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Biological assessment of the Baltic Sea 2022

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Kurzfassung

2022 wurden auf den 5 Monitoring-Fahrten 146 **Phytoplankton**arten erfasst. Die durchschnittliche Jahresbiomasse im Untersuchungsgebiet der südlichen und zentralen Ostsee betrug in diesem Jahr $1015 \mu\text{g l}^{-1}$ und lag damit etwas über dem 20-Jahresmittel. In 2022 begann die Phytoplankton-Frühjahrsblüte Anfang Februar in der südlichen Ostsee und entwickelte sich sukzessive rasch Richtung Norden. Die auf den 3 Frühjahrsfahrten gemessenen Chl a Konzentrationen lagen etwa zwischen ~ 1 und $\sim 10 \mu\text{g l}^{-1}$ Chl a , wobei die auf der Februar- bzw. Mai Fahrt gemessenen Werte deutlich niedriger waren als im März. Generell wichen die auf allen 3 Frühjahrsfahrten erfassten Chl a -Dynamiken stark von den Biomassemustern ab, was sich mit einer für diese Jahreszeit untypischen Unterrepräsentation von Diatomeen erklären lässt. In der Frühjahrsblüte 2022 bestimmten mixotrophe Taxa mit prominenten akzessorischen Pigmenten wie Dinoflagellaten, bzw. mixotrophe Ciliaten, insbesondere *Mesodinium rubrum*, die Frühjahrsgemeinschaften der zentralen Ostsee. Die Phytoplankton Biomassekonzentrationen lagen im Frühling 2022 zwischen $150 \mu\text{g l}^{-1}$ im Süden und $\sim 3000 \mu\text{g l}^{-1}$ in der zentralen Ostsee und spiegelten die hier im Frühling typische, räumlich sukzessive Biomasseentwicklung der Frühjahrsblüte wider. Im Sommer 2022 war die Biomassezusammensetzung des Phytoplanktons, wie schon im Vorjahr, fast ausschließlich von Diatomeen, insbesondere *Dactyosolen fragilissimus* bestimmt, welche fast 90 % der Gesamt-Phytoplanktonbiomasse in der südlichen Ostsee (Belt- und Arkona See) zu dieser Jahreszeit ausmachte. Im August 2022 wurden Phytoplankton-Gesamtbiomassen von bis zu $7000 \mu\text{g l}^{-1}$ gemessen. Wobei die Biomassen in den zentralen Becken generell wesentlich niedriger blieben als in den von Diatomeen dominierten südlichen Seegebieten. Hier waren auch typische Cyanobakteriengemeinschaften vertreten, die jedoch nur 5 - 10 % der von Diatomeen produzierten Biomassen im Süden erreichten. Im November hatte sich in den zentralen Becken eine gemischte Diatomeen-Dinoflagellaten Gemeinschaft etabliert. Im Frühling 2022 kam es in der Kieler Bucht zu einer Blüte der potentiell toxischen Diatomee *Pseudo-nitzschia*, die jedoch keine Probleme verursachte. Im Jahr 2022 war in der südlichen Ostsee der Diatomeenanteil an der Frühjahrsblüte relativ hoch, verursacht vom hohen Biomasseanteil von *Skeletonema marinoi*. Die Cyanobakterien-Biomassekonzentrationen und auch die jährliche Phytoplankton-Gesamtbiomasse bewegten sich innerhalb der jährlichen Variationsbreite des 20-Jahresmittels.

Im Jahr 2022 wurden 54 **Zooplankton**proben an 39 Stationen in der Kieler Bucht, der Mecklenburger Bucht und der Arkonasee genommen. Aufgrund schlechter Witterungsbedingungen fielen auf der Rückfahrt zwei Stationen aus, und der saisonale Zyklus des Zooplanktons ist deshalb in der Kieler Bucht unvollständig. Dies hat jedoch keine größeren Auswirkungen auf die Analyse der biologischen Vielfalt und der saisonalen Dynamik in den anderen Gebieten. Das Arteninventar wurde von euryhalinen und Brackwasserarten dominiert. Dennoch wurden auch echte marine Arten beobachtet, vor allem in der Beltsee. Dazu gehören die Cladocera-Art *Penilia avirostris*, die in großer Zahl vorkam, aber auch seltenere Arten, wie der calanoide Copepode *Calanus helgolandicus* oder die Cladocera-Art *Pleopis polyphemoides*. Im Gegensatz zu 2021 wurden auch regelmäßig Larven verschiedener mariner benthischer Taxa beobachtet. Abgesehen von *Acartia tonsa* wurden keine weiteren nicht-einheimischen Arten gefunden. Insgesamt wurden in den Proben 50 Taxa identifiziert. Die Artenzahl zeigte die üblichen jahreszeitlichen Schwankungen mit einem Maximum im Winter/Frühjahr und Herbst.

Die kurzfristige saisonale und die langfristige Dynamik in dem Gebiet war durch eine ungewöhnliche Zooplanktonzusammensetzung gekennzeichnet. Während die Rotifera und die Cladocera normalerweise durch ihre ausgeprägten Maxima im Frühjahr bzw. Herbst dominieren, lagen ihre Bestände deutlich unter den üblichen Werten und trugen nur zu 5 - 11 % zum Bestand bei. Die Copepoden dominierten die Gemeinschaft mit 59 %, gefolgt von den Copelata mit 12 %. Aufgrund der geringen Abundanz der Rotifera und Cladocera war der Bestand an Zooplankton in der Arkonasee, wo diese beiden Gruppen normalerweise sehr häufig vorkommen, gering. Daher fehlte im Jahr 2022 der typische Anstieg der Zooplanktonabundanz von der Kieler Bucht zur Arkonasee sowie das spätsommerliche Maximum des Zooplanktons in der Arkonasee. Innerhalb der Gruppe der Copepoda wurde in der Beltsee eine deutliche Verschiebung von der Dominanz der verschiedenen *Acartia*-Arten zu *Pseudocalanus* spp. beobachtet, während die Zusammensetzung in der Arkonasee wie üblich war. Das Fehlen größerer Anteile an Rotifera und Cladocera hat weitere Folgen für die langfristige Abundanz ihres Bestandes. 2022 war das 11. Jahr in Folge, in dem der Zooplanktonbestand unter dem langfristigen Durchschnitt lag. Der Bestand von $0,6 \times 10^5$ Ind. m^{-3} war der zweitniedrigste Wert nach dem Allzeitminimum von 2020 und erreichte nur 22 % des langjährigen Mittels. Alle wichtigen Zooplanktongruppen verzeichneten einen Rückgang um 38 - 95 %, mit Ausnahme der Copeleata, die um 60 % zunahm. Bei den Copepoda verringerten sich die Bestandsgrößen der meisten Taxa um 39 - 75 %, während *Pseudocalanus* spp. einen Anstieg um 208 % verzeichnete. Die Zusammensetzung des Zooplanktons und die jahreszeitliche Dynamik in der Beltsee (Kieler Bucht und Mecklenburger Bucht) waren homogen, ohne die in manchen Jahren auftretende, große räumliche Variabilität. Die jahreszeitlichen Schwankungen waren 2022 ausgeprägt, und der Saisonbeginn war früh, da die Bestände bereits im März erheblich zunahm. Copepoda dominierten die Gemeinschaft in der ersten Jahreshälfte zusammen mit dem Meroplankton, das beim Übergang vom Winter zum Frühjahr Spitzenkonzentrationen aufwies. Ihr Rückgang im Sommer war moderat, und es wurde eine ungewöhnlich hohe Dichte von *Oikopleura dioica* (Copelata) beobachtet. Im Gegensatz dazu wiesen das Meroplankton und insbesondere die Muschellarven eine geringe Bestandsgröße auf. Die Copepoda wurden im Winter/Frühjahr von ungewöhnlich hohen Konzentrationen von *Pseudocalanus* dominiert, während die Abundanz von *Acartia* ungewöhnlich gering war. Im Gegensatz zur Beltsee verlief die jahreszeitliche Entwicklung und Zusammensetzung des Zooplanktons in der Arkonasee wie üblich - mit Ausnahme des Fehlens hoher Dichten der Cladocere *Bosmina* im Sommer, wodurch sich das jährliche Zooplanktonmaximum ins Frühjahr verschob. Die Winter-Frühjahrszunahme wurde von Copepoden und Rotifera dominiert. Im Sommer wurde die Dominanz der Copepoda durch ansteigende Anteile von Meroplankton und Cladocera ersetzt. Die Copepoda zeigten die typische ausgewogene Zusammensetzung der Gemeinschaft mit mehr oder weniger ähnlichen Bestandsgrößen der wichtigsten Gattungen.

Im Herbst 2022 waren die Witterungsbedingungen in der südwestlichen Ostsee so ungünstig, dass die Beprobung des **Makrozoobenthos** an den Stationen in der Kieler und Mecklenburger Bucht sowie im Fehmarnbelt ausfallen musste. Daher steht nur ein begrenzter Datensatz zum Vergleich mit den Vorjahren zur Verfügung. Für die Station in der Kieler Bucht (N₃) konnten wir die Zeitreihe mit Probenmaterial von Kollegen des Landesamtes für Umwelt Schleswig-Holstein aufrechterhalten. Für die beiden Stationen N₁ (Fehmarnbelt) und M₂ (Mecklenburger Bucht) war

dies leider nicht möglich. Die 106 Arten, die im Jahr 2022 im Makrozoobenthos gefunden wurden, stellen eine mittlere Vielfalt dar, wenn man bedenkt, dass zwei Stationen weniger ausgewertet werden konnten. Die Anzahl der Arten, die an den sechs Messstationen gefunden wurden, schwankte zwischen 19 und 52. In allen Regionen war das Sauerstoffangebot im Bodenwasser im laufenden Jahr meist höher als 2 ml l^{-1} . Die einzigen Ausnahmen waren im August, als wir $1,7 \text{ ml l}^{-1} \text{ O}_2$ in der Kieler Bucht und $0,9 \text{ ml l}^{-1} \text{ O}_2$ im Arkonabecken gemessen haben. In der Kieler Bucht fanden wir im Vergleich zu den Vorjahren eine deutlich geringere Artenzahl, was aber wohl auch daran liegt, dass wir die Beprobung nicht selbst durchgeführt haben und z.B. keine Dredge genommen wurde. In der südlichen Mecklenburger Bucht und auch in der Pommerschen Bucht war die Vielfalt etwas geringer als im langjährigen Durchschnitt. Je nach Region reichten die Abundanzen von 518 bis 6530 Ind. m^{-2} und die Biomasse (aschefreies Trockengewicht) von $1,1 \text{ g m}^{-2}$ bis $53,8 \text{ g m}^{-2}$. Am Beispiel der Station K8 (Darßer Schwelle) führten wir eine Langzeitanalyse der letzten 4 Jahrzehnte durch. Dargestellt wird die langfristige Entwicklung von Artenzahl, Abundanz und Biomasse. Anhand ausgewählter Muschelarten (*Astarte borealis*, *Macoma balthica* und *Mya arenaria*) wird exemplarisch gezeigt, welche Veränderungen stattgefunden haben und welchen Einfluss sie auf das Ökosystem haben können. An den sechs Messstationen wurden insgesamt zehn Arten der Roten Liste Deutschlands (Kategorien 1, 2, 3 und G) beobachtet. Mit sieben war die Zahl der invasiven benthischen Arten im Jahr 2022 erwartungsgemäß gering. Sie waren alle bereits aus den Vorjahren bekannt. *Mya arenaria* und *Amphibalanus improvisus* sind seit mehr als hundert Jahren in der südlichen Ostsee häufig anzutreffen. Seit 2016 ist der Amphipode *Grandidierella japonica* aus der südlichen Ostsee bekannt und wurde auch während der vorliegenden Studie in der Kieler Bucht beobachtet. Die beiden Polychaeten *Alitta succinea* und *Marenzelleria viridis* wurden in den letzten Jahren regelmäßig bei Probenahmen gefunden. Die kryptische neozoische Dekapodenart *Palaemon elegans* ist seit Jahrzehnten etabliert und wurde in der nördlichen Pommerschen Bucht gefunden. Ein weiterer kryptischer Neozoe ist der Polychaet *Aphelochaeta marioni*, der in der Kieler Bucht (N3) beobachtet wurde.

Abstract

In 2022 a total of 146 **phytoplankton** species were recorded on 5 annual monitoring cruises. Mean annual biomass of phytoplankton in the study area was, at $1015 \mu\text{g l}^{-1}$, 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. As in previous years, also in spring 2022, *Chla* concentrations ranged from ~ 1 to $\sim 10 \mu\text{g l}^{-1}$. Highest spring concentrations were measured in March. *Chla* generally reflected phytoplankton biomass poorly, due to high representation of non-diatom and mixotroph taxa such as dinoflagellates and *Mesodinium rubrum* in all phases of the spring bloom. Phytoplankton biomass ranged from $150 \mu\text{g l}^{-1}$ in the south to $\sim 3000 \mu\text{g l}^{-1}$ in the north, reflecting the typical latitudinal progression of the spring bloom in the Baltic Sea. As during the previous year, the summer phytoplankton composition and production was largely shaped by diatoms in the southern Baltic, which is unusual in the open sea areas, but seems to establish a recurrent pattern. *Dactyosolen fragilissimus* constituted nearly 90 % of the biomass in the Belt Sea and Arkona Basin in July. Total phytoplankton biomass of $7000 \mu\text{g l}^{-1}$ was measured here during the August cruise. Like in previous years, this was contrasted by cyanobacteria dominated communities in the central Baltic, which, however, only amounted to 5 – 10 % of the biomass produced by the diatoms in the south. In November, a mixed diatom/dinoflagellate community had established in the southern basins by the time of TF1122.

In 2022 harmful *Nodularia spumigena* and specifically *Aphanizomenon* reached high biomass concentrations in Arkona, Bornholm and Gotland Basins, as typical for the summer season. A bloom of potentially toxic *Pseudo-nitzschia* spp. occurred in spring in Kiel Bight, though without causing major harm. In 2022, the diatom to dinoflagellate ratio had increased, probably due to the high Biomass shares of *Skeletonema marinoi* observed in spring. Cyanobacteria biomass was in the same range of inter-annual variation as previously. The 2022 annual phytoplankton biomass level was slightly higher than the 20- year mean of $800 \mu\text{g l}^{-1}$, as was the diatom to dinoflagellate ratio, reflecting the diatom dominance of summer and autumn communities.

In 2022, 54 **zooplankton** samples were taken on 39 stations in the Kiel Bight, the Bay of Mecklenburg and the Arkona Basin. Due to bad weather conditions, two stations were cancelled on the return journey and the seasonal cycle of zooplankton is incomplete in the Kiel Bight, but no major implications for the analysis of the biodiversity and seasonal dynamics exist in the other areas. The species inventory was dominated euryhaline and brackish species. Nevertheless, true marine species were observed, primarily in the Belt Sea. These include the cladoceran *Penilia avirostris* that occurred in high numbers but also species which were generally rare such as calanoid copepod *Calanus helgolandicus* or the cladoceran *Pleopis polyphemoides*. In contrast to 2021, larvae of various benthic taxa with a marine affinity were also regularly observed. Apart from *A. tonsa*, no other non-indigenous species were found. In total, 50 taxa were identified in the samples. The species number showed the usual seasonal variation with a maximum in winter-spring and autumn. The short-term seasonal and the long-term dynamics in the area was characterized by an unusual zooplankton composition. While the Rotifera and the Cladocera are usually dominating by their pronounced maxima in spring and autumn, respectively, their stocks were considerably below the usual values and contributed only 5-11% to the stock. Copepods were largely dominating the community by 59% followed by

Copelata with 12%. Due to low abundance of rotifers and cladocera, the stock of zooplankton was low in the Arkona Basin where the two groups are usually very abundant. Therefore, the typical increase in zooplankton abundance from the Kiel Bight to the Arkona Basin was lacking in 2022, as well as the late summer maximum of the zooplankton in the Arkona Basin. Among the group of copepods, a major shift from the dominance of the diverse *Acartia* species to *Pseudocalanus* spp. was observed in the Belt Sea, while the composition in the Arkona Basin was as usual. The lack of major contributions of rotifers and cladocerans had further consequences for the long-term abundance of the stock. 2022 was the 11th year in row with zooplankton stock below the long-term average. The stock of 0.6×10^5 ind. m^{-3} was the second lowest value after the all-time minimum observed in 2020 and achieved only 22% of the long-term mean. All major zooplankton groups showed a decline by 38-95% except the Copelata that increased by 60%. Within the copepods, stocks sizes of most taxa were reduced by 39-75%, while *Pseudocalanus* spp. showed an increase by 208%. The zooplankton composition and seasonal dynamics in the Belt Sea (Kiel Bight and Bay of Mecklenburg) was homogenous without the large spatial variability that occurs in some years. The seasonal variation was pronounced in 2022 and the start of the season was early since stocks increased already considerably in March. Copepods dominated the community during the first half of the year together with the meroplankton that show peak concentrations in the winter-spring transition. Their decline in summer was moderate, and an unusual high density of *Oikopleura dioica* (Copelata) was observed. In contrast, meroplankton and especially the bivalve larvae showed a low stock size. The copepods were dominated by unusual high concentrations of *Pseudocalanus* in winter-spring, while the abundance of *Acartia* was unusually low. In contrast to the Belt Sea, the seasonal development and composition of zooplankton in the Arkona Basin was as usual except the lack of high densities of the cladoceran *Bosmina* in summer that shifted the annual zooplankton maximum into spring. The winter-spring increase was dominated by copepods and rotifers. During summer, the dominance of the copepods was replaced by increasing proportions of meroplankton and cladocera. The copepods showed the typical balanced composition of the community with more or less similar stock sizes of the major genera.

In the autumn of 2022, the weather conditions in the southwestern Baltic Sea were so harsh that sampling of **macrozoobenthos** the stations in the Kiel and Mecklenburg Bays and Fehmarn Belt had to be cancelled. Thus, only a limited data set is available for comparison with previous years. For the station in the Kiel Bight (N3), we were able to maintain the time series with sampling material from colleagues at the SH State Office for the Environment. Unfortunately, this was not possible for the two stations N1 (Fehmarnbelt) and M2 (Mecklenburg Bay). The 106 species found in the macrozoobenthos in 2022 represent a medium diversity, remembering that two stations less could be evaluated. The species number found at the six monitoring stations ranged between 19 and 52. In all regions, the oxygen supply in bottom waters in the current year was mostly higher than 2 ml l^{-1} . The only exceptions were in August, when we measured 1.7 ml l^{-1} in Kiel Bight and 0.9 ml l^{-1} in Arkona Basin. In the Kiel Bight we found a significantly lower number of species compared to previous years, but this is probably also due to the fact that we did not carry out the sampling ourselves and, for example, no dredge was taken. In the southern Mecklenburg Bay and also in the Pomeranian Bay, the diversity was somewhat lower than the long-term average. Depending on the region, the abundances ranged from 518 to 6530 ind. m^{-2} ,

and the biomass (ash free dry weight) from 1.1 g m⁻² to 53.8 g m⁻². Using the example station K8 (Darss Sill), a long-term analysis of the last 4 decades is carried out. The long-term development of the number of species, abundance and biomass is presented. Selected mussel species (*Astarte borealis*, *Macoma balthica* and *Mya arenaria*) are used to show which exemplary changes have taken place and what influence they can have on the ecosystem. A total of ten species from Germany's Red List (categories 1, 2, 3 and G) were observed at the six monitoring stations. With seven, the number of benthic invasive species in 2022 was low, as expected. They were all already known from previous years. *Mya arenaria* and *Amphibalanus improvisus* have been common faunal elements in the southern Baltic Sea for more than a hundred years. Since 2016, the amphipod *Grandidierella japonica* is known from the southern Baltic Sea and was also observed in Kiel Bight during the present study. The two polychaetes *Alitta succinea* and *Marenzelleria viridis* were regularly found during sampling in recent years. Finally, the cryptic neozoan decapod species *Palaemon elegans* has been established for decades and was found in northern Pomeranian Bay. Another cryptic neozoan is the polychaete *Aphelochaeta marioni*, which was observed in the Kiel Bight (N3).

1 Introduction

This report presents the results of the biological monitoring conducted 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 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 2022 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 growth season and were conducted in February (EMB286: 07.02. - 17.02.2022), March (EMB290: 23.03. - 04.04.2022), May (EMB293: 03.05. - 21.05.2022), August (EMB298: 04.08. - 15.08.2022) and November (EMB305: 05.11. - 18.11.2022).

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/J1 (eastern Gotland Basin) are taken on the outward leg only.

Phytoplankton sampling was performed at 9 stations, 5 of them being located in the German Exclusive Economic Zone (EEZ), the other 4 stations in Danish, Swedish, Polish and Latvian territorial waters (Table 1). All stations were sampled according to the plan in 2022.

Zooplankton sampling was performed at five 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 station N3 in Kiel Bight and during the return journey on station M2 in the Bay of Mecklenburg in November 2022, respectively.

Samples of the macrozoobenthos are usually taken once a year at eight stations. In 2022, the samples were taken in November (see Table 1 and Table 3). In autumn 2022, the weather conditions in the south-western Baltic Sea were so harsh that sampling of the stations in the Kiel (N3) and Mecklenburg Bays (M2) and Fehmarn Belt (N1) had to be cancelled. Thus, only a limited data set is available for comparison with previous years. For the station in the Kiel Bight, we were able to maintain the time series with sampling material from colleagues at the State Office for the Environment of Schleswig-Holstein. Unfortunately, this was not possible for the two stations N1 and M2.

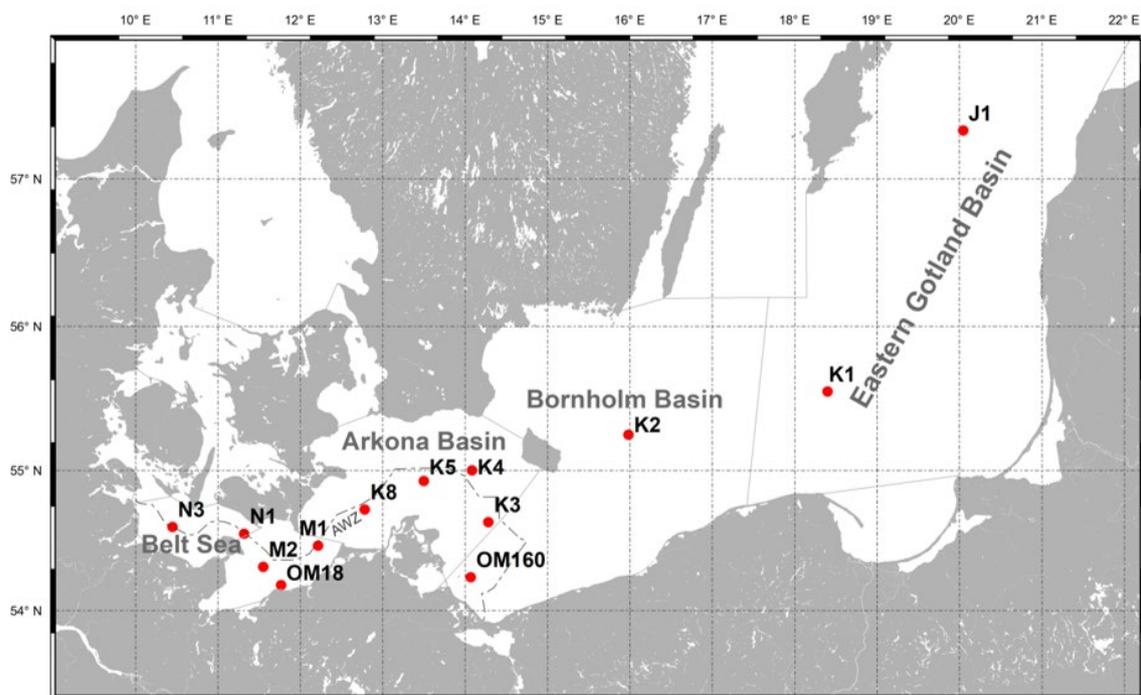


Fig. 1: Station grid for biological sampling in the Baltic Sea with depiction of the border of the Exclusive Economic Zone Germany (AWZ) and the borders between the main HELCOM basins.

Table 1: Sampling statistics (number of sampling events) for the different parameters specified for regular monitoring stations in 2022 (Chl = Chlorophyll a, PP = Phytoplankton, ZP = Zooplankton; B = Benthos). Due to bad weather in November, no sampling of benthos was possible at stations N1, N3 and M2, and partially no sampling of zooplankton at N3, M2. 1* = We received the benthos samples taken by the State Office for the Environment of Schleswig-Holstein.

Station number	IOW-station number	Latitude	Longitude	Sea area	Chl	PP	ZP	B
Belt Sea								
N3	TF0360	54°36,0'N	10°27,0'E	Kiel Bay	5	5	4	1*
N1	TF0010	54°33,1'N	11°19,2'E	Fehmarnbelt	-	-	-	1
M2	TF0012	54°18,9'N	11°33,0'E	Bay of Mecklenburg	10	10	9	-
OM18	TF0018	54°11,0'N	11°46,0'E	Bay of Mecklenburg	-	-	-	1
M1	TF0046	54°28,0'N	12°13,0'E	Bay of Mecklenburg	10	10	10	-
Arkona Basin								
K8	TF0030	54°43,4'N	12°47,0'E	Arkona Basin, west	2	2	-	1
K5	TF0113	54°55,5'N	13°30,0'E	Arkona Basin, central	10	10	10	-
K4	TF0109	55°00,0'N	14°05,0'E	Arkona Basin, east	5	5	5	1
Pomeranian Bay								
K3	TF0152	54°38,0'N	14°17,0'E	Pomeranian Bay	-	-	-	-
OM160	TF0160	54°14,4'N	14°04,1'E	Pomeranian Bay	-	-	-	-
Bornholm Basin								
K2	TF0213	55°15,0'N	15°59,0'E	Bornholm Basin	10	10	-	-
Gotland Basin								
K1	TF0259	55°33,0' N	18°24,0' E	Eastern Gotland Basin	5	5	-	-
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 chlorophyll *a* is used directly as parameter describing phytoplankton bulk biomass or production.

Samples for the determination of chlorophyll *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) based on PEG_BVOL2022, which was confirmed by HELCOM's Phytoplankton Expert Group PEG during the meeting in April 2022.

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. The net was equipped with an operating/closing mechanism released by a drop messenger and a T.S.K Flowmeter (Tsurumi-Seiko Co. Ltd., Yokohama, Japan) for the measurement of the filtrated water. The net was operated with a hauling speed of 0.5 m/s. In the case of a well-mixed water column, a single net catch was conducted from a two 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 cod end of the net. The samples were preserved in Borax-buffered, 4% aqueous formaldehyde solution and stored at cool/dark conditions until processing in the laboratory. In total, 54 zooplankton samples were collected at 39 stations. Table 2 provides the details about the timing and specific depth layers that were sampled over the season at the respective monitoring stations.

Table 2: Sample statistics of zooplankton hauls on monitoring cruises between January and November 2022.

	TF-02-2022 EMB286 07.02. - 17.02. Depth (m)	TF-03-2022 EMB290 23.03. - 04.04. Depth (m)	TF-05-2022 EMB293 03.05. - 21.05. Depth (m)	TF-08-2022 EMB298 04.08. - 15.08. Depth (m)	TF-11-2022 EMB305 05.11. - 18.11. Depth (m)
Station	from – to				
N3	15 – 0	15 – 0	15 – 0	15 – 0	–
M2	21 – 0	21 – 0	21 – 9 – 0	22 – 0	22 – 15 – 0
	21 – 0	21 – 0	21 – 0	22 – 9 – 0	–
M1	26 – 0	25 – 13 – 0	26 – 10 – 0	26 – 06 – 0	22 – 0
	25 – 0	26 – 12 – 0	26 – 0	22 – 0	22 – 12 – 0
K5	43 – 25 – 0	43 – 0	46 – 34 – 0	44 – 0	44 – 23 – 0
	44 – 0	45 – 0	45 – 19 – 0	41 – 0	41 – 26 – 0
K4	45 – 27 – 0	43 – 28 – 0	46 – 33 – 0	45 – 0	45 – 32 – 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 2023). 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 2023), marine Bryozoa were listed as Gymnolaemata. The databases of the information system on Aquatic Non-Indigenous Species (AquaNIS 2023) and of the European Network on Invasive Species (NOBANIS 2023) served as references for the classification of invasive species.

2.5 Macrozoobenthos

Due to bad weather in November 2022, benthos investigations were undertaken at only five stations from the Mecklenburg Bay to the Pomeranian Bay (Table 3 and Fig. 1). One type of Van Veen grab samplers was deployed (about 1000 cm², weighing 70 kg). Three hauls were taken at each station. For the station in the Kiel Bight, we (N₃) were able to maintain the time series with sampling material (same type of van Veen grab used) from colleagues at the State Office for the Environment of Schleswig-Holstein. 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 the five stations sampled by the IOW, a “Kieler Kinderwagen” botanical dredge with a 1 m rectangular mouth and a mesh size of 5 mm was deployed. Especially in relation to vagile and rarer species, the dredge yielded finds that would be missed with the grab alone.

Further processing of samples, incl. those of Schleswig-Holstein, 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 (expressed as ash free dry weight, afdw, throughout the whole report) were also recorded. 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 2022. *=this station was not sampled during our campaign, we got the samples taken by SH State Office for the Environment*

HELCOM-ID	IOW-ID	Date	depth	north	east	sea area
N ₃ *	360	03.11.2022	18	54° 36.00	10° 27.00	Kiel Bight
OM18	018	16.11.2022	20.5	54° 11.00	11° 46.00	Mecklenburg Bay, south
K8	030	15.11.2022	20.0	54° 44.00	12° 47.40	Darss Sill
K4	109	15.11.2022	47.0	55° 00.00	14° 05.00	Arkona Basin
K3	152	14.11.2022	30.0	54° 38.00	14° 17.00	Pomeranian Bay, north
OM160	160	14.11.2022	13.6	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 was taken twice and analysed separately to test parallel deviations. The results were entered into the range control chart. The fluorometer was 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 2022.1 and 2022.2 were passed with good results.

Phytoplankton

From every tenth sample, two abundant species were counted a second time, and the replicate results were entered into the range control chart. This procedure complies with the strategy agreed internationally by the HELCOM Phytoplankton Expert Group. Expert identification of phytoplankton species depends on the analyst's level of knowledge. PEG therefore runs annual training courses and undertakes regular ring tests. Two annual PEG meetings took place online in 2022: April 4. - 5. and October 24. - 25., which were attended by representatives of all Baltic Sea States. Samples taken in January/February 2022 were counted based on the previous ICES and HELCOM biovolume file PEG_BIOVOL2021, while the new list was adopted for the counting of all cruise samples collected in 2022 thereafter, i.e. following biovolume file PEG_BIOVOL2022.

The spring meeting specifically addressed the implementation of molecular methods in phytoplankton monitoring and respective future activities of PEG in this regard. A Guideline document for harmonized implementation of DNA based phytoplankton monitoring in the Baltic Sea area had been generated in 2021/2022 (JERNEY et al. 2023) by experts including Members of PEG. The resulting publication was introduced at the meeting. 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 2022, to (PEG_BIOVOL2022) to assure up-to date taxonomy and biovolume information.

