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Summer mesozooplankton community of Moller Bay (Novaya Zemlya Archipelago, Barents Sea)

KEYWORDS
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Abstract

Novaya Zemlya Archipelago is the eastern boundary of the Barents Sea. The plankton of this region have been less intensively studied than those of other Arctic areas. This study of the mesozooplankton assemblage of Moller Bay was conducted in August 2010. The total mesozooplankton abundance and biomass ranged from 962 to 2980 individuals m^{-3} (mean ± SD: 2263 ± 921 indiv. m^{-3}) and from 12.3 to 456.6 mg dry mass m^{-3} (mean ± SD: 192 ± 170 DM m^{-3}) respectively. Copepods and appendicularians were the most numerous groups with *Oithona similis*, *Pseudocalanus* spp., *Acartia* spp., *Calanus glacialis* and *Oikopleura vanhoeffenni* being the most abundant and frequent. Mesozooplankton abundance tended to decrease with depth, whereas an inverse pattern was observed for the total biomass. Total mesozooplankton biomass was negatively correlated with water temperature and positively correlated with salinity and chlorophyll *a* concentration. Comparison with previous data showed significant interannual variations in the total zooplankton stock in this region that may be due to differences in sampling seasons, climatic conditions and the distribution of potential food sources (phytoplankton and seabird colonies).

The complete text of the paper is available at http://www.iopan.gda.pl/oceanologia/

1. Introduction

Mesozooplankton communities are major components of the food webs in polar seas (Auel & Hagen 2002, Walkusz et al. 2009). They are the main link between primary producers and higher trophic levels (nekton, marine mammals and seabirds) and the benthos (Wassmann et al. 2006). The functioning of planktonic assemblages in Arctic seas is strongly influenced by environmental conditions (Matishov (ed.) 2011). As a consequence, climate governs interannual variations in the plankton composition, abundance and biomass (Dalpadado et al. 2003). Thus, mesozooplankton can be considered a good indicator of climatic changes especially in Arctic seas (Matishov et al. 2004, Sakshaug et al. (eds.) 2009).

The Barents Sea is affected by two main water masses. Warm Atlantic waters flow into its south-western and western areas from the Norwegian Sea (Matishov et al. 2009). Cold Arctic waters are transported from the Arctic Ocean into the northern and eastern Barents Sea (Wassmann et al. 2006). Other water masses (Coastal waters and Polar Front waters) are mixtures of waters from these two sources (Loeng 1991, Matishov et al. 2009). Some warming events due to Atlantic water inflow have been registered in the Barents Sea in the 21st century (Matishov et al. 2009), although a cooling trend has been observed in the region since 2007 (Matishov (ed.) 2011).

The plankton of the coastal zones of the southern Barents Sea has been well investigated (Timofeev 2000, Dvoretsky & Dvoretsky 2009b), but little is known about the mesozooplankton structure of the northern and eastern regions (Dvoretsky & Dvoretsky 2009a, Dvoretsky 2011). Moreover, there are no published data on temporal variations and interannual changes of mesozooplankton assemblages in those regions. The aim of this study was to describe the spatial distribution of mesozooplankton in Moller Bay, a coastal site near Novaya Zemlya Archipelago, and to compare our data with previous results in order to detect possible year-to-year variations.

2. Methods

Moller Bay is located off the west coast of Novaya Zemlya (Figure 1). The hydrographic regime of the research site is affected by the Novaya Zemlya coastal current and the Litke current. The upper layer is occupied by warm waters, while cold waters occur below 50 m (Matishov (ed.) 1995).

