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Copepods dominate the mesozooplankton spring-summer community in a South Norwegian fjord

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Sammendrag

I dette studiet ble sesongvariasjonen blant dyreplanktonsamfunnet gjennom vår og sommer i 2019 ved Midtfjordsskjær (MFS), Sør-Norge, undersøkt. Dyreplanktonprøver ble samlet inn ved bruken av et finmasket plankton-nett (60 μm) og dyreplankton ble identifisert ved bruken av mikroskopering av 5 ml stikkprøver. Den totale abundansen (antall dyreplankton) til dyreplankton varierte fra 754 – 1620 ind. m^{-3} og høyest abundans ble funnet i mai. Holoplankton dominerte vår- og sommersamfunnene ved MFS og utgjorde mellom 85,6 – 98,8% av total andel dyreplankton. Hoppekreps (copepoder) utgjorde mesteparten av dyreplanktonsamfunnet ved MFS gjennom vår og sommer med en abundans mellom 707 – 1474 ind. m^{-3} (85,3 – 96,4%) av den totale dyreplankton-abundansen. Copepoder ble funnet i alle livsstadier både om våren og om sommeren. Copepode nauplius-larver var en viktig del av den totale abundansen til copepodene og utgjorde mellom 21,4 – 74,7% gjennom vår og sommer. Cyclopoide copepoder var den mest abundante gruppen om våren og var dominert av *Oithona* spp.. Calanoide copepoder ble mer abundante blant copepodene om sommeren og var dominert av *Acartia* spp. og *Paracalanus/Pseudocalanus* spp. copepoditter. *Microsetella* spp. dominerte blant de harpacticoide copepodene og ble hovedsakelig funnet om våren. Andelen av Meroplankton var lav gjennom hele studieperioden og utgjorde på det meste 14,4% av den totale mengden dyreplankton. Flerbørstemarkere (Polychaeta) og rankeføttinger (Cirripedia) dominerte blant meroplanktonet om våren, mens Polychaeta og snegler (Gastropoda) dominerte om sommeren. En klyngeanalyse av prøvene basert på Bray-Curtis likhet indikerte en inndeling av dyreplanktonsamfunnene i tre hovedperioder; tidlig vår (mars), som korresponderte til pre-bloomstringsfasen i fytoplanktonsamfunnet, vår (april – mai) som korresponderte til oppbloomstringen – sen-oppbloomstringsfasen av fytoplanktonsamfunnet og sommer (juni – juli) som representerte en periode med lav algebiomasse.

Abstract

In this study the seasonality of the mesozooplankton community in spring and summer of 2019 at Midtfjordsskjær (MFS), South Norway, was investigated. Zooplankton samples were collected using a fine mesh sized plankton net (60 μm) and zooplankton were identified by microscopy based on 5 ml subsamples. Total zooplankton abundance ranged from 754 – 1620 ind. m^{-3} and peak abundance was found in May. Holoplankton dominated spring and summer communities at MFS constituting between 85,6 – 98,8% of total zooplankton. Copepods were the biggest contributors to the zooplankton community at MFS during spring and summer with abundance ranging between 707 – 1474 ind. m^{-3} (85,3 – 96,4%) of total zooplankton abundance. All copepod life stages were found in spring and summer and copepod nauplii were an important part of total copepod abundance and constituted between 21,4 – 74,7% in spring and summer. Cyclopoid copepods were the most abundant group in spring and were dominated by *Oithona* spp.. Calanoid copepods became more abundant among the copepods in summer and were dominated by *Acartia* spp. and *Paracalanus/Pseudocalanus* spp. copepodites. *Microsetella* spp. dominated among the harpacticoid copepods and was mostly found in spring. Meroplankton abundance was low throughout the study period and constituted maximum 14,4% of total zooplankton abundance. Polychaeta and Cirripedia dominated the meroplankton in spring, while Polychaeta and Gastropoda dominated in summer. A cluster analysis based on Bray-Curtis similarities among samples indicated a division of the zooplankton communities in three main periods; early spring (March), which corresponded to the pre-bloom phase in the phytoplankton community, spring (April – May) which corresponded to the bloom – late bloom phase of the phytoplankton community and summer (June – July) which represented a period of low algal biomass.

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1 Introduction

Zooplankton can be found in lakes, oceans and across coastlines worldwide and are important grazers of phytoplankton (Calbet, 2001; Calbet & Landry, 2004; Lampert et al., 1986). Additionally, zooplankton have proven to influence the abundances of lower trophic levels in plankton communities (Ventelä et al., 2002; Wiackowski et al., 1994). Moreover, zooplankton serve as a key link between primary producers and fish in the pelagic food web (Cushing, 1989) as they are important prey for larval and post-larval fish (Baier & Purcell, 1997; Fossum & Ellertsen, 1994; Lebour, 1920).

Mesoplankton is one of several size categories in which metazooplankton resides and specifies the size class 0,2 – 20 mm (Sieburth et al., 1978). Mesozooplankton comprise two of the main plankton groups found in coastal areas: holoplankton and meroplankton (Lee et al., 2006). Holoplankton are organisms that spend their entire lifecycle as plankton in the water column, while meroplankton are usually larval stages of larger benthic invertebrates.

Copepods (Arthropoda: Crustacea) are the most common holoplanktonic taxon, and is dominated by adults and juvenile copepodites (Sieburth et al., 1978). Additionally, abundances of water fleas (Crustacea: Cladocera) can regularly be found in coastal zooplankton communities (Nielsen & Andersen, 2002; Viñas et al., 2007). Furthermore, filter-feeders such as appendicularians (Chordata) and predators like arrow worms (Chaetognatha) can at times also be important taxa among the zooplankton (Eloire et al., 2010). Moreover, comb jellies (Ctenophora) and jellyfish (Cnidaria) are also a part of the zooplankton community. In terms of meroplanktonic taxa, larvae of mussels (Mollusca: Bivalvia), snails (Mollusca: Gastropoda) and bristle worms (Annelida: Polychaeta) are commonly found (Michelsen et al., 2017a; Silberberger et al., 2016; Stübner et al., 2016). And during certain seasons, the abundances of barnacle larvae (Crustacea: Cirripedia) and larvae of sea urchins or sea stars (Echinodermata) can be high (Stübner et al., 2016; Van Ginderdeuren et al., 2014). Finally, larvae of moss animals (Bryozoa) and horseshoe worms (Phoronida) as well as zoea larvae of lobsters and crabs (Crustacea: Decapoda) are usually less commonly found in zooplankton communities (Selifonova, 2012; Stübner et al., 2016).

Copepods undergo a complex life cycle which includes multiple naupliar and copepodite stages before they reach adult life (Landry, 1983). During development different lifestyle strategies are utilized, from lecithotrophic (non-feeding) seen in early nauplii stages to heterotrophic (feeding) performed by all life stages (Landry, 1983). In estuaries and coastal

waters Cladocera can quickly become an important part of the holoplankton or the total plankton community when waters become stratified (Allan, 1976; Gieskes, 1971; Viñas et al., 2007). The first occurring cladocerans are overwintering females and females hatched from resting eggs and later matured (Allan, 1976), hence resting eggs produced by marine cladocerans are important for successful seasonal recruitment (Onbé, 1985).

Meroplanktonic larvae are primarily produced by benthic invertebrates with low mobility to help with dispersion of young individuals to suitable areas (Mileikovsky, 1971) and can undergo morphological changes during their development (Crisp, 1962; Mileikovsky, 1971). Production of these larvae is important as they may settle as new recruits to communities or populations (Mileikovsky, 1971). Spawning of meroplankton larvae by adults can take place over longer periods of time or can happen in one or several short intense spawning events (Mileikovsky, 1971). During release events of meroplanktonic larvae meroplankton may reach high abundances and even constitute most of total zooplankton in the area (Stübner et al., 2016). Depending on environmental conditions or their taxonomic group, meroplankton may spend hours to months living planktonic, and during this time larvae and early juvenile stages of meroplankton may either utilize a heterotrophic or lecithotrophic lifestyle (Mileikovsky, 1971; Thorson, 1950). Meroplanktonic larvae may travel far to colonize new or existing areas far from their place of origin depending on their time spent as plankton, the hydrography and currents (Mileikovsky, 1968).

The plankton communities along the Norwegian Skagerrak coast have changed throughout the last decades (Johannessen et al., 2012). While phytoplankton spring blooms usually occurred in March followed by lower algal biomass during summer and a distinct autumn bloom in the 1990s, the data indicated that the phytoplankton blooms of the 2000s occurred in late February, with higher biomass than earlier followed by summer blooms of lower biomass and with autumn blooms almost gone (Johannessen et al., 2012). In terms of zooplankton communities, copepod data showed no specific trends for most species/groups, but the two most abundant groups, *Paracalanus/Pseudocalanus* spp. and *Oithona* spp., have decreased drastically after 2002 (Johannessen et al., 2012). The seasonality of *Paracalanus/Pseudocalanus* spp. showed an increase in abundance in early May, followed by a decrease, and then a huge increase resulting in maximum abundance in July (Johannessen et al., 2012).

Outside of Plymouth, the abundance of copepods compared to other taxa is at its highest during autumns and winters and can make up as much as 90% of the total zooplankton

abundance during winter months (Eloire et al., 2010). The study also showed that copepods on average make up over 60% of the total zooplankton abundance between 1988 and 2007 with calanoid copepods being the biggest contributor of 37%, followed by cyclopoids (23%) and harpacticoids (1%) (Eloire et al., 2010).

The seasonality of the zooplankton community in the northern part of Kattegat showed that copepods make up about 70% of the zooplankton community in February-April and averaged 46% in May-November (Olsson & Ölundh, 1974). Additional results from the same study showed that meroplankton comprised the main part of the zooplankton community during summer and in October-November, and on an average made up 33% of the total zooplankton abundance between May-November. Comparably, holoplankton other than copepods accounted for 21% during the same period. Peak copepod abundance occurred in June, July and September with *Acartia longiremis*, *A. clausi*, *Pseudocalanus elongatus*, *Paracalanus parvus* and *Oithona similis* being the most common taxa (Olsson & Ölundh, 1974).

In Sandsfjord, located on the southwestern coast of Norway, the plankton community structure was investigated across a transect in the summer. Results from Nielsen and Andersen (2002) showed that copepods dominated the mesozooplankton and that total copepod biomass seemed to increase towards the mouth of the fjord. *Oithona* spp. (mainly *Oithona similis*) and *Microsetella norvegica* were the two most abundant copepod taxa, with *Oithona* spp. comprising about 60% of copepod abundance at all stations, while *Calanus finmarchicus* was most important in terms of biomass (Nielsen & Andersen, 2002). Additionally, *Evadne nordmanni* was the dominating cladoceran, while *Podon* sp. were much less abundant. Finally, meroplankton biomass increased across the transect towards the mouth dominated by bivalve and gastropod veligers, polychaete larvae and cirriped nauplii. They were and mostly found in the upper 10 meters of the water column.

2 Study aims

The aims of this study are to: (1) establish which zooplankton taxa, based on microscopy, are present at the Midtfjordsskjær (MFS) station during the spring and summer period of 2019 using a fine mesh size plankton net (60 μm); (2) investigate the abundance of the different taxa throughout the sampled period; (3) study the seasonal variability of the sampled zooplankton taxa.

3 Methodology

Sampling site

Midtjordsskjær, hereafter shortened to MFS, sampling station (58°08'54''N 6°83'09''E) in Inner Spindsfjorden, Farsund, South Norway is 106 m deep and a part of Lister Oceanographic and Biologic Station for Education and Research time series. The station is located slightly west of the border between Skagerrak and North Sea. It is a semi-enclosed basin with several sills around 30 m and sheltered by outer skerries (Figure 1). The MFS station was accessible for sampling using a small vessel and all collections were done using manually held gear (or a winch when available) which could be handled by 1-2 people.

