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Studies on the Arctic pack-ice habitat and sympagic meiofauna – seasonal and regional variabilities

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Summary

Sea ice is the main structural feature of polar seas. It plays an important role in energy transfer between ocean and atmosphere, but also serves as a natural habitat for a variety of organisms.

Salt ions of the sea water are not included into the crystal structure of sea ice during freezing. These remain in the widely ramified system of brine channels within the ice. The brine channels are characterized by diameters of a few micro- to millimeters and provide a habitat for the so called sympagic (= ice associated) community. This association comprises bacteria, fungi, algae and protozoans, as well as metazoans. The investigated sympagic meiofauna of Arctic pack ice mainly consists of copepods, nematodes, rotifers, turbellarians and nauplii.

Late summer and winter pack ice of the central Arctic Ocean, the northern Fram Strait and the Storfjord (south of Spitsbergen) was sampled during three expeditions. The aim of this investigation was to evaluate the qualitative and quantitative composition of sympagic meiofauna as well as the controlling ice parameters of their distribution. Therefore, identical methods for sampling and sampling processing were used to obtain a comparison of seasonal and regional variability. This study presents for the first time an extensive, quantitative data set of environmental factors influencing composition, abundance and distribution of sympagic meiofauna organisms in wintertime Arctic pack ice. These data are compared with summer data of the same region. Additionally, the investigation of an extended area from south of Spitsbergen to the North Pole provides a unique base to evaluate regional variability of composition, abundance and distribution of sympagic meiofauna.

The results demonstrate the influence of seasonally variable parameters in the upper part of the ice. During winter, ice temperatures are close to $-22\text{ }^{\circ}\text{C}$, brine salinities exceed values of 200 and brine volumes are generally less than 5% generating an extreme environment within the upper part of the ice. In the lowermost part of the ice, where sympagic meiofauna typically accumulates in so-called bottom communities, only minor seasonal variations occur. At these depths, favourable physical conditions could support the colonization of sympagic meiofauna organisms. However, faunal analyses only show single specimens of most taxa in winter pack ice except for an increase of nauplii to high abundances. Therefore, an active strategy of meiofauna species to overwinter in the ice is not indicated. Insufficient food availability (chlorophyll *a* concentration $< 1.0\ \mu\text{g chl } a\ \text{l}^{-1}$) seems to play an important role. Nevertheless, single specimens seem to survive the winter and to ensure the communities maintenance by high reproduction rates during spring. Another possible overwintering strategy could be the production of resting stages, which transform to active organisms under improved environmental conditions in the spring. However, resting stages were not found in the wintertime ice samples.

Pack ice samples show minor geographical differences in the development of pack ice

habitat and their associated sympagic meiofauna along a transect across the eastern basin of the Arctic Ocean. This uniformity in samples of the Transpolar Drift implies a similar spatial and temporal formation of pack ice, in this case along Siberian shelves. The occurrence of benthic species within the pack ice points to an overwintering strategy of individual organisms assuring the communities maintenance. Comparison of community structures of all stations clearly indicates the stronger influence of seasonal factors on the distribution of sympagic meiofauna compared to regional factors.

Zusammenfassung

Meereis ist ein wesentliches strukturierendes Merkmal der polaren Ozeane. Es spielt nicht nur im Energieaustausch zwischen Ozean und Atmosphäre eine wesentliche Rolle, sondern dient auch unterschiedlichen Organismen als Lebensraum.

Während des Gefrierprozesses werden die im Meerwasser enthaltenen Salzionen nicht in die Kristallstruktur des Eises mit eingeschlossen, sondern verbleiben im Inneren des Eises in einem stark verzweigten, solegefüllten Kanalsystem. Diese Solekanäle, deren Durchmesser in der Regel im μm - bis mm- Bereich liegen, dienen einer speziell angepassten, sogenannten „sympagischen“ (= eisassoziierten) Lebensgemeinschaft als Lebensraum. Diese Gemeinschaft umfasst neben Bakterien, Pilzen, Algen und Protozoen auch Metazoen. Im arktischen Packeis setzt sich die Gruppe der Metazoen (sympagische Meiofauna) vornehmlich aus Copepoden, Nematoden, Rotatorien, Turbellarien, sowie Nauplien zusammen.

Auf insgesamt drei Expeditionen wurde Packeis des zentralen arktischen Ozeans, der nördlichen Framstraße, sowie des Storfjordes (ein Fjord südlich von Spitzbergen) im späten Sommer und Winter beprobt. Schwerpunkt der Untersuchungen war die qualitative und quantitative Erfassung der sympagischen Meiofauna, sowie der wesentlichen, die Verteilung der Organismen kontrollierenden Eisparameter. Die einheitlich angewandten Beprobungs- und Untersuchungsmethodiken ermöglichten dabei einen Vergleich sowohl saisonaler als auch regionaler Variabilitäten. Die vorliegende Arbeit präsentiert zum ersten Mal umfassende Daten über die Lebensbedingungen, sowie über die Zusammensetzung, Häufigkeit und Verteilung der sympagischen Meiofauna im winterlichen Packeis der Arktis und vergleicht diese mit Sommerdaten aus derselben Region. Mit der Untersuchung eines geographisch ausgedehnten Gebietes, das sich vom südlichen Teil Spitzbergens bis zum Nordpol erstreckt, liefert diese Arbeit außerdem die Grundlage zur Abschätzung der regionalen Variabilität in der Zusammensetzung, Verteilung und Häufigkeit der sympagischen Meiofauna.