The oceanographic and biological sampling was performed at five stations in August 2010 on board of the r/v 'Dalnie Zelentsy' (Table 1,

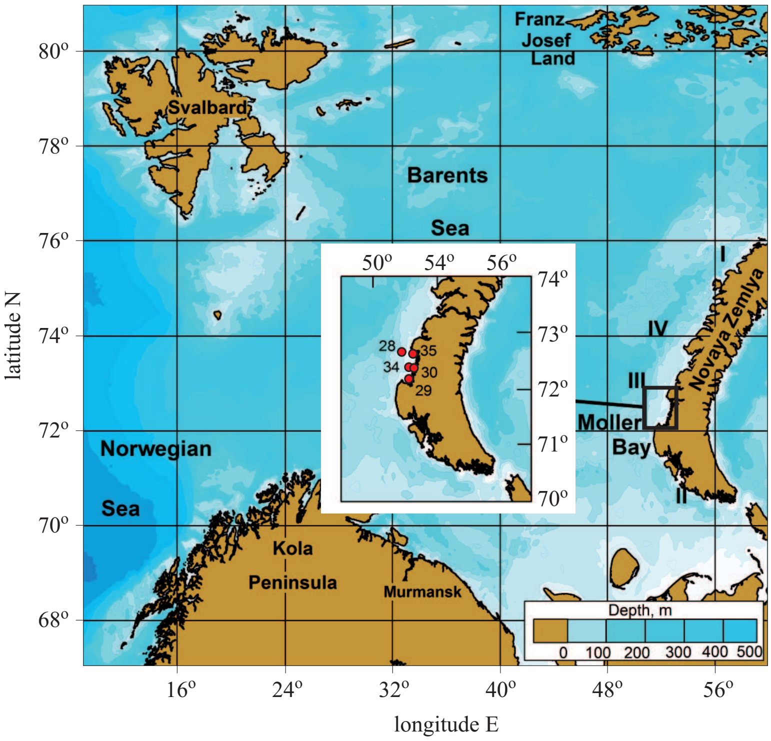

Figure 1. Map of sampling stations in Moller Bay (E. Barents Sea) in August 2010. I–IV – sites for interannual comparison of zooplankton biomass (see Table 3)

Figure 1). Vertical profiles of temperature and salinity were registered using a SBE 19plus SEACAT profiler at each station. Stratified zooplankton samples were collected by making vertical hauls with a Juday net (mesh size 0.168 mm; 0.11 m^2) (Table 1). The volume of filtered water was estimated by multiplying the rope length by the area of the net mouth, assuming 100% efficiency. The samples were preserved in 4% formalin. For the determination of chlorophyll *a* concentration, 5 L water samples were collected from the surface, pycnocline and bottom layers with a Niskin bottle. The samples were filtered through screens of 0.5 μm pore-size. In the laboratory, chlorophyll *a* was determined spectrophotometrically after acetone extraction. These data have been recently published (Vodopyanova 2011).

After the large zooplankton had been sorted, identified, counted and removed, each sample was subsampled, depending on the amount of zooplankton, and the numbers of individuals per cubic metre were calculated. Biomass data [mg DM, dry mass m^{-3}] were calculated from abundances

Table 1. Net tow stations sampled during the cruise with average temperature (T, °C), salinity and chlorophyll a concentrations [mg m^{-3}] in Moller Bay (E. Barents Sea), August 2010

St.	Date August 2010	Time	Latitude	Longitude	Depth [m]	Sampled layers [m]	$T_{0-\text{bottom}}$	$S_{0-\text{bottom}}$	Chl $a_{0-\text{bottom}}$
28	25	2:46	72°40′N	51°46′E	68	70–50, 50–25, 25–10, 10–0	1.7 ± 2.0	34.32 ± 0.40	0.70 ± 0.39
29	25	9:15	72°10′N	51°14′E	26	23–10, 10–0	3.7 ± 0.7	33.96 ± 0.22	0.32 ± 0.26
30	25	13:05	72°22′N	51°32′E	12	10–0	2.7 ± 0.3	34.03 ± 0.15	0.49 ± 0.36
34	25	22:05	72°23′N	51°19′E	55	52–25, 25–10, 10–0	2.3 ± 2.2	34.15 ± 0.57	0.66 ± 0.32
35	26	8:20	72°36′N	51°30′E	28	25–10, 10–0	1.5 ± 1.3	34.39 ± 0.26	0.34 ± 0.17