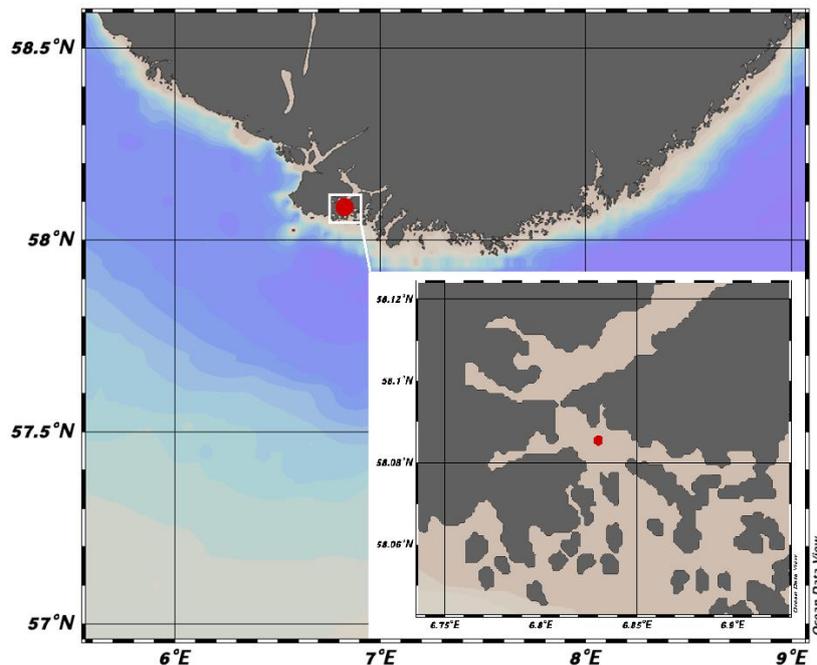


Figure 1 – MFS sampling station (red dot) located in Inner Spindsfjorden, Farsund (58°08'54''N 6°83'09''E) in South Norway.

Zooplankton sampling method

A plankton net from KC Denmark with 0,5 m ring diameter and 60 µm mesh size attached to a filtering cod end was used to collect the zooplankton material from March 30th to July 29th 2019. The water column (90 – 0) was sampled by lowering the net before hauling it back up at 0,5 – 1 m/s. All zooplankton samples were put in a temporary placeholder (i.e. bucket with

a lid) until they were brought to the lab where the samples were filtered through a 63 µm sized sieve before they were fixated in 70 % ethanol and then stored at 4 °C. Re-fixation of samples happened 2 – 14 days after each sample originally had been fixated. All samples were filled so each container held 200 ml and stored at 4 °C until further use.

Zooplankton identification

Samples were homogenized via turning the samples carefully hundred times. 5 ml of the sample (1 ml in the case of the March 30th sample) was then taken out as a subsample using a pipette. To make sure plankton did not get stuck during pipetting, the tip of the pipette was cut at an angle to increase the size of the opening. The complete subsample was counted, and plankton were identified to the lowest taxonomic level possible using a Olympus SZX16 stereomicroscope. Identification of the zooplankton were based on available literature, and photos were taken during identification using an Olympus SC50 camera. Larger gelatinous plankton belonging to Ctenophora and Cnidaria were mostly removed from samples prior to fixation and were not counted. Plankton identified as hydrozoans were counted and their abundance estimated for each sample. They were, however, not included in the figures because of uncertainty as to which degree they could have been removed at some sampling points together with the larger gelatinous plankton. Similarly, small individuals that could not be identified to any major taxon were counted but are not included in the study because of uncertainties regarding them belonging to the plankton community. Furthermore, zooplankton samples between early May and late June were not collected due to a broken net, thus leaving a gap in the data set between May 6th and June 26th.

Zooplankton was identified to the lowest taxonomic unit possible, either to species, cf. species, genus or phylum. Copepodites of *Paracalanus* sp. and *Pseudocalanus* sp. are grouped together as “Para/Pseudocalanus cop” due to the difficulty in distinguishing the two. The group “Calanoida non det” consists of one individual identified as calanoid which could not be identified to a lower taxonomic level due to being damaged. *Centropages* spp. consist of copepodites of *Centropages* cf. *typicus*, *Centropages hamatus* males and *Centropages* sp. copepodites which were grouped together because of their low abundance. “Cyclopoida non det” consist of individuals identified as cyclopoids but being too damaged for any lower taxonomic identification. Harpacticoid adults and copepodites could not be distinguished properly and were placed in the group “Harpacticoida non det”.

Environmental sampling

A hand-held CTD profiler (SAIV model 204; SAIV AS) with added sensors to measure fluorescence, turbidity and/or dissolved oxygen was used for collecting vertical oceanographic and environmental data. The probe was adjusted to the sea water condition for one minute before being lowered towards the seabed at a pace of 0,5m/s. After reaching the required depth (ca. 90 m), the profiler was pulled upwards again with the same speed. Ocean Data View (ODV) was used to visualize the data collected by the CTD probe (Schlitzer, 2018).

Data visualization and analysis

Zooplankton abundances were calculated and plotted using Excel. Similarity among samples was analyzed using PRIMER7 (Clarke & Gorley, 2015). The Basic multivariate analysis wizard was run using square root transformation and Bray-Curtis similarity resemblance. The branch support was analyzed using SIMPROF (999 permutations and 5% significance level). The Cophenetic Correlation Coefficient was calculated to estimate the goodness-of-fit of the clustering. Additionally, a non-metric Multi-Dimensional Scaling (nMDS) analysis was run also based on Bray-Curtis similarities (figure not included as it showed a similar result to the clustering analysis).

4 Results

Total zooplankton abundance

Total zooplankton abundance (Figure 2) peaked on Mai 6th 2019 with 1620 individuals per m^{-3} . The lowest amount of zooplankton abundance was found on the July 29th 2019, with 754 individuals per m^{-3} . 905 individuals per m^{-3} were found on March 30th, while 1028 individuals per m^{-3} were found April 6th, 2019. On April 26th, the total zooplankton abundance was 1213 individuals per m^{-3} . The abundance of zooplankton was still high in late June (26th) of 2019, with 1404 individuals per m^{-3} . On July 12th, total zooplankton abundance had decreased to 854 individuals per m^{-3} .

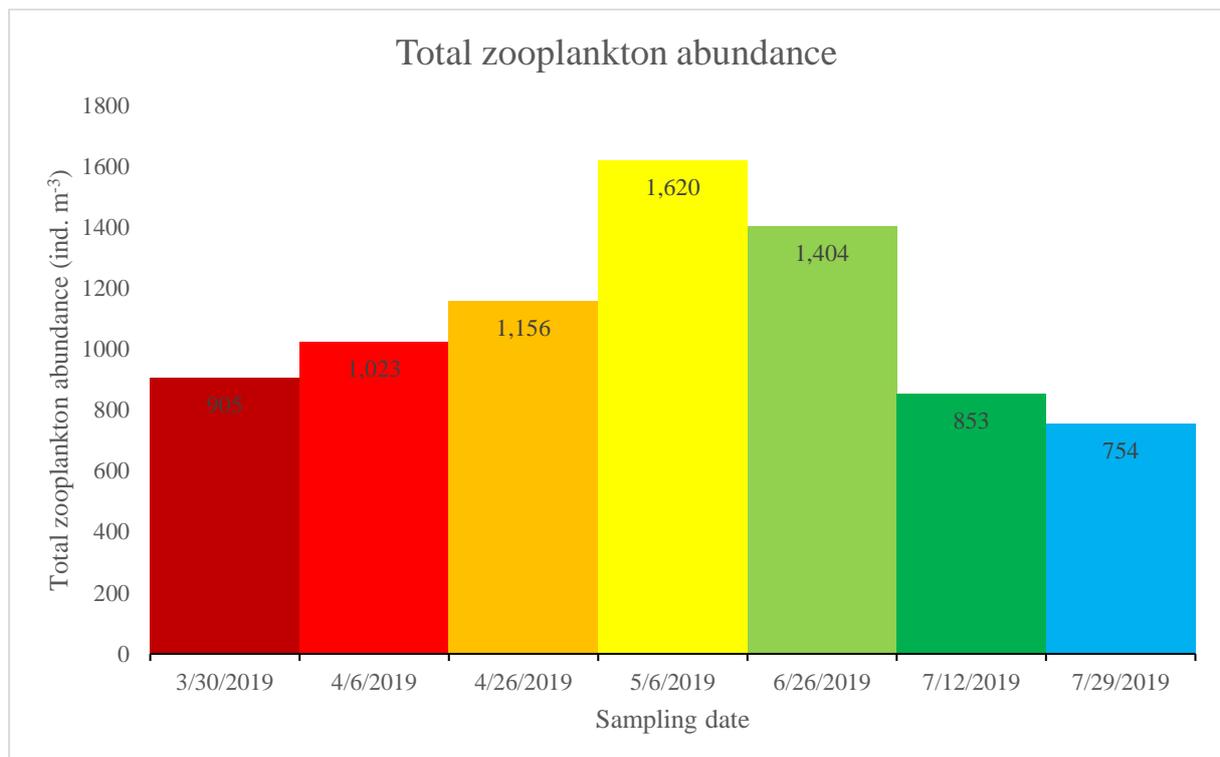


Figure 2 – Total zooplankton abundance (ind. m^{-3}) found between March 30th and July 29th, 2019. Each bar represents a different sampling date and total zooplankton abundance is written at the top of each bar.

Holoplankton vs. meroplankton

Holoplankton constituted most of the zooplankton in each sample (85,6 - 98,8%, Figure 3). 85,6% of the March 30th sample was holoplankton, while meroplankton constituted the remaining 14,4%. The sample from April 6th was also dominated by holoplankton (89,3%). Holoplankton continued to dominate in the sample from April 26th (92,0%), and peaked on May 6th, both in terms of abundance (1601 ind. m⁻³) and contribution (98,8%). Samples from June and July were continuously dominated by holoplankton, with June 26th, July 12th and July 29th each consisting of 97,9%, 95,1% and 95,5% holoplankton respectively.

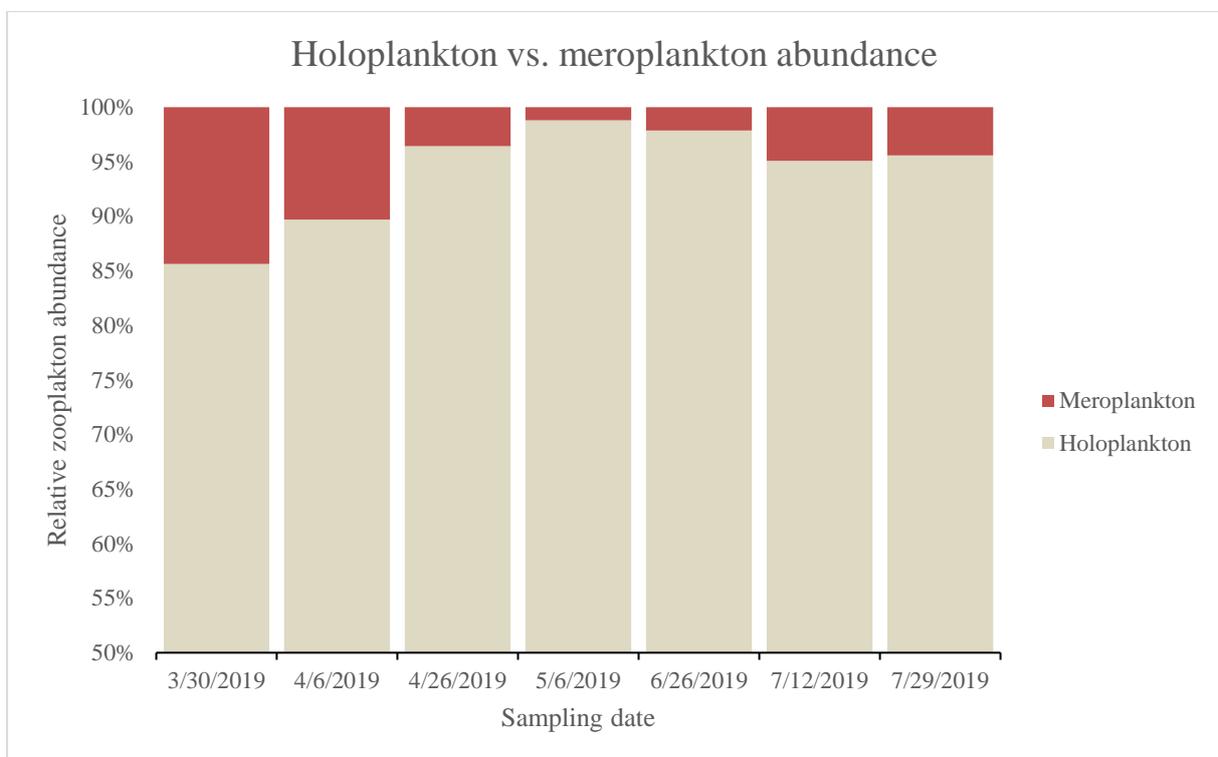


Figure 3 – The relative abundance of holoplankton (cream) and meroplankton (red) in each sample during spring and summer of 2019. Note that the scaling starts at 50% (to make the relative abundance of meroplankton more visible).