Die Ergebnisse der Untersuchungen zeigen, dass der obere Bereich des Eises durch starke saisonale Veränderungen geprägt ist. Mit Eistemperaturen nahe $-22\text{ }^{\circ}\text{C}$, Sole-salinitäten größer 200 und Solevolumina meist unter 5%, kommt es in diesem Bereich des Eises zu sehr extremen Bedingungen. Im unteren Bereich des Eises, in dem sich in der Arktis die sympagische Meiofauna typischerweise zu so genannten Bodengemeinschaften akkumuliert, wurden nur geringfügige saisonale Veränderungen festgestellt. Dieser Bereich bietet somit auch im Winter günstige physikalische Voraussetzungen für eine Besiedelung durch sympagische Meiofauna Organismen. Die faunistischen Untersuchungen zeigen jedoch, dass mit der Ausnahme von Nauplien, die mit hohen Abundanz vertreten sind, nur vereinzelte Organismen im Winter vorkommen. Eine Überwinterung aller Organismen findet im Eis somit nicht statt. Vermutlich spielt hierbei eine unzureichende Nahrungsverfügbarkeit (Chlorophyll *a* Konzentrationen $< 1.0\ \mu\text{g}$

chl a^{-1}) eine entscheidende Rolle. Möglicherweise wird durch das Überleben einzelner Individuen im Winter und einer anschließend hohen Reproduktion während des Frühjahrs die Aufrechterhaltung der Gemeinschaft über den Winter gesichert. Eine weitere Überlebensstrategie könnte die Ausbildung von Dauerstadien sein, die sich bei einer Verbesserung der Umweltbedingungen nach dem Winter in aktive Organismen umwandeln. Dauerstadien konnten in den winterlichen Eisproben in der vorliegenden Arbeit jedoch nicht gefunden werden.

Packeisbeprobungen entlang eines Transekts durch das östliche Becken des zentralen Arktischen Ozeans zeigten geringe geographische Unterschiede in der Ausbildung des Packeis-Habitats und der sympagischen Meiofauna. Diese Uniformität lässt sich vermutlich damit begründen, dass das Packeis, das einheitlich im Gebiet der Transpolaren Drift beprobt wurde, zur selben Zeit im Gebiet der sibirischen Schelfe gebildet wurde. Das Vorkommen benthischer Formen bestätigt zudem die oben genannte Überwinterungstheorie, derzufolge das Überwintern einzelner Individuen die Aufrechterhaltung der sympagischen Meiofauna sichert. Vergleiche der Gemeinschaftsstrukturen aller beprobten Stationen zeigen deutlich, dass saisonale Prozesse die sympagische Meiofauna stärker kontrollieren als es regionale Faktoren tun.

1 General introduction

Sea ice is an important structuring feature in the marine ecosystem of polar regions. It ranges in extent between 17.5×10^6 to 28.5×10^6 km², which corresponds to a fraction of 3–6% of the total earth surface (Comiso 2003). Thus, it is one of the largest biomes on earth. The sea-ice cover considerably influences the exchange of energy between the atmosphere and the ocean. Due to the high albedo of the sea ice a high portion of solar radiation is directly reflected, influencing the global climate system and the water column (Maykut 1985, Harder 1996). Furthermore, owing to its isolating property, sea ice modifies the heat exchange between the ocean and the sea (Wettlaufer 1991, Lytle & Ackley 1996).

1.1 Arctic sea ice

In the Arctic, sea ice covers about 7×10^6 km² during the minimum extent in September and doubles in size to 14×10^6 km² during the maximum extent in March (Maykut 1985) (Fig. 1.1). The majority of Arctic sea ice is multi-year ice, which survived at least one summer melt season, and is generally thicker than 2 m (Spindler 1990). Within the Arctic Ocean, two dominant drift systems control the ice transport: (1) the Transpolar Drift, which transports ice from the western side of the basin across the pole and through the Fram Strait, and (2) a clockwise gyre in the Beaufort Sea region (Gordienko 1958) (Fig. 1.2). Roughly 10% of the sea ice in the basin annually drifts through the Fram Strait into the North Atlantic, where it melts (Maykut 1985).

