Meereswissenschaftliche Berichte

Marine Science Reports

Leibniz-Institut für
Ostseeforschung
Warnemünde

No 131 2025

Biological assessment of the Baltic Sea 2024

Michael L. Zettler, Jörg Dutz, Anke Kremp, Carolin Paul, Susanne Busch,
Michael Naumann, Sandra Kube

"Meereswissenschaftliche Berichte" veröffentlichen Monographien und Berichte des Leibniz-Instituts für Ostseeforschung Warnemünde und seiner Kooperationspartner. Die Hefte erscheinen in unregelmäßiger Folge und in fortlaufender Nummerierung. Für den Inhalt sind allein die Autoren verantwortlich.

"Marine Science Reports" publishes monographs and data reports of the Leibniz-Institute for Baltic Sea Research Warnemünde and its collaborative partners. Volumes are published at irregular intervals and numbered consecutively. The content is entirely in the responsibility of the authors.

Schriftleitung / Editorship: Dr. Sandra Kube
sandra.kube@iow.de

Die elektronische Version ist verfügbar unter / The electronic version is available on:
https://www.iow.de/meereswissenschaftliche-berichte.html

© Dieses Werk ist lizenziert unter einer Creative Commons Lizenz CC BY-NC-ND 4.0 International. Mit dieser Lizenz sind die Verbreitung und das Teilen erlaubt unter den Bedingungen: Namensnennung - Nicht-kommerziell - Keine Bearbeitung.

© This work is distributed under the Creative Commons License which permits to copy and redistribute the material in any medium or format, requiring attribution to the original author, but no derivatives and no commercial use is allowed, see:
http://creativecommons.org/licenses/by-nc-nd/4.0/

ISSN 2195-657X

Dieser Artikel wird zitiert als /This paper should be cited as:

Michael L. Zettler, Jörg Dutz, Anke Kremp, Carolin Paul, Susanne Busch, Michael Naumann, Sandra Kube: Biological assessment of the Baltic Sea 2024. Meereswiss. Ber., Warnemünde, 131 (2025), doi:10.12754/msr-2025-0131

Adressen der Autoren:
Leibniz Institute for Baltic Sea Research (IOW), Seestraße 15, D-18119 Rostock, Germany

Corresponding author: sandra.kube@io-warnemuende.de

Table of content

Kurzfassung

2024 beeinflusste eine Reihe von Einstromereignissen aus der Nordsee die **Umweltbedingungen** in den verschiedenen Gebieten der westlichen Ostsee. Im Dezember 2023 kam es zu einem mittelgroßen Major Baltic Inflow (MBI), der Anfang 2024 bis in das Tiefenwasser des Arkonabeckens gelangte. Im Januar 2024 folgte ein weiterer Einstrom. Im Juli transportierte dann ein barokliner Einstrom Salzwasser bis in das Arkonabecken, und im Dezember 2024 kam es zu einem weiteren barotropen MBI von schwacher Intensität. Die Sauerstoffkonzentration im Oberflächenwasser wird im Allgemeinen durch die saisonalen Temperaturschwankungen und die Primärproduktion gesteuert. Die höchsten durchschnittlichen Sauerstoffkonzentrationen im Oberflächenwasser der westlichen Ostsee wurden im Februar, März und Mai gemessen und lagen zwischen 8 - 9 ml l^{-1} gelöstem Sauerstoff. Im Bodenwasser führten die Einstromereignisse im Dezember 2023/Januar 2024 zu einer durchgehend guten Sauerstoffversorgung von der Kieler Bucht bis zum Bornholmbecken in Wassertiefen bis zu 60 m (> 4,5 ml l^{-1}) bis Mai 2024. Während der Sommermonate verringerte sich die bodennahe Sauerstoffkonzentration, sank jedoch nicht unter den ökologisch kritischen Wert von 2 ml l^{-1}. Die Temperatur des Oberflächenwassers (SST) lag in der westlichen Ostsee ganzjährig über dem langjährigen Durchschnitt. Im Winter und Frühjahr lagen die Temperaturen 2 - 3 K über dem Durchschnitt. Auch die Sommertemperatur des Oberflächenwassers war außergewöhnlich warm und erreichte von der Kieler Bucht bis zum Bornholmbecken Werte > 20 °C. Im Vergleich zum langjährigen Mittel waren die SST-Werte in der westlichen Ostsee im Sommer damit ca. 3 K wärmer. Die Temperaturentwicklung im November 2024 spiegelte die herbstliche Abkühlung und die Erosion der saisonalen Sprungschicht in der Oberflächenschicht wider. Von der Kieler Bucht bis zum Bornholmbecken lagen die Oberflächentemperaturen um 2 - 2,5 K über dem langjährigen Mittel. Betrachtet man die Nährstoffdaten des Winters als Reservoir für das Phytoplanktonwachstum des Jahres, so zeigten weder die Nitrat- noch die Phosphatdaten in den Oberflächengewässern der westlichen Ostsee im letzten Jahrzehnt einen signifikanten Trend. Die Oberflächenkonzentrationen von Nitrat und Phosphat im Februar betrugen in der Mecklenburger Bucht 6,43 µmol l^{-1} bzw. 0,63 µmol l^{-1} und lagen damit im Bereich der letzten Dekade. Das DIN/DIP-Verhältnis im Oberflächenwasser (Summe der Ammonium-, Nitrat- und Nitritkonzentrationen im Verhältnis zur Phosphatkonzentration) lag im Februar 2024 zwischen etwa 10 mol mol^{-1} im westlichen Teil und 6 mol mol^{-1} in der Bornholmsee. Das N/P-Verhältnis zeigte einen abnehmenden Trend von West nach Ost: Kieler Bucht/Mecklenburgische Bucht 9–11 mol mol^{-1}, Arkonasee 6 mol mol^{-1} und Bornholmsee 5 mol mol^{-1}. Dieses Muster ähnelte der Situation im Vorjahr und bestätigte erneut, dass Stickstoff vom westlichen Teil bis zur zentralen Ostsee ein limitierender Faktor war, wodurch diazotrophe Cyanobakterien gegenüber Primärproduzenten, die auf Nitrat angewiesen sind, im Vorteil waren.

2024 wurden im Februar, März, Mai, August und November an 6 Stationen in der Beltsee (Kieler Bucht, Mecklenburger Bucht) und in der Arkonasee insgesamt 30 **Phytoplankton**proben analysiert. Die mittlere jährliche Biomasse im Untersuchungsgebiet betrug 1740 µg l^{-1}. Dieser Wert war mehr als dreimal so hoch wie im Jahr 2023 und etwa doppelt so hoch wie das 20-jährige Mittel. Insgesamt wurden im Untersuchungsgebiet 143 Phytoplankton-Taxa erfasst, wobei die höchste Anzahl an Taxa im Februar (86) und November (87) verzeichnet wurde. Insbesondere die großen Kieselalgen *Dactyliosolen fragilissimus* und *Cerataulina pelagica* bildeten eine hohe Biomasse und wurden als die dominierenden Arten im Jahr 2024 identifiziert, gefolgt von der Cyanobakterie *Nodularia spumigena*. Die saisonale Dynamik der Phytoplanktonverteilung zeigte typische zeitliche Verschiebungen der Frühjahrsblüte von Südwesten nach Nordosten und ausgeprägte Biomassepeaks im Frühjahr, Sommer und Herbst in verschiedenen Gebieten. Die Frühjahrsblüte des Phytoplanktons wurde bereits Anfang Februar im westlichsten Teil des Untersuchungsgebiets (Kieler Bucht) festgestellt und wurde fast ausschließlich von Kieselalgen, insbesondere *Skeletonema marinoi*, dominiert. Während diese Blüte in

der Kieler Bucht im März bereits zurückging, erreichte sie zu diesem Zeitpunkt in der Mecklenburger Bucht ihren Höhepunkt. Allerdings war die Phytoplankton-Biomasse der Frühjahrsblüte in der Mecklenburger Bucht im Vergleich zu den Februarwerten in der Kieler Bucht deutlich geringer. Weiter östlich, von der Darßer Schwelle bis zur Arkonasee, wurde der Höhepunkt der Frühjahrsblüte im März festgestellt. Dies spiegelt die typische zeitliche Verschiebung der Frühjahrsblüte von Süden nach Norden in der Ostsee wider. Im Gebiet der Darßer Schwelle dominierte der mixotrophe Ciliat *Mesodinium rubrum* die Frühjahrsgemeinschaft, gefolgt von der Kieselalge *Skeletonema marinoi*. Im Gegensatz dazu bildeten Dinoflagellaten, vor allem *Peridiniella catenata* und Mitglieder der Gymnodinales, nach *M. rubrum* die zweitgrößte Gruppe in der Frühjahrsblüte der zentralen Arkonasee. Weiter östlich in der Arkonasee dominierten Kieselalgen, insbesondere *Skeletonema marinoi*, das Frühjahrsphytoplankton. Im Mai war die Phytoplanktonbiomasse auf den niedrigsten Wert im gesamten Untersuchungsgebiet gesunken, was das Ende der Frühjahrsblüte widerspiegelte. Im August wurden im gesamten Untersuchungsgebiet von der Kieler Bucht bis zur östlichen Arkonasee recht hohe Phytoplanktonbiomassewerte gemessen, was auf eine Sommerblüte hindeutete. In der Mecklenburger Bucht wurden zu dieser Zeit die höchsten Werte der Phytoplanktonbiomasse des gesamten Gebiets und des gesamten Jahres 2024 gemessen. Diese Blüte wurde gleichermaßen von der Cyanobakterie *Nodularia spumigena* und der Kieselalge *Dactyliosolen fragilissimus* dominiert. Im November wurde im östlichen Teil des Untersuchungsgebiets von der Kadetrinne bis zur östlichen Arkonasee eine ausgeprägte Herbstblüte gemessen. Diese Herbstblüte wurde fast ausschließlich von der Kieselalge *Cerataulina pelagica* dominiert. 2024 wurden im Untersuchungsgebiet 13 potenziell toxische oder schädliche Algen-Taxa registriert (15 Taxa 2023, 8 Taxa 2022). Während die meisten Arten insgesamt nur in geringer Häufigkeit vorkamen, traten Prymnesiales an fast allen Stationen sehr häufig auf und bildeten im Mai im Gebiet der Darßer Schwelle sogar eine Blüte aus. Die Werte des Diatomeen-Dinoflagellaten-Index überschritten im Frühjahr 2024 in der Kieler und Mecklenburger Bucht sowie in der Arkonasee den Schwellenwert für einen guten Umweltzustand. Die Cyanobakterien-Biomasse wurde in einem Langzeitkontext an den sechs Messstationen in der Beltsee und der Arkonasee bewertet. In der Kieler und Mecklenburger Bucht war die Cyanobakterien-Biomasse im Vergleich zu den Vorjahren aufgrund der Häufigkeit von *Nodularia spumigena* während des Probenahmezeitraums stark erhöht. Offensichtlich fand die Probenahme in der Mecklenburger Bucht im August 2024 direkt während einer Blaualgenblüte statt. Im zentralen und östlichen Arkona Becken lag die mittlere Gesamtbiomasse der Cyanobakterien im August 2024 hingegen weit unter dem 20-jährigen Mittelwert.

Im Jahr 2024 wurde das **Zooplankton** an fünf Stationen in der Kieler Bucht, der Mecklenburger Bucht und der Arkonasee untersucht. Trotz der Einstromereignisse 2024 war die Anzahl der erfassten Taxa (58) im Vergleich zu historischen Werten während eines MBI (max. 70 Taxa) gering. Die kalten Zuflüsse im Winter erreichten die Arkonasee, hatten jedoch aufgrund der geringen Abundanz und Aktivität des Zooplanktons nur geringen Einfluss auf die Artenzahl. Die Zuflüsse im Frühjahr und Sommer beschränkten sich weitgehend auf die Beltsee, hatten jedoch insbesondere in der Mecklenburger Bucht größere Auswirkungen. Hier überlagerte ausströmendes Brackwasser das salzige Bodenwasser, und die daraus resultierende Mischung aus Brackwasser- und marinen Arten erhöhte die Artenzahl auf 32–35. Verantwortlich für diesen Anstieg waren verschiedene meroplanktische Larven, stenohaline Copepoda-Arten und eine Reihe von Hydrozoa, die typischerweise mit Salzwassereinströmen in Verbindung stehen. Im Herbst nahm die Artenvielfalt, insbesondere in der Kieler Bucht, deutlich ab. Dies ist eventuell auf die hohen Sommertemperaturen zurückzuführen, da die meisten der angetroffenen Arten thermophil sind. Gleichzeitig war eine ungewöhnlich hohe Häufigkeit von *Oithona* in der Beltsee zu sehen. Zwei der während der warmen Jahreszeit angetroffenen Arten werden als nicht heimische Arten (NIS) klassifiziert – die Copepoden-Art *Acartia tonsa* und die Cladoceren-Art *Penilia avirostris*. Mit *Acartia hudsonica* wurde eine weitere NIS im Frühjahr in der Beltsee gefunden.

Hierbei handelt es sich aber um einen Einzelfund. Die Zusammensetzung des Zooplanktons wurde in der Beltsee im Jahresmittel von Copepoden dominiert. Dies ist eine typische Situation, die auf den geringen Einfluss von Brackwasser zurückzuführen ist. In der Arkonasee hingegen ging die ungewöhnliche Dominanz der Copepoda in den Jahren 2019–2023 im Jahr 2024 zurück, dafür waren 2024 zunehmende Bestände von Cladocera zu verzeichnen, die in diesem Gebiet üblicherweise häufig vorkommen. Die Häufigkeit der Rädertierchen blieb hingegen auf einem historisch niedrigen Niveau. Die saisonale Dynamik und die Zusammensetzung des Zooplanktons in der Kieler Bucht und der Mecklenburger Bucht waren wie üblich sehr ähnlich. Die Winter- und Frühjahrsbestände waren etwas kleiner als üblich und wurden von Copepoda und Meroplankton dominiert, welches sich durch einen hohen Anteil an Bryozoenlarven auszeichnete. Im Mai stieg die Zooplanktonabundanz über den langjährigen Mittelwert und bestand größtenteils aus Copepoda verschiedener Gattungen wie *Temora*, *Centropages*, *Acartia* und *Pseudocalanus*. Die beiden letztgenannten Gattungen waren in der Mecklenburger Bucht generell häufiger als in der Kieler Bucht. Im Sommer war die Abundanz gering, was hauptsächlich auf die geringen Bestände an Meroplankton zurückzuführen war. In der Gruppe der Copepoda, die normalerweise die Fauna dominieren, überwogen thermophile Arten wie *Acartia tonsa* und *Oithona*. *Oithona* erreichte im Herbst eine ungewöhnlich hohe Abundanz. Die saisonale Dynamik des Zooplanktons in der Arkonasee unterschied sich deutlich von der Beltsee, da das Gebiet 2024 unter starkem Brackwassereinfluss stand, unter dem die Dominanz der Copepoda typischerweise weniger ausgeprägt ist. Hier waren die Winterbestände geringer als üblich, und neben den Copepoda hatten die Appendikularia und das Meroplankton einen größeren Anteil an der Gemeinschaft. Im Frühjahr nahmen Cladocera und Rotifera zusammen mit den Copepoda-Gattungen *Pseudocalanus* und *Acartia* zu. Im August trat zum ersten Mal seit 2022 ein typisches Maximum der Cladocere *Bosmina* auf. *Oithona* war nur im Herbst sehr häufig, aber die ungewöhnlichen Maxima, die in der Beltsee auftraten, blieben aus. Die langfristige Veränderung der jährlichen mittleren Abundanz der wichtigsten Zooplanktongruppen – Copepoda, Cladocera und Rotifera – zeigte innerhalb der drei großen Becken einen unterschiedlichen Trend. In der Kieler Bucht und der Mecklenburger Bucht stieg die Copepodenpopulation 2024 über den langfristigen Durchschnitt, während sie in der Arkonasee weiter zurückging. In allen Gebieten erholte sich die Cladocera-Population nach einer Reihe von Jahren mit geringer Abundanz und erreichte wieder ihren langfristigen Durchschnitt. Im Gegensatz dazu scheinen die Rotifera in allen Gebieten zu verschwinden.

Im Herbst 2024 konnte die Beprobung des **Makrozoobenthos** an allen acht Stationen entlang der deutschen Ostseeküste erfolgen, beginnend in der Kieler Bucht über die Mecklenburger Bucht, die Darßer Schwelle, das Arkona Becken bis hin zur Pommernbucht. Für die meisten Stationen steht ein umfangreicher Datensatz von Herbstbeprobungen seit 1980 für die Langzeitanalyse zur Verfügung. Die insgesamt 145 Arten, die im Jahr 2024 im Makrozoobenthos gefunden wurden, stellen eine relativ hohe Vielfalt dar. Die Anzahl der Arten, die jeweils an den acht Messstationen gefunden wurden, schwankte zwischen 9 und 82. Im Vergleich zum langjährigen Mittel waren die Artenzahlen im Fehmarnbelt und in der Mecklenburger Bucht signifikant reduziert. In der Kieler Bucht, an der Darßer Schwelle, in der Arkonasee und in der Pommernbucht wurde eine erhöhte Diversität beobachtet. An einigen Stationen wurden neue Arten (die in den letzten 20 Jahren an diesen Stationen nie beobachtet wurden) gefunden. Allerdings war 2024 keine neue Art für das Untersuchungsgebiet festgestellt worden. Die Nacktschnecke *Philine punctata* scheint sich vermehrt auszubreiten und ist seit ihrem ersten Nachweis in der Kieler und Mecklenburger Bucht im Vorjahr inzwischen bis zur Darßer Schwelle verbreitet. Durch die Messwerte der 5 Messkampagnen des IOW konnte kein Sauerstoffmangel im Untersuchungsgebiet festgestellt werden (vgl. oben). Es besteht jedoch der Verdacht, dass zumindest der Fehmarnbelt und Teile der Mecklenburger Bucht im Zeitraum August/September von einem Defizit betroffen waren. Das machte sich in der stark reduzierten Diversität und Dichte der angetroffenen benthischen Arten bemerkbar. Je nach Region reichten die Abundanzen von 112 bis 8421 Ind. m^{-2} und die Biomasse (aschefreies Trockengewicht) von 1,3 g m^{-2} bis 30,1 g m^{-2}. Am Beispiel der Station N1 (Fehmarnbelt) führten wir eine Langzeitanalyse der letzten 3 Jahrzehnte durch. Dargestellt wird die langfristige Entwicklung von Artenzahl, Abundanz und Biomasse. Zur Einordnung der Ergebnisse wurden auch die Sauerstoff- und Salzgehaltswerte am Boden über diesen Zeitraum ausgewertet und teilweise dargestellt. Anhand ausgewählter Arten (*Diastylis rathkei* und *Abra alba*) wird exemplarisch gezeigt, welche Veränderungen stattgefunden haben und welchen Einfluss sie auf das Ökosystem haben können. Zum dritten Mal (nach 2021) wurden die Langzeitdaten zur Berechnung des Benthic Quality Index (BQI) und damit auch des ökologischen Zustands herangezogen. Die Hälfte der Stationen befand sich im Laufe der Jahre in einem „guten“ Zustand. Drei sind im Laufe der Jahre immer als „schlecht“ bewertet worden, eine weitere zwischen "schlechtem" und „gutem“ Zustand. An den acht Messstationen wurden insgesamt 22 Arten der Roten Liste Deutschlands (Kategorien 1, 2, 3 und G) beobachtet. Hervorzuheben wären hierbei neben regelmäßig anzutreffenden Arten wie beispielsweise *Arctica islandica* und Arten der Gattung *Astarte*, auch etwas seltener zu beobachtende Taxa wie *Halitholus yoldiaearcticae* und *Euchone papillosa*. *Aporrhais pespelecani*, *Tritia reticulata* und Scalibregma inflatum traten wie im Vorjahr ebenfalls auf. Mit 10 war die Zahl der invasiven benthischen Arten genauso hoch wie im Vorjahr. Alle Arten waren bereits aus den Vorjahren bekannt. *Mya arenaria* und *Amphibalanus improvisus* sind seit mehr als hundert Jahren in der südlichen Ostsee häufig anzutreffen. Vier Polychaetenarten (*Alitta succinea*, *Marenzelleria neglecta*, *M. viridis* und *Aphelochaeta marioni*) wurden in den letzten Jahren regelmäßig bei Probenahmen gefunden. Die dekapoden Krebse *Rhithropanopeus harrisii* und *Palaemon elegans* treten regelmäßig in den Messkampagnen auf. Die ursprünglich aus Nordamerika stammende Muschel *Rangia cuneata*, die 2017/2018 erstmals in unserem Untersuchungsgebiet beobachtet wurde, kommt vor allem in den Brackgewässern von Bodden und Haffen vor, wird aber auch zunehmend auf der Oderbank gefunden. In den letzten zehn Jahren haben wir an unseren acht Messstationen insgesamt 16 nicht-einheimische Arten (NIS) gefunden. Der langfristige Trend der letzten 10 Jahre bei den Ankünften lag bei 0,7 NIS pro Jahr.

Abstract

In 2024, a series of inflow events from the North Sea affected the **environmental conditions** in the different basins of the western Baltic Sea. In December 2023, there was a medium-sized Major Baltic Inflow (MBI) event, which reached the deep waters of the Arkona Basin in early 2024. This was followed by another inflow in January 2024. In July, a baroclinic inflow transported highly saline water into the Arkona Basin and in December 2024 another barotropic MBI of weak intensity occurred. The oxygen concentration in surface water is in general controlled by the seasonal changing temperature and primary production. The highest average oxygen concentrations in surface waters of the western Baltic Sea were observed in February, March and May and ranged between about 8 - 9 ml l^{-1} dissolved oxygen. In the bottom water, the Major Baltic Inflow events of December 2023/January 2024 resulted in a consistently good oxygen supply from Kiel Bight to Bornholm Basin in water depths down to 60 m (> 4.5 ml l^{-1}) up to May 2024. During the summer months, oxygen concentrations decreased but did not fall below the ecological critical value of 2 ml l^{-1}. The temperature of the surface waters was higher than the long-term average in the western Baltic Sea. The winter and spring water temperatures were about 2 - 3 K above the long-term average. Summer temperature of the surface water was exceptional warm and reached values above 20 °C from Kiel Bight to Bornholm Basin. Compared to the long-term mean, the SST values were 3 K warmer in the western Baltic Sea. The general temperature distribution in November 2024 reflected the autumnal cooling and the erosion of the seasonal thermocline in the surface layer. From the Kiel Bight to Bornholm Basin surface temperatures were 2 - 2.5 K higher than the long-term mean. Considering the winter nutrient data as reservoir for the phytoplankton growth of the year, neither nitrate nor phosphate data showed a significant trend in surface waters of the western Baltic Sea during the last decade. The February surface concentrations of nitrate and phosphate were 6.43 µmol l^{-1} and 0.63 µmol l^{-1} respectively in Mecklenburg Bight and thus within the decadal range. The surface water DIN/DIP ratio (sum of ammonium, nitrate, and nitrite concentrations versus the phosphate concentration) ranged between about 10 mol mol^{-1} in the western part and 6 mol mol^{-1} in the Bornholm Sea in February 2024. The N/P ratio showed a decreasing trend from west to east: Kiel Bight/Mecklenburg Bight 9 - 11 mol mol^{-1}, Arkona Sea 6 mol mol^{-1} and Bornholm Sea 5 mol mol^{-1}. The distribution pattern is similar to the situation in the previous year and confirmed again that nitrogen was a limiting factor from the western part up to the Baltic Proper, giving diazotrophic cyanobacteria an advantage compared to primary producers that depend on nitrate.

In February, March, May, August, and November 2024, a total of 30 **phytoplankton** samples were analyzed at six stations in the Belt Sea (Bay of Kiel, Bay of Mecklenburg) and the Arkona Sea. The mean annual biomass in the study area was 1740 µg l^{-1}. This value was more than 3 times higher than in 2023, and about twice as hight as the 20-year mean. A total of 143 phytoplankton taxa was recorded in the study area, with the highest number of taxa recorded in February (86) and November (87). In particular, the large diatoms *Dactyliosolen fragilissimus* and *Cerataulina pelagica* build up a high biomass and were identified as the most dominant species in 2024, followed by the cyanobacteria *Nodularia spumigena*. The seasonal dynamics of phytoplankton distribution showed typical time shifts of the spring bloom from southwest to northeast and pronounced biomass peaks in spring, summer and autumn in different areas. The spring bloom of phytoplankton was already detected in the beginning of February in the most western part of the study area (Bay of Kiel) and nearly exclusively dominated by diatoms, particularly *Skeletonema marinoi*. While this bloom already had declined in the Bay of Kiel in March, it reached its peak in the Bay of Mecklenburg at that time. However, the phytoplankton biomass of the spring bloom was much lower in the Bay of Mecklenburg compared to the February values in the Bay of Kiel. Further east, from Darss Sill to the Arkona Basin, spring bloom peak was detected in March, reflecting the typical south-to-north progression of the spring bloom across the Baltic Sea basins. At Darss Sill the mixotrophic ciliate *Mesodinium rubrum* dominated the

spring community, followed by the diatom *Skeletonema marinoi*. In contrast, dinoflagellates - primarily *Peridiniella catenata* and members of Gymnodinales - comprised the second most abundant group after *M. rubrum* in the spring bloom of the central Arkona Basin. Further east in the Arkona Basin, diatoms, particularly *Skeletonema marinoi*, dominated the spring phytoplankton. In May, phytoplankton biomasshad decreased to lowest values in the entire study area, reflecting the end of the spring bloom period. In August quite high values of phytoplankton biomass were measured across the entire study area from the Bay of Kiel to the eastern Arkona Basin, indicating a summer bloom event. In the Bay of Mecklenburg, the highest phytoplankton biomass values of the entire area and entire year 2024 were measured. This bloom was equally dominated by the cyanobacteria *Nodularia spumigena* and the diatom *Dactyliosolen fragilissimus*. In November a pronounced autumn bloom was measured in the eastern part of the study area from Kadet Trench to the eastern Arkona Basin. This autumn bloom was almost exclusively dominated by the diatom *Cerataulina pelagica.* In 2024, 13 potentially toxic or harmful algal taxa were recorded in the study area (15 taxa in 2023, 8 taxa in 2022). Whereas most of the species occurred in overall low abundances, Prymnesiales reached high abundances at almost all stations and even bloom concentration in May in the Darss Sill area. The values of the diatom-dinoflagellate index exceeded the good environmental status threshold in the Bays of Kiel and Mecklenburg and in the Arkona Sea in spring 2024. The annual cyanobacteria biomass in the study area was assessed in a long-term context at the six monitoring stations in Belt Sea and Arkona Basin. In the Bays of Kiel and Mecklenburg, cyanobacterial biomass was strongly enhanced compared to previous years due to high abundance of *Nodularia spumigena* during sampling period. Apparently, the sampling in Mecklenburg Bay took place in August 2024, right during a cyanobacteria bloom. In the central and eastern Arkona Basin, in contrast, the mean total cyanobacteria biomass was far below the 20-years mean value in August 2024.

The **zooplankton** was monitored on 5 stations in the Bay of Kiel, the Bay of Mecklenburg and the Arkona Basin in 2024. Despite the inflows, the number of 58 recorded taxa in 2024 was low compared to historical values during major Baltic inflows (max. 70 taxa). The cold inflows during winter reached the Arkona Sea, but had as expected only little influence on the species number due to the low abundance and low activity of the zooplankton. The spring and summer inflows were largely confined to the Belt Sea, but had a larger impact, particularly in the Bay of Mecklenburg. Here, outflowing brackish water was overlaying the salty bottom water and the resulting mix of brackish and marine species elevated the species number to 32-35. Diverse meroplanktonic larvae, stenohaline copepod species and a number of hydrozoans typically associated with inflows were responsible for this increase. The diversity was reduced in the autumn, particularly in the Bay of Kiel, which likely reflects the high summer temperatures since most of the species encountered were thermophilic. This was associated with an unusual high abundance of *Oithona* in the Belt Sea. Two of the species encountered during the warm season are classified as non-indigenous species (NIS) – the copepod *Acartia tonsa* and cladoceran *Penilia avirostris*. Another NIS – the copepod *Acartia hudsonica* – was observed as single observation during May in the Belt Sea. The annual mean composition of the zooplankton was dominated by copepods in the Belt Sea. This is a typical situation owed to the low influence of brackish water in the surface. In the Arkona Sea, however, the unusual abundance of copepods during 2019-2023 was reduced in 2024 due to increasing stocks of cladocerans, typically common in the area. The abundance of rotifers, however, remained on a historically low level. The seasonal dynamics and the composition of the zooplankton in the Bay of Kiel and the Bay of Mecklenburg was as usual very similar. The winter and spring stocks were slightly lower than usual and dominated by copepods and meroplankton, which was characterized by a high percentage of bryozoan larvae. In May, the zooplankton increased to a concentration above the long-term mean and consisted largely of copepods of the diverse genera such as *Temora*, *Centropages, Acartia* and *Pseudocalanus*. The latter two genera had a higher contribution to the copepod stock in the Bay of Mecklenburg than in Bay of

Kiel. The summer abundance was low, mainly due to low stocks of meroplankton. While copepods typically dominate the fauna, thermophilic species such as *Acartia tonsa* and *Oithona* dominated. *Oithona* achieved an unusual high abundance in autumn. The seasonal dynamics of the zooplankton in the Arkona Sea differed from the Belt Sea because the area was under strong brackish influence in 2024 and the dominance of copepods was less pronounced, which is typical for the brackish water. Winter stocks were lower than usual and apart from copepods, appendicularians and meroplankton showed a larger contribution to the community in winter. In spring, cladocerans and rotifers increased together with the copepod genera *Pseudocalanus* and *Acartia*. In August, a typical maximum of the Cladocera *Bosmina* occurred for the first time since 2022. *Oithona* was only abundant in autumn, but the unusual maxima occurring in the Belt Sea were lacking. The long-term change in the annual mean abundance of the major groups of the zooplankton – copepods, cladocerans and rotifers – displayed a divergent trend within the three major basins. In the Bay of Kiel and the Bay of Mecklenburg, copepods increased above the long-term mean while they continued to decline in the Arkona Sea. In all areas, however, Cladocera recovered from a series of years with low abundance and occurred at their long-term mean concentrations. In contrast, rotifers seem to disappear in all areas.