Samples taken in January/February 2022 were counted based on the previous ICES and HELCOM biovolume file PEG_BIOVOL2021, while a new, updated, list was adopted for the counting of all samples collected from cruises EMB290 (March 2022) onwards, following the biovolume file PEG_BIOVOL2022.

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 (Variation coefficient < 1 %). Individual operator and within-laboratory precision was similarly tested (Variation coefficient 1.3 – 1.9 %). Data stored in IOW 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 2022 monitoring season confirmed high accuracy. In addition, internal and external audits of our analysis groups were successfully passed. In 2022 we received the re-accreditation by DAkkS (Deutsche Akkreditierungsstelle).

Spring bloom

In February (EMB286) the spring production had already started in the entire study area, as indicated by *Chl a* values ranging from 2,33 $\mu\text{g l}^{-1}$ at station M1 in the eastern Bay of Mecklenburg (BM-E) to 0,8 $\mu\text{g l}^{-1}$ at Station K2 in Bornholm Basin (BB) (Fig. 2). The typical spatial pattern of bloom development from south to north with highest *Chl a* concentrations in the westernmost station Kiel Bight (ZETTLER et al. 2020, DUTZ et al. 2022), was not entirely reflected: On the outbound journey, highest *Chl a* concentrations were measured in the Bay of Mecklenburg rather than in westernmost Kiel Bight. However, southward increasing *Chl a* concentrations measured on the inbound return journey one week later suggest that the spring bloom had commenced by the end of the EMB 286 cruise in the western Baltic – as in the previous year.

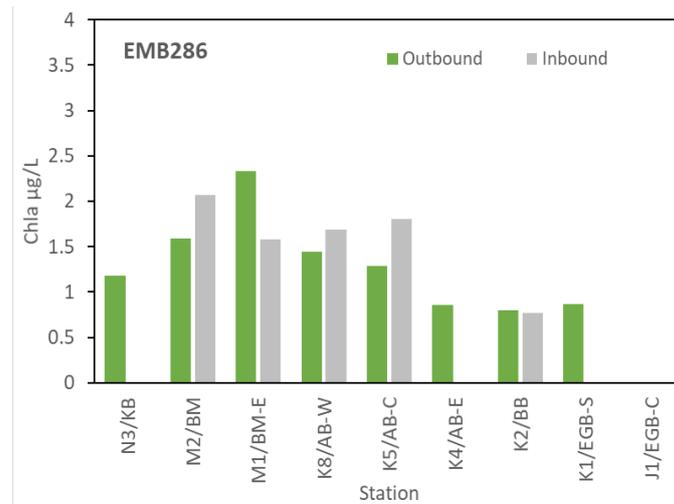


Fig. 2: *Chl a* concentrations ($\mu\text{g l}^{-1}$) at sampling stations along outbound (green bars) and inbound (grey bars) transects of the February cruise EMB286.

Biomass data (Fig. 3) reflected the typical northward progression of the spring bloom onset more clearly than *Chl a*, which – as in 2021 - is most likely attributed to the prevalence of non-diatom taxa in the community. Highest biomass values (268.81 $\mu\text{g l}^{-1}$ and 288.55 $\mu\text{g l}^{-1}$) were measured at Station M2 in the southeast, the Bay of Mecklenburg. This differs from the usual pattern, as highest biomass concentrations are usually encountered in the Kiel Bight. Possibly, specific regional hydrographic conditions were responsible for the regional differences. As typical for the early spring season, phytoplankton production declined latitudinally towards the northeast. Here, biomass concentrations amounted to 51.30 $\mu\text{g l}^{-1}$ at station K1 in the eastern Gotland Basin (EGB-south) and 49.15 $\mu\text{g l}^{-1}$ at station K2 in Bornholm Basin (BB), which is roughly 20 % of the concentrations measured in the south. Compared to 2021, highest measured biomass concentrations were >50 % lower during the cruise in February 2022, likely reflecting slight differences in timing of cruise and/or bloom onset between the years.

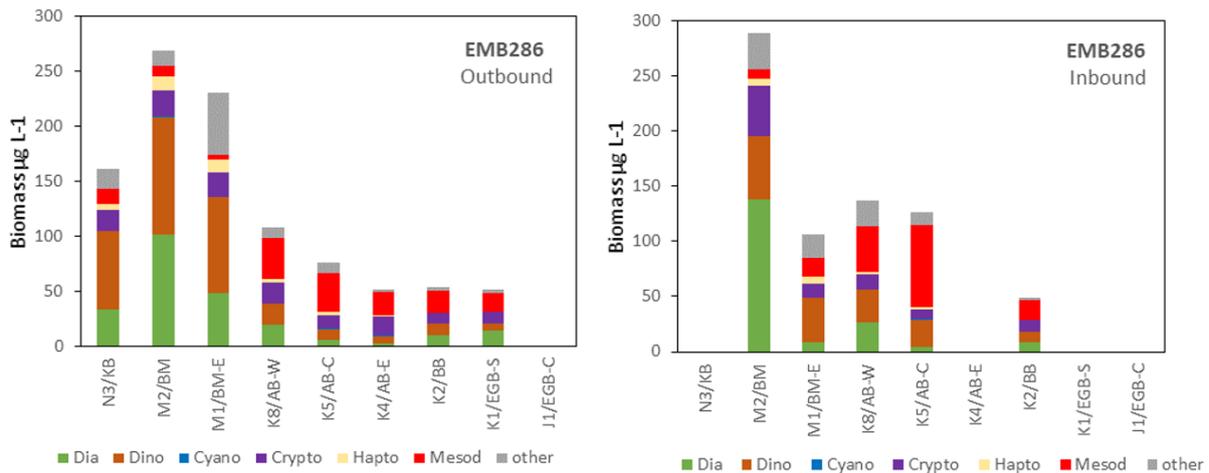


Fig. 3: Total phytoplankton biomass ($\mu\text{g l}^{-1}$) and contribution of major taxa measured from samples taken on EMB286. Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Hapto = Haptophytes, Mesod = Mesodinium rubrum.

In the Belt Sea area (Kiel Bight and Bay of Mecklenburg), dinoflagellates constituted in total 38 – 45 % of phytoplankton biomass on the outbound and 20-38%, respectively, on the inbound journey of cruise EMB286 (Fig. 3). The dinoflagellate community was represented largely by small species of Gymnodiniales and *Tripos muelleri*, a large gonyaulacoid species, as well as *Dinophysis norvegica*, a potentially toxic boreal dinoflagellate typically occurring in marine cold water habitats (REGUERA et al.2012 (Table 5, Fig. 4). Diatom biomass shares in February were highest in the Bay of Mecklenburg, where *Guinardia* spp. and *Coscinodiscus radiatus* contributed 37 % (outbound) and 48 % (inbound) respectively at Station M2. Compared to diatoms and dinoflagellates, cryptophytes and haptophytes as well as the ciliate *Mesodinium rubrum* had minor biomass shares in the Belt Sea, a pattern that changed latitudinally towards the central basins, and with later timing of sampling.

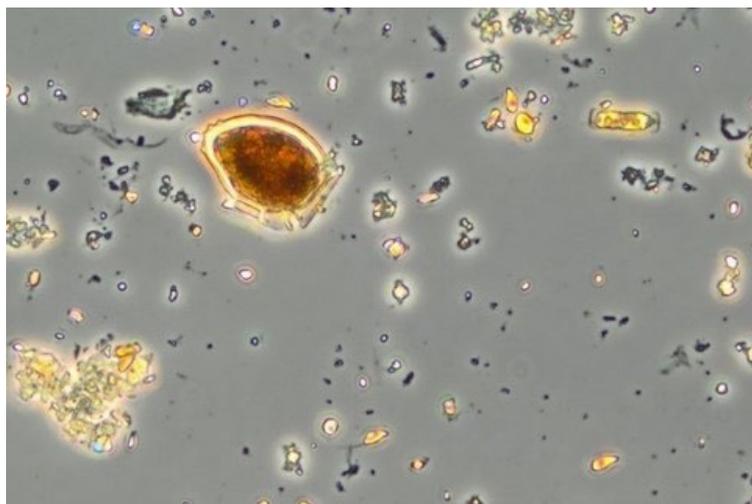


Fig. 4: Typical cryptophyte *Teleaulax* spp. in a *Dinophysis* spp. dominated community of the Belt Sea in February 2022.

In February, phytoplankton biomass was still low in Arkona Basin and onwards on the outbound journey. Biomass concentrations of 49 - 50 $\mu\text{g l}^{-1}$ were measured in eastern Arkona Basin, Bornholm Basin and southern Gotland Basin. Here the spring bloom was still in an early stage of

development. However, on the inbound return journey, phytoplankton biomass concentrations had already increased significantly in Arkona Basin, indicating that the onset of the spring bloom was cascading northwards.

As in 2021, Chl_a and biomass dynamics were not well synchronized in the 3 northern basins during the February cruise (Fig. 2, Fig. 3). This mismatch likely reflects the relatively high representation of non-diatom taxa (dinoflagellates, cryptophytes and the ciliate *Mesodinium rubrum*) in the respective communities of the Baltic Proper. In contrast to diatoms, dinoflagellates and cryptophytes have prominent accessory pigments that may mask Chl_a (HONGO et al. 2019) *Mesodinium rubrum* harbours (klepto-) plastids acquired from mixotrophic cryptophytes.

Phytoplankton community composition differed, as expected, between the Belt Sea and the Baltic Proper (Bornholm and Gotland Basins). While in the Belt Sea community mainly marine diatoms and dinoflagellates were prominent, *Mesodinium rubrum*, *Teleaulax* and *Dinophysis spp* (Fig. 4), as well as *Actinocyclus octonarius* and Gymnodiniales shaped the February communities of the Baltic Proper. *Mesodinium rubrum*, together with *Teleaulax* constituted more than 50 % of phytoplankton biomass in the Arkona Basin. As expected, species diversity decreased gradually from 63 in the Belt Sea to 45 in Arkona Basin, and further from 36 in Bornholm-Basin to 23 in Gotland Basin (Table 5).

Table 5: Percent biomass shares of the 10 most important phytoplankton species present in the 4 major sea areas during the cruise in February 2022, EMB286 (TFo222).

Belt Sea		Arkona Basin	
Species	% Biomass	Species	% Biomass
<i>Gymnodiniales</i>	10.97	<i>Mesodinium rubrum</i>	42.07
<i>Teleaulax</i>	10.78	<i>Teleaulax</i>	9.09
<i>Tripos muelleri</i>	9.95	<i>Heterocapsa rotundata</i>	8.60
<i>Guinardia delicatula</i>	7.59	<i>Actinocyclus octonarius</i>	5.90
<i>Mesodinium rubrum</i>	5.38	<i>Gymnodiniales</i>	5.75
<i>Coscinodiscus radiatus</i>	4.73	<i>Plagioselmis prolonga</i>	4.59
<i>Guinardia flaccida</i>	4.63	Unicell spp.	3.45
<i>Prymnesiales</i>	4.18	<i>Rhizosolenia setigera</i>	3.37
<i>Rhizosolenia setigera</i>	4.07	<i>Eutreptiella</i>	2.26
<i>Dinophysis norvegica</i>	3.73	<i>Prymnesiales</i>	2.13
Total number of recorded taxa	63	Total number of recorded taxa	45
Bornholm Basin		Eastern Gotland Basin	
Taxon	%Biomass	Taxon	% Biomass
<i>Mesodinium rubrum</i>	36.37	<i>Mesodinium rubrum</i>	34.37
<i>Actinocyclus octonarius</i>	17.98	<i>Actinocyclus octonarius</i>	26.76
<i>Gymnodiniales</i>	15.55	<i>Teleaulax</i>	16.57
<i>Teleaulax</i>	13.57	<i>Peridiniella catenata</i>	7.17
<i>Plagioselmis prolonga</i>	4.94	Unicell spp.	3.85
Unicell spp.	1.85	<i>Gymnodiniales</i>	3.13
<i>Gyrodinium spirale</i>	1.07	<i>Plagioselmis prolonga</i>	2.01
<i>Eutreptiella</i>	0.87	<i>Protoperidinium</i>	1.53
<i>Prymnesiales</i>	0.79	<i>Hemiselmis</i>	0.98
<i>Peridiniella catenata</i>	0.79	<i>Snowella</i>	0.69
Total number of recorded taxa	36	Total number of recorded taxa	23

By the time of the March cruise (EMB290) *Chla* concentrations had increased significantly in the entire study area and now ranged from 1.33 $\mu\text{g l}^{-1}$ at Station M1 in eastern Bay of Mecklenburg (outbound) to 9.70 $\mu\text{g l}^{-1}$ in western Arkona Basin (inbound) (Fig. 5). The *Chla* peak at Station K8 was somewhat isolated and likely reflects a local, small-scale situation, since concentrations in the surrounding sea areas were significantly lower. By the time of the return journey, the *Chla* peak had disappeared at this station, which supports such an interpretation. While the spatial *Chla* pattern on the outbound transect probably captured the peak production of the spring bloom, comparably lower concentrations on the inbound journey probably indicated the beginning of spring bloom decline.

Apart from a slight temporal delay, *Chla* pattern and magnitude were similar to the previous year, and representative for the spring bloom in the Baltic Sea. Nevertheless, seasonal peak values of *Chla* found in the northern Basins already in March, might reflect the recent trend of earlier timing of the spring bloom in the northern Baltic Sea (HJERNE et al. 2019).

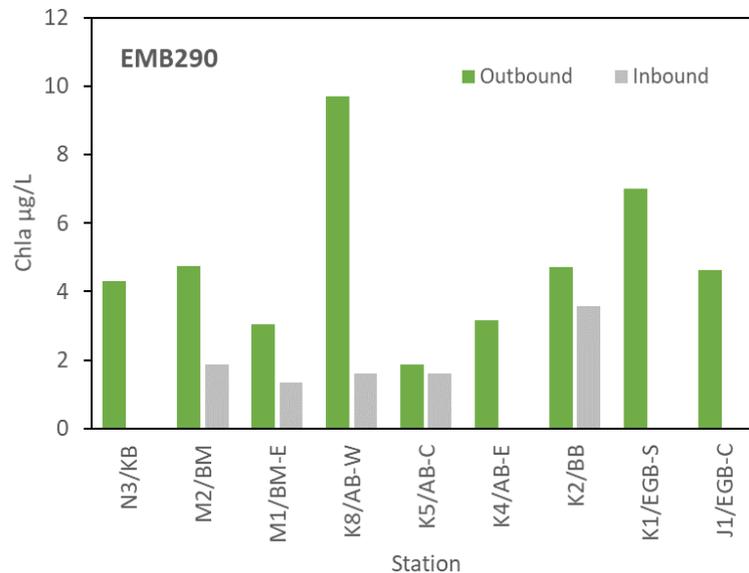


Fig. 5: *Chla* concentrations ($\mu\text{g l}^{-1}$) at sampling stations along the S-N (dark green) and N-S (grey) legs of the March cruise EMB286.

Phytoplankton biomass dynamics on the March cruise (EMB290) reflected *Chla* dynamics, particularly on the outbound journey (Fig. 5). This is due to the general high representation of diatoms in phytoplankton communities, particularly in Belt Sea and Arkona Basin. Total phytoplankton biomass captured during EMB290 ranged from 327 $\mu\text{g l}^{-1}$ at Station K5 (central Arkona Basin) to 2948 $\mu\text{g l}^{-1}$ at Station K8 (western Arkona Basin). Both are neighbouring stations along the transect, but each with specific local phytoplankton dynamics.

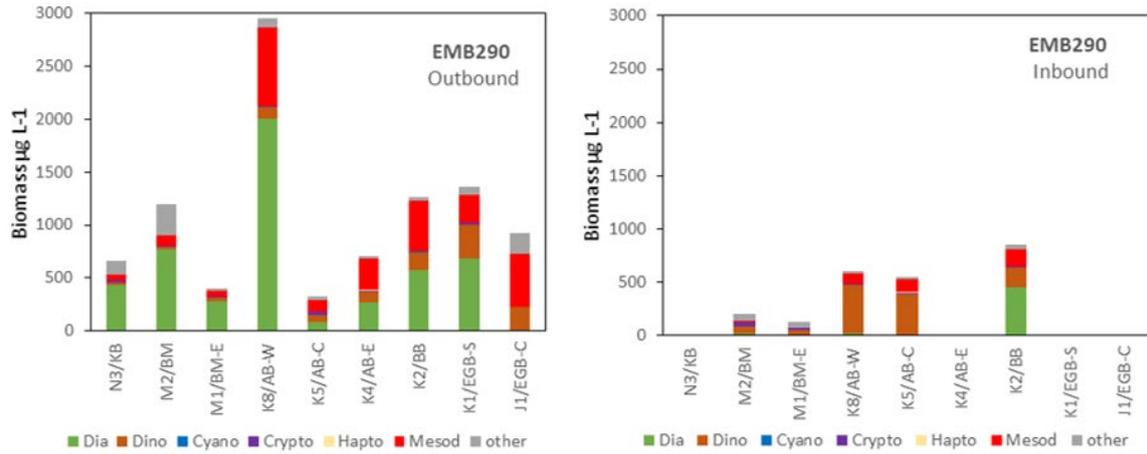


Fig. 6: Total phytoplankton biomass ($\mu\text{g l}^{-1}$) and contribution of major taxa measured from samples taken during northward and southward transects of EMB 290 (TF0322) in March 2022. Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Mesod = *Mesodinium rubrum*, Prym = *Prymnesiophytes*.

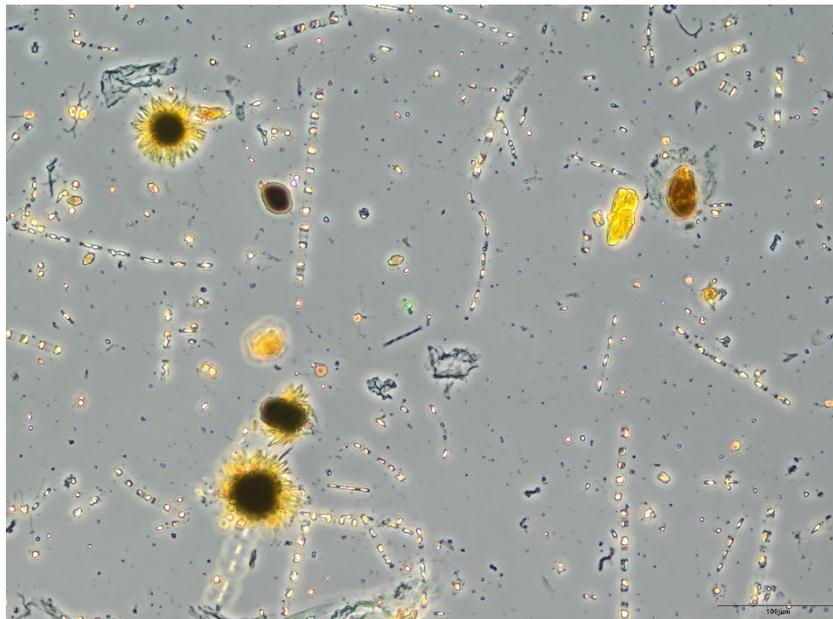


Fig. 7: Phytoplankton community in Arkona Basin in March 2022 featuring *Skeletonema marinoi* and *Mesodinium rubrum* during cruise EMB290.

In contrast to 2021, when biomass composition largely differed among basins in March, the composition was spatially uniform in March 2022 - but had changed significantly on the inbound journey of the May cruise in 2022 (EMB293, TF0522). At the two southernmost stations of the Belt Sea, diatoms, particularly *Skeletonema marinoi*, (Fig. 7) dominated the phytoplankton biomass in March, contributing >40 % of the total phytoplankton biomass in the Belt Sea and the Arkona Basin (Table 6). Besides *S. marinoi*, *Mesodinium rubrum*, a kleptoplast-based phototrophic ciliate was highly represented in all investigated sea areas in March (Fig. 7). Similarly, the phagotrophic flagellate *Ebria tripartita* was with up to 10 % biomass share (Table 6) a prominent taxon of the phytoplankton community at many stations. Although the species is a herbivorous phagotrophic grazer (UITTO et al. 1997) it is routinely monitored as a heterotrophic

phytoplankton, similar to non-phototrophic dinoflagellates. At the time of the inbound return journey of TFO322 in March, diatom dominance that had been observed on the resp. outbound journey in the Belt- and Arkona Basins, had switched to a dinoflagellate/*Mesodinium rubrum* dominance. Dinoflagellate biomass contributions had changed northward from 3 to 23 % on the outbound journey to 29 to 76 % on the inbound return. Accordingly, diatom shares decreased to 2- 10 % (excluding K2 in the Bornholm Basin).

Table 6: Percent biomass shares of the 10 most important phytoplankton species present in the 4 major sea areas during the March cruise in 2022, EMB290.

Belt Sea		Arkona Basin	
Species	% Biomass	Species	% Biomass
<i>Skeletonema marinoi</i>	45.44	<i>Skeletonema marinoi</i>	41.47
<i>Ebria tripartita</i>	13.49	<i>Mesodinium rubrum</i>	26.68
<i>Mesodinium rubrum</i>	9.07	<i>Gymnodiniales</i>	17.37
<i>Unicell spp.</i>	4.52	<i>Thalassiosira</i>	2.71
<i>Thalassiosira</i>	4.05	<i>Ebria tripartita</i>	2.15
<i>Teleaulax</i>	3.51	<i>Chaetoceros</i>	1.44
<i>Heterocapsa rotundata</i>	3.09	<i>Heterocapsa rotundata</i>	1.39
<i>Gymnodiniales</i>	2.60	<i>Teleaulax</i>	1.17
<i>Guinardia delicatula</i>	2.32	<i>Peridiniella catenata</i>	0.93
<i>Chaetoceros</i>	1.73	<i>Unicell spp</i>	0.60
Total number of recorded taxa	60	Total number of recorded taxa	53
Bornholm Basin		Eastern Gotland Basin	
Taxon	%Biomass	Taxon	% Biomass
<i>Mesodinium rubrum</i>	30.64	<i>Mesodinium rubrum</i>	33.38
<i>Skeletonema marinoi</i>	29.17	<i>Thalassiosira</i>	15.89
<i>Thalassiosira</i>	17.00	<i>Peridiniella catenanta</i>	15.04
<i>Peridiniella catenata</i>	11.47	<i>Skeletonema marinoi</i>	12.18
<i>Ebria tripartita</i>	2.74	<i>Eutreptiella</i>	9.69
<i>Gyrodinium spirale</i>	1.75	<i>Apocalathium spp. CPX</i>	3.22
<i>Gymnodiniales</i>	1.74	<i>Peridiniella danica</i>	1.50
<i>Actinocyclus octonarius</i>	0.84	<i>Chaetoceros</i>	1.42
<i>Chaetoceros</i>	0.83	<i>Ebria tripartita</i>	1.15
<i>Teleaulax</i>	0.76	<i>Gyrodinium spirale</i>	1.11
Total number of recorded taxa	35	Total number of recorded taxa	41

The number of phytoplankton taxa recorded in March 2022 was highest in Belt Sea (60) and Arkona Basin (53), decreasing towards the north, with 40 taxa recorded in Bornholm- and 43 taxa found in Gotland Basin (Table 6). Generally, representation of taxa was comparable to previous years. (DUTZ et al. 2022, KREMP et al. 2024).

By May 2022, Chl a concentrations had dropped to the early spring bloom levels of the February cruise, and ranged from 0.92 $\mu\text{g l}^{-1}$ in the south (Kiel Bight, Station) to 2.91 $\mu\text{g l}^{-1}$ in the north (Bornholm Basin) (Fig. 8). Interestingly, Chl a concentrations had increased at the time of the inbound return journey at all sampled stations. This was somewhat unexpected, as the peak of the phytoplankton spring typically “travels” successively from south to north and is usually declining already in the southern and central basins in May (e.g. DUTZ et al. 2022). Nevertheless, differences or changes in regional water transport patterns, e.g. as a result of increased river run-

off, which coincide with nutrient inflow (LEHMANN et al. 2022) may change phytoplankton production dynamics. Generally, Chl a concentrations in May 2022 were similar to the ones encountered at the same time the year before (KREMP et al. 2024).

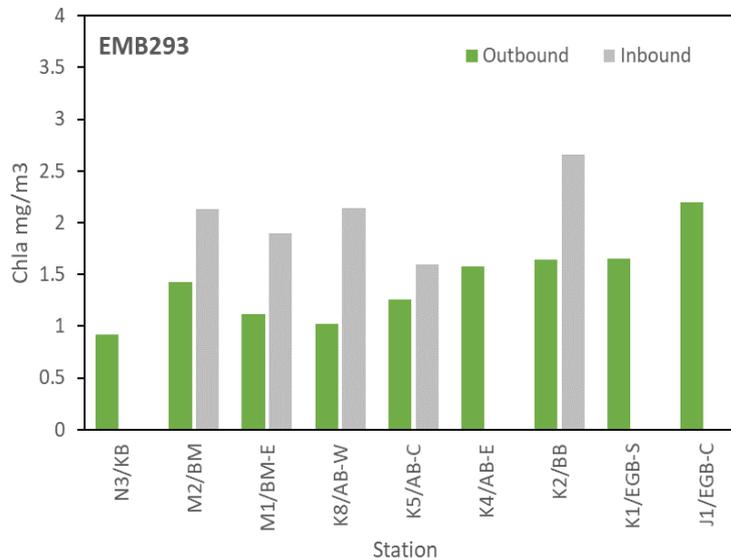


Fig. 8: Chl a concentrations ($\mu\text{g l}^{-1}$) at sampling stations along the S-N (dark green) and N-S (grey) legs of the May cruise EMB293.

Total biomass in May ranged from $72.63 \mu\text{g l}^{-1}$ at Station K8 in western Arkona Basin, to $665 \mu\text{g l}^{-1}$ in Eastern Gotland Basin (J1, EGB-C), which corresponds to approximately half of the biomass concentration measured in May 2021. Nevertheless, the values reflect typical phytoplankton biomass levels at this time of the year (DUTZ et al. 2022). Spatial biomass dynamics (Fig. 9) corresponded only poorly to Chl a dynamics, which can be explained by nearly complete absence of diatom taxa. Generally, patterns of biomass composition, spatial distribution and progression along the cruise transect were typical for the late stages of the spring bloom (KREMP et al. 2024). Phytoplankton biomass composition differed significantly between outbound and inbound journeys, indicating a rapid community turnover. While *Mesodinium rubrum* was well represented and even dominant in the southern and central Baltic basins on the outbound journey (Table 7), it had disappeared by the time of the inbound return. Instead, haptophytes, specifically *Prymnesiales*, had increased in biomass shares and now dominated the phytoplankton communities at most stations (Table 7). As common at this time of the year, dinoflagellates were well represented in the communities, with typical taxa such as *Tripes muelleri* and Gymnodiniales in the Belt Sea, Peridinales in the Arkona Basin, and typical cold water dinoflagellates such as *Peridniella catenata*, *Apocalathium malmogiense* and *Gymnodinium corollarium* in the northern basins. Concentrations of filamentous cyanobacteria were generally negligible at all stations in May, however, coccoid cyanobacteria constituted nearly 50 % of biomass in the Kiel Bight at the time of sampling in May.

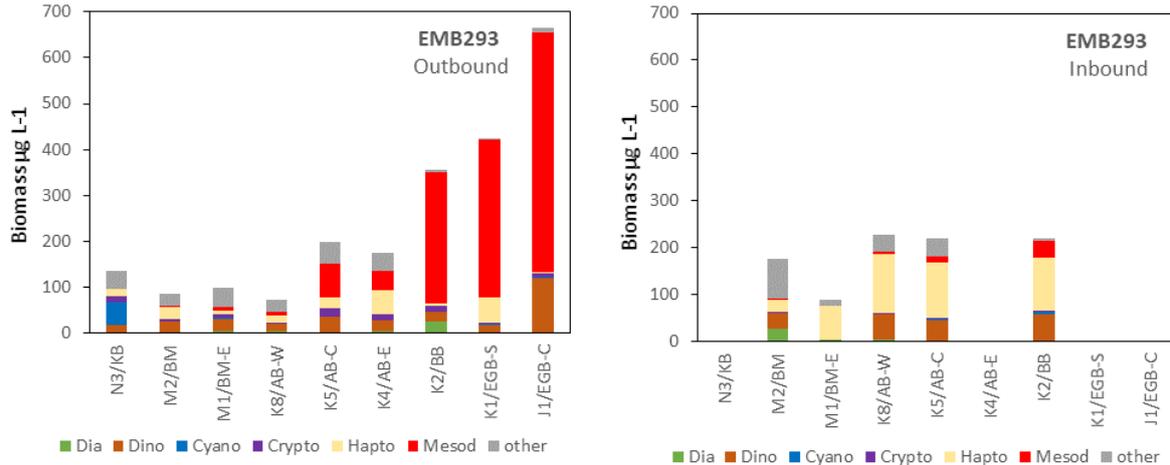


Fig. 9: Total phytoplankton biomass ($\mu\text{g l}^{-1}$) and contribution of major taxa measured from samples taken during northward and southward return transects of cruise in May 2022 (EMB293). Dia = Diatoms, Dino = Dinoflagellates, Cyano = Cyanobacteria, Crypto = Cryptophytes, Mesod = Mesodinium rubrum, Prym = Prymnesiophytes

Table 7: Percent Biomass shares of the 10 most important phytoplankton species present in the 4 major sea areas in May 2022, on EMB293.

Belt Sea		Arkona Basin	
Species(% Biomass	Species	% Biomass
<i>Prymnesiales</i>	27.70	<i>Prymnesiales</i>	37.80
<i>Unicell spp.</i>	11.10	<i>Mesodinium rubrum</i>	15.90
<i>Plagioselmis prolonga</i>	10.03	<i>Pyramimonas</i>	11.35
<i>Pyramimonas</i>	8.88	<i>Gymnodiniales</i>	10.21
<i>Gymnodiniales</i>	6.59	<i>Heterocapsa rotundata</i>	5.28
<i>Telonema</i>	5.04	<i>Telonema</i>	4.44
<i>Heterocapsa rotundata</i>	5.00	<i>Teleaulax</i>	3.57
<i>Dactyosolen fragilissimus</i>	4.98	<i>Unicell spp.</i>	2.15
<i>Tripos muelleri</i>	3.66	<i>Peridinales</i>	2.01
<i>Mesodinium rubrum</i>	2.80	<i>Plagioselmis prolonga</i>	1.02
Total number of recorded taxa	38	Total number of recorded taxa	39
Bornholm Basin		Eastern Gotland Basin	
Taxon	%Biomass	Taxon	% Biomass
<i>Mesodinium rubrum</i>	56.62	<i>Mesodinium rubrum</i>	79.67
<i>Prymnesiales</i>	20.46	<i>Peridiniella catenata</i>	6.76
<i>Apocalathium spp. CPX</i>	4.85	<i>Prymnesiales</i>	5.01
<i>Actinocyclus</i>	4.31	<i>Dinophysis acuminata</i>	1.85
<i>Peridinales</i>	4.16	<i>Gymnodiniales</i>	1.30
<i>Gymnodiniales</i>	2.25	<i>Teleaulax</i>	1.14
<i>Teleaulax</i>	1.84	<i>Peridiniella danica</i>	0.63
<i>Unicell spp.</i>	0.74	<i>Dinophysis norvegica</i>	0.57
<i>Dinophysis acuminata</i>	0.71	<i>Dinophysis acuta</i>	0.35
<i>Dinophysis norvegica</i>	0.68	<i>Dinobryon balticum</i>	0.32
Total number of recorded taxa	32	Total number of recorded taxa	33

The number of phytoplankton taxa recorded in May 2022 was uniformly distributed in the study area, ranging from 38 species in the Belt Sea to 39 in the Arkona Basin; 32 in Bornholm Basin and 33 in Gotland Basin. Particularly in the northern basins, species richness was lower than in previous years at the time of the May cruise.