using published dry weights and length/mass relationships (Chislenko 1968, Vinogradov & Shushkina 1987, Mumm 1991, Richter 1994). The diversity of the mesozooplankton community was assessed with Shannon's index H' based on the abundance of each species or taxon. Linear regression analyses were used to test relationships between biological and physical parameters. The faunal resemblance between samples was measured by the quantitative Bray-Curtis dissimilarity coefficient (Bray & Curtis 1957) of fourth-root-transformed abundance data. All the means were presented as values ± SD (standard deviation).

3. Results

The seawater temperature varied between −0.3°C (at station 34 near the bottom) and 4.8°C (at the same station near the surface). Salinity ranged from 33.31 (st. 34 at 0 m) to 34.72 (st. 28 near the bottom). The water column in Moller Bay was characterized by a marked stratification during the sampling period. The depth of the pycnocline varied from 10 to 25 m over the study site. Over the entire area, chlorophyll *a* concentrations in the bottom layer were low (0.19 ± 0.09 mg m^{-3}), the maximum being found in the 25–0 m layer (1.23 ± 0.82 mg m^{-3}).

Altogether, 32 taxa were identified, including Copepoda nauplii and *Pseudocalanus* spp. (Table 2). The total mesozooplankton abundance varied from 962 to 2980 indiv. m^{-3} with a maximum at st. 28 and a minimum at st. 30. The relative importance of the different taxa varied among stations, although copepods were by far the most numerous group, amounting to 73.7–96.2% (86.5 ± 9.9%) of the total mesozooplankton abundance. Among them, *Oithona similis*, *Pseudocalanus* spp., *Acartia* spp. and *Calanus glacialis* were the most abundant and frequent. All age stages (from nauplii to adults) were detected for the common copepod taxa. Appendicularia (*Fritillaria borealis* and *Oikopleura vanhoeffenni*) also attained a high relative numerical abundance (1.5–21.9, 10.5 ± 8.7%).

The estimated mesozooplankton biomass was the lowest at st. 30 (12.3 mg DM m^{-3}) and the highest (456.6 DM m^{-3}) at st. 28. The large copepod *C. glacialis*, represented mainly by late copepodid stages, and the larval *O. vanhoeffenni* were co-dominant in terms of the total mesozooplankton biomass, respectively averaging 66.2 ± 12.5% and 12.5 ± 11.0%.

The diversity index value (H') of the mesozooplankton community ranged between 1.41 (st. 30) and 2.17 (st. 34). The overall mean was 1.76 ± 0.28. Taxon richness varied among stations from 13 to 20 taxa per sample.

Table 2. Composition and zooplankton abundance/biomass [individuals m^{-3} mg^{-1} dry mass m^{-3}] in Moller Bay (E. Barents Sea), August 2010