In autumn 2024, **macrozoobenthos** sampling was carried out at all 8 (eight) stations along the German Baltic Sea coast, starting in the Bay of Kiel and extending to the Bay of Mecklenburg, the Darss Sill, the Arkona Basin and the Pomeranian Bay. For most stations, a comprehensive dataset of autumn sampling since 1980 is available for long-term analysis. The total of 145 species found in the macrozoobenthos in 2024 represented a relatively high diversity. The number of species found at each of the eight monitoring stations varied between 9 and 82. Compared to the long-term average, the number of species was significantly reduced in the Fehmarnbelt and Bay of Mecklenburg. Increased diversity was observed in the Bay of Kiel, the Darss Sill, the Arkona Sea and the Pomeranian Bay. New species (which had never been observed at these stations in the last 20 years) were found at some stations. However, no new species was detected for the study area in 2024. The nudibranch *Philine punctata* appears to be spreading and, since its first detection in the Bays of Kiel and Mecklenburg in the previous year, has now spread as far as the Darss Sill. No oxygen deficiency could be detected in the study area based on the measured values from the 5 measurement campaigns. However, it is suspected that at least the Fehmarnbelt and parts of the Bay of Mecklenburg were affected by a deficit in the period August/September. This was noticeable in the greatly reduced diversity and density of the benthic species encountered. Depending on the region, the abundances ranged from 112 to 8421 ind. m^{-2} and the biomass (ash-free dry weight) from 1.3 g m^{-2} to 30.1 g m^{-2}. Using the example of station N1 (Fehmarnbelt), we carried out a long-term analysis of the last 3 decades. The long-term development of species numbers, abundance and biomass is shown. To categorise the results, the oxygen and salinity values at the bottom over this period were also analysed and partially presented. Selected species (*Diastylis rathkei* and *Abra alba*) are used as examples to show what changes have taken place and what impact they may have on the ecosystem. For the third time (after 2021), the long-term data were used to calculate the Benthic Quality Index (BQI) and thus also the ecological status. Half of the stations have been in ‘good’ status over the years. Three have always been assessed as ‘poor’ over the years, another one between “poor” and ‘good’ status. A total of 22 species on the German Red List (categories 1, 2, 3 and G) were observed at the eight monitoring stations. In addition to regularly encountered species such as *Arctica islandica* and species of the genus *Astarte*, somewhat less frequently observed taxa such as *Halitholus yoldiaearcticae* and *Euchone papillosa* should also be emphasised. *Aporrhais pespelecani*, *Tritia reticulata* and *Scalibregma inflatum* also occurred as in the previous year. At 10, the number of invasive benthic species was the same as in the previous year. All species were already known from previous years. *Mya arenaria* and *Amphibalanus improvisus* have been common in the southern Baltic Sea for more than a hundred years. Four polychaete species (*Alitta succinea*, *Marenzelleria neglecta*, *M. viridis* and *Aphelochaeta marioni*) have been regularly found during sampling in recent years. The decapod crustaceans *Rhithropanopeus harrisii* and *Palaemon elegans* occur regularly in the sampling campaigns. The bivalve *Rangia cuneata*, which originally comes from North America and was first observed in our study area in 2017/2018, is mainly found in the brackish waters of Bodden and Haffen, but is also increasingly found on the Oderbank. In the last ten years, we have found a total of 16 non-indigenous species (NIS) at our eight monitoring stations. The long-term trend in arrivals over the last 10 years has been 0.7 NIS per year.

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. 2024). 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 for example on the influence of climatic change (HELCOM 2013a), endangered species (HELCOM 2025) 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 actually 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 (2013b, 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.

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. 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 (EMB356: 06.02. - 21.02.2024), March (EMB337: 19.03. - 03.04.2024), May (EMB340: 25.04. - 15.05.2024), August (EMB346: 06.08. - 20.08.2024) and November (EMB353: 07.11. -22.11.2024).

Within the regular monitoring programme, plankton samples should be collected at two time points of each cruise at each station, if possible. There is a lag of about 7 to 12 days between sampling at a given station. Thus, five cruises yield a maximum of 10 samples per station per year.

Phytoplankton sampling was performed at 5 stations located in the German Exclusive Economic Zone (EEZ). In addition, station K4 (TF0109) was included, representing the northern part of the Arkona Basin, but being located just beyond the border of the German EEZ in Danish waters. Additionally, samples were taken in the Bornholm and Gotland Basins, however, analyses of these stations are not part of this report. In 2024, stations were sampled only once for phytoplankton community analyses during each cruise. Chl *a* sampling was done twice per cruise if cruise track allowed, except for March, when only one Chl *a* sample was taken at each station (Table 1, Table 2).

Zooplankton sampling was performed at 5 stations in the German (EEZ). Additionally, samples were taken in the Bornholm Basin, however, analyses of this station is not part of this report. Samples were taken twice during each cruise (Table 1).

Samples of the macrozoobenthos are usually taken once a year at 8 stations (Fig. 1). In 2024, the samples were taken in November as usual (Table 1 and Table 4).

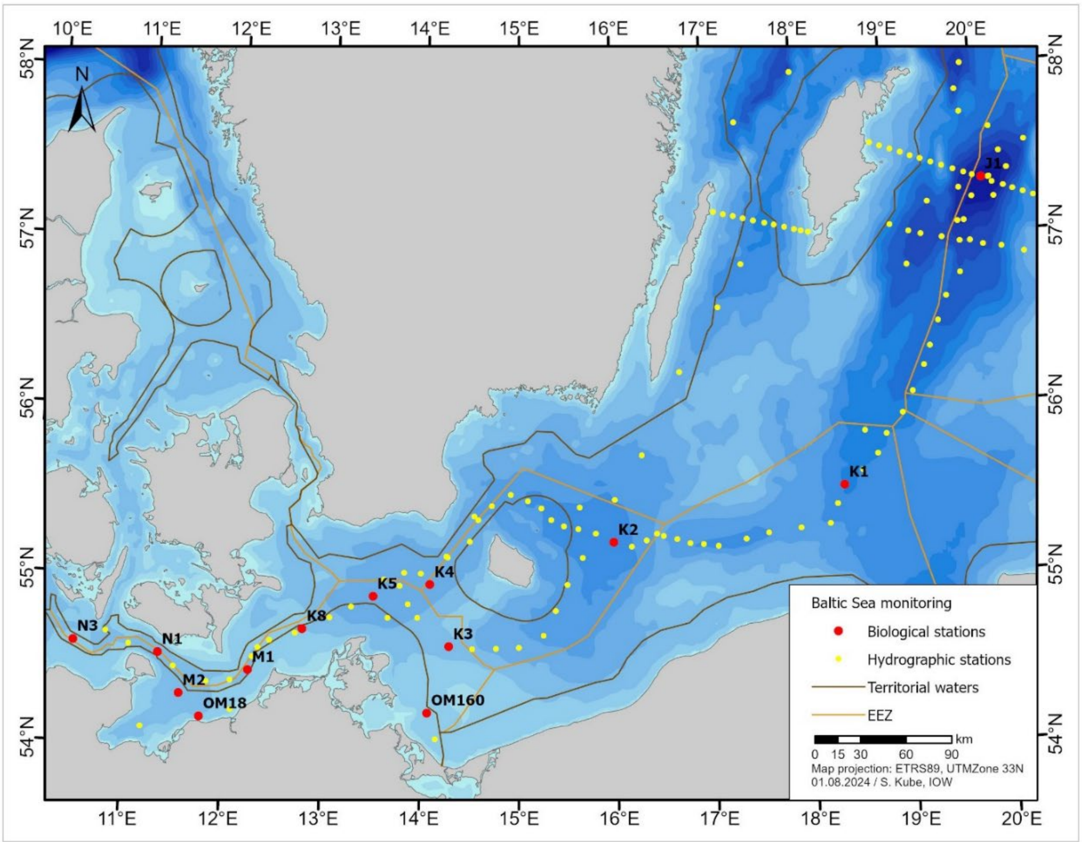

Fig. 1: Station grid for biological sampling in the Baltic Sea with depiction of the border of the Exclusive Economic Zone Germany (EEZ).

Table 1: Sampling statistics (number of sampling events) for the different parameters specified for regular monitoring stations in 2024 (Chl = Chlorophyll a*, PP = Phytoplankton, ZP = Zooplankton; B = Benthos).*

Station number	**IOW-station no**	**Latitude**	**Longitude**	**Sea area**	**Chl**	**PP**	**ZP**	**B**
Belt Sea								
N3	TF0360	54°36,0'N	10°27,0'E	Bay of Kiel	5	5	5	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	9	5	10	1
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	9	5	10	-
Arkona Basin								
K8	TF0030	54°43,4'N	12°47,0'E	Arkona Basin, west	8	5	-	1
K5	TF0113	54°55,5'N	13°30,0'E	Arkona Basin, central	9	5	10	-
K4	TF0109	55°00,0'N	14°05,0'E	Arkona Basin, east	6	5	5	1
Pomeranian Bay								
K3	TF0152	54°38,0'N	14°17,0'E	Pomeranian Bay	-	-	-	1
OM160	TF0160	54°14,4'N	14°04,1'E	Pomeranian Bay	-	-	-	1
Bornholm Basin*								
K2	TF0213	55°15,0'N	15°59,0'E	Bornholm Basin	10	5	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	-	-

*analyses of these samples are not part of this report

2.2 Chlorophyll *a*

Samples for the determination of chlorophyll a (Chl *a*) concentrations were collected together with phytoplankton samples, at standard depths of 1, 5, 10, 15 m for a pooled sample and, occasionally, other depths, using a rosette water sampler. 200-500 ml of the pooled sample were filtered on glass-fibre filters (Whatman GF/F), which were flash-frozen in liquid nitrogen (-196 °C) and stored at -80 °C. In total, 46 chlorophyll samples were collected at 6 stations (Table 1). Ethanol (96 %) was used for the extraction, as specified by HELCOM (2017b). Chl *a* was determined according to Wasmund et al. (2011) as total chlorophyll a, phaeopigments were not considered seperatly. However, the used method based on a specially configured fluorometer (TURNER-Fluorometer 10-AU-005-CE) that eliminates interference from chlorophyll *b* (procedure by Welschmeyer 1994). Thus, the presented Chl *a* values are comparable with chlorophyll *a* values corrected for phaeopigments by acidification mathods (Lorenzen 1967).

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 (up to 6 months). In total, 30 phytoplankton samples were collected at 6 stations (Table 2).

Table 2: Phytoplankton (PP) and chlorophyll a (Chl a*) data in 2024 for different cruises and sampling stations. (X: one sample taken per cruise, XX two samples taken per cruise with app. 10 days in between), geographical locations see Fig. 1.*

Station number	**IOW-station number**	**EMB356 6.02.-21.02.**		**EMB337 19.03.-3.04.**		**EMB340 25.04.-15.05.**		**EMB346 6.08.-20.08.**		**EMB353 7.11.-22.11.**	
		PP	**Chl *a***	**PP**	**Chl *a***	**PP**	**Chl *a***	**PP**	**Chl *a***	**PP**	**Chl *a***
Belt Sea											
N3	TF0360	X	X	X	X	X	X	X	X	X	X
M2	TF0012	X	XX	X	X	X	XX	X	XX	X	XX
M1	TF0046	X	XX	X	X	X	XX	X	XX	X	XX
Arkona Basin											
K8	TF0030	X	XX	X	X	X	X	X	XX	X	XX
K5	TF0113	X	XX	X	X	X	XX	X	XX	X	XX
K4	TF0109	X	X	X	X	X	X	X	X	X	XX

Phytoplankton biomass was analysed based on cell concentrations of individual species determined microscopically using the standard method of Utermöhl (1958). Individuals were assigned to size classes according to HELCOM guidelines (Olenina et al. 2006; HELCOM 2023b). For the most abundant species at least 50 individuals per sample were counted. All in all at least 500 individuals were counted per sample to reduce the statisticall error to < 10 %. Cell concentrations of each species and size classes were multiplied by specific biovolumes of identified species and respective size classes. Assuming a density of 1 g cm^{-3} the figure of biovolume equates to the biomass (wet weight).

Counting, calculation and data output were facilitated by the software "OrgaCount" (AquaEcology Oldenburg), based on the biovolume files of the HELCOM Phytoplankton Expert Group (PEG). Samples taken in 2024 were counted based on the ICES and HELCOM biovolume file PEG_BIOVOL2024 (https://www.ices.dk/data/Documents/ENV/PEG_BVOL.zip).

2.4 Mesozooplankton

The sampling of zooplankton followed the HELCOM COMBINE manual (HELCOM 2021). Vertical net tows were taken with a Work-Party 2 net (WP-2) equipped with 100 µm mesh size. The net was operated with a 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 hauls were taken with a speed of 0.5 m s^{-1} during the up-casts in the water column. In the case of a well-mixed water column, a single net catch was conducted from 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 25° were avoided during sampling by adding sufficient weight to the cod end of the net (> 40 kg). The samples were preserved in Borax-buffered, 4 % aqueous formaldehyde solution and stored under cool and dark conditions until their processing in the laboratory. In total, 69 zooplankton samples were collected at 5 stations in 2024. Table 3 provides the details about the timing and specific depth layers that were sampled over the season at the respective monitoring stations.

Table 3: Sample statistics of zooplankton hauls on monitoring cruises from February to November 2024.

	EMB356	**EMB337**	**EMB340**	**EMB346**	**EMB353**
	TF-02-2024	**TF-03-2024**	**TF-05-2024**	**TF-08-2024**	**TF-11-2024**
	06.02. - 21.02.	**19.03. - 03.04.**	**25.04. - 15.05.**	**06.08. - 20.08.**	**07.11. - 22.11.**
Station	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)
OMBMP-	from – to	from - to	from - to	from - to	from – to
N3	16 – 0	15 – 0	15 – 8 – 0	16 – 0	15 – 0
M2	22 – 17 – 10 – 0	21 – 10 – 0	22 – 0	19 – 11 – 0	21 – 0
	22 – 0	21 – 11 – 0	21 – 8 – 0	20 – 10 – 0	21 – 0
M1	23 – 0	23– 0	26 – 14 – 0	24 – 10 – 0	22 – 0
	22 – 12 – 0	25 – 8 – 0	21 – 7 – 0	26 – 10 – 0	22 – 0
K5	42 – 22 – 0	45 – 33 – 0	45 – 20 – 0	44 – 14 – 0	44 – 18 – 0
	44 – 38 – 0	45 – 27 – 0	44 – 37 – 0	44 – 18 – 0	44 – 22 – 0
K4	47 – 20 – 0	46 – 31 – 0	45 – 23 – 0	41 – 11 – 0	45 – 28 – 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 Bogorov chambers. Several subsamples from the total sample were analysed. With the exception of nauplii and tintinnids, a minimum of 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 zooplankton species followed an internal IOW species list summarizing the long-term records in the western Baltic Sea, the "Zooplankton Atlas of the Baltic Sea" (Telesh et al. 2008, 2009) and the species list of the HELCOM EG Zoo working group. The taxonomic classification in this report is based on the World Register of Marine Species (WoRMS 2025). 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 2025), marine Bryozoa were listed as Gymnolaemata. The databases of the information system on Aquatic Non-Indigenous Species (AquaNIS 2025) and of the European Alien Species Information Network (EASIN 2025) served as references for the classification of invasive species.

2.5 Macrozoobenthos

In November 2024, benthos investigations were undertaken at eight stations from the Bay of Kiel to the Pomeranian Bay (Table 4 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. Each haul was rinsed in seawater through a 1 mm mesh sieve. The sieve residue was transferred to beakers and fixed in 4 % buffered formalin (HELCOM 2017a). Additionally, at all stations sampled, 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 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 far 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 4: Station list of macrozoobenthic investigations in November 2024 (EMB353).

HELCOM-ID	IOW-ID	date	depth	north	east	sea area
N3	360	08.11.2024	18.8	54° 36.00	10° 27.00	Bay of Kiel
N1	010	08.11.2024	29.0	54° 33.20	11° 20.00	Fehmarnbelt
M2	012	07.11.2024	25.3	54° 18.90	11° 33.00	Bay of Mecklenburg
OM18	018	07.11.2024	21.0	54° 11.00	11° 46.00	Bay of Mecklenburg (south)
K8	030	09.11.2024	23.3	54° 44.00	12° 47.40	Darss Sill
K4	109	09.11.2024	49.4	55° 00.00	14° 05.00	Arkona Basin
K3	152	10.11.2024	32.0	54° 38.00	14° 17.00	Pomeranian Bay, north
OM160	160	10.11.2024	15.0	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 round 2024.2 was passed with good results.

Phytoplankton

For phytoplankton quality assurance as implemented by HELCOM PEG, two abundant species were counted twice from every tenth sample, and replicate results were entered into the range control chart. PEG runs annual training courses and undertakes regular ring tests, in which IOW participates (latest November 2024).

Mesozooplankton

The quality assurance followed the protocol for internal quality control concerning documentation and analyses provided by HELCOM (2021). This includes a duplicate analysis of every 20th zooplankton sample as an intra-laboratory routine to check the reliability of the zooplankton analysis. In addition, the validity of counting results and assessment of their accuracy was tested. Deviations of repeated analyses were well below the threshold value for critical errors (variation coefficients 0.09 – 0.17 %). Individual operator and within-laboratory precision was low (variation coefficient 2.5 – 4.7 %). Data stored in databases was quality-checked and validated.

Macrozoobenthos

The IOW macrozoobenthos working group has participated in all QA measures to date. The results of the latest ring test from spring 2018, presented by the Umweltbundesamt (UBA) in March 2019, confirmed the high quality of the macrozoobenthos analyses. Internal double checks of four samples of the 2023 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).

3 Abiotic conditions in 2024

This chapter summarizes the environmental conditions in the study area in the south-western Baltic Sea. The physical and chemical data were obtained at the same five monitoring cruises as the biological data, as well as from continuous measurements of the MARNET stations (https://www.iow.de/marnet.html).

Inflow events and salinity

The series of years from 2017 to 2022 which were characterised by weak salt water inflow activity into the Baltic Sea was interrupted in the end of 2023/beginning 2024. During December 2023 intensified inflow activity was recorded, which was classified as midsized Major Baltic Inflow (MBI) event after MOHRHOLZ (2018) and imported a salt mass of 1.7 Gt (salinity >15 g kg^{-1}) into the deep water of the Arkona Basin. In January a next event of 1.3 Gt salt import followed shortly and during spring 2024 the first events arrived in the eastern Gotland Basin in the upper part of the deep-water layer in 90-140 m water depth. In July, a baroclinic event transported highly saline water of up to 23 g kg^{-1} into the Arkona Basin and in December a next barotropic MBI event of weak intensity occurred (1.1 Gt salt import). In general, the inflow activity has restarted since the end of 2023.

At the MARNET monitoring platform “Darss Sill” salinity ranged in mean from 9.01±1.69 g kg^{-1} at 7 m depth and 14.15±3.87 g kg^{-1} at 19 m throughout the year 2024. A maximum of 23.85 g kg^{-1} was recorded at these bottom sensor level on 24 July, as signal of baroclinic inflow activity. The deeper sensors capture near-bottom salinity variability, thus serving as sensitive indicators of inflow activity. Unlike the annual means of 2016 (15.6 ± 3.5 g kg^{-1}) and 2014 (14.9 ± 3.4 g kg^{-1}), which both experienced strong inflow events, the year 2024 still exhibited above-average mean salinity suggesting moderate to intensified inflow activity. The bottom water of the Arkona Basin (40 m) showed a mean of 14.66±2.17 g kg^{-1} and varied a lot during the year. A minimum of 8.01 g kg^{-1} (12 March) after three weeks of an intensive outflow period and a maximum of 20.99 g kg^{-1} (4 January) as result of the MBI in December 2023. The 95th percentile at 40 m was ∼17.90 g kg^{-1}, with 1136 h (∼12.9%) exceeding 17 g kg^{-1}, pointing to episodic saline intrusions in winter and late summer to early autumn.

At the MARNET bouy “Arkona Basin” a persistent thermal stratification was established in mid-May and lasted until late September. During the onset, bottom intrusions carried relatively cool, saline water with a temperature signature of about 8 °C (early–late May), consistent with the timing of baroclinic inflow signals further upstream at Darss Sill. Near-surface waters at 7 m experienced marked freshening into early June (minimum salinity ∼6.94 g kg^{-1} on 7 June), reinforcing the vertical haline gradient. A second phase of baroclinic inflow activity starting in mid-June elevated the bottom temperature towards a quasi-steady ∼12 °C, while near-bottom salinity fluctuated chiefly in the 16– 18 g kg^{-1} range. Throughout July to September, the water column remained strongly two-layered. The lowest oxygen saturation at 40 m occurred on 11 September (minimum ∼ 10%), reflecting prolonged isolation of the bottom layer under sustained thermal and haline stratification (stagnation period).

Oxygen

The oxygen concentration in surface water is in general controlled by the seasonal changing temperature and primary production. Physical processes like mixing and upwelling can intermediately cause a deviating oxygen concentration.

In 2024, the highest average oxygen concentrations measured during the monitoring campaigns in surface waters of the western Baltic Sea were observed in February, March and May and ranged between about 350-400 µmol l^{-1} (about 8-9 ml l^{-1}) dissolved oxygen. After the summer minimum in August 270-280 µmol l^{-1} (about 6 ml l^{-1}), subsequent cooling and enhanced input of atmospheric oxygen in autumn increased the oxygen concentration of surface water to 306-320 µmol l^{-1} (about 7 ml l^{-1}) oxygen in November. In the bottom water, the Major Baltic Inflow events of December 2023/January 2024 resulted in a consistently good oxygen supply from Kiel Bight to Bornholm Basin in water depths down to 60 m (> 200 µmol l^{-1} / 4.5 ml l^{-1}) up to May 2024. Afterwards depletion started and lowered the oxygen concentrations in the entire region during the summer months. In August, oxygen levels of lower than 200 µmol l^{-1} / 4.5 ml l^{-1} were detected below 15 m water depth in the Mecklenburg Bight, below 25 m water depth in the Arkona Basin and below 50 m water depth in the Bornholm Basin.

Temperature

The winter of 2023/2024 continued a series of warm winters compared with the 30 years reference period 1991-2020 and was in Warnemünde the tenth warmest since 1948. Thus, the sea surface cooling of the Baltic Sea was weaker compared to the reference period. Considering especially the study area for the biological investigations in the western Baltic Sea, the SST ranged between 4.4 °C in the Kiel Bight and 2.8 °C to 4.0 °C at the Darss Sill to the central Bornholm Basin in February 2024. Thus, the climatological mean of 2.5 °C was exceeded by 0.3 to 2.0 K. No temperature stratification was observed up to 45 m water depth, the bottom water of the Arkona Basin, in February 2024. An exception was the deep water of the Bornholm Basin, below the halocline in about 45 m water depth, which showed deep water temperatures of 6-9 °C. In March 2024 the SST in the Baltic Sea was with 5.6 °C in the Danish straits /Kiel Bight to 4.8-5.0 °C in the Arkona Basin and 4.0-4.4 °C in the Bornholm Basin above February and about 2-3 K above the climatological mean. The upper layer was well mixed down to the bottom from Kiel Bight to Arkona Basin. Warmer bottom water of 6-8 °C was found below the halocline in the Bornholm Basin, like in February. In May 2024 the intensive warming of the SST has started and the seasonal thermocline started to establish throughout the Thalweg transect of the western Baltic Sea in 20-25 m water depth. The sea surface temperatures ranged from 6-9 °C in the Mecklenburg Bight to Arkona Basin at the end of April and increased up to a maximum of 13.3 °C in the Arkona Basin to the mid of May. The long-term mean value (1900-2005) in this subregion is 7.48 °C in May. From the Danish Straits to the Arkona Basin the thermocline depth was at 10 m (Kiel Bight) to 25 m (Arkona Basin). Below this thermocline the cold winter water has had a core temperature of 4-6 °C in the Bornholm Basin. Below the intermediate layer the temperatures increased a bit and the key station Bornholm Deep showed a bottom water temperature of about 6.61 °C at April 26th in 2024. In August 2024, the surface temperature in the Baltic Sea reached its annual maximum. The surface temperature was exceptional warm and reached values above 20 °C from Kiel Bight to Bornholm Basin and up to the central Baltic. Compared to the long-term mean, the SST values were 3 K too warm in the western Baltic Sea. The typical summer thermal stratification developed throughout the Baltic Sea. The seasonal thermocline was found at depths of about 15-20 m in the western Baltic Sea. Below the thermocline warm baroclinic summer inflows had replaced the former cool bottom water in the Arkona Basin. Maximum bottom water temperature ranged between 11.48 °C in the Arkona Basin and 7,13 °C in the Bornholm Basin, which was not influenced by inflow at the bottom of 90 m water depth. The baroclinic inflow water was found in the Bornholm Basin below the halocline in 50-70 m water depth, but did not have reached the bottom. The general temperature distribution in November 2024 reflected the autumnal cooling and the erosion of the seasonal thermocline in the surface layer. From the Kiel Bight to Bornholm Basin surface temperatures were about 11-11.5 °C, which was about 2-2.5 K higher than normal. From the Belt Sea to the Bornholm Basin the bottom water was only slightly warmer than the surface water layer, all areas within 1 K difference. The bottom layer of the Arkona Basin showed a maximum deep-water temperature of 12.1 °C and 11.6 °C at the surface.

Inorganic nutrients

The concentration of inorganic nutrients in the water column was measured on the Thalweg transect between the Mecklenburg Bight and the western Gotland Sea during all cruises in 2024.

Considering the winter (February) nutrient data as reservoir for the phytoplankton of the year, neither nitrate nor phosphate data showed a significant trend in surface waters of the western Baltic Sea during the last decade. Inter- and intraannual variations of nutrient concentrations are quite high in the shallow water due to mixing, upwelling and nutrient load from rivers. Nitrate surface concentrations ranged between 2.8 µmol l^{-1} (2019) and 5.8 µmol l^{-1} (2013, 2022) in February in Mecklenburg Bight. Phosphate surface concentrations ranged between 0.6 µmol l^{-1} (2014, 2017) and 0.9 µmol l^{-1} (2013) in February in Mecklenburg Bight between 2013 and 2022.

In 2024, the February surface concentrations of nitrate and phosphate were 6.43 µmol l^{-1} and 0.63 µmol l^{-1} respectively in Mecklenburg Bight and thus within the decadal range. In February 2024, the phosphate concentration ranged in the western Baltic Sea from 0.52 in the Kiel Bight to 0.63 µmol l^{-1} in the Mecklenburg Bight in the surface mixed layer. The Arkona Basin and Bornholm Deep showed 0.60 µmol l^{-1} and 0.61 µmol l^{-1} phosphate concentrations at the surface. A phosphate maximum of 1.68 µmol l^{-1} at bottom near water depths of about 88 m was visible in the Bornholm Sea. The nitrate concentration in surface water decreased from 6.43 µmol l^{-1} in the Mecklenburg Bight to 3.05 µmol l^{-1} at the Bornholm Basin. In the entire area of the western Baltic Sea nitrate concentrations were determined in bottom near water depths between 6.04-6.93 µmol l^{-1}, with exception of 4.61 µmol l^{-1} in the Kiel Bight. In March, nitrate was considerably consumed in the western Baltic Sea and declined to 0.11 µmol l^{-1} in the Kiel Bight to 0.64 µmol l^{-1} in Bornholm Sea surface water. The concentration distribution of phosphate reflected as well consumption in the western Baltic Sea surface water. The measured range was from 0.06 µmol l^{-1} in Kiel Bight to 0.37-0.41 µmol l^{-1} in the Arkona and Bornholm Seas. In May, surface water showed depleted nitrate concentrations in the entire area, in the Arkona Basin even up to the mid layer of 20 m water depth. Phosphate concentrations showed as well low concentrations but only local close to the detection limit (Kiel Bight to Mecklenburg Bight). Arkona Basin and Bornholm Basin showed surface concentrations of 0.13-0.29 µmol l^{-1} of phosphate. In August surface water phosphate was depleted in the western Baltic Sea (0.0-0.01 µmol l^{-1}). The nitrate concentrations stayed on depleted level like in May. In the bottom near water layer phosphate ranged from 0.53 µmol l^{-1} (Kiel Bight) to 1.51 µmol l^{-1} (Bornholm Deep). Nitrate concentrations showed bottom near values low levels of 0.11 µmol l^{-1} (Kiel Bight) to higher levels of 5.63 µmol l^{-1} at Mecklenburg Bight to 8.88 µmol l^{-1} at the Bornholm Deep. In November, the concentrations of nitrate and phosphate stayed low like in summertime because of more intensive than usual consumption of ongoing primary production.

The surface water DIN/DIP ratio (sum of ammonium, nitrate, and nitrite concentrations versus the phosphate concentration) ranged between about 10 mol mol^{-1} in the western part and 6 mol mol^{-1} in the Bornholm Sea in February 2024. The N/P ratio showed a decreasing trend from west to east: Kiel Bight /Mecklenburg Bight 9-11 mol mol^{-1}, Arkona Sea 6 mol mol^{-1} and Bornholm Sea 5 mol mol^{-1}. The distribution pattern is similar to the situation in the previous year and confirmed again that nitrogen was a limiting factor from the western part up to the Baltic Proper, giving diazotrophic cyanobacteria an advantage compared to primary producers that depend on nitrate.

4 Results and discussion

4.1 Phytoplankton and chlorophyll *a*

4.1.1 Spatial patterns of phytoplankton community composition and seasonal succession

Belt Sea: Bay of Kiel (N3), Bay of Mecklenburg (M2), Kadet Trench (M1)

In Kiel Bight (N3), Chl *a* concentration was already elevated at the beginning of February, reaching 4.93 µg l^{-1} (Fig. 2). This was consistent with the corresponding phytoplankton biomass of 1682 µg l^{-1}, representing a maximum of the spring bloom measured at this location. The community was nearly exclusively dominated by diatoms, particularly *Skeletonema marinoi*. Chl *a* concentrations in the Bay of Mecklenburg showed values of 2.27 µg l^{-1} at station M2 and 2.46 µg l^{-1} at station M1 at the beginning of February. Corresponding phytoplankton biomass was 209 µg l^{-1} and 237 µg l^{-1}, respectively. Whereas at M2 diatoms dominated the community biomass almost exclusively, composition at M1 was more diverse, consisting of diatoms (50 %), followed by dinoflagellates and cryptophytes. High biomass levels of this magnitude are not unusual in February in the Bays of Kiel and Mecklenburg, especially if the winter has not been particularly cold. In 2020, the level was almost 2500 µg l^{-1} in the Bay of Kiel at the beginning of February.