Summer bloom

In August 2022 (cruise EMB298), Chl a concentrations were uniformly distributed in the entire study area and differed only slightly between outbound and inbound transects (Fig. 10). Values ranged from 1.63 $\mu\text{g l}^{-1}$ in the south (Kiel Bight, station N3) to 3.23 $\mu\text{g l}^{-1}$ in the north (eastern Gotland Basin J1). Highest Chl a levels were measured at the northernmost station (J1) in the central Gotland Basin where massive cyanobacterial blooms regularly occur.

However, like in 2020 and 2021, cyanobacteria were not particularly prominent in terms of biomass representation in July, specifically in the southern Basins. Here, diatoms dominated the summer phytoplankton community, constituting high biomass (apparently not reflected by Chl a) of up to 6500 $\mu\text{g l}^{-1}$. *Dactyosolen fragilissimus* dominated the summer phytoplankton biomass in the Belt Sea and the Arkona Basin (Table 8, Fig. 11), forming nearly monospecific blooms there. The species is relatively sparsely pigmented which results in a high biomass to Chl a ratio, and explains the apparent mismatch of Chl a and biomass dynamics seen in the July data. Other diatom taxa and typical warm-water dinoflagellates and cyanobacteria (Fig. 12) were only minor components of the southern Baltic phytoplankton communities during the cruise in August (EMB298).

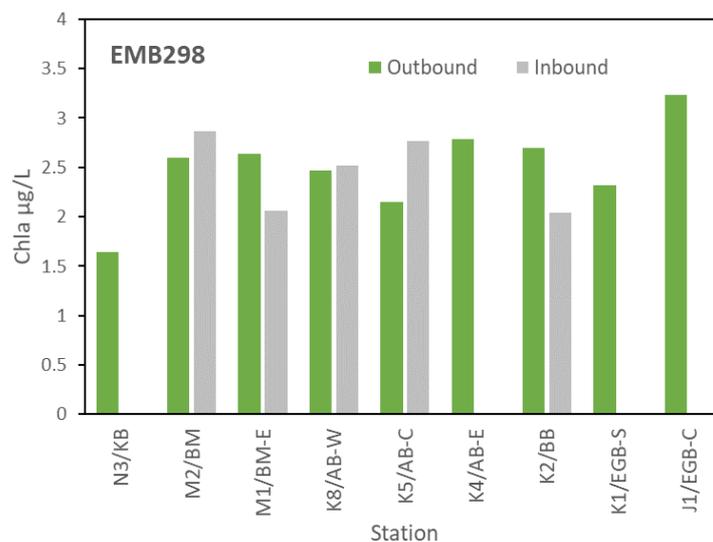


Fig. 10: Chl a concentrations ($\mu\text{g l}^{-1}$) at sampling stations along the S-N outbound (dark green) and N-S inbound, return (grey) transects of cruise EMB298 in August 2022.

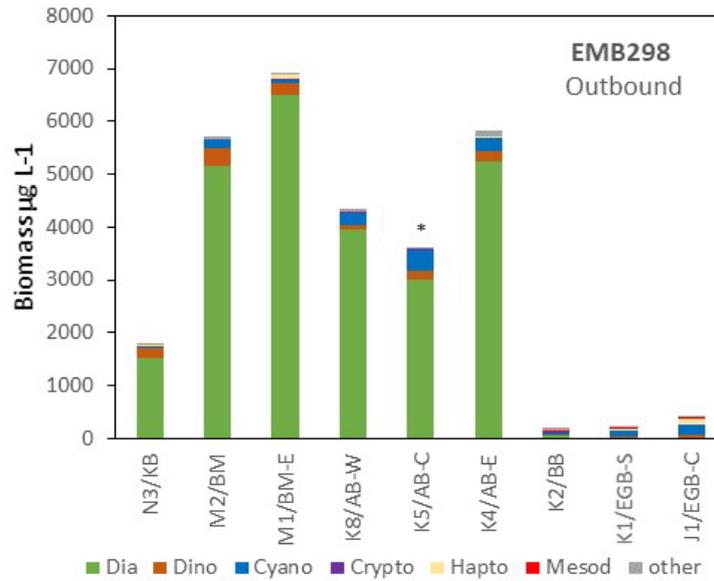


Fig. 11: Biomass concentrations ($\mu\text{g l}^{-1}$) at sampling stations along the S-N outbound transect of cruise EMB298 (Tf0822) in August 2022. *Sample taken on the inbound return journey. Only outbound samples were analysed.



Fig. 12: Typical summer phytoplankton community at station M1 (Bay of Mecklenburg) in August 2022 (cruise EMB298, Tf0822) featuring the dominant diatom *Dactyosolen fragilissimus*, filamentous cyanobacteria and the toxic dinoflagellate *Alexandrium pseudogonyaulax*.

In 2022, significant cyanobacteria biomass shares were only found in the phytoplankton community of the Eastern Gotland Basin (Fig. 11), where cyanobacteria constituted 46 to 49% of total phytoplankton biomass at stations K1 and J1 respectively. Besides *Aphanizomenon* and *Nodularia spumigena* also *Pseudanabaena limnetica* and *Aphanotece paralleliformis* contributed significant biomass shares of the summer cyanobacteria community here.

Taxon distribution mostly reflected the typical pattern of diversity in the Baltic Sea, with number of taxa being highest in the Belt Sea. The number of taxa recorded in Bornholm Basin in July was unusually low in July 2022.

Table 8: Percent Biomass shares of the 10 most important phytoplankton species present in the 4 major studied sea areas during cruise in August 2022 (EMB298, Tfo822).

Belt Sea		Arkona Basin	
Species	% Biomass	Species	% Biomass
<i>Dactyosolen fragilissimus</i>	86.11	<i>Dactyosolen fragilissimus</i>	88.53
<i>Proboscia alata</i>	4.36	<i>Aphanizomenon</i>	4.47
<i>Tripos muelleri</i>	3.57	<i>Tripos muelleri</i>	1.49
<i>Dolichospermum</i>	0.85	<i>Nodularia spumigena</i>	1.24
<i>Aphanizomenon</i>	0.81	<i>Karlodinium veneficum cf.</i>	0.97
<i>Alexandrium pseudogonyaulax</i>	0.80	<i>Dolichospermum</i>	0.58
<i>Prymnesiales</i>	0.76	<i>Cymbomonas tetramitiformis</i>	0.52
<i>Rhizosolenia setigera</i>	0.46	<i>Alexandrium pseudogonyaulax</i>	0.47
<i>Guinardia flaccida</i>	0.31	<i>Flagellates</i>	0.43
<i>Gymnodiniales</i>	0.29	<i>Prymnesiales</i>	0.32
Total number of recorded taxa	60	Total number of recorded taxa	43
Bornholm Basin		Eastern Gotland Basin	
Taxon	%Biomass	Taxon	% Biomass
<i>Dactyosolen fragilissimus</i>	22.33	<i>Aphanizomenon</i>	19.18
<i>Pyramimonas</i>	19.08	<i>Prymnesiales</i>	18.95
<i>Mesodinium rubrum</i>	10.85	<i>Nodularia spumigena</i>	8.92
<i>Teleaulax</i>	10.30	<i>Mesodinium rubrum</i>	6.41
<i>Plagioselmis prolunga</i>	6.58	<i>Pseudanabaena limnetica</i>	5.92
<i>Heterocapsa rotundata</i>	6.20	<i>Chroococcales</i>	5.65
<i>Gymnodiniales</i>	6.09	<i>Karlodinium veneficum</i>	5.36
<i>Unicell spp.</i>	5.93	<i>Teleaulax</i>	3.98
<i>Eutreptiella</i>	5.53	<i>Aphanotece paralleliformis</i>	3.27
<i>Aphanizomenon</i>	2.91	<i>Pyramimonas</i>	2.18
Total number of recorded taxa	23	Total number of recorded taxa	46

Autumn bloom

In November 2022, Chl a values ranged from 2.83 $\mu\text{g l}^{-1}$ in the eastern Gotland Basin to 3.41 $\mu\text{g l}^{-1}$ in the Bay of Mecklenburg and were thus in the same range as in November 2021 (Fig. 13). Spatial variation along the transect was low and values measured on the inbound return journey only differed at stations M1 in the Bay of Mecklenburg and K2 in Bornholm Basin. Here Chl a concentrations had decreased significantly when sampled again on the way back, probably due to local hydrographic conditions. The Chl a levels of the November cruise were comparable to the ones measured in March or August 2022, suggesting that phytoplankton communities were still growing actively at that time. In fact, the situation captured during the November cruise (TF1122) represents facets of the autumn phytoplankton bloom, which can be highly productive until late into the autumn, despite potentially suboptimal light conditions. Sufficient availability of dissolved inorganic nutrients in autumn likely supports such blooms.

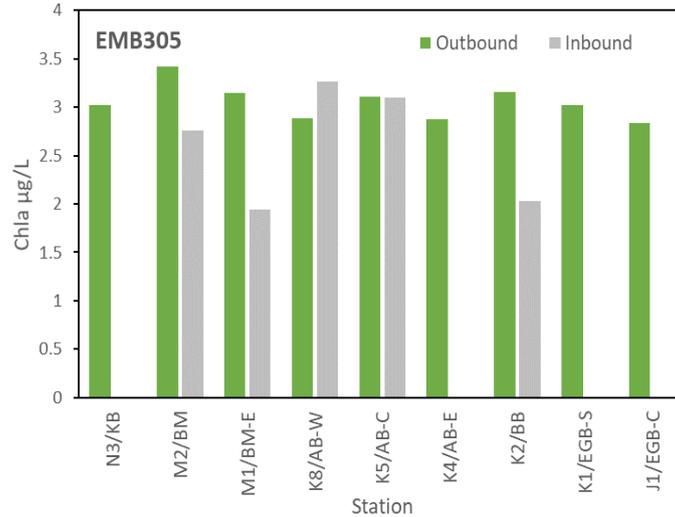


Fig. 13: Chla concentrations ($\mu\text{g l}^{-1}$) at sampling stations along the S-N outbound (dark green) and N-S inbound return (grey) transects of cruise EMB305 in November 2022.

Total phytoplankton biomass measured in November ranged from $51 \mu\text{g l}^{-1}$ at Station K1 in the Eastern Gotland Basin to $777 \mu\text{g l}^{-1}$ in the Kiel Bight which is comparable to the November cruise in 2021 (Fig. 14). As with the previous cruises, biomass data poorly aligned with Chla data – the latter suggesting uniform biomass distribution along the transect in November 2022: In contrast to Chla, total phytoplankton biomass concentrations sharply decreased from $777 \mu\text{g l}^{-1}$ at station N3 in the Kiel Bight and $126 \mu\text{g l}^{-1}$ at station K8 in the Arkona Basin. Stations further in the north had significantly lower biomass concentrations of 50 to $80 \mu\text{g l}^{-1}$ - except for the central eastern Gotland Basin where a biomass of $196 \mu\text{g l}^{-1}$ was detected. Total biomass was largely driven by diatoms and dinoflagellates. Diatom shares ranged from 72 % in Kiel Bight to 6.8 % in the central Arkona Basin. Highest dinoflagellate shares were found in the central Arkona Basin (54.63 %). *Mesodinium rubrum* contributed 30% of biomass at J1 in the central eastern Gotland Basin.

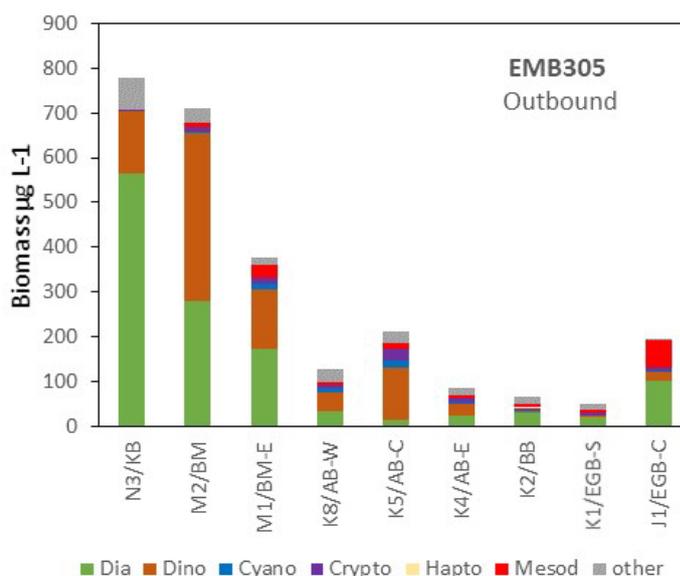


Fig. 14: Biomass concentrations ($\mu\text{g l}^{-1}$) at sampling stations along the S-N outbound transect of cruise EMB305 (TF1122) in November 2022. Only outbound samples were analysed.

Table 9: Percent Biomass shares of the 10 most important phytoplankton species present in the 4 major studied sea areas during the cruise in November 2022 (EMB305, TF1122).

Belt Sea		Arkona Basin	
Species	% Biomass	Species	% Biomass
<i>Pseudosolenia calcar-avis</i>	15.77	<i>Tripos muelleri</i>	17.80
<i>Pseudo-nitzschia</i>	12.32	<i>Gymnodiniales</i>	14.90
<i>Cerataulina pelagica</i>	10.74	<i>Teleaulax</i>	9.47
<i>Tripos muelleri</i>	6.97	<i>Coscinodiscus granii</i>	7.90
<i>Polykrikos schwartzii</i>	6.14	<i>Mesodinium rubrum</i>	6.39
<i>Ditylum brightwellii</i>	5.26	<i>Ebria tripartita</i>	5.59
<i>Prorocentrum micans</i>	4.80	<i>Aphanizomenon</i>	5.01
<i>Gymnodiniales</i>	4.02	Unicell spp.	4.63
<i>Gyrodinium spirale</i>	3.73	<i>Prorocentrum micans</i>	3.99
<i>Octactis speculum</i>	3.44	<i>Dactyosolen fragilissimus</i>	2.93
Total number of recorded taxa	78	Total number of recorded taxa	48
Bornholm Basin		Eastern Gotland Basin	
Taxon	%Biomass	Taxon	% Biomass
<i>Actinocyclus octonarius</i>	24.26	<i>Coscinodiscus granii</i>	47.20
<i>Coscinodiscus granii</i>	16.96	<i>Mesodinium rubrum</i>	26.91
<i>Mesodinium rubrum</i>	12.79	<i>Gymnodiniales</i>	5.45
Unicell spp.	12.54	<i>Teleaulax</i>	4.52
<i>Gymnodiniales</i>	7.09	Unicell spp.	4.01
<i>Teleaulax</i>	5.40	<i>Actinocyclus octonarius</i>	1.72
<i>Eutreptiella</i>	3.12	<i>Dinophysis norvegica</i>	1.58
<i>Ebria tripartita</i>	2.60	<i>Aphanizomenon</i>	1.57
<i>Prymnesiales</i>	2.25	<i>Eutreptiella</i>	0.72
<i>Chaetoceros danicus</i>	2.17	<i>Dinophysis acuminata</i>	0.71
Total number of recorded taxa	26	Total number of recorded taxa	34

In November, a mixed community, predominantly consisting of diverse marine diatoms and dinoflagellates, was found in the Belt Sea, consisting of 78 mainly marine species and including potentially toxic *Pseudo-nitzschia* (Table 9). The Arkona community contained 48 marine (*Dactyosolen fragilissimus*, and *Tripos muelleri*) and brackish species (*Mesodinium rubrum* and *Aphanizomenon*) in Bornholm and Gotland samples consisted of typical brackish taxa including *Actinocyclus octonarius*, Prymnesiales and *Teleaulax*. Here phytoplankton species diversity was lower with 26 and 34 recorded taxa respectively.

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

In 2022, altogether 146 phytoplankton species / taxa were recorded in monitoring samples capturing the uppermost 10 m of the water column, which is 19 less than in 2021. A complete list of recorded species with biomass ranks and annual average biomass values can be found in supplementary (Table Appendix 1). As in 2021, diatoms were the most important biomass producers, specifically *Dactyosolen fragilissimus* which, at times contributed nearly 90 % of the phytoplankton biomass in the southern basins of the study area. The kleptoplastic ciliate *Mesodinium rubrum* ranked number 2, being highly abundant in spring, and occurring together with *Skeletonema marinoi*, rank 3. As in 2021, cyanobacteria played a minor role in terms of biomass production in 2022. Table 10 shows occurrences of toxic and potentially harmful taxa

at sampled stations in 2022. Under conditions of climate change, when temperatures of surface waters rise, the risk of harmful algal bloom formation increases (WELLS et al. 2015). Particularly species, adapted to warm water, 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 2022, *Pseudonitzschia spp.* reached bloom abundances in the Kiel Bight in March (cruise EMB290). This species produces domoic acid, a toxin that affects the nervous system and may cause diarrhea (DERMASTIA et al. 2022) when contaminated shellfish is consumed. A cyanobacteria bloom, dominated by *Aphanizomenon*, encountered in Arkona Basin in July (cruise EMB298), the species was present in the water column at all times, though mostly at low concentrations. Generally, a number of toxic taxa were found at low concentrations throughout the study area on all cruises (Table 10).

Table 10: Occurrence of toxic/ bloom forming and invasive phytoplankton taxa in 2022. + = present, ++ = abundant (1-10 % biomass share), +++ = very abundant (> 10 % biomass share), ++++ = bloom (>50 % biomass share). *Dinophysis spp.* includes *D. acuminata*, *D. norvegica*, *D. acuta*; *Pseudo-nitzschia spp.* contains records of *P. pseudodelicatissima group*, *P. pungens*, *P. seriata* and *P. multiseriata*.

Species/Station	IOW and BSH cruise	TF360 N3	TF0012 M2	TF0046 M1	TF030 K8	TF113 K5	TF109 K4	TF0213 K2	TF259 K1	TF271 J1
Cyanophyceae										
<i>Dolichospermum spp.</i>	EMB293						+			
		++	+	+	+	+	++		+	+
<i>Nodularia spumigena</i>	EMB298		+	+	+	+	+		+++	++
	EMB305		+	+		++	+			
<i>Aphanizomenon sp.</i>	EMB290					+			+	+
	EMB293						+	+		+
	EMB298	+	++	+	++	++++	++	++	++	+++
	EMB305		+	++	++	++	++	++	+	++
Dinophyceae										
<i>Alexandrium pseudogonyaulax</i>	EMB298	++	+	+	+	+	+			
<i>Prorocentrum cordatum</i>	EMB298	+	+	+	+	+	+	+		
	EMB305	+	+	+	+	+	+		+	
<i>Dinophysis spp.</i>	EMB286	++	++	++		+			+	
	EMB290	+				+				+
	EMB293	++				++		++	++	++
	EMB298	+	+	+					+	+
	EMB305	+	++			+	+			++
Bacillariophyceae										
<i>Pseudo-nitzschia spp.</i>	EMB286	+	+	+						
	EMB290	++++								
	EMB305	+++	++	+	+	+				
Raphidophyceae										
<i>Heterosigma akashiwo</i>	EMB286	++	++	+++		+				

3.1.3 Long-term trends

Biomass

The average phytoplankton biomass mean of 2022, $1015 \mu\text{g l}^{-1}$, was above the annual biomass mean over the past 20 years, and higher than in the previous year (Fig. 15).

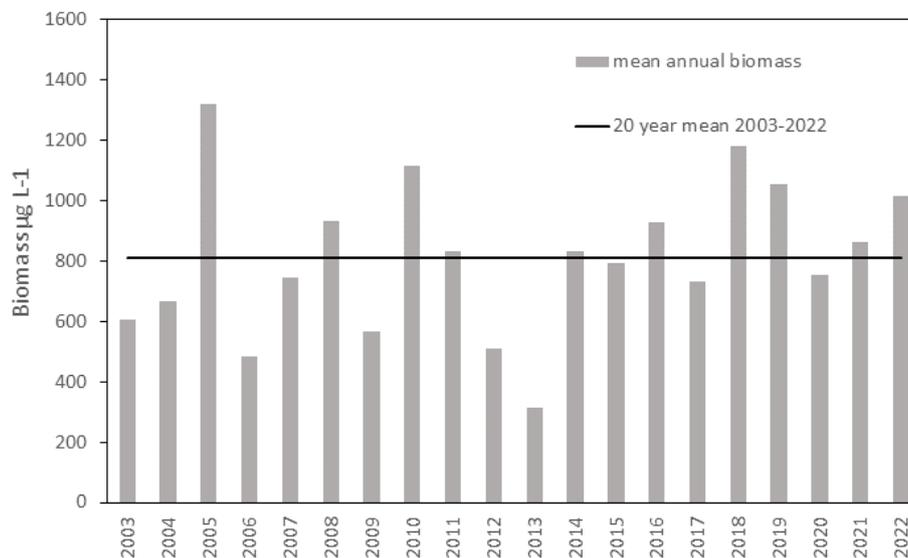


Fig. 15: Mean annual biomass values (all stations and samplings) for the period between 2003 and 2022.

Diatom/Dinoflagellate ratio

In 2022, the diatom/dinoflagellate ratio was 8.35, twice as high as the year before and significantly higher than the 20-year mean (Fig. 16). 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. 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. Thus, the indicated current trend of diatom dominance and steadily increasing proportion of diatoms in the community should principally benefit the environmental status. On the other hand, sedimentation of large diatom blooms, such as the massive summer blooms of *Dactyosolen fragilissimus* observed increasingly in the past few years, may enhance oxygen consumption in bottom waters and might lead to anoxic conditions in the sediments, which, like cyanobacteria blooms (VAHTERA et al. 2007) increase the internal phosphorus loading. The dominance of diatoms in the Baltic summer blooms is a recent phenomenon that needs to be investigated. In 2022, no large dinoflagellate blooms were observed in the study area.

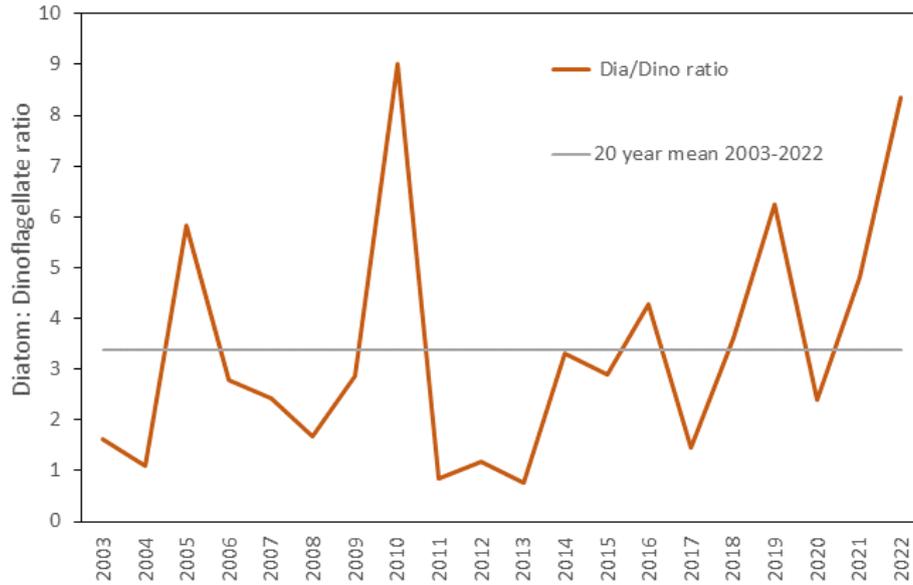


Fig. 16: Mean annual ratio of diatoms to dinoflagellates per sampling and station based on biomass concentrations ($\mu\text{g l}^{-1}$). The black line marks the 20-year mean, dotted line = trendline.

Cyanobacteria biomass

Cyanobacteria biomass (Fig. 17) was, at $35.25 \mu\text{g l}^{-1}$, higher than in 2021, and reflected the 20-year mean $31.76 \mu\text{g l}^{-1}$ closely. Generally, cyanobacteria biomass has been varying largely interannually, and trends cannot be identified.

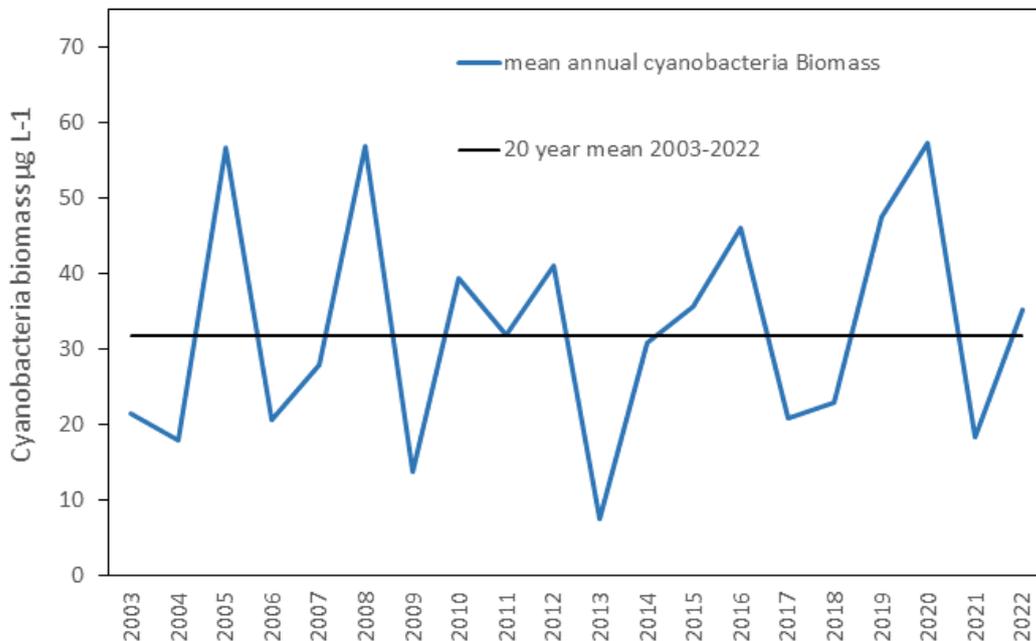


Fig. 17: Mean annual averages of cyanobacterial biomass for the period 2003-2022 per sampling and station ($\mu\text{g l}^{-1}$). The black line marks the 20-year mean.

3.2 Mesozooplankton

3.2.1 Species composition and non-indigenous species

A total of 50 taxa were identified in the Kiel Bight, the Bay of Mecklenburg and the Arkona Basin during the sample analysis (see Table Appendix 2). This represents the usual number of taxa that is encountered in the area (44 - 50 taxa). Only during years with strong inflow characteristics such as 2016, the inventory can be higher due to the presence of taxa occurring in the Kattegat (up to 73 taxa, WASMUND et al. 2018b, 2019). Euryhaline and brackish species and only few true marine species dominated the taxa list. Zooplankton typical for a higher salinity encountered in 2022 were the calanoid copepod *Calanus helgolandicus* in August/November and the harpacticoid copepod *Microsetella* spp. that occurred year-round in the Belt Sea. Apart from the copepods, the cladocerans *Pleopis polyphemoides* and *Penilia avirostris* were observed in summer in the Belt Sea together with some chaetognaths. In contrast to the previous year, larvae of various benthic taxa (*Liocarcinus*, *Ophiura*, *Asterias*, *Phoronis*) and gelatinous Cnidaria (*Euphysa*, *Rathkea*, *Sarsia*) were regularly observed as well.

The usual seasonal variation in the number of taxa was observed in 2022, with higher numbers in autumn and winter (Fig. 18). Typically, more taxa are found in the Kiel Bight (station N3) and Bay of Mecklenburg (station M2) in winter due to the seasonal maximum of the salinity in the Belt Sea (DUTZ & WASMUND 2023). The minimum in taxa number occurring in spring is a regular feature in the western Baltic Sea and is explained by the disappearance of meroplankton and the halophilic gelatinous zooplankton. In summer, the species numbers increased again by the presence of thermophilic species such as the copepods *Acartia tonsa* and *Paracalanus parvus*, the cladocerans *Podon* spp. and several species of rotifers of the genus *Keratella*. In contrast to spring, there were no spatial patterns in the taxa numbers in summer and autumn.

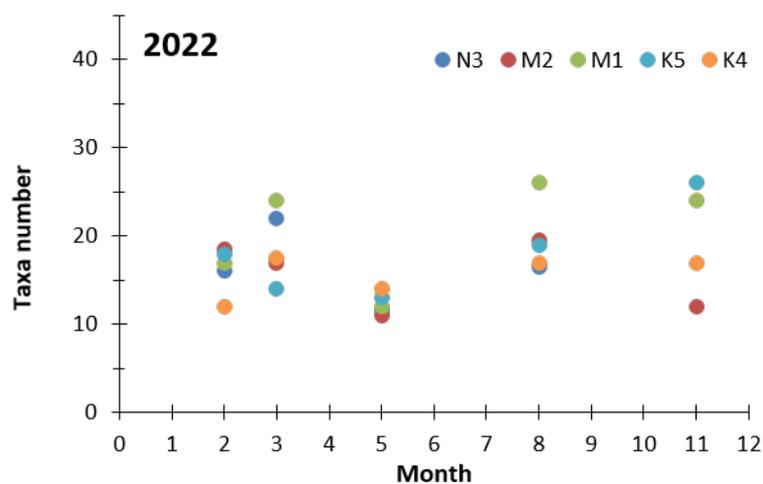


Fig. 18 Seasonal variation of the number of taxa occurring at the monitoring stations in the investigation area in 2022 (N3: Kiel Bight, M2, M1: Bay of Mecklenburg, K5, K4: Arkona Basin).