Dominant taxa

Copepoda constituted most of the zooplankton found, making up roughly 85 – 96% of the samples (Figure 5). On March 30th Polychaeta made up 11,9% of the sample, while Copepoda made up 85,3%. Gastropoda, Bivalvia and Appendicularia made up the rest of the sample contributing with 0,9%, 1,5% and 0,3% respectively. In the sample from April 6th the number of taxa increased and Copepoda continued to dominate (89,6%). Echinodermata (2,9%) and Cirripedia (2,0%) were found for the first time on this date and Cladocera made up a small part of the sample contributing 0,1%. Finally, Polychaeta (1,95%), Gastropoda (1,7%) and Bivalvia (1,9%) also contributed to the April 6th sample. Chaetognatha was first found on April 26th and constituted only 0,09% of the sample. Polychaeta (0,9%), Echinodermata (0,4%), Gastropoda (0,3%) and Bivalvia (0,4%) were also present in the sample in lesser amounts. Except for Copepoda which made up most of the sample (96,4%), Cirripedia contributed the most to the April 26th sample making up 1,9%. On May 6th, the abundance of Cladocera was 127 ind. m⁻³ which constituted 7,8% of the sample. Cirripedia (0,6%), Polychaeta (0,4%), Gastropoda (0,1%) and Echinodermata (0,1%) were present in the sample in small amounts, while Copepoda continued to dominate (91%). On June 26th, Copepoda constituted 95,9%, with Cladocera being the second highest contributor (1,9%). The rest of the taxa found, Polychaeta (0,8%), Bivalvia (0,5%), Gastropoda (0,4%), Bryozoa (Cyphonautes larvae 0,4%) and Cirripedia (0,1%) all constituted little to the sample. Both samples from July were heavily dominated by Copepoda, making up 89,6% and 93,7% on July 12th and July 29th, respectively. Polychaeta and Cladocera were present in both samples but were more prevalent in the July 12th sample (3,4% and 5,4%) than in the July 29th sample (0,8% and 1,7%). Cirripedia and Gastropoda were also found on both dates, with Cirripedia only making up 0,4% and 0,1% on each respective date, while Gastropoda constituted 0,6% and 2,8%. Bryozoa, Decapoda and Phoronida showed up in the July 12th sample, with their respective percentages being 0,2%, 0,1% and 0,4%. Finally, Bivalvia was found on July 29th and constituted 0,7% of the sample.

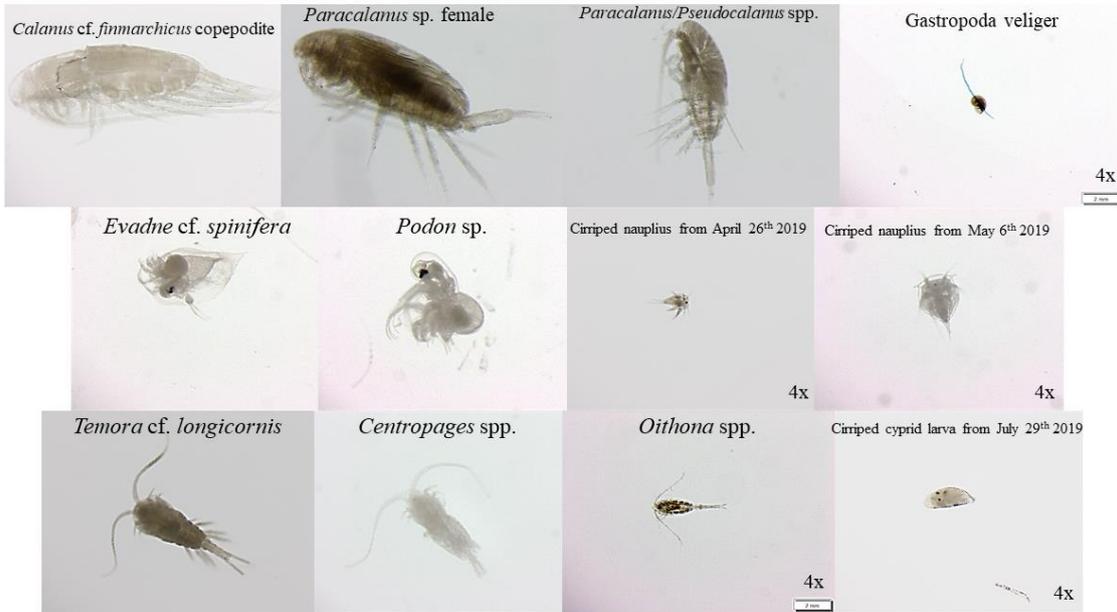


Figure 4 – Some of the taxa identified by microscopy at the MFS station between March 30th and July 29th, 2019. Photos are taken using an Olympus SC50 camera.

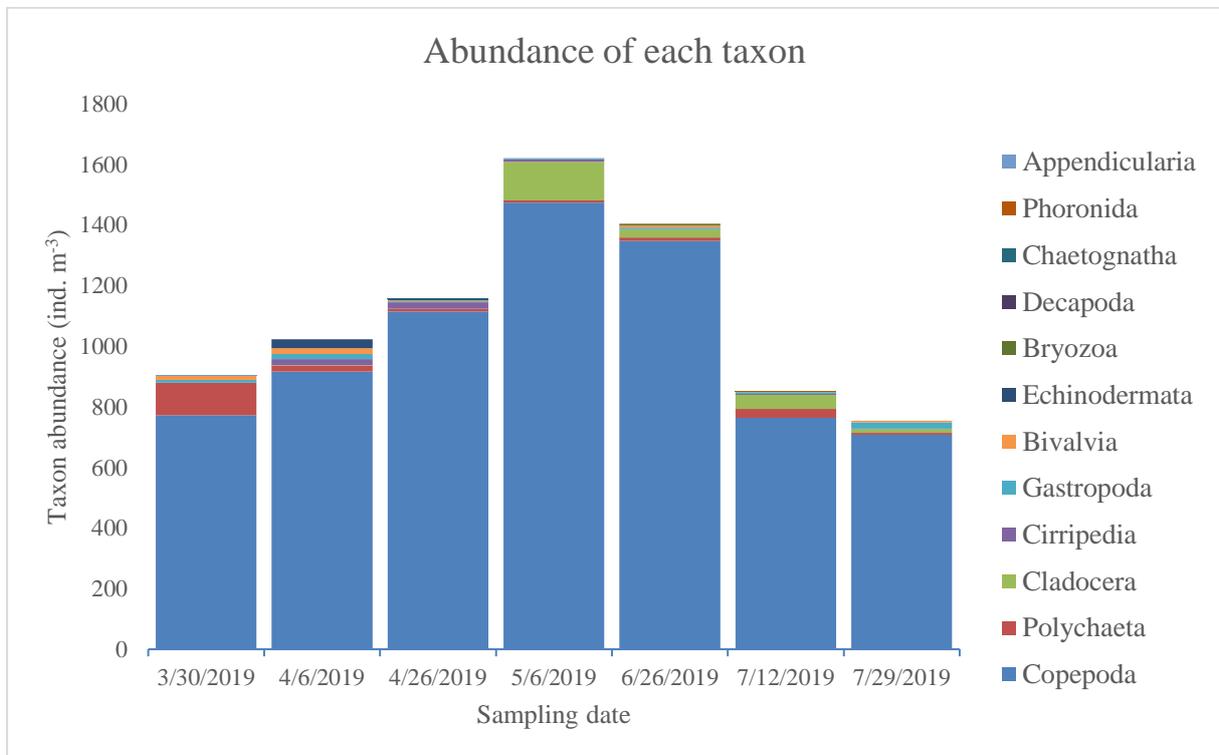


Figure 5 – Abundance (ind. m⁻³) of every major taxon identified in samples from MFS in spring and summer of 2019. Each major taxon is represented by a different color.

Copepod order abundance

All three copepod orders contributed relatively equal amounts to the late March sample, where Calanoida constituted 37,8% and Cyclopoida and Harpacticoida 31,6% and 30,7%, respectively (Figure 6). Cyclopoida dominated the samples from April and May and had their peak abundance on June 26th with 411 ind. m⁻³. Harpacticoida abundance ranged from 5,65 ind. m⁻³ in late July to 178,8 ind. m⁻³ on May 6th. Calanoida dominated in both samples from July and their abundance ranged between 84,9 – 376,9 ind. m⁻³ throughout the sampling period.

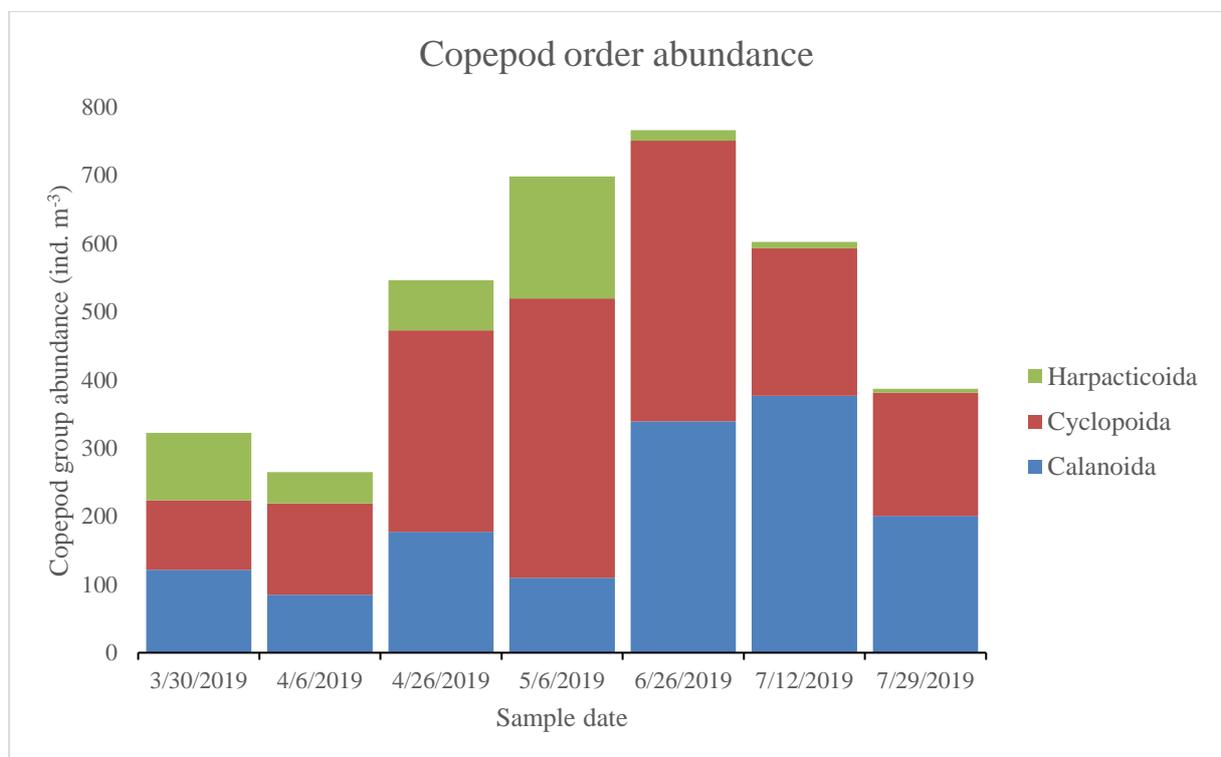


Figure 6 – Abundance (ind. m⁻³) of the three main copepod orders in the 2019 spring and summer samples. Calanoida (blue), Cyclopoida (red), and Harpacticoida (green) are presented in different colors.