In March, both Chl *a* values and phytoplankton biomass had decreased in Kiel Bight (N3) compared to February, reflecting the decline of the spring bloom. Phytoplankton biomass was still dominated to a large extend by diatoms. Chl *a* concentrations in the Bay of Mecklenburg showed values of 3.69 µg l^{-1} in the central Bay of Mecklenburg (M2) and 2.48 µg l^{-1} more to the east (Kadet Trench, M1). Phytoplankton biomass was 769 µg l^{-1} at M2 and 501 µg l^{-1} at M1, reflecting a peak of the spring bloom period. The phytoplankton community biomass was build-up by diatoms, followed by the mixotrophic ciliate *Mesodinium rubrum*.

By the end of April, Chl *a* concentrations at station M2 and M1 had decreased compared to March, indicating the decline of the spring bloom in the Bay of Mecklenburg.

In May Chl *a* concentrations reached 1.87 µg l^{-1} in the Bay of Kiel, and 1.81 µg l^{-1} in the central Bay of Mecklenburg (M2) and 2.95 µg l^{-1} further east (M1). Phytoplankton biomass in the Bay of Kiel (N3) reached 159 µg l^{-1} and the community predominantly consisted of diatoms and haptophytes (Prymnesiales). At the central station of the Bay of Mecklenburg (M2) a phytoplankton biomass of 203 µg l^{-1} was measured. The biomass consisted of species summarized as \`others´ (unidentified flagellates of various size-classes, *Pyramimonas* spp., *Telonema* spp.), dinoflagellates (*Heterocapsa rotundata*) and haptophytes (Prymnesiales). At the eastern station of the Bay of Mecklenburg (Kadet Trench, M1) phytoplankton biomass was 145 µg l^{-1}. Here the phytoplankton biomass consisted almost entirely of species summarized as \`others´, mainly comprising unidentified flagellates of various size-classes.

In August Chl *a* concentrations ranged from 1.12 µg l^{-1} at station N3 to 3.15 µg l^{-1} at station M1. At station M2 Chl *a* (6.93 µg l^{-1}) and phytoplankton biomass (11500 µg l^{-1}) reached their highest values of the entire sampling period, indicating a summer bloom event. Biomass was equally dominated by the cyanobacteria *Nodularia spumigena* and the diatom *Dactyliosolen fragilissimus*. At stations N3 and M1 phytoplankton biomass likewise reached high values of 1070 µg l^{-1} and 5011 µg l^{-1}, respectively. Diatoms, specifically *D. fragilissimus*, constituted 70 % (N3) and 87 % (M1) of total phytoplankton biomass.

In November Chl *a* concentrations ranged from 4.56 µg l^{-1} in the Bay of Kiel (N3) to values of 3.65 µg l^{-1} at the central station in the Bay of Mecklenburg (M2) and 3.97 µg l^{-1} at the eastern station (Kadet Trench, M1). In the Bay of Kiel (N3) a phytoplankton biomass of 579 µg l^{-1} was measured. The community consisted predominantly of various diatom species (*Guinardia delicatula*, *Pseudo-nitzschia* sp., *Pseudosolenia calcar-avis*), followed by dinoflagellates (*Tripos lineatus*, *T. muelleri*, *T. fusus*). At station M2 phytoplankton biomass reached 825 µg l^{-1}. Here various dinoflagellates – predominantly *T. muelleri* and species of the Scripsiella group - dominated the community biomass by 49 %, followed by diatoms (*Cerataulina pelagica*) with 40 % of total biomass. At station M1, diatoms (*C. pelagica*) even accounted for approximately 90 % of total phytoplankton biomass.

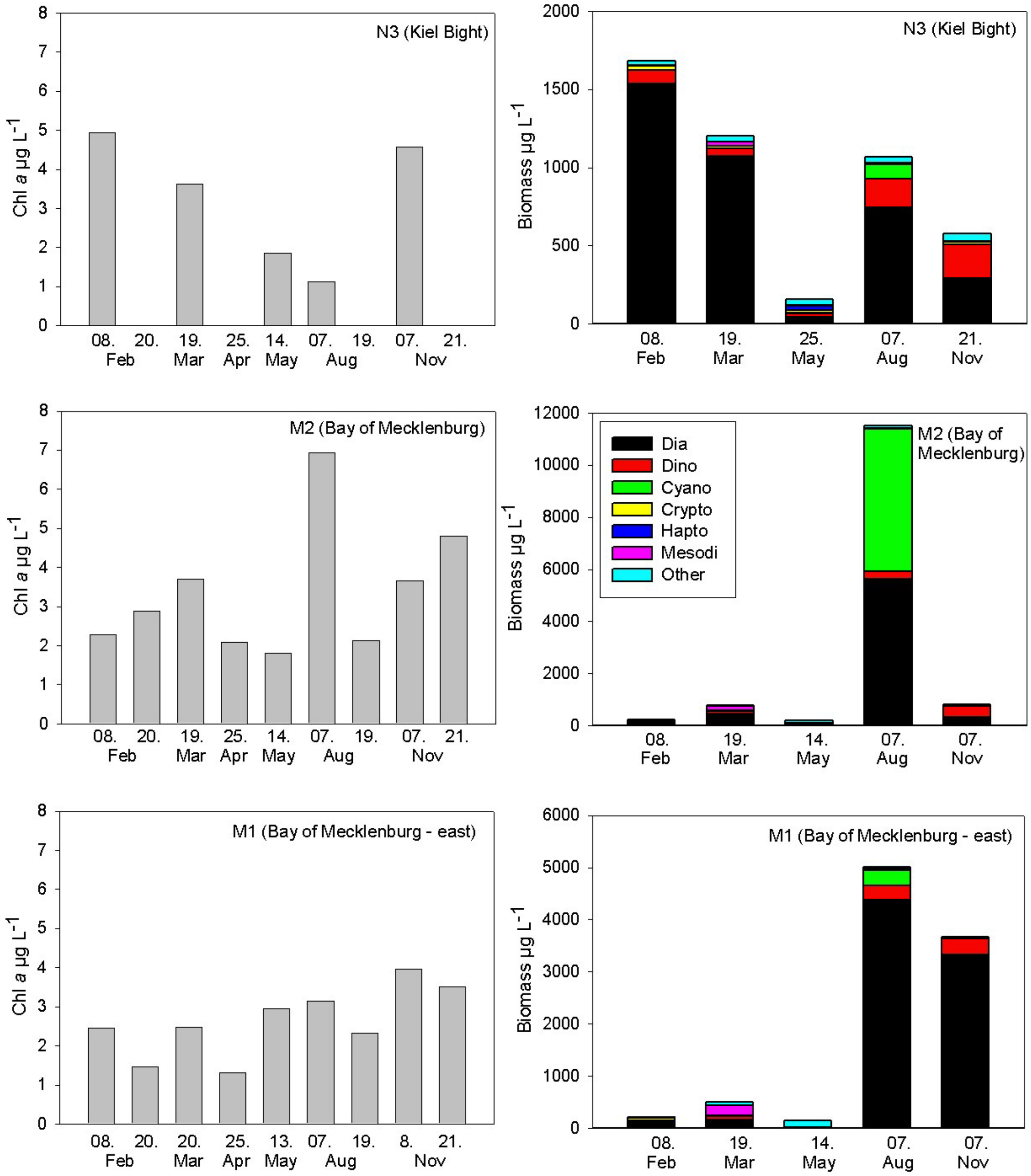

Fig. 2: Chl a *concentrations (left column) and biomass composition (right column) in 2024 at Bay of Kiel and the sampling stations M1 and M2 in the Bay of Mecklenburg.*

Arkona Basin: Darss Sill (K8), Arkona Sea (K5, K4)

In the Arkona Basin (Fig. 3), Chl *a* concentrations in early February were still low across all three monitoring stations, in contrast to the higher values observed in the Belt Sea during the same sampling period. This pattern reflects the typical south-to-north progression of the spring bloom across the Baltic Sea basins. Chl *a* concentrations were below 1 µg l^{-1} in the first half of February but had already increased in the second half (3.19 µg l^{-1}) in the central Akona Sea (K5) with progression of the spring bloom period. Corresponding phytoplankton biomass was between 62 µg l^{-1} (K8) and 47 µg l^{-1} (K4), dominated by *M. rubrum* and diatoms, particularly *S. marinoi*.

The peak of the spring bloom was reached at all three stations in March. Chl *a* ranged at that time from 3.19 µg l^{-1} at station K8 to 4.35 µg l^{-1} at station K5 and 4.08 µg l^{-1} at station K4 in the eastern Arkona Basin. Corresponding total phytoplankton biomass was 472 µg l^{-1} at K8, highest values were measured at station K5 with 906 µg l^{-1}, and 385 µg l^{-1} at K4. At station K8 *M. rubrum* dominated the community, followed by the diatom *S. marinoi*. In contrast, dinoflagellates - primarily *Peridiniella catenata* and members of Gymnodinales - comprised the second most abundant group after *M. rubrum* at K5. Further east at station K4, instead, diatoms, particularly, *S. marinoi*, accounted for 78% of the total phytoplankton biomass.

In May, Chl *a* concentrations had decreased compared to March, indicating that the annual spring bloom was ending. Chl *a* concentration reached 1.41 µg l^{-1} at K8 in the western Arkona Basin, and 2.62 µg l^{-1} at K5 in central Arkona Basin and 1.65 µg l^{-1} at K4 in eastern Arkona Basin. Likewise total phytoplankton biomass had decreased. At station K8 phytoplankton biomass was 182 µg l^{-1} and the community was dominated by Haptophytes (Prymnesiales) by about 50 %. At station K5, phytoplankton biomass remained high at 790 µg l^{-1}, with *M. rubrum* continuing to represent the dominant species. At station K4 phytoplankton biomass had decreased to 283 µg l^{-1}. Community composition here was more diverse and composed predominantly of *M. rubrum*, but also Haptophytes and cyanobacteria.

In August Chl *a* concentrations ranged from 2.06 µg l^{-1} at station K8, 1.74 µg l^{-1} at station K5 to 1.99 µg l^{-1} at station K4. The increase in Chl *a* from beginning of August to mid of August (K8, K5) reflected the ongoing development of the summer bloom. However Chl *a* concentrations did not mirror the high phytoplankton biomass values observed at all stations in the Arkona Basin at the beginning of August, reaching summer bloom status. Total phytoplankton biomass was 6092 µg l^{-1} at station K8, 5717 µg l^{-1} at station K5 and 2553 µg l^{-1} at station K4. Diatoms, almost exclusively *D. fragilissimus*, dominated the bloom by more than 95 % of total biomass at all stations.

In November highest Chl *a* values and highest phytoplankton biomass of all monitoring samplings in 2024 have been measured. At 9th November Chl *a* values reached 5.60 µg l^{-1} at K8 in the western Arkona Basin, and 6.71 µg l^{-1} at K5 in central Arkona Basin and 5.96 µg l^{-1} at K4 in eastern Arkona Basin. Diatoms, almost exclusively *C. pelagica*, constituted 98 % of total biomass at all stations. Highest phytoplankton biomass values were detected at station K8 with 8133 µg l^{-1}, followed by K5 with 6852 µg l^{-1} and 4116 µg l^{-1} at station K4.

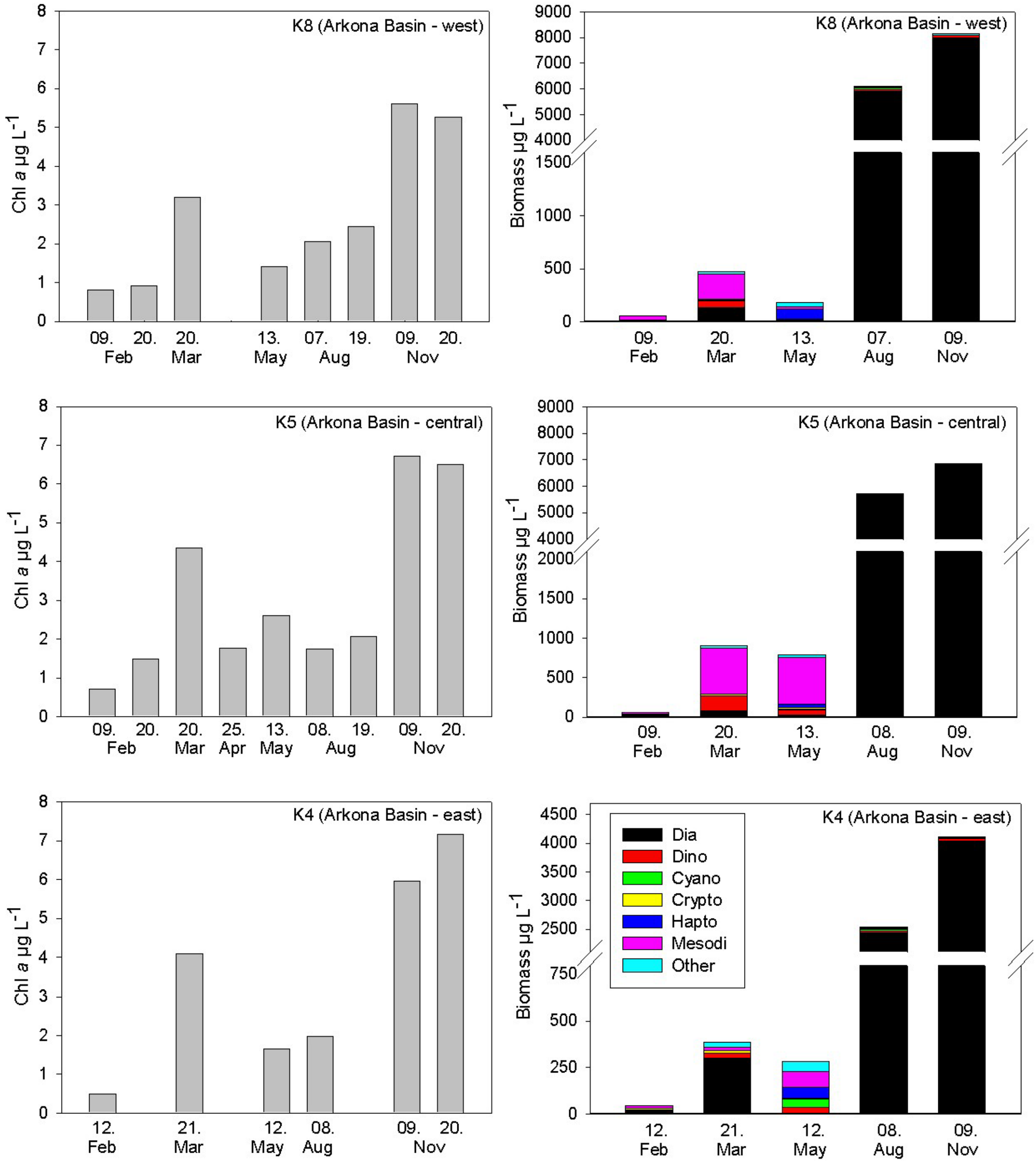

Fig. 3: Chl a concentrations (left column) and biomass composition (right column) in 2024 at the sampling stations K4, K5 and K8 in the Arkona Basin.

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

A total of 143 phytoplankton taxa were recorded in the study area (Table Appendix 1), with the highest number of taxa recorded in February (86) and November (87). In particular, the large diatoms *Dactyliosolen fragilissimus* (Fig. 4) and *Cerataulina pelagica* were identified as the overall most dominant species both in the Belt Sea and Arkona Basin in August and November, respectively (Table 5, Table 6), dominating total biomass even by more than 96 % in Arkona Basin (Table 6). In the Belt Sea in May, likewise to 2023, highest contribution to total biomass (31 %) was reached by various unidentifiable flagellates (predominantly 2-5 µm in size) and Prymnesiales (15 %, Table 5, Fig. 4). The filamentous cyanobacteria *Nodularia spumigena* (Fig. 4) was even identified as the second most dominant species in the Belt Sea in August, which is less typical for this part of the Baltic Sea (Table 5).

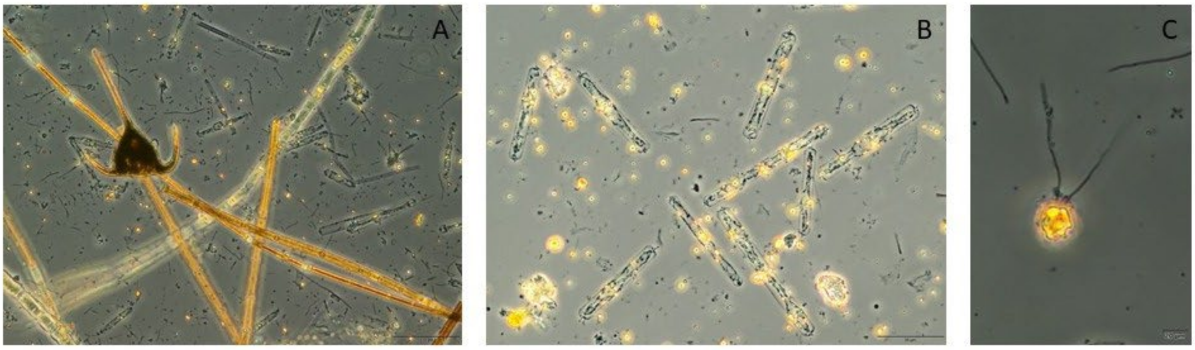

Fig. 4: Photographs of selected algae species, which formed blooms in the study area in 2023: A) Nodularia spumigena*, B)* Dactyliosolen fragilissimus*, C) Prymnesiales.*

Table 5: The 10 most abundant species and number of recorded taxa in the Belt Sea (mean of Bay of Kiel (N3), Bay of Mecklenburg (M2), Kadet Trench (M1)) at 5 monitoring cruises (February, March, May, August, November) 2024.

	Feb 24
Taxon	% Biomass
Thalassiosira nordenskioeldii	39.99
Rhizosolenia setigera	11.33
Skeletonema marinoi	10.77
Teleaulax	5.36
Thalassiosira	4.47
Guinardia flaccida	2.65
Gymnodinium	2.55
Protoperidinium depressum	2.35
Guinardia delicatula	2.3
Thalassiosira punctigera	2.22
Number of recorded taxa	**69**

	Mar 24
Taxon	% Biomass
Guinardia delicatula	25.45
Skeletonema marinoi	18.98
Mesodinium rubrum	14.88
Rhizosolenia setigera	7.33
Pseudo-nitzschia seriata GRP	5.4
Proboscia alata	2.8
Heterocapsa rotundata	2.35
Teleaulax	2.27
Ebria tripartita	2.14
Gymnodiniales	1.84
Number of recorded taxa	**71**

	May 24
Taxon	% Biomass
Flagellates	30.86
Prymnesiales	14.77
Proboscia alata	7.3
Pyramimonas	5.93
Unicell spp.	5.74
Telonema	5.43
Peridiniella danica cf.	5.39
Heterocapsa rotundata	4.64
Plagioselmis prolonga	3.59
Gymnodinium	2.54
Number of recorded taxa	**38**

	Aug 24
Taxon	% Biomass
Dactyliosolen fragilissimus	56.45
Nodularia spumigena	32.63
Proboscia alata	4.06
Tripos muelleri	2.32
Aphanizomenon	0.6
Gymnodinium	0.5
Prorocentrum micans	0.44
Gymnodiniales	0.36
Cylindrotheca closterium	0.24
Guinardia flaccida	0.17
Number of recorded taxa	**62**

	Nov 24
Taxon	% Biomass
Cerataulina pelagica	66.31
Pseudosolenia calcar-avis	4.48
Tripos muelleri	4.42
Guinardia delicatula	2.55
Pseudo-nitzschia seriata GRP	2.43
Kryptoperidinium triquetrum	2.23
Polykrikos schwartzii	1.81
Prorocentrum micans	1.56
Scrippsiella GRP	1.53
Tripos lineatus	1.53
Number of recorded taxa	**71**

Table 6: The 10 most abundant species and number of recorded taxa in the Arkona Sea (mean of Darss Sill (K8), Arkona Sea (K5, K4)) at 5 monitoring cruises (February, March, May, August, November) 2024.

Taxon	**Feb 24** % Biomass
Mesodinium rubrum	44.69
Teleaulax	11.22
Actinocyclus	10.94
Actinocyclus octonarius	9.49
Gymnodinium	3.66
Heterocapsa rotundata	2.96
Plagioselmis prolonga	2.75
Skeletonema marinoi	2.29
Gymnodiniales	2.03
Eutreptiella	1.59
Number of recorded taxa	**36**

Taxon	**Mar 24** % Biomass
Mesodinium rubrum	47.22
Skeletonema marinoi	27.02
Gymnodinium	5.87
Peridiniella catenata	4.61
Teleaulax	2.43
Ebria tripartita	2
Thalassiosira	1.77
Gymnodiniales	1.74
Heterocapsa rotundata	0,99
Gyrodinium spirale	0.91
Number of recorded taxa	**51**

Taxon	**May 24** % Biomass
Mesodinium rubrum	56.7
Prymnesiales	15.74
Aphanizomenon	4.19
Pseudopedinella	3.38
Pyramimonas	2.6
Heterocapsa cf.	2.05
Dinophysis acuminata	1.94
Gymnodinium	1.76
Heterocapsa rotundata	1.69
Teleaulax	1.46
Number of recorded taxa	**42**

Taxon	**Aug 24** % Biomass
Dactyliosolen fragilissimus	97.47
Aphanizomenon	0.47
Nodularia spumigena	0.3
Pyramimonas	0.3
Gymnodiniales	0.19
Gymnodinium	0.18
Tripos muelleri	0.18
Plagioselmis prolonga	0.12
Mesodinium rubrum	0.12
Unicell spp.	0.11
Number of recorded taxa	**26**

Taxon	**Nov 24** % Biomass
Cerataulina pelagica	96.76
Coscinodiscus commutatus	0.79
Pseudosolenia calcar-avis	0.39
Dactyliosolen fragilissimus	0.23
Tripos muelleri	0.22
Teleaulax	0.19
Coscinodiscus granii	0.18
Prorocentrum cordatum	0.12
Gymnodiniales	0.11
Mesodinium rubrum	0.1
Number of recorded taxa	**54**

In 2024, 13 potentially toxic or harmful algal taxa were recorded in the study area (Table 7). Likewise to 2023, the number of taxa was high compared to 2022, where only 8 taxa have been recorded. Whereas most of the species occurred in overall low abundances, Prymnesiales reached high abundances in May at almost all stations and even bloom concentration at station K8 in the Arkona Basin.

Table 7: Harmful phytoplankton taxa in the study area in 2024. + = present, ++ = abundant (1-10 % biomass share), +++ = very abundant (> 10 % biomass share), ++++ = bloom (>50 % biomass share).

Species/Station	**Cruise 2024**	**TF0360 N3** Bay of Kiel	**TF0012 M2** Bay of Mecklenburg	**TF0046 M1** Bay of Mecklenburg	**TF0030 K8** Arkona Sea	**TF0113 K5** Arkona Sea	**TF0109 K4** Arkona Sea
Cyanophyceae							
Dolichospermum spp	**August**	+	+	+			
Nodularia spumigena	**May**	+					
	August	++	+++	++	+	+	
	November					+	
Aphanizomenon sp.	**March**	+	+	+	+	+	+
	May			+	++	+	+++
	August	+	+	+	+	+	+
	November			+	+	+	+
Dinophyceae							
Azadimium cf.	**August**			+			
Prorocentrum cordatum	**February**			+			
	August	+	+	+			
	November	+	+	+	+	+	+
Prorocentrum micans	**August**	++	+	+			
Dinophysis acuminata	**February**		+	+			
	March	+		+			
	May					++	+ +
	August	+	+	+		+	+
	November	+	+	+	+	+	+
Dinophysis norvegica	**August**	+		+			
	November	+	+	+			
Karlodinium veneficum	**February**					+	
	March	+					
	August	+					
	November		+				
Bacillariophyceae							
Pseudo-nitzschia spp.	**February**	++	+	+			
	March	++	+	+			
	August	+					
	November	+++					
Raphidophyceae							
Heterosigma akashiwo	**March**	++	++	++			
Dictyochophyceae							
Pseudochattonella farcimen	**February**	+	+				
Prymnesiales	**February**	+	+	+	+	+	+
	March	+	+	+	+	+	+
	May	+++	+++		++++	++	+++
	August	+	+	+		+	+
	November	+	+	+	+	+	+

4.1.3 Long-term trends

Biomass

The average mean biomass of phytoplankton across the entire study area was with 1740 µg l^{-1} approximately 3 times higher than in 2023 and twice as high as the 20-years mean (Fig. 5), predominantly due to a cyanobacterial bloom event in the Bay of Mecklenburg in summer and overall high biomass in November at the time of the cruises.

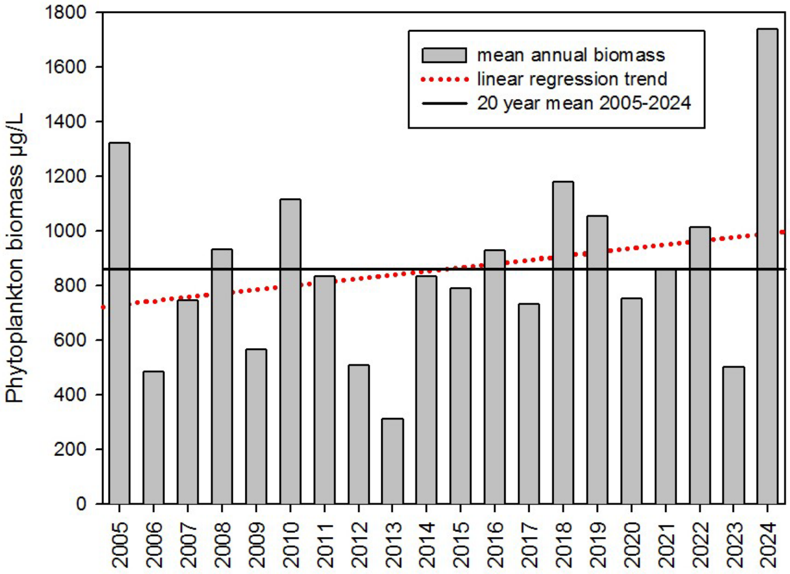

Fig. 5: Mean annual phytoplankton biomass values (all stations and samplings) for the period 2005 - 2024.

Diatom-dinoflagellate index

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 supposed to indicate a good environmental status (WASMUND et al. 2017) as it supports food web transfer. On the other hand, sedimentation of large diatom blooms may enhance oxygen consumption in bottom waters leading to anoxic conditions in the sediments, which support the internal phosphorus loading (VAHTERA et al. 2007). In contrast, dinoflagellates typically disintegrate in the water column or form resting stages that resist remineralisation in bottom sediments (SPILLING et al. 2018). Dinoflagellate dominance in summer is often related to harmful algal blooms which can disrupt trophic transfer.

The values of the dia/dino index exceeded the good environmental status threshold in the Bays of Kiel and Mecklenburg and in the Arkona Sea in spring 2024.

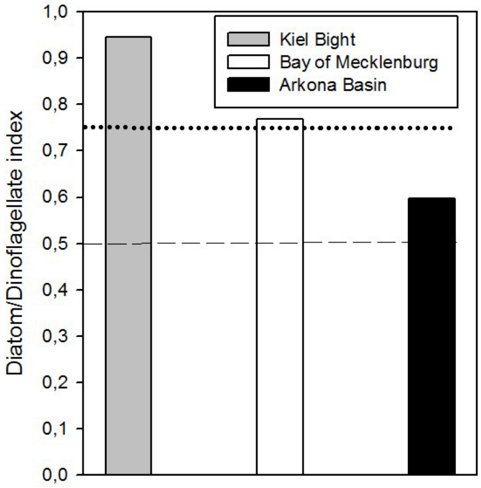

Fig. 6: The Diatom/Dinoflagellate Index, based on mean values of wet-weight biomass (March-May), in Bay of Kiel, the Bay of Mecklenburg and the Arkona Basin. The dotted line indicates the GES suggested for Bay of Kiel and the Bay of Mecklenburg. The dashed line indicates the GES suggested for the Arkona Basin.

Cyanobacteria biomass

In 2024, the annual cyanobacteria biomass in the study area was assessed in a long term context at the six monitoring stations in Belt Sea and Arkona Basin. It provides information on the general state of a sea area, assuming that high cyanobacteria biomass is a sign of environmental and ecological status deterioration in the Baltic Sea, where toxic or otherwise harmful cyanobacteria form blooms in summer. High cyanobacteria biomass may contribute to bottom water anoxia and oxygen deficiency in sediments with complex negative systemic implications.

In the Bays of Kiel and Mecklenburg (N3, M2, M1), cyanobacterial biomass was strongly enhanced compared to previous years due to high abundance of *Nodularia spumigena* during sampling period (Fig. 7). Obviously the cruise date in August 2024 coincided directly with a cyanobacterial bloom in the Bay of Mecklenburg. In the central and eastern Arkona Basin (K4, K5), the mean total cyanobacteria biomass was far below the 20 year mean value in August 2024.