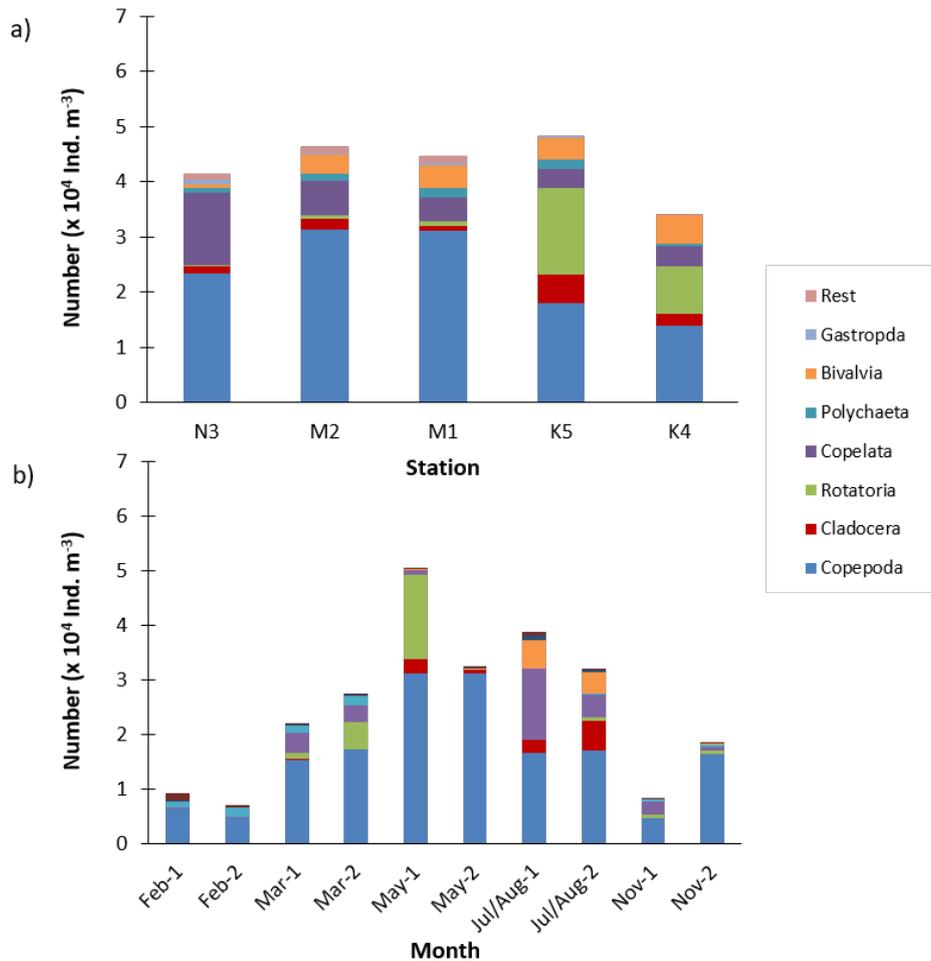


Fig. 19 Spatial (a, Kiel Bight: N3, Bay of Mecklenburg: M2, M1, Arkona Basin: K5, K4) and seasonal variation (b) of the maximal abundance of the major mesozooplankton groups in the investigation area during 2022.

The zooplankton stock in the western Baltic Sea usually shows an increase across the salinity gradient from the Kiel Bight (N3) to the Arkona Basin (K5, K4) and two dominating brackish zooplankton groups, the rotifers and the cladocerans, respectively, are responsible for this increase. The year 2022 was exceptional concerning this biogeographic characteristic because no large variation in the stock size was observed among the monitoring stations (Fig. 19). While the typical spatial shift from the dominance of copepods in Kiel Bight to the increasing importance of zooplankton groups other than copepods was observed, the stock sizes of rotifers and especially of the cladocerans were well below the usual values. Thus, copepods (range: $1.4 - 3.1 \times 10^4 \text{ ind. m}^{-3}$) were the dominating group with an average of 58.8 % of the total stocks in 2022 (Fig. 20 a-i). This is rather exceptional but was also observed in the years 2016 and 2020. In contrast to the latter years, the group of Copelata ranked second with an average of 12.4 % of the total stock instead of cladocerans or rotifers (Fig. 20). Their abundance ranged from $0.3 - 1.3 \times 10^4 \text{ ind. m}^{-3}$. With a maximum abundance below $9 \times 10^3 \text{ ind. m}^{-3}$ in the investigation area, rotifers and cladocerans contributed only 11.3 and 5.0 % to the zooplankton stock (Fig. 20 a-i). Only at station K5 in the Arkona Basin, rotifers stocks were higher than stocks of the Copelata ($1.5 \times 10^4 \text{ ind. m}^{-3}$, equivalent to 31.2 % of the stock).

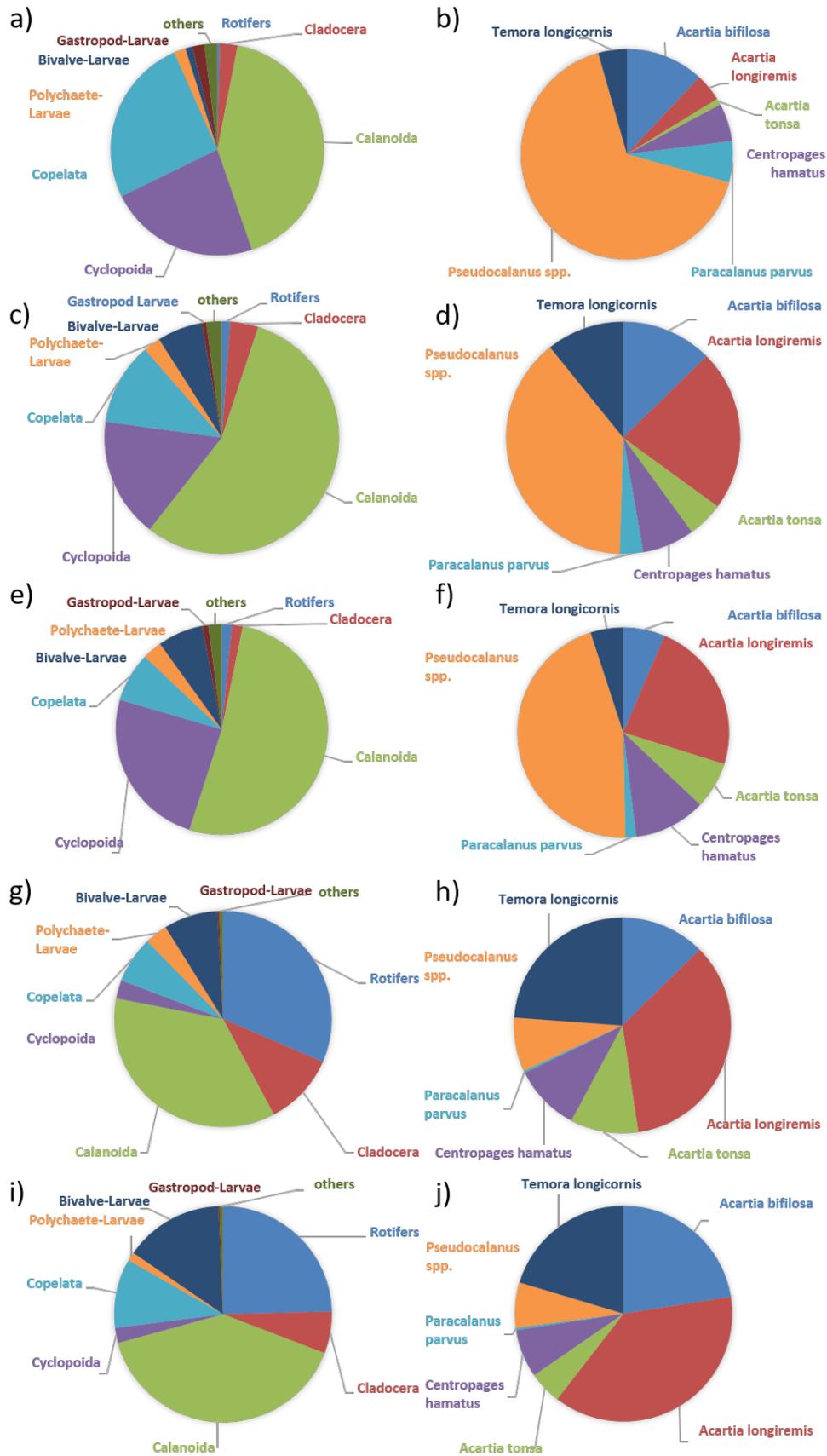


Fig. 20 Relative composition of the mesozooplankton groups (a-i) and adults of calanoid copepods (b-j) in 2022 (a-b: Kiel Bight (N3), c-d: Bay of Mecklenburg (M2) e-f: Bay of Mecklenburg (M1), g-h: Arkona Basin (K5), i-j: Arkona Basin (K4)).

Major taxonomic groups of meroplankton were the bivalves, the polychaetes and the gastropods. Their maximal concentrations were lower than in previous years and achieved 5.1 , 1.7 and 0.9×10^3 ind. m^{-3} , respectively. This represents 7.4 , 2.4 and 0.8 % of the zooplankton. Taken together, the major zooplankton groups displayed a usual seasonal pattern (Fig. 19 b). Whereas calanoid copepods and rotifers achieved their maximal concentration in spring, Copeledata and cladocerans occurred primarily in autumn.

Copepoda

Copepods were the dominating group in the zooplankton of the western Baltic Sea in 2022 (Fig. 19, Fig. 20). A common pattern in the area is the decrease in the concentrations from the Kiel Bight (N3, 1.3×10^4 ind. m^{-3}) to the Arkona Basin (K5, K4, $2.8 - 6.1 \times 10^3$ ind. m^{-3} , (Fig. 19 a, Fig. 21 a). The total abundance of $1.3 - 3.1 \times 10^4$ ind. m^{-3} including all copepodite stages was at the lower end of the typical range at which the group is observed ($3.0 - 6.4 \times 10^4$ ind. m^{-3}). Calanoid copepods dominated the stock ($1.4 - 2.9 \times 10^4$ ind. m^{-3}), cyclopoid copepods, that are exclusively represented by the genus *Oithona*, contributed on average about $1/3$ to the copepod stocks ($0.1 - 1.4 \times 10^4$ ind. m^{-3}). There was a pronounced gradient with a higher abundance of copepods in the Belt Sea (Fig. 21 a), which is typical for the Kiel Bight and the Bay of Mecklenburg (see Dutz et al. 2022). The copepods showed a strong seasonal variation with low winter stocks, a start of the season in March and a typical maximum in late spring. Stocks decreased in summer and autumn, which is regularly observed for this group (Fig. 21 b). Due to their occurrence year round, copepods form a vital link to higher trophic levels (ALHEIT et al. 2005, BERNREUTHER et al. 2018).

In contrast to the regular seasonality, the composition of the copepod community was unusual in 2022. During the last decade, the zooplankton stocks in the Kiel Bight were largely dominated by the genera *Acartia* and *Oithona*. Towards the Bay of Mecklenburg (M2, M1) and the Arkona Basin (K5, K4), their dominance declines to the benefit of a more balanced composition with additional genera like *Pseudocalanus*, *Temora* and *Centropages*. In contrast to this general pattern, the zooplankton in the Belt Sea was dominated by *Pseudocalanus* spp. and *Oithona similis* in 2022 (Fig. 20 b-f, Fig. 21 a). *Pseudocalanus* dominated particularly during the spring ($3.9 - 4.8 \times 10^3$ ind. m^{-3} , Fig. 21 b) and contributed to $39 - 66$ % of the calanoid copepods. In contrast, *Oithona* occurred primarily in summer and autumn with on average $2.6 - 4.4 \times 10^3$ ind. m^{-3} . *Acartia* species together only ranked third in abundance in 2022. Usually, a typical shift from a dominance of *A. bifilosa* to *A. longiremis* can be observed from the Belt Sea to the Arkona Basin. In 2022, *A. bifilosa* displayed rather low concentrations throughout the western Baltic Sea ($< 1.2 \times 10^3$ ind. m^{-3}), while *A. longiremis* was abundant already in the Bay of Mecklenburg at similar concentrations as observed in the Arkona Basin ($1.9 - 2.4 \times 10^3$ ind. m^{-3}). Nevertheless, the contribution of maximal 38 % of *A. longiremis* to the stock of calanoid copepods was also lower than usual (max. $49 - 63$ %).

In line with previous years, other copepod species displayed lower, but usual proportions within this group. *Temora longicornis* ranked fourth ($5 - 24$ %) followed by *Centropages hamatus* spp. ($5 - 11$ %), *Acartia tonsa* ($1 - 10$ %) and *Paracalanus parvus* ($1 - 6$ %, Fig. 21 b-j). While *P. parvus* was mainly restricted to the Kiel Bight, the other species showed increasing importance towards the Arkona Basin.

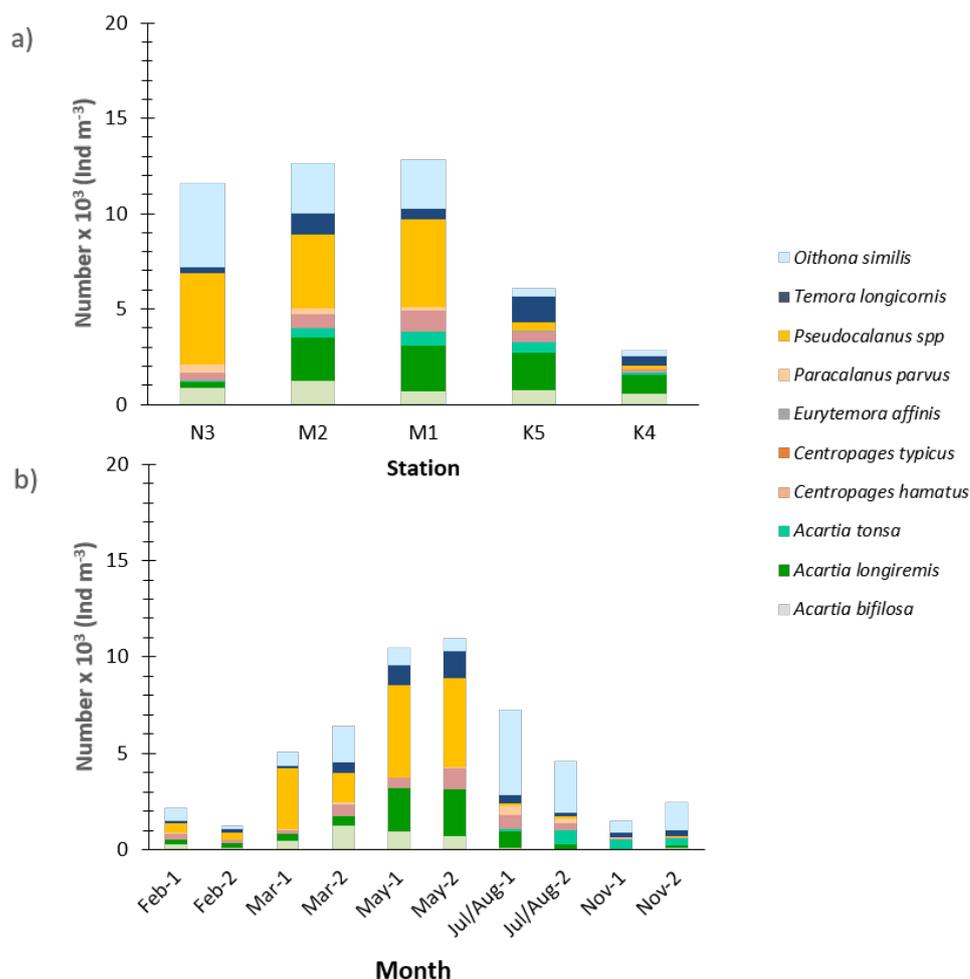


Fig. 21 Spatial (a, Kiel Bight: N3, Bay of Mecklenburg: M2, M1, Arkona Basin: K5, K4) and seasonal variation (b) of the maximal abundance of adult calanoid and cyclopoid copepods in the investigation area in 2022.

Copelata

The contribution of the Copelata to the zooplankton was unusually high compared to preceding years. While it ranged from 2.7 - 8.9 % during 2014 - 2021, the group contributed on average to 12.4 % to the total stock in 2022 (Fig. 20 a-i). The high contribution was not only caused by the low abundance of rotifers and cladocerans, but also due to high concentrations of up 1.3×10^4 ind. m⁻³ in the Kiel Bight, which represents 26 % of the total stock. As usual, a typical spatial and temporal segregation of the two species of Copelata occurring in the area was observed. *Oikopleura dioica* dominated in the Kiel Bight (N3) and the Bay of Mecklenburg (M2, M1) with $0.4 - 1.3 \times 10^4$ ind. m⁻³. In contrast to previous years, the species maximum occurred in summer and not in autumn (Fig. 2 b, see also DUTZ et al. 2022). The maxima of *Fritillaria borealis* of $3.1 - 3.6 \times 10^3$ ind. m⁻³, in contrast, occurred as usual in March in the Arkona Basin (K5, K4).

Rotifera

The rotifers are commonly characterized by temporally restricted but intense mass development in spring. Following the year 2018, in which more than 6.1×10^4 ind. m⁻³ were observed in the western Baltic Sea, concentrations were declining and were below 1.9×10^3 ind. m⁻³ in 2020. A trend of recovery was observed in 2021 (0.3 to 7.7×10^3 ind. m⁻³) which continued also in 2022 with maximum concentrations of 1.6×10^4 ind. m⁻³ (Fig. 19). Nevertheless, the maximal

concentration at which the group is observed is still low. The genus *Synchaeta* spp. is commonly the dominating rotifer. Its concentrations increased from the Kiel Bight (N3, 161 ind. m⁻³), in which a complete absence is not uncommon, toward the Arkona Basin (K5, K4, 0.9 - 1.6 x 10⁴ ind. m⁻³) in 2022. While *Synchaeta* is commonly observed in spring, the genus *Keratella* occurs primarily in summer and autumn. The abundance of the genus is usually low and varied from 10 to 603 ind. m⁻³. In 2022, three species were found, *K. cruciformis*, *K. quadrata* and *K. cochlearis*.

Cladocera

The Cladocera were not a dominating component of the zooplankton community in 2022. While this group was for a long time the major taxon since the beginning of the time series (see also chapter 3.2.3), large year-to-year fluctuations were observed in the recent years. In 2021, densities of up to 4.4 x 10⁴ ind. m⁻³ equivalent to 57 % of the total zooplankton were found. In contrast, the abundance in 2022 varied between 0.9 and 5.3 x 10³ ind. m⁻³ and was one order of magnitude lower with a maximal contribution of 10.8 % to the zooplankton stock (Fig. 19, Fig. 20). *Bosmina* spp. is usually the dominating species with maxima occurring in summer. In 2022, the species' stock size was only marginally larger than that of the other cladocerans, *Evadne nordmanni*, *Podon intermedius* and *P. leuckartii*. The maximal concentrations were observed as usual in the Arkona Basin (K5, K4) and varied between 1.3 and 4.7 x 10³ ind. m⁻³. *E. nordmanni* ranked second among the Cladocera and ranged from 0.1 to 2.3 x 10³ ind. m⁻³. While the abundance is usual for this species in the western Baltic Sea, the restriction of higher densities to the Arkona Basin are unusual because the species typically showed a more even distribution in the area during preceding years. *P. intermedius* and *P. leuckartii* displayed their typical succession with *P. leuckartii* occurring in May (0.2 – 1.5 x 10³ ind. m⁻³) and *P. intermedius* in July/August (109 - 173 ind. m⁻³) throughout the area. *Penilia avirostris* is usually observed at a low abundance restricted to the Kiel Bight (N3). In 2022, its abundance varied from 0.5 to 1.17 x 10³ ind. m⁻³. In contrast, the abundance of *Pleopis polyphemoides* was low (1 - 33 ind. m⁻³).

Meroplankton

Meroplankton contributed to 5 – 16 % to the zooplankton stock (Fig. 20 a-i). Compared to preceding years, this contribution is rather low since regularly up to 32 % were observed in the past. Usually, one of the major meroplankton groups show high concentrations of more than 1.0 x 10⁴ ind. m⁻³, like the polychaete larvae in spring or the bivalve larvae in summer (e.g., WASMUND et al. 2018b, 2019, DUTZ et al. 2022). This was not the case in 2022. Bivalve larvae were the most abundant group and achieved 0.5 – 5.1 x 10³ ind. m⁻³, with typically higher densities in the Arkona Basin (K5, K4). Polychaete larvae showed a similar biogeographic pattern, which is unusual since high densities were observed mainly in the Kiel Bight in the past. The abundance of gastropod larvae (0.1 – 1.6 x 10³ ind. m⁻³), in contrast, decreased from Kiel Bight (N3) to the Arkona Basin, as usual. As usual, larvae of the Cirripedia and Gymnolaemata were restricted to the Kiel Bight (N3) and Bay of Mecklenburg (M2, M1), where they were observed during the winter-spring transition with an abundance of 214 - 281 ind. m⁻³ and 743 - 882 ind. m⁻³, respectively.

Non-indigenous species (NIS)

Apart from *Acartia tonsa*, no other species classified as non-indigenous species were found in 2022.

3.2.2 Seasonal variation of zooplankton in the sub-areas

Kiel Bight (N3)

The low temporal resolution with only one sampling per season allows only restricted insights into the temporal dynamics of the zooplankton in the Kiel Bight (N3) during a specific year. Although the area is usually dominated by calanoid and cyclopoid copepods that are characterized by a life cycle that spans several weeks to months depending on the prevailing temperature, advection might change the community composition rapidly. This is exemplified by the presence of rare marine species particularly in the late autumn or winter, when the salinity is usually higher (see chapter 3.2.1). Rotifers, tintinnids or meroplankton may also occur only during a restricted period. In addition, the analysis of a full seasonal cycle in 2022 is not possible due to lacking samples in autumn caused by severe weather conditions that prevented net sampling. Despite this, general patterns such as a dominance of copepods during the transition from winter into spring and their decline in summer associated with a shift to a diverse community were observed in 2022. Due to the vicinity to the Kattegat and the Skagerrak, the higher species richness described for 2022 already above is typical for winter-spring in the area.

The stock displayed a strong seasonal variation with low winter stocks (6.3×10^3 ind. m^{-3}) and a maximum in August (3.3×10^4 ind. m^{-3} , Fig. 22). The increase in abundance from February to March (1.2×10^4 ind. m^{-3}) points to an early initiation of the zooplankton development since stock sizes in both months vary only little in the long-term. While copepods usually achieve their seasonal maximum in late spring and rapidly decline towards summer, their summer decrease in 2022 was moderate. This led to a summer maximum composed of copepods and an unusual high concentration of the Copelata. Typically, the cyclopoid *Oithona similis* or high concentrations of tintinnid ciliates are responsible for such deviations. The contribution of meroplankton to the zooplankton stock is traditionally high in the Kiel Bight. In 2022, this was the case during the winter-spring transition, but summer stocks were lower than usual (Fig. 22).

The abundance of zooplankton was low during winter (6.8×10^3 ind. m^{-3}). Copepods and meroplankton dominated the community and contributed to 66 % and 31 % to the community, respectively. This is very close to the long-term average of these two groups of 69 and 26 %. The abundance was 4.5 and 2.1×10^3 ind. m^{-3} (Fig. 22). Usually, polychaete larvae are by far the most abundant meroplankton group during this period. In 2022, they shared a rather equal contribution (894 ind. m^{-3}) with the Gymnolaemata (754 ind. m^{-3}). Other groups such as cirripede and gastropod larvae were lower in abundance (236 and 232 ind. m^{-3} , respectively). Among the holoplankton, Copelata (116 ind. m^{-3}) and Cladocera (105 ind. m^{-3}) were a minor group. The Copelata were represented by *Oikopleura dioica* only, which is a typical summer species. The occurrence of the individuals in the winter period likely points to remnants of the last autumn. *Evadne nordmanni* was the main cladoceran species (100 ind. m^{-3}), and only a few additional specimen of *Podon leuckartii* were observed (5 ind. m^{-3}).

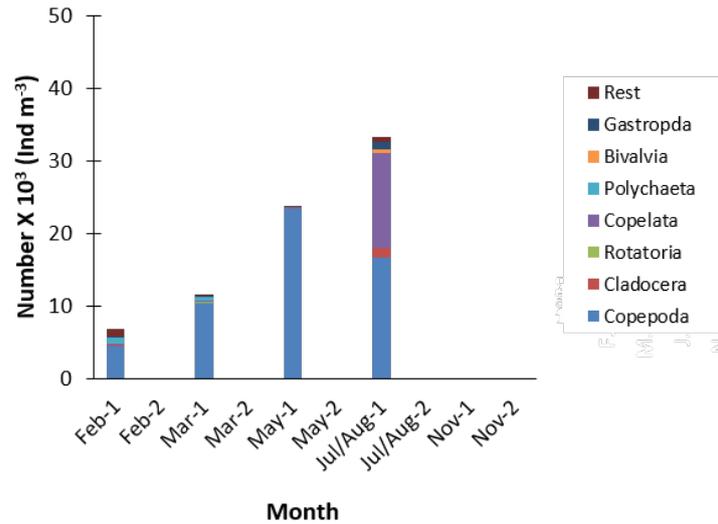


Fig. 22 Seasonal variation of the main taxonomic groups in the Kiel Bight (station N3) during the year 2022.

The stock of copepod is typically low during the winter (4.8×10^3 ind. m^{-3}). In 2022, *Oithona similis* (2.1×10^3 ind. m^{-3}) and *Pseudocalanus/Paracalanus* (1.6×10^3 ind. m^{-3}) dominated the community (Fig. 23). In comparison to 2021, *Pseudocalanus/Paracalanus* had replaced *Acartia* as the most abundant genus. Such shifts in the composition of the overwintering community and in the species accompanying the dominant species *Oithona similis* are, however, common in the Kiel Bight. Nevertheless, the abundance of *Acartia* was very low in 2022 (only 21 ind. m^{-3}). *Centropages* (647 ind. m^{-3}) and *Temora* (173 ind. m^{-3}) were minor genera but occurred at their usual concentration.

The composition of the adult copepods reflected the composition of the juvenile stock well, with *Oithona similis* (620 ind. m^{-3}) and *Pseudocalanus* spp. (289 ind. m^{-3}) dominating the community. However, *Paracalanus parvus* adults were also found (66 ind. m^{-3}), which strengthens the observation of slight influence of the last year's autumn community on the overwintering stock. Like *Oikopleura dioica*, *Paracalanus* is typically a warm-water species that shows maximal concentrations during summer and autumn. Adults of *Acartia* were entirely composed of *A. bifilosa*, no *A. longiremis* or *A. tonsa* were found.

Until March, the stock size had nearly doubled (1.2×10^4 ind. m^{-3} , Fig. 22). This early increase was largely based on the copepods, particularly by the genus *Pseudo/Paracalanus* that contributed to 90 % to the zooplankton. Meroplankton declined to 921 ind. m^{-3} , equivalent to only 8 % of the stock. This is low compared to the long-term average in the contribution of this group of 20 %, Polychaete and cirripede larvae declined particularly in their abundance, while gastropod larvae were still occurring in numbers similar to February. Among the holoplankton, the abundance of Copelata (*Oikopleura dioica*, *Fritillaria borealis*) and Cladocera (*Evadne nordmanni*) decreased to 46 and 13 ind. m^{-3} , respectively. A few rotifers of the genus *Synchaeta* were also observed (190 ind. m^{-3}). The copepods (1.0×10^4 ind. m^{-3}) showed a large increase due to the abundance of *Pseudo/Paracalanus*, which doubled to 7.4×10^3 ind. m^{-3} while *Oithona* remained on the level of February (1.8×10^3 ind. m^{-3} , Fig. 23). The genus *Acartia* increased only slightly (210×10^3 ind. m^{-3}) and was similar to *Centropages hamatus* (670 ind. m^{-3}) and *Temora longicornis* (210 ind. m^{-3}) still rare. *Pseudocalanus* spp. was the dominating species among the adult copepods (2.2×10^3 ind. m^{-3}) and contributed to 70 % of the adult stock.

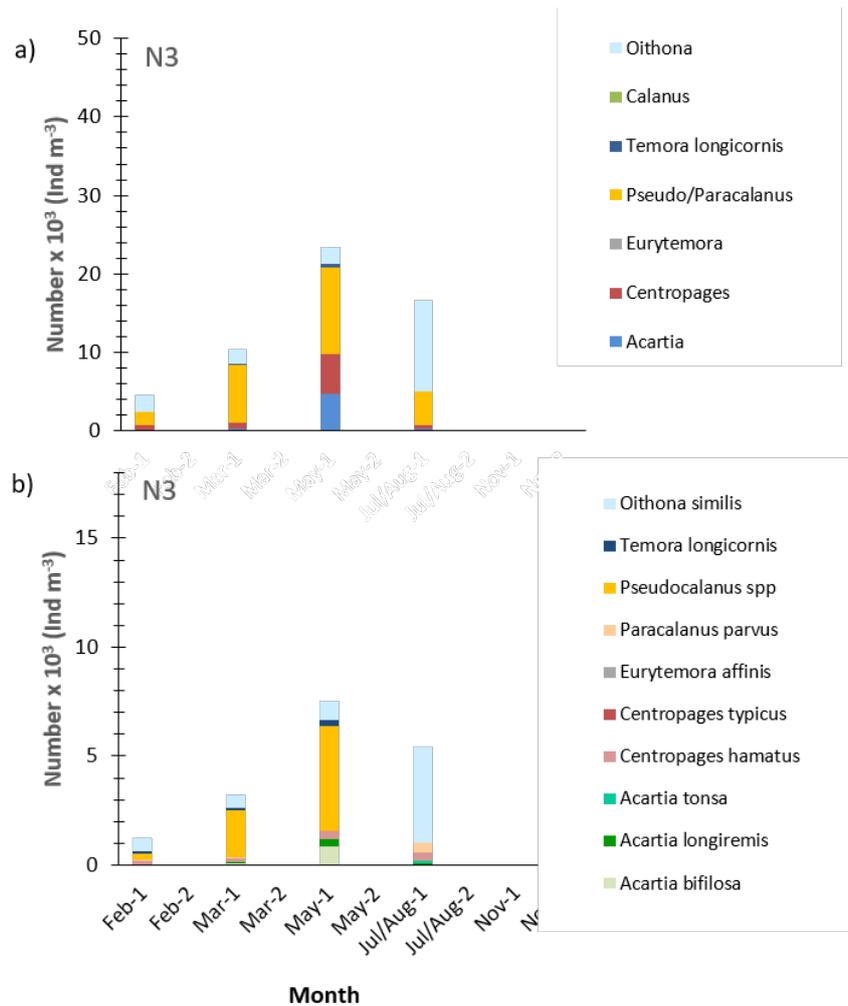


Fig. 23 Seasonal variation of the juvenile (a) and adult stages of copepods (b) in the Kiel Bight (Station N3) during the year 2022. Note the different scale in the abundance of juveniles and adults.