Abundance of calanoid copepods

The Para/Pseudocalanus cop group was the most abundant of the Calanoida and constituted between 56,5 – 78,7% with a peak abundance on July 12th with 273 ind. m⁻³ (Figure 7). *Acartia* spp. abundance ranged from 5,66 – 95,0 ind. m⁻³ with peak abundance found in late June. *Acartia* spp. consisted mainly of copepodites and most of the adults were female, except for on June 12th when more males were found. *Temora* cf. *longicornis* were found on all dates

with abundance ranging from 4,5 – 19,8 ind. m⁻³. Between the adult sexes, females usually had a higher abundance peaking on June 26th (13,58 female ind. m⁻³). *Pseudocalanus* cf. *elongatus* and *Paracalanus* sp. consisted of adults and occurred in all samples, except for *Paracalanus* sp. which did not occur in the March 30th and April 6th samples. Females were identified more often than males in both groups. Relatively low abundance was seen in spring samples, while summer samples contained the highest abundance found in both groups: 13,58 ind. m⁻³ for *Paracalanus* sp. and 22,07 ind. m⁻³ for *Pseudocalanus* cf. *elongatus*. *Calanus* cf. *finmarchicus* was only found in the summer samples of June and July in very low numbers. All individuals were identified as copepodites and abundance ranged from 1,7 – 7,9 ind. m⁻³. *Centropages* spp. occurred in the sample from March 30th and in all three summer samples, although in low numbers.

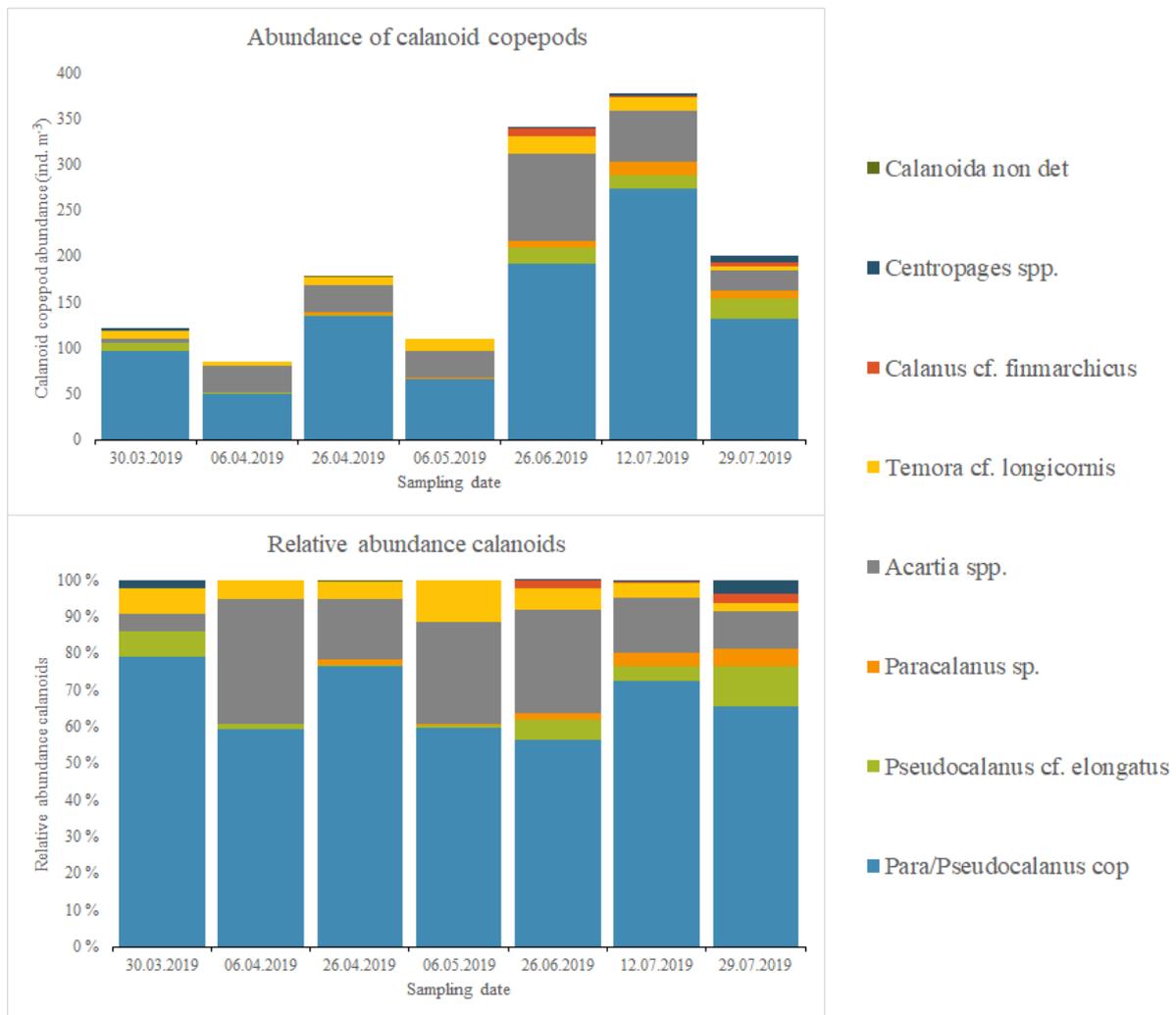


Figure 7 – Abundance (ind. m⁻³; top) and relative abundance (bottom) of calanoid copepods in March – July 2019 at MFS station. The different taxa are represented in different colors (right side).

Abundance of cyclopoid copepods

Oithona cf. similis and *Oithona cf. nana* as well as *Oithona* spp. copepodites were the most abundant groups among the cyclopoids (Figure 8). *Oithona cf. nana* was present in all samples and dominated in the late March sample and on May 6th. On May 6th, they also reached their peak abundance (227,5 ind. m⁻³) with adult females and copepodites contributing the most. *Oithona cf. similis* was mostly found as copepodites and as adult females. Abundances ranged from about 59 – 158 ind. m⁻³ and peaked on June 26th. Copepodites of *Oithona* spp. ranged from 34 – 190 ind. m⁻³ and were found in all samples except on March 30th. A small number of *Corycaeus anglicus* was found in each sample except July 29th where *Corycaeus* sp. were found.

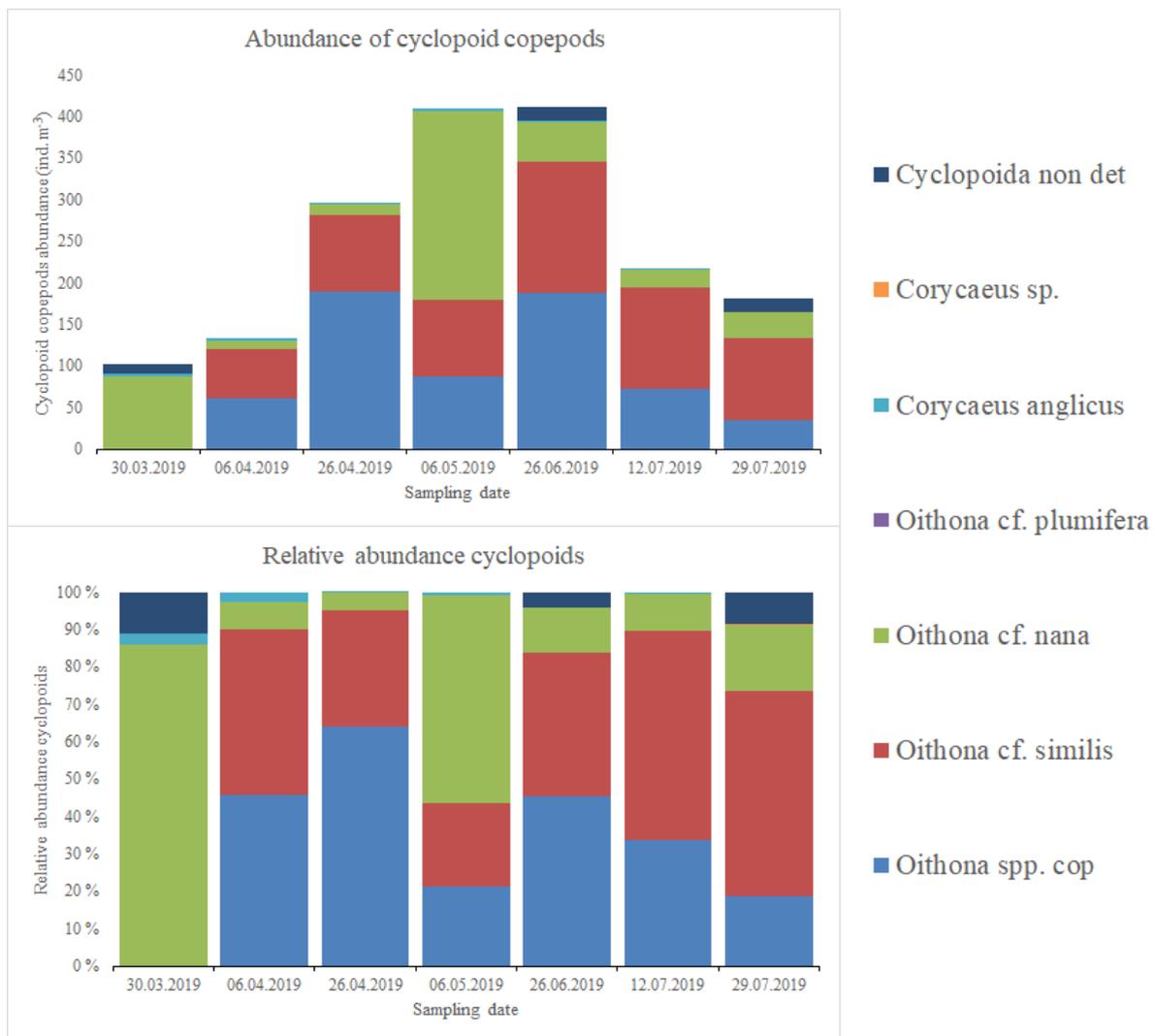


Figure 8 – Abundance (ind. m⁻³; top) and relative abundance (bottom) of cyclopoid copepods in March – July 2019 at MFS station. The different taxa are represented in different colors (right side).

Abundance of harpacticoid copepods

Harpacticoids consisted mainly of *Microsetella* spp. which were most abundant on May 6th (136,4 ind. m⁻³, Figure 9). In the samples from June and July very low numbers of harpacticoids were found, among which was one individual of the genus cf. *Parathalestris* on July 29th. Furthermore, there was one single finding of a specimen of the genus *Tisbe* on April 6th.

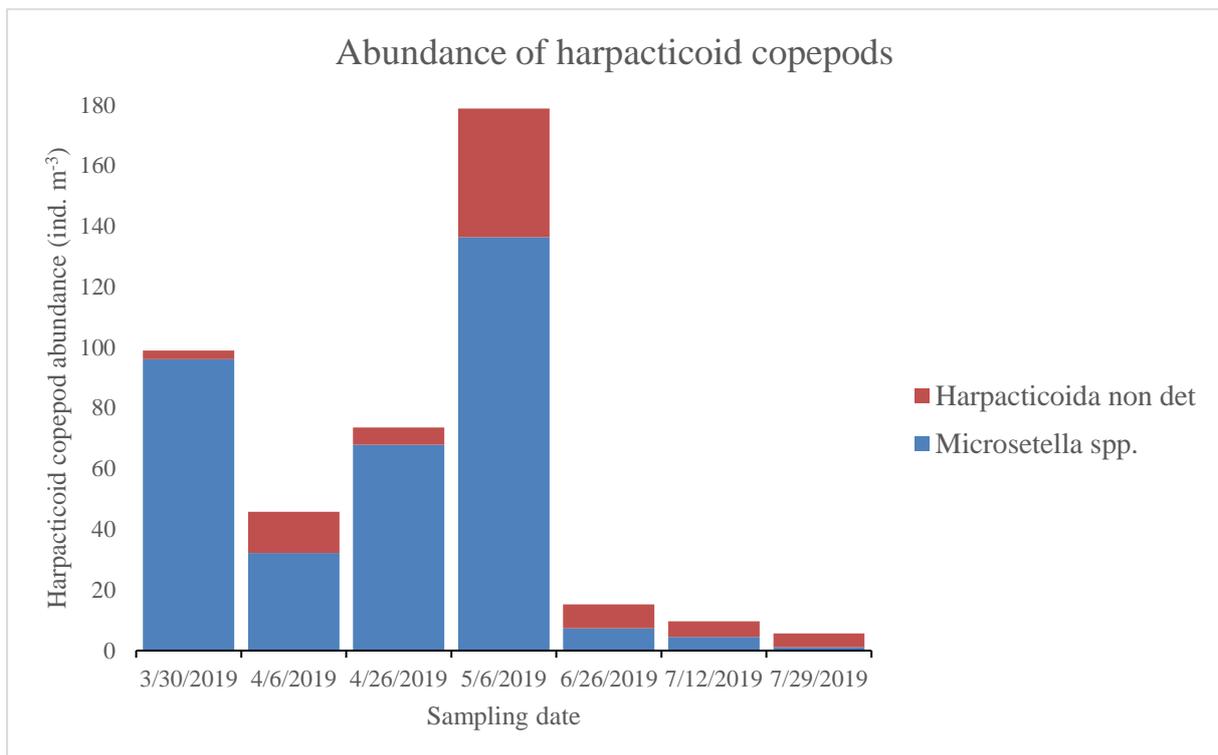


Figure 9 – Abundance (ind. m⁻³) of harpacticoid copepods in March – July 2019 at MFS station. *Microsetella* spp. is represented in blue, *Tisbe* and cf. *Parathalestris* were found in very low abundance and are included the group Harpacticoida non det (red).