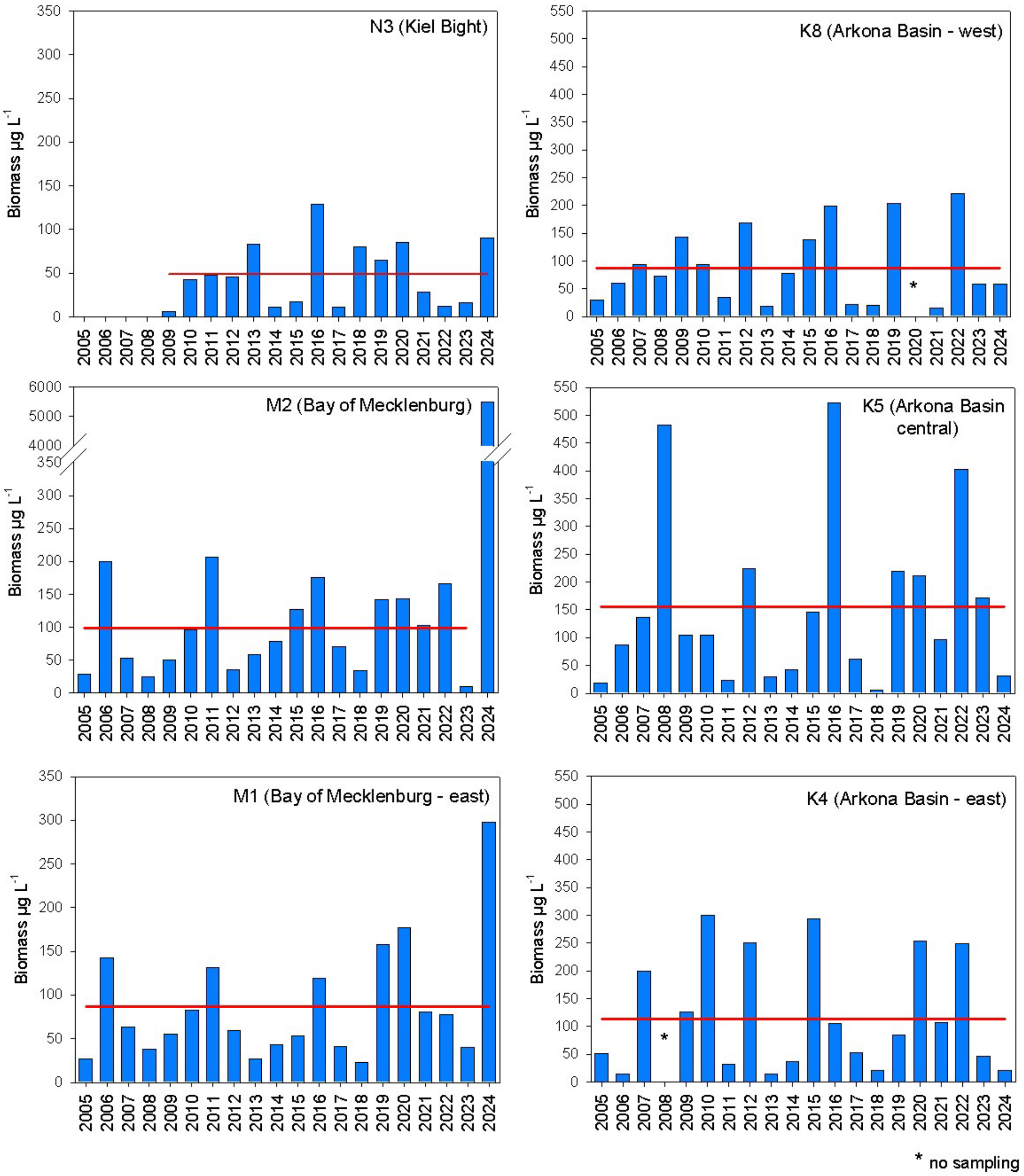

Fig. 7: Cyanobacteria biomass in a 20 year monitoring perspective at the six monitoring stations in Kiel Bight, Bay of Mecklenburg and Arkona Basin. Bars display the mean summer (August) biomass of total cyanophyceae (wet weight in µg l $^{-1}$), whereas the red lines display the 20-years mean value.

4.2 Mesozooplankton

4.2.1 Species composition and non-indigenous species

In analogy to the year 2023, the hydrographical situation in the western Baltic Sea was influenced by a series of inflow events and thermal conditions above the long-term mean. A winter inflow of saline water was responsible for an enhanced salinity in the water column of the Belt Sea and increased the bottom water salinity of 17-20 PSU below 25 m in the Arkona Sea in February. During spring and summer, further baroclinic inflows caused an increase of the salinity in the Belt Sea. The bottom water in the Bay of Mecklenburg showed unusual high levels larger than 26 PSU. At all stations in the western Baltic Sea, the sea surface temperature was above the long-term average in all seasons. Particularly in summer, values were > 2 K above the mean and exceeded 20°C. At the same time, brackish water influenced the surface salinity beyond the Darss sill in the Bay of Mecklenburg.

The seasonal variation in the number of taxa recorded in the investigation period reflected the hydrographical situation (Fig. 8). The cold winter inflow did not strongly influence the composition of the zooplankton. During this time, the salinity in the Belt Sea is usually enhanced (<15 PSU) while the transport of stenohaline species into the investigation area is low due to the generally low activity and low stock sizes of zooplankton. The observed 12-24 taxa, thus, fall well into the range of taxa numbers observed in preceding years. The Bay of Kiel, however, was characterized by a particularly low number of taxa (12, range observed in preceding years 15-23). Following the typical minimum observed in May, the number increased considerably. This is most obvious in the Bay of Mecklenburg, where it increased to 32-35 caused by a mixture of marine and brackish water species resulting from the combined influence of the enhanced bottom water salinity and the westwards extension of brackish water. In the Bay of Kiel and Arkona Sea, the influence of saline water was minor.

In total, 58 taxa were recorded in 2024 (Table Appendix 2). Compared to historical values during major Baltic inflows, the number is low (max. 70 taxa). As in previous years, the increase in biodiversity during summer is related to the occurrence of meroplankton such as echinoderm, polychaete or crustacean larvae (e.g., the genera *Liocarcinus*, *Peltogaster*, *Asterias*, *Ophiura*) and hydrozoan species (*Euphysia aurata*, *Sarsia tubulosa*, *Rathkea octopunctata*). Nevertheless, also holoplanktonic stenohaline species were observed such as the copepods *Acartia clausi* or *Calanus finmarchicus*, the cladoceran *Penilia avirostris* and the large heterotrophic dinoflagellate *Noctiluca scintillans*. These species are usually observed during major Baltic inflows (WASMUND et al. 2018, 2019).

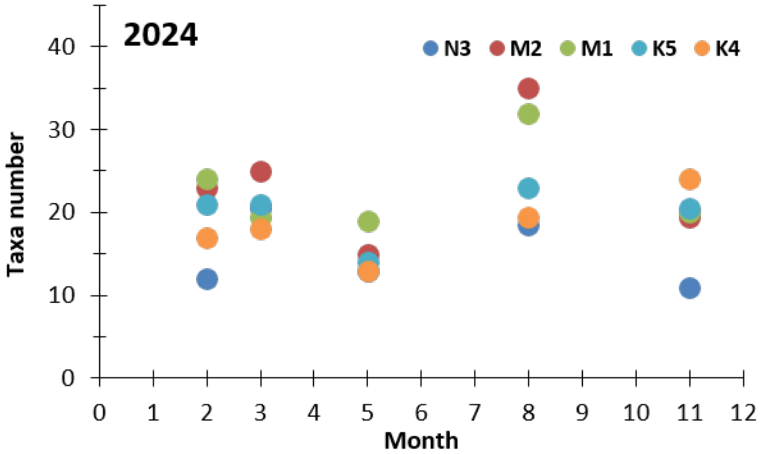

Fig. 8: Seasonal variation of the number of taxa occurring at the various monitoring stations in the south-western Baltic Sea in 2024 (OMBMP-N3: Bay of Kiel, OMBMP-M2, -M1: Bay of Mecklenburg, OMBMP-K5, -K4: Arkona Basin).

In the Baltic Sea, about 231 species are classified as non-indigenous species (NIS), but only few are planktonic (~ 15 species). Of these, three species were observed in the investigation period. The thermophilic copepod species *Acartia tonsa* occurs regularly during summer in the Belt Sea and the Arkona Sea. First records of this species in German coastal waters originate from 1981 (GOLLASCH & NEHRING 2006). However, the species was introduced to the Baltic Sea already during the 1920s. It is well established in the Baltic Sea especially in coastal water during the warm season. This applies also to the other species, the cladoceran *Penilia avirostris*. It was found primarily during the warm season in summer, but single occurrences were also recorded in November. *Penilia avirostris* is a species of the family Sididae and is distributed in temperate waters of 12-30 °C around Asia, Europe, and New Zealand. Increasing water temperatures allow the species to thrive and increase its population growth dramatically (Johns et al. 2005). In addition to these two warm water species, the cold-water copepod *Acartia hudsonica* was observed as a single find in the Bay of Mecklenburg. The species is a new record in the montitoring programme. It is classified as a boreal-temperate cold water element in the western coast of the North Atlantic and and the North Pacific where it usually occurs in the cooler first half of the year (Ueda 1986, Sullivan & McManus 1986, Rice et al. 2015). In the eastern Atlantic and the North Sea, the sibbling species *Acartia clausi* usually dominates (Krause & Martens 1990). In the Baltic Sea, it was first identified by molecular techniques in a culture established from net sampling in the Bay of Kiel (Hahn & Brennan 2024).

The annual average composition of the zooplankton showed some major difference compared to preceding years (Fig. 9). In the period 2019-2023, copepods generally dominated the composition of the zooplankton in all areas by 60-80 %. Such a dominance is usually typical for stations located in the Belt Sea, where the marine influence is large and the contribution of brackish water species is low (Dutz & Wasmund 2023, Dutz et al. 2025). In contrast, it is untypical for the areas east of the Darss Sill as for instance the Arkona Sea where the brackish influence is high. Here, the copepod prevalence (57-76%) in 2019-2023 was caused by an unusual low abundance of rotifers in spring and cladocerans in summer. This situation has shifted back to a more balanced composition due to increasing stocks of cladocerans in 2024, which contributed to 38% to the annual zooplankton stock (2023: 8 %). The abundance of rotifers, however, remained on a historically low level. No obvious trends in sea surface salinity were observed in spring 2024 that could explain the decrease in the abundance of rotifers. This suggests that peak concentrations might have shifted to an earlier occurrence outside the observation period.

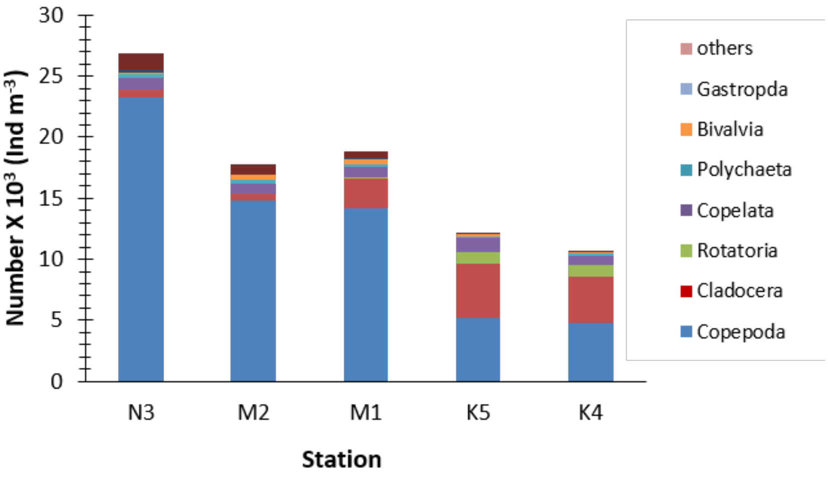

*Fig. 9: Annual mean abundance (Ind. * 10^3 m^{-3}) of the main groups of zooplankton in the south-western Baltic Sea in 2024 (OMBMP-N3: Bay of Kiel, OMBMP-M2, -M1: Bay of Mecklenburg, OMBMP-K5, -K4: Arkona Basin).*

4.2.2 Seasonal variation of zooplankton in the sub-areas

Bay of Kiel (N3, Belt Sea)

The seasonal development of the zooplankton abundance and composition in the Bay of Kiel was characterized by a rather usual situation during the winter-spring transition (Fig. 10). In winter, the abundance of the zooplankton (1.0 x 10^4 Ind. m^{-3}) corresponded the long-term average (0.9 x 10^4 Ind. m^{-3}). The increased temperatures, which were 1.0-1.3 K above the long-term mean, had no obvious effect. Copepods dominated the community with about 55% of the stock together with meroplankton (45%). Among the latter, polychaete larvae were rare in 2024 and were replaced by bryozoan larvae that occurred at unusual high concentrations (3.3 x 10^3 Ind. m^{-3}) compared to their long-term mean (0.6 x 10^3 Ind. m^{-3}). The increase in the abundance in March (1.4 x 10^4 Ind. m^{-3}) was only moderate in comparison to the year 2023 (2.0 x 10^4 Ind. m^{-3}), despite a slightly warmer sea surface temperature. Nevertheless, total abundance was above the long-term mean of 1.1 x 10^4 Ind. m^{-3}. Copepods (77%) and the Bryozoa (20%) still dominated the community, while rotifers were unusual rare. Towards May, the abundance nearly tripled (3.3 x 10^4 Ind. m^{-3}), but remained below the long-term mean. This was caused by the absence of rotifers and low meroplankton concentrations, while copepods (3.1 x 10^4 Ind. m^{-3}) and cladocerans (1.5 x 10^3 Ind. m^{-3}) were more abundant than usual. Considering the high sea surface temperature of 2.4-3.1 K above the long-term mean, the temporal maximum of rotifers and meroplankton likely occurred before the sampling. In consequence, copepods dominated the community by more than 95%.

In contrast to the winter-spring transition, the concentration of the zooplankton was low in summer (Fig. 10). This was mainly caused by the continuation of the low abundance of meroplankton observed already in May. Especially bivalve (370 Ind. m^{-3}) but also gastropod (270 Ind. m^{-3}) larvae account for the summer low that is observed since 2022. Bivalve larvae usually dominate the meroplankton with a long-term mean of (6.1 x 10^3 Ind. m^{-3}). In contrast, copepods, Copelata and cladocerans occurred at a usual abundance of 8.9, 1.6 and 1.3 x 10^4 Ind. m^{-3} and contributed to 70, 12 and 10% to the community, respectively. In comparison to previous years, however, a considerable recovery of the zooplankton stock occurred towards autumn, when an exceptionally high abundance of 6.5 x 10^4 Ind. m^{-3} was observed. This is close to the maximum concentration of 6.8 x 10^4 Ind. m^{-3} observed in this season in 2012. The maximum abundance was exclusively based on an unusual high concentration of copepods (6.0 x 10^4 Ind. m^{-3}; see below). Copelata (3.2 x 10^3 Ind. m^{-3}) and meroplankton (1.5 x 10^3 Ind. m^{-3}), in contrast, occurred at usual concentrations.

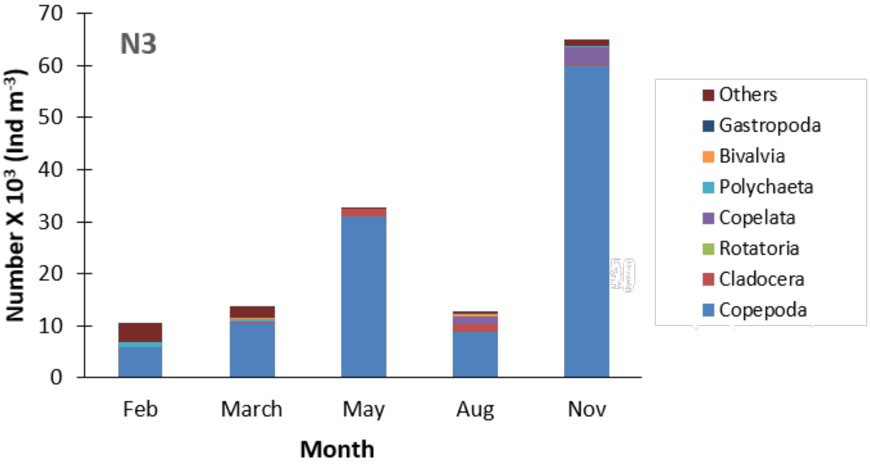

Fig. 10: Seasonal variation in the abundance of the major mesozooplankton groups (holoplankton: Copepoda, Cladocera, Rotatoria, Copelata; meroplankton: Polychaeta, Bivalvia, Gastropoda) in the Bay of Kiel (OMBMP-N3) during 2024.

The preceding years 2022-2023 were characterized by the dominance of *Pseudocalanus* spp. among the copepods during February and March and the species' abundance was close to maximum values in the entire time series. In 2024, the copepod community displayed a return to a mixed and balanced composition composed of various calanoid and cyclopoid copepods (Fig. 11). The cyclopoid copepod *Oithona* spp. dominated in February (33%) followed by *Acartia*, *Temora* and *Centropages*, which contributed to 13-24% to the copepod stock. With the increase of the stock in March and May, the contribution of *Oithona* diminished considerably in favour of the calanoid copepods, *Temora longicornis* (3.4 x 10^3 Ind. m^{-3}) and *Acartia bifilosa/Centropages hamatus* (1.1 and 1.5 x 10^4 Ind. m^{-3}) that occurred at concentrations that were 2-3 times higher than the long-term mean in March and May, respectively. This cannot fully be related to the inflow of saline water during winter since the typically cold-water genus *Pseudocalanus* spp. should have been similarly favoured.

A shift in the composition of the copepod fauna associated with the vernal warming is a regular and feature in the seasonal dynamics of the zooplankton in the Bay of Kiel (Dutz & Wasmund 2023). However, the pronounced dominance of *Oithona* among the juvenile and adult stages during summer and autumn (73-98% of the stock) that occurs since 2020 is exceptional. The year 2024 was no exception. *Oithona* spp. contributed to 85-89% and 93-98% to the stocks of copepodites and adults (Fig. 11), respectively. The thermophilic species *Acartia tonsa* and *Paracalanus parvus*, in contrast, contributed only little (6.4-10.2%).

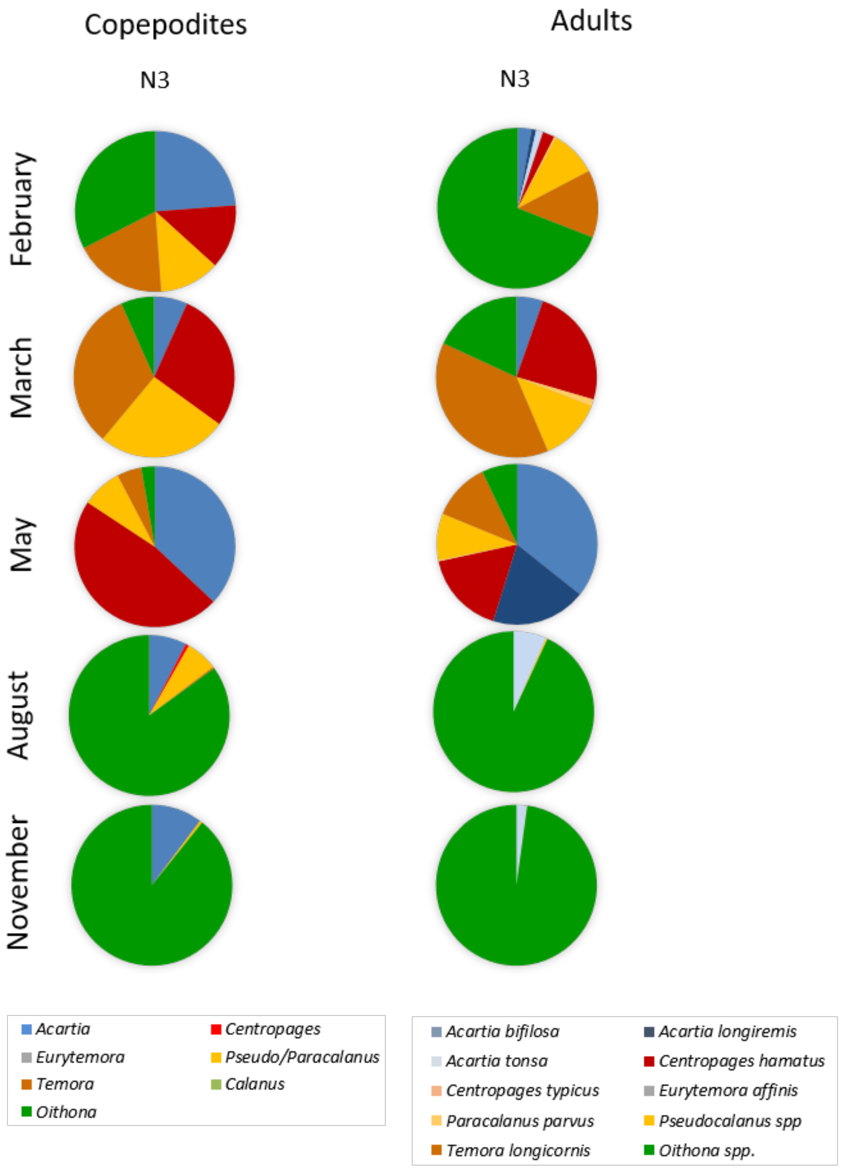

Fig. 11: Relative composition of the copepodites ($C_{I\text{-}V1}$, left panel) and adult copepods (C_{V1}, right panel) during the sampling months in the Bay of Kiel in 2024 (OMBMP-N3).

Bay of Mecklenburg (M2, M1, Belt Sea)

The Bay of Mecklenburg showed a similar seasonal variation in the abundance and composition of the mesozooplankton community than the Bay of Kiel, including the pronounced autumn maximum (Fig. 12). However, some important differences were observed such as the already mentioned higher species number during summer (chapter 4.2.1) and differences in the species composition in spring or among the two monitoring stations in the area during summer (OMBMP-M2 and –M1, Fig. 1). These are linked to the hydrographical differences with a considerably higher salinity in the bottom water during spring and the influence of brackish water at station OMBMP-M1, which is in closer proximity to the Darss Sill.

The composition of the zooplankton community in the Bay of Mecklenburg during winter showed a large similarity to the composition in the Bay of Kiel. The abundance of the stock of 9.3 x 10^3 Ind. m^{-3} was above the long-term average (6.1 x 10^3 Ind. m^{-3}) and copepods dominated the community with 76% of the stock. Among the meroplankton, bryozoan and polychaete larvae were equally abundant (0.9-1.1 x 10^3 Ind. m^{-3}) and contributed combined about 23% to the community. The spring increase during March and May was based on increasing numbers of copepods (1.1 and 1.9 x 10^4 Ind. m^{-3}), which were more abundant than the long-term mean, especially in March (0.6 x 10^3 Ind. m^{-3}). However, the dominance of copepods (77-92%) results mainly from a declining contribution of meroplankton and rotifers in March and May, respectively, similar to the Bay of Kiel.

In summer and autumn, the dynamics in the stocks of the zooplankton differed from the Bay of Kiel. At station OMBMP-M2 in the southern Bay of Mecklenburg, the stock displayed only a moderate decline to 1.3 x 10^4 Ind. m^{-3}. Copepods still dominated the community (59%), but other groups were common as well such as the bivalve larvae among the meroplankton (15%), the appendicularian *Oikopleura* (10%) or diverse Cladocera (8%). In contrast, no decline was observed at the station OMBMP-M1 in the northern Bay of Mecklenburg (2.6 x 10^4 Ind. m^{-3}). Here, a decrease in the salinity of the surface water to 7.9 indicated a strong influence of brackish water transport westwards over the Darss Sill that brought the brackish water cladoceran *Bosmina* into the area (up to 1.9 x 10^4 Ind. m^{-3}). Similar to the Bay of Kiel, however, the dominance of copepods with the maximum of 2.3-3.1 x 10^4 Ind. m^{-3} (92-95% of the community) reestablished in November. The appendicularian *Oikopleura* was the only group with a substantial contribution to the stock (4-5%, 1.2-2.3 x 10^3 Ind. m^{-3}).

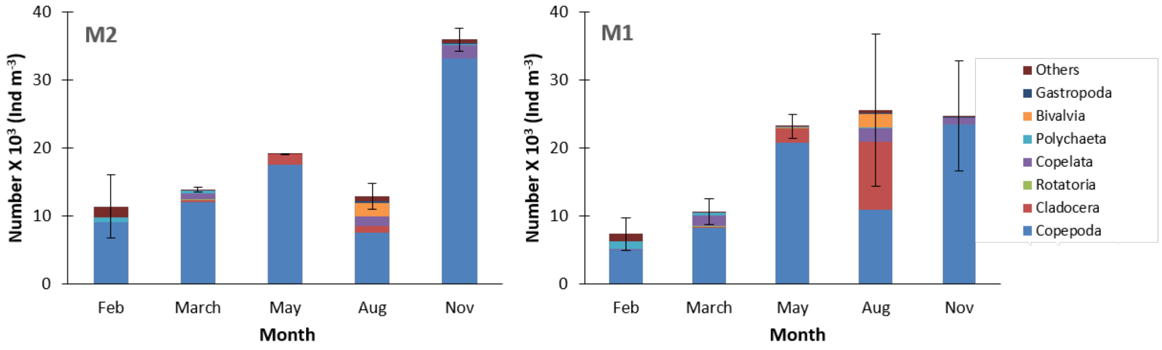

Fig. 12: Seasonal variation of the mean abundance of the major mesozooplankton groups in the Bay of Mecklenburg at station OMBMP-M2 and –M1 during 2023.

The composition of the copepod fauna differed considerably from the Bay of Kiel (Fig. 13). During winter, the cyclopoid copepod *Oithona* was more abundant than usual (on average 4 x 10^4 Ind. m^{-3}) and dominated the copepodite and adult communities by 57-80%. In spring (March, May), however, *Pseudocalanus* spp. Became dominant (44-62%) at an abundance (5.5-9.6 x 10^3 Ind. m^{-3}) close to the maximum values recorded in the time series (6.6-10.1 x 10^3 Ind. m^{-3}). Other copepods of importance were the genus *Acartia* with *A. longiremis* as a major species, *Temora longicornis* and *Centropages hamatus*. In summer and autumn, however, *Oithona* became again the dominating taxon, particularly in November (93-99%, 1.2-3.1 x 10^4 Ind. m^{-3}). In August, *A. tonsa* replaced *A. longiremis* and contributed together with *Pseudocalanus* to 50-66% to the copepod stock, but by November, their abundance has considerably decreased (max 630 Ind. m^{-3}).

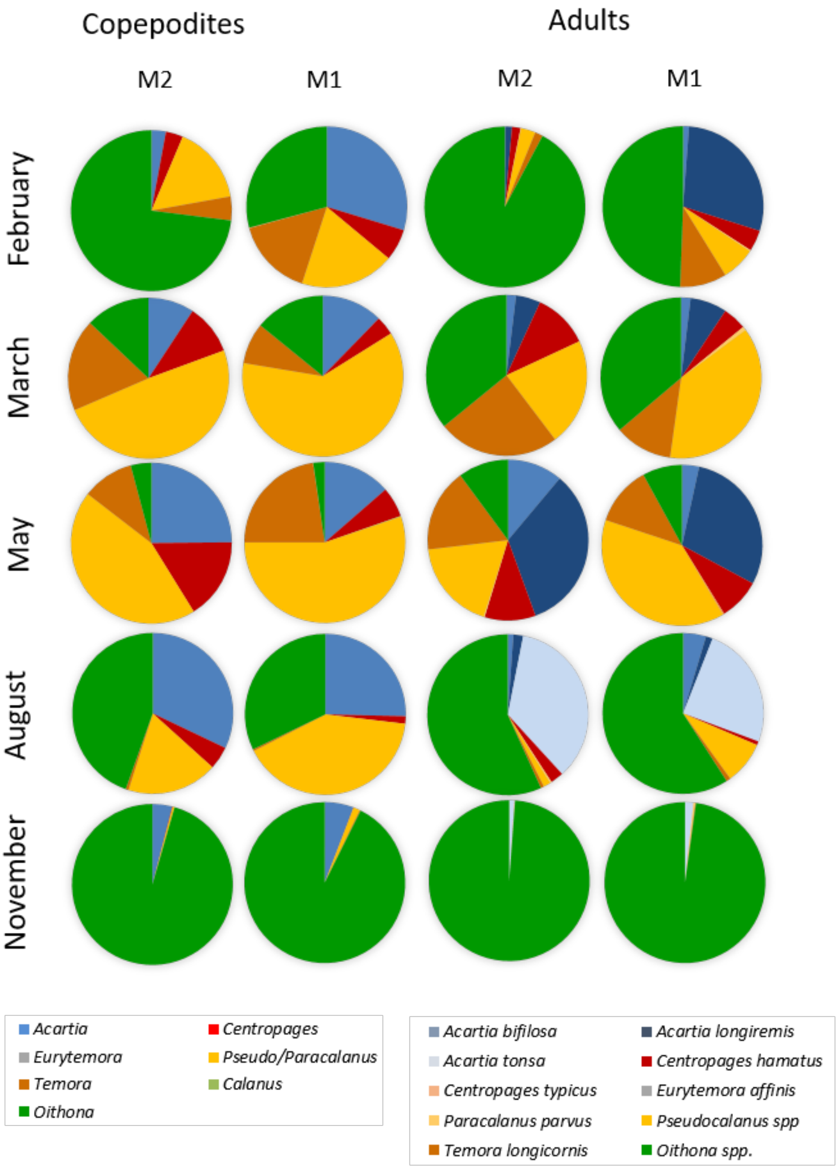

Fig. 13: Relative composition of the copepodites (C_{I-V1}, left panel) and adult copepods (C_{V1}, right panel) during the sampling months in the Bay of Mecklenburg (OMBMP-M2 and –M1).

Arkona Basin (K5, K4, Baltic Proper)

In contrast to the Belt Sea, the hydrography of the Arkona Sea was influenced by the winter inflow. This inflow elevated the salinity in the bottom water by 2.0 and increased the bottom layer depth. Due to low zooplankton abundance at this time of the year, the inflow had only little effect on the biodiversity. In spring and summer, the inflows that substantially elevated the bottom water salinity in the Belt Sea had only a minor effect on the hydrographical conditions in Arkona Sea. Here, the surface salinity was on average slightly below the mean of 1998-2024 (0.2-0.4,). In contrast, the sea surface temperature was 1.2-1.5 K above the long-term mean in May and August and the maximum of 19.9°C was recorded in August. The temperature below the surface mixed layer remained cooler than in 2023 which is important for species with an affinity to cooler water (e.g., *Acartia longiremis*) and explains their presence in 2024 in contrast to 2023.