Taxon/group	Layer			
	10–0 m	25–10 m	50–25 m	70–50 m
Acartia longiremis V–VI	$60 \pm 110/0.3 \pm 0.5$	$4 \pm 3/0 \pm 0$	$7.6 \pm 10.7/0 \pm 0.1$	–
Acartia spp. I–IV	$77 \pm 97/0.1 \pm 0.2$	$14 \pm 19/0 \pm 0$	$50 \pm 71/0.1 \pm 0.1$	–
Calanus finmarchicus	$0.9 \pm 1.6/0.1 \pm 0.3$	$14 \pm 15/3.4 \pm 4$	$123 \pm 66/20.7 \pm 7.1$	76/12
Calanus glacialis	$42 \pm 55/19.5 \pm 20.3$	$84 \pm 38/52.7 \pm 34.5$	$194 \pm 142/97.2 \pm 70.2$	229/152
Calanus hyperboreus	$0.2 \pm 0.4/0 \pm 0.1$	–	$1.7 \pm 2.4/3.1 \pm 4.4$	1/1.1
Centropages hamatus	$0.6 \pm 1.2/0 \pm 0$	–	–	–
Copepoda nauplii	$26 \pm 33/0 \pm 0$	$20 \pm 34/0 \pm 0$	$2.1 \pm 2.9/0 \pm 0$	–
Cyclopina gracilis	$0.2 \pm 0.4/0 \pm 0$	–	–	–
Ectinosoma neglectum	$0.2 \pm 0.4/0 \pm 0$	–	–	–
Metridia longa	$0.2 \pm 0.4/0 \pm 0$	$0.8 \pm 1.2/0 \pm 0$	–	–
Microcalanus pusillus	–	–	$3.3 \pm 4.7/0 \pm 0$	7/0
Microcalanus pygmaeus	–	$1.7 \pm 3.4/0 \pm 0$	$12 \pm 17/0.1 \pm 0.1$	25/0.2
Microsetella norvegica	$0.4 \pm 0.8/0 \pm 0$	$0.2 \pm 0.4/0 \pm 0$	–	–
Oithona similis	$448 \pm 127/1.1 \pm 0.4$	$268 \pm 159/0.6 \pm 0.4$	$263 \pm 102/0.5 \pm 0.3$	73/0.1
Pseudocalanus spp. I–IV	$41 \pm 40/0.3 \pm 0.2$	$267 \pm 413/1 \pm 1.2$	$126 \pm 124/0.6 \pm 0.5$	19/0.2
Pseudocalanus acuspes V–VI	$49 \pm 52/1.1 \pm 1.1$	$167 \pm 192/4.5 \pm 5.2$	$12 \pm 8/0.3 \pm 0.2$	7.4/0.2
Pseudocalanus minutus V–VI	$16 \pm 14/0.4 \pm 0.4$	$66 \pm 71/1.5 \pm 1.6$	$30 \pm 30/0.9 \pm 1$	5.6/0.1
Tisbe furcata	–	–	$11 \pm 15/0.4 \pm 0.6$	–
Aglantha digitale	$0.2 \pm 0.4/0 \pm 0$	$0.3 \pm 0.4/0 \pm 0$	–	–
Bougainvillia supercilliaris	$0.2 \pm 0.4/0 \pm 0$	$0.3 \pm 0.4/0 \pm 0$	–	–
Bivalvia (juv.)	$0.6 \pm 1.2/0 \pm 0$	–	–	–
Auricularia larvae	$1.5 \pm 3.3/0 \pm 0$	$0.2 \pm 0.4/0 \pm 0$	–	–

Table 2. (*continued*)

Taxon/group	Layer			
	10–0 m	25–10 m	50–25 m	70–50 m
Gastropoda larvae	31 ± 24/0 ± 0	21 ± 24/0 ± 0	26 ± 31/0 ± 0	13/0
Polychaeta larvae	–	–	3.8 ± 5.4/0 ± 0.1	–
Pagurus spp. zoea	0.2 ± 0.4/0 ± 0.1	0.2 ± 0.3/0 ± 0.1	0.4 ± 0.5/0.1 ± 0.1	0.5/0.1
Boroecia borealis	0.2 ± 0.4/0 ± 0	0.3 ± 0.4/0 ± 0	0.4 ± 0.5/0 ± 0	0.5/0
Limacina helicina	–	–	2.8 ± 3.9/0.1 ± 0.2	–
Parasagitta elegans	1.3 ± 2.4/0.8 ± 1.4	7.1 ± 8.8/3.5 ± 3.6	3.6 ± 1.7/3.5 ± 3.1	4.2/9
Thyssanoessa spp. furcilii	–	0.6 ± 1.2/0.2 ± 0.4	–	–
Fritillaria borealis	–	–	4.7 ± 6.6/0.1 ± 0.1	8.8/0.1
Oikopleura vanhoeffenni	106 ± 175/11.3 ± 21.8	125 ± 55/12.8 ± 7.8	112 ± 71/11.4 ± 10	97/7
Mertensia ovum	–	0.6 ± 0.9/0 ± 0	1.8 ± 0.1/0 ± 0	0.9/0
Total	903 ± 181/35.1 ± 27.1	1062 ± 632/80.3 ± 40.1	992 ± 169/139.2 ± 84	568/183

