed that the poor representation of high biomass caused by this species in comparison to Chl*a* might be due to the sparse pigmentation and the relatively low amount of Chl*a* per cell volume compared to most other species of the community. Total biomass in the western Baltic Sea amounted to maximum values between 3000 – 4000 µg l^{-1} at stations N3 and M2 to 7800 µg l^{-1} at station M1 on the return journey. Spatial biomass dynamics were similar to the previous year in the Belt Sea, however, then maximum biomass levels were 50 % lower than in 2021. Apparently, nutrient levels were high enough in the western Baltic to facilitate the development of such high diatom biomass in 2021. As in the previous year, the contribution of cyanobacteria to total biomass was very low in the western sea areas.

While cyanobacteria dominated the phytoplankton of the summer cruise in Arkona, Bornholm and Gotland Basins (Fig. 12, Fig. 13), biomass produced by the respective blooms at the time of the cruise represented only approximately 5 % of the massive diatom biomass in the south. It is possible that at the time of the cruise the typical summer cyanobacteria blooms of the central Baltic had not yet commenced. In contrast to the previous year, dinoflagellates represented only a minor fraction of the summer bloom, which was different compared to the previous years. In addition, dinoflagellates were less common in 2021 compared to the year before, 2020, when warm water species such as *Alexandrium pseudogonyaulax* or *Dinophysis* spp. were prominent in the summer phytoplankton community.

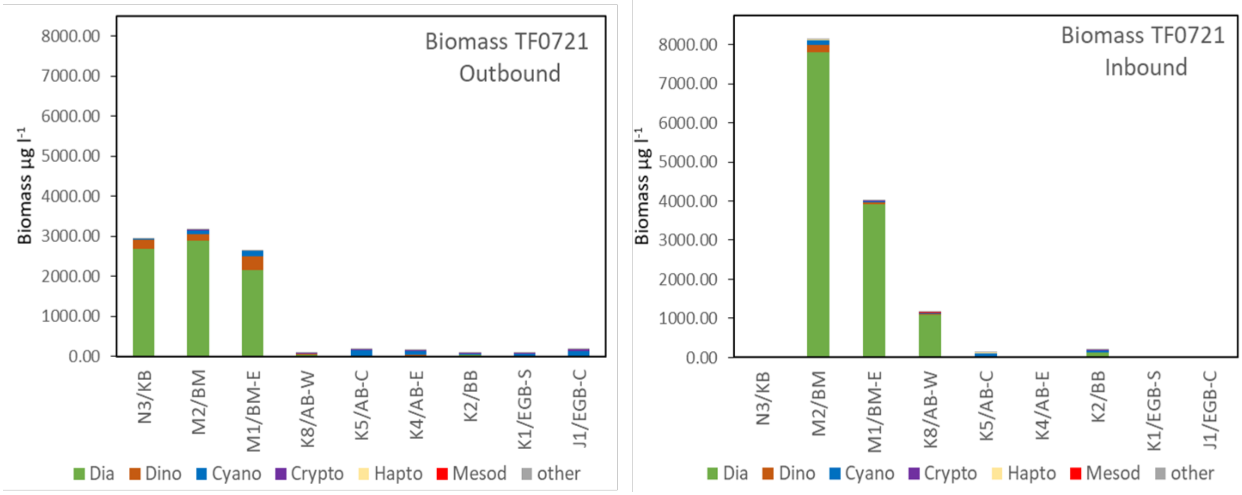

Fig. 12: Total phytoplankton biomass (µg l-1) and contribution of major taxa measured from samples taken during outbound northward and inbound southward transects of TF0721 in July 2021. Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Mesod = Mesodinium rubrum, Prym = Prymnesiophytes.

Due to the domininance of *Dactyosolen fragilissimus*, other taxa contributed little to the biomass in the Belt Sea (Table 8). Nevertheless, typical species of the summer communities were present at low concentrations, such as the dinoflagellate *Tripos muelleri* – usually an abundant species of the summer community in the Belt Sea – and dinoflagellates of Gymnodiniales. Cyanobacteria (*Pseudanabaena limnetica*, *Nodularia spumigena* and *Aphanizomenon*) constituted › 60 % of the biomass in Arkona Basin; here diatoms were much less represented than in the Belt Sea. Interestingly, diatoms were abundant again further north in Bornholm Basin – here *Chaetoceros danicus* produced a large fraction of the biomass (41 %) in July, which is unusual, as diatoms typically play a minor role in the summer phytoplankton communities of the Baltic Sea.

Cyanobacteria, *Nodularia spumigena* and *Pseudanabaena limnetica* only represented ~ 20 % of the biomass in Bornholm Basin. Cyanobacteria dominated the phytoplankton community of the Gotland Basin in July, being represented by *Pseudanabaena limnetica* (›40 % of total Biomass) and *Nodularia spumigena* (11.1 %).

The taxon distribution reflected the typical pattern of diversity with the number of taxa decreasing towards the north and being highest in the Belt Sea.

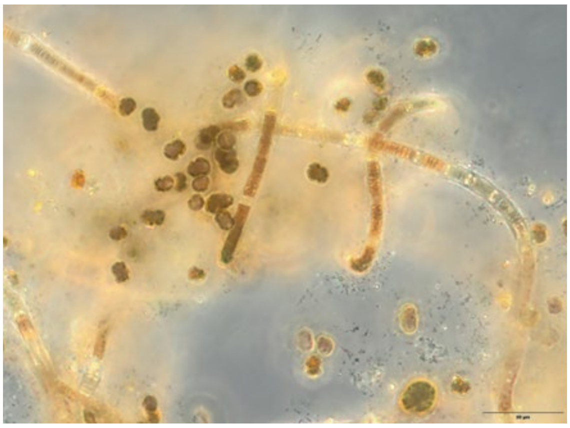

Fig. 13: Typical representation of summer phytoplankton from Bornholm Basin in 2021 showing Nodularia spumigena together with an abundant species of Gymnodiniales (Photo: IOW).

Table 8: The 10 most abundant phytoplankton taxa (percentage of total phytoplankton biomass) and total number of taxa recorded in different sea areas (upper 10 m, data from individual stations pooled) for the July cruise TF0721 in 2021.

Belt Sea		***Arkona Basin***	
Species	% Biomass	Species	% Biomass
Dactyliosolen fragilissimus	89.71	*Pseudanabaena limnetica*	41.70
Chaetoceros danicus	2.06	*Nodularia spumigena*	11.131
Tripos muelleri	1.75	*Aphanizomenon*	10.10
Gymnodiniales	1.45	*Gymnodinales*	9.04
Aphanizomenon	1.27	*Plagioselmis prolonga*	6.14
Nodularia spumigena	0.62	*Chaetoceros danicus*	4.92
Unicell *spp*	0.34	*Pseudopedinella*	4.42
Proboscia alata	0.29	*Teleaulax*	4.17
Rhizosolenia setigera f. pungens	0.27	*Prymnesiales*	3.40
Cerataulina pelagica	0.24	*Pyramimonas*	2.68
Total number of taxa	**67**	**Total number of taxa**	**37**

Bornholm Basin		***Eastern Gotland Basin***	
Taxon	% Biomass	Taxon	% Biomass
Chaetoceros danicus	40.97	*Pseudanabaena limnetica*	41,76
Nodularia spumigena	11.81	*Plagioselmis prolonga*	14.22
Plagioselmis	9.31	*Nodularia spumigena*	12.47
Pseudanabaena limnetica	8.32	Unicell *spp.*	7.05
Pyramimonas	8.30	*Pyramimonas*	6.27
Teleaulax	4.73	*Pseudopedinella*	5.19
Unicell *spp.*	4.47	*Mesodinium rubrum*	3.44
Mesodinium rubrum	3.70	*Gymnodiniales*	3.36
Actinocyclus	2.43	*Prymnesiales*	3.13
Pseudopedinella	1.67	*Leucocryptos marina*	0.92
Total number of taxa	**23**	**Total number of taxa**	**25**

3.1.1.3 Autumn bloom

In November 2021, Chl*a* values ranged from 2.7 µg l^{-1} in the south to 5.4/5.6 µg l^{-1} in the northern and central basins (Fig. 14) and were thus in the same range as in November 2020. However, values in the northern basins were higher in 2021 compared to 2020. Chl*a* concentrations had increased slightly on the inbound return journey which suggests that the autumn phytoplankton bloom was ongoing in the entire study area at the time of the TF1121 monitoring cruise. Lowest concentrations were measured at station K2 in Bornholm Basin on the outbound journey, highest at K8 in the western Arkona Basin. Nevertheless, average Chl*a* concentrations measured on both transects were in the same range across the four basins. On average, the Chl*a* levels of the November cruise were comparable to the ones obtained from the March cruise.

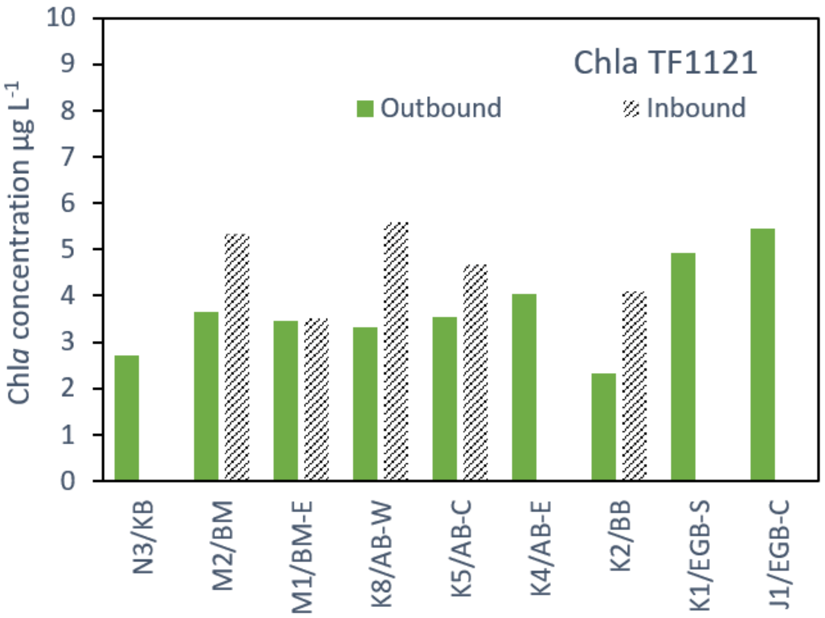

Fig. 14: Chla concentrations (µg l-1) at sampling stations along the outbound northward (green) and inbound southward (hatched grey) transect in November 2021 on TF1121.

Spatial Chl*a* dynamics corresponded relatively well with total phytoplankton biomass distribution, except for the Gotland Basin where the total amount of biomass was significantly higher than at other stations. Phytoplanktion biomass (Fig. 15) was dominated by diatoms throughout the study area, their biomass contributions were 80 to nearly 100 % at all stations except N3 and M2 in the Belt Sea. Maximum total biomass was between ~3400 µg l^{-1} in the North and ~780 µg l^{-1} in the South.

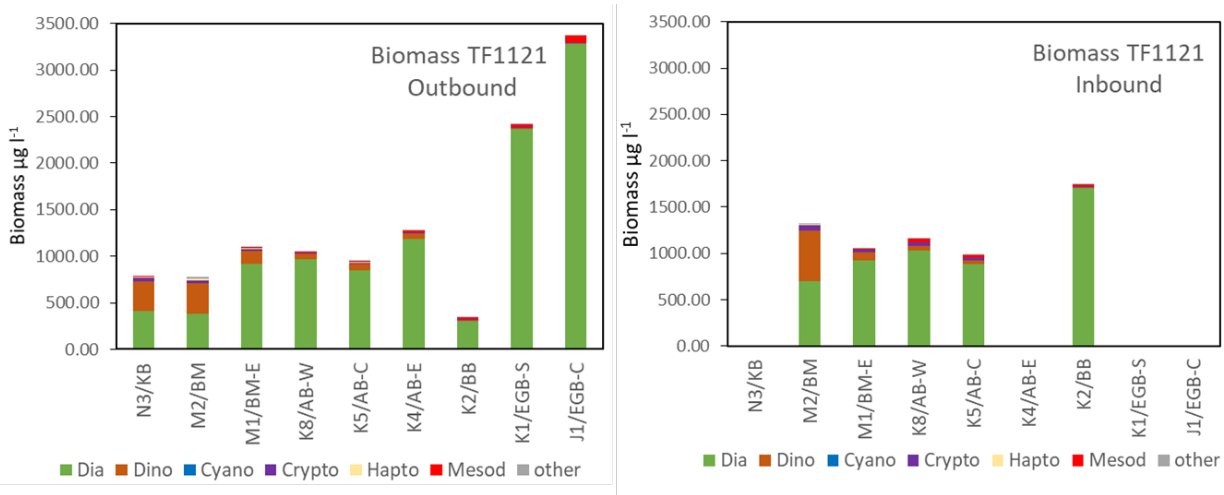

Fig. 15: Total phytoplankton biomass (µg l-1) and contribution of major taxa measured from samples taken during northward/outbound and southward/inbound transects of TF1121 in November 2021 Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Mesod = Mesodinium rubrum, Prym = Prymnesiophytes.

Table 9: The 10 most abundant phytoplankton taxa (percentage of total phytoplankton biomass) and total number of taxa recorded in different sea areas (upper 10 m, data from individual stations pooled) during November 2021, on cruise TF1121.

Belt Sea		***Arkona Basin***	
Species	% Biomass	Species	% Biomass
Cerataulina pelagica	22.25	*Coscinodiscus granii*	54.34
Pseudosolenia calcar-avis	8.92	*Coscinodiscopsis commutata*	25.17
Coscinodisccopsis commutata	5.65	*Cerataulina pelagica*	3.92
Rhizosolenia setigera	5.17	*Mesodinium rubrum*	2.48
Coscinodiscus granii	3.45	*Coscinodiscus radiatus*	1.92
Tripos lineatus	3.33	*Teleaulax*	1.89
Gymnodiniales	2.56	*Pseudosolenia calcar-avis*	1.37
Tripos muelleri	1.94	*Unicell spp.*	1.24
Unicell *spp.*	1.80	*Gymnodiniales*	1.12
Teleaulax	1.57	*Prorocentrum micans*	0.87
Total number of taxa	91	Total number of taxa	43

Bornholm Basin		***Eastern Gotland Basin***	
Taxon	%Biomass	Taxon	% Biomass
Coscinodiscus granii	90.29	*Coscinodiscus granii*	96.14
Coscinodiscus sp.	2.59	*Mesodinium rubrum*	1.69
Actinocyclus octonarius	2.53	*Actinocyclus octonarius*	1.22
Mesodinium rubrum	1.49	*Teleaulax*	0.22
Teleaulax	0.62	*Gymnodiniales*	0.15
Gymnodiniales	0.51	Unicell spp.	0.26
Chaetoceros castracanei	0.32	*Gyrodinium spirale*	0.08
Unicell *spp.*	0.28	*Eutreptiella*	0.07
Dinophysis norvegica	0.24	*Chaetoceros castracanei*	0.06
Plagioselmis prolonga	0.23	*Hemiselmis*	0.04
Total number of taxa	32	Total number of taxa	32

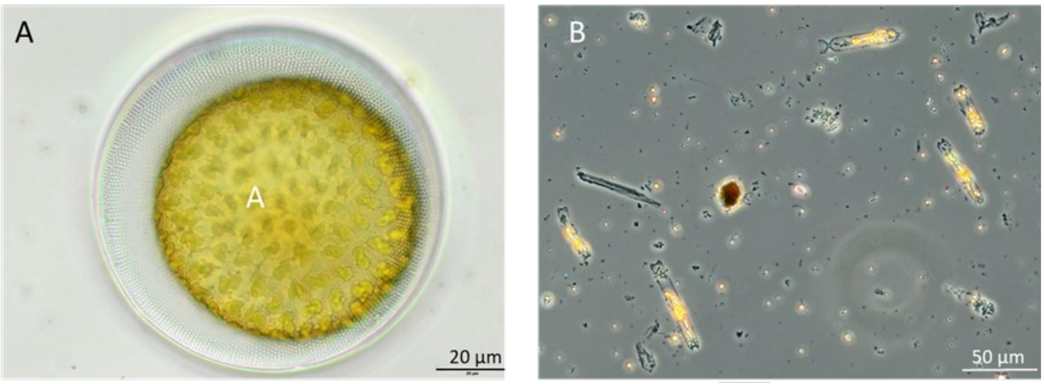

Fig. 16: Diatoms (Coscinodiscus spp. in the North (A) and Cerataulina pelagica (B, lightly coloured silica frustules) in the South, constituting high biomass shares in autumn 2021 (Photo: IOW).

Diatoms generally dominated the autumn biomass along the entire study area (Fig. 16). *Coscinodiscus* spp. constituted over 90 % of the biomass in Bornholm and Eastern Gotland Basins and *Cerataulina pelagica* (Fig. 16). Dinoflagellates only played a role in the south, i.e. Kiel Bight and Bay of Mecklenburg, (N3 and M2), where they contributed approximately 40 % of the total phytoplankton biomass. This was, however, remarkable since each dinoflagellate species never made more than 1 % of the biomass. Apparently, the many species present in their sum made a significant impact. Generally, species diversity was high in the Kiel Bight and the Bay of Mecklenburg. All together 90 different taxa were identified from the Belt Sea stations on TF1121 in autumn. Taxonomic diversity was significantly lower in all other sea areas ranging from 40 species in Arkona Basin to 32 in Bornholm and Gotland Basins.

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

In 2021 altogether, 165 phytoplankton species/taxa were recorded in the monitoring samples from 0 to 10 m water depth, 12 more than in 2020. A complete list of recorded species with biomass ranks and annual average biomass values can be found in supplementary Appendix 1. Diatoms were the most important biomass producers, specifically *Rhizosolenia fragilissimus* (31 % of total annual biomass) in the southern sea areas (Belt Sea and Arkona Basin) and *Coscinodiscus granii* (14.61 %, biomass rank 2) growing in the northern lower salinity parts of the monitored area (Arkona to Gotland Basin). These were followed by *Mesodinium rubrum* (rank 3, 12.74 %), *Skeletonema marinoi* (rank 4) and *Cerataulina bergonii* (rank 5). Prymnesiales (haptophytes) and gymnodiniales (dinoflagellates) were ranked 6th and 7th of the most common taxa. In terms of annual biomass production, cyanobacteria played a minor role in 2021 (*Aphanizomenon* ranked 28, *Pseudanabaena limnetica* ranked 20).

Table 10 shows occurrences of toxic and potentially harmful taxa at sampled stations in 2021. Under conditions of climate change, when temperatures of surface waters rise, the risk of harmful algal bloom formation increases (WELLS et al. 2015). Particularly warm water adapted species such as filamentous cyanobacteria and dinoflagellates are expected to 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 2021, only a few taxa of harmful algae contributed significant biomass shares to the phytoplankton community, though none at bloom concentrations. Species of dinoflagellates and diatoms (*Alexandrium* spp. and *Pseudonitzschia* spp.) only occurred sporadically with low biomass in the western Baltic in 2021 (Table 10). Nevertheless, in addition to the well established bloom forming species, *Heterosigma akashiwo*, a potentially fish-killing raphidophyte species, was recorded at high biomass (>15 % of total phytoplankton biomass) in Kiel Bight, as well as the potentially shellfish poisoning dinoflagellate *Azadinium spinosum*. *H. akashiwo* is listed as a non-indiginous species in the Baltic Sea, as is *Prorocentrum cordatum* (Olenina et al. 2010), which was found in July and November predominantly in the southern Basins of the study area.

Generally, harmful phytoplankton taxa were less prominent in 2021 than the year before. This is probably related to frequent dominance of diatoms in the summer bloom. Prymnesiales were present throughout the year. Nevertheless, as they are usually not identified to species level, it is difficult to tell whether or not the potentially fish-killing *Prymnesium parvum* was among them.

Table 10: Occurence of toxic/ bloom forming and invasive phytoplankton taxa in 2021. + = 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	IOW and BSH cruise	TF360 N3	TF0012 M2	TF046 M1	TF030 K8	TF113 K5	TF109 K4	TF0213 K2	TF259 K1	TF271 J1
Cyanophyceae										
Dolichospermum spp.	TF0721	+		+		+	+			
Nodularia spumigena	TF0721		+	+	++	+++	+++	++	++	+++
	TF1121				+			+		
Aphanizomenon sp.	TF0221						+			
	TF0321				+	+		+		+
	TF0521			+		++	+	++	++	++
	TF0721		++	++	++	++	+++			+
	TF1121						+	+		
Dinophyceae										
Alexandrium pseudogonyaulax	TF0721	+	+	+						
Prorocentrum cordatum	TF0721	+	+	++	++			+		
	TF1121		+	+	+	+	+			
Dinophysis spp.	TF0221	+	+	+					++	++
	TF0321	++	+	+		+				++
	TF0521		+++	++			++	++	++	+++
	TF0721		+			+				
	TF1120	++	++	+	+	+	+	+		
Bacillariophyceae										
Pseudo-nitzschia spp.	TF0221	+	+	+	+					
	TF1121	++	++	+	+	+	+			
Raphidophyceae										
Heterosigma akashiwo	TF0221	+++								

3.1.3 Long-term trends

Biomass

Average phytoplankton biomass was in 2021 with 928 µg l^{-1} slightly higher than the annual biomass mean over the past 20 years (Fig. 17).

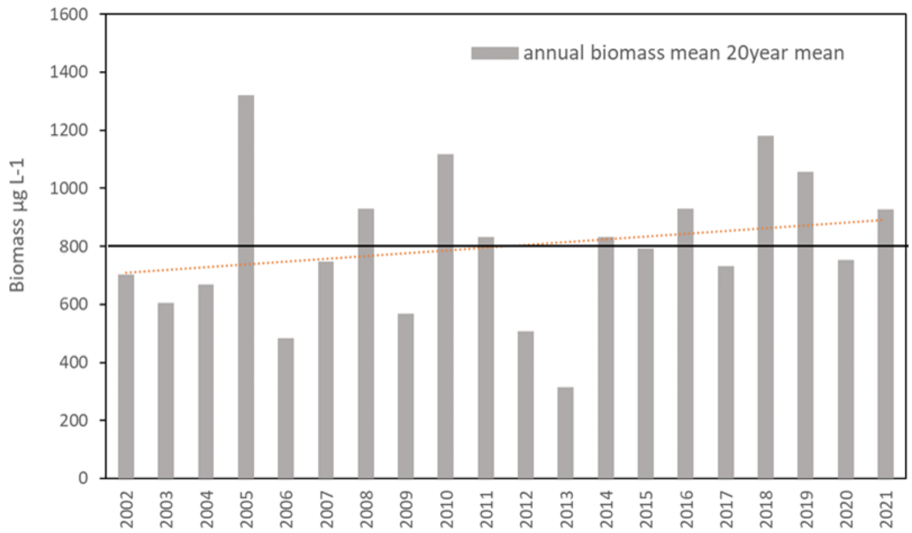

Fig. 17: Mean annual biomass values (all stations and samplings) for the period between 2002 and 2021. Dotted line = trendline, solid line = 20ys mean.

Diatom/Dinoflagellate ratio

In 2021, the diatom/dinoflagellate ratio was 4.8 and thereby higher than the 20-year mean of 3.4 (Fig. 18). 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 dinoflagellates specifically in the spring bloom is an indication for a good environmental status (Wasmund et al. 2017) 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, 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. Large dinoflagellate blooms were not observed in the study area in 2021.