In 2024, both stations (OMBMP-K5, -K4) showed a similar seasonal development and stock size, which reflects the strong influence of brackish water during spring and summer. The abundance during winter was low (1.7-2.5-x 10^3 Ind. m^{-3}, Fig. 14), mainly due to low stocks of copepods that achieved only 1.2-1.6 x 10^3 Ind. m^{-3} (long-term: 2.6 x 10^3 Ind. m^{-3}). In contrast, the appendicularian *Fritillaria* and meroplankton (polychaete and bryozoan larvae) occurred at their usual density and contributed to 15 and 13% to the stock, respectively. The increase in the zooplankton abundance in March was caused by *Fritillaria*, which was more abundant than usual (2.9 x 10^3 Ind. m^{-3}) and dominated the stock (50%). Copepods, in contrast, remained low (1.7 x 10^3 Ind. m^{-3}, long-term mean 2.8 x 10^3 Ind. m^{-3}). With the warming of the water column in May, the abundance of zooplankton rose further to the annual maximum of 2.3 x 10^4 Ind. m^{-3}. Copepods contributed to 49% of the community (1.1 x 10^4 Ind. m^{-3}), followed by diverse cladocerans (30%) and rotifers (18%). The high abundance of cladocerans is uncommon for this time of the year (6.9 x 10^3 Ind. m^{-3}), while the rotifer *Synchaeta* spp. still occurred at considerably reduced concentrations (4.1 x 10^3 Ind. m^{-3}) compared to years before 2010 (up to 7.7 x 10^4 Ind. m^{-3}). In contrast to the Belt Sea, the zooplankton did not decrease in summer (1.9-2.4 x 10^4 Ind. m^{-3}) due to a high abundance of the brackish water cladoceran *Bosmina* spp. (1.1-1.8 x 10^4 Ind. m^{-3}). Cladocera, thus, dominated the community (64-78%), while they were rare in 2022-2023. The density of the copepods (2.8-5.7 x 10^3 Ind. m^{-3}) was considerably below their long-term mean (8.2 x 10^3 Ind. m^{-3}). This was also the case in November, when copepods dominated again the community (5.6-6.0 x 10^3 Ind. m^{-3}, 81-86%).

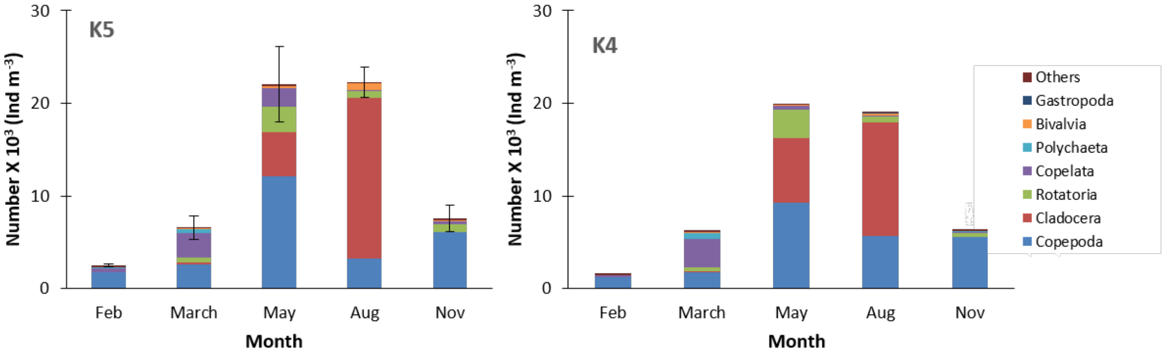

Fig. 14: Seasonal variation of the mean abundance of the major mesozooplankton groups in Arkona Basin at station OMBMP-K5 and – K4 during 2023.

Calanoid species dominated the community of copepods from winter to summer by 91-99% in 2024 (Fig. 15). This complies with the long-term community composition in the area, in which cyclopoid copepods and the genus *Oithona* only irregularly occur in significant concentrations. *Acartia*, *Temora* and *Centropages* contributed equally to the overwintering community (17-23%), but similar to preceding years, *Pseudocalanus* spp. was the most abundant copepod (35-40%). With the increase in the copepod stocks in May, however, the dominance switched to *Acartia* (17-35%), *Centropages* (15-16%) and especially *Temora* (32-47%), which occurred at concentrations above the long-term mean. Both *Temora longicornis* and *Acartia longiremis* were the dominant species. In contrast to the Belt Sea, the composition of the copepod community changed only little with its decrease in summer (Fig. 15). The abundance of *Oithona* was small compared to 2022-2023. This changed substantially in autumn, when this genus dominated the community by 45-87% and occurred at a density o (2.2-

5.9 x 10^3 Ind. m^{-3}) considerably above the long-term mean (0.9 x 10^3 Ind. m^{-3}). The only other taxon found in a relevant proportion was *Acartia*, with the thermophilic species *A. tonsa* – similar to the Belt Sea.

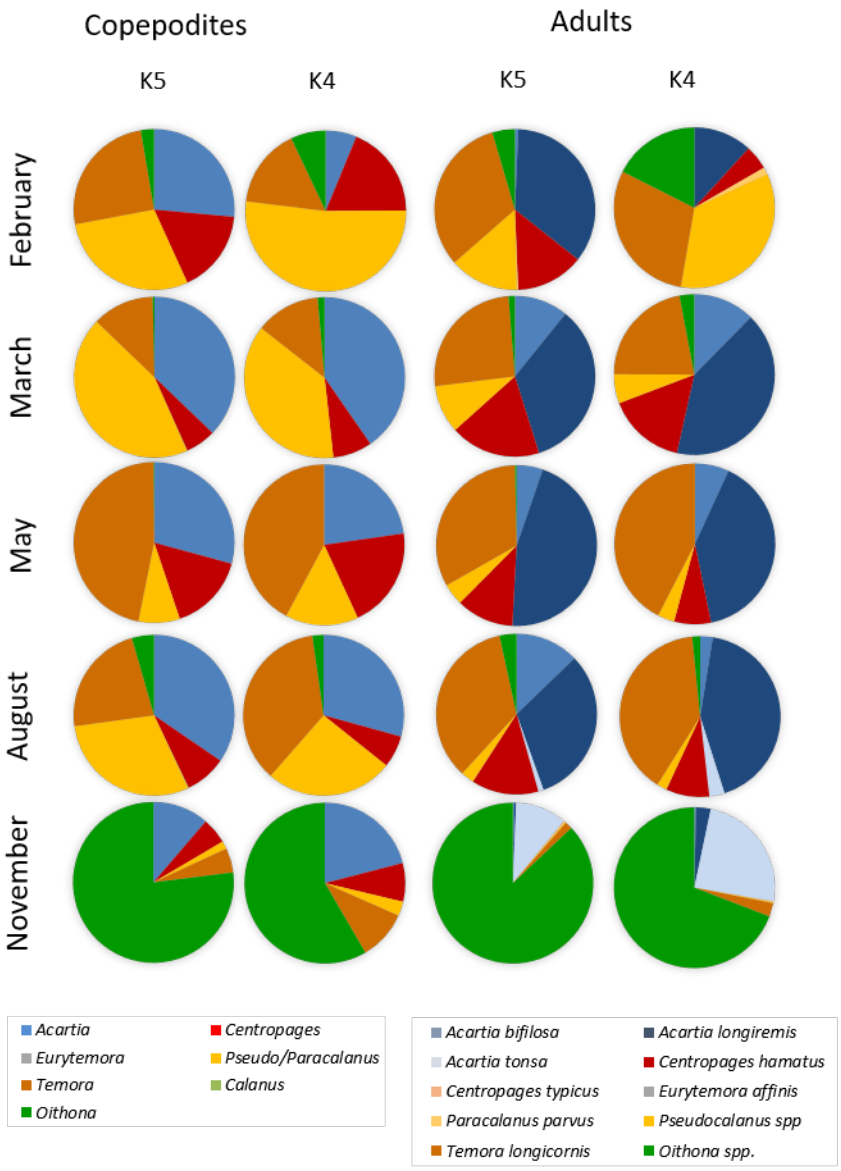

Fig. 15: Relative composition of the copepodites (C_{I-V1}, left panel) and adult copepods (C_{V1}, right panel) during the sampling months in the Bay of Mecklenburg in 2024 (OMBMP-M2 and –M1).

4.2.3 Long-term trends

Annual mean abundance

The long-term change in the annual mean abundance of the major groups of the zooplankton – copepods, cladocerans and rotifers – displayed a divergent trend within the three major basins (Fig. 16). In the Bay of Kiel and the Bay of Mecklenburg, the annual mean of copepods of 2.4 and 1.4 x 10^4 Ind. m^{-3}, respectively, was considerable above the long-term mean. The stocks of cladocerans showed a moderate increase to their long-term mean after 2-3 years of low abundance (0.6 and 1.5 x 10^3 Ind. m^{-3}), while the rotifers disappeared in both areas since 2018. In consequence, copepods displayed a considerable increase in their dominance in the Belt Sea from a long-term average of 61-64% to 81-87% of the zooplankton stock. This increase was not only based on the unusual high abundance of *Oithona* observed in November in the Bay of Kiel and the Bay of Mecklenburg, but also on a higher abundance of copepods in February to May that more than compensated for the low abundance in August.

In contrast to the Belt Sea, annual mean abundance of the copepods (4.8 x 10^3 Ind. m^{-3}) decreased in 2024 the Arkona Sea (Fig. 16). This decline is based on a reduction of the density at all times of observation. Similar to the Belt Sea, cladocerans recovered to their mean abundance compared to 2024 and rotifers became rare since 2018. As already outlined before (4.2.2), the most likely explanation for the considerable decline of rotifers is a temporal shift of the occurrence outside the observation window that can be explained by the trend of spring warming by more 1.5 °C. The strong influence of brackish water in spring 2024 otherwise would have provided optimal conditions for the rotifer *Synchaeta*, a taxon that usually dominates, to be detected at the time of sampling. The potential causes for the decline of several taxa, however, remain largely unresolved due to a lack of data on primary production or potential predators such as gelatinous zooplankton. Both are factors that contributed to the decline of the zooplankton in the North Sea (e.g., GREVE et al. 2004). Due to their overall decline, the contribution of the copepods to the annual mean stock declined to 41%.

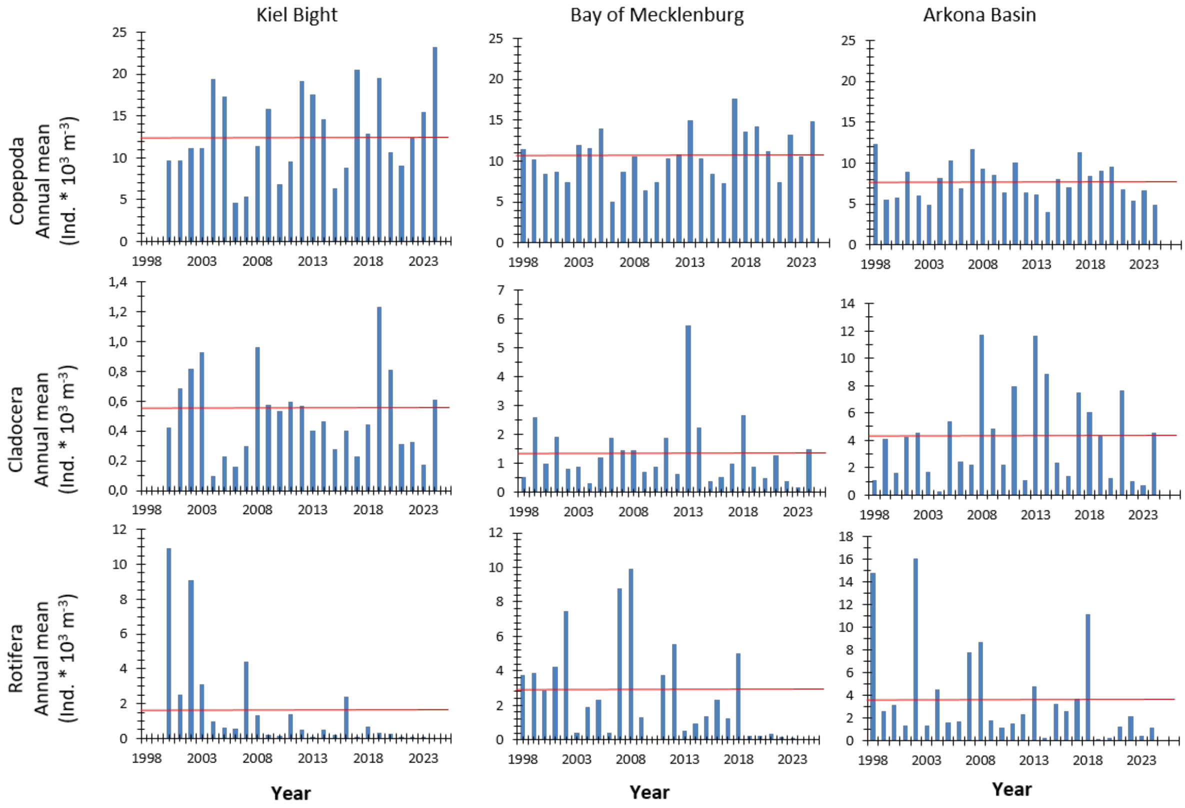

Fig. 16: Long-term variation of the annual mean abundance of the three dominant zooplankton groups in the Bay of Kiel (OMBMP-N3), the Bay of Mecklenburg (OMBMP-M2, -M1) and the Arkona Basin (OMBMP-K5, -K4). Bars display the annual mean within each Basin in a particular year (computed from the seasonal means of all stations within the basins), the red line indicates the long-term mean within each basin.

Zooplankton biomass and mean size

The zooplankton stock biomass and mean size of relevant taxa are part of the core indicator for the state of the pelagic ecosystem of the Baltic Sea in the framework of HELCOM (HELCOM 2023c). In the western Baltic Sea, the indicator is not fully implemented and threshold values for the evaluation of zooplankton status in summer are not established, yet. Regarding the biomass of the relevant taxa, a recovery from the last years' minimum in the long-term time series was recorded with summer values of 125.2, 197.1 and 216.2 mg wet weight m^{-3} in the Bay of Kiel, the Bay of Mecklenburg and the Arkona Basin, respectively. However, the biomass in 2024 was still 20-22% below the long-term mean of 186.2, 244.1 and 308.5 mg wet weight m^{-3}, respectively.

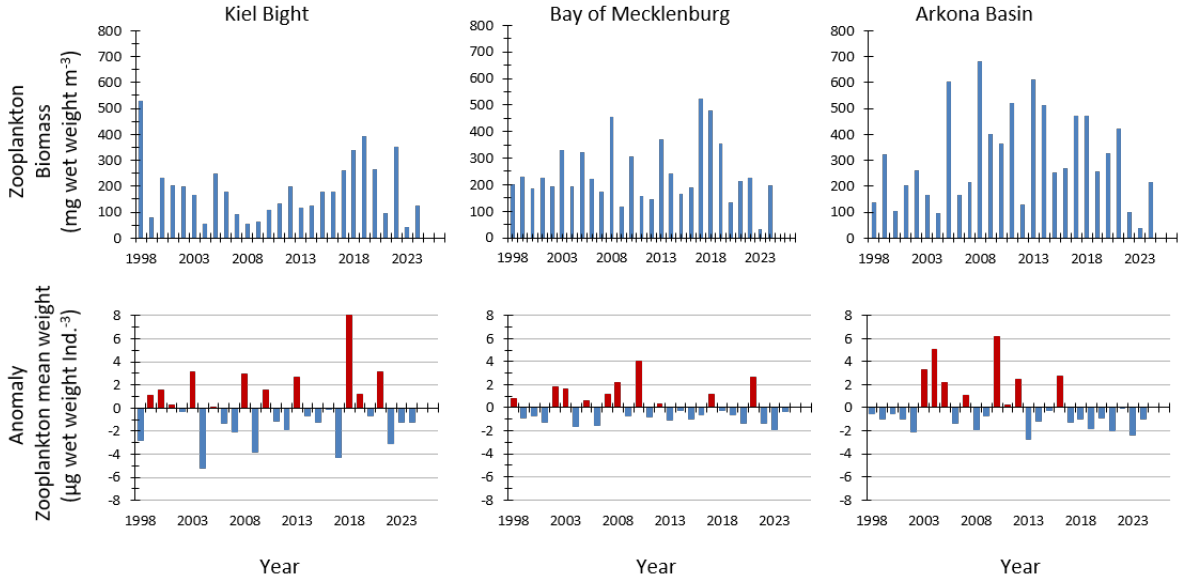

Fig. 17: Long-term variation of the mean biomass and the anomalies of the mean size of selected zooplankton groups relevant for the HELCOM zooplankton indicator MSTB in August in the Bay of Kiel (OMBMP-N3), the Bay of Mecklenburg (OMBMP-M2, -M1) and the Arkona Basin (OMBMP.K5, -K4). Bars display the mean of all stations in each Basin (biomass) or the positive (red)/negative (blue) anomalies (mean size).

The zooplankton mean size is calculated as quotient of the mean biomass and the mean abundance in summer. Anomalies are computed as the difference between the actual values within a year and the long-term mean (Fig. 17). Despite the increasing biomass of the sum of indicator-relevant taxa in 2024, the mean weight displayed negative anomalies for all monitoring areas. Especially in the Arkona Sea, an eight-year long series of negative values was continued. The causes behind the low values in 2024 differed among the areas. In the Bay of Kiel, the mean weight was 1.2 µg Ind.$^{-1}$ below the long-term mean of 11.5 µg Ind.$^{-1}$ despite the considerable increase in copepod abundance. Here, the decline in the mean weight is explained by a shift from the usually 'heavy' calanoid copepods to the small cyclopoid copepod *Oithona* that dominated the community by 85% (compare 4.2.2) and got more abundant in recent years (Dutz et al. 2022, Zettler et al. 2024). In contrast to the Bay of Kiel, the Bay of Mecklenburg and the Arkona Sea were under the strong influence of brackish water originating from the Baltic proper in summer. *Oithona* is usually less abundant in this water (Dutz 2018, Dutz & Wasmund 2023). In 2024, the species was increasingly replaced by the small cladoceran *Bosmina* during the transition from the Belt Sea to the Arkona Sea which caused a deacrease of the mean size of 0.4-0.9 µg Ind.$^{-1}$ below the long-term average in the two areas (10.4 and 10.6 µg Ind.$^{-1}$).

4.3 Macrozoobenthos

4.3.1 Sediments and oxygen

At all 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 8). Chemical parameters were measured in all samples taken during the five cruises per year (see chapter 3). A relative good oxygen supply was observed at all stations during the samplings almost all year round. Almost no values lower than 2 ml l^{-1} were measured at any station during the five cruises. Only in Fehmarnbelt (N1) slightly lower values were measured in August. Fig. 18 shows the development of the lowest oxygen values at this station during the last four decades. 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 and 6.9 PSU (Table 8).

Table 8: Abiotic parameters at 8 monitoring stations in autumn 2024 (Org = organic content of sediment in %, GS = median grain size in µm, O_2 = oxygen content of near bottom water in ml l^{-1}, S = salinity at near bottom water in PSU). HUB based on Marx et al. (2024)

Station	**Org** **%**	**GS** **(µm)**	**O_2** **(ml l^{-1})**	**S** **(PSU)**	**MSRL (BHT)** **Broad habitat types**	**HUB**
N3	1.16	222	5.25	24.0	infralittoral sand	AA.J3L3
N1	3.52	15	4.96	23.6	circalittoral mud	AB.H3L3
M2	9.42	16	5.38	20.1	circalittoral mud	AB.H3L3
OM18	1.81	113	4.93	21.0	infralittoral sand	AA.J3L3
K8	0.33	209	4.96	15.9	circalittoral sand	AB.J3L9
K4	12.92	10	4.18	18.3	circalittoral mud	AB.H3L9
K3	0.41	222	4.88	8.6	circalittoral sand	AB.J3L1
OM160	0.20	192	6.72	6.9	circalittoral sand	AB.J3L9

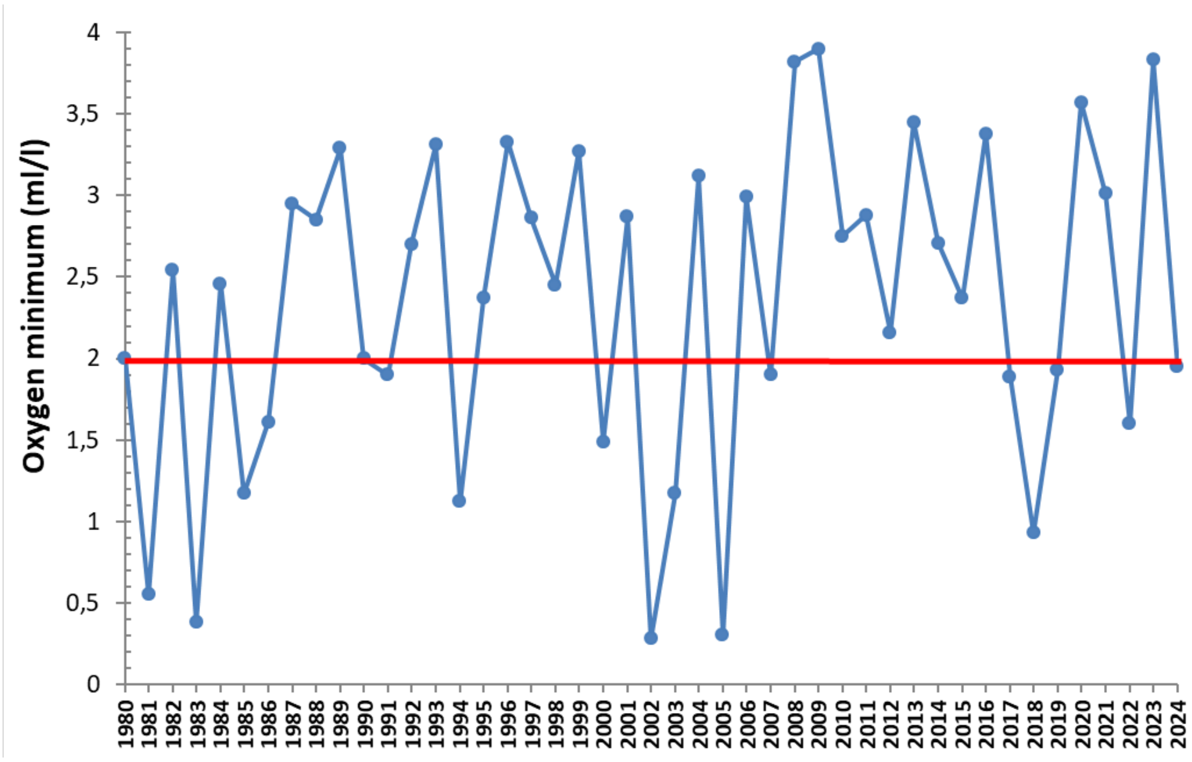

Fig. 18: The lowest annual oxygen levels in the near-bottom water of the Fehmarn Belt (N1) from 1980 to 2024. The red line shows the threshold value of 2 ml l^{-1}.

4.3.2 Macrozoobenthos at the stations

Our monitoring stations belong to five 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 (Table 8). Using the HELCOM Underwater biotope and habitat classification system (Table 8), the stations could be assigned to five categories (ZETTLER & DARR 2023, MARX et al. 2024).

Compared with the period 1991 to 2023, in 2024 the number of species was relatively high at 145 (Table Appendix 3, Fig. 19 and Fig. 22). At two stations (N1, M2) we observed significant lower diversity as the median. At almost all other stations, the yearly values were higher to the long-term mean. Only in the Bay of Mecklenburg (OM18) it was unchanged from previous years (Fig. 19). This year, for the first time, the opportunistic polychaete *Capitella capitata* was observed to dominate the abundance at the stations in the Fehmarnbelt (N1) and in the Mecklenburg Bay (M2) with around 40 %. (Fig. 20, Table 9).

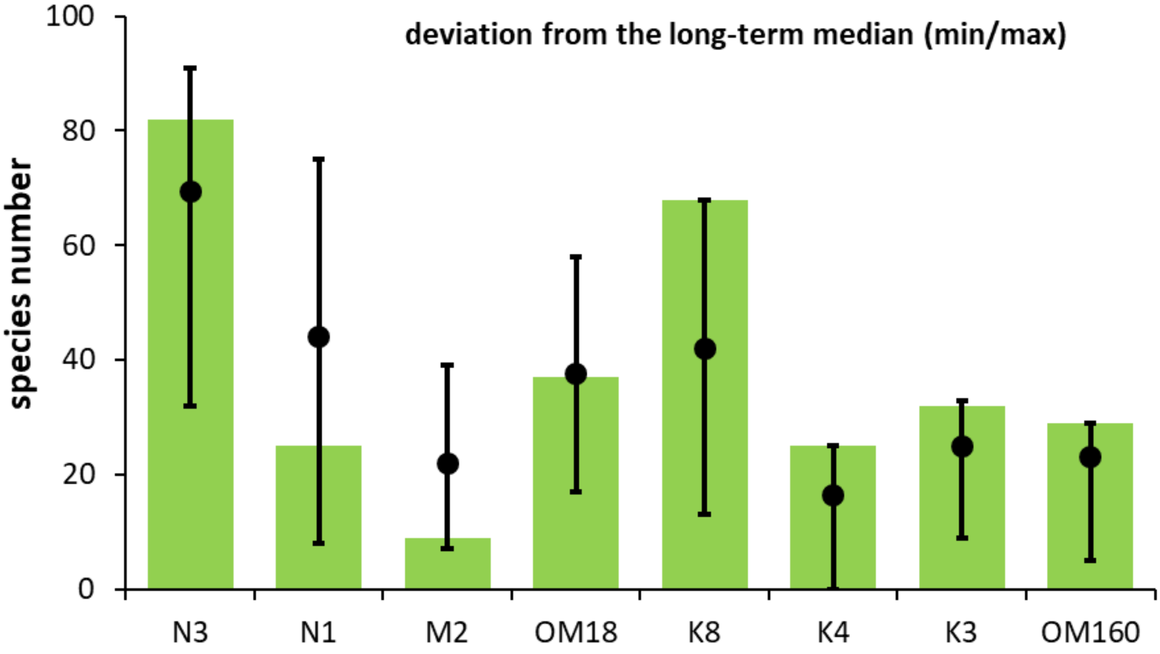

Fig. 19: Number of species (columns) of macrozoobenthos at eight monitoring stations in November 2024. The median values of the years 1991 to 2024 are shown as dots; the minimum and maximum values are indicated as interval. The stations are plotted from west to east (Bay of Kiel = N3 to Pomeranian Bay = OM160).

Fig. 20: Capitella capitata *dominated the stations N1 (Fehmarnbelt) and M2 (Bay of Mecklenburg) with about 40%. The specimens shown are from M2.*

The increase in diversity at most stations is in stark contrast to the significant decrease in the Fehmarnbelt and Mecklenburg Bight. It was assumed that a previous lack of oxygen must be the cause of the decline. However, the annual measurements from the five monitoring cruises gave no indication of a persistent oxygen deficiency. At just under 2 ml/l, the lowest values were recorded in the Fehmarnbelt in August. However, a deficiency between the measurements cannot be ruled out. The campaigns took place in February, March, May, August and November. We expect an undetected decline in September.

At some stations new observed species (never observed during the last 20 years at these stations) were found. These species are listed below:

=>N3: *Halitholus yoldiaearcticae, Philine punctata, Pseudopolydora antennata*

=>N1: *Filellum serpens, Flabelligera affinis, Barentsia* sp.

=>M2: none

=>OM18: *Nephtys pente*

=>K8: *Campanulina pumila, Clava multicornis, Filellum serpens, Cadlina laevis, Philine punctata, Tenellia adspersa, Nicolea zostericola, Monocorophium insidiosum, Amathia* sp.

=>K4: *Callopora lineata*

=>K3: *Heteromastus filiformis, Terebellides stroemii,*

=>OM160: none

As last year, *Philine punctata* continues to spread and has now reached more or less the entire area between the Bay of Kiel and the Island of Rugia (Fig. 19).

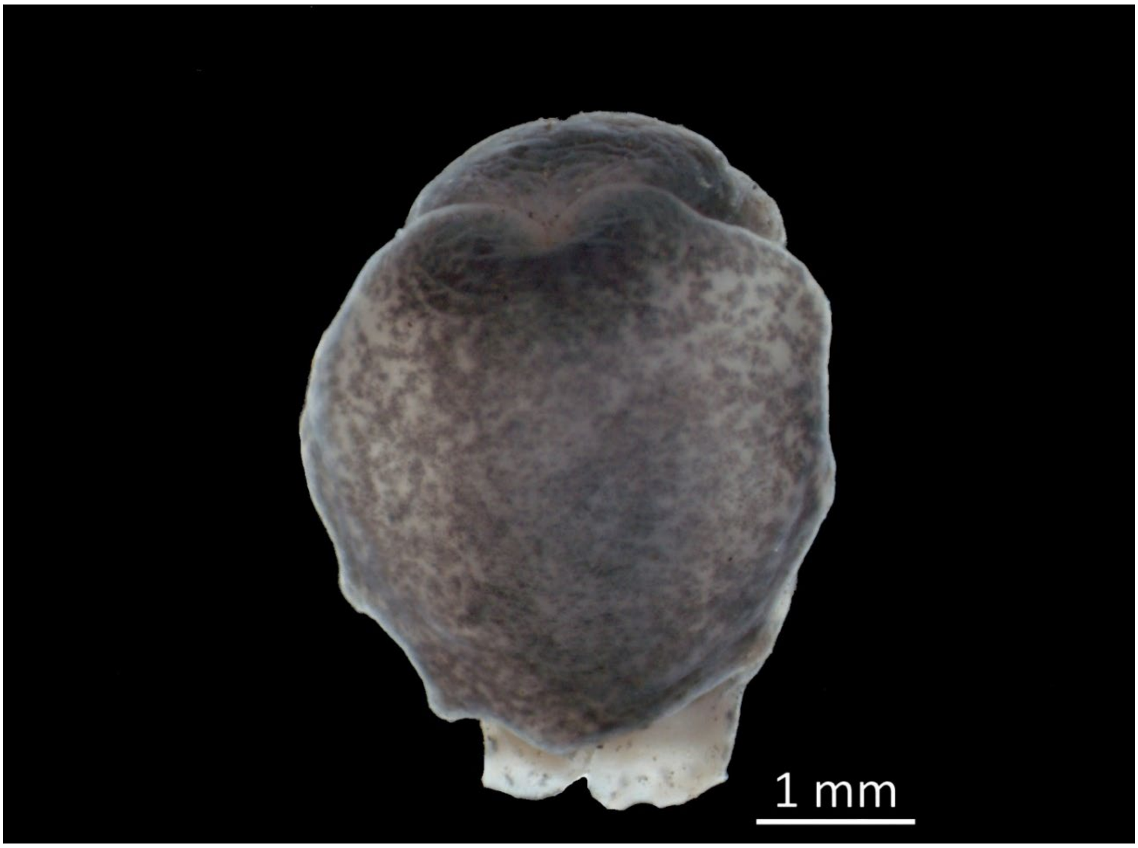

Fig. 21: Philine punctata (here from K8) continues to spread along the whole German Baltic.