In May, the stock increased further (2.3×10^4 ind. m^{-3}) and was dominated completely by the copepods (Fig. 22). They contributed to 98 % to the zooplankton. This has only become a regular feature of the spring composition of the zooplankton in recent years. In the early 2000s, meroplankton and rotifers were abundant. The only other holoplanktonic group observed in May 2022 were the cladocerans (150 ind. m^{-3}), with *Evadne nordmanni* and *Podon leuckartii* having an equal share. Among the copepods (Fig. 23), the concentration of *Pseudo/Paracalanus* further increased to 1.1×10^4 ind. m^{-3} ; however, the dominance of this genus was reduced to 47 % of the copepod stock because the abundance of *Centropages* and *Acartia* have also increased to 4.9 and 4.8×10^3 ind. m^{-3} . The density of *Oithona* and *Temora*, in contrast, still remained on the winter levels. Among the adult copepods, *Pseudocalanus* spp. was still the most abundant genus (4.9×10^3 ind. m^{-3}) followed by *Oithona similis* (864 ind. m^{-3}) and *Acartia bifilosa* (862 ind. m^{-3}). *A. longiremis* was observed in small numbers (306 ind. m^{-3}) as well as *Centropages hamatus* (420 ind. m^{-3}) and *Temora longicornis* (315 ind. m^{-3}).

The warming of the water column during summer usually results in a shift in the community composition in which the cold-water species vanish to the benefit of warm-water species. This was also the case in the Kiel Bight in 2022 (Fig. 22). Nevertheless, some clear differences to preceding years were observed. While the contribution of 50 % of the copepods to the stock met

the long-term mean well, their abundance was still unusually high (1.6×10^4 ind. m^{-3}). This applied also to density of the Copelata that achieved 1.3×10^4 ind. m^{-3} and, thus, an unusual high share of more than 39 % of the community. Such high concentrations are usually observed during autumn. *Oikopleura dioica* was the only species and, thus, occurred earlier than usual. In contrast, the abundance of meroplankton and in particular of the bivalve larvae was one order of magnitude lower than usual (526 ind. m^{-3}). Gastropods, in contrast, were more abundant (947 ind. m^{-3}). Larvae of echinoderms (70 ind. m^{-3}) and bryozoans (35 ind. m^{-3}) contributed less to the community. Cladocerans had a low abundance as well. *Evadne nordmanni* and *Podon leuckartii* occurred at a density of 140 ind. m^{-3} . However, unusual high numbers of *Penilia avirostris* were observed (1088 ind. m^{-3}).

The composition of the copepod showed a large shift (Fig. 23). The dominance of the genera *Pseudo/Paracalanus* (4.2×10^3 ind. m^{-3}) was replaced by *Oithona* (1.2×10^4 ind. m^{-3}), which contributed to 70 % of the stock. *Oithona similis* dominated also the adults stock (4.8×10^3 ind. m^{-3}). The composition of adult stock suggests also that a shift from *Pseudocalanus* to *Paracalanus* occurred within the group of *Pseudo/Paracalanus* since *Paracalanus parvus* was the only species found (456 ind. m^{-3}). *Centropages* and *Acartia* were the two other genera observed during summer, their abundance was low (456 and 281 ind. m^{-3}). Three species of *Acartia* were identified; in addition to *A. bifilosa* and *A. longiremis*, the warm-water species *A. tonsa* occurred in low numbers.

Bay of Mecklenburg (M2, M1)

The similarity in the composition and seasonal variation of the zooplankton in the Kiel Bight and the Bay of Mecklenburg is generally high. This was also the case in 2022 (Fig. 20, Fig. 22, Fig. 24). The Bay of Mecklenburg represents a transition area into the Baltic Proper and may show the influence of marine as well as Baltic surface water often in combination with the prevailing wind conditions (DUTZ & WASMUND 2023). In 2022, there was a marked resemblance to the Kiel Bight. Thus, copepods (max. $3.9 - 4.3 \times 10^3$ ind. m^{-3}) dominated the community strongly with a contribution of on average 74 % of the community (Fig. 20 c, e). Although the abundance of Copelata had diminished (max. $4.3 - 6.1 \times 10^3$ ind. m^{-3}), they still had a significant share (15 %). The contribution of cladocerans and rotifers of less than 3 % was also low. In the past, contributions of more than 20 % were common, indicating that the Baltic influence in the area was low in 2022. This is also reinforced in the composition of the copepods (Fig. 20 d, f). Although *Acartia*, *Temora* and *Centropages* increased in abundance (max. $1.1-7.3 \times 10^3$ ind. m^{-3}), *Pseudocalanus* (max. $1.5-1.8 \times 10^4$ ind. m^{-3}) and *Oithona* ($0.9-1.4 \times 10^4$ ind. m^{-3}) dominated the community in spring and summer, respectively (Fig. 26). The low abundance of meroplankton observed already in the Kiel Bight was also remarkable in the Bay of Mecklenburg. While most meroplankton occurred at the usual density, the bivalve larvae ($3.3 - 3.9 \times 10^3$ ind. m^{-3}) displayed a considerable reduction in the stock size by one order of magnitude compared to previous years ($5.7 - 14.1 \times 10^3$ ind. m^{-3}).

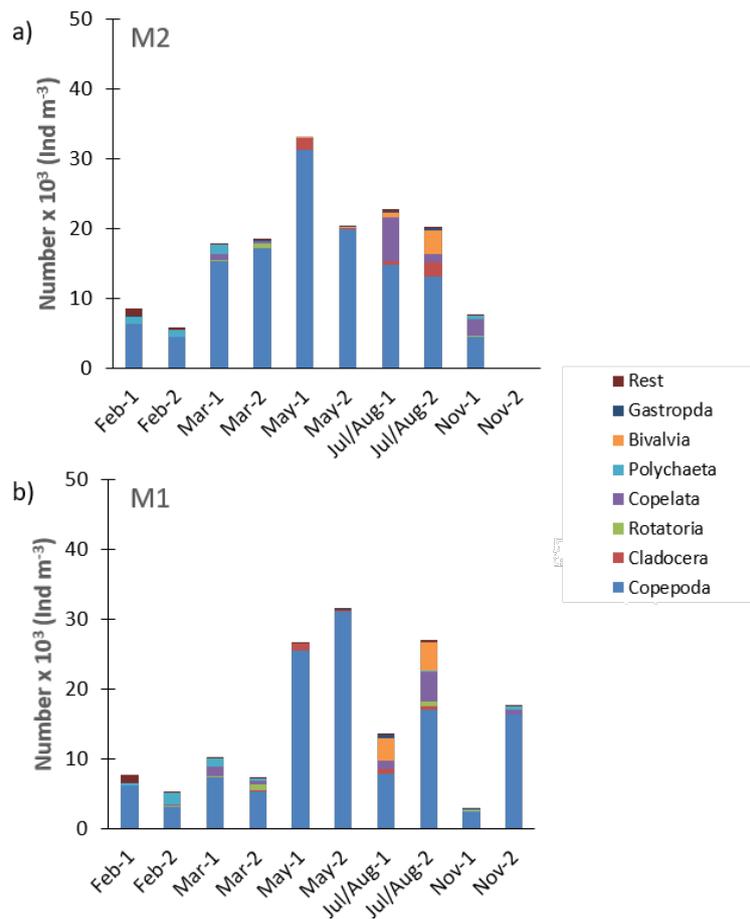


Fig. 24 Seasonal variation of the main taxonomic groups at stations M2 (a) and M1 (b) in the Bay of Mecklenburg during the year 2022.

Similar to the Kiel Bight, the stock of the zooplankton showed a strong seasonal variation that contrasts the preceding year (Fig. 24). The early increase in stocks already in March was more pronounced in the central area of the Bay (station M2) than in the northern area (station M1). The early development is reinforced by stock sizes in March ($0.7 - 1.9 \times 10^4 \text{ ind. m}^{-3}$) that were higher than usual, particularly in the group of copepods. The maximum abundance was achieved in May ($2.0 - 3.3 \times 10^4 \text{ ind. m}^{-3}$), which is typical for the area. However, the dominance of copepods during this time is unusual, since the early maxima were mostly caused by the peak concentrations of rotifers in the past. Due to a lower density of Copelata in the Bay, the autumn maximum that was observed in the Kiel Bight was lacking. Nevertheless, zooplankton remained abundant ($1.3 - 2.7 \times 10^4 \text{ ind. m}^{-3}$). There was a strong decline of the zooplankton in the autumn ($2.9 - 7.8 \times 10^3 \text{ ind. m}^{-3}$). However, at station M1 in the northern Bay of Mecklenburg, copepods were still abundant in one sample ($1.8 \times 10^4 \text{ ind. m}^{-3}$).

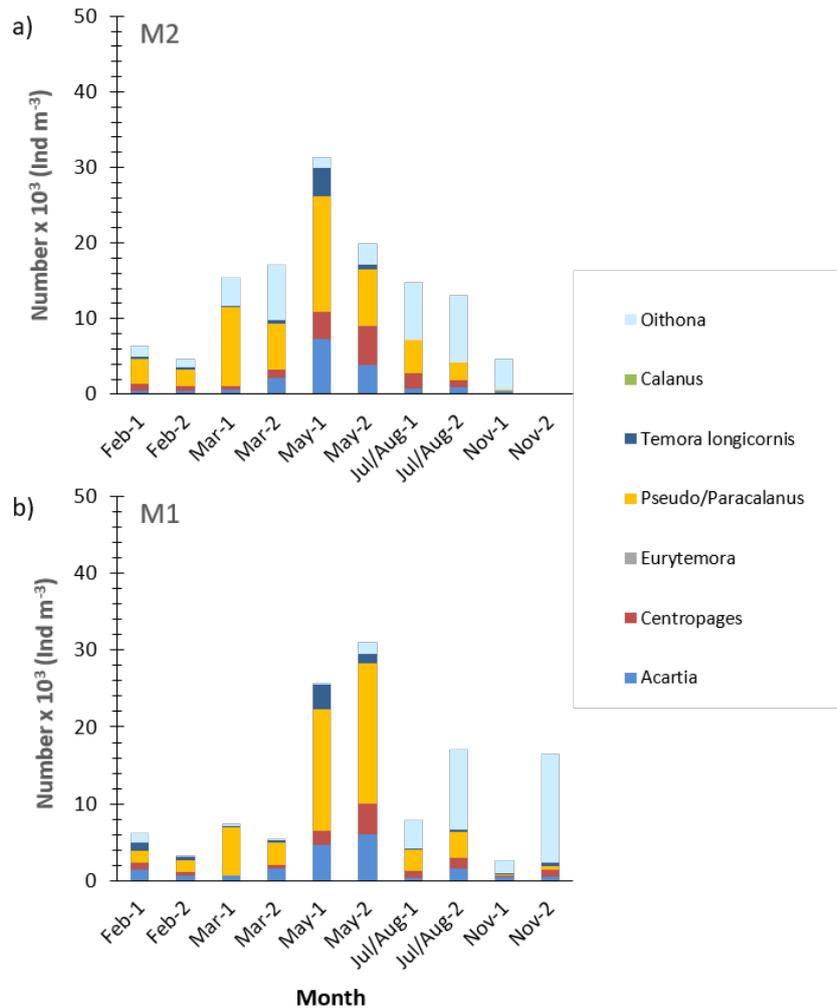


Fig. 25 Seasonal variation of the composition of the copepodite stages (sum of stages C₁-C₆) at stations M2 (a) and M1 (b) in the Bay of Mecklenburg during the year 2022.

The overwintering stock (8.7×10^3 ind. m⁻³) was low as usual (Fig. 24). Copepods (6.4×10^3 ind. m⁻³) and meroplankton (2.2×10^3 ind. m⁻³) were dominating (98 % of the stock), other groups were only of minor importance such as the cladoceran *Evdne nordmanni* (31 - 81 ind. m⁻³) or the appendicularian *Oikopleura dioica* (7.4 ind. m⁻³) as remnant of the late autumn community of the preceding year. The meroplankton consisted primarily of polychaete ($0.4 - 1.7 \times 10^3$ ind. m⁻³) and gymnolaemate larvae (259 - 881 ind. m⁻³), while cirripede (19 - 266 ind. m⁻³), gastropod (44 - 54 ind. m⁻³) and bivalve larvae (7 - 8 ind. m⁻³) were of minor importance. With the exception of the bivalve larvae, meroplankton occurred at their usual concentrations.

The winter stock of copepods was dominated by *Pseudo/Paracalanus* ($1.6 - 3.2 \times 10^3$ ind. m⁻³, Fig. 25), with *Pseudocalanus* spp. as the major species (Fig. 26). Similar to Kiel Bight, *Paracalanus* was present at low numbers – again likely as remnants of the autumn community. Other copepods of importance were the cycloid copepod *Oithona* ($0.2 - 1.4 \times 10^3$ ind. m⁻³) and *Centropages* ($0.4 - 0.9 \times 10^3$ ind. m⁻³), while numbers of *Acartia* and *Temora* were still low (< 500 ind. m⁻³). About one third of the adult copepods consisted of *Pseudocalanus* (242 - 363 ind. m⁻³), followed by *Oithona similis* (43 - 231 ind. m⁻³), *Centropages hamatus* (111 - 264 ind. m⁻³) and *Acartia bifilosa*/*A. longiremis* (25 - 309 ind. m⁻³).

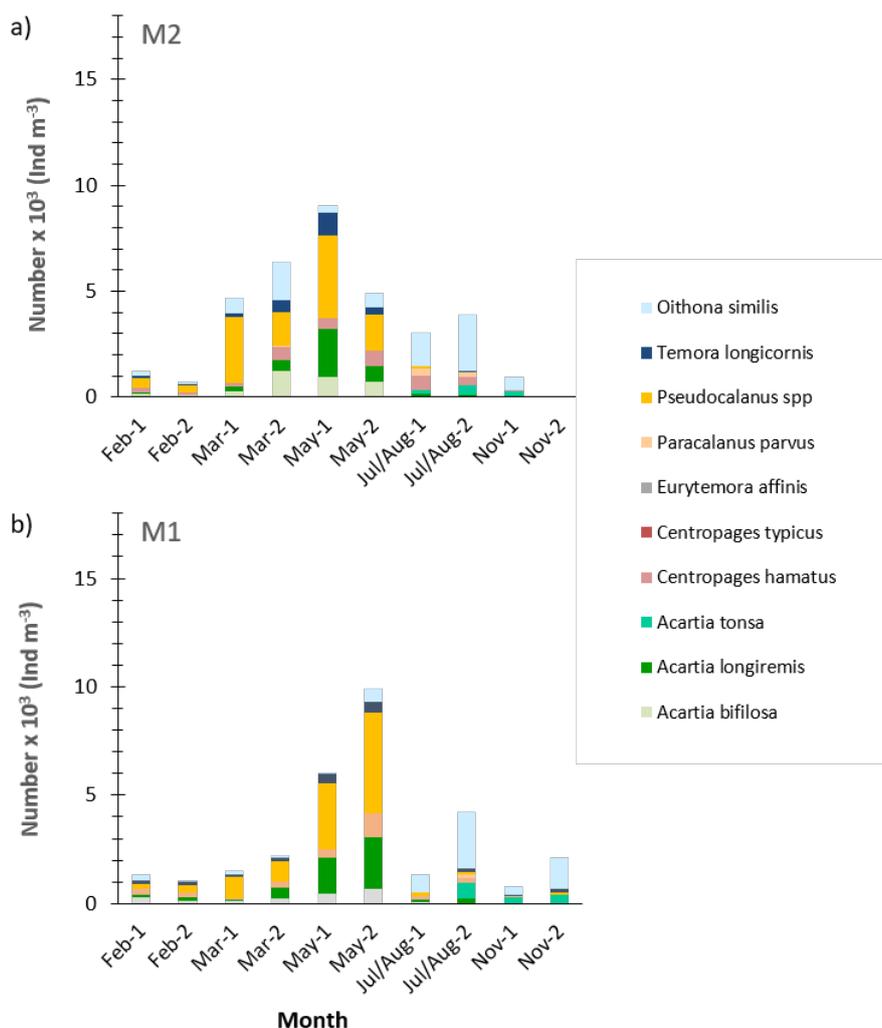


Fig. 26 Seasonal variation of the composition of adult stages of copepods (stage C_6) at stations M2 (a) and M1 (b) in the Bay of Mecklenburg during the year 2022.

The increase in the stock size in March was caused by the copepods ($0.5-1.7 \times 10^4 \text{ ind. m}^{-3}$) and the Copelata ($0.3 - 1.4 \times 10^3 \text{ ind. m}^{-3}$), while the density of the meroplankton did not change ($0.2 - 1.3 \times 10^3 \text{ ind. m}^{-3}$). Among the Copelata, *Fritillaria borealis* had completely replaced *Oikopleura dioica* in response to the beginning spring bloom. Polychaete larvae still were the most abundant meroplankton ($1.2 - 1.2 \times 10^3 \text{ ind. m}^{-3}$). They vanished already during March and were replaced by the rotifer *Synchaeta* sp. ($630 - 882 \text{ ind. m}^{-3}$). The cladocerans *Evadne nordmanni* and *Podon leuckartii* occurred regularly but at low abundance ($< 120 \text{ ind. m}^{-3}$). The increase in the copepods was related to *Pseudocalanus* ($0.3 - 1.0 \times 10^4 \text{ ind. m}^{-3}$) and *Oithona* ($3.7 - 7.3 \times 10^3 \text{ ind. m}^{-3}$). However, *Oithona* was abundant at station M2 only. *Acartia* and *Centropages* started to increase as well ($0.5 - 2.1 \times 10^3 \text{ ind. m}^{-3}$), while the abundance of *Temora* remained low ($< 600 \text{ ind. m}^{-3}$). Among the adults copepods (Fig. 26), the stocks of *Pseudocalanus* ($0.9 - 3.1 \times 10^3 \text{ ind. m}^{-3}$) and *Oithona similis* ($0.7 - 1.8 \times 10^3 \text{ ind. m}^{-3}$) increased considerably at station M2. The density of other species was still low.

The copepods were mainly responsible for the further increase of the zooplankton stock in May ($2.0 - 3.3 \times 10^4 \text{ ind. m}^{-3}$, Fig. 24). Meroplankton had largely disappeared ($40 - 273 \text{ ind. m}^{-3}$) and was replaced by the Cladocera as the second most abundant group ($0.2 - 1.7 \times 10^3 \text{ ind. m}^{-3}$).

Evadne nordmanni and *Podon leuckartii* were the main species, but occurred in strongly varying concentrations (32 - 1714 ind. m⁻³). The meroplankton consisted of bivalve (40 - 190 ind. m⁻³), gastropod (8 - 136 ind. m⁻³) and cirripede larvae (11 - 136 ind. m⁻³). Similar to the Kiel Bight, the composition of the copepod community deviated from the preceding years (Fig. 25, Fig. 26). While the abundance of *Acartia* (3.9 - 7.3 x 10³ ind. m⁻³) and *Oithona* (1.3 - 2.7 x 10³ ind. m⁻³) was lower than in the period 2016 - 2021, *Pseudocalanus* was considerably more abundant (0.7 - 1.8 x 10⁴ ind. m⁻³) and dominated the copepod community with a contribution of 51% to the stock (Fig. 25). *Centropages* and *Temora* had increased in stock size and occurred at their usual densities of 1.9 - 5.1 and 0.7 - 3.8 x 10³ ind. m⁻³, respectively. Among the adults (Fig. 26), *Pseudocalanus* spp. (1.6 - 4.6 x 10³ ind. m⁻³), *A. longiremis* (0.7 - 2.4 x 10³ ind. m⁻³) and *C. hamatus* (0.4 - 1.1 x 10³ ind. m⁻³) outnumbered *T. longicornis*, *A. bifilosa* and *O. similis* (< 10³ ind. m⁻³).

In August, the community became more diverse in the Bay of Mecklenburg (Fig. 24). Copepods still dominated the community (0.8 - 1.5 x 10⁴ ind. m⁻³) and contributed 51 % to the zooplankton stock. Copelata (1.1 - 6.2 x 10³ ind. m⁻³) and meroplankton (1.0 - 4.1 x 10³ ind. m⁻³) were abundant as well and shared 15% of the stock, respectively. As usual, *Oikopleura dioica* had completely replaced *Fritillaria borealis*. Bivalve larvae dominated the meroplankton (0.7 - 3.9 x 10³ ind. m⁻³), while gastropod, echinoderm and diverse crustacean larvae were observed in low numbers (< 350 ind. m⁻³). The Cladocera contributed to 5% of the stock (0.4 - 2.1 x 10³ ind. m⁻³), with the majority consisting of *Evadne nordmanni* (0.2 - 1.4 x 10³ ind. m⁻³) and lower concentrations of *Bosmina* spp. (33 - 136 ind. m⁻³), and *Podon intermedius* (67 - 178 ind. m⁻³). Few chaetognaths and cnidarians were observed as well (< 76 ind. m⁻³). The copepod community had shifted considerably in the composition, mirroring the seasonal change in the Kiel Bight (Fig. 25, Fig. 26). The genus *Oithona* dominated (0.4 - 1.0 x 10⁴ ind. m⁻³) and contributed to 58 % to the stock, followed by *Pseudo/Paracalanus* with 25% (2.3 - 4.3 x 10³ ind. m⁻³). *Acartia* and *Centropages* occurred at their usual density of 0.2 - 1.6 and 0.8 - 2.0 x 10³ ind. m⁻³, respectively. *Temora*, however, was less abundant than usual (33 - 402 ind. m⁻³). *Oithona similis* was by far the most abundant species among the adult copepods (0.8 - 2.7 x 10³ ind. m⁻³). *Paracalanus parvus* (248 - 321 ind. m⁻³) had largely replaced *Pseudocalanus* spp. (24 - 134 ind. m⁻³). The genus *Acartia* was represented by three species, with *A. tonsa* being slightly more abundant (31 - 737 ind. m⁻³) than *A. longiremis* (33 - 201 ind. m⁻³) and *A. bifilosa* (34 - 71 ind. m⁻³).

By November, the zooplankton community had declined to 0.3 - 1.7 x 10⁴ ind. m⁻³ (Fig. 24). There was a large variability due to an unusual high concentration of *Oithona* in one sample on station M1. Copepods (0.3 - 1.6 ind. m⁻³), meroplankton (262 - 763 ind. m⁻³) and Copelata (115 - 2435 ind. m⁻³) were dominating the community with an average of 69, 13 and 12% of the stock. Polychaete larvae were the most abundant meroplankton 136 - 513 (ind. m⁻³). *Oithona similis* was dominating the copepodite and adult stocks by more than 83% (0.2 - 1.4 x 10⁴ ind. m⁻³), other genera were comparatively rare (< 380 ind. m⁻³).

Arkona Basin (K5, K4)

The seasonal timing of the increase and the maxima of the zooplankton is generally very variable in the Arkona Basin. This is related to the abundance of the two major groups, the rotifers and the cladocerans, that shape the seasonal variation together with the copepods by their very high numbers in spring or autumn. In 2021 for instance, there was a late summer maximum caused

by the high abundance of the cladoceran *Bosmina* spp. In 2022, in contrast, the early maximum of the rotifer *Synchaeta* spp. shifted the maximum of the zooplankton ($1.8 - 2.9 \times 10^4$ ind. m^{-3}) into spring (Fig. 27). Nevertheless, copepods dominated the community on an annual basis (40 %) followed by the rotifers (28 %) and the meroplankton (14 %, Fig. 20 g, i). The contribution of Cladocera was unusually low (9 %) considering that the group contributed to more than 40 % to the stock in the past. Apart from this shift in the dominance associated with the reduced stock size of the Cladocera, the abundance of the other groups were well within the range that is typically observed in the area. In contrast to the Belt Sea that was characterized by unusually high densities of *Pseudo/Paracalanus*, also no remarkable shifts in the composition of the copepods occurred. Therefore, the copepod community was as usual balanced with more or less similar stock sizes of the major genera (Fig. 28). The abundance of *Acartia*, *Centropages*, *Pseudo/Paracalanus* and *Temora* varied within a similar range of $1.3 - 5.8 \times 10^3$ ind. m^{-3} . Only *Oithona* was observed at a lower concentration ($0.7 - 1.3 \times 10^3$ ind. m^{-3}).

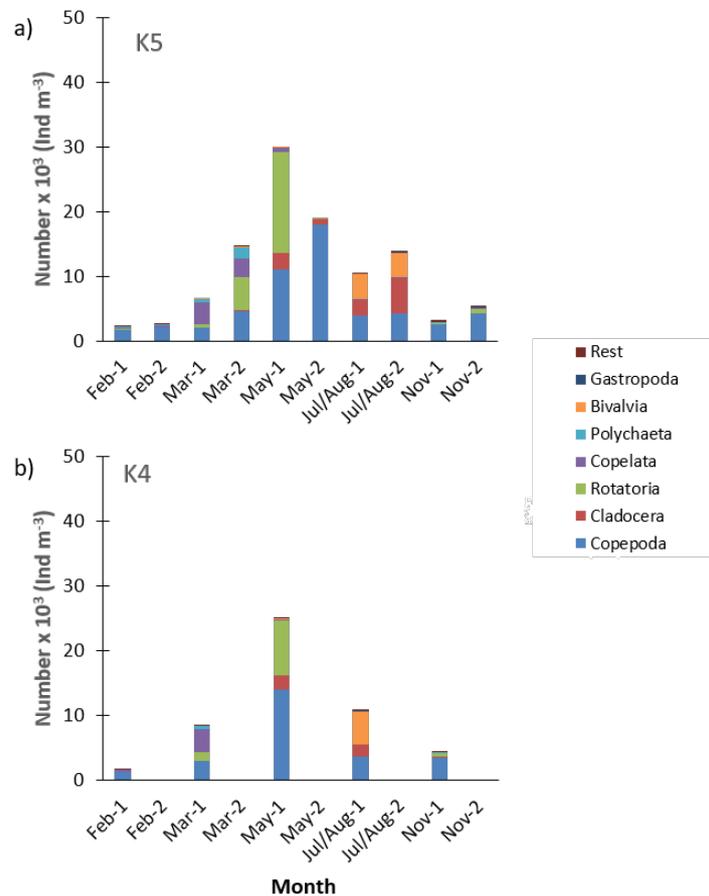


Fig. 27 Seasonal variation of the main taxonomic groups at stations K5 (a) and K4 (b) in the Arkona Basin during the year 2022.

The overwintering stock of $1.6 - 2.3 \times 10^3$ ind. m^{-3} was only slightly below the long term mean (Fig. 27). This applies also to the composition of the stock that was dominated by the copepods with a contribution of 77 %. Copelata ($185 - 258$ ind. m^{-3}) and meroplankton ($74 - 318$ ind. m^{-3}) constituted 10 % of the stock size, respectively. As usual, *Fritillaria borealis* was the only species occurring in the winter-spring period. Polychaete larvae were the most abundant meroplankton ($24 - 246$ ind. m^{-3}) followed by few bivalve and gymnolaemate larvae. The rotifer stock was low ($14 - 64$ ind. m^{-3}) and only a few specimens of the cladoceran *Evadne nordmanni* were found (1 -

3 ind. m⁻³). *Acartia* (407 - 667 ind. m⁻³) and *Pseudo/Paracalanus* (485 - 766 ind. m⁻³) dominated among the copepods (Fig. 28), while *Temora*, *Centropages* and *Oithona* occurred at low numbers (52 - 276 ind. m⁻³). A few *Eurytemora* were observed as well. This was reflected in the composition of the adult copepod stock (Fig. 29) in which *Acartia* was the main species followed by *Pseudocalanus* spp., *Centropages hamatus*, *Acartia bifilosa* and *Temora longicornis* that had a similar but low abundance (< 200 ind. m⁻³).

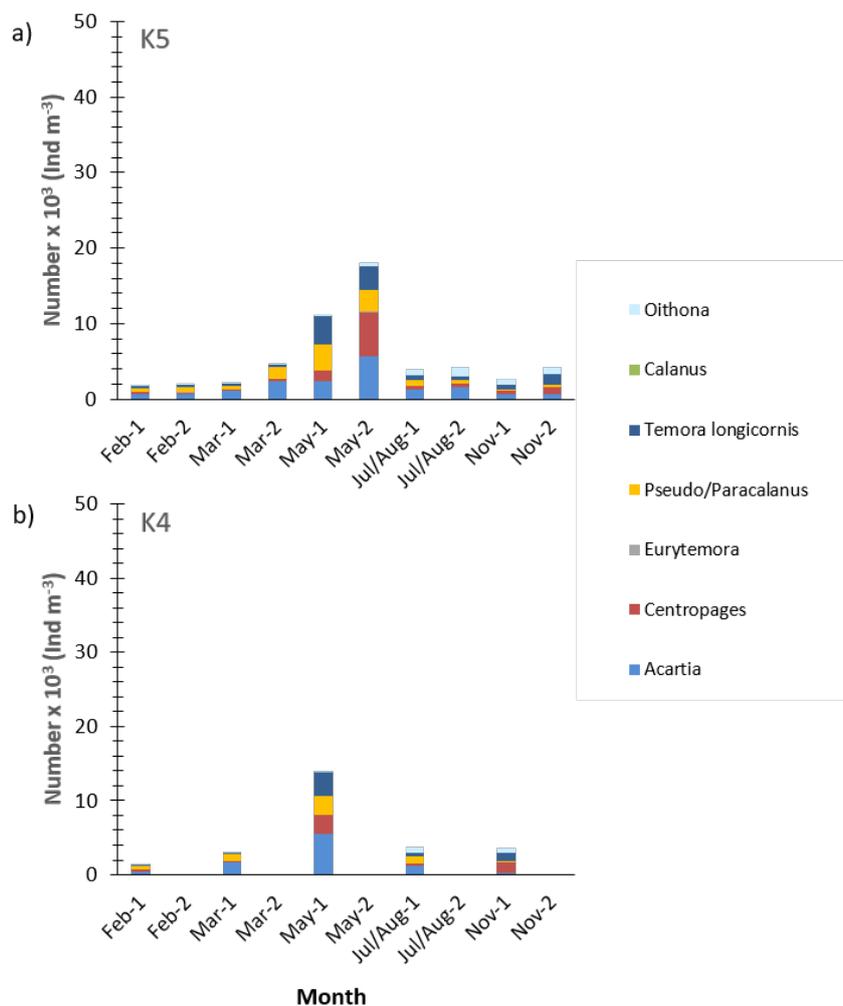


Fig. 28 Seasonal variation of the composition of the copepodite stages (sum of stages C₁-C₆) at stations K5 (a) and K4 (b) in the Bay of Mecklenburg during the year 2022.