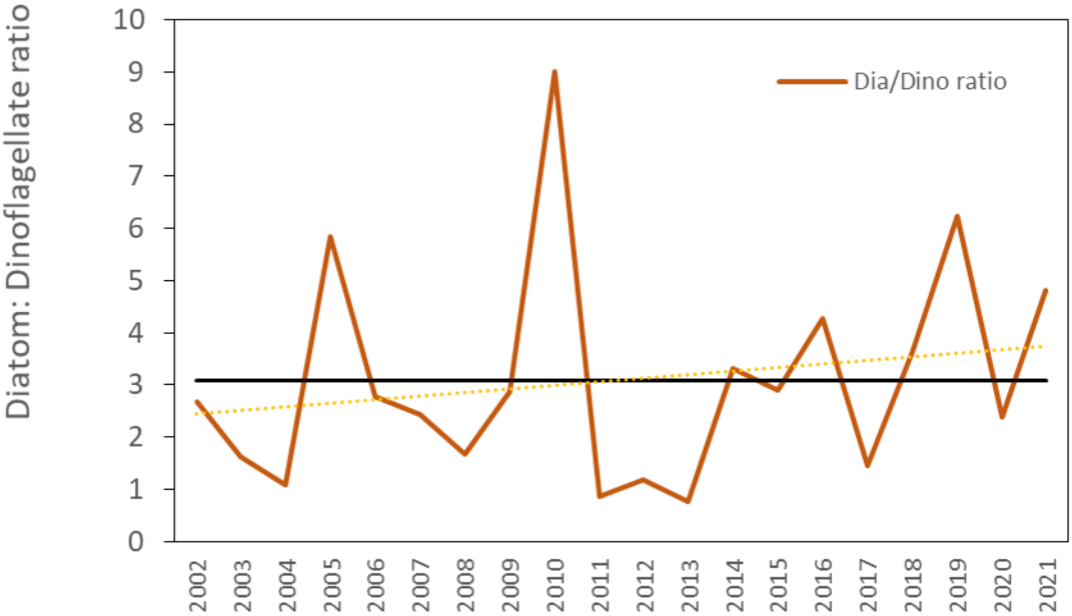

Fig. 18: Mean annual ratio of diatoms to dinoflagellates based on biomass concentrations per sampling and station (µg l-1), 2002 - 2021. The black line marks the 20-year mean, dotted line = trendline.

Cyanobacteria biomass (Fig. 19) was with 18.32 µg l^{-1} significantly lower than during the previous year and compared to the 20-year mean. This reflects the dominance of diatoms at the time of the July cruise 2021, which had grown to a biomass much higher than during the spring bloom in March. The relative dominance of diatoms in a summer bloom is unusual and further research is needed to find an explanation for this pattern.

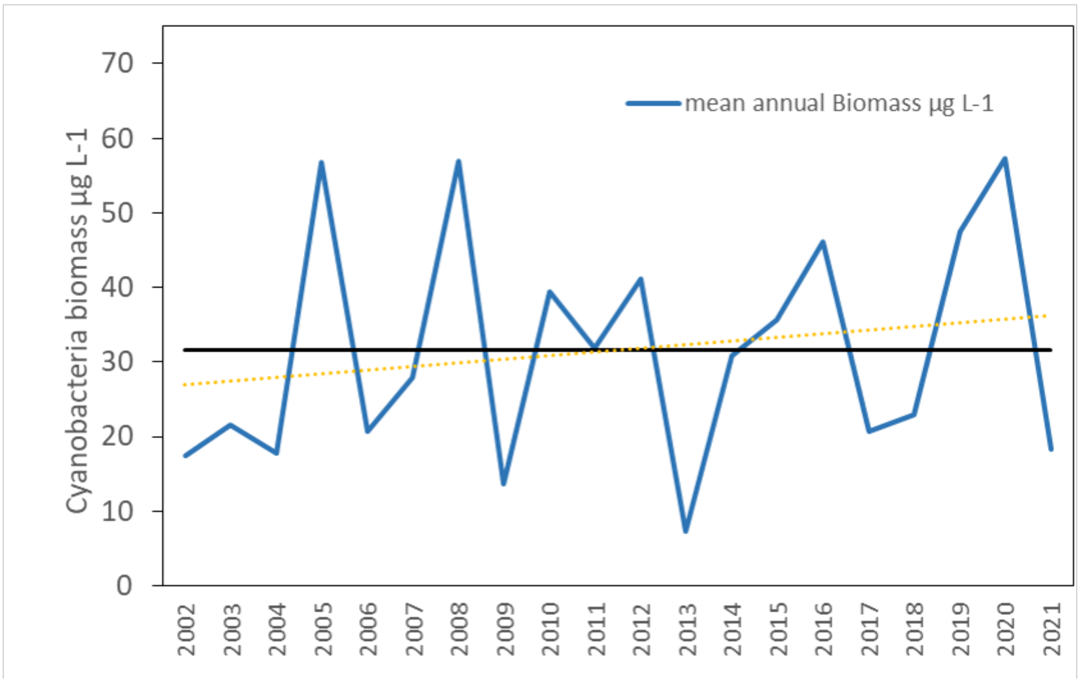

Fig. 19: Mean annual cyanobacterial biomass for the period 2002 – 2021, based on per sampling and station (µg l-1). The black line marks the 20-year mean, dotted line = trendline.

3.2 Mesozooplankton

3.2.1 Species composition and non-indigenous species

A total of 45 taxa were identified in the Kiel Bight, the Bay of Mecklenburg and the Arkona Basin during the sample analysis (Appendix 2). The species inventory largely resembled the taxa observed during previous years with a dominance of euryhaline and brackish species and few true marine species. The number of taxa was in the lower range of those 44 - 50 taxa recorded during the years 2018 - 2020, which followed an exceptional peak during 2016 - 2017 (63 - 73 taxa, WASMUND et al. 2018, 2019, DUTZ et al. 2022). In contrast to the previous years, several Hydrozoa like *Stauridiosarsia gemmifera* or *Euphysa aurata*, larvae of benthic taxa or crustaceans like ostracods were not observed in 2021. Additionally, only few halophilic taxa occurred. These included the copepod *Centropages typicus*, the cladoceran *Penilia avirostris*, chaetognaths of the family Sagittidae spp. or the hydrozoan *Sarsia tubulosa*, which are all restricted in their occurrence to the southern Kattegat and SW Baltic Sea (TELESH et al. 2009, JASPERS et al. 2021).

The species richness showed only little seasonal variation in 2021 and remained below 25 in each season without a typical minimum in May (Fig. 20). This minimum occurred regularly in previous years and was attributed to an increased species number in February, March and July with up to 35 taxa. In addition, no clear spatial trend in species richness appeared. While the species number has usually been higher in the Kiel Bight and the Bay of Mecklenburg in previous years, it was rather similar (13 - 25 taxa) to the Arkona Basin (14 - 24 taxa) in 2021. This was related to the lower species number of meroplankton and hydrozoans during the year 2021 since these taxa occur primarily in winter and summer in the western areas, and thus related to a lower number of observations of halophilic species in the investigation area.

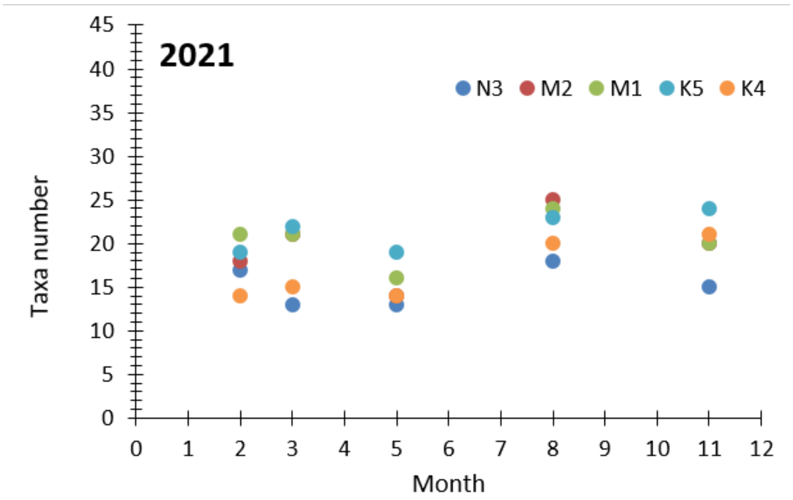

Fig. 20: Seasonal variation of the number of mesozooplankton taxa recorded at different stations in the investigation area in 2021.

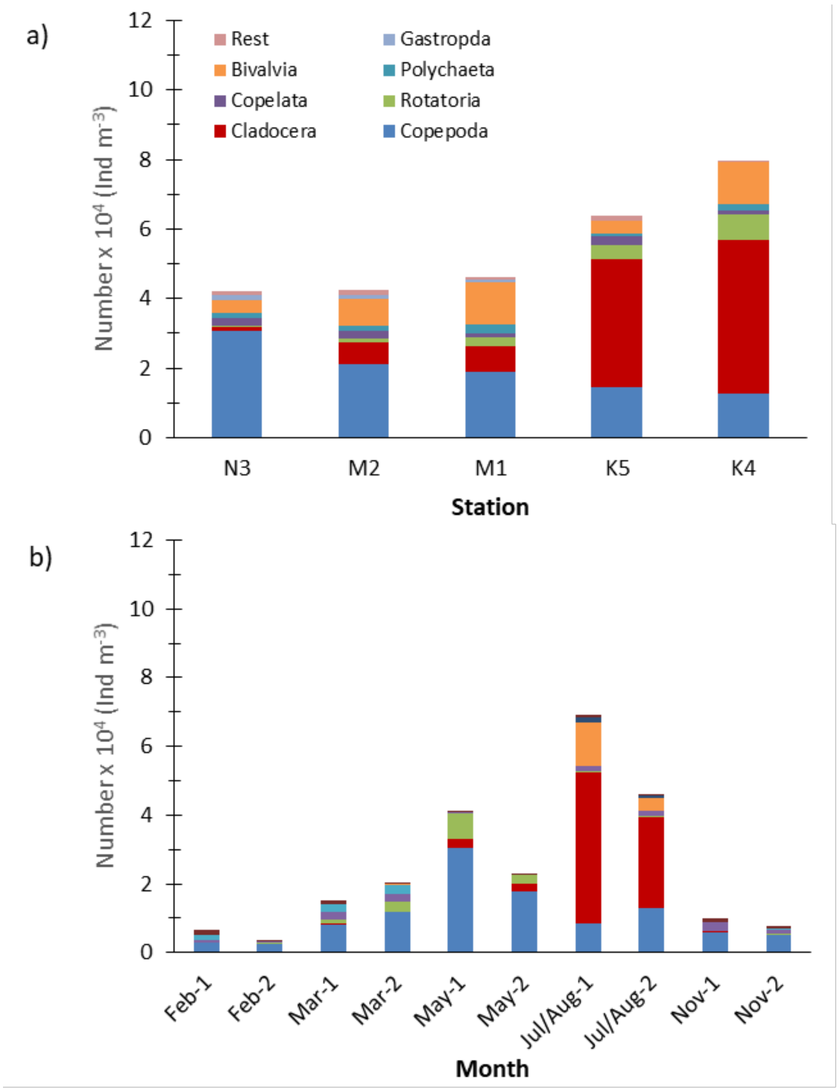

Fig. 21: Spatial (a) and seasonal variation (b) of the main zooplankton groups based on the maximal abundance observed at each station during our cruises from February - November (a) and on the maximal abundance observed during the respective months in the whole investigation area (station N3 - K4) in 2021. Numbers in b indicate duplicate hauls usually offset by 1 week (see Table 2).

Based on the maximal concentrations, zooplankton abundance ranged from 4.3 to 8.0 x 10^4 ind. m^{-3} in the Kiel Bight (N3) and in the Arkona Basin (K4), respectively (Fig. 21a). These numbers indicate an increase in the stock size by 40 % compared to the previous year. Regarding the long-term development, however, values are still low (see WASMUND et al. 2017, 2018b, 2019, DUTZ et al. 2022 and chapter 3.2.3). An increase of the density of cladocerans in the Arkona Basin was mainly responsible for this marginal recovery. In contrast to the preceding year, they were the numerically dominating taxon in 2021 (Fig. 21a, b). With a maximum abundance of 0.1 - 4.4 x 10^4 ind. m^{-3} in the investigation area, they contributed to 3 - 57 % to the zooplankton stock (Fig. 22 a-i). Copepods were the second most abundant group with a maximum abundance ranging from 1.3 - 3.1 x 10^4 ind. m^{-3} (Fig. 21a, b), which is equivalent to 16 - 69 % of the stock (Fig. 22 a-i). The proportion of cyclopoid copepods, however, remained below 10 %, which is considerably lower than their share in previous years (>20 %).

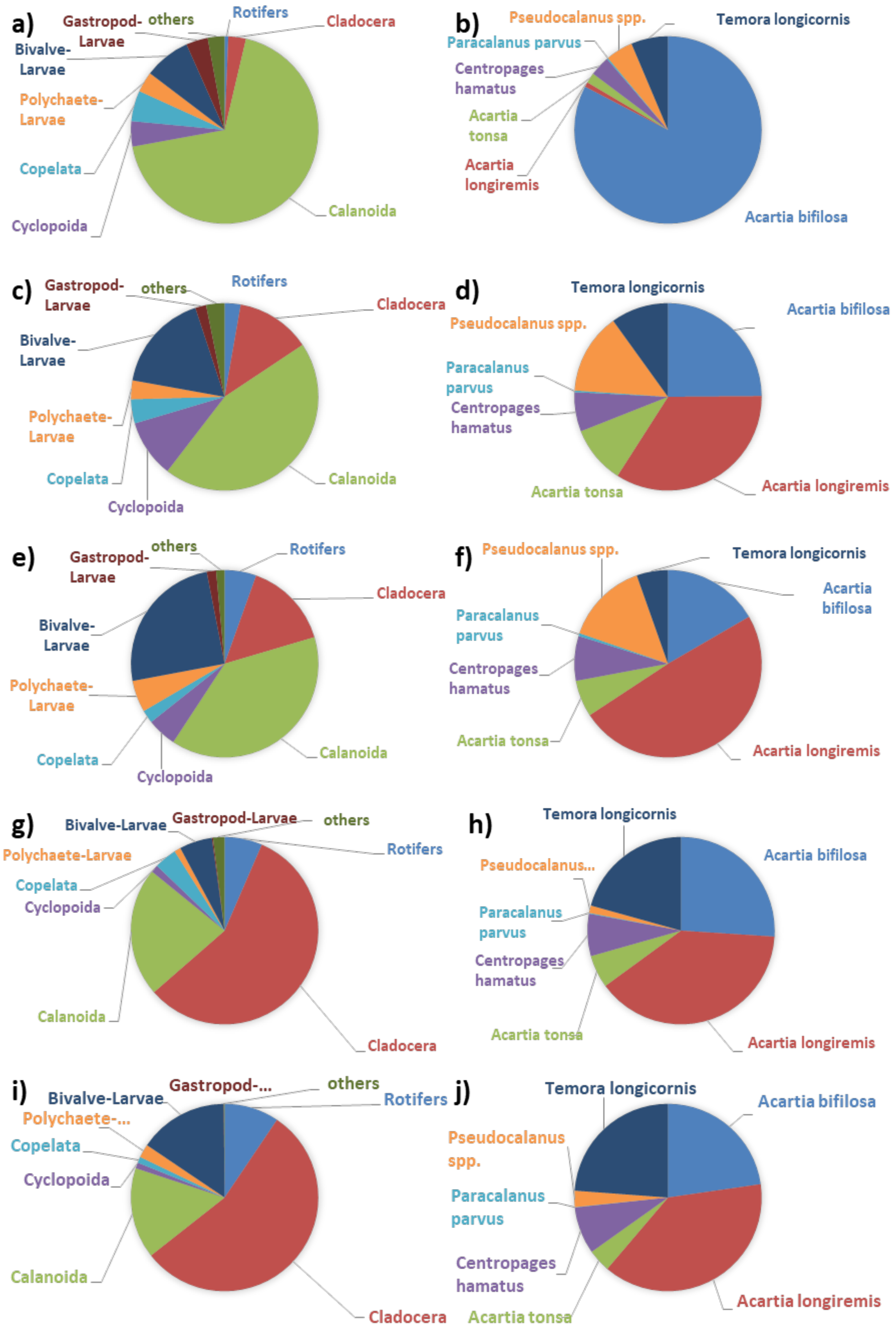

Fig. 22: Relative composition of the mesozooplankton groups (a-i) and adults of calanoid copepods (b-j) in 2021 (a-b: Kiel Bight (N3), c-d: Bay of Mecklenburg (M2) e-f: Bay of Mecklenburg (M1), g-h: Arkona Basin (K5), i-j: Arkona Basin (K4)).

The rotifers were also low in abundance in 2021 (Fig. 22 a-i). With maximum of 7.6 x 10^3 ind. m^{-3}, they contributed to 1 - 9 % to the community and ranked only forth in the abundance of groups. Copelata displayed a low abundance as well. Their maximal concentration was below 2.5 x 10^3 ind. m^{-3} and, thus, less than 4 % of the total zooplankton (Fig. 22 a-i). Major groups of meroplankton were bivalves, polychaetes and gastropods. Their maximal concentrations were similar to previous years and achieved 12.3, 2.7 and 1.6 x 10^3 ind. m^{-3}, respectively. This represents 25, 5 and 4 % of the zooplankton. The four major zooplankton groups displayed a usual seasonal pattern (Fig. 21 b). Whereas calanoid copepods and rotifers had their maximal concentration in spring, cladocerans and bivalve larvae occurred primarily in autumn.

Copepoda

Although only second with regard to the relative abundance, the ubiquitous copepods occur year-round with a seasonal maximum in spring (Fig. 23a, b) and form a vital trophic link between the primary production and higher trophic levels (ALHEIT et al. 2005, BERNREUTHER et al. 2018; NOVOTNY et al. 2022). A common pattern in the western Baltic Sea is the decrease in concentrations from the Kiel Bight (N3, 1.6 x 10^4 ind. m^{-3}) to the Arkona Basin (K5, K4, 5.3 - 5.8 x 10^3 ind. m^{-3}, Fig. 21 a, Fig. 23 a). The abundance was generally similar to the preceding years.

Calanoid copepods dominated the stock (1.3 - 2.9 x 10^4 ind. m^{-3}), while the cyclopoid copepods - only represented by the genus *Oithona* - remained low in abundance (0.8 - 1.9 x 10^3 ind. m^{-3}, Fig. 22 a, Fig. 23 a). This is rather unusual since the latter can contribute to more than one third of the copepod stock, particularly in the Kiel Bight and the Bay of Mecklenburg (see DUTZ et al. 2022 for comparison). The decline of *Oithona* concentrations towards the Baltic Proper, however, occurs regularly in the western Baltic Sea (see Fig. 22 a-i). Nevertheless, their abundance in the Arkona Basin was also lower than commonly observed.

As usual, the genus *Acartia* dominated the adult copepods in all areas (Fig. 22 b-j). In contrast to previous years, *Acartia bifilosa* (max. 83 %, average 35 %) was the single most important species. However, this dominance is based on a single observation in the Kiel Bight in May (N3, Fig. 23 a). *Acartia longiremis*, in contrast, was the major species in the Bay of Mecklenburg (M2, M1) and the Arkona Basin (K5, K4) as usual, and contributed 34 - 49 % to the stock of the adult calanoid copepods. This compositional shift within the genus *Acartia* is a common feature in the western Baltic Sea. *Acartia tonsa* contributed only little to the zooplankton (Fig. 22 b-i, 1.8 - 10 %, 200 - 800 ind. m^{-3}).

In line with previous years, other copepod species displayed lower proportions within this group. *Temora longicornis* ranked third (5 -– 24 %) followed by *Pseudocalanus* spp. (1 - 14 %) and *Centropages hamatus* (3 - 8 %, Fig. 22 b-j). As usual, *Pseudocalanus* spp. contributed primarily to the zooplankton in the Kiel Bight (N3) and the Bay of Mecklenburg (M2, M1), while the two other species increased in importance towards the Arkona Basin (Fig. 23 a, K5, K4). The abundance of *Paracalanus parvus* was unusually low in 2021 (3 - 45 ind. m^{-3}). The species can be common in the Kiel Bight, but was only of minor importance. *Eurytemora affinis* occurred regularly during summer 2021 at low density, while only a few specimens of *Centropages typicus* were found in the Kiel Bight.

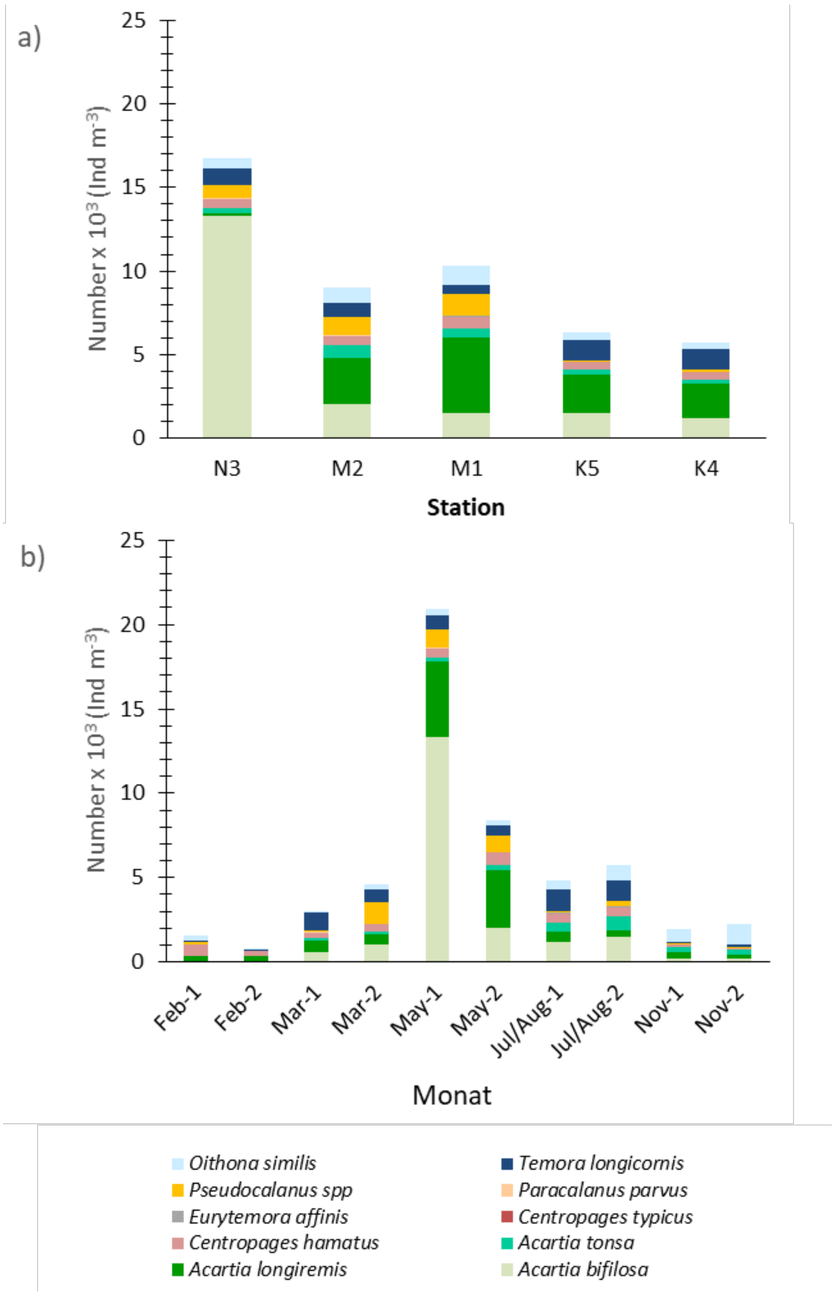

Fig. 23: Spatial (a) and seasonal variation (b) of the adult calanoid and cyclopoid copepods based on the maximal abundance observed at each station during our cruises from February - November (a) and on the maximal abundance observed during the respective months in the whole investigation area (station N3-K4) in 2021. Numbers in b indicate duplicate hauls usually offset by 1 week (see Table 2).

Cladocera

The Cladocera have resumed their typical dominance in the western Baltic Sea in 2021 and showed densities of 0.1 x to 4.4 x 10^4 ind. m^{-3} equivalent to 3 - 57 % of the total zooplankton (Fig. 21a, Fig. 22a-i). This is based particularly on the genus *Bosmina* that displayed a strongly reduced density in the previous year, but also on other common species such as *Evadne nordmanni, Podon intermedius* and *P. leuckartii*. As usual, cladocerans were a major component of the zooplankton in spring and summer and increased from the Kiel Bight (N3) towards the Arkona Basin (K4-5, Fig. 21 a, b). *Bosmina* spp. was mainly restricted to the Arkona Basin where it achieved up to 4.3 x 10^4 ind. m^{-3} during summer. *E. nordmanni*, in contrast, is more evenly distributed in the western Baltic Sea. The species ranked second among the Cladocera and its densities ranged from 1.0 to 3.1 x 10^3 ind. m^{-3}. While the maxima of *E. nordmanni* occurred in summer in the Kiel Bight (N3) and the Bay of Mecklenburg (M2, M1), they were observed in the Arkona Basin (K5, K4) already in spring. *P. intermedius* and *P. leuckartii* were more common than in the year 2020 (56 – 1150 ind. m^{-3}). They displayed a common succession with *P. leuckartii* occurring in May and *P. intermedius* in July/August. Other species were rare. *Penilia avirostris* was only observed in the Kiel Bight (N3) and the Bay of Mecklenburg (M2, M1) at 4 – 22 ind. m^{-3}; *Pleopis polyphemoides* was found only twice.