Fig. 22 shows the taxa found at our eight monitoring stations in 2024 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 109 in total; in 2024, 53 species were identified. Other species-rich groups in 2024 were Mollusca (25), Crustacea (25), Bryozoa (11) and Cnidaria (12).

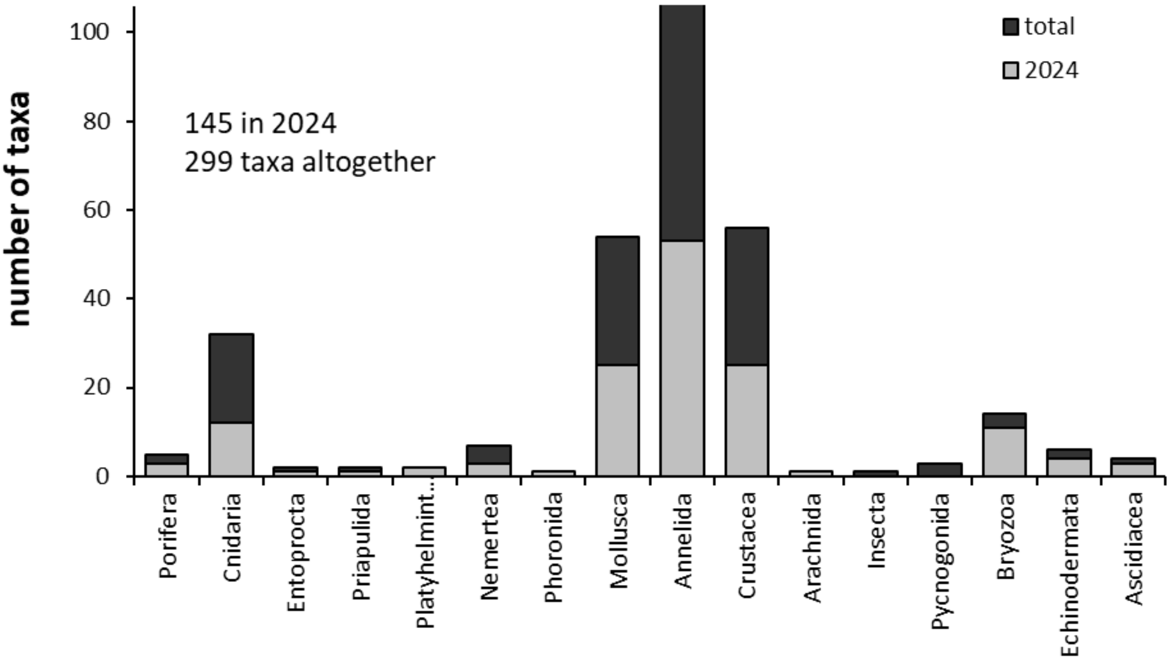

Fig. 22: Taxonomical classification of macrozoobenthos at the eight monitoring stations in November 2024 (grey). The species number of the entire monitoring period from 1991 to 2024 at 8 stations is also indicated (black columns).

Depending on the sea area, abundances varied between 112 (Fehmarnbelt) and 8421 ind. m-^{2} (Pomeranian Bay) (Fig. 23, Table Appendix 3). At most stations, the abundance is significantly (N3, N1, M2, OM18, K8) below the long-term average (Fig. 23) or within the long term mean (K4, OM160). The only exception is station K3 in the northern Pomeranian Bay, where a slightly higher abundance was observed.

Which species predominated in a particular marine area varied greatly and depended largely on the salinity and substrate or even the periods of oxygen deficiency (Table 9). While the abundances (with few exceptions) were mainly dominated by polychaetes, bivalves determined the biomass. In the Bay of Kiel (N3) the cirriped *Balanus crenatus* and the phoronid *Phoronis* sp. dominated the abundance. In the Fehmarnbelt and Bay of Mecklenburg (N1 and M2), the polychaete *Capitella capitata* dominated the density. *Scoloplos armiger* played a dominant role at several stations. Other dominant species at different stations were the polychaetes *Ampharete balthica, A. cirrata*, *Pygospio elegans* and *Terebellides stroemii*, the bivalves *Arctica islandica, Macoma balthica* and *Mytilus edulis* (see Table 9 for detailed information). The gastropod *Peringia ulvae* ends the round and occurred very frequently at 3 locations. At the western stations (N3 to 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 9: Dominance (%) in abundance and biomass at the eight monitoring stations during November 2024. The stations are plotted from west to east (Bay of Kiel = N3 to Pomeranian Bay = OM160).

Abundance in %	**N3**	**N1**	**M2**	**OM18**	**K8**	**K4**	**K3**	**OM160**
Ampharete baltica				21	14			
Ampharete cirrata						10		
Arctica islandica		21	18					
Balanus crenatus	25							
Capitella capitata		39	45					
Macoma balthica							12	
Mytilus edulis							10	
Peringia ulvae			21	10				54
Phoronis sp.	14							
Pygospio elegans					37		57	21
Scoloplos armiger				21	11	28	14	
Terebellides stroemii						22		
Tubificinae		18						
Biomass in %								
Arctica islandica	11	100	100	91				
Astarte borealis	59				82			
Astarte elliptica	20					41		
Macoma balthica						11	23	
Mya arenaria								69
Mytilus edulis							61	
Nephtys ciliata						29		

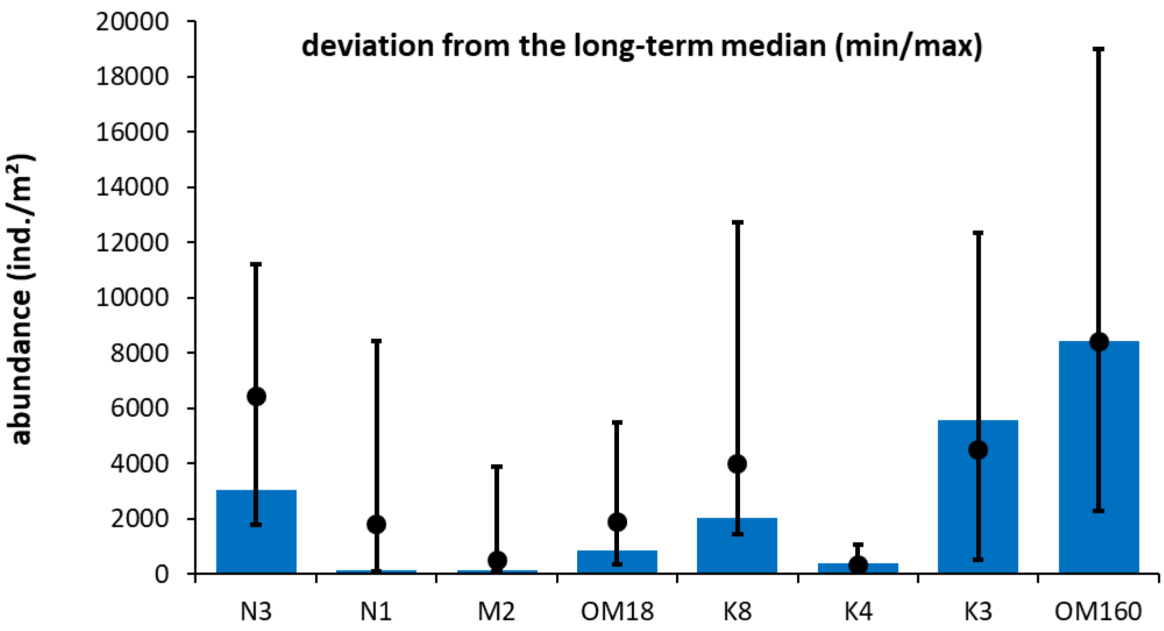

Fig. 23: Total abundances (columns) of macrozoobenthos at eight monitoring stations in November 2024. The median values for the years 1991 to 2024 are shown as dots; the minimum and maximum values are indicated as intervals. The stations are plotted from west to east (Bay of Kiel = N3 to Pomeranian Bay = OM160).

Compared with their long-term averages, almost all stations showed a lower total biomass in 2024 (Fig. 24). The biomasses in Mecklenburg Bay were significantly lower than the long-term average. *Arctica islandica* dominated the biomass with almost 100% (Fig. 25). At the Arkona Basin (K4) and the Pomeranian Bay (K3 and OM160), the biomass was within the long-term average or slightly higher (Fig. 24).

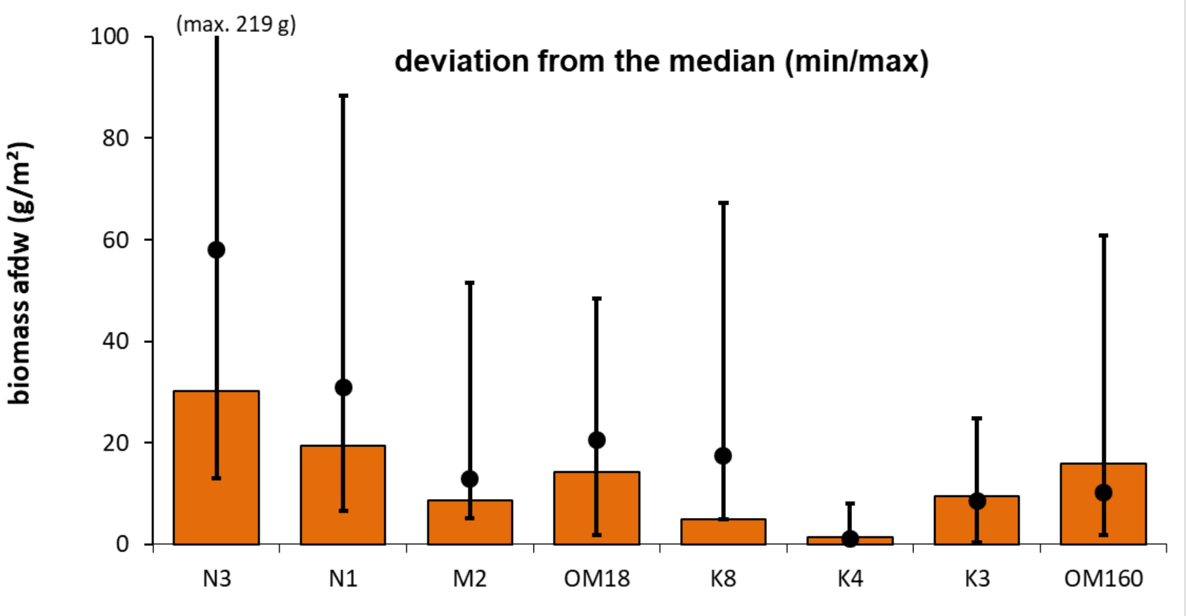

Fig. 24: Total biomass (columns, as ash free dry weights, afdw) of macrozoobenthos at eight monitoring stations in November 2024. The median values for the years 1991 to 2024 are shown as dots and the minimum and maximum values are indicated as intervals. The stations are plotted from west to east (Bay of Kiel = N3 to Pomeranian Bay = OM160).

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. 23 and Fig. 24. 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 2024 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 (ZETTLER et al. 2017).

The reasons for the strong decrease (collapse) of the benthic community at stations Fehmarnbelt (N1) and Bay of Mecklenburg (M2) (see also Figs. 20 to 22) can not explained. Normally, previous oxygen deficiency phases are responsible for such declines. This time, however, we were unable to detect any such deficiency in our measurement data during the five monitoring cruises per year. It is possible that the oxygen levels were significantly lower between the August cruise and the November cruise, which could explain the collapse of the communities. Although speculative, this is the only real logic explanation. A combined heatwave would also be conceivable, but this cannot be proven with our methodological approach.

Fig. 25: In 2024 the dominant species of the dredge samples in the Bay of Mecklenburg (M2) was Arctica islandica.

4.3.3 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). As it is not possible to present all long-term developments in diagrams, we change the example of a selected station every year. This year, station N1 (Fehmarnbelt) will be analysed as an example in order to present a comprehensive long-term data series. Here, long-term data of more than 30 years are available. The station in the Fehmarnbelt (about 28 m deep) is characterised abiotically by a generally moderate oxygen content and high salinity values. The fluctuations are relatively high and essentially depend on the oxygen supply in the summer months. The number of species is generally high. The minimum and maximum values are 8 and 75 respectively (Fig. 26). Over the last 30 years, a significant decline in diversity has occurred regularly, as illustrated by the ‘frayed edge’ of the graph (Fig. 26). It became particularly clear in the years 1992, 1993, 2002, 2005, 2008, 2010, and 2016, related to periods of low oxygen levels (see also Fig. 18). In total, more than 198 macrozoobenthic species have been detected over the past 3 decades. Interestingly, the species numbers in the 1990s were almost lower than in the following decades. This is probably due to the fact that the method was changed: Since the end-1990s, we also use a dredge to determine species richness. In general, several total community collapses have been observed in this area in recent decades. In all measured biotic parameters (taxonomy, abundance and biomass), partly significant changes can be observed over the years (Fig. 26, Fig. 27, Fig. 28).

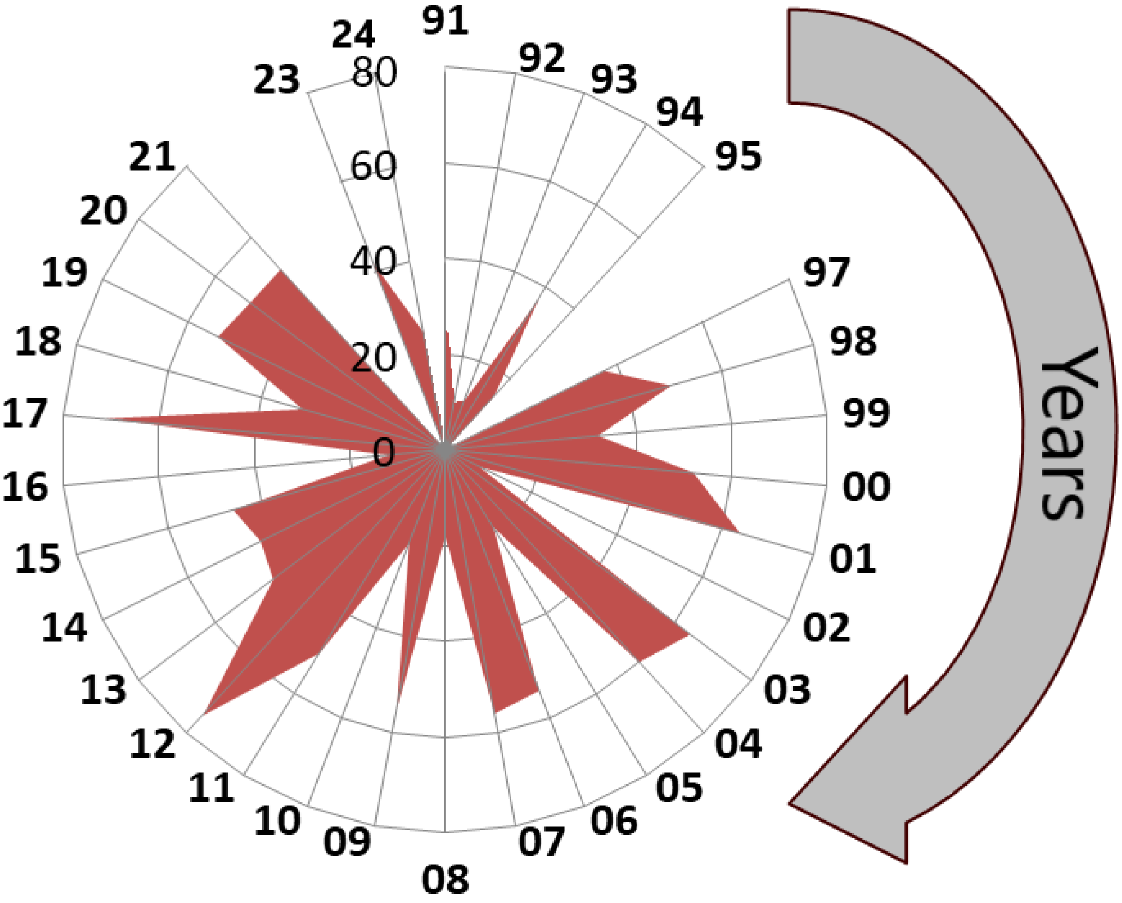

Fig. 26: Long-term development of species number of macrozoobenthic taxa in the Fehmarnbelt (N1), 1991 - 2024. No data are available for 1996 and 2022.

From 1980 to about the mid-2000s, a continuous increase in species diversity was observed (Fig. 26). 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 for phytoplankton, zooplankton, zoobenthos and fish could be observed in the Baltic Sea (see WASMUND & ZETTLER 2023).

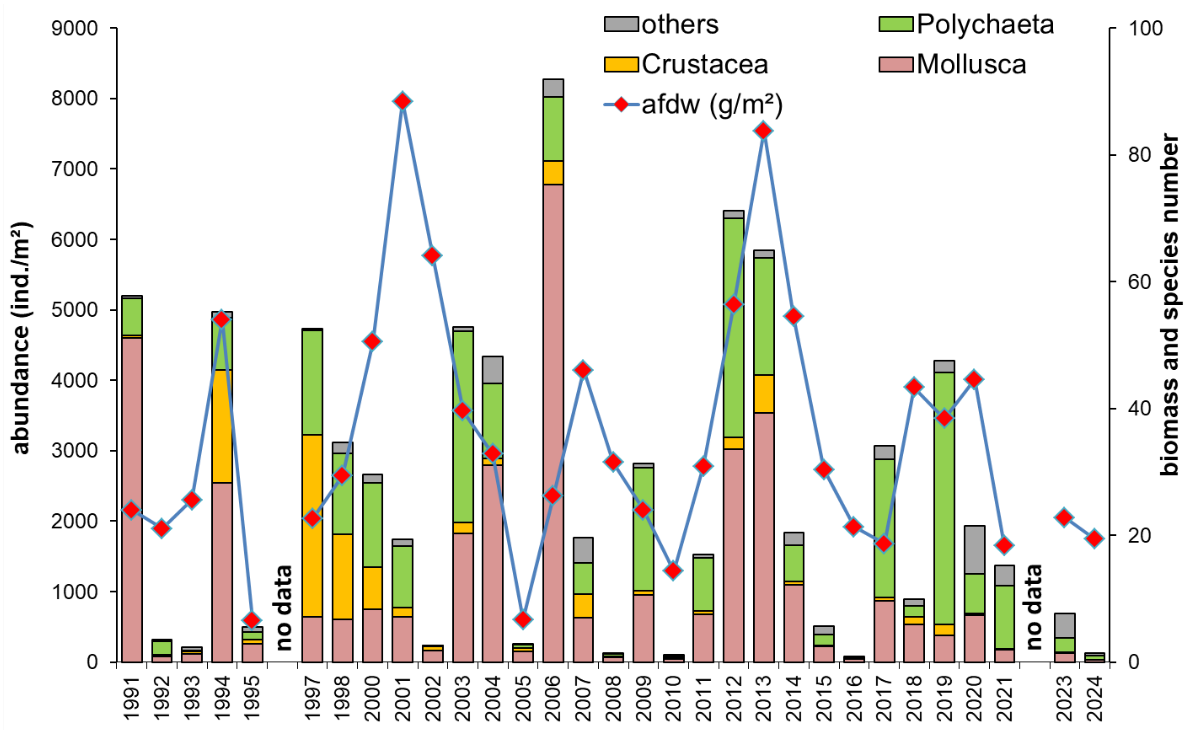

Fig. 27: Long term development of abundance and biomass of macrozoobenthic taxa in the Fehmarnbelt (N1), 1991 - 2024. Columns show the abundance; the bold line shows the biomass (ash free dry weight, afdw). No data are available for 1996 and 2022.

In some years polychaetes and crustaceans were the dominant taxa (Fig. 27). While the proportion of crustaceans has declined in recent years, molluscs and polychaetes are flourishing. What is striking is the virtual collapse in e.g. 2018, when the abundance showed a significant drop. Similar developments were also observed in the 1980s. On the one hand, this can be explained by the patchiness of the distribution of organisms on the sea floor: The random inclusion of larger quantities and larger organisms influences abundance and biomass by chance. On the other hand, it is surprising that the diversity of species and the population sizes of the predominant species have remained relatively constant over the decades. Species that occur again and again are *Arctica islandica*, *Macoma balthica*, *Bylgides sarsi*, *Scoloplos armiger* and *Diastylis rathkei*.

As an example the development of the cumacean *Diastylis rathkei* is shown (Fig. 28). In some years, the population reached high abundance peaks, which also influenced the total abundance at this station. As far as biomass is concerned, the contribution of *D. rathkei* is quite low. Here, the species *Abra alba* and *Arctica islandica* in particular can have a much greater influence on the total biomass (e.g. Fig. 29). The fluctuations of the latter species of course have an impact on the total biomass at the station and are mostly reflected by the peaks in Fig. 27.

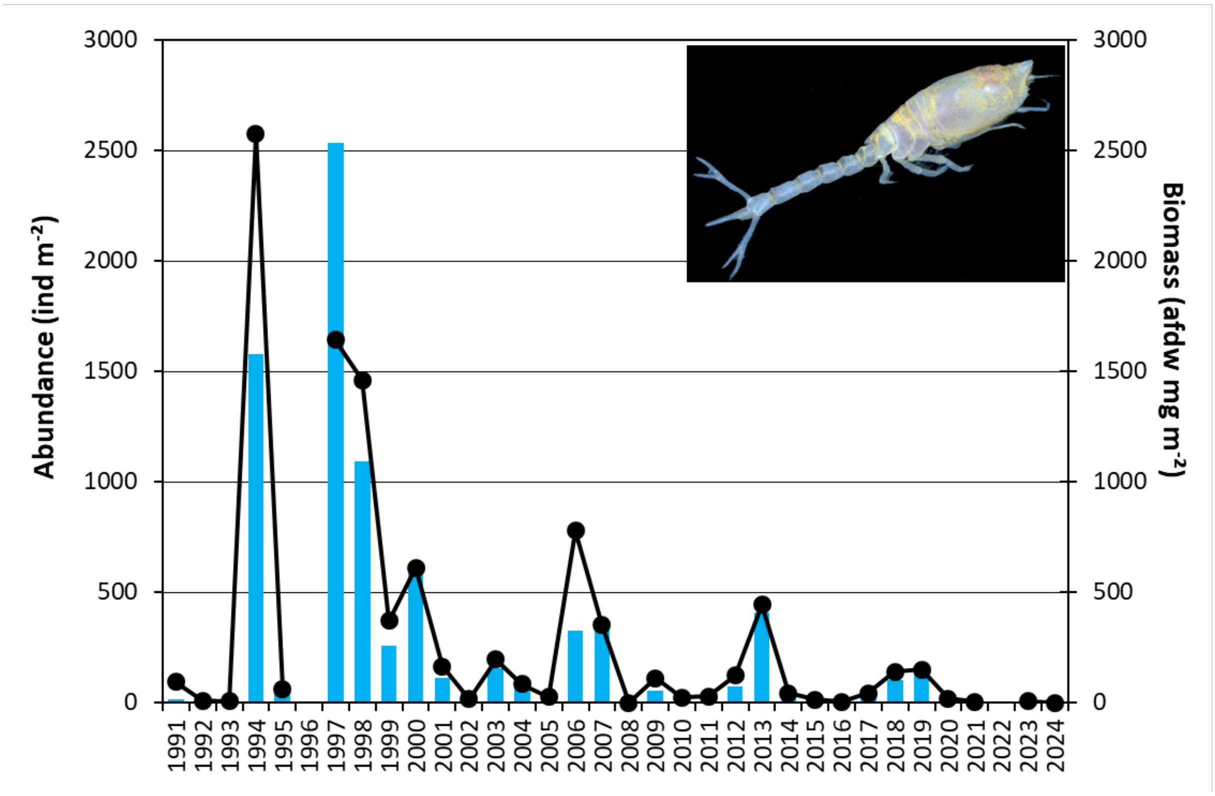

Fig. 28: Long-term development of the abundance (column) and biomass (line) of the cumacean Diastylis rathkei *in Fehmarnbelt (N1), 1991 - 2024 (samples taken every autumn). No data available for 1996 and 2022.*

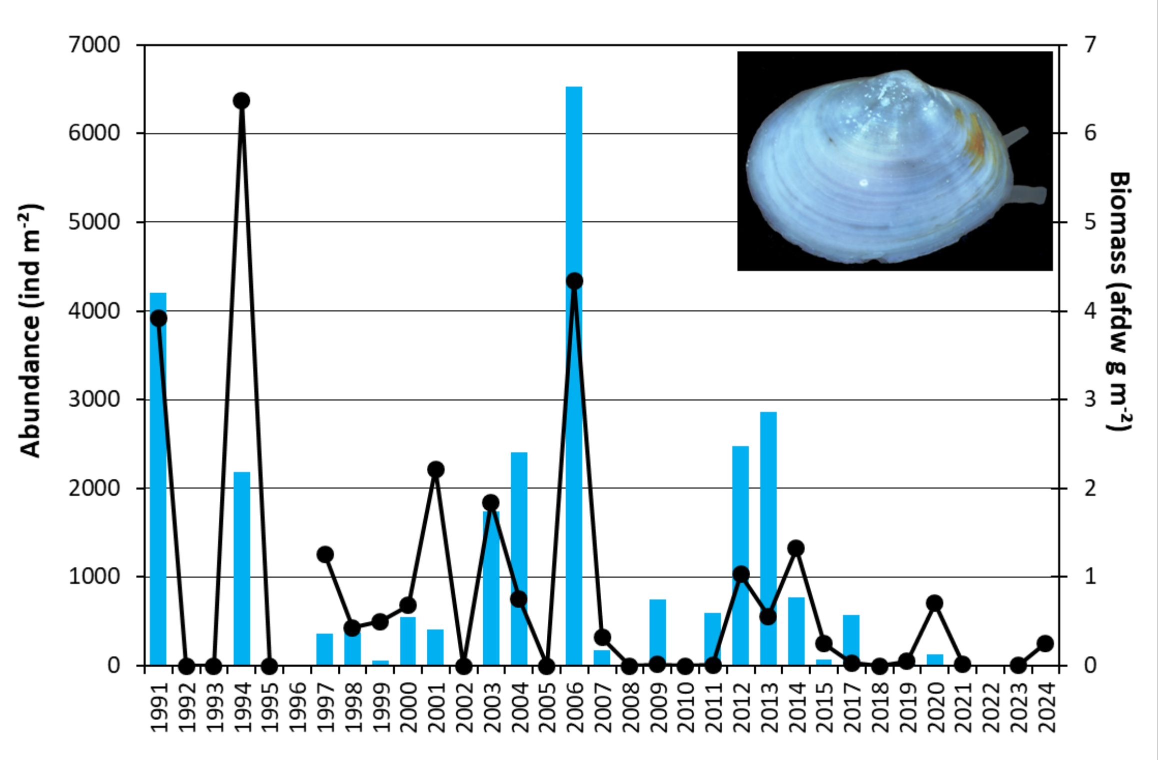

Fig. 29: Long-term development of the abundance (column) and biomass (line) of the bivalve Abra alba *in Fehmarnbelt (N1), 1991 - 2024 (samples taken every autumn). No data available for 1996 and 2022.*

4.3.4 Red List

This section refers to the Red List of bottom-dwelling invertebrates by Rachor et al. (2013). Of a total of 145 species in 2024, 22 are classed as threatened (1, 2, 3, G) (Fig. 30, Table Appendix 3). Four species are classed as being near threatened. Currently, 71 species are classed as being of least concern. Data are deficient for 25 species, and 23 taxa were not evaluated in the Red List. The anthozoan *Halcampa duodecimcirrata* is critically endangered. It was detected in the Arkona Basin (K4) in very low densities. The polychaete *Euchone papillosa* (category 2, endangered) were found in the Bay of Kiel (N3). We observed specimens of *Arctica islandica* (ocean quahog; category 3, vulnerable) at western stations (N3 to OM18) and in the deeper Arkona Basin (K4) at various levels of abundance. The hydrozoan *Halitholus yoldiaearcticae* and Montagu's Astarte (*Astarte montagui*) occurred in the Bay of Kiel (N3). 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 15 species observed in 2024 were distributed across almost all sea areas: 11 species in Bay of Kiel (N3), 2 at the Fehmarnbelt (N1), 2 at the Bay of Mecklenburg (OM18), 5 at the Darss Sill (K8), 2 in Arkona Basin (K4) and 1 in northern Pomeranian Bay (K3). Examples are the ascidian *Styela coriacea*, the polychaetes *Nereimyra punctata, Scalibregma inflatum* and *Travisia forbesii* (Fig. 31). Others are the gastropods *Aporrhais pespelecani* and *Tritia reticulata*, which occur in the western part of the investigation area (N3).

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 (Table Appendix 3). The strong salinity gradient and its effect on the distribution of red listed marine species are clearly visible. No species of the Helcom Red List were found (Helcom 2025).