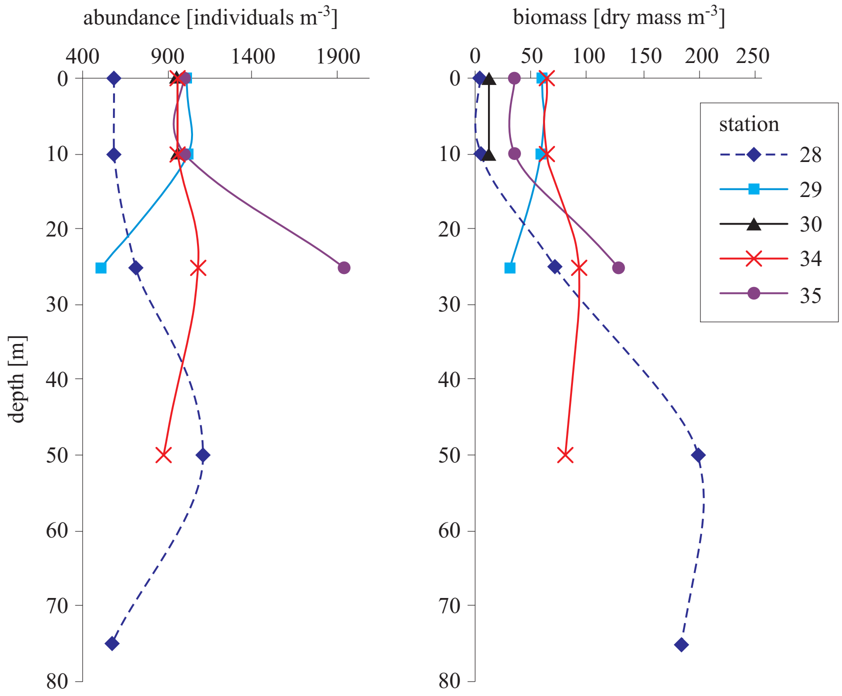

Figure 2. Vertical distribution of mesozooplankton abundance [individuals m^{-3}] and biomass [mg dry mass m^{-3}] in Moller Bay (E. Barents Sea) in August 2010

The vertical distributions of total mesozooplankton abundance and estimated biomass are shown in Figure 2. The minimum total abundance of mesozooplankton was recorded in the upper 10 m of the water column (Figure 2a). This layer was dominated by *O. similis* ($51.8 \pm 19.6\%$) and *Acartia* spp. ($14.0 \pm 21.5\%$). Abundance peaked in the 10–25 m layer, where *Pseudocalanus* spp. ($38.2 \pm 44.7\%$), *O. similis* ($29.2 \pm 21.2\%$) and *O. vanhoeffenni* ($16.3 \pm 10.3\%$) prevailed. Estimated mesozooplankton biomass tended to increase with depth (Figure 2b). In the 0–10 m and 10–35 m layers, *C. glacialis* accounted for $52.9 \pm 33.7\%$ and $60.3 \pm 16.3\%$ of the total mesozooplankton biomass, while its average proportion was $> 66\%$ in the deeper layers. Another large copepod, *Calanus finmarchicus*, was concentrated in the 25–50 m layer, where it accounted for $16.3 \pm 4.8\%$ of the total biomass. In contrast, *O. vanhoeffenni* made up the largest portion of the total mesozooplankton biomass in the upper layers ($> 21\%$); below 25 m, however, its relative biomass was $< 7\%$.