Rotifera

In contrast to the Cladocera, rotifers showed only a slight recovery from very low abundance in the period 2019 - 2020 (Fig. 21a, Fig. 22a-i). While densities of more than 6.1 x 10^4 ind. m^{-3} were common before these years, the abundance of the group in 2021 ranged from 0.3 to 7.7 x 10^3 ind. m^{-3}, which is equivalent to only <9 % of the total zooplankton stock. The genus *Synchaeta* spp. dominated in all areas, with highest numbers in the Arkona Basin (K4-5, 4.2 – 7.6 ind. x 10^3 m^{-3}) and the Bay of Mecklenburg (M1-2, 1.2 – 2.7 x 10^3 ind. m^{-3}). *Keratella* occurred at numbers of 7 - 67 ind. m^{-3} exclusively in the Arkona Basin. Common species were *K. cruciformis*, *K. quadrata* and *K. cochlearis*.

Copelata

Copelata contributed to 1 – 5 % to the stock (Fig. 22 a-i), which is low since the group usually can achieve up to 15 % of the zooplankton. The main species occurring in the area displayed a typical spatial segregation with *Oikopleura dioica* dominating in the Kiel Bight (N3) and the Bay of Mecklenburg (M1-2) in autumn and *Fritillaria borealis* in the Arkona Basin (K4-5) during spring, respectively. This was also the case in 2021. However, while *F. borealis* occurred at usual densities of 0.8 – 2.5 x 10^3 ind. m^{-3}, the abundance of *O. dioica* (0.4 – 2.2 x 10^3 ind. m^{-3}) was below the range of 4.1 – 8.9 x 10^3 ind. m^{-3} at which the species is regularly observed.

Meroplankton

Meroplankton contributed to 7 – 32 % to the zooplankton stock (Fig. 22 a-i). Polychaete larvae usually dominate the spring plankton in the Kiel Bight and achieve regular concentrations of 0.4 – 2.1 x 10^4 ind. m^{-3}. In 2021, the abundance of the group did not exceed 2.6 x 10^3 ind. m^{-3}, and indicate only a small recovery from their low number observed in 2020 (<900 ind. m^{-3}). Bivalve larvae were the dominant group (Fig. 22 a-i) and were observed at concentrations of 0.3 – 1.2 x 10^4 ind. m^{-3}. In 2021, no spatial gradient with a higher abundance in the shallow Kiel Bight did occur and maximal concentrations were found in the Bay of Mecklenburg and the Arkona Basin. Gastropods were as usual a minor component of the zooplankton (28-1100 ind. m^{-3}) and were more common in the Kiel Bight (N3, Fig. 21 a). Cirripede and echinoderm larvae were restricted to the Kiel Bight (N3) and Bay of Mecklenburg (M2, M1), where they were observed during the winter-spring transition (170 - 1450 ind. m^{-3}) and in summer (11 - 79 ind. m^{-3}), respectively.

Non-indigenous species (NIS)

Except *Acartia tonsa*, no other organisms classified as non-indigenous species were found in 2021. However, *A. tonsa* is a regular member of the zooplankton in the western Baltic Sea since the 1920s (Ojaveer & Kotta 2015). The species occurs regularly in the western Baltic Sea, but is only a minor component of the zooplankton. In 2021, the abundance ranged from 200 to 800 ind. m^{-3}, which is the regular density at which the species was observed in the past. Apart from NIS, some species with affinity to saline water occurred in the area. The presence of the cladoceran *Penilia avirostris* and *Centropages typicus* indicate the transport of water originating from the North Sea into the Baltic Sea (Russel 1970, Gieskes 1971, CPR-Team 2004, Greve et al. 2004). However, their single occurrence and lack of other species likely indicate that this transport was of minor importance in 2021 as indicated by the hydrographical conditions (Naumann et al 2023). This is supported by the wide distribution of brackish taxa in the western Baltic Sea.

3.2.2 Seasonal variation of zooplankton in the sub-areas

Kiel Bay (N3)

The seasonal development of zooplankton in the Kiel Bight (N3) is investigated with a low temporal resolution of one sample in each season and, thus, insights into the seasonal dynamics and temporal succession of groups are limited. In the past, the zooplankton in this area displayed a high seasonal variability associated with the occurrence of rotifers, tintinnids or the cyclopoid copepod *Oithona*. Nevertheless, some general patterns prevail, such as the dominance of copepods as the major group and a seasonal shift from copepods in winter and spring to a more diverse community in summer and autumn. In this regard, the zooplankton development in 2021 has been a normal year. The species richness is usually higher due to the vicinity to the Kattegat and the Skagerrak. As pointed out above, truly marine species, however, were rare in 2021.

The total stock of zooplankton showed a pronounced seasonal variation with a maximum in May, which is not always common for the Kiel Bight (Fig. 24 a). Deviations from this general pattern occur by irregular peak densities of the cyclopoid copepod *Oithona* or the tintinnid ciliates in winter and autumn. In 2021, however, both groups were rare. The overwintering stock of 4.6×10^3 ind. m^{-3} was considerably lower than in the period 2017-2020 ($> 1.0 \times 10^4$ ind. m^{-3}), but similar to the beginning of the decade. The zooplankton abundance of 1.1 and 3.1×10^4 ind. m^{-3} in March and May, respectively, was well in the range of concentrations observed in the past. In summer and autumn, however, it rapidly declined to values of 1.1×10^4 ind. m^{-3} and 5.9×10^3 ind. m^{-3}, respectively, which were again below those of previous years (Fig. 24 a).

As usual, copepods were the main zooplankton group in the Kiel Bight in 2021, where they dominated particularly in the transition from winter to spring (March - May). In contrast to the period 2010 - 2020, however, the cyclopoid copepod *Oithona* was rare and contributed only little to the stock (Fig. 24 b). With the decline in copepods in summer, the community got more diverse with increased contributions of cladocerans, Copelata and meroplankton. Maximal concentrations of the Cladocera were in the range of previous records ($0.8 - 3.0 \times 10^3$ ind. m^{-3}). Their occurrence was restricted to summer in 2021, but could occur also during May in previous years. *Evadne nordmanni* was as usual the dominant cladoceran species followed by *Podon intermedius* and *P. leuckartii*.

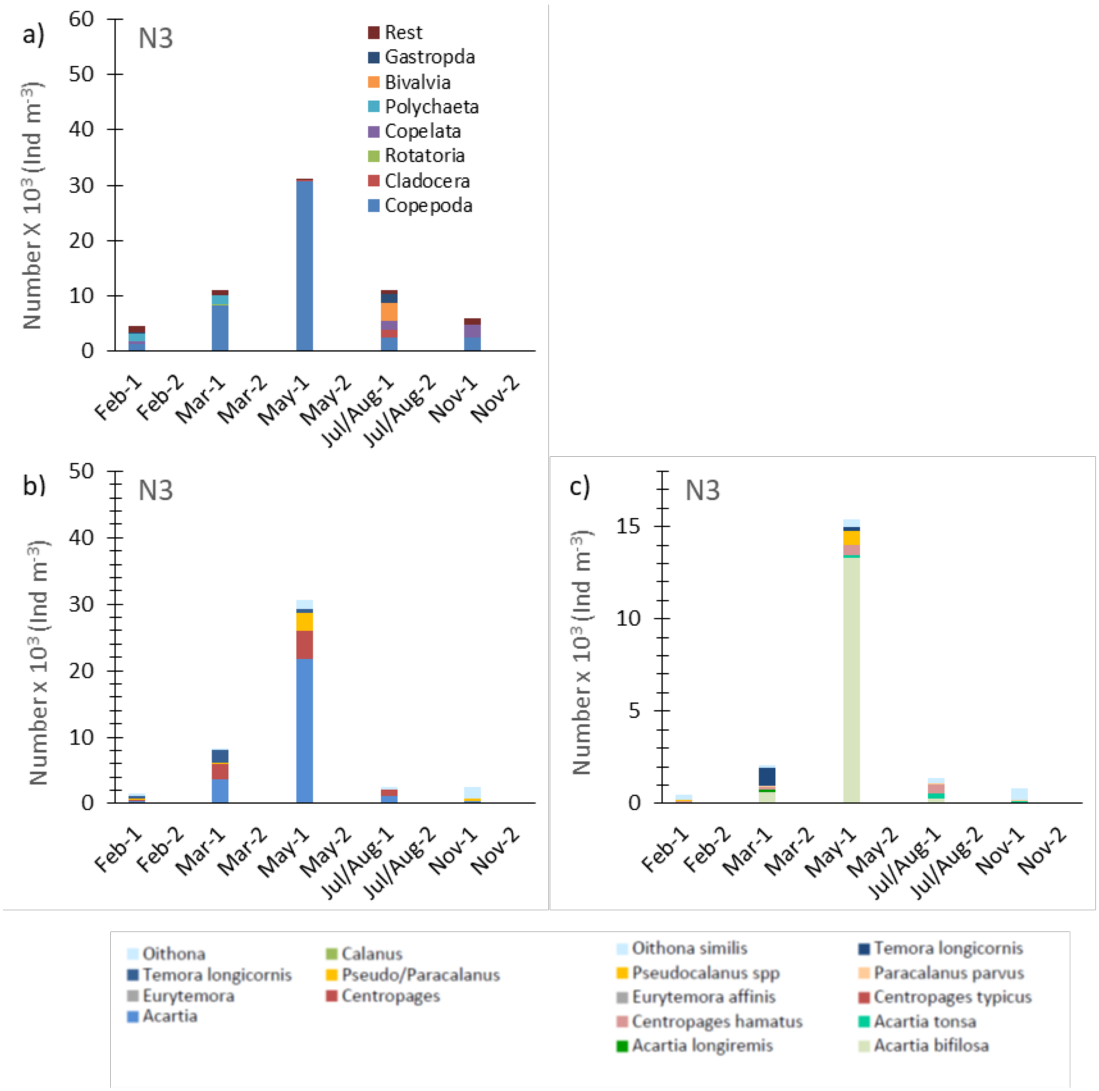

Fig. 24: Seasonal variation of the main taxonomic groups (a), of juvenile (b) and adult stages of copepods (c) in the Kiel Bight during the year 2021. Note the different scale in the abundance of juveniles and adults.

Oikopleura dioica is the major species of Copelata in the Kiel Bight and occurred during the second half of the year. Its abundance of 1.5 – 2.2 x 10^3 ind. m^{-3} was in the lower range of observations during previous years (1.2 – 10.6 x 10^3 ind. m^{-3}). Meroplankton was abundant in the winter/spring transition and during summer. Polychaetes typically contribute to the zooplankton in February and March, while bivalve larvae were the single most important group in summer. The genus *Acartia* was the most important copepod followed by *Centropages* and *Pseudo/Paracalanus* (Fig. 24 b). In contrast to previous years, the diversity was low in 2021 and *Acartia bifilosa* dominated the community (Fig. 24 c).

The abundance of zooplankton was low during winter (4.6 x 10^3 ind. m^{-3}, Fig. 24). Meroplankton (2.8 x 10^3 ind. m^{-3}) contributed to more than 50 % of the community with larvae of polychaetes (1.2 x 10^3 ind. m^{-3}) and bryozoans (1.1. x 10^3 ind. m^{-3}) as major groups. Cirripede and gastropod larvae were only a minor component (‹ 200 ind. m^{-3}). The stocks of copepods were low (1.4 x 10^3 ind. m^{-3}). *Acartia*, *Pseudo/Paracalanus* and *Oithona* contributed equally to to stock (334 – 391 ind. m^{-3}). *Oithona* was dominating among the adult copepods (264 ind. m^{-3}).

The community composition changed only little until March, apart from an increasing abundance of copepods to 8.6 x 10^3 ind. m^{-3} (Fig. 24). With polychaete and bryozoan larvae, meroplankton was still abundant (2.5 x 10^3 ind. m^{-3}). The abundance of the genera *Acartia* (3.8x 10^3 ind. m^{-3}), *Centropages* (2.2 x 10^3 ind. m^{-3}) and *Temora* (1.9 x 10^3 ind. m^{-3}) increased by a factor of 10, while the density of *Pseudo*/*Paracalanus* (243 ind. m^{-3}) and *Oithona* (252 ind. m^{-3}) decreased. *Temora longicornis* (1027 ind. m^{-3}) and *Acartia bifilosa* (594 ind. m^{-3}) were the major species (Fig. 24 c).

In May, the zooplankton abundance had further increased to the seasonal maximum of 3.1 x 10^4 ind. m^{-3} with calanoid copepods as the major contributor to the stock (2.9 x 10^4 ind. m^{-3}, Fig. 24 a). Except for a few gastropod larvae (37 ind. m^{-3}), the meroplankton had vanished. The Cladocera as second most important group were also rare (241 ind. m^{-3}). As usual, *Evadne nordmanni* and *Podon leuckartii* were the major species (185 and 46 ind. m^{-3}). *Acartia* spp. was the dominant copepod genus (2.2 x 10^4 ind. m^{-3}), followed by *Centropages* (4.3 x 10^3 ind. m^{-3}), *Pseudo/Paracalanus* (2.7 x 10^3 ind. m^{-3}) and *Oithona* (1.3 x 10^3 ind. m^{-3}). *Acartia bifilosa* entirely dominated the community of adult copepods (2.1 x 10^3 ind. m^{-3}). Other species such as *Pseudocalanus* spp. (241 ind. m^{-3}), *Centropages hamatus* (241 ind. m^{-3}) and *Temora longicornis* (241 ind. m^{-3}) were rare (Fig. 24 c).

In contrast to previous years, the abundance of zooplankton decreased rapidly from spring to summer (1.1 x 10^4 ind. m^{-3}) along with a typical shift in the community composition (Fig. 24 a). The copepods considerably declined to 2.6 x 10^3 ind. m^{-3}, while meroplankton (5.1 x 10^3 ind. m^{-3}), Copelata (1.5 x 10^3 ind. m^{-3}) and Cladocera (1.3 x 10^3 ind. m^{-3}) increased. Bivalve larvae were the single most abundant group (3.4 x 10^3 ind. m^{-3}). Gastropod larvae were abundant as well (1.6 x 10^3 ind. m^{-3}), while echinoderm and crustacean larvae occurred at low density (79 and 32 ind. m^{-3}). The increase in the copelate *Oikopleura dioica* is typical for the time of the year in the Kiel Bight (1.5 x 10^3 ind. m^{-3}). *Evadne nordmanni* was still the major cladoceran species (1.0 x 10^3 ind. m^{-3}), while *Podon intermedius* (261 ind. m^{-3}) replaced *P. leuckartii*. Despite the considerable decline among the copepods, *Acartia* was still the major copepod genus (1.2 x 10^3 ind. m^{-3}) followed by *Centropages* (774 ind. m^{-3}) and *Oithona* (521 ind. m^{-3}). *Pseudo/Paracalanus* further decreased to (32 ind. m^{-3}) and none of the other genera occurred. The dominance of *A. bifilosa* among the adult copepods vanished, though (253 ind. m^{-3}). The species occurred together with *Centropages hamatus*, *Acartia tonsa* and *Oithona* spp. at similar concentrations of 529, 253 and 308 ind. m^{-3}, respectively.

In autumn, the zooplankton concentration decreased further to 5.8 x 10^3 ind. m^{-3}. Copepods (2.6 x 10^3 ind. m^{-3}) and *Oikopleura dioica* (2.3 x 10^3 ind. m^{-3}) were equally abundant. Meroplankton was diverse, but present at low abundance: cirripede, bryozoan, phoronid and polychaete larvae occurred at 158, 764, 24 and 44 ind. m^{-3}, respectively. *Oithona* dominated among the copepods (1.9 x 10^3 ind. m^{-3})*,* while *Acartia* and *Pseudo/Paracalanus* became rare (425 and 250 ind. m^{-3}). *Centropages hamatus and Temora longicornis* occurred only occasionally (7 and 2 ind. m^{-3}), and *Oithona similis* dominated among the adult specimens (641 ind. m^{-3}).

Bay of Mecklenburg (M2 and M1)

The zooplankton in the Bay of Mecklenburg usually shows a strong resemblance to the composition and seasonal development in the Kiel Bight. At times, a transitional gradient with a stronger Belt Sea influence at station M2 in the western part of the area and a stronger influence of the Baltic Proper at the eastern station M1 might appear. In 2021, however, differences between stations were small. The dominance of copepods during winter-spring combined with a shift in community composition towards the summer resembles largely the seasonal development in the Kiel Bight. Higher contributions of rotifers in spring and of cladocerans in summer indicate, however, the influence of the central Baltic Sea (Fig. 25, Fig. 26).

The total concentration of zooplankton did not show the strong seasonal variation in stock size associated with the summer decline in the Kiel Bight (Fig. 25 a, b). A higher abundance of Cladocera and meroplankton compensated for the rather strong and unusual decrease of copepods from spring to summer at both stations. This pattern occurred also in the preceding year, but was uncommon before. In addition, the total abundance with a maximum of 1.5 – 2.5 x 10^4 ind. m^{-3} in May was at the lower end of concentrations that were observed during spring to summer in the past (1.1 – 8.5 x 10^4 ind. m^{-3}). This applies also to the low density of zooplankton in winter (3.4 – 3.9 x 10^3 ind. m^{-3}) and autumn (3.2 – 5.9 x 10^3 ind. m^{-3}), which are, in contrast to the Kiel Bight, a regular observation in the area.

The composition of the zooplankton resembled broadly that of preceding years and that of the Kiel Bight. Copepods (1.6 – 2.1 x 10^4 ind. m^{-3}) and bivalve larvae (0.3 – 1.2 x 10^4 ind. m^{-3}) were dominant taxa followed by cladocerans (1.8 – 7.2 x 10^3 ind. m^{-3}). The copepods showed a pronounced seasonality with maximum in May and a summer decline (Fig. 27 a-d). Similar to Kiel Bight, the cyclopoid copepod *Oithona* was less abundant in 2021 (0.9 – 4.7 x 10^3 ind. m^{-3}, Fig. 27 a, b), while it has been one of the dominant genera in the preceding decade with up to 2.8 x 10^4 ind. m^{-3}. The genus *Acartia* was also the dominant genus (5.4 – 9.3 2.1 x 10^4 ind. m^{-3}). However, A*. bifilosa* (1.5 – 2.02.1 x 10^4 ind. m^{-3}) contributed less to the community than *A. longiremis* (2.7 – 4.4 2.1 x 10^4 ind. m^{-3}). In addition, both *Pseudo/Paracalanus* (6.9 - 7.1 x 10^3 ind. m^{-3}), *Temora* (1.6 – 3.0 x 10^3 ind. m^{-3}) and *Centropages* (1.3 – 3.0 x 10^3 ind. m^{-3}) were major contributors to the stock. The cladocerans occurred in spring and summer (Fig. 27 a, b). *Evadne nordmanni* was the dominant species during the year (6.9 - 7.1 x 10^3 ind. m^{-3}), but *Bosmina* spp. displayed a similar abundance during summer (6.9 - 7.1 x 10^3 ind. m^{-3}). Similar to Kiel Bight, *Podon leuckartii* occurred mainly in spring (111 - 458 ind. m^{-3}). It was replaced by *P. intermedius* in summer (573 - 1150 ind. m^{-3}). Other species such as *Pleopis polyphemoides* and *Penilia avirostris* were rare (5-22 ind. m^{-3}). The rotifer *Synchaeta* spp. was found during May but at low abundance (0.9 - 2.6 x 10^3 ind. m^{-3}). Similarly, the abundance of the copelate *Oikopleura dioica* (1.1 – 1.9 x 10^3 ind. m^{-3}) was below concentrations observed in the past (4.0 – 8.9 x 10^3 ind. m^{-3}). The meroplankton, in contrast, was generally divers, with cirripede, bryozoan and polychaete larvae occurring in winter - spring and bivalve, gastropod, echinoderm and phoronid larvae in summer - autumn. Except bivalve (6.9 - 7.1 x 10^3 ind. m^{-3}) and bryozoan larvae (6.9 - 7.1 x 10^3 ind. $m^{-3)}$, their abundance was, however, low.

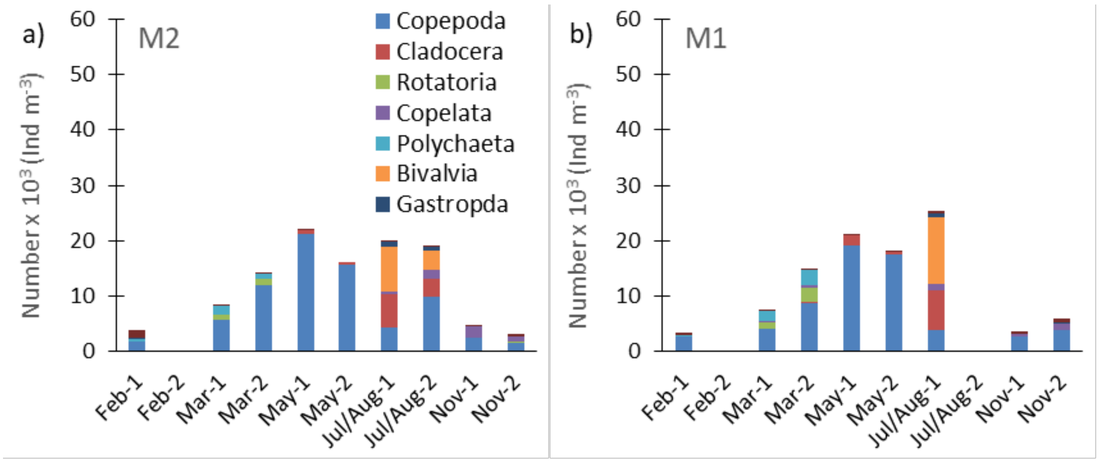

Fig. 25: Seasonal variation of the main taxonomic groups at stations M2 (a) and M1 (b) in the Bay of Mecklenburg during the year 2021.

In contrast to the Kiel Bight, the overwintering stocks of the zooplankton were not low and ranged from 3.4 to 3.9 x 10^3 ind. m^{-3} (Fig. 25 a, b). Among the holoplankton, copepods dominated the community (1.8 – 2.9 x 10^3 ind. m^{-3}). *Pseudo/Paracalanus* and *Centropages* were major genera (1.1 – 1.2 x 10^3 ind. m^{-3}), others were generally rare (‹ 340, Fig. 27 a, b). Apart from the copepods, *Fritillaria borealis* and *Oikopleura dioica* (Copelata, 38 - 92 ind. m^{-3}) and the rotifer *Synchaeta* spp. (2-18 ind. m^{-3}) occurred in low numbers. Meroplankton was abundant as well (0.5 – 2.2 x 10^3 ind. m^{-3}). Bryozoan larvae were present in large numbers (0.3 – 1.5 x 10^3 ind. m^{-3}), while polychaetes, bivalves and gastropods constituted only a minor component.

During spring, the stock increased rapidly to 0.8 – 2.1 and 1.6 – 2.1 x 10^4 ind. m^{-3} in March and May, respectively (Fig. 25 a, b). Copepods, rotifers, cladocerans and polychaete larvae were generally major contributors. Copepods dominated the stock and displayed a steady increase from March (0.4 – 1.2 x 10^4 ind. m^{-3}) to May (1.5 – 2.1 x 10^4 ind. m^{-3}). *Acartia* (2.7 – 9.3 x 10^3 ind. m^{-3}) together with *Centropages* (1.2 -3.0 x 10^3 ind. m^{-3}), *Pseudo/Paracalanus* (0.7 – 6.9 x 10^3 ind. m^{-3}) and *Temora* (0.4 – 3.0 x 10^3 ind. m^{-3}) were important genera, while the stocks of *Oithona* (152-825 ind. m^{-3}) remained low (Fig. 26 a, b). Among the adult copepods, *Acartia longiremis* (1.2 – 4.4 x 10^3 ind. m^{-3}) dominated, followed by *A. bifilosa* (0.3 – 2.0 x 10^3 ind. m^{-3}) and *Pseudocalanus* spp. (0.1 – 1.3 x 10^3 ind. m^{-3}, Fig. 26 c, d). The rotifer *Synchaeta* spp. (0.9 – 2.6 x 10^3 ind. m^{-3}) and polychaete larvae (0.8 – 2.6 x 10^3 ind. m^{-3}) occurred primarily in March and largely disappeared until May (Fig 26 a, b). Other meroplankton such as cirripede, bivalve and gastropod larvae was rare. Cladocerans, in contrast, increased considerably until May (0.3 – 1.8 x 10^3 ind. m^{-3}). *Evadne nordmanni* and *Podon leuckartii* were the main species.