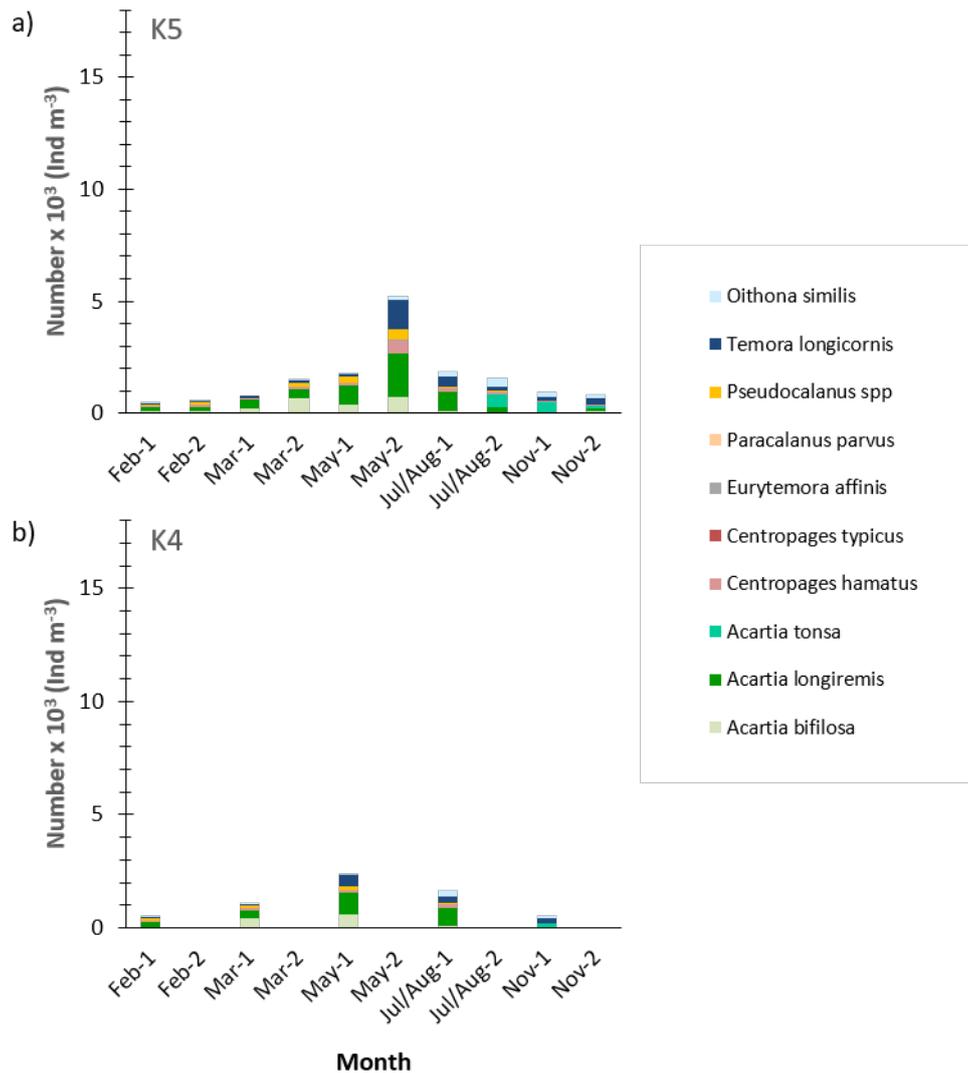


Fig. 29 Seasonal variation of the composition of adult stages of copepods (stage C₆) at stations M2 (a) and M1 (b) in the Bay of Mecklenburg during the year 2022.

The zooplankton stock increased during March from 6.4×10^3 ind. m^{-3} to 1.5×10^4 ind. m^{-3} (Fig. 27). The copepod dominance declined to 42 % of the stock ($2.0 - 4.7 \times 10^3$ ind. m^{-3}) because the Copelata that show their seasonal maximum in March (22 %, $3.0 - 3.5 \times 10^3$ ind. m^{-3}), the rotifers (18%, $0.4 - 5.0 \times 10^3$ ind. m^{-3}) and the meroplankton (17%, $0.4 - 1.7 \times 10^3$ ind. m^{-3}) had a disproportionally stronger increase. These major groups occurred at their usual abundance. The species composition changed only little, with *Synchaeta* spp. and *Fritillaria borealis* still being the main species. Polychaete larvae constituted the major meroplankton groups ($0.5 - 1.6 \times 10^3$ ind. m^{-3}), and only a few gastropod or gymnolaemate larvae were observed (< 100 ind. m^{-3}). Among the copepods (Fig. 28), the stock size of *Acartia* ($1.4 - 2.5 \times 10^3$ ind. m^{-3}) and *Pseudo/Paracalanus* ($0.6 - 1.6 \times 10^3$ ind. m^{-3}) started to increase. All other genera remained on their winter levels (< 300 ind. m^{-3}). The increase among the adult copepods reflected this by the elevation of the stock size of the *Acartia* species (Fig. 29). *A. bifilosa* and *A. longiremis* showed a similar abundance (190 - 650 ind. m^{-3}).

The stock increased further to the annual maximum until May (Fig. 27). The mean abundance of zooplankton of $1.3 - 3.0 \times 10^4$ ind. m^{-3} was, however, below the long - term average. This is mainly

related to the group of rotifers that typically show their maxima during this time with up to 6.0×10^4 ind. m^{-3} . In 2022, the maximum abundance amounted to only 1.5×10^4 ind. m^{-3} . Considering the low abundance of rotifers from 2019-to 2021 ($1.1 - 7.5 \times 10^3$ ind. m^{-3}), however, this might indicate a recovery of the rotifers in May. Copepods still were the major zooplankton ($1.1 - 1.8 \times 10^4$ ind. m^{-3}) and contributed to 58 % to the stock (Fig. 20), followed by the rotifers (33 %) that were represented by *Synchaeta* spp. The Cladocera increased in stock size ($0.7 - 2.5 \times 10^3$ ind. m^{-3} , 7 %). Similar to the Belt Sea, *Evadne nordmanni* ($0.5 - 2.3 \times 10^3$ ind. m^{-3}) and *Podon leuckartii* (119 - 660 ind. m^{-3}) dominated during spring. The stocks of *Fritillaria borealis* (Copelata) had declined to 149 - 784 ind. m^{-3} (4 % of the zooplankton). This is commonly observed in the area. Meroplankton showed likewise a very low concentration (40 - 145 ind. m^{-3}). Bivalve larvae were the only group of importance (37 - 132 ind. m^{-3}) Among the copepods, *Acartia* ($2.3 - 5.7 \times 10^3$ ind. m^{-3}) and *Pseudo/Paracalanus* ($2.6 - 3.8 \times 10^3$ ind. m^{-3}) increased further in numbers (Fig. 28), but also the stock of *Centropages* and *Temora* was now considerably larger with on average $1.4 - 5.9$ and $3.2 - 3.8 \times 10^3$ ind. m^{-3} , respectively. In contrast, *Oithona* remained rare (56-336 ind. m^{-3}). The abundance of *Acartia* was lower than usual and the species composition was more balanced with the major genera contributing to 21 - 32 % to the stock. *Acartia longiremis* ($0.8 - 1.9 \times 10^3$ ind. m^{-3}) and *Temora longicornis* ($0.1 - 1.3 \times 10^3$ ind. m^{-3}) dominated the stock as usual during May (Fig. 29), other species occurred with less than 700 ind. m^{-3} .

Due to the low abundance of the cladocerans, copepods (34 %) and meroplankton (38 %) were major contributors to the stock in August (Fig. 27). Since the copepods decreased considerably and displayed also a lower abundance than usual ($3.9 - 4.3 \times 10^3$ ind. m^{-3}), the share of meroplankton was higher than usual (12 %). The bivalves ($3.8 - 5.3 \times 10^3$ ind. m^{-3}) were the major meroplankton group, gastropod and cirripede larvae contributed only little (70 - 152 and 9 - 10 ind. m^{-3} , respectively). Cladocera were low in abundance, particularly due to low *Bosmina* spp. stocks ($1.3 - 4.7 \times 10^3$ ind. m^{-3}). Other species displayed a one order of magnitude lower abundance. While *Evadne nordmanni* (176 - 467 ind. m^{-3}) occurred year round, *Podon intermedius* (76 - 165 ind. m^{-3}) had replaced *P. leuckartii*. *Oikopleura dioica* occurred at low numbers (44 - 143 ind. m^{-3}), the species in never a prominent part of the zooplankton in the Arkona Basin. Among the copepods, most genera except the cyclopoid *Oithona* were reduced in their abundance (Fig. 28). *Acartia* ($1.1 - 1.6 \times 10^3$ ind. m^{-3}) and *Oithona* ($0.8 - 1.3 \times 10^3$ ind. m^{-3}) were still present in higher numbers, whereas all other genera were below 1.0×10^3 ind. m^{-3} . The abundance of the different species within the adult copepods was low (Fig. 29). *Acartia longiremis* was slightly more abundant than the other species (214 - 852 ind. m^{-3}). With *Acartia tonsa* (0 - 571 ind. m^{-3}) and *Paracalanus parvus* (9 - 19 ind. m^{-3}) warm-temperate species were present, but were found at low numbers.

In November, the zooplankton density dropped to $3.1 - 5.2 \times 10^3$ ind. m^{-3} (Fig. 27). All major groups occurred below their usual abundance and, thus, the stock was the lowest in the recent decade. Copepods dominated considerably (81 %, $2.6 - 4.2 \times 10^3$ ind. m^{-3}), which is a usual observation for autumn in the area. Rotifers contributed only little (9%, 14 - 608 ind. m^{-3}); both *Synchaeta* (560 - 594 ind. m^{-3}) and *Keratella* (8 - 14 ind. m^{-3}) were present. All other groups contributed less than 3 % to the stock. Copelata were represented by both *Fritillaria borealis* (1 - 12 ind. m^{-3}) and *Oikopleura dioica* (42 - 157 ind. m^{-3}). *Evadne nordmanni* (96 - 122 ind. m^{-3}) was the only cladoceran species that was found. All major larval groups such polychaetes, bivalves,

gastropods and cirripedes were found in the meroplankton. Their abundance was below 100 ind. m⁻³. All major genera of the copepods were still present in the zooplankton. *Temora* and *Centropages* were slightly dominating with usual concentrations of 0.5 - 1.4 x 10³ ind. m⁻³, respectively, whereas *Acartia* was below (262 - 707 ind. m⁻³) and *Oithona* above the expected density (561 - 971 ind. m⁻³). *Temora longicornis*, *Acartia tonsa* and *Oithona similis* were found in reasonable numbers among the adult community (< 111 - 280 ind. m⁻³); other species were rare.

3.2.3 Long-term trends

Based on the maximal abundance at the five monitoring stations, the zooplankton shows a continuously low stock size varying between 0.4 and 2.0 x 10⁵ ind. m⁻³ since the year 2011 (Fig. 30 a). The year 2022 was no exception and the stock of 0.6 x 10⁵ ind. m⁻³ is the second lowest value after the all-time minimum observed in 2020. This is only 22 % of the long-term mean of 2.6 x 10⁵ ind. m⁻³ for the years 1995-2022, but also only 37 % of the mean of the recent decade from 2010-2022 (1.5 x 10⁵ ind. m⁻³). The annual anomalies of the total zooplankton abundance emphasize that 2022 is the 11th year in row in which the zooplankton is below the long-term average (Fig. 30b). The anomaly was calculated by subtracting the long-term annual average of the total zooplankton abundance in 1995-2020 (B , log₁₀-transformed) from the annual maximum total abundance (b , log₁₀-transformed) according to MACKAS & BEAUGRAND (2010):

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

Except the Copelata, all zooplankton groups displayed a considerable reduction in the stock size. This was most pronounced in the Cladocera (-95 %, long-term mean 9.6 x 10⁴ ind. m⁻³), the polychaete larvae (-93 %, 2.6 x 10⁴ ind. m⁻³) and the rotifers (-81 %, 8.2 x 10⁴ ind. m⁻³). Remarkably, these zooplankton groups show a temporally limited period of occurrence in the seasonal cycle such as winter-spring (polychaete larvae), spring (rotifers) and summer (Cladocera). Calanoid and cyclopoid copepods were 50-53 % below their long-term mean (1.8 and 0.9 x 10⁴ ind. m⁻³, respectively), while gastropod and bivalve larvae were reduced by 38-66 % (0.2 and 1.4 x 10⁴ ind. m⁻³, respectively). Copelata, in contrast, displayed an increase by 60 % in comparison to their long-term mean (8.1 x 10³ ind. m⁻³, respectively). This is mainly related to the unusual high concentrations observed during summer in the Belt Sea.

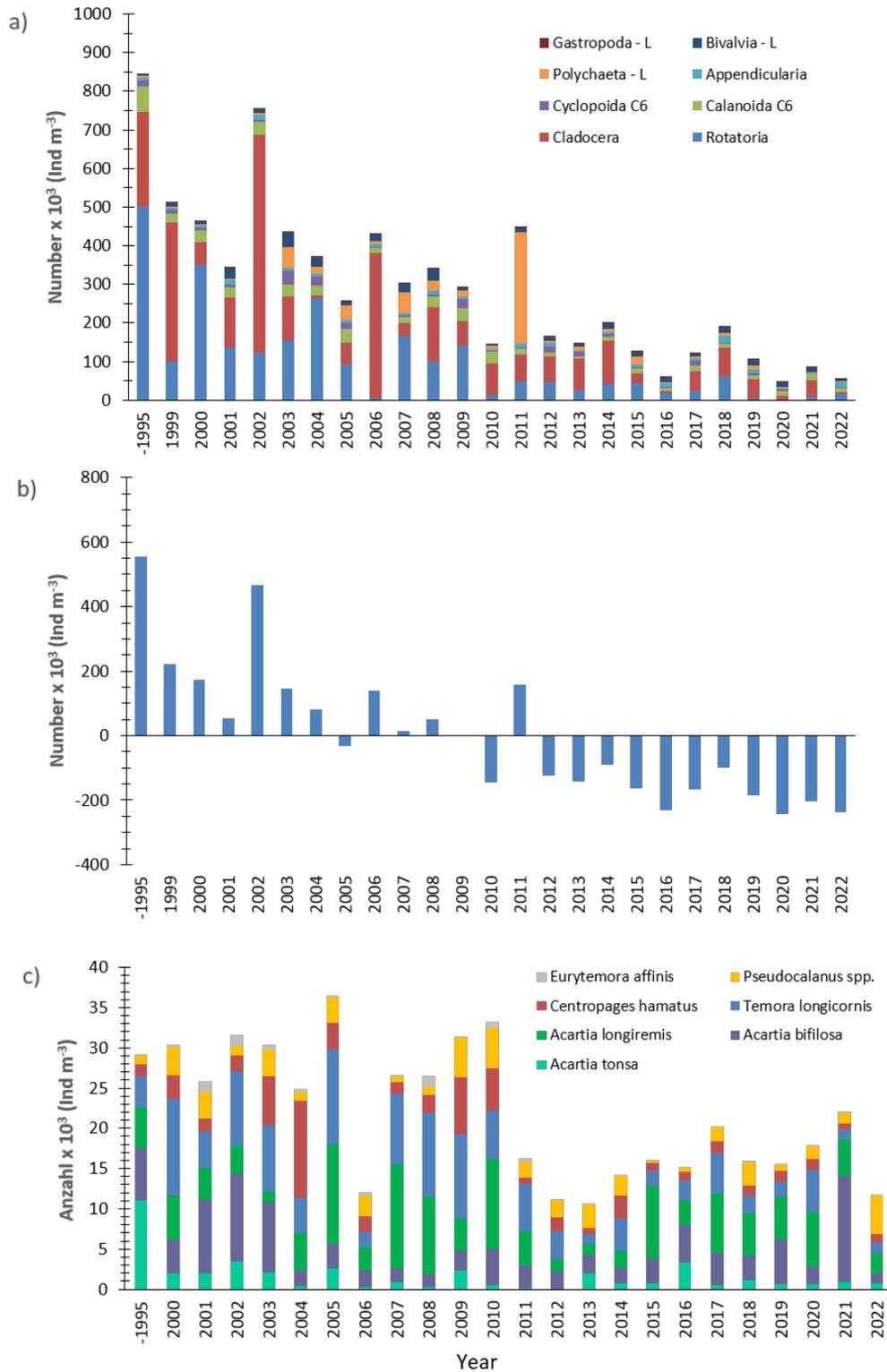


Fig. 30 Long-term trends in the maximal abundance of a) holoplanktonic taxa (Rotatoria, Cladocera, Cyclopoida, Calanoida, Copelata) and meroplanktonic taxa (Polychaeta, Bivalvia, Gastropoda), b) in the anomalies of the total zooplankton abundance and c) of seven calanoid copepod species in the years 1995 to 2022 across all stations (Kiel Bight: N3, Bay of Mecklenburg: M2, M1, Arkona Sea: K4, K5).

The slow recovery of the calanoid copepods from their minimum in 2012-2013 apparently lasted only until 2021 and did not continue in 2022 (Fig. 30 c). This ecologically important group showed one of their lowest values during the whole time series. The community showed a marked change

in the composition during 2022, again observed primarily in the Belt Sea by a shift from the genus *Acartia* to *Pseudo/Paracalanus*. The three *Acartia* species (*A. longiremis*, *A. bifilosa*, *A. tonsa*) usually dominate the community, but were considerably reduced by 39 to 60 % compared to their long-term mean ($1.2\text{-}4.5 \times 10^3$ ind. m^{-3}). This reduction was even more pronounced in *Temora longicornis* (-75 %) and *Centropages hamatus* (-58 %) with long-term stock sizes of 5.3×10^3 ind. m^{-3} and 2.6×10^3 ind. m^{-3} , respectively. In contrast, *Pseudocalanus* spp. showed an increase by 208 % (2.3×10^3 ind. m^{-3}). Since the species usually does not dominate the community, the increase could not compensate for the strong decline in the stocks of the other species.

The causes for the decline of the total zooplankton stock can be manifold and may originate from a decline in nutrient concentrations and primary production or an increased predation by gelatinous plankton (GREVE et al. 2004). However, gelatinous zooplankton is not monitored in the western Baltic Sea and a detailed analysis of potential causes is therefore not possible. The fact that the strongest changes in the stock size occurred in those groups with a limited temporal presence in the water column may also indicate shifts in timing and that peaks are simply missed in a rather infrequent sampling scheme. Rotifers and cladocerans, in particular, can have short periods of mass development.

3.3 Macrozoobenthos

3.3.1 Sediments and oxygen

At five of the six 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. in prep). A good oxygen supply could be observed at all stations during the samplings almost all year round. The only exceptions were in August, when we measured 1.7 ml l^{-1} in Kiel Bight and 0.9 ml l^{-1} in Arkona Basin. When the benthos was sampled in November 2022, the values for all stations were above 2 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 24.3 and 8.0 psu (Table 11).

Table 11: Abiotic parameters at 6 monitoring stations in autumn 2022 (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).

Station	Org %	GS (μm)	O_2 (ml/l)	S (psu)	MSRL (BHT) Broad habitat types
N3	-	-	4.13	23.7	infralittoral sand
OM18	1.55	119	2.46	24.3	infralittoral sand
K8	0.41	219	6.63	8.9	circalittoral sand
K4	12.32	11	8.08	17.2	circalittoral mud
K3	0.48	217	4.62	9.6	circalittoral sand
OM160	4.19	193	6.67	8.0	circalittoral sand

3.3.2 Macrozoobenthos at the stations

Our monitoring stations belong to four different macrozoobenthic communities along the salinity and depth gradient (see GOGINA et al. 2016). Regarding the MFSD broad habitat types (EU-Kommissionsbeschluss 2017/848/EU 2017) they belong to three categories (see Table 11). Using the HELCOM Underwater biotope and habitat classification system (HUB, not shown here), the stations could be assigned to four categories (ZETTLER & DARR 2023, Marx et al. 2024).

Compared with the period 1991 to 2021, the number of species was medium at 106 (Table Appendix 3, Fig. 31 and Fig. 34). At three stations (K8, K3, K4) we observed slightly higher diversity as the median. At stations OM18 the value was within the long-term average. Only at stations N3 and OM160 the diversity was lower as the median (Fig. 31). As in the years before the ocean quahog *Arctica islandica* reached high abundances and biomass (ash free dry weight, afdw), especially at the western stations (Fig. 32).

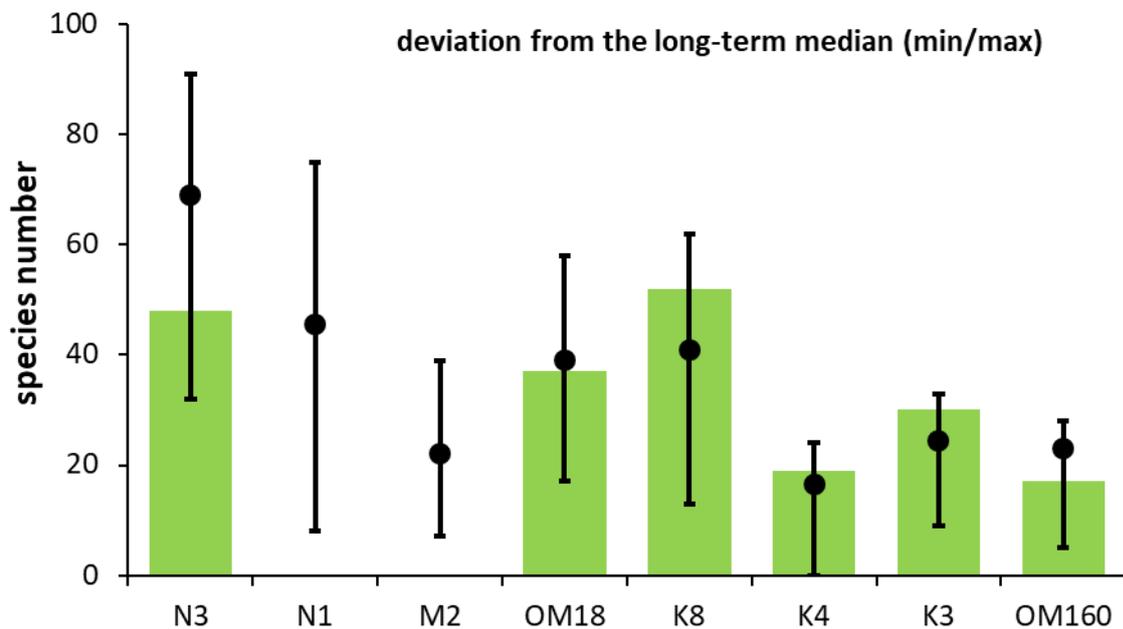


Fig. 31: Number of species (columns) of macrozoobenthos at eight monitoring stations in November 2022. The median values of the years 1991 to 2022 are shown as dots; the minimum and maximum values are indicated as interval. The stations are plotted from west to east (Kiel Bight = N3 to Pomeranian Bay = OM160). N1 and M2 no data in 2022.



*Fig. 32: The dredge sample of Mecklenburg Bay (OM18) was dominated by *Arctica islandica* (alive and empty shells) and starfish (*Asterias rubens*).*

In general, neither a significant increase nor decrease in macrozoobenthos species was observed in 2022. However, at some stations new observed species (never observed during the last 20 years at these stations) were found. These species are listed below:

⇒N3: *Lineus viridis*, *Aphelochaeta marioni*, *Grandidierella japonica*

⇒OM18: *Lineus viridis*, *Hiatella arctica*, *Philine quadripartita*

⇒K8: *Lineus viridis*, *Dyopedos monacanthus*

⇒K4: none

⇒K3: *Sarsia tubulosa*

⇒OM160: none

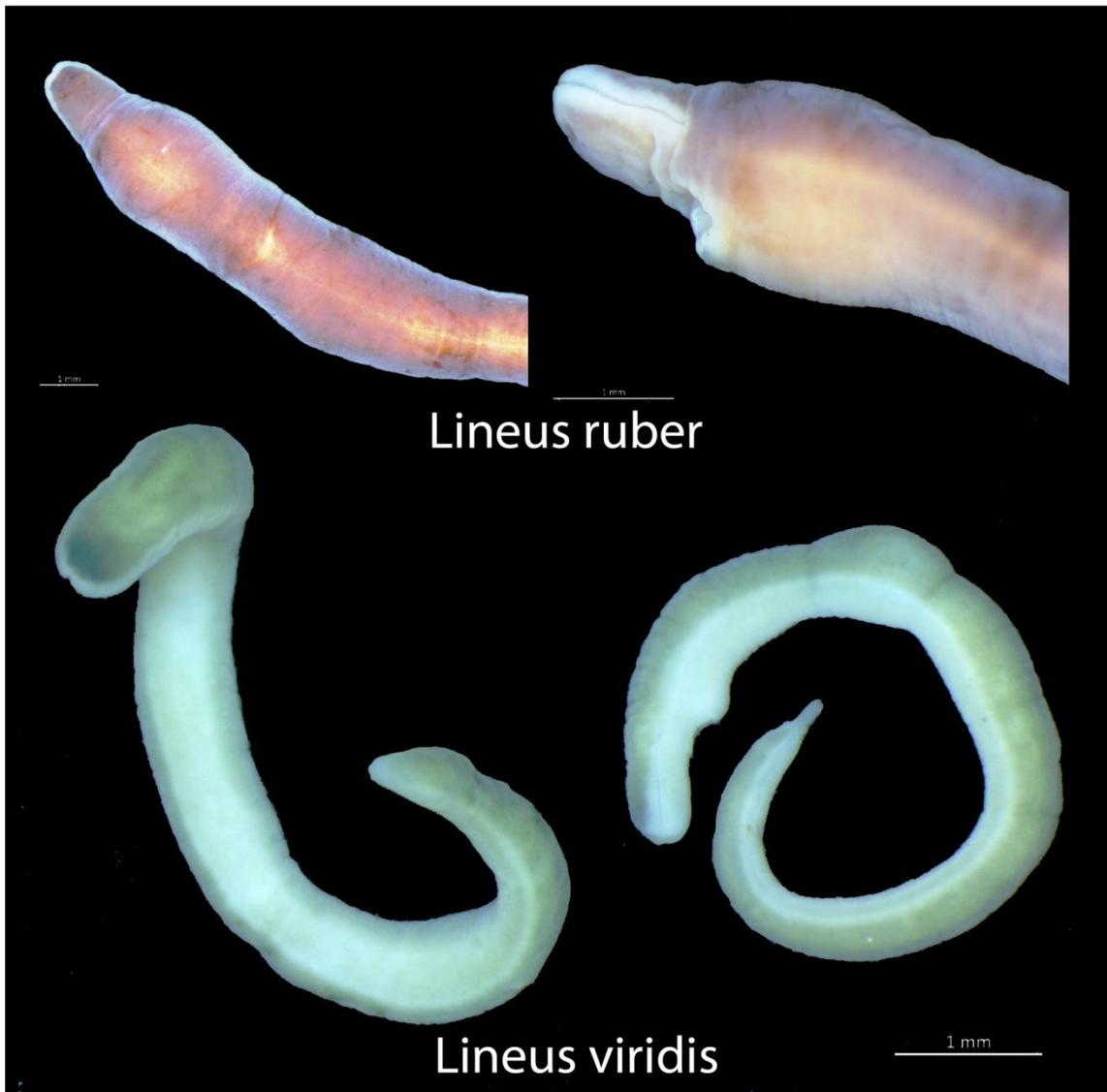


Fig. 33: In contrast to its very common sister species Lineus ruber, L. viridis was first observed during the monitoring campaigns of the last 20 years. At the three western stations (N3, OM18 and K8) this nemertean species occurred in 2022.

Fig. 34 shows the taxa found at our six monitoring stations in 2022 and the total number of species found in measurements since 1991 (for all 8 stations we usually sample). As in the years before the Annelida (here mainly Polychaeta) emerged as the group that is richest in species number, numbering 106 in total; in 2022, 35 species were identified. Other species-rich groups in 2022 were Mollusca (24), Crustacea (23), Bryozoa (8) and Cnidaria (5).

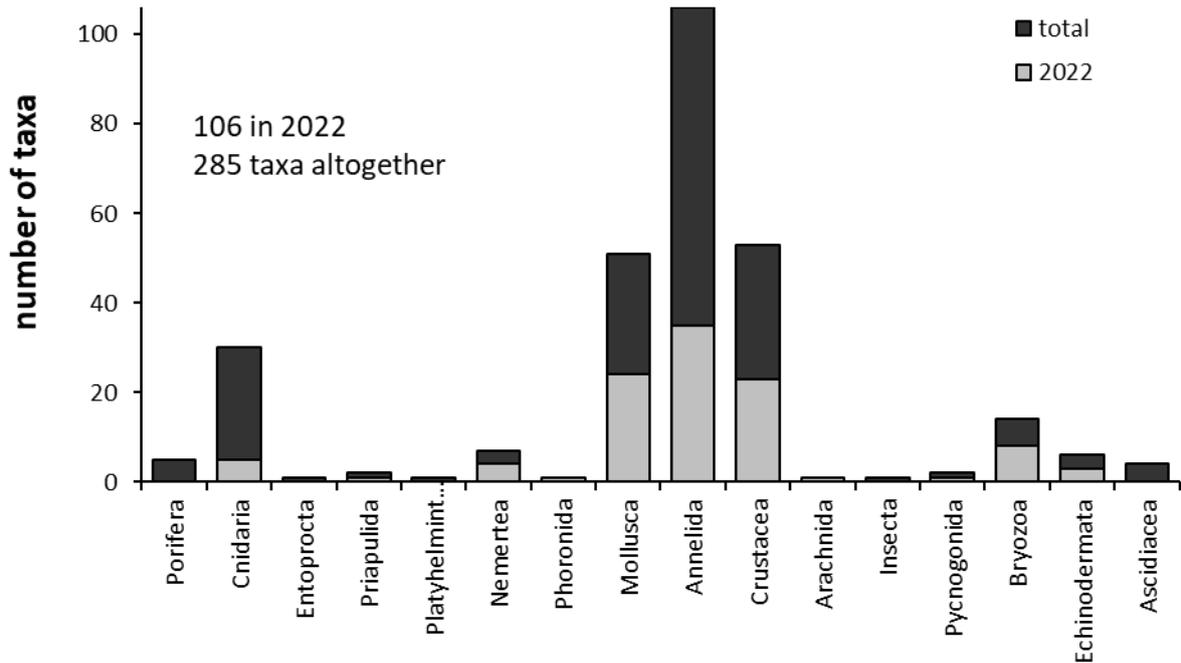


Fig. 34: Taxonomical classification of macrozoobenthos at the six monitoring stations in November 2022 (grey). The species number of the entire monitoring from 1991 to 2022 of 8 stations is also indicated (black columns).

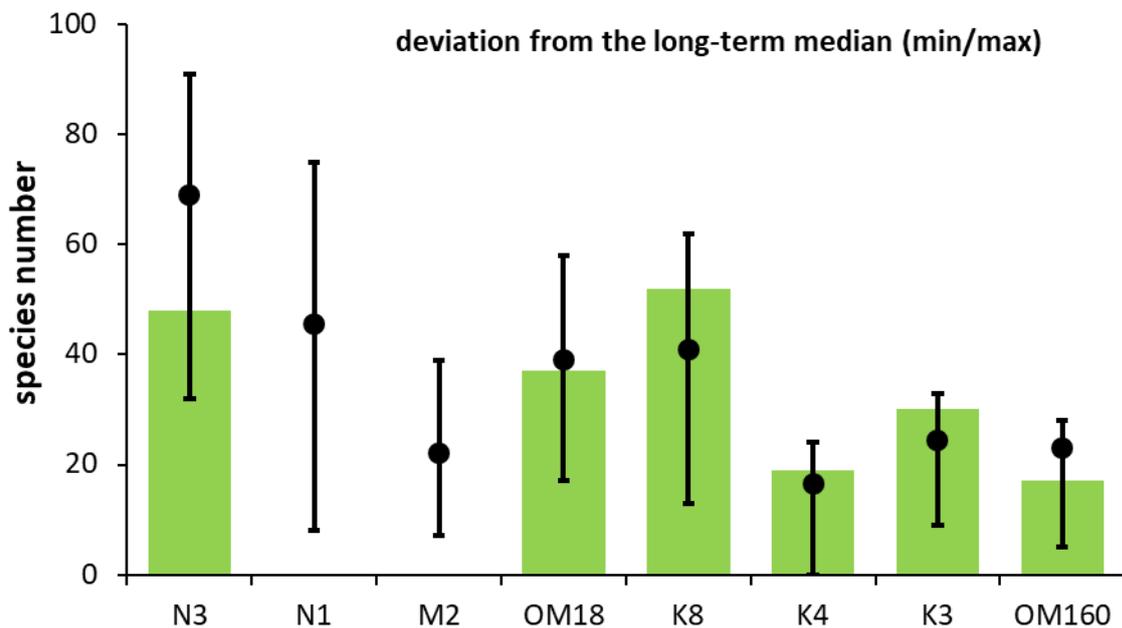


Fig. 35: Number of species (columns) of macrozoobenthos at 8 monitoring stations in November 2022. The median values for the years 1991 to 2022 are shown as dots; the minimum and maximum values are indicated as intervals. The stations are plotted from west to east (Kiel Bight = N3 to Pomeranian Bay = OM160). N1 and M2: no sampling in 2022. N3: no dredge sampling in 2022.