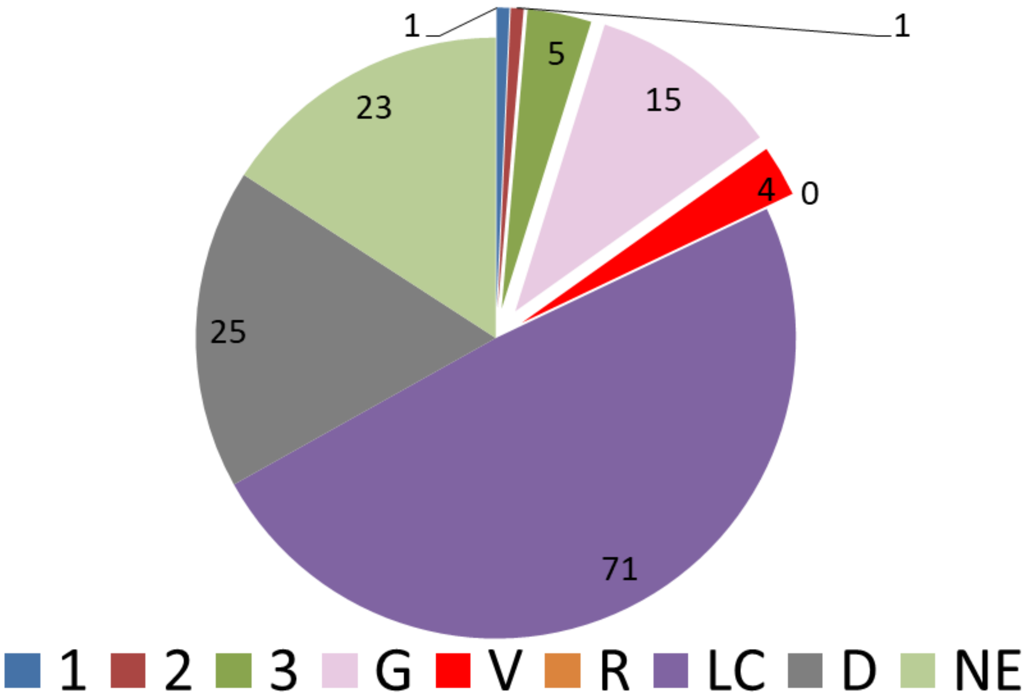

Fig. 30: Distribution of red list categories (Rachor et al. 2013) in relation to macrozoobenthos in autumn 2024 (1=critically endangered, 2=endangered, 3=vulnerable, G=probably vulnerable, V=near threatened, R=extremely rare, LC=least concern, D=data deficient, NE=not evaluated); the given values are the absolute species numbers.

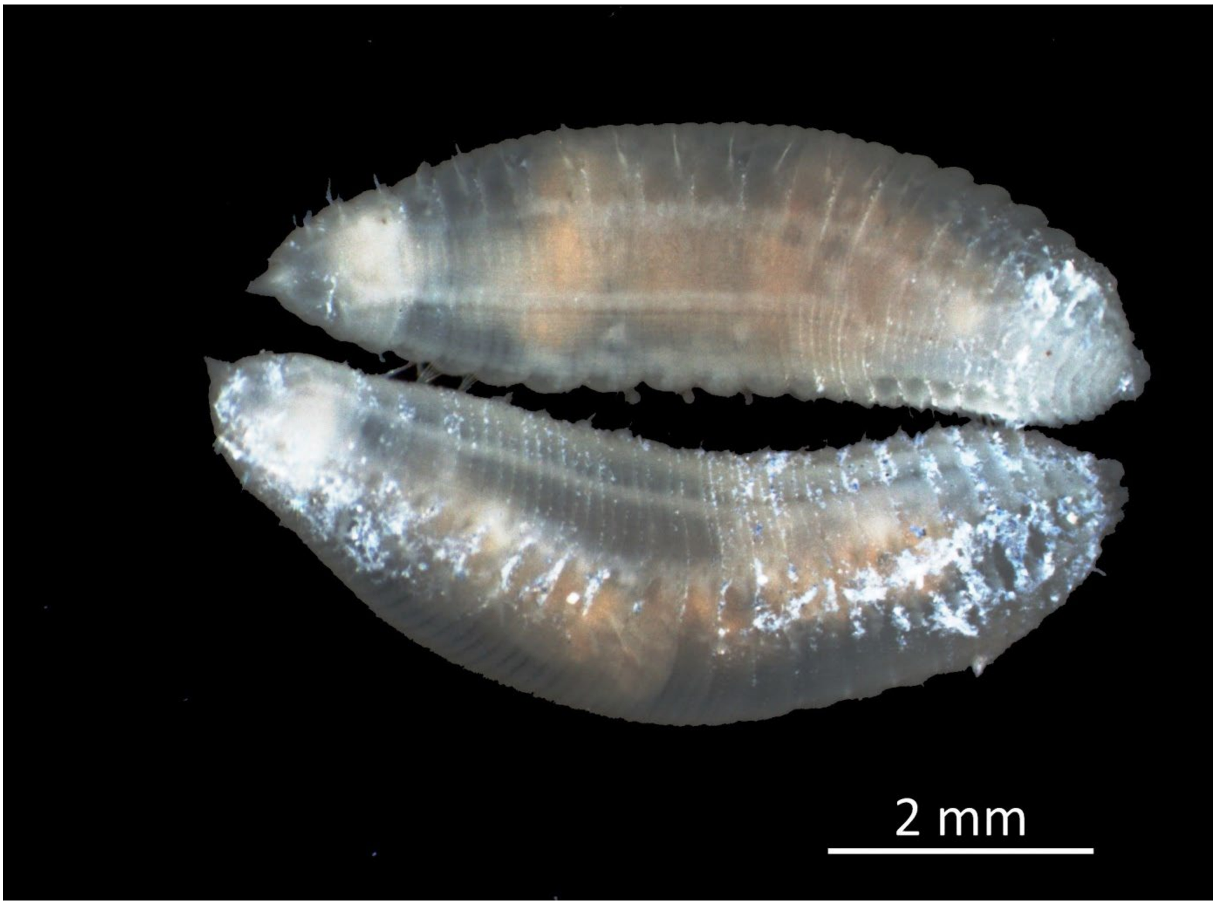

Fig. 31: The red-listed polychaete Travisia forbesii was found on the Darss Sill (K8) (see this picture) and in the northern Pomeranian Bay (K3).

4.3.5 Benthic Quality Index (BQI)

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

With regard to the BQI (indicator to be used within the MFSD descriptor D6C5 = condition of the benthic habitat), it also has to be highlighted that conceptually many stations per BHT are required to reach a sound assessment result. BQI-values at individual stations should be considered with caution as they are subject to natural variability. However, significant changes over time may nevertheless be visible. Consequently, the present study shows how such an assessment of the benthic component would look like and whether it could be usefully applied. For this purpose, we applied the Benthic Quality Index in an adapted form to the data of our eight long-term stations, initially from 2006 to 2021 (Kremp et al. 2021), now extended to include the data from 2022 to 2024. The BQI is used for basin-wide assessments within HELCOM and also serves as an additional German indicator (with some specific adaptations (BMUV 2024).

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

The eight stations (N3, N1M2, OM18, K8, K4, K3, and OM160) were sampled once a year for 19 years (2006 to 2024). With the exception of 2022, in which two stations could not be sampled due to poor weather conditions, three hauls were always carried out. All data were used to calculate the Benthic Quality Index (BQI). In total, we have 142 samples at the stations, each with 3 replicates (3 hauls), i.e. a total of 426 individual hauls.

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

Equation 1:

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

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

In case of spatial, temporal or methodological disparities between samples, HELCOM (2023) recommends bootstrapping. This is used as a safety method to assign a lower value to values with a high uncertainty (Carstensen, 2007; Leonardsson et al., 2009). However, since the samples were taken from the same sites every autumn, always with three hauls each, no spatial, temporal or methodological inconsistencies are to be expected. The bootstrapping procedure was therefore not carried out.

The sensitivity value is calculated from the abundance of species at a site and is based on the assumption that sensitive species mainly occur at undisturbed sites with a high diversity, whereas tolerant species mainly dominate at disturbed sites with a low diversity (Rosenberg et al., 2004). Due to differences in community composition and sensitivity of individual taxa along different natural gradients, the sensitivity values to be used are not the same for the whole Baltic Sea. Therefore, Schiele et al. (2016) divided the Baltic Sea into 19 Ecological Indicator Groups (EIG) based on the factors salinity, water depth and sampling method used. They calculated the sensitivity value per taxon ($ES50_{0,05}$) for each subgroup. Five of the 19 subgroups are relevant for the German Baltic Sea (EIG2 to EIG6).

For all years, each station was assessed as "good" or "poor" using the calculated BQI values and the associated threshold values for the specific EIG (BLANO 2024, Schaub et al., 2024). For each station, the proportion of hauls per station that had received the rating "good" over the entire sampling period was then calculated (EcoQ status "good" in %). According to HELCOM (2023), an area is classified as “poor” if more than 20 % of the hauls per station are rated as “poor”. Therefore, stations that had received at least 80 % EcoQ status of "good" over the 18 years were rated "good" overall. Stations with less than 80 % "good" status were rated "poor" (overall rating, see Fig. 32 and Fig. 33).

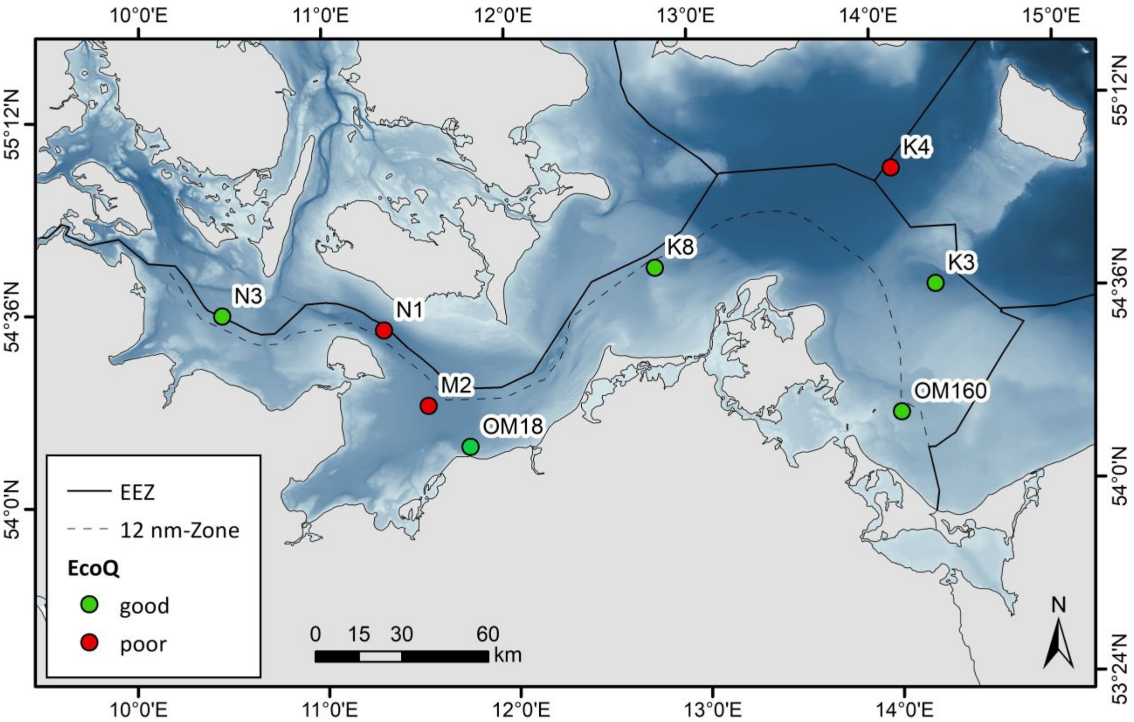

Fig. 32: Locations and EcoQ (Ecological Quality) assessment of the eight stations studied with FixSal (modelled mean water depth and salinity), averaged over 19 years (2006 - 2024); EEZ = exclusive economic zone; 12 nm zone = twelve nautical mile zone; projection: LAEA - ETRS89; background: Bathymetrie BSH (2012).

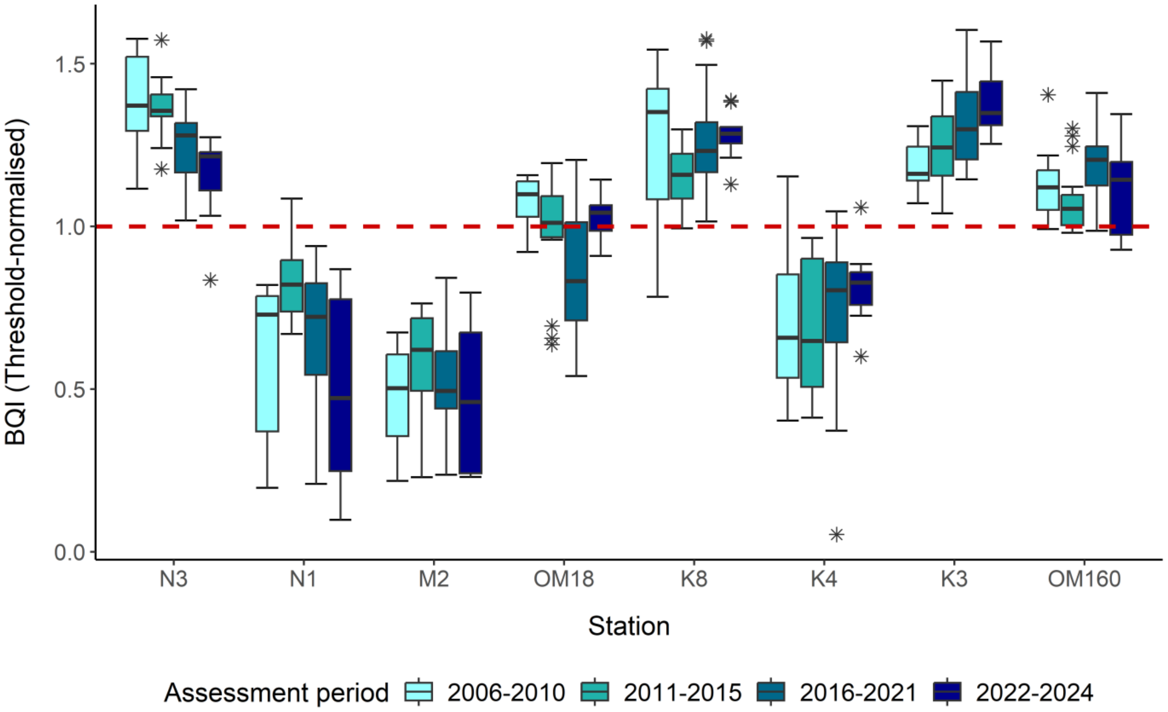

Fig. 33: Boxplots of the normalised BQI (Benthic Quality Index) values per station for four different assessment periods (2006 – 2010, 2011 – 2015, 2016 – 2021, 2022 – 2024) according to FixSal (modelled mean water depth and salinity); the BQI was normalised by the threshold value for the respective EIG (Ecological Indicator Group; BMUV 2024).

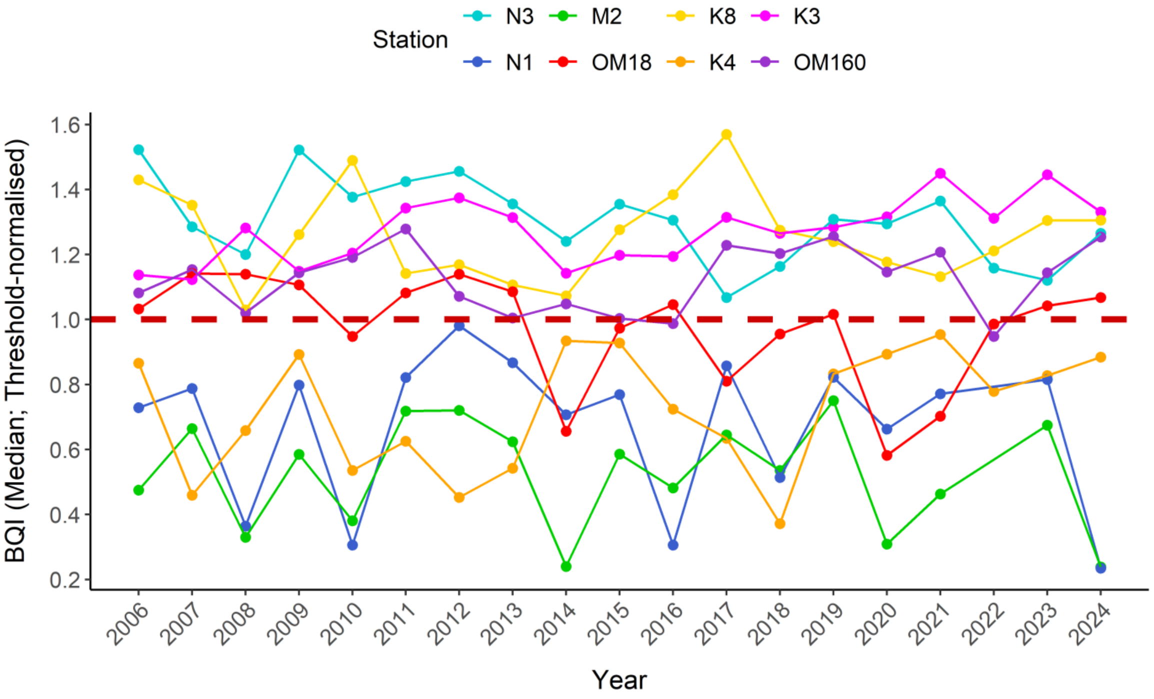

Fig. 34: The normalised BQI (Benthic Quality Index) value for each station (median of the three hauls) over time (2006 to 2024) according to FixSal (modelled mean water depth and salinity); the BQI was normalised by the threshold value for the respective EIG (Ecological Indicator Group; BLANO 2024); the red line marks the boundary between a "good" (> 1) and "poor" (< 1) ecological status.

In summary, the stations in the Bay of Kiel (N3), Darss Sill (K8), northern Pomeranian Bay (K3) and Pomeranian Bay (OM160) always show a "good" ecological status (Fig. 32, Fig. 33, Fig. 34). The Arkona Basin (K4), the Fehmarnbelt (N1) and the Bay of Mecklenburg (M2) were always in a “poor” condition (Fig. 33, Fig. 34). The southern Bay of Mecklenburg (OM18) lies in the border area between “poor” and “good”, but with a slight overweight in “good”.

The map of the BHT assessment of the German Baltic Sea, which was created in our working group and leads to GES threshold values for the entire German Baltic Sea and is not the subject of this study, shows a high degree of agreement with the station values presented here (BMUV 2024, p. 173-174). The circalittoral mud of the Bay of Kiel, Bay of Mecklenburg and Arkona Sea do not achieve good environmental status. Only the infralittoral sands of the Pomeranian Bay and with some exceptions also the circalittoral sands of the Arkona Sea can be described as good. The main reason for this is likely to be the irregularly recurring oxygen deficiency events in the deeper basins of the southern Baltic Sea and the resulting adverse effects on living organisms.

4.3.6 Non-indigenous species (NIS)

The role of NIS in the open Baltic Sea is negligible (Zettler et al. 2014, 2018). Ten species were observed at our eight monitoring stations in 2024 (Table Appendix 3). *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, Meng et al. 2024). The spionid polychaete *Marenzelleria neglecta* finds suitable habitat conditions in coastal waters. We found this species and also the sister species *M. viridis* at the Oderbank (OM160). In addition, for the polychaetes *Alitta succinea* and *Aphelochaeta marioni*, it is not clear whether they are neozoic or cryptic native species (Lackschewitz et al. 2022). The tunicates *Molgula manhattensis* and the decapod *Rhithropanopeus harrisii*, both originally from North America, were found in the Bay of Kiel (N3), the Darss Sill (K8) and the Pomeranian Bay (OM160) respectively. None of these observed NIS was recorded for the first time; all have been established for years. The bivalve *Rangia cuneata,* a North American species, was observed on the Oderbank where it was detected several times during the last 6 years. It is more common in the coastal waters of Greifswald, Rugia and Stettin (Zettler & Alf 2021). Over the last ten years, we have found a total of 16 non-indigenous species (NIS) at our eight monitoring stations with 7 new arrivals (Fig. 35). The long-term trend over the last 10 years of arrival was 0.7 NIS per year (the first year acts as the status quo). In comparison to Denmark (see Staehr et al. 2020) both the total number and the rate of arrival is similar. For Danish marine waters and estuaries (North and Baltic Sea together) the authors present 16 (+6 species outside the monitoring programme) marine benthic invertebrates species (what is definitely not complete). However, if you only look at the Baltic and Belt Sea itself, around 1 to 7 non-native species are detected each year (Staehr et al. 2020). The calculated Danish NIS arrival trend is around 0.9, but it is not really easy to extract from the given data. In German inner-coastal waters, the introduction rates are 0.2 to 1.2 NIS per year (e.g. Zettler & Zettler 2024), which is more or less in the same range as we found in the present study.

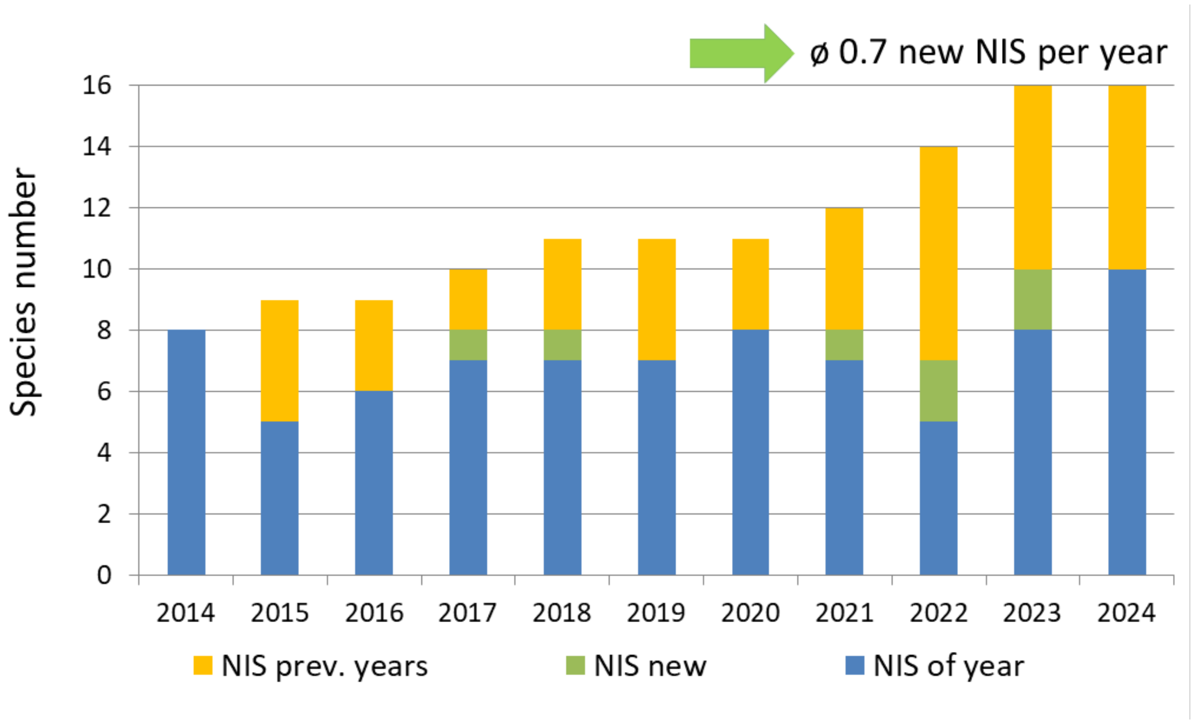

Fig. 35: Monitoring of the non-indigenous species (NIS) at eight monitoringstations from 2014 to 2024. Blue=NIS-species of the respective year without the new species, green=new discoveries, orange=species known from previous years but not found this year. The year 2014 acts as status quo. The mean NIS per year are calculated from the following years.

Acknowledgements

The authors wish to thank the colleagues of the Leibniz Institute for Baltic Sea Research, who were involved in the monitoring programme, particularly those who dealt with the sampling and analyses of the biological samples, Christin Fechtel, Christian Burmeister, Uwe Hehl, Frank Pohl, Stefanie Schubert, Svenja Zimmermann, as well as those who dealt with the data management, Dr. Steffen Bock, Dr. Susanne Feistel, Anja Zettler and Solvey Hölzel. We would like to thank Dr. Katharina Romoth for calculating the Benthic Quality Index (BQI). Sincere thanks to the captain and crew of the research vessel „Elisabeth Mann Borgese“. The monitoring was supported by the cruise leaders Dr. Volker Mohrholz (EMB 356), Dr. Joachim Kuss (EMB 337), Dr. Michael naumann (EMB340), Dr. Jörg Dutz (EMB 346) and Dr. Sandra Kube (EMB353). We are grateful to the Federal Maritime and Hydrographic Agency (BSH) for funding parts of the monitoring programme in the German EEZ, for their administrative support and for supporting discussions and proof reading of this report.

References

AQUANIS, 2025: www.aquanis.com. Assessed: 30.06.2025.

BMUV (HRSG.) (2024): Zustand der deutschen Ostseegewässer 2024. Aktualisierung der Anfangsbewertung nach § 45c, der Beschreibung des guten Zustands der Meeresgewässer nach § 45d und der Festlegung von Zielen nach § 45e des Wasser-haushaltsgesetzes zur Umsetzung der Meeresstrategie-Rahmenrichtlinie. Bund/Länder-Arbeitsgemeinschaft Nord- und Ostsee (BLANO), 15. Oktober 2024. URL: https://mitglieder.meeresschutz.info/de/berichte/zustandsbewer-tungen-art8-10.html

CARSTENSEN, J., 2007: Statistical principles for ecological status classification of Water Framework Directive monitoring data. Marine Pollution Bulletin 55, 3–15. https://doi.org/10.1016/j.marpolbul.2006.08.016

DUTZ, J., 2018: Evaluation of the HELCOM Zooplankton Core Indicator ‚Zooplankton Mean Size and Total Stock (MSTS)' along a salinity gradientin the western Baltic Sea. Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit, 44p.

DUTZ, J., KREMP, A., ZETTLER, M. L., 2022: Biological assessment of the Baltic Sea 2020. Meereswiss. Ber., Warnemünde 120, 1-82. http://doi.io-warnemuende.de/10.12754/msr-2022-0120

DUTZ, J., WASMUND, N., 2023: Seasonal aspects and short-term variability of the pelagic offshore ecosystem. In: Schubert, H., Müller, F. (eds) Southern Baltic coastal systems analysis. Ecological Studies, vol 246: 153-161, Springer, Cham. https://doi.org/10.1007/978-3-031-13682-5_16

DUTZ, J., ZETTLER, M. L., KREMP, A., PAUL, C., KUBE, S., 2025: Biological assessment of the Baltic Sea 2023. Meereswiss. Ber., Warnemünde 129. doi:10.12754/msr-2025-0129.

EASIN, 2025: easin.jrc.ec.europa.eu/easin. Assessed: 30.06.2025.

EU-KOMMISSIONSBESCHLUSS 2017/848/EU, 2017: Beschluss (EU) 2017/848 der Kommission vom 17. Mai 2017 zur Festlegung der Kriterien und methodischen Standards für die Beschreibung eines guten Umweltzustands von Meeresgewässern und von Spezifikationen und standardisierten Verfahren für die Überwachung und Bewertung sowie zur Aufhebung des Beschlusses 2010/477/EU. Amtsblatt der Europäischen Union, L 125/43, 18.5.2017.

GOGINA, M., NYGÅRD, H., BLOMQVIST, M., DAUNYS, D., JOSEFSON, A.B., KOTTA, J., MAXIMOV, A., WARZOCHA, J., YERMAKOV, V., GRÄWE, U., ZETTLER, M.L., 2016: The Baltic Sea scale inventory of benthic faunal communities in the Baltic Sea. ICES Journal of Marine Science 73: 1196-1213. https://doi.org/10.1093/icesjms/fsv265

GOLLASCH, S., NEHRING, S., 2006: National checklist for aquatic alien species in Germany. Aquatic Invasions **1**, 245-269.

GREVE, W., REINERS, F., NAST, J., HOFFMANN S., 2004: Helgoland Roads meso- and macrozooplankton time-series 1974 to 2004: lessons from 30 years of single spot, high frequency sampling at the only off-shore island of the North Sea. Helgol. Mar. Res. 58, 275-288.

HAHN, A., BRENNAN, R.S. 2024: Phenotypic plasticity drives seasonal thermal tolerance in a Baltic copepod. Journal of Experimental Marine Biology and Ecology 576, 152014.

HELCOM, 1987: First periodic assessment of the state of the marine environment of the Baltic Sea area, 1980-1985; background document. Baltic Sea Environment Proceedings 17 B, 1-351.

HELCOM, 1990: Second periodic assessment of the state of the marine environment of the Baltic Sea, 1984-1988; background document. Baltic Sea Environment Proceedings 35 B, 1-432.

HELCOM, 1996: Third periodic assessment of the state of the marine environment of the Baltic Sea, 1989-1993; background document. Baltic Sea Environment Proceedings 64 B, 1-252.

HELCOM, 2002: Environment of the Baltic Sea area, 1994-1998. Baltic Sea Environment Proceedings 82 B, 1-215.

HELCOM, 2010: Ecosystem Health of the Baltic Sea 2003–2007: HELCOM Initial Holistic Assessment. Balt. Sea Environ. Proc. No. 122.

HELCOM, 2013a: Climate change in the Baltic Sea area. HELCOM Thematic Assessment in 2013. Baltic Sea Environment Proceedings 137, 1-70.

HELCOM, 2013b: HELCOM core indicators. Final report of the HELCOM CORESET project. Baltic Sea Environment Proceedings 136, 1-74.

HELCOM, 2014: Eutrophication status of the Baltic Sea 2007-2011- A concise thematic assessment. Baltic Sea Environment Proceedings 143, 1-41.

HELCOM, 2017a: Manual for marine monitoring in the COMBINE programme of HELCOM. Internet, Last updated July 2017: https://helcom.fi/action-areas/monitoring-and-assessment/monitoring-guidelines/combine-manual/

HELCOM, 2017b: Guidelines for monitoring of chlorophyll a. Internet, Last updated July 2017: https://helcom.fi/wp-content/uploads/2019/08/Guidelines-for-measuring-chlorophyll-a.pdf

HELCOM, 2018: State of the Baltic Sea. Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155.

HELCOM, 2020: https://helcom.fi/baltic-sea-trends/indicators/, incl. https://indicators.helcom.fi/filtering/

HELCOM, 2021: Guidelines for monitoring of mesozooplankton. https://helcom.fi/wp-content/uploads/2019/08/Guidelines-for-monitoring-of-mesozooplankton.pdf. 12 p. Assessed: 13.09.2021.

HELCOM, 2023a: State of the Baltic Sea 2023. Third HELCOM holistic assessment 2016-2021. Baltic Sea Environment Proceedings 194.