As already described above, the community composition changed considerably from late spring to summer. Most prominent was the considerable decrease in copepod numbers by more than 50 % (0.4 - 1.0 x 10^4 ind. m^{-3}, Fig. 25, Fig. 26). In contrast to Kiel Bight, cladocerans and bivalve larvae, however, increased in summer in the Bay of Mecklenburg and the total zooplankton stock remained rather constant (1.8 - 2.5 x 10^4 ind. m^{-3}). Only few other zooplankton groups contributed to the plankton in low numbers such as the gastropod larvae (0.7 – 0.8 x 10^3 ind. m^{-3}) or the Copelata (0.6 – 1.6 x 10^3 ind. m^{-3}).

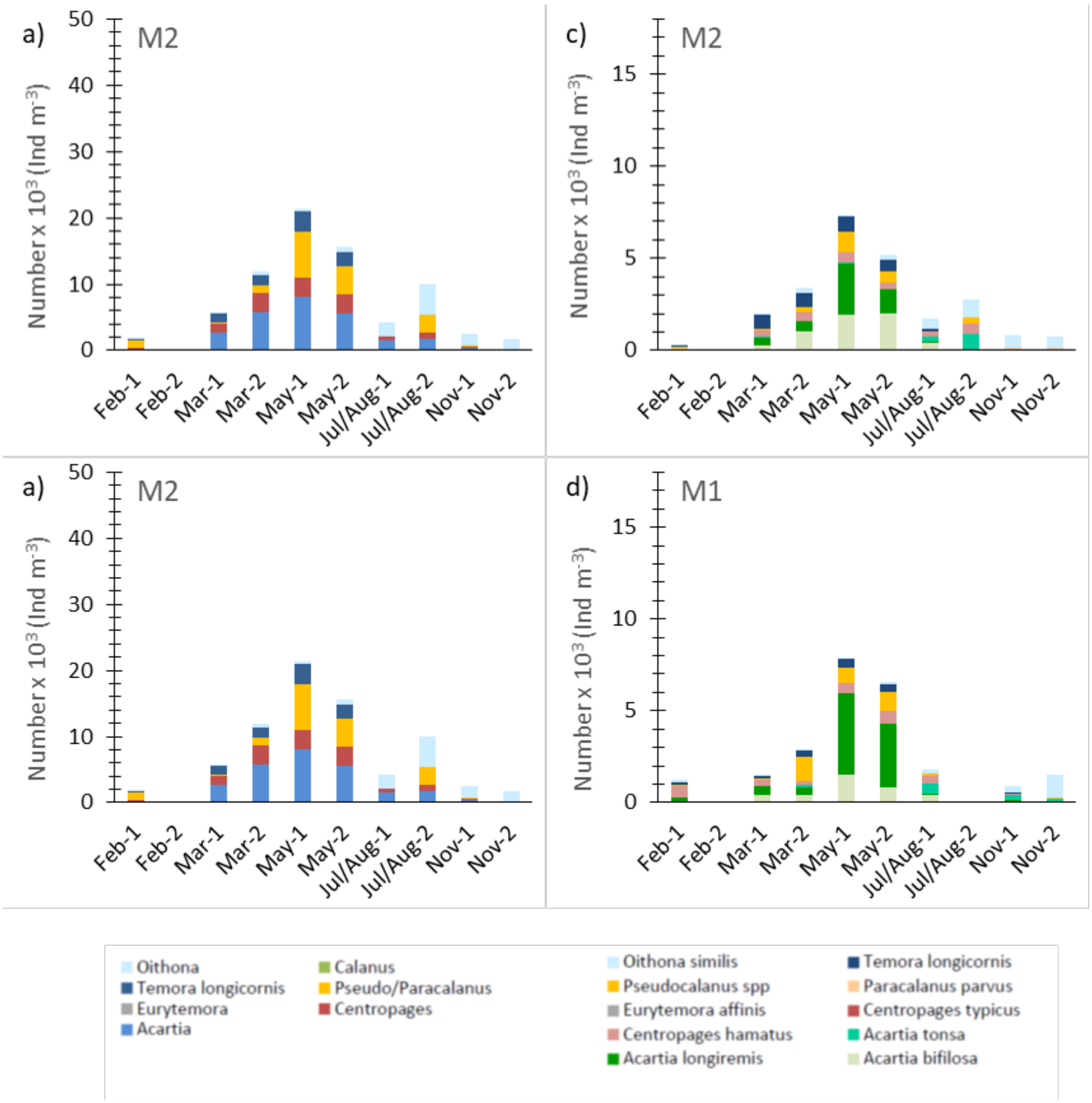

Fig. 26: Seasonal variation of juvenile (a, b) and adult stages of copepods (c, d) at stations M2 and M1 in the Bay of Mecklenburg during the year 2021. Note the different scale in the abundance of juveniles and adults.

The composition of copepods also changed (Fig. 26 a-d). Among the copepodites stages, *Acartia* remained as the major genus (1.4 – 1.7 x 10^{3} ind. m^{-3}), but the dominance of *Acartia tonsa* among the adult copepods suggest that a major change in the taxonomic composition had occurred. *Pseudo/Paracalanus* were also still common (0.8 – 2.7 x 10^{3} ind. m^{-3}), while *Oithona* spp. increased considerably in abundance (0.8 – 4.6 x 10^{3} ind. m^{-3}). Nevertheless, *Oithona* was far less abundant than during preceding years (up to 2.8 x 10^{4} ind. m^{-3}). All other genera played only a minor role.

The total stock size declined considerable in autumn (Fig. 25, Fig. 26). The abundance of 3.2 - 5.9 x 10^{3} ind. m^{-3} is well in the range of the density observed in the past. Only in the beginning of the decade, exceptional high autumn concentrations occurred (> 6.5 x 10^{4} ind. m^{-3}). Except for copepods (1.6 – 3.8 x 10^{3} ind. m^{-3}) and Copelata (0.5 – 1.9 x 10^{3} ind. m^{-3}), nearly all other zooplankton groups vanished. *Oithona* spp. was the only copepod genus occurring in high numbers (1.3 – 2.4 x 10^{3} ind. m^{-3}). Copelata were represented by *Oikopleura dioica* that typically shows autumn maxima in this area. Apart from these two taxa, only bryozoan larvae occurred in reasonable numbers (159 – 668 ind. m^{-3}).

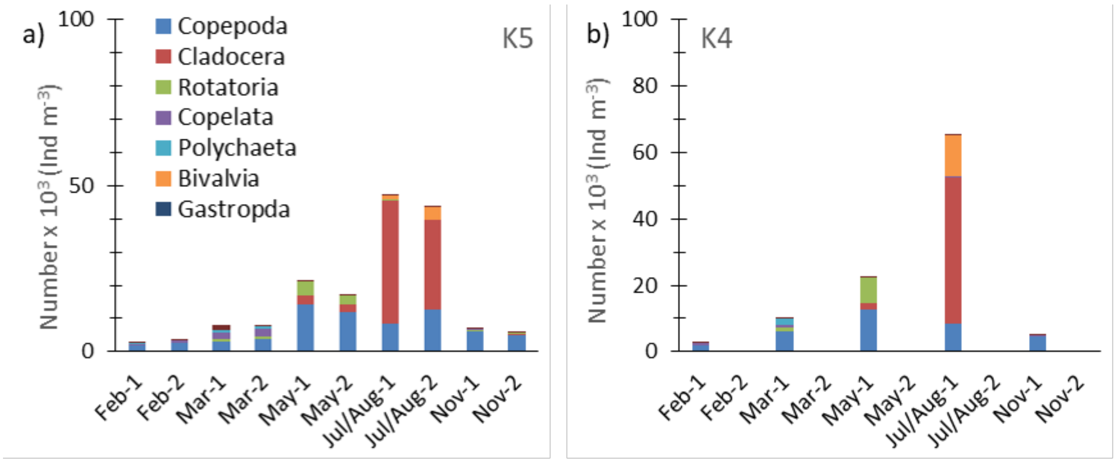

Fig. 27: Seasonal variation of the main taxonomic groups at stations K5 (a) and K4 (b) in the Arkona Basin during the year 2021.

Arkona Basin (K4 and K5)

The timing of the seasonal increase and the maxima of zooplankton in the Arkona Basin has been variable in the past. The seasonal pattern is primarily shaped by the occurrence and abundance of both the rotifers and the cladocerans that can occur in very high numbers in spring or autumn, respectively. Since 2019, both groups have been unusually low in their density, however, and the seasonal zooplankton dynamics of the zooplankton were largely determined by the copepods (see DUTZ et al. 2022 for comparison). In 2021, rotifers remained low in their stock size, while cladocerans apparently recovered from their low concentrations (Fig. 27 a, b). The occurrence of the zooplankton maximum was, therefore, in summer and considerably later compared to the zooplankton in the Belt Sea.

On an annual basis, copepods (mean 43 % of the stock) and cladocerans (mean 42 %) dominated the zooplankton in the Arkona Basin. While the copepods were abundant from spring to summer (0.8 – 1.4 x 10^4 ind. m^{-3}), cladocerans displayed the usual peak abundance in July/August only (2.6 – 4.4 x 10^4 ind. m^{-3}, Fig. 27 a, b). The density of copepods was at the lower end of the range of previous concentrations in the area (1.2 – 2.9 x 10^4 ind. m^{-3}). The community composition resembled in principle the preceding years. *Acartia* was the dominating genus in the Arkona Basin similar to the other areas (Fig. 28), particularly in spring when concentrations achieved 4.9 – 6.6 x 10^3 ind. m^{-3}. *Centropages* was abundant in spring (3.7 – 4.6 x 10^3 ind. m^{-3}) but decreased in summer when *Temora* replaced it (2.5 – 5.7 x 10^3 ind. m^{-3}). The abundance of *Pseudo/Paracalanus* (max. 886 – 1060 ind. m^{-3}) and *Oithona* (max. 796 – 835 ind. m^{-3}) was generally lower than in preceding years. *Acartia longiremis* was the main adult species in the Arkona Basin with high concentrations in spring (2.1 – 2.3 x 10^3 ind. m^{-3}, Fig. 28 c, d). In summer, *Acartia bifilosa* achieved higher densities (0.8 – 1.5 x 10^3 ind. m^{-3}) than *A. longiremis* (373 - 563 m^{-3}) and the species' contribution to the stock was higher than usual (>23 %). *Temora longicornis* was abundant in summer as well (0.5 – 1.3 x 10^3 ind. m^{-3}); all other species played a minor role.

In contrast to the copepods, cladocerans resumed their usual densities (1.8 – 8.2 x 10^4 ind. m^{-3}). The community was dominated by *Bosmina* spp (2.6 – 4.3 x 10^3 ind. m^{-3}) which occurred typically in July/August (Fig. 28 a, b). *Evadne nordmanni* was abundant in spring (1.8 – 2.1 x 10^3 ind. m^{-3}). A regular pattern in the Arkona Basin is the replacement of *Podon leuckartii* by *P. intermedius* (1.8 – 2.1 x 10^3 ind. m^{-3}) from spring to summer; both species occurred at low density of 175 – 355 and 220 – 374 ind. m^{-3}, respectively. Other groups were much less important. The abundance of rotifers was one magnitude lower than usual (1.1 – 6.1 x 10^4 ind. m^{-3}) and the group contributed on average only 5.8 % to the zooplankton stock. A peak abundance of 4.2 – 7.6 x 10^3 ind. m^{-3} of *Synchaeta* was recorded in May (Fig. 28 a, b). The genus *Keratella* was of minor importance (36 – 67 ind. m^{-3}). The copelate *Fritillaria borealis* occurred at usual concentrations in winter/spring mainly (0.4 – 2.5 x 10^3 ind. m^{-3}, Fig. 28a, b). Typical for the area, *Oikopleura dioica* replaced *Fritellaria* in autumn. The species disappears towards the Baltic Prpoper and its abundance was therefore low (60 – 402 ind. m^{-3}). Other holoplankton was rare; Ctenophora were found in spring and autumn at low numbers (2- 18 ind. m^{-3}).

A gradient with deceasing numbers of meroplankton from Kiel Bight to the Arkona Basin is a common pattern observed in the monitoring of the western Baltic Sea. This is particularly the case with regard to the density of polychaetes, cirripedes and bryozoans. Thus, bivalve larvae were the main meroplankton and contributed to 6 -15 % to the zooplankton in the Arkona Basin. Similar to the other areas, the group was abundant in summer (0.4 – 1.2 x 10^4 ind. m^{-3}). The density of polychaete, gastropod and crustacean larvae was below 700 ind. m^{-3}.

Winter stocks were typically low (2.6 – 3.5 x 10^3 ind. m^{-3}) and dominated entirely by the copepods (1.8 – 2.6 x 10^3 ind. m^{-3}, Fig. 28 a, b). *Acartia*, *Centropages*, *Pseudo/Paracalanus* and *Temora* were recorded at simial density of 270 - 673 ind. m^{-3}. (Fig. 29 a, b). Among the adults, *Acartia longiremis* dominated (300 ind. m^{-3}). Other groups of importance were the Copelata (*Fritellaria borealis*, 472 - 733 ind. m^{-3}). Other holoplankton (Cladocera, Rotifera) were rare. Meroplankton (polychaetes, bivalves, cirripedes) occurred in low numbers (31 – 106 ind. m^{-3}). Until March, the zooplankton stock had doubled (0.6 – 1.0 x 10^3 ind. m^{-3}). While the copepod numbers increased slightly (3.0 – 5.9 x 10^3 ind. m^{-3}, Fig. 28 a, b), the copelate *Oikopleura dioica* (1.4 – 2.5 x 10^3 ind. m^{-3}), the rotifer *Synchatea* (0.6 – 1.4 x 10^3 ind. m^{-3}) and polychaete larvae (0.7 – 1.8 x 10^3 ind. m^{-3}) increased considerably. Little changes were recorded in the composition of the copepods (Fig. 28 a-d). Development stages of *Acartia* (1.4 – 3.6 x 10^3 ind. m^{-3}) and *Pseudocalanus* 886 – 971 ind. m^{-3}) got more abundant, other genera and adult numbers remained unchanged. *Acartia longiremis* was still the dominant species (352 - 703 ind. m^{-3}).

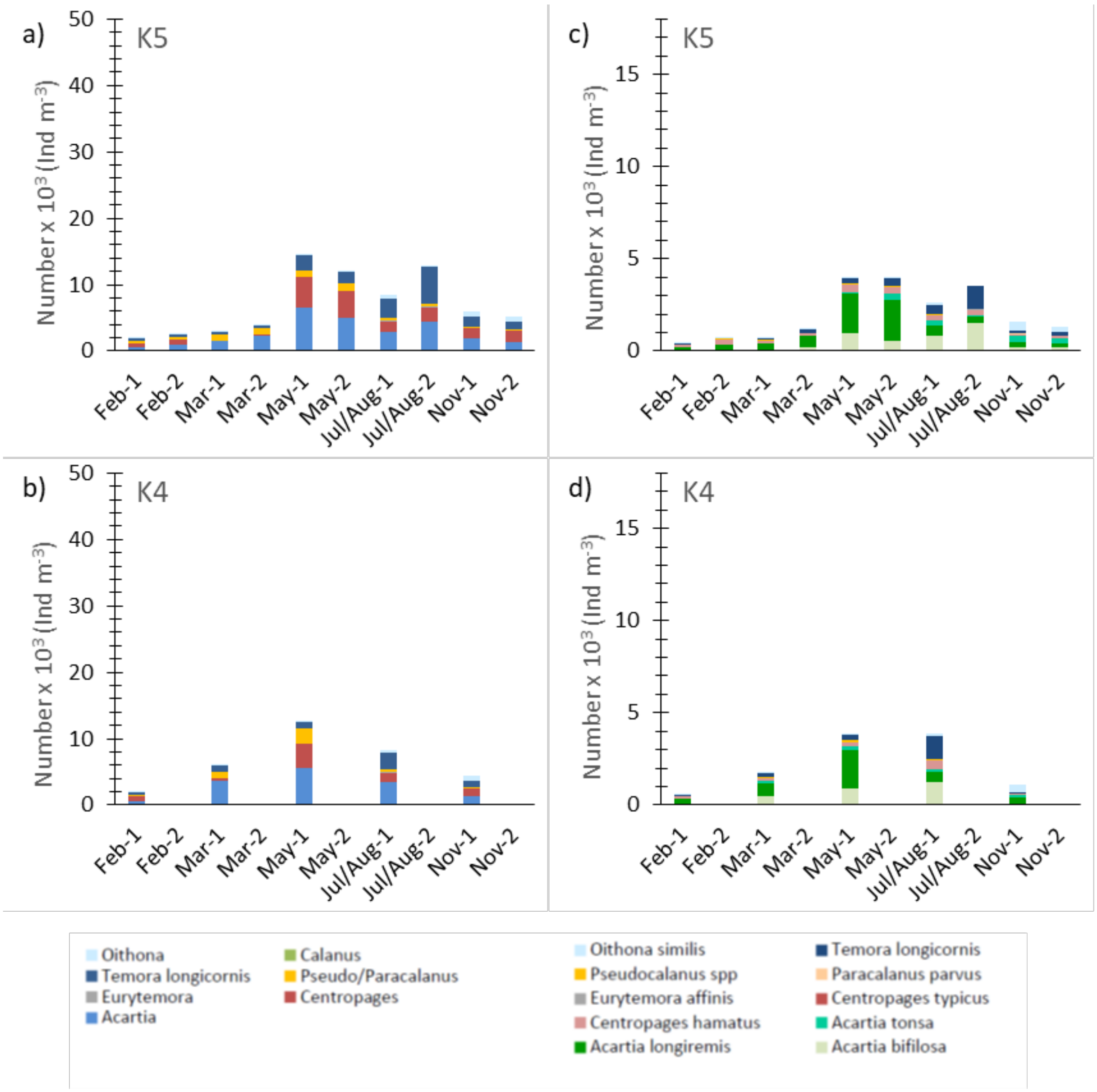

Fig. 28: Seasonal variation of juvenile (a, b) and adult stages of copepods (c, d) at stations K5 and K4 in the Arkona Basin during the year 2021. Note the different scale in the abundance of juveniles and adults.

In May, stocks increased by a factor of two to three due to copepods, cladocerans and rotifers (1.7 – 2.2 x 10^4 ind. m^{-3}). *Acartia* still dominated the stock (5.0 – 6.6 x 10^3 ind. m^{-3}), followed by *Centropages* (4.1 – 4.6 x 10^3 ind. m^{-3}) and *Temora* (1.1 – 2.3 x 10^3 ind. m^{-3}). *Pseudo/Paracalanus* (0.8 – 2.3 x 10^3 ind. m^{-3}) and *Oithona* (24 - 72 ind. m^{-3}), in contrast, displayed no change in density since winter (Fig. 29 a, b). *Acartia longiremis* was the major species among the adults of the copeods (2.1 – 2.3 x 10^3 ind. m^{-3}). *A. bifilosa* (523 - 938 ind. m^{-3}) *Centropages hamatus* (214 - 424 ind. m^{-3}) and *Temora longicornis* (285 - 389 ind. m^{-3}) followed with lower density. In addition, small numbers of *A. tonsa* were observed (91 - 328 ind. m^{-3}), which is unusually early since the species occurs mainly in summer. The stock of the cladocerans increased due to *Evadne nordmanni* (1.8 – 2.1 x 10^3 ind. m^{-3}) and *Podon leuckartii* (175 - 355 ind. m^{-3}). Although the rotifer *Synchaeta* spp. increased to its early, seasonal maximum of 2.7 – 7.6 x 10^3 ind. m^{-3}, numbers were one magnitude lower than usual (>1.0 x 10^4 ind. m^{-3}). In contrast to copepods, cladocerans and rotifers, the abundance of the copelate *Fritillaria dioica* declined considerably (34 - 126 ind. m^{-3}), which is expected from previous years. Meroplankton got rare. Most conspicuous, the polychaetes decreased to 5 - 18 ind. m^{-3}, while the density of bivalves remained constant (7 - 41 ind. m^{-3}).

In summer, the zooplankton stocks further increased to 4.3 – 6.5 x 10^4 ind. m^{-3} due to the peak of the cladoceran *Bosmina* spp. (2.6 – 4.3 x 10^4 ind. m^{-3}). *Evadne nordmanni* decreased in density (144 - 311 ind. m^{-3}) and, similar to the Belt Sea, *Podon intermedius* (220 – 340 ind. m^{-3}) replaced P*. leuckartii*. Apart from the cladocerans, copepods kept a high abundance (0.8 – 1.2 x 10^4 ind. m^{-3}). The density of *Acartia* slightly decreased (2.9 - 4.4 x 10^3 ind. m^{-3}); *Temora* displayed a further increase (2.4 – 5.7 x 10^3 ind. m^{-3}). *Centropages* and *Pseudo/Paracalanus* also decreased, while *Oithona* remained rare. The composition of the adult community changed. *Acartia bifilosa* (0.8 – 1.5 x 10^3 ind. m^{-3}) and *Temora longicornis* (0.5 – 1.3 x 10^3 ind. m^{-3}) were major species, while no other species exceeded 600 ind. m^{-3}. Rotifers and Copelata were only a minor component of the plankton. Among the meroplankton, bivalve larvae achieved their seasonal maximum (0.1 – 1.1 x 10^4 ind. m^{-3}). Gastropod and crustacean larvae were common; other groups were rare.

The autumn stocks were again low (5.2 – 7.3 x 10^3 ind. m^{-3}) and were dominated by copepods (4.4 – 5.9 x 10^3 ind. m^{-3}). All other taxa occurred at densities lower than 550 ind. m^{-3}. The copelate *Oikopleura dioica* achieved its low autumn maximum (60 - 402 ind. m^{-3}); *Fritillaria borealis*, however, was present in small numbers as well (22 - 102 ind. m^{-3}). *Synchaeta* spp. occurred at 147 – 342 ind. m^{-3}, while the genus *Keratella* was rarely found (7 - 9 ind. m^{-3}). The cladocerans were mainly represented by *Evadne nordmanni* (58 – 158 ind. m^{-3}) and only few *Podon intermdius* (<10 ind. m^{-3}). The genera *Acartia* (1.3 – 2.0 x 10^3 ind. m^{-3}), *Centropages* (1.2 – 1.6 x 10^3 ind. m^{-3}) and *Temora* (0.9 – 1.5 x 10^3 ind. m^{-3}) continued to dominate the copepod composition. *Oithona* got slightly more abundant (661 – 835 ind. m^{-3}). Among the adults *Acartia longiremis*, *A. bifilosa, A. tonsa* and *Oithona* spp. occurred in similar numbers ranging from 200 – 500 ind. m^{-3}. Meroplankton vanished (207 – 280 ind. m^{-3}), but was generally diverse in low numbers with larvae of bivalves, cirripeds, gastropods, echinoderms and crustaceans.

3.2.3 Long-term trends

The year 2021 continued a long-lasting decline of the stock size of zooplankton since the turn of the century (Fig. 29 a). Although the maximal abundance of the total zooplankton showed some recovery from the long-term low in 2020, the concentration of 0.8 x 10^5 ind. m^{-3} is the third lowest value recorded in the time series since 2000. Thus, the stock size achieved only 33 % of the long-term mean of 2.7 x 10^5 ind. m^{-3} for the years 2000-2021, but also only 56 % of the mean of the recent decade from 2010 - 2021 (1.5 x 10^5 ind. m^{-3}). This is illustrated by the annual anomalies of the maximal abundance (B'), which were calculated by subtracting the long-term annual average of the total zooplankton abundance in 1995 - 2020 (B, $\log_{10}$-transformed) from the annual maximum total abundance (b, $\log_{10}$-transformed) according to MACKAS & BEAUGRAND (2010):

$$B'(t) = \log_{10}[b(t)] - \log_{10}[B]$$

The anomalies are generally negative since 2010 and indicate only a short period of apparent recovery in the year 2011 (Fig. 29 b). The small increase in the abundance by 50 % in 2021 compared to the year 2020 originated from the recovery of cladocerans. These achieved roughly their mean density in the recent decade in 2021 (5.6 x 10^4 ind. m^{-3}) but only half of their long-term mean 2000 - 2021 (1.1 x 10^5 ind. m^{-3}). In contrast, stocks of the rotifers of 7.5 x 10^3 ind. m^{-3}, the cyclopoid copepods of 1.2 x 10^3 ind. m^{-3}, the Copelata of 2.5 x 10^3 ind. m^{-3} and polychaete larvae of 2.7 x 10^3 ind. m^{-3} were considerably below their long term means of 84.7, 9.4, 8.0, 26.8 x 10^3

ind. m^{-3}, respectively. The stocks of bivalve and gastropod larvae of 1.2 and 0.2 x 10^{3} ind. m^{-3}, however, were similar to their long-term mean.