Compared with the period 1991 to 2022, the number of species was low at 119 (Table Appendix 3, Fig. 34, Fig. 35). The number of species in the Kiel Bight (N3) was significantly lower than the long-term trend, not least due to the lack of use of the dredge. Three stations (OM18, K4, K3)

showed similar values to the mean, whereas the number of species was significantly higher at the Darss Sill (K8) and lower values were observed in the Pomeranian Bay (OM160) (Fig. 35).

Depending on the sea area, abundances varied between 518 (Arkona Basin) and 6530 ind. m⁻² (northern Pomeranian Bay) (Fig. 36, Table Appendix 3). At most stations, the abundance is slightly (OM18) or even significantly (N3, OM160) below the long-term average (Fig. 36) or in the long term mean (K8, K4). The only exception is station K3 in the northern Pomeranian Bay, where a significantly higher abundance was observed.

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), the polychaetes *Ampharete baltica*, *Scoloplos armiger* and the phoronid *Phoronis* sp. dominated the density. *Scoloplos armiger* played at several stations a dominant role. Other dominant species at different stations were the polychaetes *Ampharete cirrata* and *Pygospio elegans*, the cumacean *Diastylis rathkei* or the bivalves *Kurtiella bidentata* and *Macoma balthica* (see Table 12 for detailed information). At the two western stations (N3 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 six monitoring stations during November 2022. The stations are plotted from west to east (Kiel Bight = N3 to Pomeranian Bay = OM160).

Abundance in %	N3	OM18	K8	K4	K3	OM160
<i>Ampharete baltica</i>	14					
<i>Ampharete cirrata</i>				44		
<i>Diastylis rathkei</i>				22		
<i>Kurtiella bidentata</i>	11					
<i>Macoma balthica</i>		16				
<i>Peringia ulvae</i>						60
<i>Phoronis</i> sp.	14					
<i>Pygospio elegans</i>			52		70	26
<i>Scoloplos armiger</i>	31	30		11	15	
Biomass in %						
<i>Ampharete cirrata</i>				16		
<i>Arctica islandica</i>	20	89				
<i>Astarte borealis</i>	67		11			
<i>Astarte elliptica</i>				14		
<i>Diastylis rathkei</i>				10		
<i>Macoma balthica</i>				55	35	17
<i>Mya arenaria</i>						57
<i>Mytilus edulis</i>			78			
<i>Peringia ulvae</i>						13
<i>Pygospio elegans</i>					14	
<i>Scoloplos armiger</i>					35	

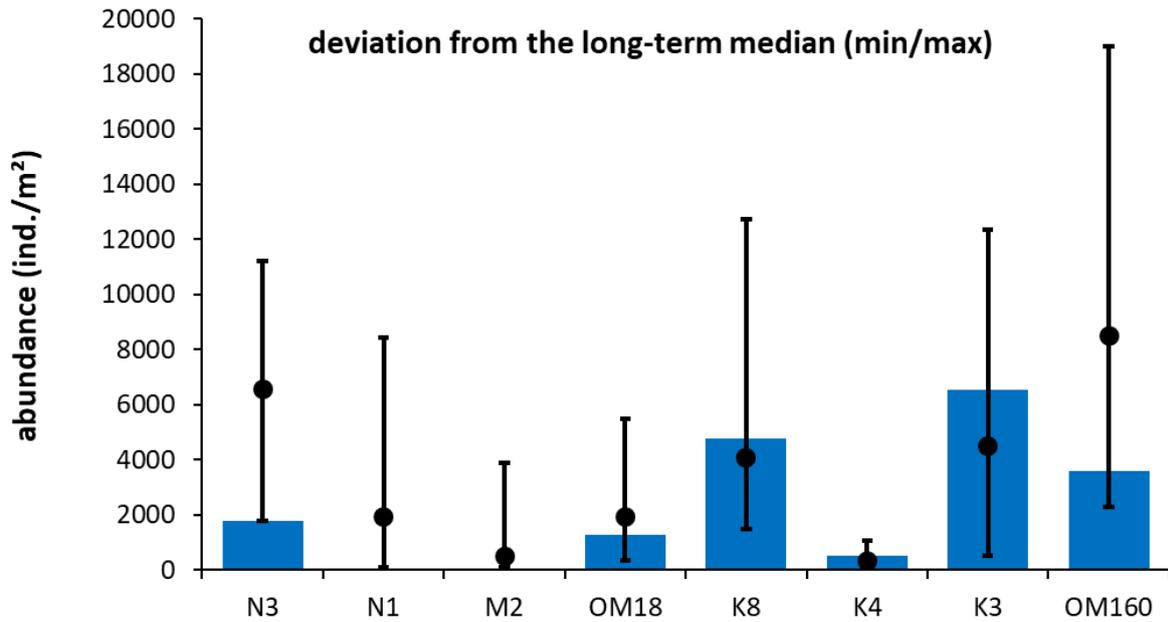


Fig. 36: Total abundances (columns) of macrozoobenthos at eight monitoring stations in November 2022. The median values for the years 1991 to 2022 are shown as dots; the minimum and maximum values are indicated as intervals. The stations are plotted from west to east (Kiel Bight = N3 to Pomeranian Bay = OM160). N1 and M2: no sampling in 2022.

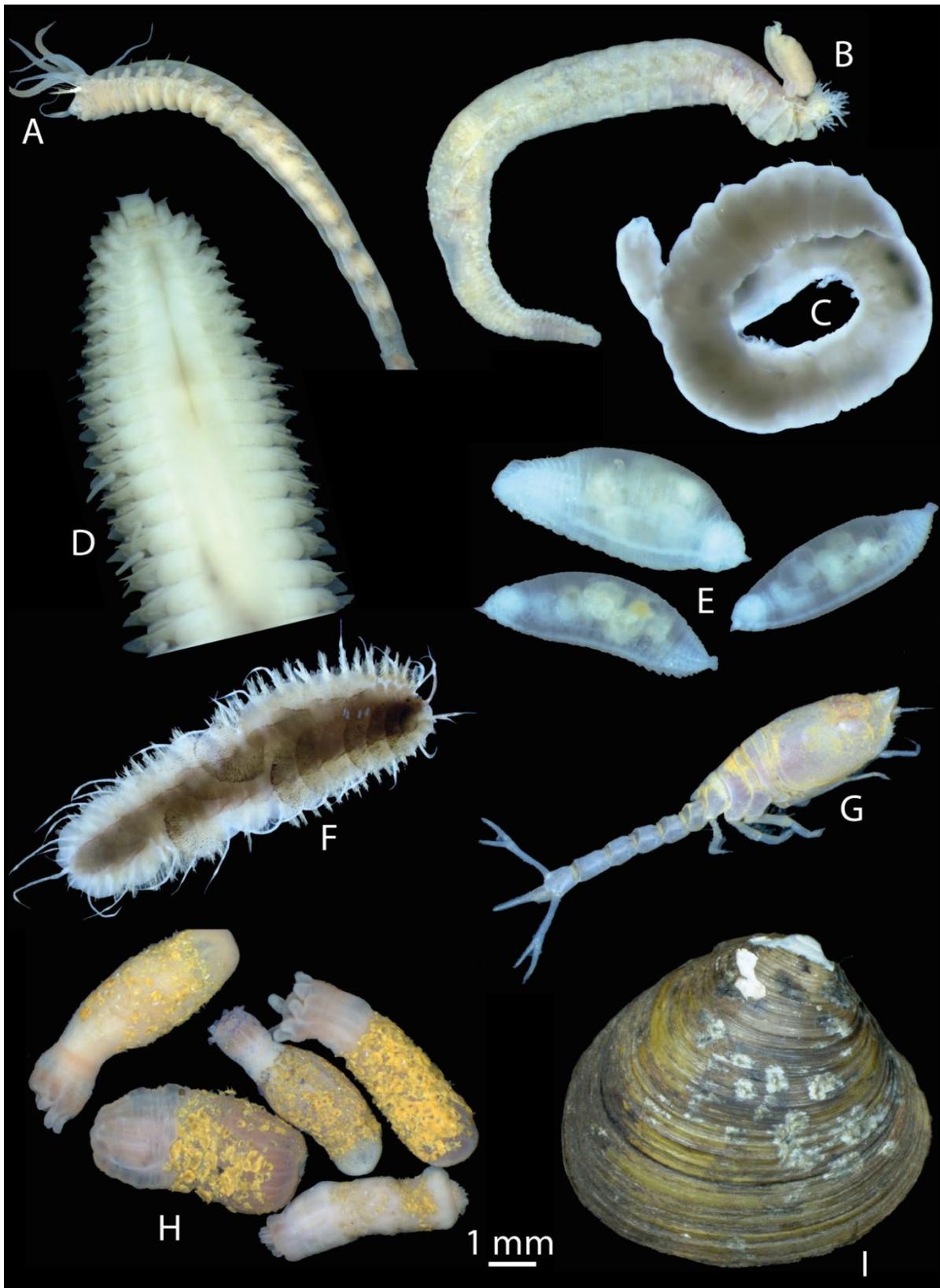


Fig. 37: A selection of observed species during the monitoring in November 2022. A: *Ampharete cirrata* Webster & Benedict, 1887 from K4, B: *Terebellides stroemii* Sars, 1835 from K4, C: *Capitella capitata* (Fabricius, 1780) from K8, D: *Nephtys hombergii* Savigny in Lamarck, 1818 from K4, E: *Travisia forbesii* Johnston, 1840 from K8, F: *Harmothoe imbricata* (Linnaeus, 1767) from OM18, G: *Diastylis rathkei* (Krøyer, 1841) from K4, H: *Halocampa duodecimcirrata* (Sars, 1851) from K4 and I: *Astarte montagui* (Dillwyn, 1817) from K8.

Compared with their long-term averages, four stations (N₃, OM18, K₃, OM160) show a lower total biomass in 2022 (Fig. 38). Significantly higher than the long-term median were the values at the Darss Sill (K₈), caused by masses of *Mytilus edulis* (Fig. 39). At the Arkona Basin (K₄), the biomass was within the long-term average (Fig. 38).

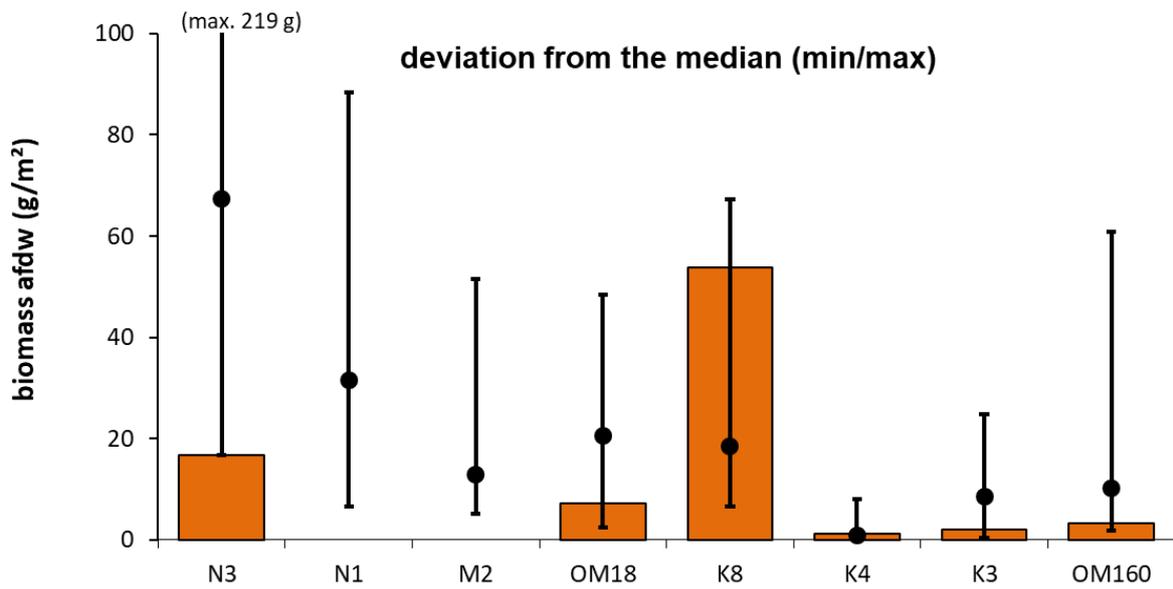


Fig. 38: Total biomass (columns, as ash free dry weights, afdw) of macrozoobenthos at eight monitoring stations in November 2022. The median values for the years 1991 to 2022 are shown as dots and the minimum and maximum values are indicated as intervals. The stations are plotted from west to east (Kiel Bight = N₃ to Pomeranian Bay = OM160). N₁ and M₂: no sampling in 2022.



Fig. 39: In 2022 the dominant species of the dredge sample at the Darss Sill (K₈) was *Mytilus edulis*, which dominated also the grab samples.

Both for abundance and biomass, analysis of our long-term data in part revealed considerable fluctuations that are illustrated as error bars (min/max) in the Fig. 36 and Fig. 38. 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 2022 data). Not least, however, the randomness of sampling and the clustered distribution of organisms are responsible for these fluctuations in the data. 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 (see ZETTLER et al. 2017).

3.3.3 Long-term trends

Long-term data sets are crucial in assessing the state of the marine system and its ecological processes, to disentangle human-induced and natural changes, short-term fluctuations and long-term trends (WASMUND & ZETTLER 2023). Due to the aforementioned failure to sample the western stations in the Fehmarn Belt (N1) and Mecklenburg Bay (M2) in 2022, the usual presentation of long-term trends makes little sense for these stations (see ZETTLER et al. 2020, DUTZ et al. 2022, KREMP et al. 2024.). Therefore, station K8 (Darss Sill) will be evaluated as an example this year in order to present a comprehensive long-term data series. Here, long-term data of more than 40 years are available. The station at the Darss Sill is characterized abiotically by a high variability of the parameters and, due to its topographical position, is located directly in the border area of many marine species. Although in comparison to the western stations (Kiel and Mecklenburg Bay) a drastic decrease in species diversity can be observed in 2022, it is relatively high compared to the eastern stations (Arkona Basin, Pomeranian Bay, Oderbank). In total, more than 140 macrozoobenthic species have been detected over the past 4 decades. However, depending on fluctuating abiotic key parameters such as salinity and oxygen, colonization and reproduction success also vary. But there have been no total community collapses in this area in recent decades. This is consistent with our observations, which showed no serious hypoxic disturbances in this area during this time (ZETTLER et al. 2017). Nevertheless, in all measured biotic parameters (taxonomy, abundance and biomass), partly significant changes can be observed over the years (Fig. 40, Fig. 41, Fig. 42).

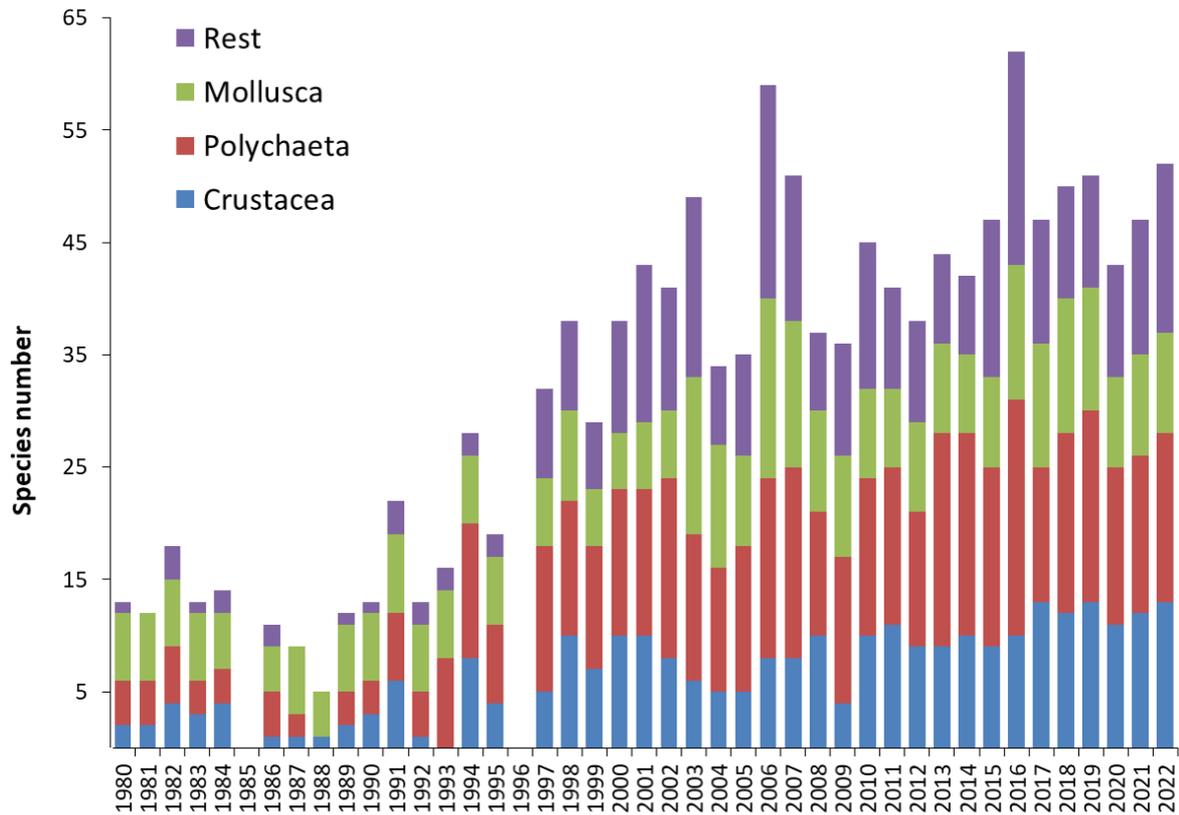


Fig. 40: Long-term development of species number of macrozoobenthic taxa at the Darss Sill (K8), 1980 - 2022.

From 1980 to about the mid-2000s, a continuous increase in species diversity was observed (Fig. 40). Since then, species numbers have levelled off around a very high value (about 45 species). At least in terms of diversity, the crustaceans have diversified over the years. During the last decades two regime shifts could be observed at this monitoring station (WASMUND & ZETTLER 2023).

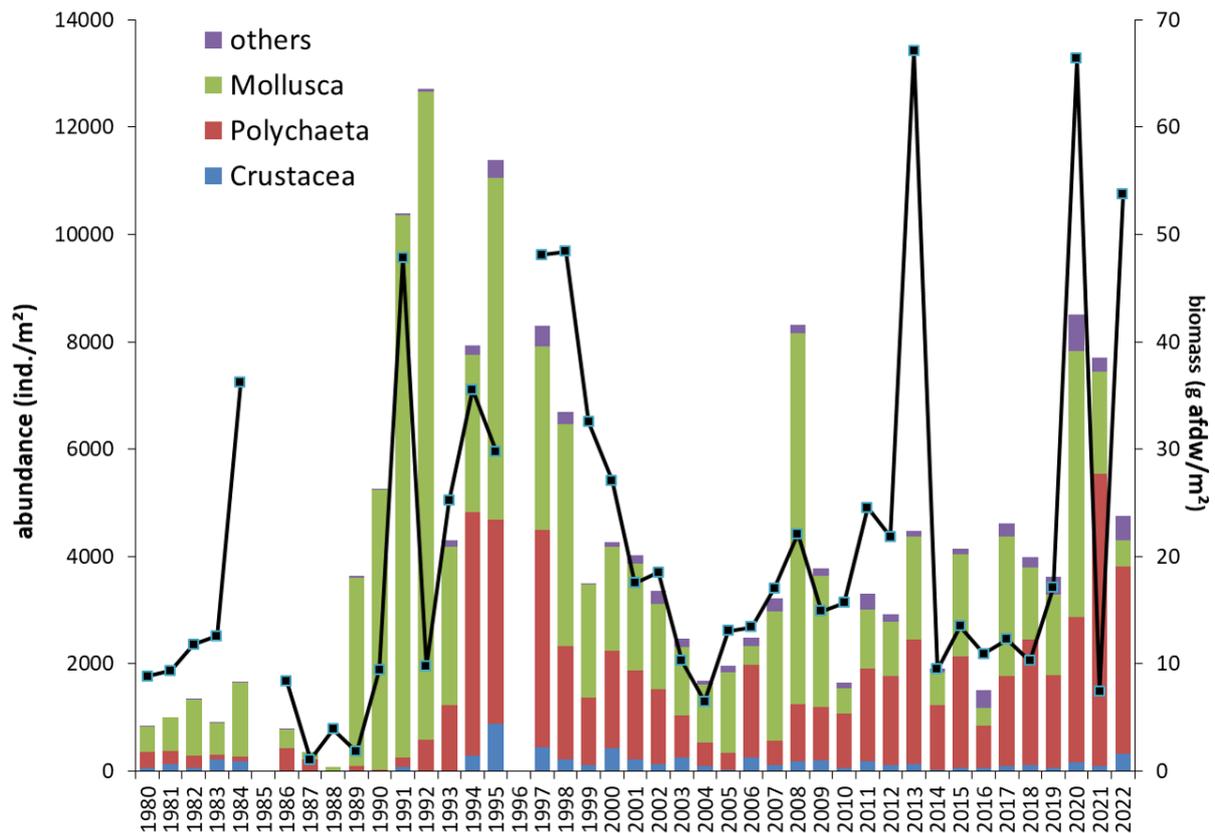


Fig. 41: Long term development of abundance and biomass of macrozoobenthic taxa at the Darss Sill (K8), 1980 - 2022. Columns show the abundance; the bold line shows the biomass (ash free dry weight, afdw).

While in the first decades of the time series, mainly molluscs were the dominant representatives of the macrozoobenthos, since the mid-1990s polychaetes represented the main part (Fig. 41). However, this sovereignty changed again in the mid/end of the 2000s to be ruled again by polychaetes until today. Crustaceans and other taxonomic groups, on the other hand, hardly played a role. Although there has not been much change internally in the composition among molluscs, there has been considerable variation in their density in some cases (Fig. 42). Peak values in density, as with *Mya arenaria*, can be explained by the reproductive successes of previous years, which were only reflected to a limited extent in the biomass of subsequent years due to high mortality. In general, however, a slightly downward trend in the abundance of larger mussel species can be observed. *Astarte borealis* as well as *Macoma balthica* and also *Mya arenaria* hardly reach the high abundance and biomass levels of former years. We have omitted the representation of *Mytilus edulis* here because the probability of detection is obviously too erratic. Accordingly, the fluctuations from year to year are extremely high but do not depend on population developments but rather on random capture using the method described (van Veen). However, these fluctuations of course have an impact on the total biomass at the station and are mostly reflected by the peaks in Fig. 41.

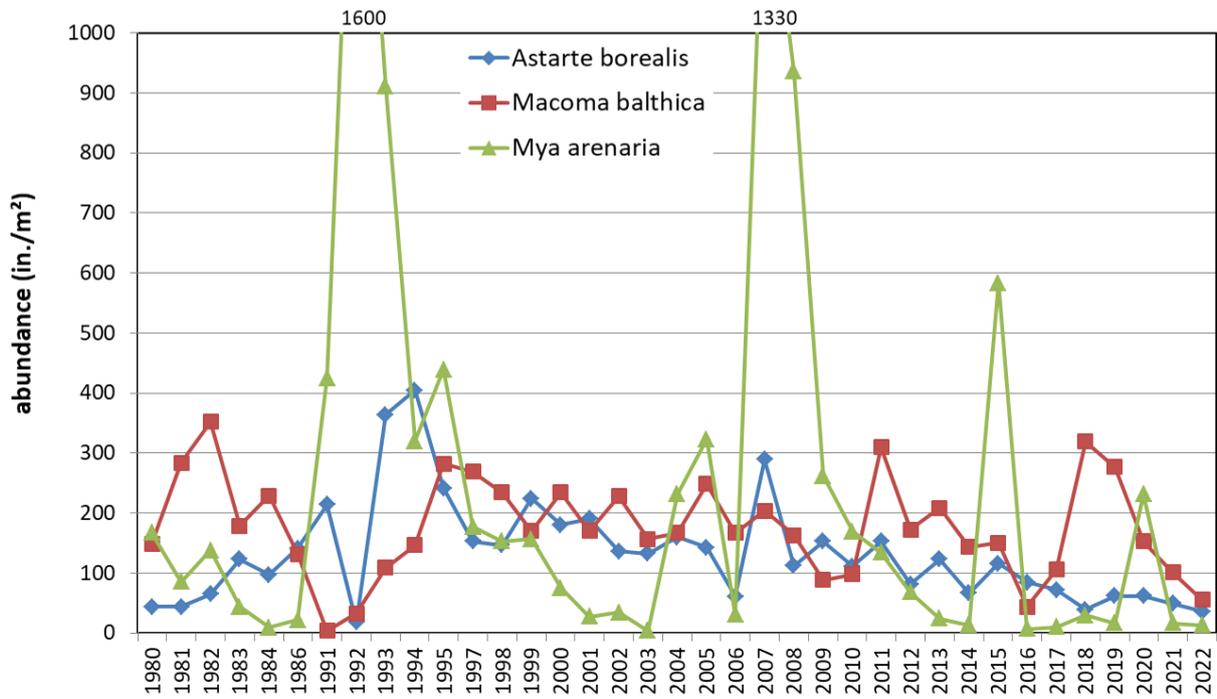


Fig. 42: Long-term development of the abundance of three bivalve species (*Astarte borealis*, *Macoma balthica* and *Mya arenaria*) at the Darss Sill (K8), 1980 - 2022 (samples taken every autumn).

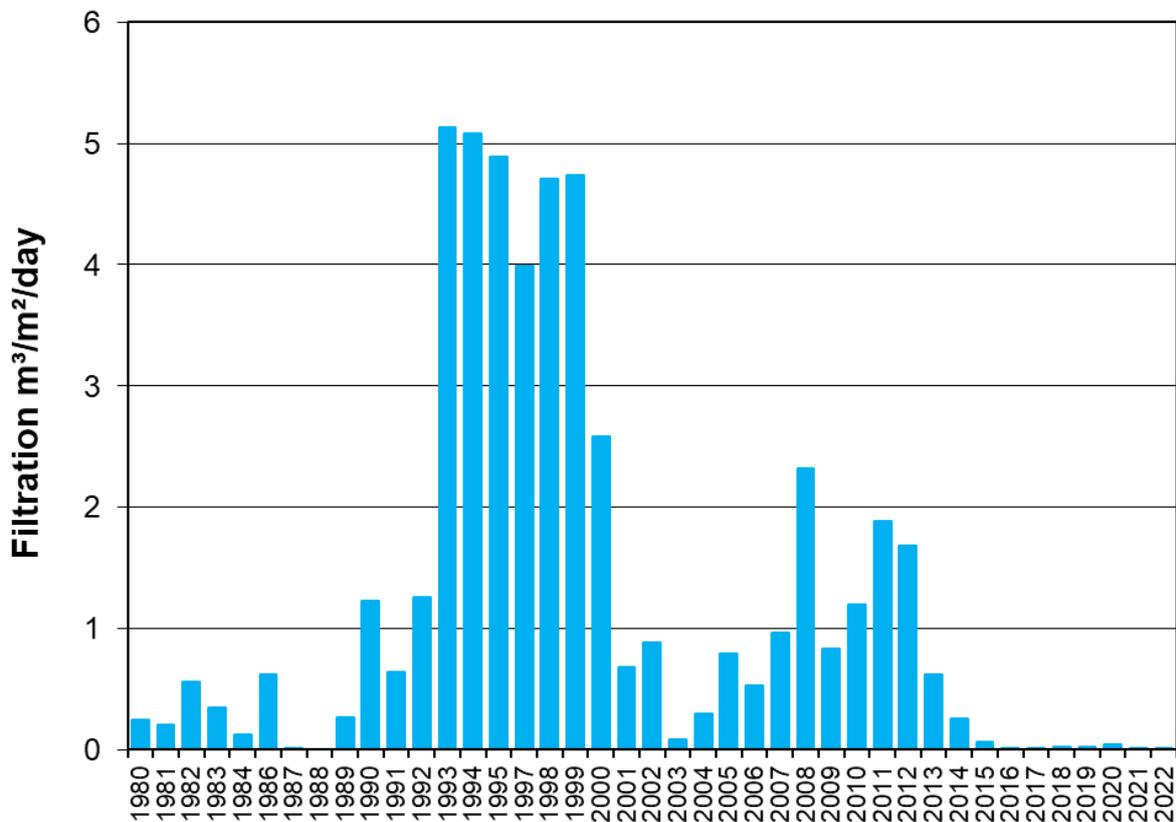


Fig. 43: Long-term development of calculated area-specific population filtration rates of *Mya arenaria* at Darss Sill (K8), 1980 - 2022 (samples taken every autumn).

In particular, a change in the abundance or biomass of mussels means that their influence on specific ecosystem services changes, too. Such ecosystem function can be, for example, filtration services. We analysed this using the extensive data set from *Mya arenaria* (Fig. 43). We took the formulas used from FORSTER & ZETTLER (2004) and transferred them to the data from station K8. It is quickly and easily apparent that the filtration performance can fluctuate extremely depending on the reproductive and growth success and thus also the influence of this key species on the system.

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 106 species in 2022, 10 are classed as threatened (1, 2, 3, G) (Fig. 44, Table Appendix 3). Four species are classed as being near threatened. One species is categorised as extremely rare. Currently, 63 species are classed as being of least concern. Data are deficient for 11 species, and 17 taxa on the Red List were not evaluated. The anthozoan *Halcapa duodecimcirrata* is critically endangered. It was detected in the Arkona Basin (K4) in very low densities (Fig. 37H). We observed specimens of *Arctica islandica* (ocean quahog; category 3, vulnerable) at western stations (N3 and OM18) and in the deeper Arkona Basin (K4) at various levels of abundance. Montagu's Astarte (*Astarte montagui*) occurred in the Kiel Bight (N3) and at the Darss Sill (K8) (Fig. 37I). 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 seven species observed in 2022 were distributed across almost all sea areas: 5 species in Kiel Bight (N3), 3 at the Darss Sill (K8), 1 in Arkona Basin (K4) and 1 in northern Pomeranian Bay (K3). An example is the polychaete *Travisia forbesii*, which occurs in sandy or gravelly soils and was found at the Darss Sill (K8) (Fig. 37E).