HELCOM, 2023b: Guidelines for monitoring of phytoplankton species composition, abundance and biomass. Internet, Last updated May 2023: https://helcom.fi/wp-content/uploads/2023/05/Guidelines-for-monitoring-of-phytoplankton-species-composition-abundance-and-biomass-1.pdf

HELCOM, 2023C: Zooplankton mean size and total stock (MSTS). - https://indicators.helcom.fi/indicator/zooplankton/

HELCOM, 2025: HELCOM Red List II of Baltic Sea species in danger of becoming extinct. Baltic Sea Environment Proceedings No.205. 1-126.

ITIS, 2025: www.itis.gov/. Assessed: 30.06.2025.

JOHNS, D. G., EDWARDS, M., GREVE, W., ST. JOHN, A. W. G. 2005: Increasing prevalence of the marine cladoceran *Penilia avirostris* (Dana, 1852) in the North Sea. Helgol. Mar. Res. 59 (3): 214–218. doi:10.1007/s10152-005-0221-y. ISSN 1438-3888.

KRAUSE, M., MARTENS, P., 1990: Distribution patterns of mesozooplankton biomass in the North Sea Helgoländer Meeresuntersersuchungen 44, 295-327.

LACKSCHEWITZ, D., REISE, K., BUSCHBAUM, C., KAREZ, R., 2022: Neobiota der deutschen Nord- und Ostseeküste. Eingeschleppte Arten in deutschen Küstengewässern. Hrsg.: Landesamt für Landwirtschaft, Umwelt, und ländliche Räume des Landes Schleswig-Holstein (LLUR), 394 pp.

LEONARDSSON, K., BLOMQVIST, M., ROSENBERG, R. 2009: Theoretical and practical aspects on benthic quality assessment according to the EU-Water Framework Directive - Examples from Swedish waters. - Marine Pollution Bulletin 58, 1286–1296. https://doi.org/10.1016/j.marpolbul.2009.05.007

LORENZEN, C.J., 1967: Determination of chlorophyll and pheo-piments: spectrophotometric equations. Limnol. Oceanogr. 12, 343-346.

MARX, D., FELDENS, A., PAPENMEIER, S., FELDENS, P., DARR, A., ZETTLER, M.L., HEINICKE, K., 2024: Habitats and biotopes in the German Baltic Sea. Biology MDPI 13: 6. https://doi.org/10.3390/biology13010006

MENG, S., STRAHL, J., BÖRNER, A., KRIENKE, K., ZETTLER, M.L., WROZYNA, C. 2024: The bay barnacle Amphibalanus improvisus (Darwin, 1854) in the Pleistocene of Europe? A review of Pleistocene Balanidae of northern Central Europe. Journal of Quaternary Science 39(4): 547-565. https://doi.org/10.1002/jqs.3603

MOHRHOLZ, V., 2018: Major Baltic inflow statistics – reviewed. Front. Mar. Sci. 5, 384. doi: 10.3389/fmars.2018.00384

ÖBERG, J., 2017: Cyanobacterial blooms in the Baltic Sea in 2017. HELCOM Baltic Sea Environment Fact Sheets 2017. Online. http://helcom.fi/baltic-sea-trends/environmentfact-sheets/eutrophication/cyanobacterial-blooms-in-the-baltic-sea/

OLENINA, I., HAJDU, S., ANDERSSON, A., EDLER, L., WASMUND, N., BUSCH, S., GÖBEL, J., GROMISZ, S., HUSEBY, S., HUTTUNEN, M., JAANUS, A., KOKKONEN, P., LEDAINE, I., NIEMKIEWICZ, E., 2006: Biovolumes and size-classes of phytoplankton in the Baltic Sea. Baltic Sea Environment Proceedings 106, 1-144.

RACHOR, E. BÖNSCH, R., BOOS, K., GOSSELCK, F., GROTJAHN, M., GÜNTHER, C.-P., GUSKY, M., GUTOW, L., HEIBER, W., JANTSCHIK, P., KRIEG, H.-J., KRONE, R., NEHMER, P., REICHERT, K., REISS, H., SCHRÖDER, A., WITT, J., ZETTLER, M.L., 2013: Rote Liste der bodenlebenden wirbellosen Meerestiere. - Naturschutz und Biologische Vielfalt 70 (2): 81-176.

RICE, E., DAM, H.G.,STEWART, G., 2015: Impact of climate change on estuarine zooplankton: surface water warming in Long Island Sound is associated with changes in copepod size and community structure. Estuaries and Coasts 38, 13-23.

ROSENBERG, R., BLOMQVIST, M., NILSSON, H. C., CEDERWALL, H., DIMMING, A., 2004: Marine quality assessment by use of benthic species-abundance distributions: A proposed new protocol within the European Union Water Framework Directive. Marine Pollution Bulletin 49, 728–739 https://doi.org/10.1016/j.marpolbul.2004.05.013

SCHAUB, I., FRIEDLAND, R., ZETTLER, M.L. 2024: Good-Moderate boundary setting for the environmental status assessment of the macrozoobenthos communities with the Benthic Quality Index (BQI) in the south-western Baltic Sea. Marine Pollution Bulletin 201: 116150 doi: 10.1016/j.marpolbul.2024.116150

SCHIELE, K. S., DARR, A., ZETTLER, M. L., BERG, T., BLOMQVIST, M., DAUNYS, D., ET AL. 2016: Rating species sensitivity throughout gradient systems - a consistent approach for the Baltic Sea. Ecological Indicators 61: 447-455 https://doi.org/10.1016/j.ecolind.2015.09.046

SPILLING, K., OLLI, K., LEHTORANTA, J., KREMP, A., TEDESCO, L., TAMELANDER, T., TAMMINEN, T., 2018: Shifting diatom—dinoflagellate dominance during spring bloom in the Baltic Sea and its potential effects on biogeochemical cycling. Frontiers in Marine Science 5, 327.

STAEHR, P.A., JAKOBSEN, H.H., HANSE0N, J.L.S., ANDERSEN, P., CHRISTENSEN, J., GÖKE, C., THOMSEN, M.S., STEBBING, P.D. 2020: Trends in records and contribution of non-indigenous and cryptogenic species to marine communities in Danish waters: potential indicators for assessing impact. Aquatic Invasions 15(2): 217-244.

TELESH, I., POSTEL, L., HEERKLOSS, R., MIRONOVA, E., SKARLATO, S., 2008: Zooplankton of the Open Baltic Sea: Atlas. BMB Publication No.21. - Meereswiss. Ber., Warnemünde, 73, 1–251.

TELESH, I., POSTEL, L., HEERKLOSS, R., MIRONOVA, E., SKARLATO, S., 2009: Zooplankton of the Open Baltic Sea: Extended Atlas. BMB Publication No.21. - Meereswiss. Ber., Warnemünde, 76, 1–290.

UEDA, H., 1987: Temporal and spatial distribution of the two closely related *Acartia* species *A. omorii* and *A. hudsonica* (Copepoda, Calanoida) in a small inlet water of Japan. Estuarine, Coastal and Shelf Science 24, 691-700.

UTERMÖHL, H., 1958: Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Internationale Vereinigung für Theoretische und Angewandte Limnologie 9, 1-38.

VAHTERA, E., CONLEY, D. J., GUSTAFSSON, B. G., KUOSA, H., PITKÄNEN, H., SAVCHUK, O. P., WULFF, F., 2007: Internal ecosystem feedbacks enhance nitrogen-fixing cyanobacteria blooms and complicate management in the Baltic Sea. Ambio 36, 186-194.

WASMUND, N., BUSCH, S., GÖBEL, J., GROMISZ, S., HÖGLÄNDER, H., HUSEBY, S., JAANUS, A., JAKOBSEN, H.H., JOHANSEN, M., JÜRGENSONE, I., KOWNACKA, J., KRASNIEWSKI, W., LEHTINEN, S., OLENINA, I., V.WEBER, M., 2018: Cyanobacteria biomass 1990-2017. HELCOM Baltic Sea Environment Fact Sheet 2018a. http://helcom.fi/baltic-sea-trends/environmentfactsheets/ eutrophication/cyanobacteria-biomass/

WASMUND, N., DUTZ, J., KREMP, A., ZETTLER, M.L., 2019: Biological assessment of the Baltic Sea 2018. Meereswissenschaftliche Berichte, Warnemünde 112, 1-100. http://doi.org/10.12754/msr-2019-0112

WASMUND, N., DUTZ, J., POLLEHNE, F., SIEGEL, H., ZETTLER, M.L., 2018: Biological assessment of the Baltic Sea 2017. - Meereswiss. Ber., Warnemünde 108, 1-101.

WASMUND, N., KOWNACKA, J., GÖBEL, J., JAANUS, A., JOHANSEN, M., JURGENSONE, I., POWILLEIT, M., 2017: The Diatom/Dinoflagellate Index as an indicator of ecosystem Changes in the Baltic Sea 1. Principle and handling instruction. Frontiers in Marine Science 4, 22.

WASMUND, N., POLLEHNE, F., POSTEL, L., SIEGEL, H., ZETTLER, M.L., 2011: Biologische Zustandseinschätzung der Ostsee im Jahre 2010. Meereswissenschaftliche Berichte, Warnemünde 85, 1-87.

WASMUND, N., ZETTLER, M.L., 2023: Long-term trends of the offshore ecosystems. In: Schubert, H., Müller, F. (eds) Southern Baltic coastal systems analysis. Ecological Studies, vol 246: 163-174, Springer, Cham. https://doi.org/10.1007/978-3-031-13682-5_17

WELSCHMEYER, N.A., 1994: Fluorometric analysis of chlorophyll a in the presence of chlorophyll b and pheopigments. Limnol. Oceanogr. 39, 1985-1992.

WORMS, 2025: www.marinespecies.org/. Assessed: 30.06.2025.

ZETTLER, A., ZETTLER, M.L. 2024: Status und Verbreitung der Gebietsfremden Arten (Neobiota) in den deutschen Küstengewässern der Ostsee 2023. Ergebnisse des Rapid Assessments 2023. Projektbericht für das Bundesamt für Naturschutz. https://www.researchgate.net/publication/379310520_Status_und_Verbreitung_der_Gebietsfremden_Arten_Neobiota_in_den_deutschen_Kustengewassern_der_Ostsee_2023

ZETTLER, M.L., ALF, A., 2021: Bivalvia of German marine waters of the North and Baltic Seas. ConchBooks, Harxheim: 329pp.

ZETTLER, M.L., BEERMANN, J., DANNHEIM, J., EBBE, B., GROTJAHN, M., GÜNTHER, C.P., GUSKY, M., KIND, B., KUHLENKAMP, R., ORENDT, C., RACHOR, E., SCHANZ, A., SCHRÖDER, A., SCHÜLER, L., WITT, J., 2018: An annotated checklist of macrozoobenthic species in German waters of the North and Baltic Seas. Helgoland Marine Research 72, 5 (10pp). https://doi.org/10.1186/s10152-018-0507-5

ZETTLER, M.L., DARR, A., 2023: Benthic habitats and their inhabitants. In: Schubert, H., Müller, F. (eds) Southern Baltic coastal systems analysis. Ecological Studies, vol 246: 97-102 Springer, Cham. https://doi.org/10.1007/978-3-031-13682-5_8

ZETTLER, M.L., FRIEDLAND, R., GOGINA, M., DARR, A., 2017: Variation in benthic long-term data of transitional waters: Is interpretation more than speculation? PLoS ONE 12 (4): e0175746. https://doi.org/10.1371/journal.pone.0175746

ZETTLER, M.L., KARLSSON, A., KONTULA, T., GRUSZKA, P., LAINE, A., HERKÜL, K., SCHIELE, K., MAXIMOV, A., HALDIN, J., 2014: Biodiversity gradient in the Baltic Sea: A comprehensive inventory of macrozoobenthos data. Helgoland Marine Research 68: 49-57. https://doi.org/10.1007/s10152-013-0368-x

ZETTLER, M.L., KREMP, A., DUTZ, J., 2024: Biological assessment of the Baltic Sea 2022. - Meereswissenschaftliche Berichte, Warnemünde 125, 1-85.

Appendix

Table Appendix 1: List of phytoplankton-taxa recorded in 2024 on five monitoring cruises. (X) reflects the presence of taxa on cruises.

Taxon	**Feb**	**Mar**	**May**	**Aug**	**Nov**
Actinocyclus	x		x		x
Actinocyclus octonarius	x	x	x		
Alexandrium pseudogonyaulax				x	
Amphidinium crassum		x		x	
Amphidinium longum	x				
Amphidinium sphenoides		x	x	x	x
Apediella radians	x	x	x		x
Aphanizomenon		x	x	x	x
Aphanothece		x			x
Apocalathium CPX	x	x	x	x	x
Attheya longicornis		x		x	x
Attheya septentrionalis				x	
Azadinium	x		x	x	x
Binuclearia lauterbornii	x	x	x		x
Botryococcus				x	x
Centrales		x	x	x	x
Cerataulina pelagica	x	x		x	x
Chaetoceros	x	x			x
Chaetoceros castracanei		x	x		x
Chaetoceros ceratosporus		x			
Chaetoceros convolutus	x				x
Chaetoceros curvisetus	x				
Chaetoceros danicus	x	x		x	x
Chaetoceros debilis	x				
Chaetoceros decipiens	x	x			
Chaetoceros septentrionalis	x	x		x	x
Chaetoceros similis	x		x		
Chaetoceros sociales					x
Chaetoceros subtilis	x	x			
Chaetoceros throndsenii		x	x	x	
Chaetoceros whigamii		x			
Choanoflagellatea	x	x	x		x
Chroococcales		x	x	x	x
Cocconeis			x		

Coscinodiscopsis commutata					x
Coscinodiscus granii					x
Coscinodiscus radiatus	x				x
Cochlodinium		x			
Cyclotella	x	x			
Cylindrotheca closterium	x			x	x
Cymbomonas tetramitiformis				x	
Dactyliosolen fragilissimus	x		x	x	x
Dictyocha fibula					x
Dinobryon			x	x	
Dinobryon borgei			x		
Dinobryon faculiferum		x	x	x	x
Dinophysis acuminata	x	x	x	x	x
Dinophysis norvegica				x	x
Diplopsalis CPX				x	
Ditylum brightwellii					x
Dolichospermum				x	x
Dolichospermum lemmermannii			x	x	x
Ebria tripatita	x	x	x	x	x
Eucampia zodiacus	x				x
Eutreptiella	x	x	x	x	x
Flagellates	x	x	x	x	x
Guinardia delicatula	x	x			x
Guinardia flaccida	x	x		x	x
Gyrosigma cf.	x				
Gymnodiniales	x	x	x	x	x
Gymnodinium	x	x	x	x	x
Gyrodinium	x				
Gyrodinium flagellare	x	x			x
Gyrodinium spirale	x	x	x		x
Hemiselmis	x	x	x	x	x
Hetrocapsa cf.			x		
Heterocapsa rotundata	x	x	x	x	x
Hetrocapsa triquetra cf.	x	x			x
Hetrosigma cf.	x				
Karlodinium veneficum	x	x	x	x	x
Katablepharis remigera	x	x	x	x	x
Katodinium glaucum	x	x	x		

Kryptoperidinium triquetrum					x
Laboea strobila		x		x	x
Lemmermaniella parva			x		
Lennoxia faveolata	x	x			x
Leptocylindrus minimus	x				x
Leucocryptos marina	x	x	x	x	x
Melosira arctica		x			
Mesodinium rubrum	x	x	x	x	x
Micracanthodinium claytonii				x	x
Micracanthodinium setiferum cf.					x
Miraltia throndsenii				x	
Monoraphidium contortum			x		
Navicula		x			
Nitzschia longissima	x				x
Nitzschia paleacea	x			x	
Nodularia spumigena			x	x	x
Oblea rotunda spp. CPX					x
Octactis speculum	x	x	x		x
Oocystis		x	x		
Peridinales	x	x	x	x	x
Peridiniella catenata		x	x		
Peridiniella danica	x				
Peridiniella danica cf.			x		x
Plagioselmis prolonga	x	x	x	x	x
Planktolyngbya	x				x
Polykrikos schwartzii					x
Porosira glacialis		x			
Proboscia alata	x	x	x	x	x
Prorocentrum cordatum	x			x	x
Prorocentrum micans	x			x	x
Protoperidinium	x	x		x	x
Protoperidinium bipes	x	x			x
Protoperidinium brevipes	x	x			
Protoperidinium depressum	x				
Protoperidinium divergens					x
Protoperidinium oblongum cf.				x	
Protoperidinium pallidium		x			
Protoperidinium pellucidum	x	x			

Protoperidinium thorianum					
Prymnesiales	x	x	x	x	x
Pseudanabaena	x			x	x
Pseudanabaena limnetica	x	x		x	x
Pseudochattonella farcimen	x				
Pseudonitzschia	x	x			x
Pseudinitzschia delicatissima GRP	x	x			
Pseudonitzschia seriata GRP	x	x		x	x
Pseudopedinella		x	x	x	x
Pseudosolenia calcar-avis	x			x	x
Pterosperma	x			x	
Pyramimonas	x	x	x	x	x
Rhizosolenia minima		x			x
Rhizosolenia hebetate f. semispina	x	x			
Rhizosolenia setigera	x	x			x
Rhizosolenia setigera f. pungens	x				x
Scrippsiella GRP	x	x		x	x
Skeletonema marinoi	x	x	x		x
Snowella	x	x	x		x
Telonema	x	x	x	x	x
Teleaulax	x	x	x	x	x
Thalassiosira	x	x			
Thalassiosira anguste-lineata	x				
Thalassiosira nordenskioeldii	x	x			
Thalassiosira punctigera	x				
Thalassionema nitzschioides	x	x	x	x	
Trachelomonas					x
Tripos fusus	x			x	x
Tripos lineatus					x
Tripos muelleri		x		x	x

Table Appendix 2: Seasonal occurrence of taxa found in the investigation area in 2024 with information on original description, taxonomic rank and taxonomic life science identifier according to the Aphia Database (AphiaID) of the world register of marine species (WoRMS).

	rank	AphiaID	Feb	March	May	Aug	Nov
Protozoa							
Tintinnidae Claparède & Lachmann, 1858	Family	183533	o	o	o	o	
Noctiluca scintillans (Macartney) Kofoid & Swezy, 1921	Species	109921				o	
Annelida (Larvae)							
Polychaeta - Trochophora	Subphylum		o	o	o	o	o
Polychaeta Grube, 1850	Subphylum	883	o	o	o	o	o
Harmothoe spp. Kinberg, 1856	Genus	129491	o	o			
Pectinaria spp. Savigny in Lamarck, 1818	Genus	129437				o	
Arthropoda - Crustacea							
Copepoda							
Acartia Dana, 1846	Genus	104108	o	o	o	o	o
Acartia (Acanthacartia) bifilosa (Giesbrecht, 1881)	Species	345919	o	o	o	o	o
Acartia (Acartiura) clausi (Giesbrecht, 1892)	Species	149755	o				
Acartia (Acartiura) longiremis Lilljeborg, 1853	Species	346037	o	o	o	o	o
Acartia (Acartiura) tonsa Dana, 1849	Species	345943	o		o	o	o
Acartia (Acartiura) hudsonica Pinhey, 1926	Species	149751			o		
Calanus Leach, 1816	Species	104466	o		o		
Centropages Krøyer, 1849	Genus	104159	o	o	o	o	o
Centropages hamatus Lilljeborg, 1853	Species	104496	o	o	o	o	o
Eurytemora Giesbrecht, 1881	Genus	104240	o	o	o	o	
Eurytemora affinis Poppe, 1880	Species	104872	o	o	o	o	
Euterpina acutifrons Dana, 1847	Species	116162		o	o	o	
Harpacticoida G. O. Sars, 1903	Order	1102	o	o	o	o	o
Microsetella spp. Brady & Robertson, 1873	Genus	115341	o	o	o	o	o
Oithona Baird, 1843	Genus	106485	o	o	o	o	o
Oithona spp. Baird, 1843	Genus	106642	o	o	o	o	o
Oithona similis Claus, 1866	Species	106656	o	o	o	o	o
Paracalanus parvus Claus, 1863	Species	104685	o	o	o	o	o
Pseudocalanus spp. Boeck, 1872	Genus	104165	o	o	o	o	o
Temora Baird, 1850	Genus	104241	o	o	o	o	o
Temora longicornis O.F.Müller, 1785	Species	104878	o	o	o	o	o
Phyllopoda							
Bosmina spp. Baird, 1845	Genus	106265	o		o	o	
Evadne nordmanni Lovén, 1836	Species	106273	o	o	o	o	o
Podon leuckartii G. O. Sars, 1862	Species	106277				o	o
Podon intermedius Lilljeborg, 1853	Species	106276	o	o	o		o
Pleopis polyphemoides (Leuckart,1859)	Species	247981				o	
Penilia avirostris Dana, 1849	Species	106272				o	o

	rank	AphiaID	Feb	March	May	Aug	Nov
other Crustacea (Larvae)							
Balanus spp. Costa, 1778	Genus	106122	o	o	o	o	o
Carcinus maenas Linnaeus, 1758	Species	107381				o	
Crangon Fabricius, 1789.	Genus	107007				o	
Facetotecta Grygier, 1985	Subclass	150305	o			o	
Liocarcinus Stimpson, 1871	Genus	106925					
Bryozoa (Larvae)							
Gymnolaemata Allman, 1856	Class	1795	o	o	o	o	o
Chaetognatha							
Sagittidae Claus and Grobben, 1905	Family	5953					o
Chordata							
Fritillaria borealis Lohmann, 1896	Species	103375	o	o	o	o	o
Oikopleura dioica Fol 1872	Species	103407	o	o		o	o
Teleostei (Larvae)	Infraclass	293496	o	o	o	o	
Echinodermata (Larvae)							
Asterias spp. Linnaeus, 1758	Genus	123219				o	
Echinus spp. Linnaeus, 1758	Genus	123386				o	
Ophiura spp. Lamarck, 1801	Genus	123574				o	
Cnidaria & Ctenophora							
Ctenophora Eschscholtz, 1829	Phylum	1248	o	o	o	o	o
Antothecata Cornelius, 1992	Order	13551	o	o		o	o
Leptothecata Cornelius, 1992	Order	13552					o
Euphysa aurata Forbes, 1848	Species	117561	o	o		o	
Rathkea octopunctata M. Sars, 1835	Species			o			
Sarsia tubulosa M. Sars, 1835	Species	565161					o
Phoronida (Larvae)							
Phoronis muelleri Selys-Longchamps, 1903	Species	206663				o	o
Platyhelminthes							
Alaurina spp. Metschnikoff, 1861	Genus	142785	o			o	o
Leptoplanidae Stimpson, 1857	Family	142062				o	o
Mollusca (Larvae)							
Bivalvia Linnaeus, 1758	Class	105	o	o	o	o	o
Gastropoda Cuvier, 1797	Class	101	o	o	o	o	o
Rotifera							
Synchaeta spp. Ehrenberg, 1832	Genus	134958	o	o	o		o
Keratella cochlearis(Gosse, 1851)	Species	134990	o	o		o	o
Keratella quadrata O. F. Muller, 1786	Species	134992	o	o		o	o

*Table Appendix 3: Distribution of macrozoobenthos at six stations in November 2024. In the right column the red list (Rachor et al. 2013) species are indicated (1=critically endangered, 2=endangered, 3=vulnerable, G=probably vulnerable, V=near threatened, R=extremely rare, D=data deficient, *=least concern, ne=not evaluated). Neozoan species are indicated in yellow.*

Taxa	**N3**	**N1**	**M2**	**OM18**	**K8**	**K4**	**K3**	**OM160**	**RL**
Amphipoda									
Corophium volutator								1	*
Crassicorophium crassicorne	1				1				*
Gammarus oceanicus					1		1		*
Gammarus salinus					1		1	1	*
Gammarus zaddachi							1	1	*
Melita palmata								1	V
Microdeutopus gryllotalpa	1				1			1	*
Monocorophium insidiosum	1				1				*
Monoporeia affinis							1		3
Anthozoa									
Halcampa duodecimcirrata						1			1
Sagartia undata		1							3
Arachnida									
Halacaridae	1				1				ne
Ascidiacea									
Dendrodoa grossularia		1			1				V
Molgula manhattensis	1								D
Styela coriacea	1								G
Bivalvia									
Abra alba	1			1					*
Arctica islandica	1	1	1	1		1			3
Astarte borealis	1			1	1	1			G
Astarte elliptica	1	1		1		1			G
Astarte montagui	1								3
Cerastoderma glaucum								1	*
Hiatella arctica	1								*
Kurtiella bidentata	1								*
Macoma balthica	1			1	1	1	1	1	*
Musculus niger	1								G
Musculus subpictus	1								G
Mya arenaria					1		1	1	*
Mytilus edulis	1	1		1	1	1	1	1	*
Nucula nitidosa		1							*
Parvicardium pinnulatum	1			1	1				D
Rangia cuneata								1	ne
Bryozoa									
Alcyonidium polyoum	1	1			1		1		D
Amathia sp.	1				1				ne
Callopora lineata	1				1	1			*

Taxa	N3	N1	M2	OM18	K8	K4	K3	OM160	RL
Cribrilina punctata	1								*
Einhornia crustulenta	1	1	1	1	1		1	1	*
Electra pilosa	1	1			1	1			*
Escharella immersa	1	1							*
Eucratea loricata	1	1		1					V
Farrella repens	1				1				D
Flustra foliacea	1								*
Walkeria uva	1				1				*
Cirripedia									
Amphibalanus improvisus				1				1	ne
Balanus crenatus	1			1	1				*
Cumacea									
Diastylis rathkei	1			1		1	1		*
Decapoda									
Crangon crangon	1				1	1	1	1	*
Palaemon adspersus					1				V
Palaemon elegans					1				*
Rhithropanopeus harrisii								1	ne
Echinodermata									
Asterias rubens	1	1		1	1	1			*
Echinocyamus pusillus	1								G
Ophiura albida	1			1					*
Psammechinus miliaris	1								*
Entoprocta									
Barentsia sp.	1	1							ne
Gastropoda									
Acanthodoris pilosa					1				*
Aporrhais pespelecani	1								G
Cadlina laevis					1				*
Onchidoris muricata	1				1				*
Peringia ulvae			1	1	1	1	1	1	*
Philine punctata	1	1		1	1				*
Retusa truncatula	1								*
Tenellia adspersa					1				G
Tritia reticulata	1								G
Hydrozoa									
Bougainvillia muscus					1				D
Campanulina pumila					1				ne
Clava multicornis					1				D
Clytia hemisphaerica					1				D
Filellum serpens	1	1			1				D
Halitholus yoldiaearcticae	1								3
Hartlaubella gelatinosa	1	1			1		1		D
Hydractinia echinata	1								*
Opercularella lacerata					1				D
Sertularia cupressina		1							G
Isopoda									

Taxa	N3	N1	M2	OM18	K8	K4	K3	OM160	RL
Cyathura carinata								1	D
Idotea balthica					1				*
Idotea chelipes								1	D
Jaera albifrons					1		1		*
Mysida									
Gastrosaccus spinifer					1				ne
Mysis mixta					1		1		ne
Neomysis integer							1	1	ne
Praunus flexuosus								1	ne
Praunus inermis	1								ne
Nemertea									
Cyanophthalma obscura					1				ne
Lineus ruber					1				ne
Lineus viridis	1				1				ne
Oligochaeta									
Baltidrilus costatus							1		*
Enchytraeidae							1	1	ne
Nais elinguis							1		*
Tubificinae	1	1	1	1	1		1	1	ne
Tubificoides benedii				1	1		1	1	*
Phoronida									
Phoronis sp.	1	1	1	1					ne
Plathelminthes									
Planoceridae								1	ne
Stylochoidea					1			1	ne
Polychaeta									
Alitta succinea	1			1	1		1	1	D
Ampharete baltica	1			1	1	1			*
Ampharete cirrata				1		1	1		*
Aphelochaeta marioni	1								*
Arenicola marina	1				1				*
Aricidea minuta	1								*
Aricidea suecica				1	1	1			*
Bylgides sarsi	1			1	1	1	1		*
Capitella capitata	1	1	1	1	1				*
Dipolydora quadrilobata	1		1	1	1	1			*
Erinaceusyllis erinaceus	1								D
Eteone longa					1				*
Euchone papillosa	1								2
Exogone naidina	1								D
Fabricia stellaris							1		D
Fabriciola baltica	1				1				G
Flabelligera affinis		1							D
Harmothoe imbricata	1			1	1				D
Hediste diversicolor							1	1	*
Heteromastus filiformis					1	1	1		*
Lagis koreni	1	1	1	1	1				*
Levinsenia gracilis	1		1						*
Marenzelleria neglecta								1	ne

Taxa	**N3**	**N1**	**M2**	**OM18**	**K8**	**K4**	**K3**	**OM160**	**RL**
Marenzelleria viridis								1	ne
Neoamphitrite figulus	1								*
Nephtys caeca	1								*
Nephtys ciliata	1	1		1		1			*
Nephtys hombergii						1			*
Nephtys pente				1					D
Nereimyra punctata	1								G
Nicolea zostericola					1				*
Paradoneis eliasoni	1	1							*
Parexogone hebes	1								D
Pherusa plumosa	1								D
Pholoe baltica	1								*
Phyllodoce mucosa				1		1			*
Polydora ciliata	1			1		1			*
Polydora cornuta	1			1	1				*
Pseudopolydora antennata	1								D
Pseudopolydora pulchra	1			1					*
Pygospio elegans	1			1	1		1	1	*
Scalibregma inflatum	1								G
Scolelepis foliosa					1				*
Scoloplos armiger	1			1	1	1	1		*
Spio goniocephala					1				*
Terebellides stroemii	1					1	1		*
Travisia forbesii					1		1		G
Trochochaeta multisetosa	1			1		1			D
Porifera									
Halichondria panicea					1				G
Haliclona oculata		1							D
Halisarca dujardinii					1				D
Priapulida									
Halicryptus spinulosus							1		ne
species number 145	**82**	**25**	**9**	**37**	**68**	**25**	**32**	**29**	
abundance (ind m^{-2})	3019	112	128	832	2011	392	5565	8421	
biomass (afdw g m^{-2})	30.1	19.4	8.7	14.2	4.9	1.3	9.4	15.9	

Zettler ML, Dutz J, Kremp A, Paul C,
Busch S, Naumann M, Kube S:
Biological assessment of the Baltic
Sea 2024.

CONTENT

Leibniz-Institut für
Ostseeforschung
Warnemünde
iow