The calanoid copepods are an ecologically important group and showed signs of a slow recovery from their minimum during 2012 - 2013 (Fig. 29 c). The maximum of 1.5 x 10^{4} ind. m^{-3} in 2021, however, is still below the long-term mean of 1.9 x 10^{4} ind. m^{-3}. *Acartia* was the dominating genus in 2021, which is common over the time series. *A. bifilosa* displayed the highest value ever recorded for the species (1.3 x 10^{4} ind. m^{-3}). However, as discussed above (see 3.2.2 Kiel Bight), this is based on a single value recorded in the Kiel Bight and, thus, has to be interpreted with care. Except this extreme record, the species achieved its long-term mean of 4.3 x 10^{3} ind. m^{-3}. Similarly, the abundance of *A. longiremis* of 4.5 x 10^{3} ind. m^{-3} was close to its long-term mean of 5.6 x 10^{3} ind. m^{-3}. *A. tonsa* was a minor species (804 ind. m^{-3}) and occurred well in the range of past concentrations (long-term mean of 1.2 x 10^{3} ind. m^{-3}). The abundance of *Temora longicornis* (1.3 x 10^{3} ind. m^{-3}), *Centropages hamatus* (0.7 x 10^{3} ind. m^{-3}) and *Pseudocalanus* spp. (1.3 x 10^{3} ind. m^{-3}), in contrast, was below their long-term means of 5.6, 2.7 and 2.2 x 10^{3} ind. m^{-3}, respectively.

The causes for the decline of the total zooplankton stock can be manifold. In the North Sea, a reduction in the zooplankton abundance during the 1990s was attributed to a decline in nutrient concentrations or an increased predation by gelatinous plankton (GREVE et al. 2004). However, the long-term trends reflect changes in maximal density during a rather infrequent sampling scheme. This does not allow a detailed analysis of potential causes. Rotifers and cladocerans, in particular, can have short periods of mass development that can be easily missed in infrequent sampling programmes. In addition, data about predator abundance, especially those of gelatinous zooplankton, are not available for the western Baltic Sea.

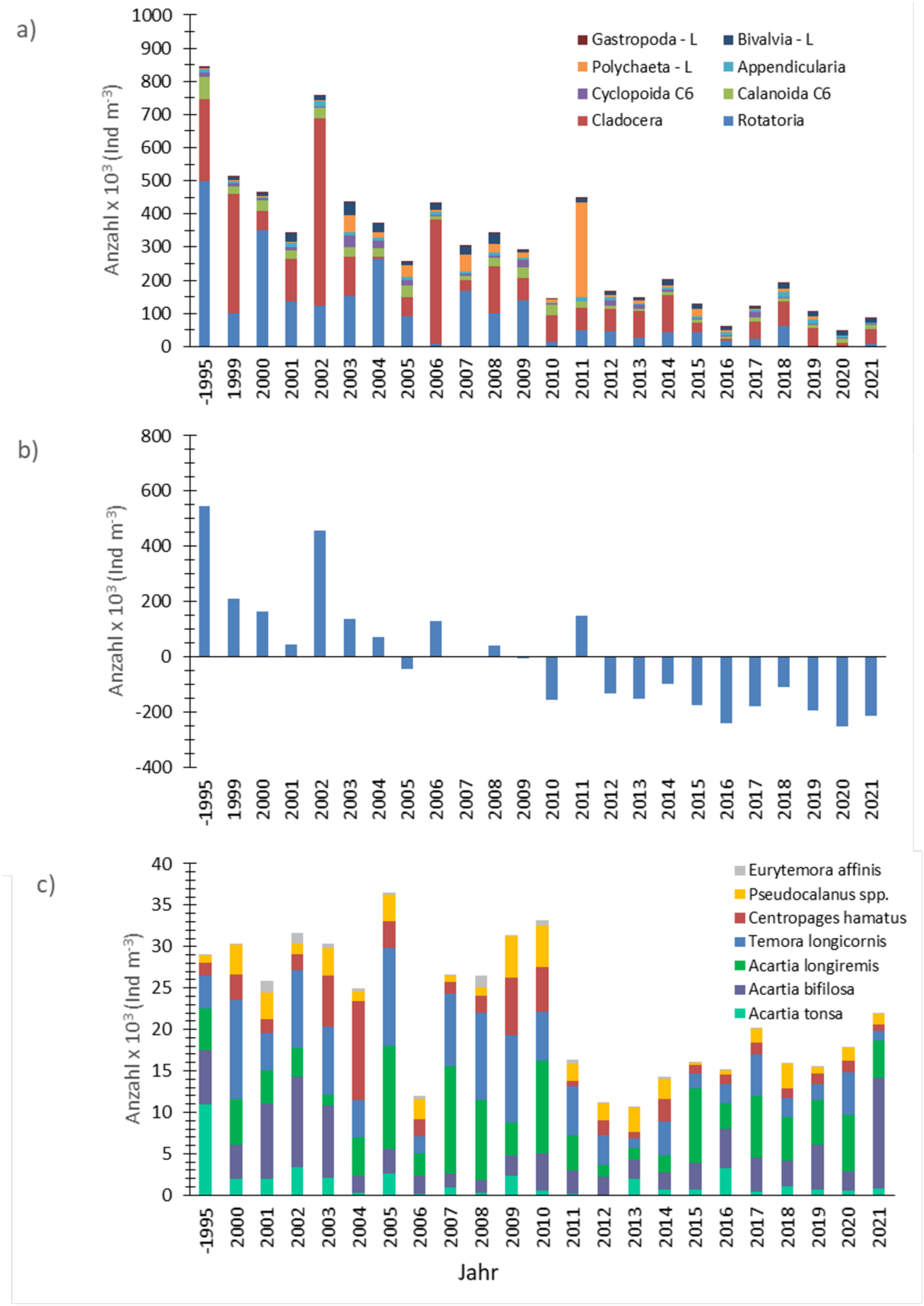

Fig. 29: Long-term trends in the maximal abundance of a) holoplanktonic taxa (Rotatoria, Cladocera, Cyclopoida, Calanoida, Copelata) and meroplanktonic taxa (Polychaeta, Bivalvia, Gastropoda), b) in the anomalies of the total zooplankton abundance and c) of seven calanoid copepod species in the years 1995 to 2021.

3.3 Macrozoobenthos

3.3.1 Sediments and oxygen

At each of the eight monitoring stations, samples were taken with additional Van Veen grabs for the analysis of the particle size and organic content of sediment. CTD dips were done to determine associated parameters such as oxygen concentrations and near-bottom salinity (Table 11). Chemical parameters were measured in all samples taken during the five cruises per year (not content of this report, see NAUMANN et al. (2023)). A good oxygen supply could be observed at all stations during the samplings almost all year round. No values lower than 2 ml l^{-1} were measured at any station. Fig. 30 shows an example for Mecklenburg Bay (M2), where oxygen demands have been frequently observed in the past. When the benthos was sampled in November 2021, the values for all stations were above 4 ml l^{-1} (Table 11).

For almost all stations, the salinity was at a long-term average value for the respective area. The autumn bottom water salinity ranged from west to east between 23.2 and 8.1 psu (Table 11).

Table 11: Abiotic parameters at 8 monitoring stations in autumn 2021 (Org = organic content of sediment in %, GS = median grain size in µm, O_2 = oxygen content of near bottom water in ml/l, S = salinity at near bottom water in psu) and Broad habitat type (EU, 2017) regarding MSFD (Directive 2008/56/EC).

Station	Org %	GS (µm)	O_2 (ml/l)	S (psu)	MSFD (BHT) Broad habitat type
N3	1.24	203	4,79	23,2	infralittoral sand
N1	1,63	228	6,67	23,0	circalittoral sand
M2	8,19	16	5,69	20,8	circalittoral mud
OM18	1,86	97	5,00	21,4	infralittoral sand
K8	0,43	216	7,11	15,1	circalittoral sand
K4	11,91	17	4,80	17,0	circalittoral mud
K3	0,30	232	4,98	14,5	circalittoral sand
OM160	0,17	190	7,16	8,1	circalittoral sand

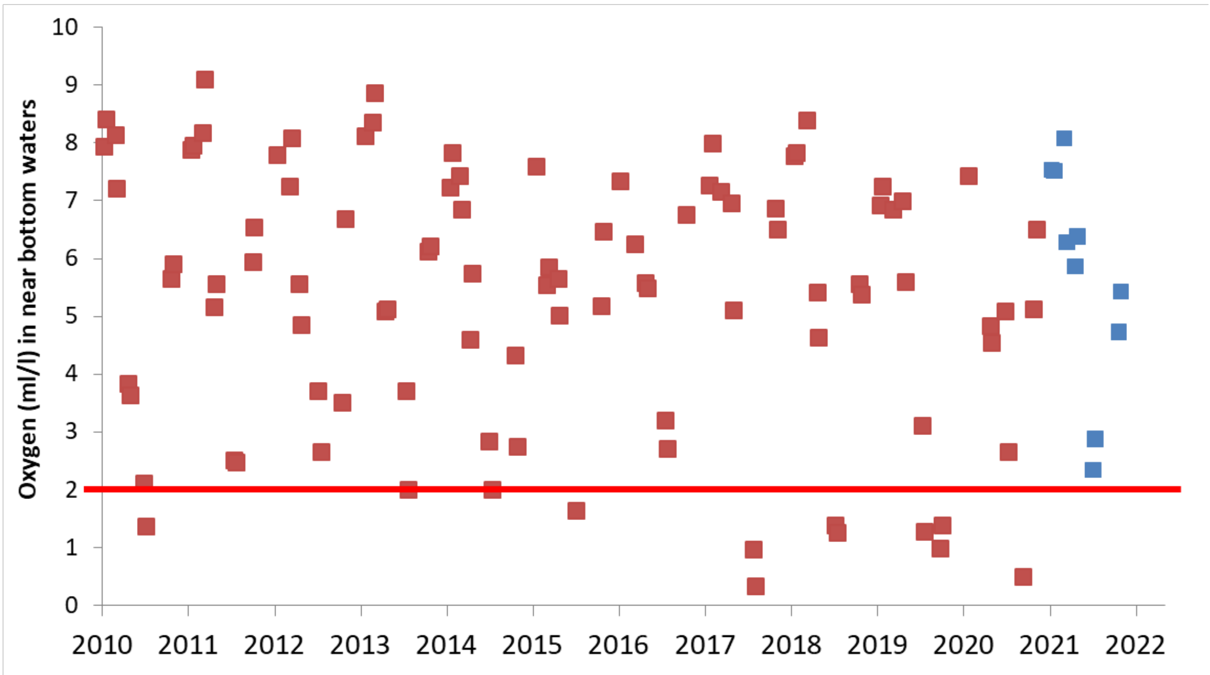

Fig. 30: The development of the oxygen content in the near-bottom water of the Mecklenburg Bay (M2) from 2010 to 2021. The red line shows the threshold value of 2 ml l^{-1}. The blue dots are the measured values from 2021. The lowest values were always measured in summer and/or autumn.

3.3.2 Macrozoobenthos at the stations

In November 2021, we deployed three Van Veen hauls to collect the samples from each of the eight 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 (GOGINA et al. 2016). Regarding the MFSD broad habitat types (EU 2017) they belong to three categories (Table 11). Using the HELCOM Underwater biotope and habitat classification system (HUB, not shown here), the stations could be assigned to five categories (ZETTLER & DARR 2023).

Compared to the period 1991 to 2021, the number of species was medium at 124 (Appendix 3, Fig. 31 and Fig. 33). At five stations (N1, K8, K3, K4, 160) we observed slightly higher diversity than the median. At stations N3 and M2 the values were within the long-term average. Only at station OM18 the diversity was lower than the median (Fig. 31). As in the years before, the ocean quahog *Arctica islandica* reached high abundances and biomass, especially at the western stations (Fig. 32).

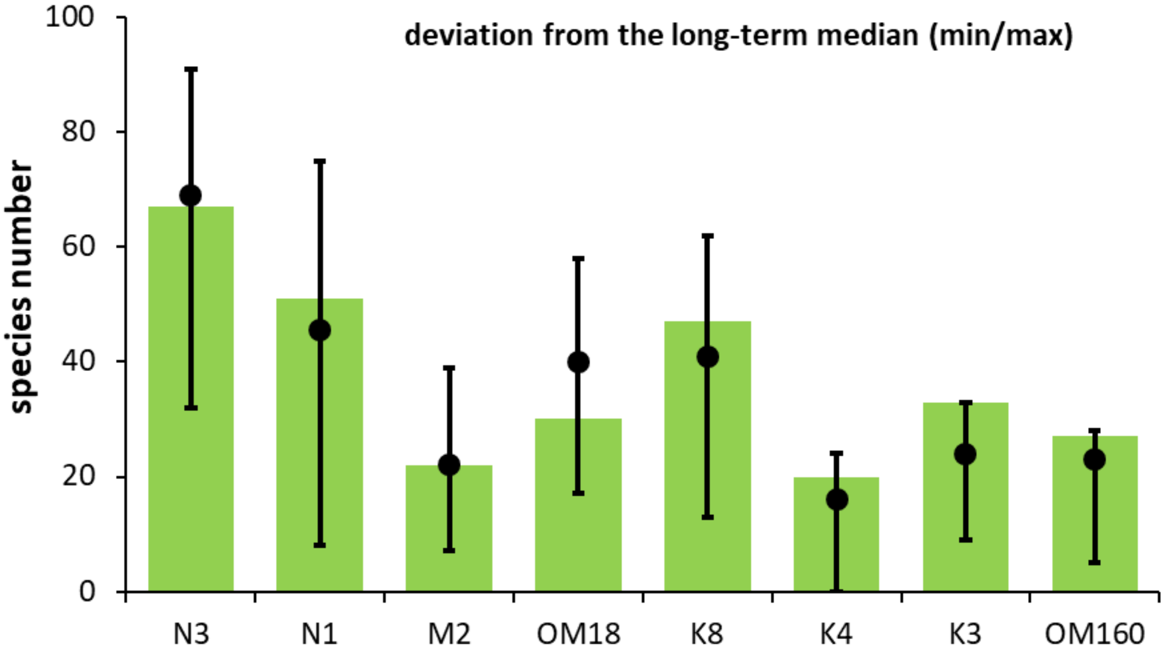

Fig. 31: Number of species (columns) of macrozoobenthos at eight monitoring stations in November 2021. The median values of the years 1991 to 2021 are shown as dots; the minimum and maximum values are indicated as interval. The stations are plotted from west to east (Kiel Bay = N3 to Pomeranian Bay = OM160).

*Fig. 32: The dredge sample of the Fehmarnbelt (N1) in November 2021 was dominated by Arctica islandica (alive and empty shells), brittle stars (*Ophiura albida*) and starfish (*Asterias rubens*) (Photo: IOW).*

In 2021, a recovery of the benthic stock was generally observed at all stations, even if the long-term average was not yet reached in the southern Mecklenburg Bay. Additionally, at some stations new observed species were found (never observed during the last 20 years at these stations). These species are listed below:

=›N3: none

=›N1: *Polycirrus medusa*

=›M2: *Astarte borealis, Nucula nitidosa*

=›OM18: *Hydractinia echinata*

=›K8: *Fabricia stellaris, Fabriciola baltica, Palaemon adspersus, Palaemon varians, Flustra foliacea*

=›K4: *Tubificoides benedeni*

=›K3: *Varicorbula gibba, Enchytraeidae, Myrianida* sp.*, Sphaerodoropsis baltica*

=›OM160: none

Fig. 33 shows the taxa found at our eight monitoring stations in 2021 as well as the total number of species found in surveys since 1991. Not just in 2021 (see ZETTLER et al. 2014, 2018, 2020), the Annelida (Polychaeta and Oligochaeta) emerged as the group that is richest in species number, numbering 105 in total; in 2021, 44 species were identified. Other species-rich groups in 2021 were Mollusca (26), Crustacea (20), Bryozoa (10) and Cnidaria (9).

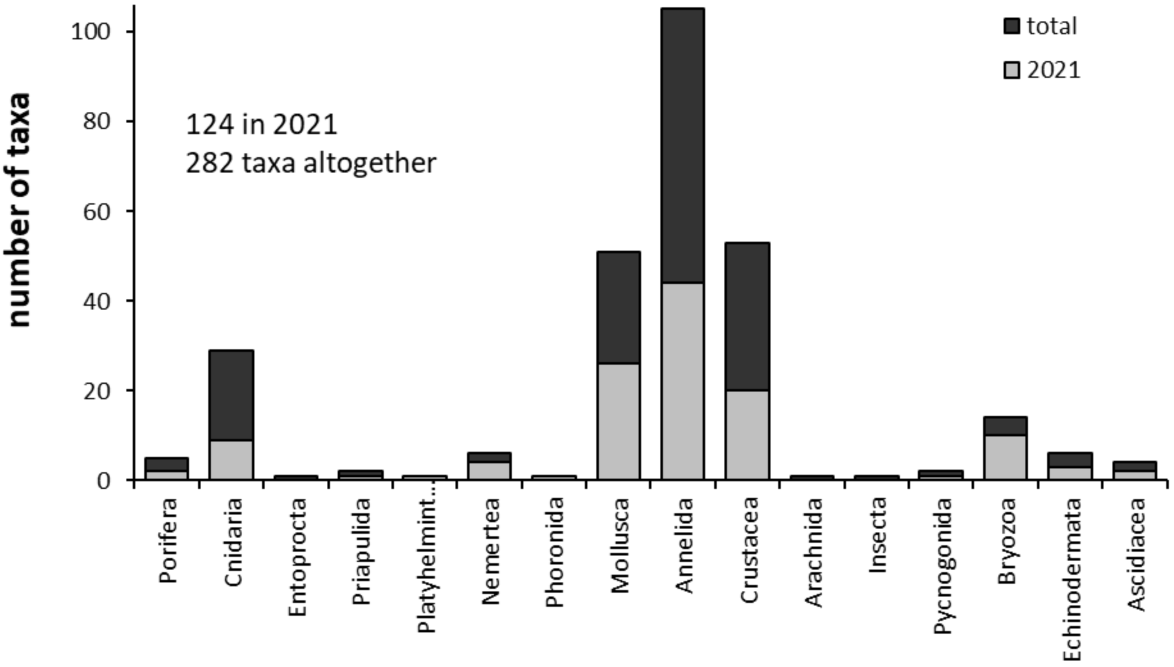

Fig. 33: Taxonomical classification of macrozoobenthos at the eight monitoring stations in November 2021 (grey). The species number of the entire monitoring from 1991 to 2021 is also indicated (black columns).

Depending on the sea area, abundances varied between 254 (Mecklenburg Bay) and 7687 ind. m^{-2} (Darss Sill) (Fig. 34, Appendix 3). At most stations, the abundance is slightly (N1, M2, OM18, K4) or even significantly (N3, K3, OM160) below the long-term average (Fig. 34). The only exception is station K8 at the Darss Sill, where significantly higher abundances were observed in 2021.

Which species was dominant in a given sea area varied greatly; it depended essentially on salinity and substrate (Table 11). While the abundances were mainly dominated by polychaetes, bivalves determined the biomass. In the western part (N3 and N1), the polychaetes *Ampharete baltica*, *Lagis koreni* and the phoronid *Phoronis* sp. dominated the density. Other dominant polychaetes were *Pygospio elegans*, *Scoloplos armiger* and *Terebellides stroemii* (see Table 12 for detailed information). At the four western stations (N3, N1, M2 and OM18) *Arctica islandica* was the dominant biomass species, while at the eastern stations (K8, K4, K3, OM160) *Macoma balthica*, *Mytilus edulis* or *Mya arenaria* were more important.

Table 12: Dominance (%) in abundance and biomass at the eight monitoring stations in November 2021. The stations are plotted from west to east (Kiel Bay = N3 to Pomeranian Bay = OM160).

Abundance in %	**N3**	**N1**	**M2**	**OM18**	**K8**	**K4**	**K3**	**OM160**
Ampharete baltica	35	29						
Arctica islandica			19					
Lagis koreni	10	16	19					
Macoma balthica							14	
Mytilus edulis							26	
Peringia ulvae			28	74	18			47
Phoronis sp.	11	15						
Pygospio elegans					61		33	25
Scoloplos armiger						18	12	
Terebellides stroemii						42		
Varicorbula gibba			13					
Biomass in %								
Arctica islandica	43	95	98	98				
Astarte borealis	53				42			
Macoma balthica						69	25	27
Mya arenaria								54
Mytilus edulis					33		59	

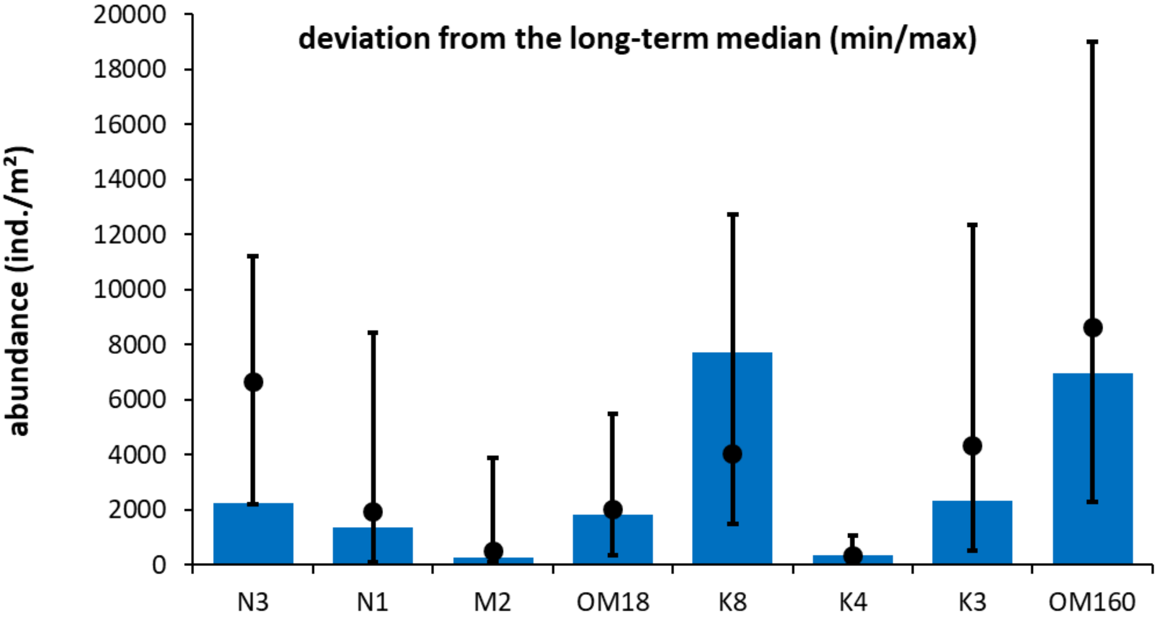

Fig. 34: Total abundances (columns) of macrozoobenthos at eight monitoring stations in November 2021. The median values of the years 1991 to 2021 are shown as dots; the minimum and maximum values are indicated as interval. The stations are plotted from west to east (Kiel Bay = N3 to Pomeranian Bay = OM160).

Compared with their long-term averages, four stations (N3, N1, K8, K3) show a lower total biomass (Fig. 35). Significant higher than the long-term median were the values in the Mecklenburg Bay (M2), caused by adult *Arctica islandica* (Fig. 36). At all other stations, the biomass was within the long-term average (Fig. 35).