Abundance of copepod life stages

Copepod nauplii abundance varied from 161 ind. m⁻³ to 775 ind. m⁻³ throughout the sampling period, with lowest abundance on July 12th and highest on May 6th (Figure 10). Copepodite abundance was low on March 30th (178 ind. m⁻³) and highest in the June 26th sample (635 ind. m⁻³). Adult copepods consisted of adult cyclopoid and calanoid copepods, with most of them being female. Peak abundance of adult copepods was found on June 26th (119 ind. m⁻³) and the lowest amount was found on March 30th (45 ind. m⁻³). Adult and copepodite harpacticoids were of low abundance and not included in the figure.

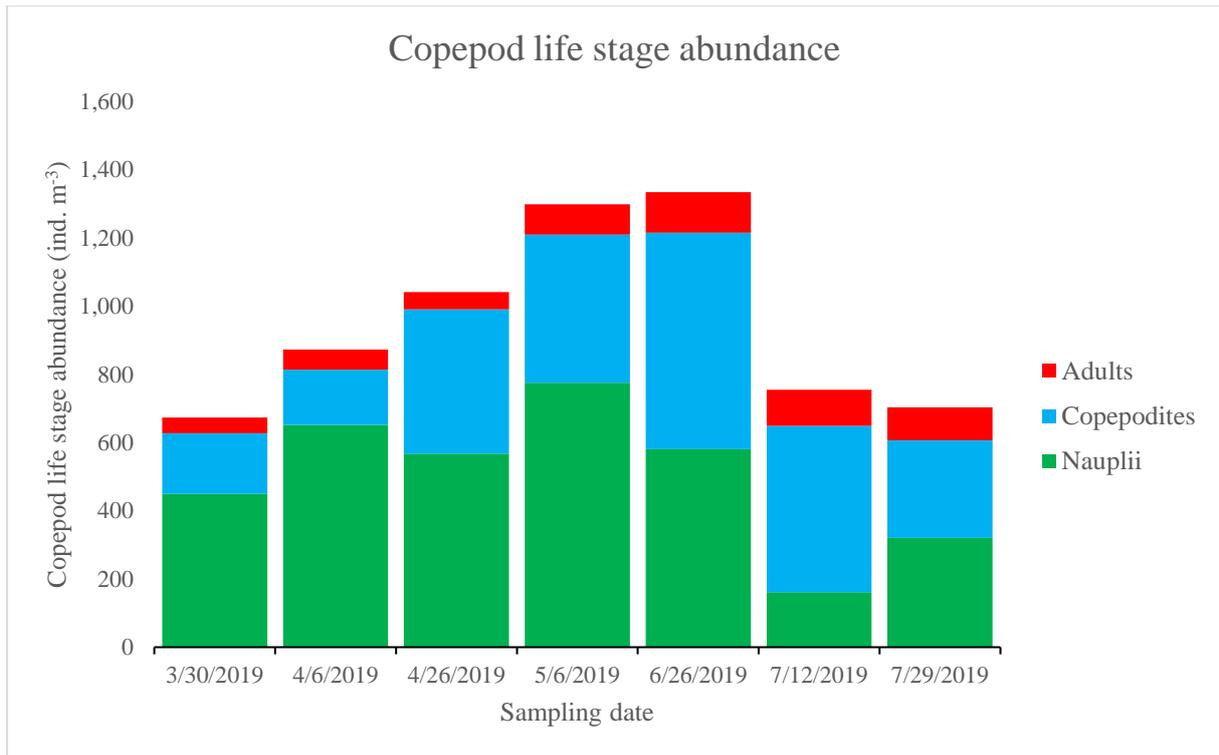


Figure 10 – Abundance (ind. m⁻³) of different copepod life stages identified from the MFS station in March – July 2019. Different stages are shown in by different colors, nauplii (green), copepodites (light blue), and adults (red).

Abundance of meroplankton taxa

Polychaeta occurred most consistently among the meroplankton and constituted roughly 18 – 83% (Figure 11). Cirripedia first occurred April 6th and were a relatively substantial part of the meroplankton in April and May. In June and July Cirripedia were found in lower amounts, with abundance ranging from 0,57 – 3,40 ind. m⁻³ and on July 29th no cirriped nauplii were found, only cirriped cyprid larvae (Figure 4). Gastropoda and Bivalvia were found in all samples except for Bivalvia on two occasions (May 6th, and July 12th). Gastropoda peak abundance was on July 29th (20,9 ind. m⁻³), while Bivalvia had a peak abundance on April 6th with 18,7 ind. m⁻³. Echinodermata peak abundance was on April 6th (30 ind. m⁻³) which constituted 28,6% of the sample. Phoronida and Decapoda were found only on July 12th, Phoronida with an abundance of 2,8 ind. m⁻³, while only a single decapod zoea larva was found. Bryozoa were found in low abundances on June 26th (5 ind. m⁻³) and July 12th (1,7 ind. m⁻³).

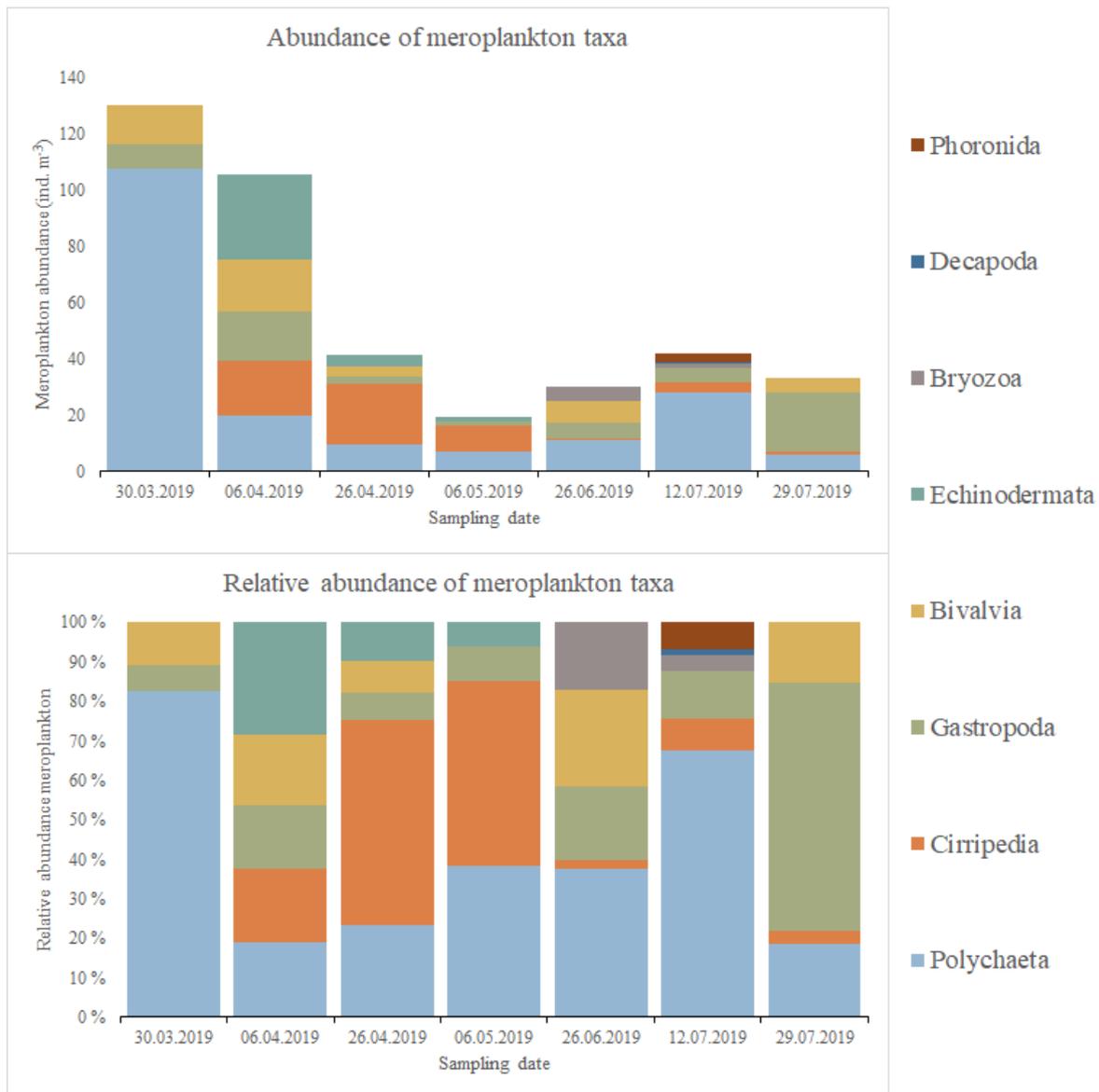


Figure 11 – Abundance (ind. m⁻³; top) and relative abundance (bottom) of meroplankton in March – July 2019 at MFS station. The different taxa are represented in different colors (right side).

Sample comparisons

Results from the cluster analysis indicated that there were three main sample groups (Figure 12). The first group was in early spring (March 30th), another group was found containing the April and May samples, and the last group consisted of the summer samples (June – July). With a Cophenetic Correlation Coefficient of 0,88, the clustering can be considered as a good fit.

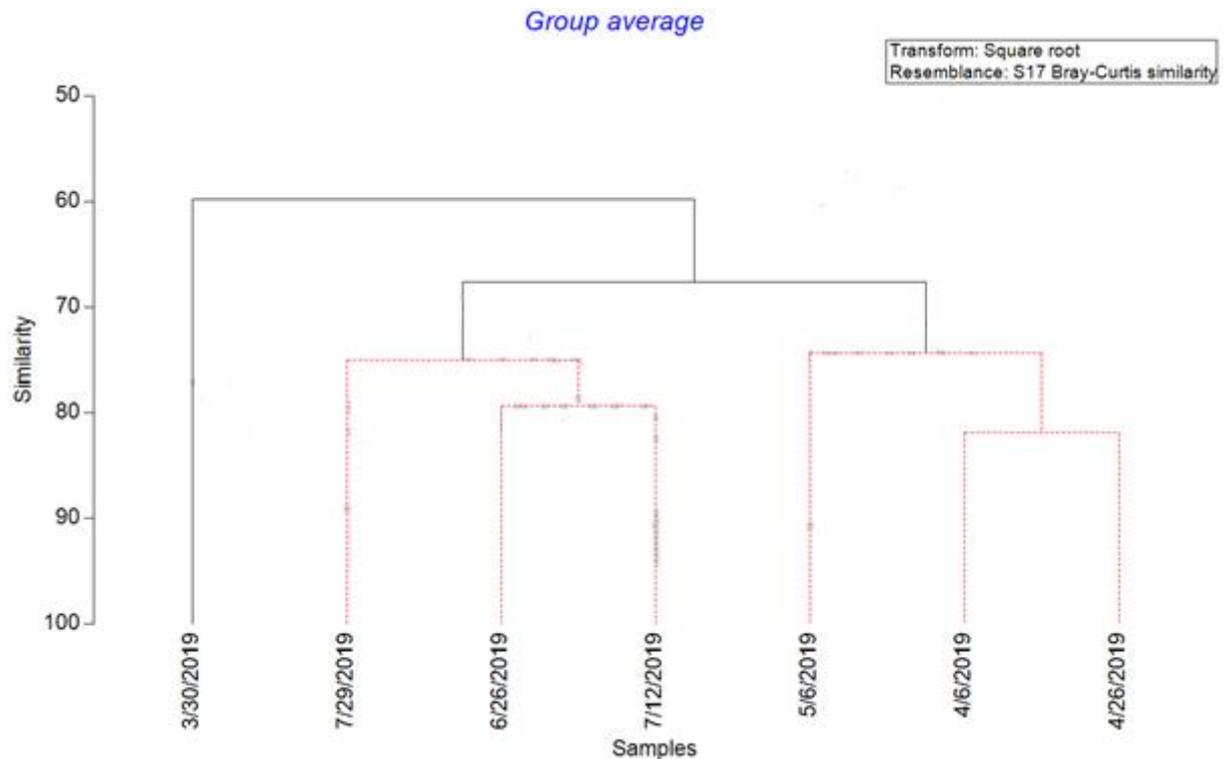


Figure 12 – Dendrogram showing the result from cluster analysis between samples based on Bray-Curtis similarities. The similarity scale is shown on the left, scaling from 50 – 100, indicating how similar samples are. There were three main groups of samples: early spring (late March sample), mid-to late spring (April – May) and summer (June – July). Black lines indicate divisions with statistical support, whereas red lines indicate sub-structures with no statistical support.