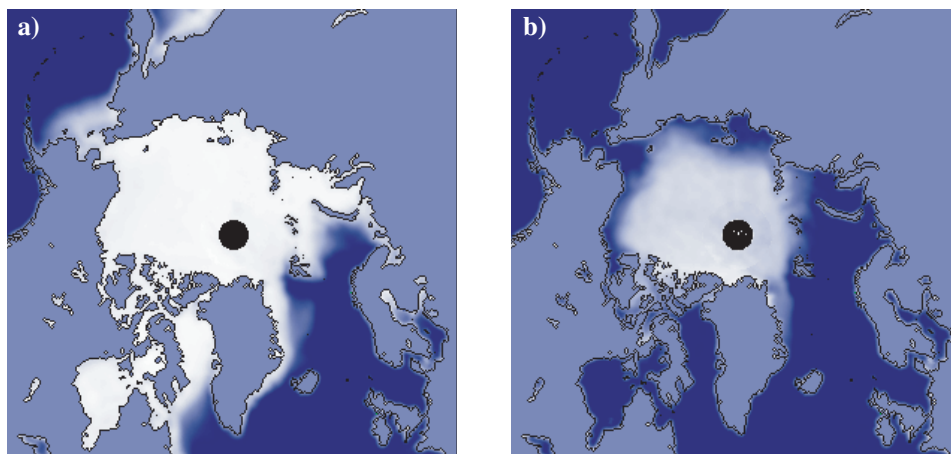


Figure 1.1: Sea-ice distribution in (a) March and (b) September for the northern hemisphere (monthly averages: 1978–1991). The intensity of white colour indicates the percentage of ice cover, the black area in the center of the picture denotes missing data. Modified after Schweitzer (1995).

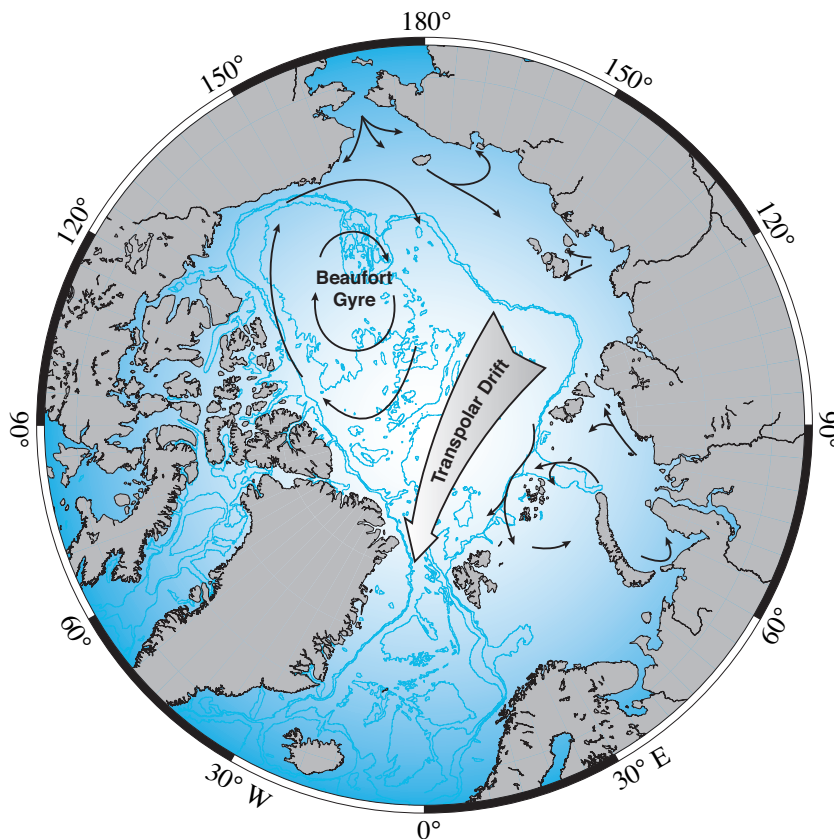


Figure 1.2: Major ice-drift patterns in the Arctic Ocean. Modified after Gordienko (1958).

The ice enclosed into the Beaufort Gyre can remain in the Arctic basin for 2.5–30 years, while the ice entrained in the Transpolar Drift Stream generally leaves the basin after 2–3 years (Melnikov 1997). However, the boundaries between the two systems are not distinct, and ice drifting at the periphery of one system can be incorporated into the other. Furthermore, average travel time of multi-year sea ice as well as ice thickness in the central Arctic Basin show a pronounced variability as a response to dynamic and thermodynamic factors (e.g., Rothrock et al. 1999, Tucker et al. 2001, Pfirmann et al. 2004).

1.2 Sea-ice formation

During sea-ice formation, a two-phase system develops consisting of solid ice crystals and liquid brine. Small freshwater ice crystals (frazil ice), which are in the range of a few millimetres, form at or near the surface of the water when the water temperature is below the freezing point. Due to their lower density the ice crystals ascend to the water surface, where they accumulate to grease ice. Depending on the weather conditions, different ice-formation processes lead to the development of a continuous ice cover. Under turbulent conditions (wind, waves), the crystals are pushed together forming so-called pancakes.

Due to wave action, these pancakes dip into the water, surrounding grease ice is loaded onto the pancakes and thus, rims of the pancakes thicken. Finally, the pancakes freeze together due to continuously low temperatures. Under calm conditions, the grease ice directly freezes into a solid ice cover (nilas) without previous pancake formation. After the formation of a closed ice cover, further ice thickening occurs by congelation growth at the ice underside. In contrast to granular ice, formed during the initial freezing process, congelation leads to the formation of columnar ice, which is characterized by elongated grain shapes (for detail see: World Meteorological Organization 1970, Maykut 1985, Weeks & Ackley 1986, Lange et al. 1989). The liquid brine, forming in between the crystals due to the rejection of salts that are not incorporated into the crystal lattice, accumulates in the brine-channel system, a branched system of channels and pockets, which penetrates the ice. Brine-channel diameters range from several micrometers to several centimetres (Weissenberger 1992, Eicken 2003).