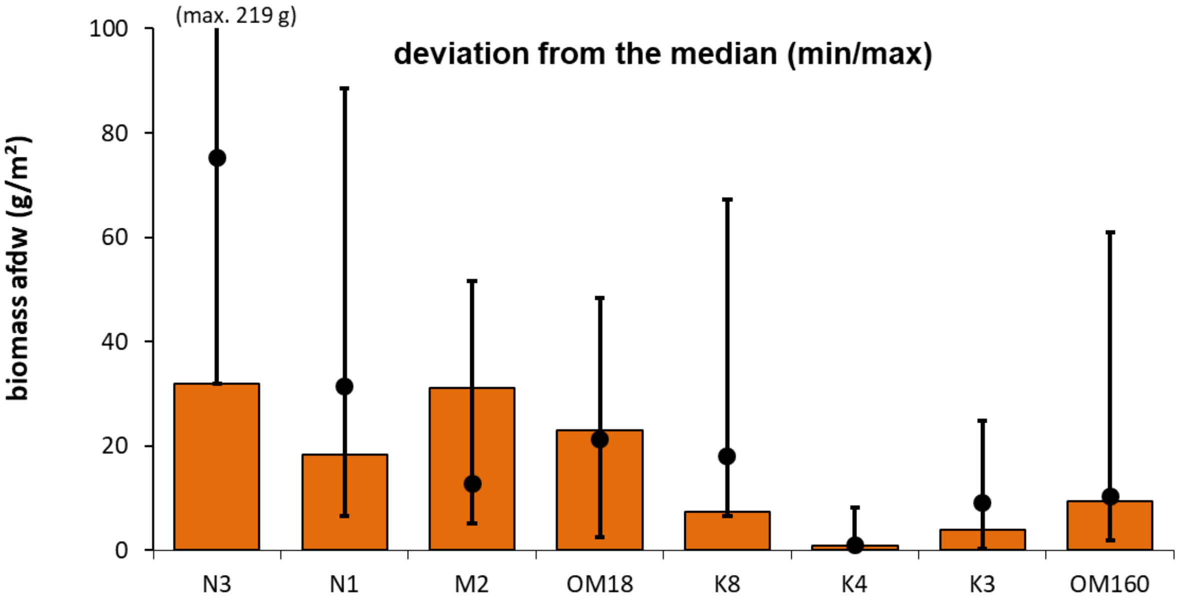

Fig. 35: Total biomass (columns) of macrozoobenthos at eight monitoring stations in November 2021. The median values of the years 1991 to 2021 are shown as dots and the minimum and maximum values are indicated as intervals. The stations are plotted from west to east (Kiel Bay = N3 to Pomeranian Bay = OM160).

Fig. 36: In 2021 the dominant species of the dredge sample in the Mecklenburg Bay (M2) was Arctica islandica, which dominated also the grab samples.

Both for abundance and biomass, analysis of long-term data in part revealed considerable fluctuations that are illustrated as error bars (min/max) in the Fig. 34 and Fig. 35. The fluctuations essentially relate to the population dynamics of long-lived species (especially molluscs) in terms of biomass or the mass development of opportunistic species (e.g. polychaetes). Another general influence can be a population collapse following a phase of oxygen deficiency (although no lack of oxygen was observed in our 2021 data). Not least, however, the randomness of sampling and the clustered distribution of organisms are responsible for these fluctuations. Human induced direct effects are not evidently visible in the analysed 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. In general, the causes for the fluctuations can be manifold and variable, especially in the transitional area of the southern Baltic Sea (Zettler et al. 2017).

3.3.3 Long-term trends

The Fig. 37, Fig. 38 and Fig. 39 present a follow-up to the corresponding presentations of the monitoring report from 2019 and earlier (Wasmund et al. 2019, Zettler et al. 2020) of long-term trends of macrozoobenthos' species number, abundance and biomass at the 8 monitoring stations. The fluctuations mainly reflect the influence of changing oxygen conditions (cf. Naumann et al. 2023).

Fig. 37 shows the cumulative number of species (see also previous reports, e.g. WASMUND et al. 2019, ZETTLER et al. 2020, DUTZ et al. 2022). As expected, species diversity falls from west to east (Kiel Bay N3 to Pomeranian Bay OM160). During the considered period of the last 16 years, the station N1 (Fehmarnbelt) in some years was characterised by a severe loss of species due to oxygen deficiency. In 2008, 2010 and 2016, a reduction of species number up to 50 % was found compared to the previous or subsequent years. In 2014, 2016 and 2020 a dramatic loss in species number occurred also in the Bay of Mecklenburg (M2). In 2020, the low-oxygen conditions in the Mecklenburg Bay in summer led to a loss of species and abundance (DUTZ et al. 2022). No further significant changes were observed. In the last year (2021), the species diversity recovered at almost all stations again (Fig. 37).

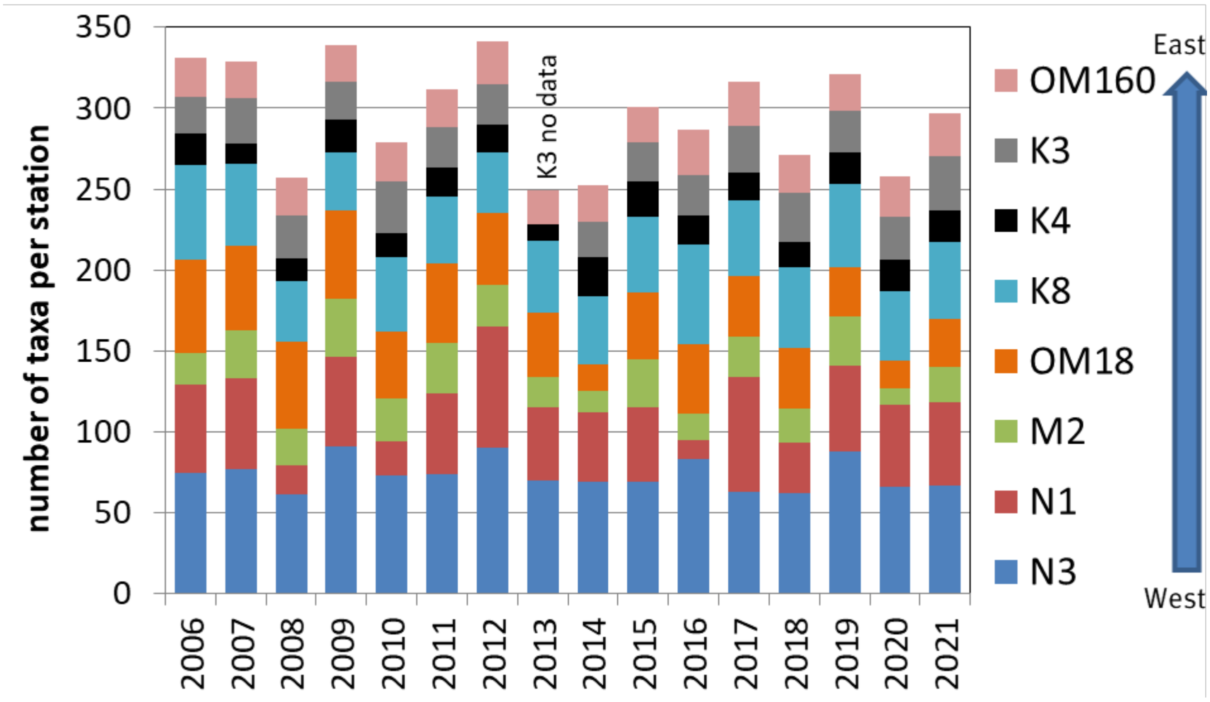

Fig. 37: Cumulative number of taxa of macrozoobenthos at eight monitoring stations from 2006 to 2021. The station values are added in each column.

In terms of abundance, the situation is different (Fig. 38). Due to the strong decrease in abundance mainly in the Kiel and Pomeranian Bay (Fig. 34) the overall density was also low (Fig. 38). In the Kiel Bay (N3), for example, this was essentially due to the halving of the density values of *Phoronis* sp. compared to 2020. This phoronid is known for its extreme abundance fluctuations, which can hardly be explained. However, the extreme declines of the bivalve *Kurtiella bidentata* and the polychaete *Dipolydora quadrilobata* were also responsible for this. While the former is often dependent on fluctuating of salinity and thus on changing reproductive success in the Kiel Bay, the spionid polychaetes are known to be opportunists and show extreme fluctuations in occurrence. In the Pomeranian Bay (K3, OM160), the sharp increase in density in 2020 was due to the tripling of the abundance of *Peringia ulvae*, whose population collapsed in 2021. Such "outliers" with densities *Peringia ulvae* of over 10,000 individuals per square meter were also observed in 2008 and 2015. Nothing is known about the causes of the increase and subsequent collapse.

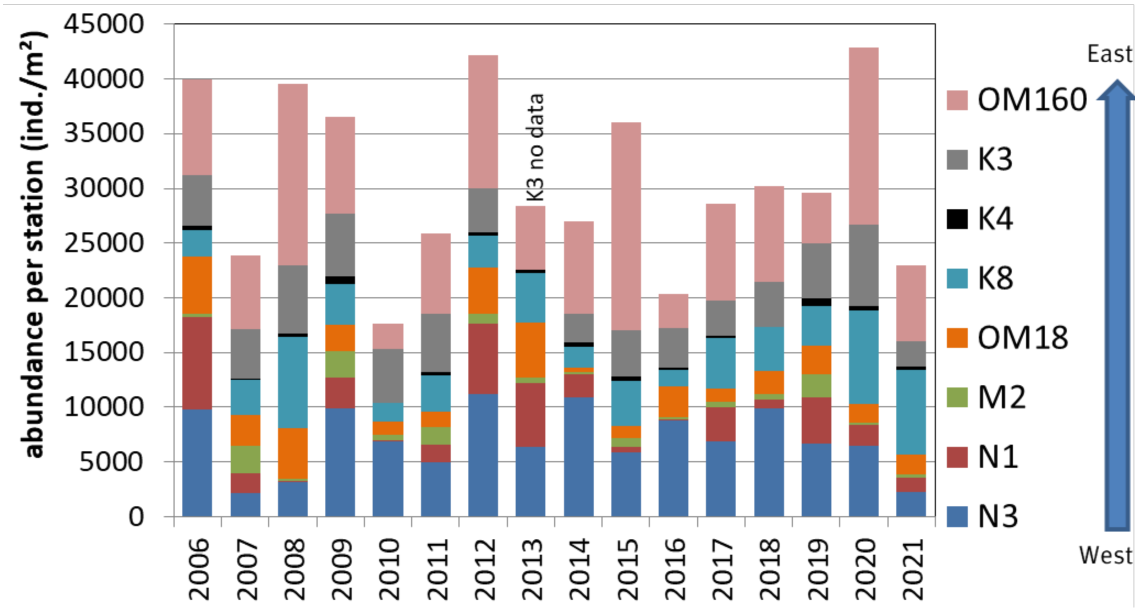

Fig. 38: Cumulative abundance of macrozoobenthos at 8 monitoring stations from 2006 to 2021. The station values are added in each column.

Fig. 39 illustrates the long-term trend in biomass. Firstly, it is obvious that the highest values were observed in the west (Kiel Bay = N3), followed by the Bay of Mecklenburg (M2, OM18) and Fehmarnbelt (N1). Secondly, it is obvious that biomass has not changed as much as the species numbers or abundance. Nevertheless, we can observe a clear decline in biomass during the last years (2014 - 2021 compared with 2007 - 2013). So far, we cannot say whether this is a significant trend. 2021 was the year with the lowest total biomass value of the entire study period (Fig. 39). The reasons for this decline are speculative: For some reason, the large bivalves seem to have been reduced in abundance (and therefore biomass) since a few years. Variations in populations may also be relevant for the decline, especially if caused by oxygen deficits. We see however, no sharp decline in biomass in 2021 like those that we saw in species numbers and abundance due to oxygen deficiency at Fehmarnbelt (N1) in 2008, 2010 and 2016, and in the Bay of Mecklenburg (M2, OM18) in 2014 and 2020. The dominant species (mussels of the genera *Arctica* and *Astarte*) with high individual weights buffer the loss of other species and their weights for the total biomass, but there are limits to this compensation as well.

Overall, the total biomass observed in 2021 was lowest for the entire study period, except for the Mecklenburg Bay (M2, OM18), especially the westernmost stations in the Kiel Bay and Fehmarnbelt (N3 and N1) show low biomass values. The high biomass at the Darss Sill (K8) in 2020 was mainly caused by *Mytilus edulis*, a species which occurs very patchy and can therefore not be sampled representatively during the years. For example, the biomass of *M. edulis* was about 24 times higher in our 2020 oberservations than in 2021.

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, WASMUND & ZETTLER 2023) and to the monitoring reports of the preceding years (e.g. WASMUND et al. 2019, ZETTLER et al. 2020). In these studies, the development of major macrozoobenthic parameters (abundance, biomass, species number) has been interpreted relying on the modelling of the long-term fluctuations of salinity and oxygen, in combination with 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) and GOGINA & ZETTLER (2023).

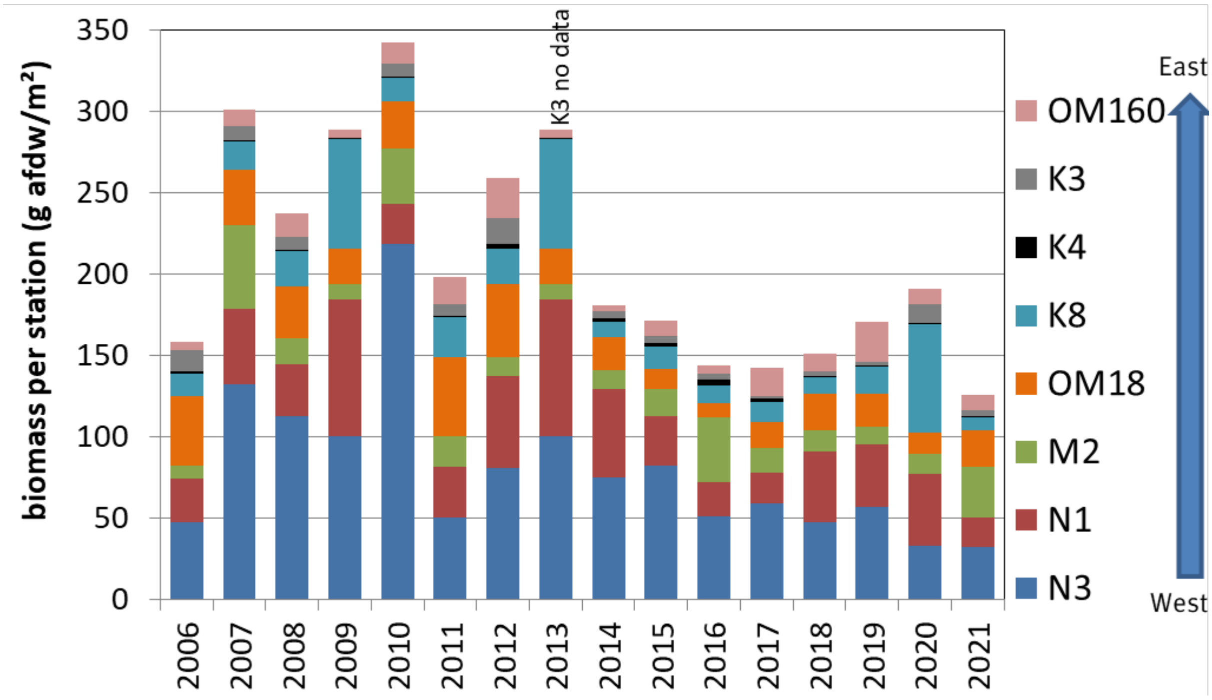

Fig. 39: Cumulative biomass of macrozoobenthos at 8 monitoring stations from 2006 to 2021. The station values are added in each column.

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 124 species, 15 are classed as threatened (1, 2, 3, G) (Fig. 40, Appendix 3). Five species are classed as being near threatened. One species is categorised as extremely rare. Currently, 68 species are classed as being of least concern. Data are deficient for 18 species, and 17 taxa on the Red List were not evaluated. The anthozoan *Halcampa duodecimcirrata* is critically endangered. It was detected in the Arkona Basin (K4) in very low densities. We observed specimens of *Arctica islandica* (ocean quahog; category 3, vulnerable) at all western stations (N3, N1, M2, and OM18) and in the deeper Arkona Basin (K4) at various levels of abundance. Montagu's Astarte (*Astarte montagui*) occurred in the Kiel Bay only. The hydrozoan species *Halitholus yoldiaearcticae* was observed in the Fehmarnbelt (N1) and northern Pomeranian Bay (K3). Category G of the Red List (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 considered to be at risk (uncategorized). The 11 species observed in 2021 were distributed across almost all sea areas: 5 species in Kiel Bay (N3), 5 at the Fehmarnbelt (N1), 1 at the Mecklenburg Bay (M2), 2 at southern Mecklenburg Bay (OM18), 3 at the Darss Sill (K8), 1 in Arkona Basin (K4) and 2 in northern Pomeranian Bay (K3).

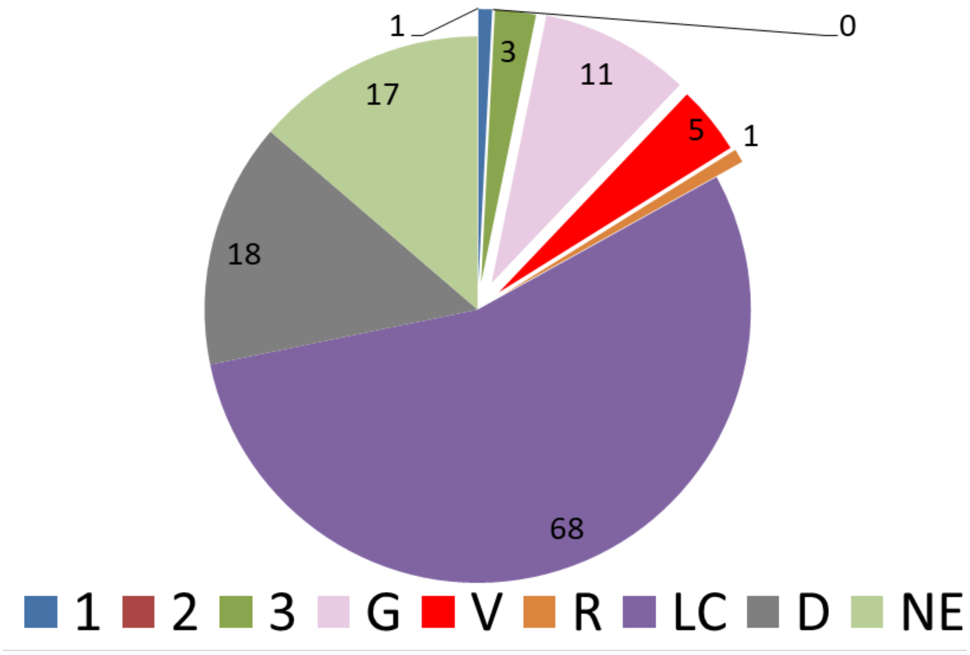

Fig. 40: Distribution of red list categories (RACHOR et al. 2013) in relation to macrozoobenthos in autumn 2021 (1=critically endangered, 2=endangered, 3=vulnerable, G=probably vulnerable, V=near threatened, R=extremely rare, LC=least concern, D=data deficient, NE=not evaluated); the given values are the absolute species numbers.

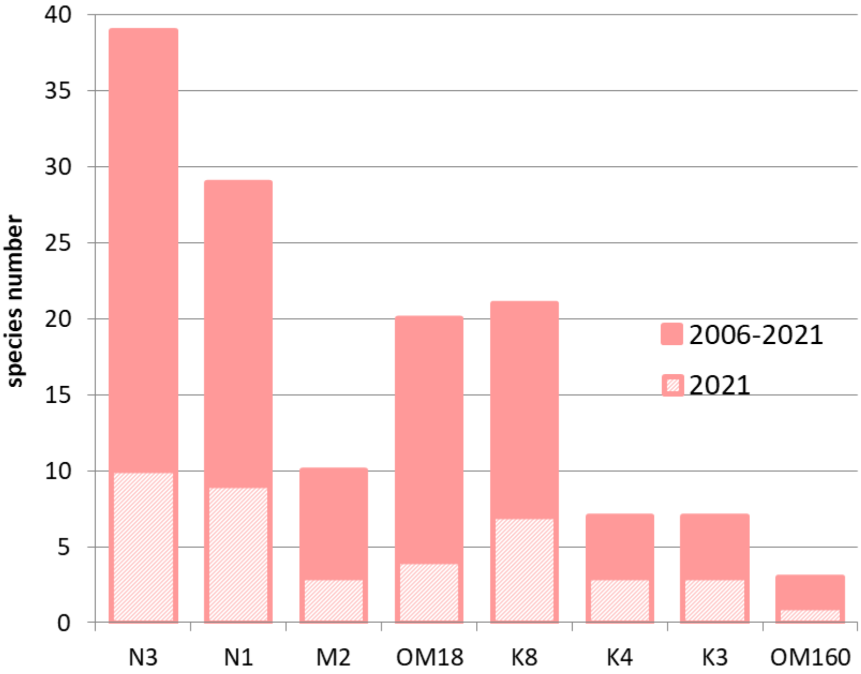

Fig. 41: Number of red listed species (categories 1, 2, 3, G, V and R) (RACHOR et al. 2013) at the eight monitoring stations in 2021 and in total (2006 - 2021). The stations are plotted from west to east (Kiel Bay = N3 to Pomeranian Bay = OM160).

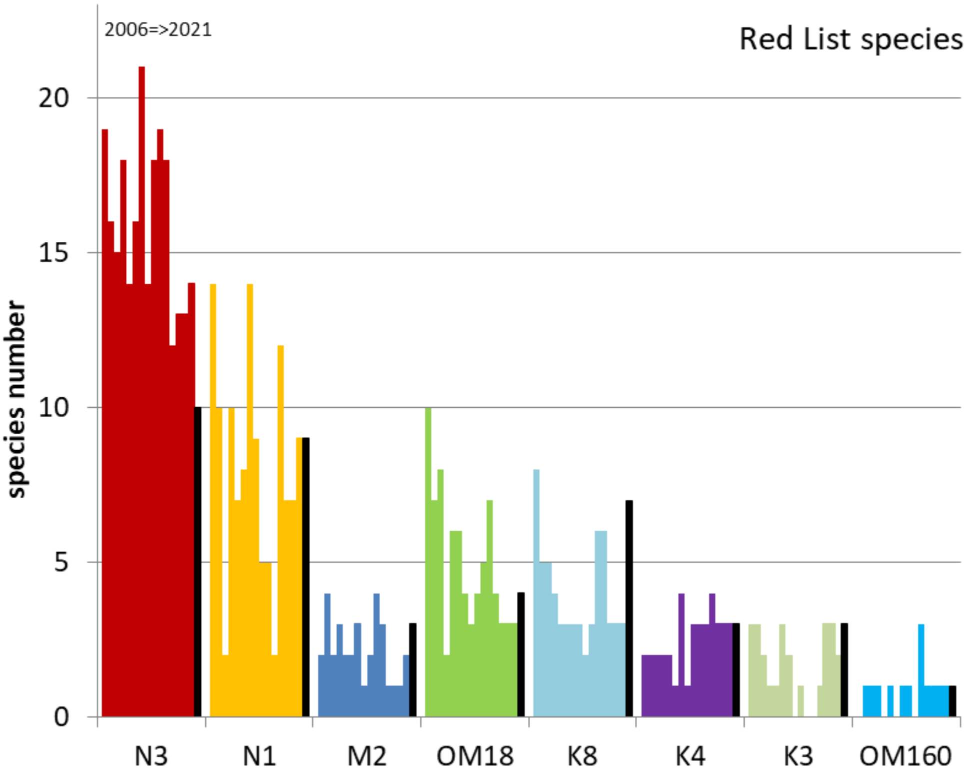

Fig. 42: Development of the number of red listed species (categories 1, 2, 3, G, V and R) (RACHOR et al. 2013) at the eight monitoring stations from 2006 to 2021. The values of 2021 are highlighted in black colour. The stations are plotted from west to east (Kiel Bay = N3 to Pomeranian Bay = OM160).

In general, the number of potentially occurring red listed species at the monitoring stations is decreasing systematically along the salinity gradient from west to east (Fig. 41 and Fig. 42). The percentage of red listed species in 2021 in comparison to observations during the whole study period (2006 to 2021) ranges between 16 % and 43 % (Fig. 41). At all stations in 2021, 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. Only in the Kiel Bay (N3) the number of Red List species was significantly lower than in previous years. The reasons for this are not yet exactly known. It remains to be assumed that the influx of demanding species from the Kattegat via the nearby Belts is absent in some years.