Linear regression analyses indicated that the total mesozooplankton biomass (B, mg DM m^{-3}) was negatively correlated with water temperature (T, °C) but positively with salinity (S) and chlorophyll a concentration

(Chl a): $\mathrm{B} = -112.9\,T + 460.4$, $R^2 = 0.341$, $\mathrm{B} = 583\,S - 19731$, $R^2 = 0.397$, $p = 0.012$, $\mathrm{B} = 686.5$ Chl $a - 153.0$, $R^2 = 0.510$.

4. Discussion

The mesozooplankton structure of Moller Bay has been described for the first time. The hydrographic conditions in the bay were found to resemble those described by Matishov et al. (2004) over several summers in the eastern Barents Sea. In the present study, chlorophyll a concentrations in the 0–25 m layer (0.54–1.74 mg m^{-3}) were surprisingly high compared with other areas of the eastern Barents Sea. For instance, before the bloom periods, the phytoplankton biomass reaches moderate values with chlorophyll a concentrations of 0.5 mg m^{-3} (Matishov (ed.) 1995) but during the spring bloom the chlorophyll a concentration can exceed 6 mg m^{-3} (Matishov (ed.) 1997). Therefore, we observed the intensive growth of phytoplankton near the Archipelago in August 2010. Moreover, the presence of early copepodid stages suggests the spawning of common copepod species even though adults and late copepodids were more abundant. This finding also suggests that the zooplankton community was in the active phase. The pattern observed is in good agreement with earlier results from coastal sites in the southern and south-eastern Barents Sea (Wassmann et al. 2006, Matishov (ed.) 2009).

In the present study, the structure of the mesozooplankton community in Moller Bay was characterized by the dominance of copepod species. Similar findings have been documented in other Arctic regions (Greenland Sea, White Sea, Icelandic waters, Beaufort Sea, Kara Sea, Arctic Ocean) during summer seasons (Mumm 1991, Richter 1994, Auel & Hagen 2002, Fetzer et al. 2002, Walkusz et al. 2009). Species richness was relatively high (32 taxa) compared to the total number of zooplankton taxa (72) that can be found in the eastern Barents Sea (Dvoretsky & Dvoretsky 2012). This result is expected, because Arctic coastal areas have a richer zooplankton fauna than the open sea because of the greater diversity of biotopes (Timofeev 2000). Shannon's indices in Moller Bay were comparable to those recorded near Novaya Zemlya in 2006 (Dvoretsky & Dvoretsky 2009a). The vertical structure of mesozooplankton abundance in Moller Bay was also consistent with that reported from the southern Barents Sea (Dvoretsky & Dvoretsky 2012) and other Arctic regions (e.g. Błachowiak-Samołyk et al. 2007). We found that the mesozooplankton biomass below 50 m was composed mostly of *Calanus glacialis*. This can be explained by the diel vertical migration of Arctic zooplankton in late summer (Timofeev 2000). Almost all the samples in Moller Bay were collected during the daytime, when the major zooplankton taxa (*Calanus* spp. and other copepods) tended to descend into deep water layers.

To detect interannual variations in the mesozooplankton community off the Novaya Zemlya Archipelago, we combined data for Moller Bay and the results obtained in 1992, 2006, 2007 in adjacent waters and coastal locations (Table 3). Average water temperatures were similar in all studies, but mesozooplankton abundance and biomass varied widely (Table 3). We think that such differences between these periods can be attributed to three major factors.

Firstly, the studies covered the mid- and late-summer periods. Polar zooplankton demonstrates a clear seasonal cycle with a peak coinciding with the phytoplankton bloom (Matishov (ed.) 1997), and communities in different successional phases may differ in their total abundance and biomass (Timofeev 2000). For example, in Fram Strait, the maximum total zooplankton biomass was three times higher in August than in May (Błachowiak-Samołyk et al. 2007).