1.3 Sea-ice habitat

Environmental conditions within the brine-channel system depend on different factors. In granular ice, an irregular network of brine channels and pockets develops, while channels are more vertically oriented in columnar ice (Weissenberger et al. 1992). Furthermore, the size of sea-ice brine inclusions is distinctively associated with the temperature (Eicken et al. 2000). Brine volume is calculated as a function of ice temperature and ice bulk salinity (Frankenstein & Garner 1967, Leppäranta & Manninen 1988), brine salinity as a function of the ice temperature (Assur 1958). A decrease in ice temperature from $-4\text{ }^{\circ}\text{C}$ to $-10\text{ }^{\circ}\text{C}$, for example, leads to an increase in brine salinity from 68 to 142, and air temperatures near $-20\text{ }^{\circ}\text{C}$ in winter cause brine volumes of less than 1% and brine salinities above 200. Light conditions in the sea ice are also quite variable. Next to varying day lengths from 0 to 24 hours, light conditions inside the ice are also affected by reflection, scattering and absorption (Maykut & Grenfell 1975, Palmisano et al. 1987). Thus, snow cover, ice thickness and the structure and distribution of brine and other inclusions can lead to attenuation of incident irradiance down to values $< 0.1\%$ (Maykut 1985).

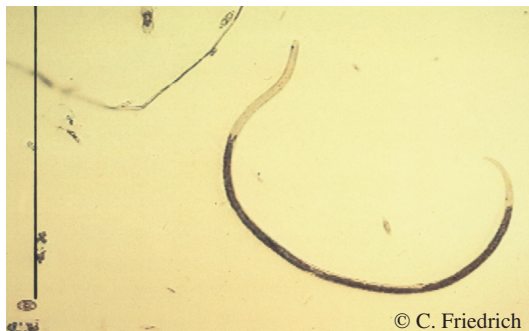
1.4 Sympagic community

Despite of highly variable and extreme properties, the brine-channel system offers a unique habitat for the so-called sympagic (= ice-associated) community consisting of viruses, fungi, bacteria, protists and metazoans (e.g., Alexander 1980, Horner 1985a, Spindler et al. 1990, Carey 1992, Gradinger et al. 1992, Horner et al. 1992, Swadling et al. 1997). Next to small metazoans living within the ice, a specialized under-ice fauna consisting of several species of amphipods is described for the Arctic (e.g., Lønne & Guliksen 1991a,b, Poltermann 2001, Werner & Gradinger 2002). Sympagic metazoans live within the ice or at the ice-water interface, either permanently (autochthonous) or temporarily (allochthonous).

First observations of the sea-ice biota date back to the end of the 19th century when first polar expeditioners observed brownish or greenish coloured ice floes caused by microalgae (Ehrenberg 1841, Hooker 1847). Early investigations focused predominately on ice algae (for historical review see Horner 1985b), and until now sea-ice algae and factors controlling primary production are still the main focus of sea-ice investigations.

1.5 Sympagic meiofauna

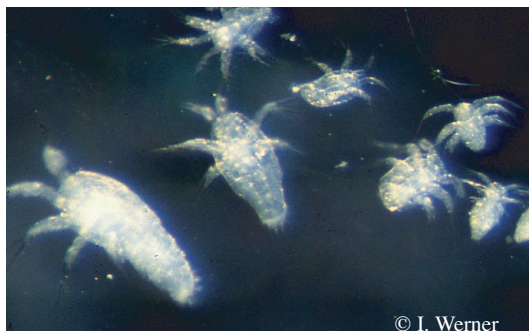
With the exception of bacteria, the heterotrophic component of the sea-ice community has received much less attention than the autotrophic. Andriashev (1968) gave a detailed description of the sea-ice fauna for the first time and described the composition of copepods, nematodes, rotifers, turbellarians and various larvae in the Arctic (Fig. 1.3). Since then several investigations of the sea-ice fauna followed, mainly focussing on fast ice due to its accessibility (e.g., Carey & Montagna 1982, Kern & Carey 1983, Chengalath 1985, Grainger & Mohammed 1986, Grainger & Hsiao 1990, Carey 1992, Michel et al. 2002, Wiktor & Szymelfenig 2002). Comparatively few studies investigated the sympagic fauna of Arctic pack ice (Gradinger et al. 1992, Friedrich 1997, Gradinger 1999a, Friedrich & De Smet 2000, Friedrich & Hendelberg 2001, Nozais et al. 2001).



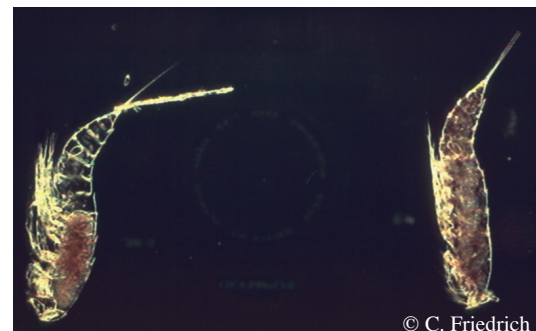
nematod



turbellarian



nauplii



harpacticoid copepods

Figure 1.3: Examples of typical meiofauna organisms occurring in Arctic sea ice.