3.3.5 Benthic Quality Index (BQI)

A Baltic Sea monitoring network was initially established as a follow-up of the coming into force of the Helsinki Convention in 1979/1980. The original aim of the monitoring of the marine environment conducted by the bordering countries was the determination of long-term changes caused by human influences (initially mainly eutrophication and hazardous substances and later on also climate change) based on selected environmental parameters and biological components at selected stations (at least one per Baltic Sea basin). Due to increasing pressure on the aquatic environment, the European Union adopted several directives (e.g. FFH, WFD and MSFD) that include the obligation to monitor environmental changes and states. However, the directives pursue very differing goals and require much more effort to implement than the first monitoring and assessment activities. Consequently, our monitoring strategies have evolved over time. Nevertheless, it has to be stressed, that the monitoring performed within the framework of HELCOM in no way meets all the requirements of the different European directives. Neither do our few stations cover all of the different habitat types according to MSFD in the Baltic Sea (broad habitat types, BHT, EU-Commission Decision 2017/848/EU 2017, we have three out of eight, see Table 11). Nevertheless, they are a valuable tool for detecting long-term changes and their causal relationships, e.g. for gradual processes such as eutrophication and climate change.

With regard to the BQI (indicator to be used within the MFSD criterion D6C5 = condition of the benthic habitat), it also has to be highlighted that conceptually many stations per BHT are required to reach a sound assessment result. BQI-values at individual stations should be considered with caution as they are subject to natural variability. Nevertheless, significant changes over time might be visible. Consequently, the present study will show how such an assessment of the benthic component would look like and whether it could be usefully applied. For this purpose, we applied the Benthic Quality Index in an adapted form to the data of our eight long-term stations. The BQI is used for basin-wide assessments within HELCOM as part of the core state indicator "Soft-bottom macrofauna” (https://indicators.helcom.fi/indicator/soft-bottom-macrofauna/) and also serves as an additional German indicator (with some specific adaptations (Zustand der deutschen Ostseegewässer 2018)).

We are aware that the stationwise approach as presented here is unusual, as HELCOM monitoring is not designed to assess distinct habitat types via BQI. Nevertheless, we can show quite clearly how the stations develop over longer periods and where stable or where rather variable conditions prevail.

The eight stations (N3, N1, M2, OM18, K8, K4, K3, and OM160) were sampled once a year for 16 years (2006 to 2021). Three hauls were always taken. All data were used to calculate the Benthic Quality Index (BQI). In total, we have 128 samples at the stations, each with 3 replicates (3 hauls), i.e. a total of 384 individual hauls.

The BQI was calculated using the formula for the BQI according to Leonardsson et al. (2009) (equation 1).

Equation 1:

$$BQI = \left(\sum_{i=1}^{S_{classified}} \left(\frac{N_i}{N_{classified}} \times ES50_{0,05i} \right) \right) \times log_{10}(S+1) \times \left(\frac{N_{total}}{N_{total}+5} \right)$$

Where S is the number of taxa, N_i the abundance of taxon i, $N_{classified}$ the number of individuals with a sensitivity value and N_{total} the sum of all individuals on the sampled plot. The $ES50$ corresponds to the expected number of taxa from 50 randomly selected individuals of a sampling plot. The $ES50_{0,05}$ is the sensitivity value for taxon i according to Schiele et al. (2016). It corresponds to the lower 5 % percentile of all $ES50$ values determined for this taxon (Rosenberg et al. 2004).

In case of spatial, temporal or methodological disparities between samples, HELCOM (2018) recommends bootstrapping. This is used as a safety method to assign a lower value to values with a high uncertainty (Carstensen 2007; Leonardsson et al. 2009). However, since the samples were taken from the same sites every autumn, always with three hauls each, no spatial, temporal or methodological inconsistencies are to be expected. The bootstrapping procedure was therefore not carried out.

The sensitivity value is thus calculated from the abundance of species at a site and is based on the assumption that sensitive species mainly occur at undisturbed sites with a high diversity, whereas tolerant species mainly dominate at disturbed sites with a low diversity (ROSENBERG et al. 2004). Due to differences in community composition and sensitivity of individual taxa along different natural gradients, the sensitivity values to be used are not the same for the whole Baltic Sea. Therefore, SCHIELE et al. (2016) divided the Baltic Sea into 19 Ecological Indicator Groups (EIG) based on the factors salinity, water depth and sampling method used. They calculated the sensitivity value per taxon ($ES_{50_{0,05}}$) for each subgroup. Five of the 19 subgroups are relevant for the German Baltic Sea (EIG2 to EIG6).

For all years, each station was assessed as "good" or "poor" using the calculated BQI values and the associated threshold values for the specific EIG (hitherto unpublished results of our working group). For each station, the proportion of hauls per station that had received the rating "good" over the entire sampling period was then calculated (EcoQ status "good" in %, see Table 13). According to HELCOM (2018), an area is classified as “poor” if more than 20 % of the hauls per station are rated as “poor”. Therefore, stations that had received at least 80 % EcoQ status of "good" over the 16 years were rated "good" overall. Stations with less than 80 % "good" status were rated "poor" (overall rating, see Table 13).

Table 13: For each station, the mean BQI (Benthic Quality Index; median; per haul station over 16 years), the mean normalised BQI (median; per haul station over 16 years; normalised over the threshold of the respective EIG), the EIG (Ecological Indicator Group) used, the EcoQ status "good" (percentage of haul stations with EcoQ (Ecological Quality) status of "good") and the overall assessment “Rating” (stations were assessed as “poor” if less than 80% of the haul stations had EcoQ status "good") over the entire sampling period; FixSal (modelled mean water depth and salinity).

Station	BQI_FixSal (Median)	BQI_FixSal normalised (Median)	Used EIG FixSal	EcoQ-Status „good“ (%) FixSal	Rating
N3	10.60	1.33	EIG 2	100.00	good
N1	7.30	0.77	EIG 3	2.08	poor
M2	5.02	0.53	EIG 3	0.00	poor
OM18	8.11	1.02	EIG 2	58.33	poor
K8	6.30	1.21	EIG 4b	91.67	good
K4	3.65	0.70	EIG 4b	4.17	poor
K3	4.34	1.24	EIG 5	100.00	good
OM160	3.95	1.12	EIG 5	87.50	good

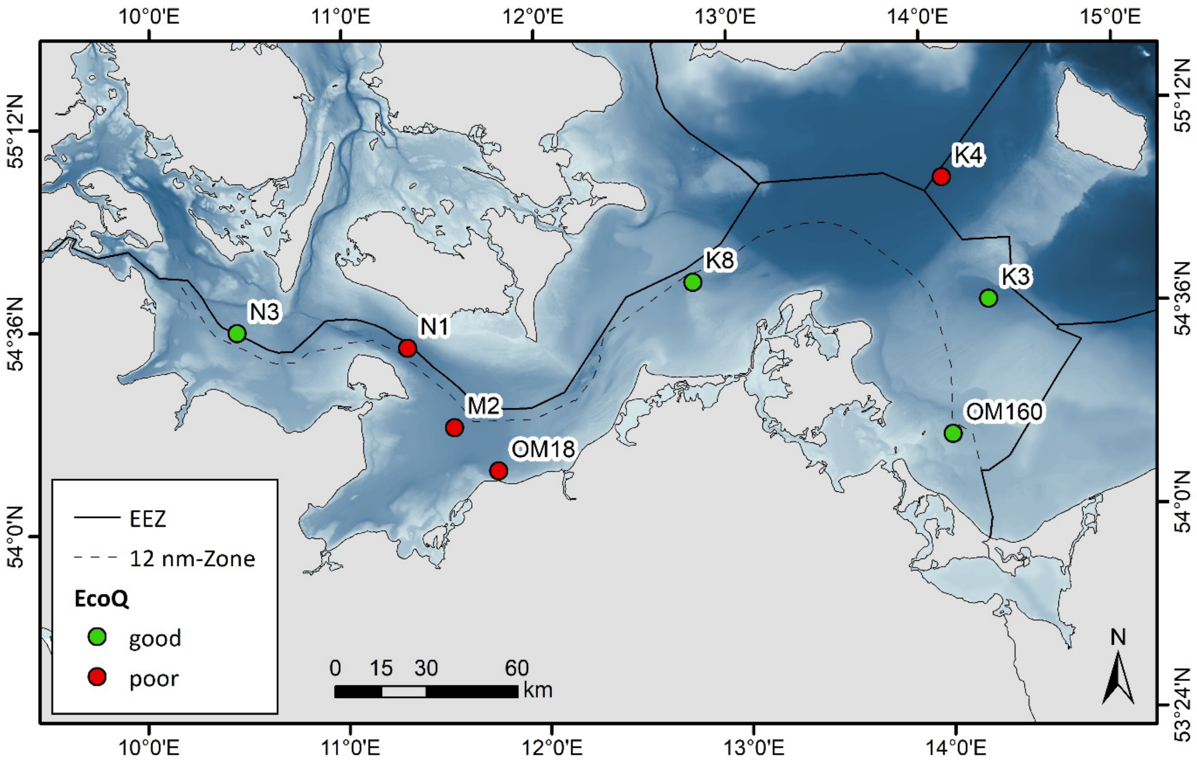

Fig. 43: Locations and EcoQ (Ecological Quality) assessment of the eight stations studied with FixSal (modelled mean water depth and salinity), averaged over 16 years (2006 - 2021); EEZ = exclusive economic zone; 12 nm zone = twelve nautical mile zone; projection: LAEA - ETRS89; background: Bathymetrie BSH (2012).

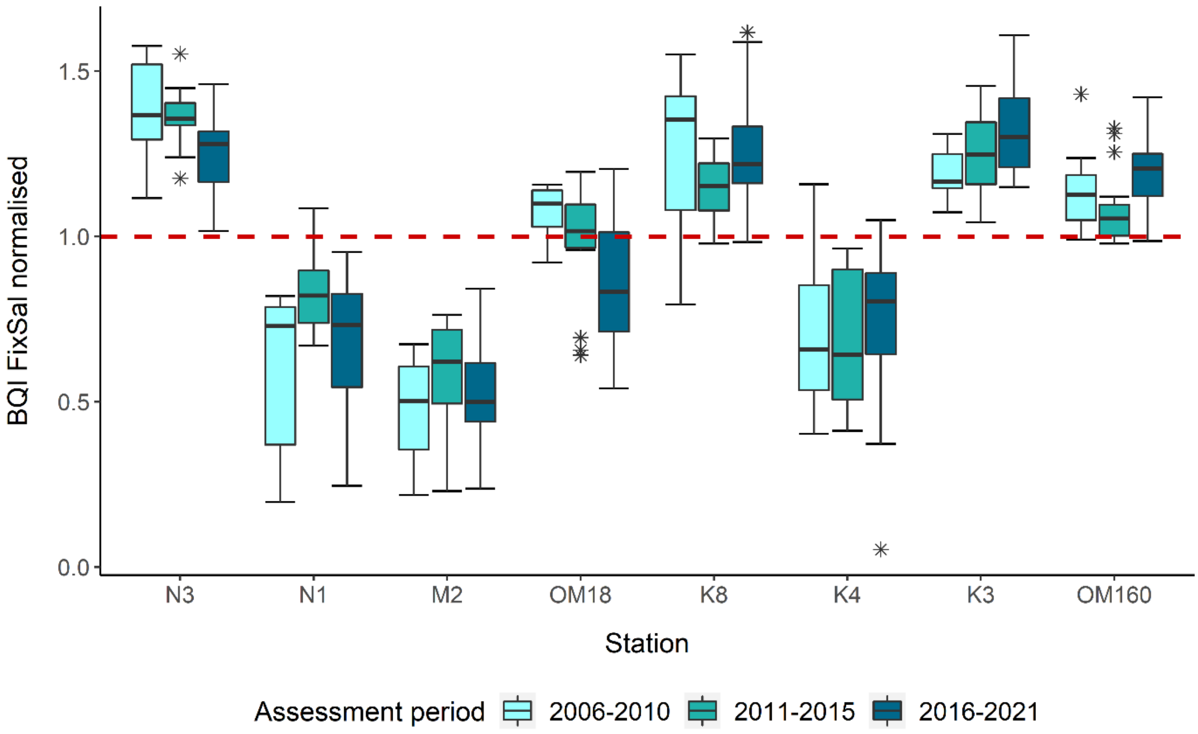

Fig. 44: Boxplots of the normalised BQI (Benthic Quality Index) values per station for three different assessment periods (2006 – 2010, 2011 – 2015, and 2016 – 2021) according to MSFD-assessment periods. FixSal (modelled mean water depth and salinity); the BQI was normalised by the threshold value for the respective EIG (Ecological Indicator Group).

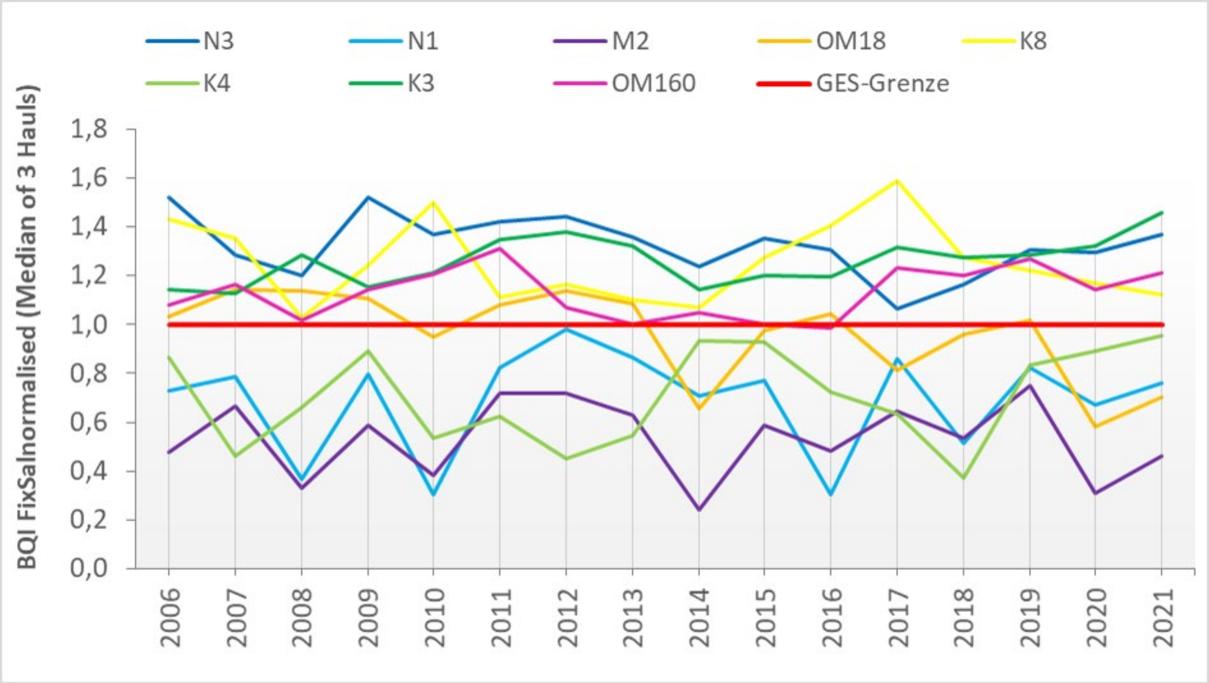

Fig. 45: The normalised BQI (Benthic Quality Index) value for each station (median of the three hauls) over time (2006 to 2021) according to FixSal (modelled mean water depth and salinity); the BQI was normalised by the threshold value for the respective EIG (Ecological Indicator Group); the red line marks the boundary between a "good" (> 1) and "poor" (< 1) ecological status (GES = Good Environmental Status).

In summary, the stations in the Kiel Bay (N3), Darss Sill (K8), northern Pomeranian Bay (K3) and Pomeranian Bay (OM160) always show a "good" ecological status (Fig. 43, Fig. 44, Fig. 45). The Arkona Basin (K4) and the Mecklenburg Bay (M2) were more than 50 % in a “poor” condition (Table 13). Fehmarnbelt (N1) and the southern Mecklenburg Bay (OM18) were more than 70 % in "good" condition, but also more than 20 % in "poor" condition and are therefore assessed as "poor" according to the threshold rules. Especially for the southern Mecklenburg Bay (OM18) we see a negative trend comparing the three different evaluation periods given in Figure 44. No trend was observed for the other stations or sea areas. The evaluation was relatively unchanged regardless of the assessment periods used in the 6-yearly MSFD assessment.

The map of the BHT assessment of the German Baltic Sea, which is currently being compiled in our working group, resulting in GES thresholds for the whole German Baltic Sea and not subject of the present study, shows a high degree of agreement with the station values shown here. The circalittoral muds of the Bay of Kiel, Mecklenburg Bay and Arkona Sea do not achieve good environmental status. Only the infralittoral sands of the Pomeranian Bay and with some exceptions also the circalittoral sands of the Arkona Sea can be assessed as good. The main reason for this is likely to be the irregularly recurring oxygen deficiency events in the deeper basins of the southern Baltic Sea and the resulting adverse effects on the organisms living there.

3.3.6 Non-indigenous 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 eight monitoring stations in 2021. *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 (ZETTLER & ALF 2021). Two polychaete species 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 the Pomeranian Bay (K3 and OM160) both species occur sympatrically and reached noteworthy abundances in 2021. In addition, the decapod crab *Rhithropanopeus harrisii,* which originates from North America, was found at the Oderbank (OM160). Finally, the ascidian species *Molgula manhattensis* was observed in the Kiel Bay (N3). It is not clear whether this is a neozoan or a cryptic indigenous species (LACKSCHEWITZ et al. 2022). None of the observed NIS was recorded for the first time; all have been established for years.

Extended Summary

In 2021, the **phytoplankton** spring bloom in the study area started in early February, as indicated by Chl*a* concentrations between ~1 and 3.5 µg l^{-1} measured during the February cruise. Nevertheless, it developed quickly during the cruise, resulting in significantly increased concentrations on the return journey along the same track. Chl*a* data reflected phytoplankton biomass poorly due to the high representation of non-diatom and mixotrophic taxa. The ichthyotoxic Raphidophyte *Heterosigma akashiwo* for example, contributed a significant biomass share of nearly 15 % in Kiel Bight. Biomass in the western Baltic was dominated by the mixotrophic ciliate *Mesodinium rubrum* and flagellate phytoplankton and communities were generally shaped by brackish species. This was also reflected by a comparably low taxa number (64 in Belt Sea to 35 in Bornholm Basin) encountered during the cruise.

By March, Chl*a* concentrations had increased significantly in the entire study area, reaching the 2021-measured maximum of ~10 µg l^{-1} in Bornholm Basin, and generally indicating significant phytoplankton production in the central basins. Nevertheless, as in February, spatial Chl*a* and biomass data poorly matched, due to dominance of mixotrophic phytoplankton and *Mesodinium rubrum* in the south and east. In March diatoms were locally abundant and contributed high biomass shares in Arkona and Bornholm Basins. The number of recorded taxa ranged between 64 in the Belt Sea and 40 in Bornholm Basin.

By May, Chl*a* levels had declined (1.3 µg l^{-1} -– 3.36 µg l^{-1}) throughout the study area, suggesting that the spring bloom was in a late stage at the time of the monitoring cruise. Again, Chl*a* dynamics poorly reflected phytoplankton biomass distribution due to dominance of *Mesodinium rubrum* in the north and a strong dinoflagellate/haptophyte/cryptophyte representation in the south. Diatoms were practically absent from the community along the entire S-N (outbound) transect. Total biomass concentrations increased by an order of magnitude from ~150 µg l^{-1} in the south to ~1500 µg l^{-1} in the north, reflecting the typical latitudinal delay of bloom timing. Species diversity was low in May: a minimum of 36 taxa was encountered in the Arkona Basin, 40 taxa were recorded in each of the other basins.

The summer phytoplankton composition and production consisted of mostly diatoms in the southern Baltic, which is unusual, at least in the open sea area. *Dactyosolen fragilissimus* constituted 80 to >90 % of the biomass in the Bay of Mecklenburg in July. Total phytoplankton biomass of 3000 to nearly 8000 µg l^{-1} was measured in the western Baltic during the July cruise. This was contrasted by cyanobacteria dominated communities in the central Baltic, which only amounted to 5 % of the biomass produced by the diatoms in the south. Compared to 2020, dinoflagellates and respective toxic taxa, eg. *Alexandrium* spp. and *Dinphysis* spp. were hardly encountered in the summer community captured in July. Diversity was low, with 67 taxa present in the Belt Sea, 37 in Arkona and only 23 and 25 taxa, respectively, in Bornholm and Gotland Basins

The November cruise was represented by intermediate Chl*a* levels ranging from 2.7 µg l^{-1} in the south to 5.4/5.6 µg l^{-1} in the north – similar to 2020. Biomass was dominated by diatoms throughout the study area resulting in biomass shares of 80 to 100 % at most of the stations. Accordingly, biomass dynamics corresponded well with Chl*a*. Biomass was high in the north amounting to ~3400 µg l^{-1} compared to ~780 µg l^{-1} in the south. In all areas the phytoplankton composition was dominated by diatoms, mostly *Coscinodiscus* spp. and *Cerataulina pelagica*, constituting more than 90 % of the biomass in the northern Basins.

In 2021 altogether 165 phytoplankton species/taxa were recorded in monitoring samples from 0 - 10 m water depth, which is slightly more than in previous years. In contrast to 2020, none of the toxic bloom formers of the Baltic Sea occurred at bloom concentrations, i.e. constituting more than 50 % of the total phytoplankton biomass. In summer, *Nodularia spumigena* and *Aphanizomenon* had 10 % - 50 % biomass shares in Arkona, Bornholm and Gotland Basins, which is a typical situation here. *Azadinium* spp. were recorded as well as a substantial biomass of potentially fish killing *Heterosigma akashiwo*. In comparison to previous years, neither *Alexandrium* spp., nor *Pseudo-nitzschia* spp. reached significant cell concentrations.

2021 mean phytoplankton biomass, diatom to dinoflagellate ratio and cyanobacteria biomass were in the same range of inter-annual oscillations as in previous years. The 2021 annual phytoplankton biomass level was consistent with the 20-year mean. The diatom to dinoflagllate ratio was higher than the 20- year mean, suggesting more diatoms were present in respective communities, which is generally considered good for the status of the Baltic Sea. Cyanobacteria biomass was below average, which is also considered beneficial for improvement of the overall status of the Baltic Sea.

In 2021, the sampling of **zooplankton** commenced largely as planned. Due to bad weather conditions, three stations had to be cancelled on the return journey. This had no major implications for the analysis of the biodiversity and seasonal dynamics of the zooplankton in the study area. Altogether, 57 zooplankton samples were collected at 37 stations in the Kiel Bight, the Bay of Mecklenburg and the Arkona Basin.

The species composition was dominated by euryhaline and brackish taxa. In total, only 45 taxa were recorded, which is in the lower range of the 44 - 73 taxa during the previous years. The low number is related to the absence of halophilic zooplankton, including hydrozoans, rare crustaceans like ostracods and larvae of benthic species that have their distribution centre outside the Baltic Sea. In addition, neither a spatial decrease from Kiel Bight to the Arkona Basin nor a strong seasonal variation in species number, that is usually common in the area, were observed in 2021.

The maximum zooplankton abundance achieved 8.0 x 10^4 ind. m^{-3}. Although this represents an increase in the abundance of zooplankton compared to the preceding year by approximately 40 %, this is the third lowest value recorded in the time series since 2000 and only 33 % of the long-term mean. Thus, negative long-term anomalies since 2010 indicate a trend of continuously decreasing zooplankton abundance in the recent decade. Although cladocerans showed a slight increase in 2021, their abundance together with that of rotifers, Copelata, cyclopoid and calanoid copepods, and polychaete larvae was considerably below their long-term means. Only bivalve and gastropod larvae achieved their long-term average concentrations. Among the calanoid copepods, the genus *Acartia* with the species *A. bifilosa*, *A. longiremis* and *A. tonsa* showed no trend in their abundance, while the stock sizes of *Temora longicornis*, *Centropages hamatus* and *Pseudocalanus* spp. were lower than their long-term means.

Cladocera dominated the zooplankton composition (max. 4.4 x 10^4 ind. m^{-3}) followed by the copepods (max. 3.1 x 10^4 ind. m^{-3}), mollusc larvae (max. 1.6 x 10^4 ind. m^{-3}) and rotifers (max. 7.6 x 10^3 ind. m^{-3}). The contribution of cyclopoid copepods to the copepods was unusually low and rotifers remained considerably below their historical concentrations, which have already been observed in the preceding year. The genus *Acartia* with the species *A. longiremis* and *A. bifilosa* was most abundant among the copepods. A typical shift in dominance of the two species occurred along the salinity gradient. Among the cladocerans, *Bosmina* spp. dominated numerically in summer with peak concentrations in the Arkona Basin. *Evadne nordmanni*, in contrast, occurred in the entire western Baltic Sea during spring and summer. The Copelata showed also their typical compositional shift with *Fritillaria borealis* replacing *Oikopleura dioica* from the Kiel Bight to the Arkona Basin. *Oikopleura dioica*, however, was less abundant than usual, similar to the rotifer *Synchaeta*. Apart from *Acartia tonsa*, no other organisms classified as non-indigenous species were found in 2021.