The second possibility relates to climatic conditions (Dalpadado et al. 2003). The zooplankton communities of the central and western Barents Sea are strongly dependent on the advection of species of Atlantic origin (e.g. *Calanus finmarchicus*) from the Norwegian Sea (Wassmann et al. 2006); the eastern region is more affected by Arctic waters. In 2006 and 2007, *C. finmarchicus* was the most abundant species off the southern coast of Novaya Zemlya (Dvoretsky & Dvoretsky 2009a), and this was connected with the anomalously high inflow of Atlantic waters into the Barents Sea during those periods (Matishov et al. 2009). In 2010, this species was replaced by the cold-water species *C. glacialis*. Its occurrence is consistent with recent results showing cooling in the Barents Sea (Matishov (ed.) 2011). The larger mesozooplankton biomass in 2010 may therefore be explained by the advection of *C. glacialis* with the cold Arctic waters. The dominance of this species in the near-bottom layers and the negative correlation between estimated biomass and water temperature support such a scenario.

Thirdly, it is a common observation that coastal sites are more productive than open sea areas, owing to the transport of organic matter and nutrients from the land. The influence of freshwater discharge on the pelagic ecosystem in the eastern Barents Sea is very low (Matishov (ed.) 1995). However, there is another important source of biogenic elements near Novaya Zemlya – seabird colonies. Large colonies of planktivorous birds are located on the northern and western coasts of Novaya Zemlya (in Arkhangelskaya Bay and Moller Bay) but there are hardly any along

Table 3. Comparison of temperature conditions (T, °C; mean ± SD), average mesozooplankton abundance (N, individuals m^{-3}) and biomass (B, dry mass m^{-3}) off the southern, south-western and northern coasts of Novaya Zemlya (E. Barents Sea). See Figure 1

Site	Date/Sampled layer	Location	T	N	B	Source
Arkhangelskaya Bay (I)	August 1967/50 m	75°50′N, 59°00′E	–	–	160–313	Zelikman & Golovkin (1972)
Chernaya Bay (II)	17.07.1992/50 m	70°42′N, 54°38′E	1.4 ± 2.4	–	32	Timofeev (1992)
Open waters (III)	19.08.2006/55 m	72°50′N, 51°45′E	1.5 ± 2.3	319	26	Dvoretsky & Dvoretsky (2009a)
Open waters (IV)	02.09.2007/60 m	73°27′N, 53°00′E	2.0 ± 1.7	1630	12	Dvoretsky & Dvoretsky (unpublished)
Moller Bay	25–26.08.2010/10–75 m	72°20′N, 51°20′E	2.1 ± 1.9	2263 ± 921	192 ± 170	This study

the southern coast (e.g. in Chernaya Bay). Their excrement enriches the coastal waters with organic matter and nutrients. As a result, the bacterial and phytoplankton biomass is the largest in the Arctic bays with seabird colonies (Stempniewicz et al. 2007, Matishov (ed.) 2011). These food resources are utilized by the zooplankton, which can achieve high biomass levels. A positive relationship between chlorophyll *a* concentration and total mesozooplankton biomass supports this expected relationship. This might also explain why Appendicularia were the second most dominant group in Moller Bay. Usually, they make up just a minor part of the total zooplankton biomass in the Barents Sea (Dvoretsky & Dvoretsky 2009a,b, 2012). However, larvaceans (tunicates) are known to have high growth rates, and population densities can increase rapidly when food supplies are plentiful (high concentrations of microplankton) (Gorsky & Fenaux 1998). It is likely that their high stock in the study area was associated with the influence of seabird colonies.

We conclude that the mesozooplankton distribution and biomass in Moller Bay was determined largely by environmental variables. Interannual variations in the total zooplankton stock may have been due to differences in sampling seasons, climatic conditions and the distribution of food sources.

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