Environmental data

From early April a distinct bloom transpired, whereas throughout May slightly increased values in fluorescence can be seen and in July a deeper bloom at about 20 m occurred (Figure 13c). Haloclines were formed in the upper-most water layers throughout the sampling period, while deeper haloclines occurred in April and June (Figure 13b). The water temperature started to increase in the upper water layers in June (Figure 13a), and an additional halocline can be seen in June. In July the water temperature reached maximum values, while the deeper haloclines became less distinct.

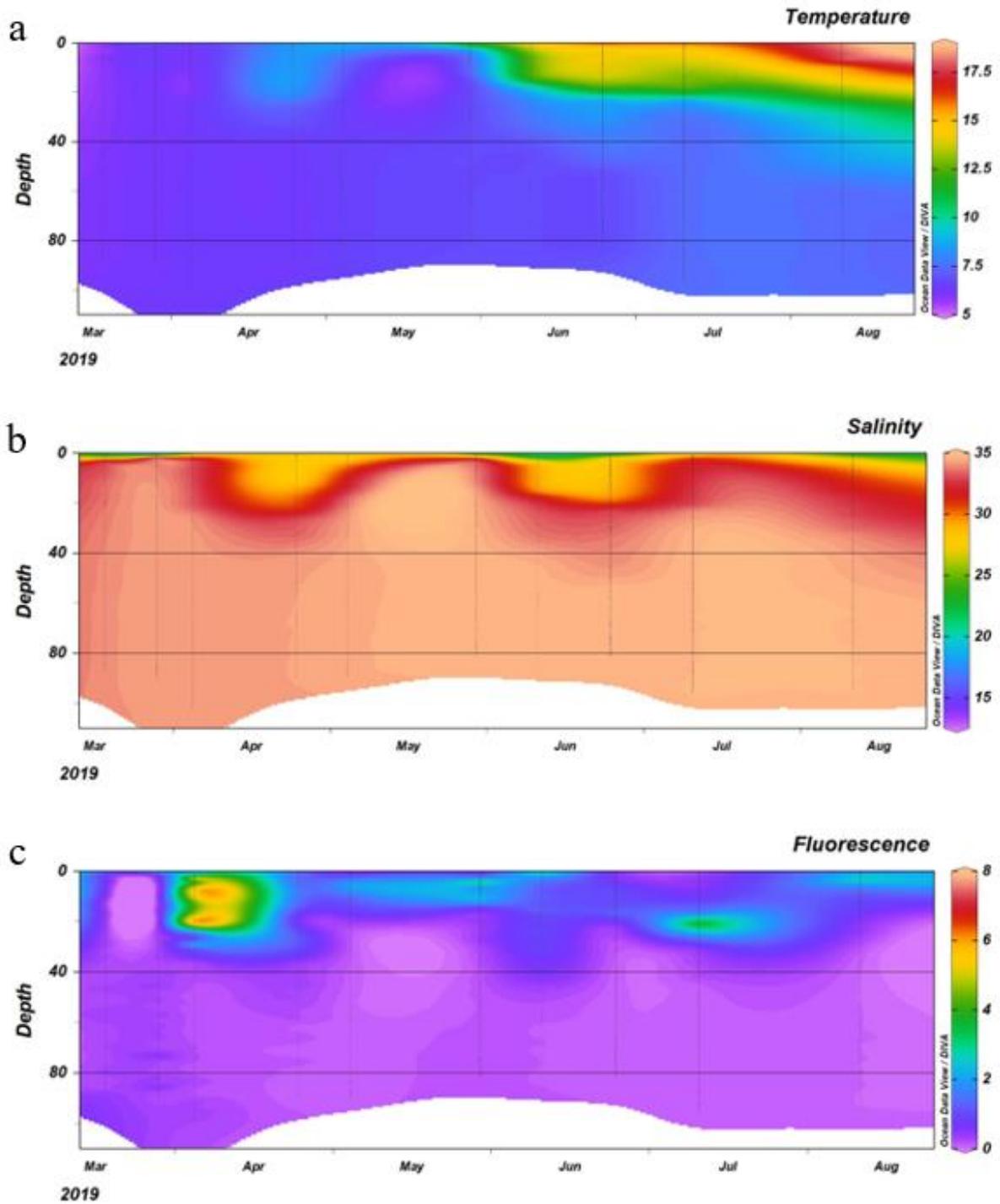


Figure 13 – Visualization of the vertical profiles of temperature (a), salinity (b), and fluorescence (c) obtained from the CTD profiler. Depth (y axis) is measured in meter. Color scales (right side) indicate the level of each measurement (temperature, salinity or fluorescence). Horizontal lines are present for 40 m and 80 m depth, and vertical lines indicate when CTD profiles were taken.

5 Discussion

Copepods comprised between 85 – 96% of total zooplankton in spring and summer samples from 2019 at the MFS station (Figure 5). They are the most abundant group of zooplankton found in both the North Sea (Johns & Reid, 2001; Williams et al., 1994) and in Skagerrak (Kiørboe & Nielsen, 1994). Furthermore, in Skagerrak, a diatom bloom occur in March – April, a dinoflagellate bloom in August – September, and a mixed dinoflagellate-diatom bloom in November – December. All these blooms are dominated by small-sized food particles and help sustaining the copepod abundances in Skagerrak (Kiørboe & Nielsen, 1994). In June and July, during the period between blooms, the food particles are larger and egg production by copepods is low, however, total copepod biomass is at maximum in June – July in Skagerrak (Kiørboe & Nielsen, 1994). *Paracalanus/Pseudocalanus* spp. and *Oithona* spp. abundances in southern Norway have drastically dropped since 2002, however, they still remain the two most dominant copepod taxa in Skagerrak, southern Norway (Johannessen et al., 2012), as observed in spring and summer of 2019 at the MFS station.

The sample similarities indicated three distinct clusters of zooplankton communities relating to phytoplankton blooms; 1) early spring (late March sample) corresponded to the pre-bloom phase and showed similar abundances of all copepod orders as well as the highest meroplankton abundances, 2) spring (April – May) which corresponded to the bloom- late phytoplankton bloom and late-bloom phase and Cyclopoida dominated among the copepods, *Acartia* spp. and *Paracalanus/Pseudocalanus* spp. copepodites dominated among calanoid copepods and Cirripedia and Echinodermata dominated the meroplankton community, and 3) summer (June – July) with generally low phytoplankton biomass and Calanoid copepods were much more important, particularly *Paracalanus/Pseudocalanus* spp. copepodites, *Acartia* spp. and *Pseudocalanus* cf. *elongatus*. During summer harpacticoid copepods were found in very low abundances and the meroplankton community was mainly consisted of Polychaeta and Gastropoda.

Holoplankton

Calanoid copepods

The dominance of the calanoid copepods *Paracalanus/Pseudocalanus* spp., *Acartia* spp. and *Temora* cf. *longicornis* at the MFS station in South Norway corresponds to findings from the northern North Sea (Johns & Reid, 2001). Among the adult *Paracalanus* sp., females were more common, which is also observed in other *Paracalanus* populations where females constitute 66 – 99% of total adult abundance (Jang et al., 2013). *Pseudocalanus elongatus* is known to reach maximum egg production rate at the start of June in the northern North Sea (Drif et al., 2010), making it plausible that *Pseudocalanus* copepodites make up a substantial portion of the *Paracalanus/Pseudocalanus* spp. copepodites in June and July as this group had an increase in abundance after the sample from May.

Copepodites of *Calanus* cf. *finmarchicus* were found only in the summer samples in very low abundance (Figure 7). *Calanus* spp. are usually more abundant in open waters and get carried into fjords by inflow of surface water (Lindahl & Hernroth, 1988) In Gullmarfjorden, Sweden, variable numbers of *Calanus* spp. were transported into the fjord where they descended into deeper water, however, in winter or spring little to no *Calanus* spp. could be found due to them being washed out over the sill by the annual renewal of deep water (Lindahl & Hernroth, 1988). Across the fjord transect in Sandsfjorden, southwestern Norway, *Calanus* spp. decreased in abundance towards the innermost part of the fjord decreasing tenfold in the integrated biomass (Nielsen & Andersen, 2002). Adult and pre-adult *Calanus finmarchicus* overwinter in the Norwegian Trench (Heath et al., 2004) and are found in highest numbers in the Norwegian Sea around mid-May during outburst of nauplii, however, young copepodites can be observed as early as mid-April (Hirche et al., 2001).

During unfavorable conditions *Acartia* spp. can produce resting eggs (Belmonte, 1997; Uye, 1985) which may sink and be stored in the sediments before hatching when conditions are favorable (Marcus et al., 1994). Furthermore, resting eggs are important as they help maintain endemic copepod populations against strong flushing of copepods (Uye, 1980). Growth in *Acartia* spp. is isochronal (Miller et al., 1977), however, the development time of *Acartia* spp. life stages are affected by temperature (Landry, 1975). *Acartia* spp. are well adapted hunters capable of utilizing multiple prey and hunting strategies (Gismervik & Andersen, 1997; Saiz & Kiørboe, 1995). Additionally, *Acartia tonsa* is efficient in transforming food into eggs and can rapidly adapt to a changing diet and breed despite a low abundance of potential prey (Kiørboe et al., 1985).

The contribution to *Temora* cf. *longicornis* by adults and copepodites at MFS differed in spring and summer. Copepodites were the main source of contribution during the spring months (March – May), while adults, mainly females, made up most of the taxon in summer (June – July). These results are in accordance with findings from the Baltic Sea where copepodites reach high abundance in May before adults start to dominate in summer with highest abundance in the June – July shift (Dutz et al., 2010). Development time of *T. longicornis* is shorter in spring than in summer when the development of nauplii and copepodite may be 27 – 43, days and it is suggested that the increased development time is due to a smaller food supply in summer (Bakker & van Rijswijk, 1987). While samples taken at MFS include individuals from the entire water column, *T. longicornis* in Sandsfjorden, Norway, accumulated in the pycnocline and an increase in biomass was found along the transect towards the mouth of the fjord (Nielsen & Andersen, 2002). This suggests that the species could be more common further out from the MFS sampling station.

Low numbers of *Centropages* spp. were found with *Centropages hamatus* and copepodites of *Centropages* cf. *typicus* being identified. Both species can be found around the southern coast of Norway (Barnard et al., 2004) and the low numbers may be explained as peak abundance of *C. typicus* in the North Sea occur in mid-September (Lindley & Reid, 2002).