Highest numbers of sympagic metazoans are typically found in the lowermost part of

the ice (e.g., Melnikov 1997, Gradinger et al. 1999, Schnack-Schiel et al. 2001) where an exchange of water with the underlying water column is possible. Temperature as well as salinity in the bottom layers and the brine-channel system are similar to conditions found in the underlying water. Therefore, conditions do not demand the organisms to experience any acclimation. Due to increasing temperatures towards the ice underside, brine channels are larger and therefore, habitable for larger organisms.

The number of ice-inhabiting metazoan species is comparatively low, suggesting a high specialization (Friedrich 1997, Schnack-Schiel et al. 1998). Conditions within the brine-channel system are extremely variable and thus, organisms inhabiting this habitat have to be able to tolerate pronounced changes in temperature, salinity and available space. Until now, only few experimental studies have investigated this adaptability (Grainger & Mohammed 1990, Friedrich 1997, Gradinger & Schnack-Schiel 1998, Krembs et al. 2000). Detailed studies on the feeding ecology of the sympagic meiofauna are still missing, but several investigations indicate that the organisms feed on algae, bacteria and protists in the ice (Grainger et al. 1985, Hoshiai et al. 1987, Grainger & Hsiao 1990, Norrman & Andersson 1994, Janssen & Gradinger 1999). Additionally, an uptake of dissolved organic material (DOM) by osmotrophic nutrition is proposed for Arctic ice nematodes (Tchesunov & Riemann 1995).

1.6 Purpose of this study

Comparatively little work has been conducted on the seasonal and regional variability of the sympagic meiofauna in Arctic pack ice. The few existing studies on Arctic pack ice focussed mainly on the marginal seas of the Arctic Ocean. Furthermore the majority of these studies have been carried out during seasons with a favourable accessibility of the ice-covered seas, namely spring, summer and autumn (e.g., Gradinger et al. 1991, Gradinger et al. 1992, Friedrich 1997, Gradinger et al. 1999, Friedrich & De Smet 2000, Nozais et al. 2001). Pack-ice studies of sympagic meiofauna comparing different seasons within the same region, as well as studies in the central Arctic Ocean, however, are scarce (Melnikov 1997, Gradinger 1999a, Melnikov et al. 2002). Studies of wintertime pack ice are also extremely rare for both Arctic and Antarctic (Spindler et al. 1990, Melnikov 1997, Garrison & Close 1993, Melnikov et al. 2002), but are important to understand life cycles and organisms' strategies to survive in these extreme environments.

In the present study, quantitative data on abiotic environmental conditions as well as composition, abundance and distribution of sea-ice meiofauna in Arctic pack ice during winter are presented for the first time and compared to summer data from the same region. This information provides implications for possible overwintering strategies of the highly specialized sympagic meiofauna. Furthermore, a geographically large regional comparison from the Fram Strait to the North Pole was carried out during summer in order to assess spatial variability in the composition, distribution and abundance of the sympagic meiofauna.

Thus, the major aims of this study are:

- to describe the seasonal variability in the Arctic pack-ice habitat and of the sympagic

meiofauna in the same region, and

- to describe the regional variability in the Arctic pack-ice habitat and of the sympagic meiofauna during the same season (summer)

This thesis combines the results from three different expeditions, during which pack ice was studied in different seasons and different areas of the Arctic. The results are presented in separate chapters. Chapter 2 deals with physical and biological properties of Arctic pack ice during winter. Chapter 3 summarises seasonal variations in distribution patterns and abundances of sympagic meiofauna in Arctic pack ice. Chapter 4 describes the regional variability of the pack-ice habitat and the sympagic meiofauna along a transect across the eastern basin of the Arctic Ocean. Chapter 5 summarises the main conclusions of the study and presents perspectives for further investigations.

2 Physical and biological properties of Arctic pack ice during winter

2.1 Introduction

The Arctic is characterized by strong seasonal fluctuations. Air-temperature differences of 40–50 °C are usual over the course of a year as are distinct differences in the irradiance, which culminate in polar day and polar night. Not only meteorological conditions but also the most characteristic Arctic feature, the sea ice, alters. Next to quite obvious differences like ice extent, which was found by Maykut (1985) to vary between approximately 7×10^6 km in September and 14×10^6 km in March, Arctic sea ice varies seasonally also in terms of structure and properties. Brine salinity and brine volume, which are both controlled by ice temperature (Assur 1958, Frankenstein & Garner 1967, Leppäranta & Manninen 1988), show distinct seasonal differences with nearly isothermal ice in summer and steeper temperature gradients in spring and summer (Gradinger 1998).