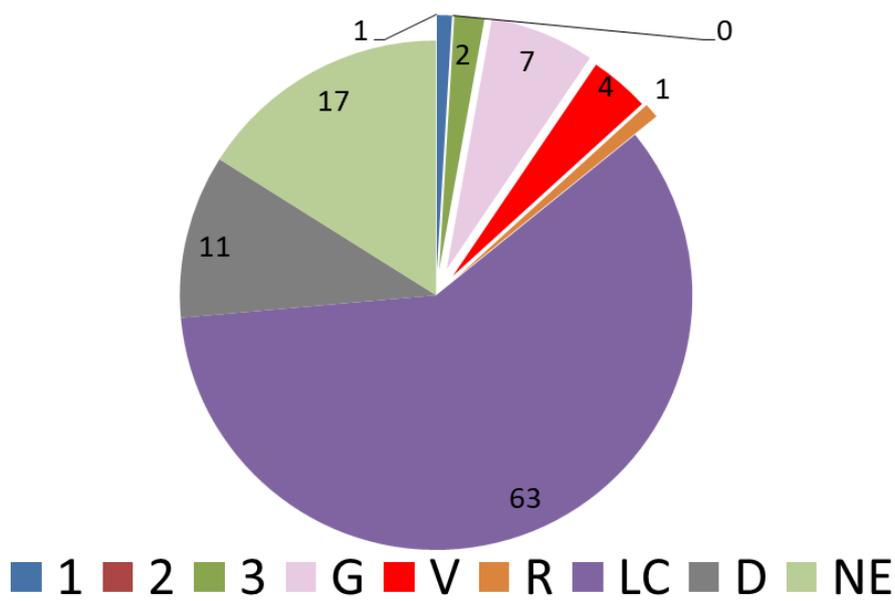


Fig. 44: Distribution of red list categories (RACHOR et al. 2013) in relation to macrozoobenthos in autumn 2022 (1=critically endangered, 2=endangered, 3=vulnerable, G=probably vulnerable, V=near threatened, R=extremely rare, LC=least concern, D=data deficient, NE=not evaluated); the given values are the absolute species numbers.

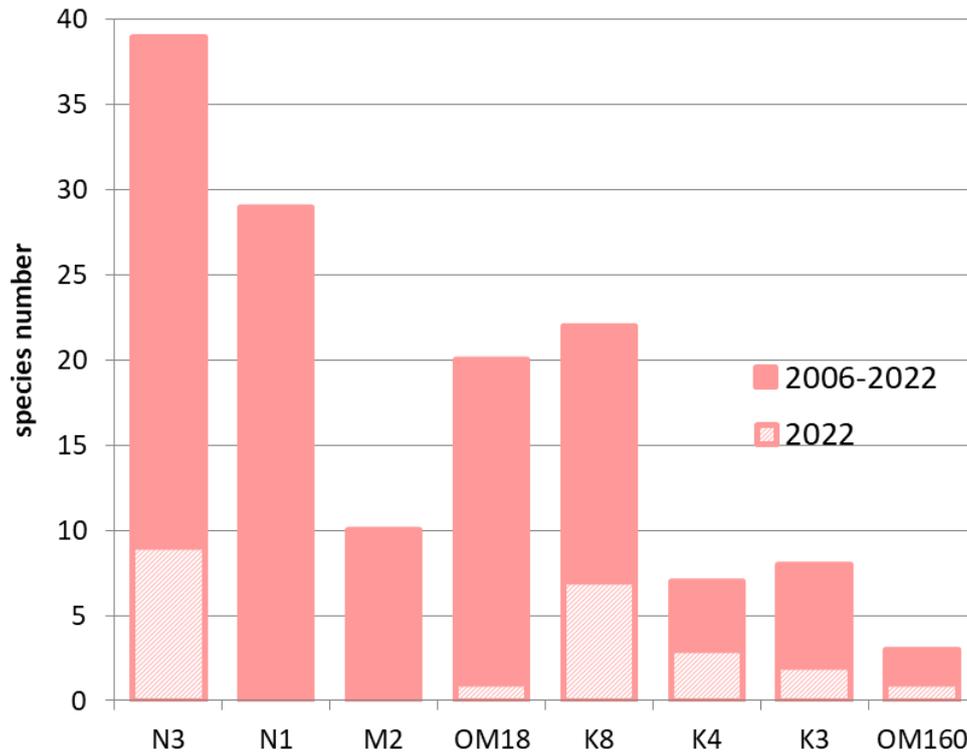


Fig. 45: Number of red listed species (categories 1, 2, 3, G, V and R) (RACHOR et al. 2013) at the six monitoring stations in 2022 and in total (2006-2022). The stations are plotted from west to east (Kiel Bight = N3 to Pomeranian Bay = OM160). N1 and M2 no data in 2022.

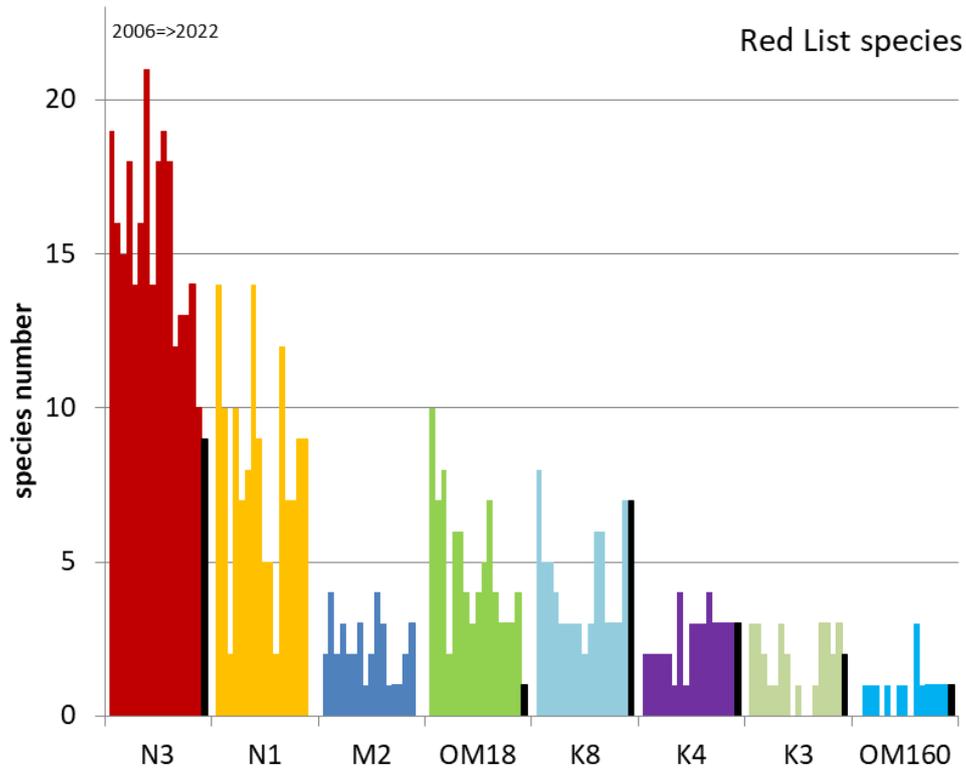


Fig. 46: Development of the number of red listed species (categories 1, 2, 3, G, V and R) (RACHOR et al. 2013) at the eight monitoring stations from 2006 to 2021. The values of 2021 are highlighted in black colour. The stations are plotted from west to east (Kiel Bight = N3 to Pomeranian Bay = OM160). N1 and M2 no data in 2022.

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. 45 and Fig. 46). The percentage of red listed species in 2022 in comparison to observations during the whole study period (2006 to 2022) ranges between 5% and 43% (Fig. 45). At all stations in 2022, the number of red listed species was comparable to the previous years or showed a slight decreasing trend (Fig. 46). The strong salinity gradient and its effect on the distribution of red listed marine species are clearly visible. Only in the Kiel Bight (N3) the number of Red List species was again 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. No species on the Helcom Red List were found (HELCOM 2013b).

3.3.5 Non-indigenous species (NIS)

The role of NIS in the open Baltic Sea is negligible (ZETTLER et al. 2014, 2018). Only seven species were observed at our six monitoring stations in 2022. *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). The spionid polychaete *Marenzelleria viridis* finds suitable habitat conditions in offshore waters. We found this species at the Darss sill (K8), but not in the Pomeranian Bay, where it was common in previous years. In addition, for the shrimp *Palaemon elegans* and the polychaetes *Alitta succinea* and *Aphelochaeta marioni*, it is not clear whether they are neozotic or cryptic native species (LACKSCHEWITZ et al. 2022). None of the observed NIS was recorded for the first time; all have been established for years. Since 2016, the amphipod *Grandidierella japonica* is known from the southern Baltic Sea and was also observed in Kiel Bight (N3) during the present study. This species is more common in brackish, estuarine areas and only occasionally found in offshore waters.

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Appendix

Table Appendix 1: List of phytoplankton-taxa recorded in 2022. Distribution, biomass means per station and sampling, and biomass ranks.

Taxon	Biomass average/station	Rank	Feb EMB286	March EMB290	May EMB293	Aug EMB298	Nov EMB305
<i>Dactyosolen fragilissimus</i>	549.15	1			x	x	
<i>Mesodinium rubrum</i>	72.09	2	x	x	x		
<i>Skeletonema marinoi</i>	60.05	3				x	x
Gymnodiniales	24.22	4	x	x		x	x
<i>Tripos muelleri</i>	22.35	5					
<i>Aphanizomenon</i>	20.05	6	x	x	x		
Prymnesiales	16.61	7					x
<i>Thalassiosira</i>	14.72	8			x		x
<i>Proboscia alata</i>	14.59	9	x	x			x
<i>Peridiniella catenata</i>	10.17	10			x	x	x
<i>Teleaulax</i>	9.13	11			x	x	x
<i>Ebria tripartita</i>	8.78	12			x		x
<i>Unicell spp.</i>	6.36	13					x
<i>Pseudosolenia calcar-avis</i>	6.35	14				x	x
<i>Nodularia spumigena</i>	5.45	15	x	x	x	x	
<i>Heterocapsa rotundata</i>	5.28	16	x	x		x	x
<i>Pseudo-nitzschia</i>	4.93	17	x	x		x	
<i>Pyramimonas</i>	4.62	18	x	x		x	x
<i>Cerataulina bergonii</i>	4.58	19			x	x	
<i>Eutreptiella</i>	4.52	20	x	x	x	x	
<i>Dolichospermum</i>	4.51	21				x	
<i>Karlodinium veneficum cf.</i>	4.09	22					
<i>Alexandrium pseudogonyaulax</i>	4.00	23	x	x		x	x
<i>Coscinodiscus granii</i>	3.82	24					
<i>Gyrodinium spirale</i>	3.07	25	x	x	x	x	x
<i>Plagioselmis prolonga</i>	2.94	26					x
<i>Chaetoceros</i>	2.81	27	x	x			x
<i>Guinardia flaccida</i>	2.60	28					
<i>Prorocentrum micans</i>	2.48	29	x	x	x		
<i>Polykrikos schwartzii</i>	2.47	30				x	x
<i>Cymbomonas tetramitiformis</i>	2.33	31	x	x			x
Peridinales	2.30	32	x	x	x	x	x
<i>Actinocyclus octonarius</i>	2.23	33	x	x	x	x	x
<i>Guinardia delicatula</i>	2.18	34	x	x	x	x	x
<i>Ditylum brightwellii</i>	2.14	35					x
<i>Telonema</i>	1.87	36					
<i>Rhizosolenia setigera f. pungens</i>	1.86	37	x	x		x	
Flagellates	1.68	38	x	x	x	x	x
<i>Rhizosolenia setigera</i>	1.60	39	x	x		x	
<i>Apocalathium spp. CPX</i>	1.58	40	x	x		x	x
<i>Octactis speculum</i>	1.56	41	x	x		x	x
<i>Proto-peridinium</i>	1.25	42				x	x

Taxon	Biomass average/station	Rank	Feb EMB286	March EMB290	May EMB293	Aug EMB298	Nov EMB305
<i>Coscinodiscus radiatus</i>	1.24	43					
<i>Dinophysis acuminata</i>	1.16	44					X
<i>Leucocryptos marina</i>	1.16	45			X	X	X
<i>Chroococcales</i>	1.07	46			X		X
<i>Dinophysis norvegica</i>	1.06	47			X	X	
<i>Katablepharis remigera</i>	1.03	48			X	X	X
<i>Kryptoperidinium triquetrum</i>	0.98	49	X	X	X	X	X
<i>Peridiniella danica</i>	0.98	50			X		
<i>Chaetoceros danicus</i>	0.93	51	X	X	X	X	X
<i>Pseudopedinella</i>	0.89	52				X	X
<i>Pseudanabaena limnetica</i>	0.86	53				X	X
<i>Karlodinium veneficum</i>	0.76	54					X
<i>Hemiselmis</i>	0.62	55			X	X	X
<i>Actinocyclus</i>	0.57	56	X	X	X	X	X
<i>Protoperidinium divergens</i>	0.51	57					
<i>Aphanothece paralleliformis</i>	0.47	58	X	X	X	X	X
<i>Katodinium glaucum</i>	0.46	59	X	X	X	X	
<i>Protoperidinium depressum</i>	0.45	60				X	
<i>Prorocentrum cordatum</i>	0.40	61	X	X	X	X	X
<i>Octactis speculum NK</i>	0.37	62					X
<i>Choanoflagellata</i>	0.37	63	X	X	X	X	X
<i>Chaetoceros curvisetus</i>	0.36	64	X	X	X	X	X
<i>Pseudochattonella farcimen</i>	0.36	65	X	X	X	X	X
<i>Chaetoceros socialis</i>	0.34	66					
<i>Cyanodictyon planctonicum</i>	0.33	67					X
<i>Tripos lineatus</i>	0.29	68	X	X	X	X	
<i>Laboea strobila</i>	0.27	69				X	X
<i>Porosira glacialis</i>	0.26	70				X	
<i>Peridiniella danica cf.</i>	0.25	71	X	X		X	
<i>Pseudanabaena limnetica cf.</i>	0.25	72	X	X	X	X	
<i>Apedinella radians</i>	0.24	73	X	X	X		X
<i>Chaetoceros subtilis</i>	0.23	74	X	X	X	X	
<i>Chaetoceros castracanei</i>	0.23	75					X
<i>Chaetoceros convolutus</i>	0.23	76				X	X
<i>Amylax triacantha</i>	0.22	77					X
<i>Chaetoceros similis</i>	0.21	78					
<i>Centrales</i>	0.20	79	X	X			
<i>Heterocapsa</i>	0.20	80	X	X	X	X	X
<i>Coscinodiscus</i>	0.18	81					X
<i>Snowella</i>	0.18	82	X	X	X	X	
<i>Gymnodinium</i>	0.17	83				X	
<i>Chaetoceros contortus</i>	0.17	84				X	X
<i>Coelosphaerium minutissimum</i>	0.17	85	X	X			
<i>Protoperidinium pellucidum</i>	0.16	86	X	X			
<i>Thalassiosira baltica</i>	0.15	87				X	X
<i>Dinobryon faculiferum</i>	0.12	88			X	X	

Taxon	Biomass average/station	Rank	Feb EMB286	March EMB290	May EMB293	Aug EMB298	Nov EMB305
<i>Azadinium cf.</i>	0.12	89	x	x		x	
<i>Micracanthodinium claytonii</i>	0.12	90					
<i>Binuclearia lauterbornii</i>	0.10	91	x	x	x	x	x
<i>Tripos longipes</i>	0.10	92					x
<i>Dinobryon</i>	0.09	93	x	x	x		
<i>Dissodinium pseudolunula</i>	0.09	94	x	x	x	x	
<i>Diplopsalis spp. CPX</i>	0.08	95	x	x	x		x
<i>Chaetoceros debilis</i>	0.08	96	x	x	x		x
<i>Chaetoceros decipiens</i>	0.07	97	x	x	x		x
<i>Dinobryon balticum</i>	0.06	98	x	x		x	
<i>Protoperidinium brevipes</i>	0.06	99	x	x	x	x	
<i>Dinobryon borgei</i>	0.06	100					
<i>Cylindrotheca closterium</i>	0.06	101	x	x			
<i>Oblea rotunda spp. CPX</i>	0.06	102	x	x		x	
<i>Tripos fusus</i>	0.06	103				x	
<i>Phalacroma rotundatum</i>	0.06	104	x	x		x	
<i>Oocystis</i>	0.06	105	x	x	x		x
<i>Dinophysis acuta</i>	0.05	106					x
<i>Gyrodinium flagellare</i>	0.05	107			x		x
<i>Pterosperma</i>	0.05	108	x	x			
<i>Cyanonephron styloides</i>	0.05	109					
<i>Melosira arctica</i>	0.05	110	x	x			
<i>Pseudo-nitzschia delicatissima</i>	0.04	111	x	x			
<i>Protoperidinium pallidum</i>	0.04	112	x	x	x	x	x
<i>Amphidinium sphenoides</i>	0.04	113	x	x		x	
<i>Synedra nitzschioides</i>	0.03	114		x		x	x
<i>Heterocapsa arctica sp frigida.</i>	0.03	115	x	x			x
<i>Gonyaulax</i>	0.03	116	x	x			
<i>Pauliella taeniata</i>	0.03	117					x
<i>Chaetoceros septentrionalis</i>	0.03	118	x	x			x
<i>Pennales</i>	0.03	119	x	x	x	x	x
<i>Chaetoceros affinis</i>	0.03	120					
<i>Tripos furca</i>	0.02	121				x	x
<i>Nitzschia longissima</i>	0.02	122	x	x	x	x	x
<i>Katablepharis</i>	0.02	123	x	x			x
<i>Cyclotella</i>	0.02	124	x	x		x	x
<i>Pseudo-nitzschia seriata GRP</i>	0.01	125	x	x	x	x	x
<i>Leptocylindrus minimus</i>	0.01	126				x	x
<i>Lennoxia faveolata</i>	0.01	127	x	x			x
<i>Amphidinium crassum</i>	0.01	128				x	
<i>Romeria</i>	0.01	129			x	x	
<i>Woronichinia</i>	0.01	130	x	x	x	x	
<i>Rhizosolenia minima</i>	0.01	131	x	x	x	x	
<i>Miraltia thronsenii</i>	0.01	132			x	x	
<i>Protoperidinium bipes</i>	0.00	133	x	x	x	x	
<i>Lemmermanniella parva</i>	0.00	134	x	x	x	x	x

Taxon	Biomass average/station	Rank	Feb EMB286	March EMB290	May EMB293	Aug EMB298	Nov EMB305
<i>Torodinium robustum</i>	0.00	135	x	x			x
<i>Monoraphidium contortum</i>	0.00	136					
<i>Attheya longicornis</i>	0.00	137					x
<i>Amphidinium longum</i>	0.00	138	x	x			x
<i>Desmodesmus</i>	0.00	139					
<i>Amphidinium sphenoides cf.</i>	0.00	140					
<i>Chaetoceros curvisetus cf.</i>	0.00	141				x	
<i>Dicroerisma psilonereiella</i>	0.00	142	x	x		x	
<i>Ethmodiscus punctiger</i>	0.00	143			x		
<i>Leptocylindrus danicus</i>	0.00	144	x	x	x	x	
<i>Thalassiosira gravida</i>	0.00	145	x	x	x	x	
<i>Trachelomonas</i>	0.00	146	x				

Table Appendix 2: Seasonal occurrence of zooplankton taxa found in the investigation area in 2022 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	0	0	0	0	
Annelida							
Polychaeta - Trochophora	Subphylum		0	0	0	0	
Polychaeta Grube, 1850	Subphylum	883	0	0	0	0	
<i>Harmothoe</i> spp. Kinberg, 1856	Genus	129491	0	0			
Arthropoda - Crustacea							
Copepoda							
<i>Acartia</i> Dana, 1846	Genus	104108	0	0	0	0	0
<i>Acartia bifilosa</i> Giesbrecht, 1881	Species	345919	0	0	0	0	0
<i>Acartia longiremis</i> Lilljeborg, 1853	Species	346037	0	0	0	0	0
<i>Acartia tonsa</i> Dana, 1849	Species	345943				0	0
<i>Calanus helgolandicus</i> Claus, 1863	Species	104466				0	0
<i>Centropages</i> Krøyer, 1849	Genus	104159	0	0	0	0	0
<i>Centropages hamatus</i> Lilljeborg, 1853	Species	104496	0	0	0	0	0
<i>Cyclopoida</i> Burmeister, 1834	Order	1101	0	0	0		
<i>Eurytemora</i> Giesbrecht, 1881	Genus	104240	0	0			0
<i>Eurytemora affinis</i> Poppe, 1880	Species	104872	0	0	0		0
<i>Euterpina acutifrons</i> Dana, 1847	Species	116162	0	0	0		0
Harpacticoida G. O. Sars, 1903	Order	1102	0	0		0	0
<i>Microsetella</i> spp. Brady & Robertson, 1873	Genus	115341	0	0	0	0	0
<i>Oithona</i> Baird, 1843	Genus	106485	0	0	0	0	0
<i>Oithona similis</i> Claus, 1866	Species	106656	0	0	0	0	0
<i>Paracalanus parvus</i> Claus, 1863	Species	104685	0	0	0	0	0
<i>Pseudocalanus</i> spp. Boeck, 1872	Genus	104165	0	0	0	0	0
<i>Temora</i> Baird, 1850	Genus	104241	0	0	0	0	0
<i>Temora longicornis</i> O.F. Müller, 1785	Species	104878	0	0	0	0	0
Phyllopoda							
<i>Bosmina</i> spp. Baird, 1845	Genus	106265			0	0	
<i>Evadne nordmanni</i> Lovén, 1836	Species	106273	0	0	0	0	0
<i>Podon intermedius</i> Lilljeborg, 1853	Species	106276				0	
<i>Podon leuckartii</i> G. O. Sars, 1862	Species	106277	0	0	0	0	0
<i>Pleopis polyphemoides</i> (Leuckart, 1859)	Species	247981				0	0
<i>Penilia avirostris</i> Dana, 1849	Species	106272				0	0

Tab. A2 continued.

	Rang	AphiaID	Feb	März	Mai	Aug	Nov
other Crustacea							
<i>Balanus</i> spp. Costa, 1778	Genus	106122	0	0	0	0	0
<i>Factotecta</i> Grygier, 1985	Subclass	150305		0			
<i>Liocarcinus</i> Stimpson, 1871	Genus	106925				0	
<i>Crangoncrangon</i> Linnaeus, 1758	Species	107552				0	
<i>Palaemon serratus</i> (Pennant, 1777)	Species	107616					
Bryozoa							
Gymnolaemata Allman, 1856	Class	1795	0	0		0	0
Chaetognatha							
Sagittidae Claus and Grobben, 1905	Family	5953		0		0	0
Chordata							
<i>Fritillaria borealis</i> Lohmann, 1896	Species	103375	0	0	0		0
<i>Oikopleura dioica</i> Fol 1872	Species	103407	0	0		0	0
Teleostei	Infraclass	293496	0	0	0	0	
Echinodermata							
<i>Ophiura</i> Lamarck, 1801	Genus	123574				0	
<i>Asterias</i> spp. Linnaeus, 1758	Genus	123219				0	
Cnidaria & Ctenophora							
Anthothecata Cornelius, 1992	Order	13551				0	0
Ctenophora Eschscholtz, 1829	Phylum	1248	0	0			0
Leptothecata Cornelius, 1992	Order	13552					
<i>Euphysa aurata</i> Forbes, 1848	Species	117561				0	
<i>Rathkea octopunctata</i> M. Sars, 1835	Species			0			
<i>Sarsia tubulosa</i> M. Sars, 1835	Species	565161				0	
Phoronida							
<i>Phoronis muelleri</i> Selys-Longchamps, 1903	Species	206663					0
Platyhelminthes							
<i>Alaurina</i> spp. Metschnikoff, 1861	Genus	142785		0		0	0
Leptoplanidae Stimpson, 1857	Family	142062	0				0
Mollusca							
Bivalvia Linnaeus, 1758	Class	105	0	0	0	0	0
Gastropoda Cuvier, 1797	Class	101	0	0	0	0	0
Rotifera							
<i>Synchaeta</i> spp. Ehrenberg, 1832	Genus	134958	0	0	0	0	0
<i>Keratella cruciformis</i> Thompson, 1892	Species	134991				0	
<i>Keratella cochlearis</i> (Gosse, 1851)	Species	134990				0	
<i>Keratella quadrata</i> O. F. Müller, 1786	Species	134992				0	0

Table Appendix 3: Distribution of macrozoobenthos at six stations in November 2022. 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. In the autumn of 2022, the weather conditions in the southwestern Baltic Sea were so harsh that sampling of the stations N3, N1 and M2 had to be cancelled. For the station in the Kiel Bight (N3), we were able to maintain the time series with sampling material from colleagues at the SH State Office for the Environment.

Taxa	N3	N1	M2	O18	K8	K4	K3	160	RL
Amphipoda									
Corophium volutator							1		*
Crassikorophium crassicorne					1				*
Dyopodos monacanthus					1				*
Gammarus oceanicus					1		1		*
Gammarus salinus					1		1	1	*
Gammarus zaddachi							1		*
Grandidierella japonica	1								ne
Melita palmata					1			1	V
Microdeutopus gryllotalpa	1			1	1				*
Monocorophium insidiosum				1					*
Pontoporeia femorata					1				V
Anthozoa									
Halcampa duodecimcirrata						1			1
Arachnida									
Halacaridae					1		1		ne
Bivalvia									
Abra alba	1			1					*
Arctica islandica	1			1		1			3
Astarte borealis	1				1				G
Astarte elliptica	1					1			G
Astarte montagui	1				1				3
Cerastoderma glaucum								1	*
Hiatella arctica				1					*
Kurtiella bidentata	1			1					*
Macoma balthica	1			1	1	1	1	1	*
Mya arenaria	1			1	1		1	1	*
Mytilus edulis	1			1	1	1	1	1	*
Parvicardium pinnulatum	1			1					D
Phaxas pellucidus	1								*
Varicorbula gibba	1			1					*
Bryozoa									
Alcyonidium polyoum					1		1		D
Callopora lineata	1				1				*
Cribrilina punctata	1								*
Einhornia crustulenta				1	1		1	1	*
Electra pilosa					1				*
Eucratea loricata	1				1				V
Farrella repens				1					D
Walkeria uva	1				1				*
Cirripedia									
Amphibalanus improvisus							1	1	ne
Cumacea									
Diastylis rathkei	1			1	1	1	1		*

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
Decapoda									
<i>Carcinus maenas</i>					1				*
<i>Crangon crangon</i>				1	1	1	1	1	*
<i>Palaemon elegans</i>							1		*
Echinodermata									
<i>Asterias rubens</i>				1	1				*
<i>Echinocyamus pusillus</i>	1								G
<i>Ophiura albida</i>	1								*
Gastropoda									
<i>Acanthodoris pilosa</i>					1				*
<i>Brachystomia scalaris</i>					1				*
<i>Facelina bostoniensis</i>				1					*
<i>Peringia ulvae</i>	1			1	1		1	1	*
<i>Philine quadripartita</i>				1					*
<i>Pusillina inconspicua</i>	1								*
<i>Retusa obtusa</i>					1				*
<i>Tritia reticulata</i>	1								G
Hydrozoa									
<i>Dynamena pumila</i>				1					D
<i>Hartlaubella gelatinosa</i>				1	1	1	1	1	D
<i>Hydractinia echinata</i>	1								*
<i>Sarsia tubulosa</i>							1		V
Isopoda									
<i>Idotea balthica</i>					1				*
<i>Idotea chelipes</i>								1	D
<i>Jaera albifrons</i>					1		1		*
Mysida									
<i>Gastrosaccus spinifer</i>	1								ne
<i>Mysis mixta</i>						1	1		ne
<i>Neomysis integer</i>					1	1	1	1	ne
<i>Praunus flexuosus</i>							1		ne
Nemertea	2			1	3				ne
<i>Lineus ruber</i>					1				ne
<i>Lineus viridis</i>	1			1	1				ne
<i>Malacobdella grossa</i>	1								ne
<i>Nemertea</i>					1				ne
Oligochaeta					2		2	2	ne
Tubificinae					1		1	1	ne
<i>Tubificoides benedii</i>					1		1	1	*
Phoronida									
<i>Phoronis sp.</i>	1								ne
Polychaeta									
<i>Alitta succinea</i>				1	1	1		1	D
<i>Ampharete baltica</i>	1			1	1		1		*
<i>Ampharete cirrata</i>	1					1			*
<i>Aphelochaeta marioni</i>	1								*
<i>Arenicola marina</i>					1				*
<i>Aricidea minuta</i>	1								*
<i>Aricidea suecica</i>					1	1			*
<i>Bylgides sarsi</i>				1	1	1	1		*
<i>Capitella capitata</i>	1				1				*
<i>Dipolydora quadrilobata</i>				1	1	1			*

Taxa	N3	N1	M2	018	K8	K4	K3	160	RL
<i>Eumida sanguinea</i>				1					*
<i>Exogone naidina</i>	1								D
<i>Fabriciola baltica</i>					1		1		G
<i>Harmothoe imbricata</i>				1	1				D
<i>Hediste diversicolor</i>							1		*
<i>Heteromastus filiformis</i>	1			1					*
<i>Lagis koreni</i>	1			1					*
<i>Marenzelleria viridis</i>					1				ne
<i>Nephtys caeca</i>	1								*
<i>Nephtys ciliata</i>	1			1		1			*
<i>Nephtys hombergii</i>	1			1		1			*
<i>Paradoneis eliasoni</i>	1								*
<i>Pholoe assimilis</i>	1								D
<i>Polydora cornuta</i>				1	1				*
<i>Prionospio steenstrupi</i>	1								*
<i>Pseudopolydora pulchra</i>				1					*
<i>Pygospio elegans</i>	1			1	1		1	1	*
<i>Scalibregma inflatum</i>	1								G
<i>Scoloplos armiger</i>	1			1	1	1	1		*
<i>Spio gonocephala</i>					1				*
<i>Terebellides stroemii</i>	1					1			*
<i>Travisia forbesii</i>					1				G
<i>Trochochaeta multisetosa</i>				1					D
Priapulida									
<i>Halicryptus spinulosus</i>					1		1		ne
Pycnogonida									
<i>Callipallene brevis</i>	1								R
species number	48			37	52	19	30	17	
abundance (ind m⁻²)	1778			1264	4741	518	6530	3574	
biomass (afdw g m⁻²)	16.7			7.1	53.8	1.1	2.1	3.4	

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CONTENT

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Acknowledgements

References

Appendix