Cyclopoid copepods

In the North Sea, *Oithona similis* make up the majority of *Oithona* spp. biomass (Nielsen & Sabatini, 1996). *Oithona* spp. were the most common cyclopoid copepods (minimum 86% in all samples) in samples from MFS from 2019, which is in line with other studies from the northern North Sea (Johns & Reid, 2001). The seasonal variation in abundance of copepodite and adult *Oithona* cf. *nana* found at MFS was similar to other reports of the species (Temperoni et al., 2011), where copepodites on average represent most of *O. nana* abundance, followed by adult females throughout the season. *Oithona* cf. *nana* at MFS station was found most abundant at the end of March and in early May and the CTD data showed relatively similar profiles at those times (Figure 13). In the study by Temperoni et al. (2011) the abundances of *O. nana* were not significantly related to temperature or Chl a, and all life stages of *O. nana* were present year-round, whereas in Kattegat, egg production by *Oithona* spp., and hence later abundances of copepodites and adults, appear to be limited by food (Kiørboe & Nielsen, 1994).

Oithona spp. has been found to spend much of its time motionless in the water column capable of feeding on a wide size range of prey organisms (Lampitt & Gamble, 1982). Additionally, adults of *O. nana* may utilize a carnivorous feeding behavior preying on copepod nauplii (Lampitt, 1978). *Oithona* cf. *similis* was among the most abundant of the *Oithona* taxa found at MFS (Figure 7). This ambush feeding species is capable of reacting to hydromechanical signals produced by prey (Svensen & Kiørboe, 2000). Studies show that *O. similis* primarily selects for ciliates while other forms of food become important when ciliate abundance is low (Castellani et al., 2005; Zamora-Terol et al., 2013). Additional results from Zamora-Terol et al. (2013) show that *O. similis* on the west coast of Greenland actively feeds during winter and can successfully reproduce in winter, suggesting that these occurrences of *Oithona* spp. succeeding even under unfavorable conditions might explain the genus' success in marine environments worldwide. Furthermore, *Oithona* spp. being able to live off small-sized food particles makes for an advantage and allow populations to remain stable (Nielsen & Sabatini, 1996).

Harpacticoid copepods

Microsetella spp. was the most common of the harpacticoid copepods at the MFS station in 2019 and was found most abundant in early May (Figure 9). In a fjord system in southwestern Norway, *Microsetella norvegica* was found to be among the most abundant copepods in July and having the third highest biomass of all copepods found (Andersen & Nielsen, 2002). These findings are very different from the results in this study as *Microsetella* spp. was found in very low abundance in samples from July. As previously stated, samples used in this study looked at individuals collected from the entire water column. Further results from Andersen and Nielsen (2002) saw *M. norvegica* to be evenly distributed in the photic zone and having highest biomass below the pycnocline. The vertical distribution of *M. norvegica* in the waters of Skagerrak and North Sea also show that the species accumulates within or just below the pycnocline (Maar et al., 2006). Additionally, *M. norvegica* seems to avoid turbulent water layers levels near the surface by actively migrating down in the water column (Maar et al., 2006), where the authors assume *M. norvegica* may rely on remote chemical detection for food. *M. norvegica* in the Inland Sea of Japan are thought to mainly feed on nano-sized particles that range from 2 – 20 μm (Uye et al., 2002).

Results from a 5-year study from Greenland show *M. norvegica* constituting over 93% of total copepod abundance in July and August, clearly defining the summer months as the

period of maximum abundance for the copepods (Arendt et al., 2013). The same study observed *M. norvegica* dominate among the mesozooplankton during most of the year making up over 50% of total copepod abundance from July through December. Similar observations of *M. norvegica* dominance have also been seen in the Inland Sea of Japan where the species at some point accounted for 86,5% of the total copepod abundance (Uye et al., 2002). *Microsetella* spp. at MFS was not identified to species or life stage. Hence, no conclusion can be drawn about the relationship between copepodites and adults. In the Inland Sea of Japan, developmental duration of *M. norvegica* from egg to adult varied from 14,3 – 31,9 days depending on the temperature when food was not limited (Uye et al., 2002).

Copepod nauplii

Nauplii found at MFS station in 2019 outnumbered older life stages in multiple samples (Figure 10). In the northwest Mediterranean, copepod nauplii also constituted 59% of the total zooplankton abundance, ranging from 40 – 74% (Calbet et al., 2001). Castellani et al. (2007) showed that contribution to biomass by naupliar stages of *Oithona* spp. can be compared to that of copepodite stages. Furthermore, a positive correlation between the relative proportion of *Oithona* spp. nauplii in the population with depth and salinity in spring was seen (Castellani et al., 2007). Copepod nauplii found at the MFS station are most likely nauplii of the most common taxa found. *Pseudocalanus elongatus* peak relative abundance is in February in the Western Channel and has higher relative abundances between April – June, and while the relative abundance of *Oithona* spp. is less fluctuating than other taxa found in the Western Channel, relative abundance is highest in February – May (Eloire et al., 2010). This could suggest that the nauplii found from late March through May at MFS in 2019 primarily belonged to *Oithona* spp. and *Pseudocalanus* spp.. Temperature has been found to influence growth rates in *Oithona* spp. nauplii, where increased temperature reduce time spent in all naupliar stages (Almeda et al., 2010). Even though *Oithona* cf. *nana* was the most common cyclopoid copepod on March 30th and on May 6th at MFS, *Oithona* cf. *similis* dominated in samples from April, suggesting that the nauplii abundances of these two taxa fluctuate in spring at the MFS station.

In the Western Channel, *Temora longicornis* relative abundance is highest throughout the summer months (June - August), whereas *Acartia clausi* has peak relative abundances in June and September, and while *Paracalanus parvus* reaches peak relative abundance in November, they can be found throughout the year (Eloire et al., 2010). Thus, nauplii found at

the MFS station in summer (June and July) likely also belong to the calanoid taxa *Temora* cf. *longicornis*, *Acartia* spp., and *P. parvus*. The duration of the different naupliar stages has been studied in calanoids, and *Pseudocalanus* sp., *A. tonsa* and *P. parvus* have seen their combined naupliar stages last 9,2 days, 9,8 days and about 8 days, respectively (Landry, 1983). Landry (1983) described that the first two naupliar stages (N1 and N2) last for a relatively short duration and feeding by nauplii does not occur until after stage three (N3) is reached, except for in *Acartia* where feeding starts one stage earlier.

Cladocera

P. avirostris is commonly found in the neritic zone of tropical/subtropical waters (Atienza et al., 2008; Marazzo & Valentin, 2003). However, it was identified in a Norwegian fjord in the 1990s (Båmstedt et al., 1998) and seems to be becoming more common in the North Sea due to increased water temperature (Johns et al., 2005), and production of resting eggs (Onbé, 1985). *P. avirostris* occurring at MFS in late July when the temperature reached >16°C (Figure 12a) seems acceptable as during the initial stages of establishment of *P. avirostris* populations, water temperature seemed to influence birth rates (Marazzo & Valentin, 2003). In Catalan Sea, high abundances of *P. avirostris* appear from July through September (Atienza et al., 2008) and the authors argue that resting eggs likely help them reestablish their population annually as they are practically absent in winter and spring.

Evadne spp. and *Podon* sp. were the two most common cladocerans found at the MFS station, both are common in North Sea and other waters tied to the MFS station and may occur in high numbers under favorable conditions (Eriksson, 1974). The two genera were not present in early April, but were instead found in high abundances in May, becoming less common in June and July. *Evadne nordmanni* have previously been reported as being the most common species of Cladocera in Clyde Sea where they became most abundant in August, while *Podon* spp. reached maximum abundance in September (Cheng, 1947). Results on seasonal occurrence of Cladocera at the MFS station in 2019 are in agreement with findings from the coastal station outside of Plymouth, as *E. nordmanni* were more abundant than *Podon* spp., and both genera were most abundant in May (Eloire et al., 2010).

Meroplankton

Meroplankton were found in all spring and summer samples, although in low abundance compared to holoplankton, and never exceeded 130 ind. m⁻³. Meroplankton abundances in other systems have reached much higher numbers (Arendt et al., 2013; Silberberger et al., 2016; Van Ginderdeuren et al., 2014), and even surpassed holoplankton in terms of both abundance and in biomass during the productive season (Stübner et al., 2016). Time series from the western English Channel see meroplankton abundance peak in March and April, coinciding with the increased water temperature (Highfield et al., 2010).

Cirripedia being among the most dominant groups of meroplankton at MFS is not surprising as Cirripedia have been known to constitute the majority in samples during spring (Michelsen et al., 2017a; Silberberger et al., 2016; Stübner et al., 2016). Increased levels of fluorescence were seen in the beginning of April (Figure 13c), indicating that the spring bloom started in early April. Cirriped larvae were first seen in the sample from April 6th which fits well as edible phytoplankton is known to stimulate the release of cirriped nauplii (Starr et al., 1991). Little is known about which species of barnacles inhabit the surrounding area of MFS and cirriped larvae were not identified to species level. Although cirriped larvae were first found in early April, cirriped nauplii peak abundance was observed in late April. A second peak in Cirripedia abundance has previously been seen in a high-Arctic fjord, which most likely was due to another species releasing their larvae (Stübner et al., 2016). In late July cyprid larvae were found, however, no nauplii occurred in the sample. In northern temperate waters, cyprid larvae of the barnacle *Balanus balanoides* settle over a short period in spring, mainly April, and while cyprid larvae can be found in March, they are most abundant in April (Pyefinch, 1948). Cyprid larvae of *Balanus crenatus* have been shown to also occur in March and April, however, these larvae are thought to settle periodically between April and September (Pyefinch, 1948).

Polychaeta were found in all samples and had highest abundances in late March and in mid-July, with polychaete larvae of the order Spionida constituting most of the Polychaeta found at MFS station. A seasonal study on the spionid polychaete *Pygospio elegans* in Scotland showed that heavy recruitment takes place twice a year, once during May and the second time during December (Bolam, 2004), however, new recruits could be found year-round. In fjords in northern Norway, polychaete abundances peak primarily around April – May (Michelsen et al., 2017a; Silberberger et al., 2016). These results are also similar to what is seen in high-Arctic fjords (Stübner et al., 2016). Off the coast of Belgium, Polychaeta constituted a higher

portion of the meroplankton in mid- and nearshore samples while being less common offshore (Van Ginderdeuren et al., 2014).

The abundance of echinoderm larvae has increased in the North Sea (Lindley et al., 1995) and has been linked to the increase of sea surface temperatures (SST), particularly during winter and spring (Kirby et al., 2008; Kirby et al., 2007). Echinodermata (pluteus larvae) at MFS were found in samples from April and May but did not occur in any of the summer samples. The seasonality of Echinodermata has been studied in sub-Arctic to high-Arctic systems which lay further north than MFS is located (Michelsen et al., 2017a; Silberberger et al., 2016; Stübner et al., 2016). In these high-altitude systems, echinoderms are usually abundant in May and can also be found in increased abundance during July. Outside of Belgium, different taxa of Echinodermata see their peak abundances at different times, ranging from May – September, and are found more abundant offshore where they can dominate total meroplankton abundance (Van Ginderdeuren et al., 2014). In spring (April) in northern Norway, Echinodermata can occur as one of the dominant taxa and are found most abundant at the inner and outer part of the fjord where meroplankton abundance was lower (Michelsen et al., 2017b). Additional results on the occurrence of Echinodermata in the same fjord show that they constitute the majority of meroplankton in June (Michelsen et al., 2017a).

Gastropoda abundance at MFS during spring and summer closely resembled that of high-Arctic studies, in which the abundance reached around 20 ind. m⁻³ in summer (Stübner et al., 2016). Gastropoda were found in all samples and dominated among the meroplankton in late July. However, on July 29th, total meroplankton abundance was lower than in early April which was when Gastropoda abundance was found second highest. In studies on the seasonality of meroplankton, gastropods dominated during summer in northeastern Black Sea (Selifonova, 2012). Whereas in a sub-Arctic shelf system, gastropods seemingly became more abundant during late summer (Silberberger et al., 2016). Yet, during spring in northern Norway, Gastropoda were one of the dominating taxa at the inner and outer part across a fjord transect (Michelsen et al., 2017b). In other high-altitude systems Gastropoda showed a clear dominance during winter, representing on average 60% of the meroplankton community while only averaging 5% and 11% during spring and summer, respectively (Michelsen et al., 2017a).