These physical and chemical parameters are of great importance for sympagic organisms, which inhabit the brine-channel system within the ice (for review see Schnack-Schiel 2003) and thus are subjected to extreme seasonal changes. Different studies have revealed the strong relationship between biotic and abiotic parameters of sea ice and distribution patterns of sea-ice biota, such as bacteria, algae, proto- and metazoans (e.g., Gosselin et al. 1986, Zhang et al. 1998, Krembs et al. 2000, Meiners et al. 2002).

Sea ice is classified into coastal fast ice and drifting pack ice, and both kinds of sea ice have been investigated to different degrees in the Arctic owing to differences in accessibility. Several studies have focused on the fast ice of the Canadian Arctic, and some of these were conducted during winter (e.g., Carey & Montagna 1982, Grainger & Hsiao 1990, Carey 1992).

Since pack-ice investigations are primarily ship-based, most studies have been conducted during seasons with favourable weather conditions, namely spring, summer and autumn. Therefore information on winter conditions is still scarce. It remains unclear, how physical and chemical parameters change during winter months and how these conditions affect biological components. Detailed information about habitat conditions of Arctic pack ice is particularly important for a better understanding of life cycles and colonization strategies of sympagic organisms.

In March and April 2003, the expedition ARK XIX-2 with RV “Polarstern” offered the opportunity to investigate pack ice under winter conditions. Results of the expedition, which are presented in this chapter, contribute to a better understanding of the full significance of seasonal changes in sea ice.

2.2 Material and methods

2.2.1 Study area

During the winter expedition ARK XIX-1 of RV “Polarstern” from March to April 2003 (Schauer & Kattner 2004) pack ice and under-ice water were sampled in two different areas: (1) in the northern Fram Strait area, and (2) in the Storfjord area south of Svalbard (Fig. 2.1).

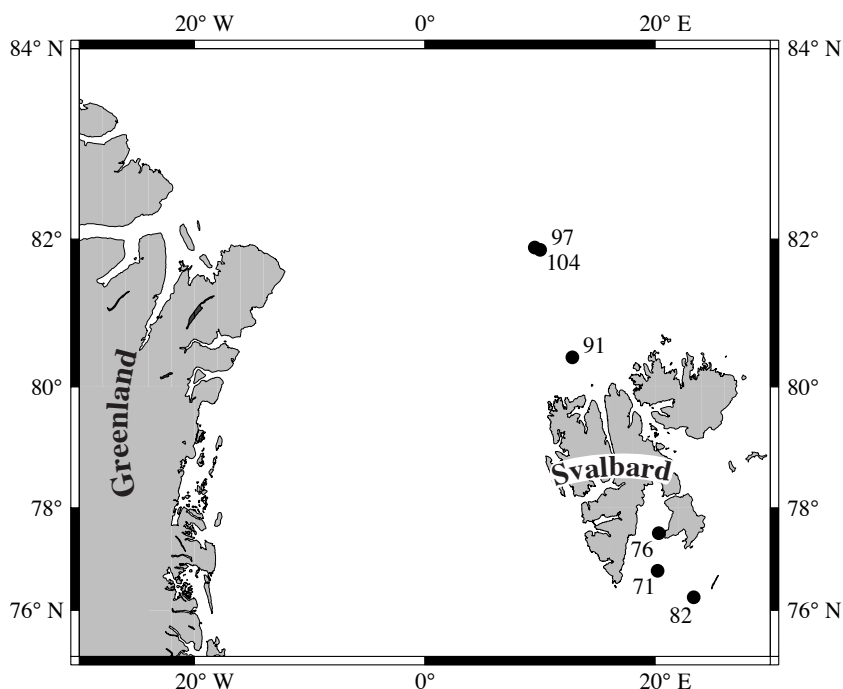


Figure 2.1: Location of sampling sites (indicated by their station numbers) during expedition ARK XIX-1 (March/April 2003) to the northern Fram Strait area (stations 91, 97 and 104) and the Storfjord area (stations 71, 76 and 82). Station numbers represent the day of the year.

The Fram Strait is a 600 km wide passage between Greenland and Spitsbergen, separating the Arctic Ocean in the north from the Greenland Sea in the south. It is the primary path for water exchanges between the Arctic Ocean with the adjacent seas. Major surface currents in the Fram Strait are: (1) the East Greenland Current (EGC), which transports Arctic water masses of low temperature and salinity as well as sea ice southward on the western side of the Fram Strait, and (2) the West Spitsbergen Current (WSC), a northward flow of warm and saline Atlantic water on the eastern side of the Fram Strait (Coachman & Aagaard 1974). The western coast of Spitsbergen is ice-free all year, while permanent ice cover in the Fram Strait is restricted to the EGC due to the continuous transport of Arctic sea ice by the Transpolar Drift, one of the major ice drift systems prevailing in the Arctic Ocean. Roughly 10% of the sea ice in the Arctic Basin annually drifts into the Greenland Sea (Maykut 1985). The northern Fram Strait area is considerably influenced by the Transpolar Drift, which transports sea ice from the western side of the

Table 2.1: Ice stations and meteorological data during the expedition ARK XIX-1 to the Storfjord area (stations 71, 76 and 82) and north of Svalbard (stations 91, 97 and 104). Station numbers represent the day of the year.