The seasonal development of the zooplankton community in the Kiel Bight was characterized by a pronounced variation. Following a low overwintering stock (4.6 x 10^3 ind. m^{-3}), the maximum density was achieved already in May (3.1 x 10^4 ind. m^{-3}). In summer and autumn, however, it rapidly declined to unusually low values (0.6 - 1.1 x 10^4 ind. m^{-3}). Copepods were the main zooplankton group and dominated the transition from winter to spring together with polychaete and bryozoan larvae. In May during the zooplankton maximum, meroplankton vanished and the zooplankton stock consisted almost entirely of copepods. *Acartia* spp. was the dominant genus followed by *Centropages*, *Pseudo/Paracalanus* and *Oithona*. *Acartia bifilosa* was the major species. Together with the strong decrease in abundance in summer and autumn, a typical shift in the community composition occurred in summer. While copepods declined, meroplankton, Copelata and Cladocera prevailed. With the further decrease in the zooplankton stock size in autumn, copepods and Copelata were dominating.

The zooplankton in the Bay of Mecklenburg did not show the strong seasonal variation in stock size associated with the summer decline in the Kiel Bight. While a dominance of copepods during winter-spring which was combined with a shift in community composition towards the summer resembled largely the seasonal development in the Kiel Bight, a considerably higher abundance of Cladocera and meroplankton compensated for the decline of copepods during summer. On an annual basis, copepods were the dominant taxa followed by meroplankton and Cladocera. Bivalve larvae replaced the polychaetes and cirripedes as most common meroplankton. Copepods dominated the low overwintering stocks (3.4 - 3.9 x 10^3 ind. m^{-3}). The stock increased rapidly until May (2.1 x 10^4 ind. m^{-3}). Copepods, rotifers, cladocerans and polychaete larvae were the main contributors. *Acartia, Pseudo/Paracalanus, Centropages and Temora* were important genera. *Acartia longiremis* was the dominating species. The community composition changed considerably from late spring to summer. Most prominent was the considerable decrease in copepod numbers, while cladocerans and bivalve larvae, however, increased in summer and the total zooplankton stock remained rather constant. Low autumn stocks consisted of Copepoda and Copelata.

In contrast to the Belt Sea, the seasonal maximum of the zooplankton stock size occurred in summer in the Arkona Basin. This seasonal pattern was caused by the recovery of high concentrations of cladocerans that were lacking since 2019. In addition, stocks of copepods remained high during the summer. On an annual basis, both groups dominated the zooplankton together with bivalve larvae, while rotifers remained low in abundance. Winter stocks were typically low (2.6 – 3.5 x 10^3 ind. m^{-3}) and dominated by several genera of copepods (*Acartia*, *Centropages*, *Pseudo/Paracalanus, and Temora*). In May, the stocks increased by a factor of two to three due to copepods, cladocerans and rotifers (1.7 – 2.2 x 10^4 ind. m^{-3}). *Acartia* and *Centropages* were dominating among the copepods; *Evadne nordmanni* was the major cladoceran. The maximum stock size of zooplankton was achieved in summer (4.3 – 6.5 x 10^4 ind. m^{-3}) due to the occurrence of peak concentrations of the cladoceran *Bosmina* spp. Copepods were still abundant, but *Temora* was the dominating group. Bivalve larvae achieved their seasonal maximum. The autumn stocks were again low and copepods were their major taxon.

This study presents the results of **macrozoobenthos** monitoring in the southern Baltic Sea in November 2021. The following parameters were measured: species richness, and the abundance and biomass of organisms per station. Compared to previous years, the number of 124 species recorded at the eight monitoring stations was average. Depending on the region, abundances varied between 254 and 7687 ind. m^{-2}. In terms of biomass, similar high variations were observed (0.8 g in the Arkona Basin to 32 g afdw m^{-2} at the Kiel Bay).

In 2021 no long lasting oxygen deficiency was observed during our cruises (Neumann et al. 2023). In all regions, the oxygen supply in bottom waters in the current year was always higher than 2 ml l^{-1}. While over the last years occasional population collapses caused by a lack of oxygen could be observed, especially in the Fehmarnbelt and in the Mecklenburg Bay, the consistently good oxygen conditions in 2021 (as far as we can see from our data) led to a recovery of the stocks. Except for the southern Mecklenburg Bay with its decline, the diversity at all stations was similar or slightly increased compared to the recent years.

Fifteen species of the German Red List (Categories 1, 2, 3 and G) were observed at the eight monitoring stations. The anthozoan *Halcampa duodecimcirrata*, very rarely observed and critically endangered in German waters, was found in the Arkona Basin, for instance. The ocean quahog *Arctica islandica* occurred at the westernmost stations of the Kiel and Mecklenburg Bay and in the Arkona Basin.

For the first time, we used long-term data from the eight monitoring stations to calculate the Benthic Quality Index (BQI) for each station. We are aware that this approach is unusual, as HELCOM monitoring is not designed to assess distinct habitat types via BQI. Nevertheless, we can show quite clearly, how the stations develop over longer periods and where stable or where rather variable conditions prevail. According to these BQI results for 2006 – 2021 (divided into three periods according to MSFD-assessement intervals), half of the stations were in “good” condition over the years. Two have become predominantly “poor” over the years, and two others are often in “good” condition, although according to the threshold rules they still fall under “poor” if you sum up all relevant assessment years. Especially for the southern Mecklenburg Bay (OM18) we see a negative trend comparing the three different evaluation periods. No trend was observed for the other stations or sea areas.

In line with the expectations, the number of non-indigenous species found during the 2021 sampling campaign was low: six species were identified, among them long-established species like *Amphibalanus improvisus* (Cirripedia) and *Mya arenaria* (Bivalvia). The recently (since the

1980s and 1990s) introduced species *Marenzelleria viridis* and *M. neglecta* (Polychaeta) are locally important in the Pomeranian Bay and reached noteworthy abundances in 2021. Additionally, the decapod crab *Rhithropanopeus harrisii*, which finds its origin in North America, was found at the Oderbank. Finally, as a cryptic neozoan species the ascidian *Molgula manhattensis* was observed in the Kiel Bay. None of the observed NIS was recorded for the first time; all have been established for years.

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Appendix

Appendix 1: List of phytoplankton taxa recorded in 2021. Distribution, biomass means per station and sampling, and biomass ranks.

species	**TF0221**	**TF0321**	**TF0521**	**TF0721**	**TF1123**	Biomass (average /station	**rank**
Actinocyclus			x	x		0.24	78
Actinocyclus octonarius	x	x	x	x	x	4.68	24
Actinocyclus senarius				x	x	0.15	90
Akashiwo sanguinea cf.				x		0.12	97
Alexandrium			x	x		0.18	85
Alexandrium cf.				x	x	0.14	91
Alexandrium pseudogonyaulax				x		0.82	52
Amphidinium		x				0.01	146
Amphidinium crassum				x		0.00	155
Amphidinium longum	x					0.00	154
Amphidinium sphenoides	x	x	x		x	0.42	68
Amylax triacantha	x	x	x	x	x	0.73	57
Apedinella radians	x	x	x		x	0.19	83
Aphanizomenon	x	x	x	x	x	6.14	18
Aphanothece		x		x		0.01	143
Aphanothece paralleliformis			x			0.02	137
Apocalathium spp. CPX		x	x			2.11	35
Attheya longicornis	x	x				0.12	96
Azadinium cf.				x	x	0.02	132
Binuclearia lauterbornii	x	x	x		x	0.08	103
Centrales	x	x		x	x	0.42	67
Cerataulina bergonii	**x**	**x**		**x**	**x**	**38.25**	**5**
Chaetoceros	x	x		x	x	0.23	79
Chaetoceros affinis	x	x			x	0.01	152
Chaetoceros castracanei	x				x	0.54	64
Chaetoceros convolutus					x	0.16	86
Chaetoceros curvisetus					x	0.05	116
Chaetoceros danicus	x	x	x	x	x	7.40	16
Chaetoceros laciniosus					x	0.01	147
Chaetoceros septentrionalis	x	x			x	2.78	30
Chaetoceros similis	x	x	x		x	0.16	87
Chaetoceros socialis				x	x	0.04	120
Chaetoceros subtilis	x	x				0.34	74
Choanoflagellatea	x	x	x	x	x	0.37	70
Chroococcales		x	x	x	x	0.26	77
Coelosphaerium minutissimum			x	x		0.05	113
Coscinodiscus					x	0.78	54
Coscinodiscus angustelineatus	x				x	0.05	112
Coscinodiscus commutatus	**x**				**x**	**21.51**	**8**

Coscinodiscus granii					**x**	**134.53**	**2**
Coscinodiscus radiatus	x			x	x	2.06	36
Cyanodictyon planctonicum		x	x	x		0.01	139
Cyanonephron styloides	x			x	x	0.01	144
Cyclotella	x	x			x	0.03	128
Cylindrotheca closterium	x	x		x	x	0.05	110
Cymbomonas tetramitiformis			x	x		0.64	62
Desmodesmus						0.00	172
Dicroerisma psilonereiella				x		0.00	161
Dinobryon balticum		x	x			0.14	92
Dinobryon balticum cf.		x				0.04	121
Dinobryon borgei		x	x	x		0.01	140
Dinobryon faculiferum		x	x	x		0.07	106
Dinophysis acuminata	x	x	x	x	x	4.78	23
Dinophysis acuta			x			0.35	72
Dinophysis norvegica	x	x	x	x	x	4.86	22
Dinophysis odiosa					x	0.02	136
Diplopsalis spp. CPX	x			x		0.16	88
Dissodinium pseudolunula					x	0.01	141
Ditylum brightwellii					x	0.27	76
Dolichospermum				x		0.01	142
Ebria tripartita	x	x	x	x	x	2.17	34
Ethmodiscus punctiger					x	0.06	109
Euglenida	x					0.01	150
Eutreptiella	x	x	x	x	x	1.28	43
Flagellates	x	x	x	x	x	0.77	55
Gonyaulax				x		0.10	99
Gymnodiniales	**x**	**x**	**x**	**x**	**x**	**29.47**	**7**
Gymnodinium			x	x		0.04	118
Gymnodinium cf.		x				1.95	37
Gymnodinium stellatum cf.				x		0.01	145
Gymnodinium verruculosum cf.	x				x	0.20	81
Gyrodinium				x		0.05	114
Gyrodinium flagellare	x	x	x	x	x	0.07	107
Gyrodinium spirale	x	x	x		x	3.04	29
Hemiselmis	x	x	x	x	x	0.73	58
Heterocapsa		x		x		0.03	125
Heterocapsa arctica subsp. frigida		x				0.02	133
Heterocapsa cf.				x		0.04	117
Heterocapsa rotundata	x	x	x	x	x	6.83	17
Heterosigma akashiwo cf.	x					2.30	33
Karlodinium veneficum cf.		x	x	x		0.13	94
Katablepharis					x	0.03	130
Katablepharis remigera	x	x	x	x	x	1.07	48
Katodinium glaucum	x	x	x	x	x	0.48	66
Kryptoperidinium triquetrum	x	x	x	x	x	0.36	71
Kryptoperidinium triquetrum cf.			x			0.00	163

Lemmermanniella parva	x			x		0.00	157
Lennoxia faveolata	x				x	0.01	148
Leptocylindrus danicus				x	x	0.09	100
Leptocylindrus minimus					x	0.03	127
Leucocryptos marina	x	x	x	x	x	1.05	49
Melosira arctica		x				0.15	89
Mesodinium rubrum	**x**	**x**	**x**	**x**	**x**	**119.98**	**3**
Micracanthodinium claytonii	x	x	x	x	x	0.09	102
Miraltia throndsenii	x	x		x		0.02	134
Monoraphidium contortum					x	0.00	164
Nitzschia longissima	x			x	x	0.18	84
Nitzschia paleacea				x		0.03	122
Nodularia spumigena				x	x	3.91	26
Oblea rotunda spp. CPX				x		0.03	123
Octactis speculum	x				x	0.12	95
Octactis speculum NK	x	x			x	0.66	59
Oocystis	x	x			x	0.00	153
Pauliella taeniata		x				0.06	108
Pennales	x	x	x	x		0.11	98
Peridiniales	x	x	x	x	x	1.80	38
Peridiniella catenata	x	x	x			11.45	11
Peridiniella danica	**x**	**x**	**x**			**11.60**	**10**
Peridiniella danica cf.				x		0.00	160
Phacus					x	0.20	82
Phalacroma rotundatum	x			x	x	0.04	119
Plagioselmis prolonga	x	x	x	x	x	3.75	27
Planktolyngbya		x		x		0.00	159
Polykrikos schwartzii					x	1.54	40
Porosira glacialis		x			x	0.09	101
Proboscia alata	x	x		x	x	1.15	46
Prorocentrum cordatum				x	x	0.63	63
Prorocentrum micans					x	1.03	50
Protoceratium reticulatum			x	x		0.05	111
Protoperidinium	x	x	x		x	1.23	44
Protoperidinium bipes	x	x		x	x	0.02	135
Protoperidinium brevipes			x			0.81	53
Protoperidinium depressum		x				1.31	41
Protoperidinium divergens					x	0.50	65
Protoperidinium pallidum	x				x	0.13	93
Protoperidinium pellucidum	x	x			x	0.77	56
Protoperidinium thorianum					x	0.07	105
Prymnesiales	**x**	**x**	**x**	**x**	**x**	**37.22**	**6**
Pseudanabaena cf.				x		0.02	131
Pseudanabaena limnetica	x	x		x	x	5.11	20
Pseudanabaena limnetica cf.				x		0.20	80
Pseudo-nitzschia	x	x			x	0.02	138
Pseudo-nitzschia delicatissima GRP	x				x	1.30	42

Pseudo-nitzschia seriata GRP					x	0.00	162
Pseudochattonella farcimen	x					0.03	126
Pseudopedinella	x	x	x	x	x	1.71	39
Pseudosolenia calcar-avis	**x**				**x**	**14.23**	**9**
Pterosperma		x	x	x		0.34	73
Pyramimonas	x	x	x	x	x	5.96	19
Pyxidicula compressa var. compressa				x		0.00	158
Rhizosolenia delicatula	x	x			x	0.89	51
Rhizosolenia flaccida	x	x		x	x	3.71	28
Rhizosolenia fragilissima f. fragilissima	**x**			**x**	**x**	**287.27**	**1**
Rhizosolenia minima		x		x		0.00	156
Rhizosolenia setigera	x	x			x	8.87	13
Rhizosolenia setigera f. pungens	x			x	x	1.22	45
Romeria				x		0.03	124
Scrippsiella GPR				x	x	0.32	75
Scrippsiella GPR cf.				x		0.01	149
Skeletonema marinoi	**x**	**x**	**x**	**x**	**x**	**62.57**	**4**
Snowella	x	x	x	x	x	0.39	69
Snowella septentrionalis	x	x				0.01	151
Spatulodinium pseudonoctiluca					x	1.14	47
Synedra nitzschioides f. nitzschioides		x	x	x		0.07	104
Teleaulax	x	x	x	x	x	7.61	15
Telonema	x	x	x	x	x	2.49	31
Thalassiosira	x	x			x	4.33	25
Thalassiosira baltica		x	x			2.31	32
Thalassiosira gravida	x				x	0.65	60
Tripos fusus					x	0.64	61
Tripos lineatus	x	x			x	5.05	21
Tripos longipes					x	0.03	129
Tripos muelleri	x	x		x	x	9.65	12
Unicell spp.	x	x	x	x	x	8.54	14
Woronichinia	x	x			x	0.05	115

Appendix 2: Seasonal occurrence of taxa found in the investigation area in 2021 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	o	
Polychaeta Grube, 1850	Subphylum	883	o	o	o	o	o
Harmothoe spp. Kinberg, 1856	Genus	129491		o			
Arthropoda - Crustacea							
Copepoda							
Acartia Dana, 1846	Genus	104108	o	o	o	o	o
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	o	o	o
Centropages Krøyer, 1849	Genus	104159	o	o	o	o	o
Centropages hamatus Lilljeborg, 1853	Species	104496	o	o	o	o	o
Centropages typicus Krøyer, 1849	Species	104499		o			o
Cyclopoida Burmeister, 1834	Order	1101		o		o	
Eurytemora Giesbrecht, 1881	Genus	104240	o			o	o
Eurytemora affinis Poppe, 1880	Species	104872		o	o	o	o
Euterpina acutifrons Dana, 1847	Species	116162	o	o	o	o	
Harpacticoida G. O. Sars, 1903	Order	1102	o				o
Microsetella spp. Brady & Robertson, 1873	Genus	115341		o	o	o	o
Oithona Baird, 1843	Genus	106485	o	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 Baird, 1850	Genus	104241	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	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		
Pleopis polyphemoides (Leuckart,1859)	Species	247981				o	
Penilia avirostris Dana, 1849	Species	106272				o	o

	Rang	TSN	Feb	März	Mai	Aug	Nov
other Crustacea							
Balanus spp. Costa, 1778	Genus	106122	o	o	o	o	o
Liocarcinus Stimpson, 1871	Genus	106925				o	
Palaemon serratus (Pennant, 1777)	Species	107616				o	
Bryozoa							
Gymnolaemata Allman, 1856	Class	1795	o	o	o	o	o
Chaetognatha							
Sagittidae Claus and Grobben, 1905	Family	5953	o				
Chordata							
Fritellaria borealis Lohmann, 1896	Species	103375	o	o	o		o
Oikopleura dioica Fol 1872	Species	103407	o			o	o
Teleostei	Infraclass	293496	o	o	o	o	
Echinodermata							
Asterias spp. Linnaeus, 1758	Genus	123219				o	
Cnidaria & Ctenophora							
Antothecata Cornelius, 1992	Order	13551					o
Ctenophora Eschscholtz, 1829	Phylum	1248	o	o	o		
Leptothecata Cornelius, 1992	Order	13552				o	o
Sarsia tubulosa M. Sars, 1835	Species	565161			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				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	o	o	o	o	o
Keratella cruciformis Thompson, 1892	Species	134991				o	
Keratella cochlearis(Gosse, 1851)	Species	134990	o				
Keratella quadrata O. F. Muller, 1786	Species	134992				o	o

*Appendix 3: Distribution of macrozoobenthos at 8 stations in November 2021. 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). Neozoan species are indicated in yellow.*

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Amphipoda									
Corophium volutator							1	1	*
Crassicorophium crassicorne					1				*
Gammarus oceanicus					1				*
Gammarus salinus					1		1	1	*
Gammarus zaddachi							1		*
Melita palmata					1			1	V
Microdeutopus gryllotalpa								1	*
Anthozoa									
Actinia equina		1							D
Cylista sp.		1							ne
Halcampa duodecimcirrata						1			1
Metridium senile		1							G
Ascidiacea									
Dendrodoa grossularia	1	1							V
Molgula manhattensis	1								D
Bivalvia									
Abra alba	1	1							*
Arctica islandica	1	1	1	1		1			3
Astarte borealis	1		1	1	1				G
Astarte elliptica	1					1			G
Astarte montagui	1								3
Cerastoderma glaucum					1			1	*
Hiatella arctica	1								*
Kurtiella bidentata	1	1	1	1					*
Macoma balthica	1			1	1	1	1	1	*
Musculus subpictus	1								G
Mya arenaria	1				1		1	1	*
Mytilus edulis	1	1	1	1	1	1	1	1	*
Nucula nitidosa			1						*
Parvicardium pinnulatum	1								D
Phaxas pellucidus	1	1							*
Varicorbula gibba	1	1	1	1			1		*
Bryozoa									
Alcyonidium polyoum	1				1		1		D
Callopora lineata	1	1	1	1	1				*
Cribrilina punctata	1	1							*
Einhornia crustulenta	1		1		1	1	1	1	*
Electra pilosa				1					*
Escharella immersa	1	1							*
Eucratea loricata	1	1	1	1	1				V
Farrella repens	1	1							D
Flustra foliacea	1				1				*
Walkeria uva	1								*
Cirripedia									
Amphibalanus improvisus				1	1			1	ne
Balanus crenatus		1			1		1		*

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Cumacea									
Diastylis rathkei	1	1	1	1	1	1	1		*
Decapoda									
Carcinus maenas				1	1				*
Crangon crangon		1		1	1	1	1	1	*
Palaemon adspersus					1				V
Palaemon elegans								1	*
Palaemon varians					1				V
Rhithropanopeus harrisii								1	ne
Echinodermata									
Asterias rubens	1	1		1	1				*
Ophiura albida	1	1	1						*
Psammechinus miliaris	1								*
Gastropoda									
Brachystomia scalaris					1				*
Facelina bostoniensis		1							*
Hermania scabra	1								R
Onoba semicostata	1								*
Peringia ulvae	1	1	1	1	1	1	1	1	*
Philine aperta	1								*
Pusillina inconspicua					1				*
Retusa obtusa		1							*
Retusa truncatula	1				1				*
Tritia reticulata				1					G
Hydrozoa									
Dynamena pumila		1		1					D
Halitholus yoldiaearcticae		1					1		3
Hartlaubella gelatinosa	1	1			1	1	1	1	D
Hydractinia echinata				1					*
Sertularia cupressina		1							G
Isopoda									
Cyathura carinata								1	D
Jaera albifrons					1		1		*
Mysida									
Neomysis integer						1	1	1	ne
Praunus flexuosus								1	ne
Nemertea									
Lineus ruber	1				1				ne
Malacobdella grossa			1						ne
Nemertea	1	1			1				ne
Tubulanus polymorphus	1								ne
Oligochaeta									
Enchytraeidae							1	1	ne
Tubificinae		1		1	1		1	1	ne
Tubificoides benedii	1				1	1	1	1	*
Phoronida									
Phoronis sp.	1	1		1					ne
Platyhelminthes									
Platyhelminthes					1			1	ne
Polychaeta									
Alitta succinea		1	1	1			1	1	D
Ampharete acutifrons	1		1			1			*

Taxa	**N3**	**N1**	**M2**	**018**	**K8**	**K4**	**K3**	**160**	**RL**
Ampharete baltica	1	1		1	1	1	1		*
Aricidea suecica	1	1			1				*
Bylgides sarsi	1	1		1	1	1	1		*
Capitella capitata	1				1		1		*
Chaetozone setosa		1							*
Dipolydora quadrilobata	1			1		1			*
Fabricia stellaris					1		1		D
Fabriciola baltica	1				1		1		G
Harmothoe imbricata	1	1		1	1				D
Harmothoe impar				1					*
Hediste diversicolor	1							1	*
Heteromastus filiformis	1		1						*
Lagis koreni	1	1	1	1					*
Levinsenia gracilis	1		1						*
Marenzelleria neglecta								1	ne
Marenzelleria viridis							1	1	ne
Myrianida sp.							1		ne
Neoamphitrite figulus	1								*
Nephtys caeca	1								*
Nephtys ciliata		1							*
Nephtys hombergii	1	1	1	1		1			*
Nereimyra punctata	1	1							G
Paradoneis eliasoni	1	1	1						*
Pherusa plumosa	1								D
Pholoe assimilis	1								D
Phyllodoce mucosa	1	1			1				*
Polycirrus medusa	1	1							D
Polydora ciliata	1				1				*
Polydora cornuta	1				1				*
Prionospio steenstrupi		1							*
Pygospio elegans	1			1	1		1	1	*
Scalibregma inflatum		1							G
Scoloplos armiger	1	1		1	1	1	1		*
Sphaerodoropsis baltica							1		D
Spio goniocephala					1				*
Terebellides stroemii	1	1				1			*
Tharyx killariensis		1							D
Travisia forbesii					1		1		G
Trochochaeta multisetosa		1	1			1			D
Porifera									
Halichondria panicea		1							G
Haliclona oculata	1								D
Priapulida									
Halicryptus spinulosus			1				1		ne
Pycnogonida									
Nymphon brevirostre		1							*
species number 124	**67**	**51**	**22**	**30**	**47**	**20**	**33**	**27**	
abundance (ind m^{-2})	**2225**	**1352**	**254**	**1795**	**7687**	**345**	**2320**	**6924**	
biomass (afdw g m^{-2})	**32.0**	**18.4**	**31.0**	**22.9**	**7.5**	**0.8**	**3.8**	**9.5**	

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CONTENT

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