Peaks in abundance of bivalve larvae are linked to changes in food availability (Brandner et al., 2017). Bivalvia abundance at MFS peaked in late June, but they were never the dominant taxon in the meroplankton community. This reflects what is seen off the coast of Belgium

where *Bivalvia* are more common nearshore but never quite dominant (Van Ginderdeuren et al., 2014). Svalbard studies show *Bivalvia* heavily dominating the meroplankton, capable of constituting between 81 and 85% of meroplankton in June and July (Brandner et al., 2017; Stübner et al., 2016). Similar observations were made in other high-latitude systems (Silberberger et al., 2016), where *Bivalvia* may represent between 39 – 72% of meroplankton in June and August (Michelsen et al., 2017a). In the northeastern Black Sea, different species of bivalves have been reported to dominate the meroplankton in spring and autumn (Selifonova, 2012). Bivalve veligers in Porsangerfjord were very uncommon in spring (Michelsen et al., 2017b), however, the authors contemplated it was due to the coarse mesh size used, as the use of coarser mesh size when sampling causes abundance loss of small plankton (Riccardi, 2010). The abundance of *Bivalvia* did not exceed 19 ind. m⁻³, despite the use of fine mesh size (60 µm) and sampling of the complete water column. Studies focusing on meroplankton show that the abundance of *Bivalvia* can differ substantially depending on which water layer is sampled (Stübner et al., 2016). An in-depth study on the seasonality of bivalve larvae was conducted in Adventfjorden, Svalbard (Brandner et al., 2017), where the authors successfully combined morphometric identification and DNA barcoding to identify the different bivalve larvae that inhabit the system. At MFS, none of the bivalve larvae were identified to species level, meaning knowledge is limited regarding the species and therefore their individual seasonality. Nevertheless, studies that provide successful in-depth results based on their methods, like Brandner et al. (2017), may prove valuable for future studies which focus on species specific seasonality.

Evaluation of methods

In this study, a fine plankton net mesh size (60 µm) was used to improve the collection of small individuals, as a coarser mesh size has proven to underestimate the abundance of small zooplankton taxa (Calbet et al., 2001; Riccardi, 2010), especially copepod nauplii (Makabe et al., 2012). However, when using a smaller ring diameter and a finer mesh size, larger, strong swimmers may be inaccurately sampled and the filtration efficiency may be lowered (Calbet et al., 2001; Miloslavić et al., 2014). Moreover, the heterogeneity of zooplankton by abiotic and biotic processes (Pinel-Alloul, 1995) is more likely to have affected the results seen in this study, as only one sample was taken on each sampling date and only one sampling station (MFS) was used. Likewise, only one subsample per sampling date could be counted due time constraints. Analysis of several subsamples could have increased the accuracy of the results.

6 Conclusion

Results on zooplankton taxa occurring at the MFS station in spring and summer of 2019 are in agreement with previous studies on mesozooplankton in the North Sea (Johns & Reid, 2001; Williams et al., 1994), and in Skagerrak (Kiørboe & Nielsen, 1994). Furthermore, *Paracalanus/Pseudocalanus* spp. and *Oithona* spp. are known to dominate among the copepods despite heavily reduced abundances in the Norwegian coast of Skagerrak after 2002 (Johannessen et al., 2012), and the same dominant taxa are also found at the MFS station in spring and summer of 2019. Larger zooplankton taxa were found in very low abundances from March 30th 2019 to July 29th 2019, and the use of a fine mesh size plankton net (60 µm) used to collect samples may have caused underestimation of the larger zooplankton (Calbet et al., 2001; Miloslavić et al., 2014). Generally, copepods and copepodites dominate among the mesoplankton (Sieburth et al., 1978). This was also the case at MFS station, whereas meroplankton abundances in spring and summer of 2019 at the MFS station were low compared to abundances of meroplankton from other studies (Silberberger et al., 2016; Stübner et al., 2016; Van Ginderdeuren et al., 2014). Heterogeneity of zooplankton by abiotic and biotic processes (Pinel-Alloul, 1995) causes zooplankton to be unevenly distributed. As only one sample was collected per sampling date and only one subsample was analyzed, results on the seasonal variability of the sampled zooplankton taxa at MFS station in spring and summer 2019 are more prone to uncertainties. Nevertheless, as indicated by the cluster analysis, the zooplankton community could be divided into three distinct groups. The periods of March, April – May and June – July corresponded to the phytoplankton pre-bloom, bloom and post-bloom phase.

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Overview of tables and figures

Figure 1 – Midtfjordsskjær (MFS) sampling station.

Figure 2 – Total zooplankton abundance.

Figure 3 – Holoplankton vs. meroplankton abundance.

Figure 4 – Pictures of some identified taxa.

Figure 5 – Abundance of each taxon.

Figure 6 – Copepod order abundance.

Figure 7 – Abundance of calanoid copepods and relative abundance of calanoids.

Figure 8 – Abundance of cyclopoid copepods and relative abundance of cyclopoids.

Figure 9 – Abundance of harpacticoid copepods.

Figure 10 – Copepod life stage abundance.

Figure 11 – Abundance of meroplankton taxa and relative abundance of meroplankton taxa.

Figure 12 – Cluster analysis between samples.

Figure 13 – Visualization of the vertical profiles of; a) temperature, b) salinity and c) fluorescence obtained from CTD profiler.

Table 1 – Number of counted plankton individuals and sorted individuals taxonomically.

Appendix

Table 1 – Table showing the number of counted plankton individuals (individuals per sample) morphologically identified at Midtfjordsskjær (MFS) sampling site at the different sampling dates in spring and summer 2019. WoRMS – World Register of Marine Species (Horton et al., 2021) was used to sort individuals taxonomically. Empty cells indicate that the taxonomic level was not available for the identified individuals.

Phylum	Class	Subclass	Order	Genus/species	stage	30.03	06.04	26.04	06.05	26.06	12.07	29.07
Arthropoda	Hexanauplia	Copepoda	Calanoida	Acartia spp.	female	0	14	2	2	16	13	14
Arthropoda	Hexanauplia	Copepoda	Calanoida	Acartia spp.	male	0	1	1	1	17	9	4
Arthropoda	Hexanauplia	Copepoda	Calanoida	Acartia spp.	cop	10	36	49	51	135	77	19
Arthropoda	Hexanauplia	Copepoda	Calanoida	Calanus cf. finmarchicus	cop	0	0	0	0	14	3	9
Arthropoda	Hexanauplia	Copepoda	Calanoida	Centropages hamatus	male	0	0	0	0	0	0	3
Arthropoda	Hexanauplia	Copepoda	Calanoida	Centropages cf. typicus	cop	0	0	0	0	1	2	0
Arthropoda	Hexanauplia	Copepoda	Calanoida	Centropages spp.	cop	5	0	0	0	0	1	10
Arthropoda	Hexanauplia	Copepoda	Calanoida	Paracalanus sp.	female	0	0	4	1	7	17	8
Arthropoda	Hexanauplia	Copepoda	Calanoida	Paracalanus sp.	male	0	0	0	0	4	7	8
Arthropoda	Hexanauplia	Copepoda	Calanoida	Pseudocalanus cf. elongatus	female	5	1	2	1	25	21	32
Arthropoda	Hexanauplia	Copepoda	Calanoida	Pseudocalanus cf. elongatus	male	10	1	0	0	7	6	7
Arthropoda	Hexanauplia	Copepoda	Calanoida	Paracalanus/Pseudocalanus	cop	170	89	239	116	339	483	233
Arthropoda	Hexanauplia	Copepoda	Calanoida	Temora cf. longicornis	female	0	1	7	1	24	20	4
Arthropoda	Hexanauplia	Copepoda	Calanoida	Temora cf. longicornis	male	0	6	1	0	3	4	2
Arthropoda	Hexanauplia	Copepoda	Calanoida	Temora cf. longicornis	cop	15	1	7	21	8	3	2
Arthropoda	Hexanauplia	Copepoda	Calanoida	non det	cop	0	0	1	0	0	0	0
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Corycaeus anglicus	female	0	0	0	0	0	1	0

Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Corycaeus anglicus	adult	0	2	0	0	0	0	0
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Corycaeus anglicus	cop	5	4	1	6	1	1	0
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Corycaeus sp.	adult	0	0	0	0	0	0	1
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona cf. nana	female	65	5	4	80	2	3	8
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona cf. nana	male	0	8	1	20	2	3	12
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona cf. nana	cop	90	5	19	302	82	31	35
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona cf. plumifera	female	0	0	0	0	0	0	1
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona cf. similis	female	0	62	66	50	95	74	61
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona cf. similis	male	0	4	2	1	8	8	5
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona cf. similis	cop	0	39	94	112	176	133	109
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	Oithona spp.	cop	0	108	335	153	331	128	60
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	non det	male	0	0	0	0	0	0	1
Arthropoda	Hexanauplia	Copepoda	Cyclopoida	non det	cop	20	0	0	0	30	0	26
Arthropoda	Hexanauplia	Copepoda	Harpacticoida	Microsetella spp.	adult/ cop mix	170	57	120	241	13	8	2
Arthropoda	Hexanauplia	Copepoda	Harpacticoida	cf. Parathalestris	adult/cop mix	0	0	0	0	0	0	1
Arthropoda	Hexanauplia	Copepoda	Harpacticoida	Tisbe sp.	adult/cop mix	0	1	0	0	0	0	0
Arthropoda	Hexanauplia	Copepoda	Harpacticoida	non det	adult/cop mix	5	19	8	67	9	8	3
Arthropoda	Hexanauplia	Copepoda	Harpacticoida	non det	cop	0	4	2	8	5	1	4
Arthropoda	Hexanauplia	Copepoda	Harpacticoida		nauplii	45	0	0	0	0	0	0
Arthropoda	Hexanauplia	Copepoda			nauplii	750	1152	1004	1370	1027	285	566
Arthropoda	Branchiopoda		Cladocera	Evadne spp.	adult	0	1	0	201	32	68	7
Arthropoda	Branchiopoda		Cladocera	Penilia avirostris	adult	0	0	0	0	0	0	9
Arthropoda	Branchiopoda		Cladocera	Podon sp.	adult	0	1	0	24	15	14	7
Arthropoda	Malacostraca	Eumalacostraca	Decapoda		brachyuran zoea larvae	0	0	0	0	0	1	0
Arthropoda	Thecostraca	Cirripedia			nauplii	0	35	38	16	1	6	0

Arthropoda	Thecostraca	Cirripedia			cyprid larvae	0	0	0	0	0	0	2
Annelida	Polychaeta	Errantia	Phyllodocida	Harmothoe	larvae	0	1	0	0	0	0	0
Annelida	Polychaeta	Errantia	Phyllodocida	Tomopteris	adult	0	0	0	0	0	1	0
Annelida	Polychaeta	Sedentaria	Spionida	Polydora	larvae	0	0	0	0	1	0	0
Annelida	Polychaeta	Sedentaria	Spionida	cf. Polydora	larvae	0	0	0	0	0	20	0
Annelida	Polychaeta	Sedentaria	Spionida		larvae	70	23	12	11	11	18	9
Annelida	Polychaeta				trochophora larvae	55	1	1	1	0	1	1
Annelida	Polychaeta				larvae non det	65	10	4	1	8	11	1
Bryozoa					cyphonautes larvae	0	0	0	0	9	3	0
Chaetognatha	Sagittoidea		Aphragmophora	Parasagitta sp.	adult	0	0	1	0	0	0	0
Chordata	Tunicata	Appendicularia	Copelata	Oikopleura cf. dioica	adult	5	0	0	0	0	0	0
Cnidaria	Hydrozoa	Hydroidolina	Leptothecata	cf. Clytia hemisphaerica	medusa	0	9	0	0	0	0	0
Cnidaria	Hydrozoa	Hydroidolina	Leptothecata	Obelia sp.	medusa	0	0	28	0	0	0	0
Cnidaria	Hydrozoa				medusa (small)	0	0	59	0	0	0	0
Cnidaria	Hydrozoa				medusa (large)	0	0	11	0	0	0	0
Echinodermata					pluteus larvae	0	53	7	2	0	0	0
Mollusca	Bivalvia				veliger larvae	25	33	6	0	13	0	9
Mollusca	Gastropoda				veliger larvae	15	30	5	3	10	9	37
Phoronida				Phoronis cf. muelleri	larvae	0	0	0	0	0	5	0
Non det					(maybe jellyfish)	0	0	2	0	0	0	0
Non det					(parasite of Acartia)	0	0	0	0	0	2	0