Station	Date	Latitude	Longitude	Sea ice cover [%]	Ice thickness [cm]	Air temp. [°C]	Snow temp. [°C]	Snow depth [cm]
71	12 Mar 03	76°48.65'N	20°13.56'E	100	78.3	-28.5	-19.7	12.0
76	17 Mar 03	77°32.15'N	20°19.83'E	95	102.5	-14.3	-16.4	14.4
82	23 Mar 03	76°16.46'N	23°21.63'E	99	84.3	-19.4	-14.7	18.2
91	01 Apr 03	80°25.95'N	12°49.06'E	100	168.0	-27.4	-26.3	10.2
97	07 Apr 03	81°53.90'N	09°34.12'E	100	175.0	-19.7	-17.8	34.0
104	14 Apr 03	81°52.04'N	10°02.81'E	100	245.5	-2.7	-4.9	9.6

basin across the central Arctic Ocean through the Fram Strait. With the exception of one station (St. 91), all stations sampled north of Svalbard were located in this area.

The currents in the Storfjord have not been studied in detail but a cyclonic current, named Sørkappstrømmen, is believed to be present, entering Storfjorden from the south-east and exiting in the southwest of the fjord (Norges Sjøkartverk 1990). This coastal current originates from the East Spitsbergen Current, which transports Arctic water southwestward through the opening between Svalbard and Frans Josef Land (Loeng 1991). It transports pack ice westward from the Barents Sea. A flaw polynya (a polynya situated between fast and pack ice), which occurs regularly in the eastern part, is a typical feature of the Storfjord and of great importance regarding the ice formation in this region (Haarpaintner et al. 2001). During the expedition ARK XIX-1 the Storfjord was completely ice-covered and the Storfjord polynya was covered by thin ice.

2.2.2 Sampling

On each of a total of six stations (Table 2.1) two ice cores (denoted A and B) were drilled with a motor-powered KOVACS ice corer (internal diameter: 9 cm) in areas of non-deformed ice. Stations 97 and 104 were sampled during a drift-ice station, which was occupied for 10 days. In order to minimize heterogeneity, all cores were drilled within an area of 1 m². Generally, the uppermost parts of the cores were cut into 20 cm segments, while the lowermost 10 cm were cut into 1–6 cm segments to give a higher depth resolution.

Under-ice water was sampled at all stations through drilled holes using a polyethylene tube (internal diameter: 4 cm) with a valve at one end. The unequipped end was lowered into the water with the valve open. At a depth of 10 m the valve was closed and the tube with the enclosed water was hoisted to the surface. Water samples were released into acid-cleaned plastic cans. With the exception of station 104, salinity, algal-pigment concentrations as well as nutrient concentrations were determined for these integrated (0–10 m) water samples.

2.2.3 Meteorological conditions and ice thickness

At all stations, meteorological conditions were characterized by measuring air and snow temperatures and by determination of snow depth. Temperature was measured with a Testotherm 720 thermometer (measurement accuracy ± 0.2 °C). Snow depth was determined from five randomly chosen thickness measurements within the sampling area.

2.2.4 Ice temperature, bulk and brine salinity, brine volume and algal pigments

Ice thickness was determined as the mean length of core A and B. Core A was used for determination of ice temperature, bulk salinity, and chlorophyll *a* content. Immediately after drilling the core was placed into an isolating PVC-pipe, and ice temperature was measured with a Testotherm 720 thermometer inside small holes, drilled into the core at 5–10 cm intervals. After cutting, the segments were placed into acid-cleaned polyethylene-boxes and melted onboard at 4 °C in the dark. Once melted, bulk salinity was measured with a WTW 190 conductometer. For determination of chlorophyll *a* concentrations melted ice samples were filtered onto Whatman GF/F filters, extracted in 90% acetone, homogenized and analyzed fluorometrically with a Turner Designs 10-AU digital fluorometer according to Evans and O'Reilly (1983). Detection limit of this method was $0.1 \mu\text{g chl } a \text{ l}^{-1}$. Based on ice-temperature and bulk-salinity measurements, brine salinity was calculated as a function of ice temperature (Assur 1958) and brine volume was calculated as a function of bulk ice salinity and ice temperature (Frankenstein & Garner 1967, Leppäranta & Manninen 1988).

2.2.5 Nutrients

Core B was cut into 1–20 cm segments, which were sealed in clean plastic bags and kept frozen (-20 °C) for analyses of nitrate, nitrite, phosphate and silicate. Measurements of nutrient concentrations were conducted at the Institute of Marine Research at the University of Kiel following standard methods as described in Spies et al. (1988).

2.2.6 Statistics

In order to determine relationships between parameters, non-parametric Spearman Rank-correlation test was used.

2.3 Results

2.3.1 Meteorological conditions and ice thickness

The results of ice-thickness measurements and meteorological investigations during ARK XIX-1 are summarized in Table 2.1. During the study period in March and April, air and snow showed typical winter temperatures with values far below 0 °C. Lowest air temperatures of close to -30 °C were measured at stations 71 and 91. Maximum air and snow temperatures were measured at the end of the cruise at station 104. All sampling sites were completely snow-covered with snow depths between 9.6 and 34.0 cm.

Ice thickness in the western Barents Sea was below 103 cm and ranged between 168 cm and 246 cm north of Svalbard.

2.3.2 Ice temperature, bulk and brine salinity, brine volume and algal pigments

At all stations ice temperature was lowest at the surface (Fig. 2.2, Fig. 2.3) and increased significantly with depth (Spearman-Rank correlation: $p < 0.05$). Values ranged between -21.9 °C and -8.3 °C in uppermost 5 cm and increased to a maximum of -2.4 °C (station 76) at the ice underside. The lowest temperature near the ice-water interface ($T = -5.2$ °C) was measured at station 91 (Fig. 2.3).

The bulk salinity of the ice ranged from $S = 0$ to 12 with lowest values near the surface, increasing with depth (Fig. 2.2, Fig. 2.3). Bulk salinity was positively correlated with depth (Spearman-Rank correlation: $p < 0.05$) with the exception of station 82. The ice core taken at this station showed highest bulk-salinity values at the surface and a second maximum near the ice underside.

Calculated brine-salinity profiles followed temperature profiles (Fig. 2.2, Fig. 2.3). Brine salinity decreased with depth and showed minimum values near the ice underside. Brine salinity was highest with $S = 223$ (station 91) in an ice segment with extremely low temperature, while most of the values ranged between $S = 40$ and 160.

Profiles of brine volume were similar for stations 76, 97 and 104 (Fig. 2.4, Fig. 2.5). Values were nearly 0% at the top of the ice and increased with depth to values varying from 9 to 21%. Brine volume was always positively correlated with depth (Spearman-Rank correlation: $p < 0.05$). Small deviations regarding this trend were found at stations 82 and 91, where brine volume peaked slightly above the ice underside. Furthermore, the elevated brine volume in the uppermost 40 cm of station 82 differed from the other stations (Fig. 2.4). Due to the lack of bulk-salinity values for the lowermost three ice segments, the brine-volume profile for station 71 is incomplete.

In some horizons of the ice cores sampled during ARK XIX-1 chlorophyll *a* (chl *a*) concentrations were below or near the detection limit ($< 0.1 \mu\text{g chl } a \text{ l}^{-1}$) (Fig. 2.4, Fig. 2.5). Most of the measured values were below $1.0 \mu\text{g chl } a \text{ l}^{-1}$, with a median of $0.2 \mu\text{g chl } a \text{ l}^{-1}$. Maximum concentration was measured near the ice-underside of station 104 ($3.4 \mu\text{g chl } a \text{ l}^{-1}$). All other profiles showed only slightly elevated chlorophyll *a* values in the interior of the ice. At stations 76, 82 and 104 chlorophyll *a* was positively correlated with depth (Spearman-Rank correlation: $p < 0.05$). Chlorophyll *a* concentrations in the under-ice water (0–10 m) were below the detection limit at all stations.

2.3.3 Nutrients

Vertical profiles of nutrient concentrations for ice and under-ice water are presented in Figure 2.6 (stations 71, 76 and 82) and Figure 2.7 (stations 91, 97 and 104).

Nitrate concentration varied between $0.2 \mu\text{mol l}^{-1}$ and $17.7 \mu\text{mol l}^{-1}$ with a median of $1.1 \mu\text{mol l}^{-1}$ and was significantly correlated with depth at stations 76, 91, 97 and 104 (Spearman-Rank correlation: $p < 0.05$). Concentrations in the under-ice water were generally higher than in the ice. Nitrite concentrations were mostly below $0.2 \mu\text{mol}$

l^{-1} (median: $0.1 \mu\text{mol l}^{-1}$) and showed slightly elevated concentrations at station 91 (maximum: $0.4 \mu\text{mol l}^{-1}$) (Fig. 2.7). Also phosphate concentrations were highest at station 91: maximum concentration was $5.1 \mu\text{mol l}^{-1}$, and in most ice segments of this station concentrations were higher than $2.0 \mu\text{mol l}^{-1}$. At the other stations values in the ice were mostly below $1.0 \mu\text{mol l}^{-1}$ and the median of all stations was $0.3 \mu\text{mol l}^{-1}$. Neither nitrite nor phosphate showed any significant correlation with depth. Silicate concentrations were generally higher in the under-ice water than in the ice and were, like nitrate, significantly correlated with depth at stations 76, 91, 97 and 104 (Spearman-Rank correlation: $p < 0.05$). Highest silicate concentration in the ice was measured at station 82 ($3.0 \mu\text{mol l}^{-1}$). With the exception of station 104, molar N/P ratios in the ice as well as in the under-ice water were below 16 (the Redfield-ratio).

In order to interpret whether variations within the ice are related to physical or biological processes, nutrient concentrations in melted ice samples are presented as a function of bulk salinity in Figure 2.8. All values were above dilution lines, extrapolated from nutrient concentrations of Arctic seawater measured in the Fram Strait in autumn (salinity: 33; nitrate: $2.2 \mu\text{M}$; nitrite: $0.08 \mu\text{M}$; phosphate: $0.31 \mu\text{M}$; silicate: $1.0 \mu\text{M}$; Meinert et al. 2003).

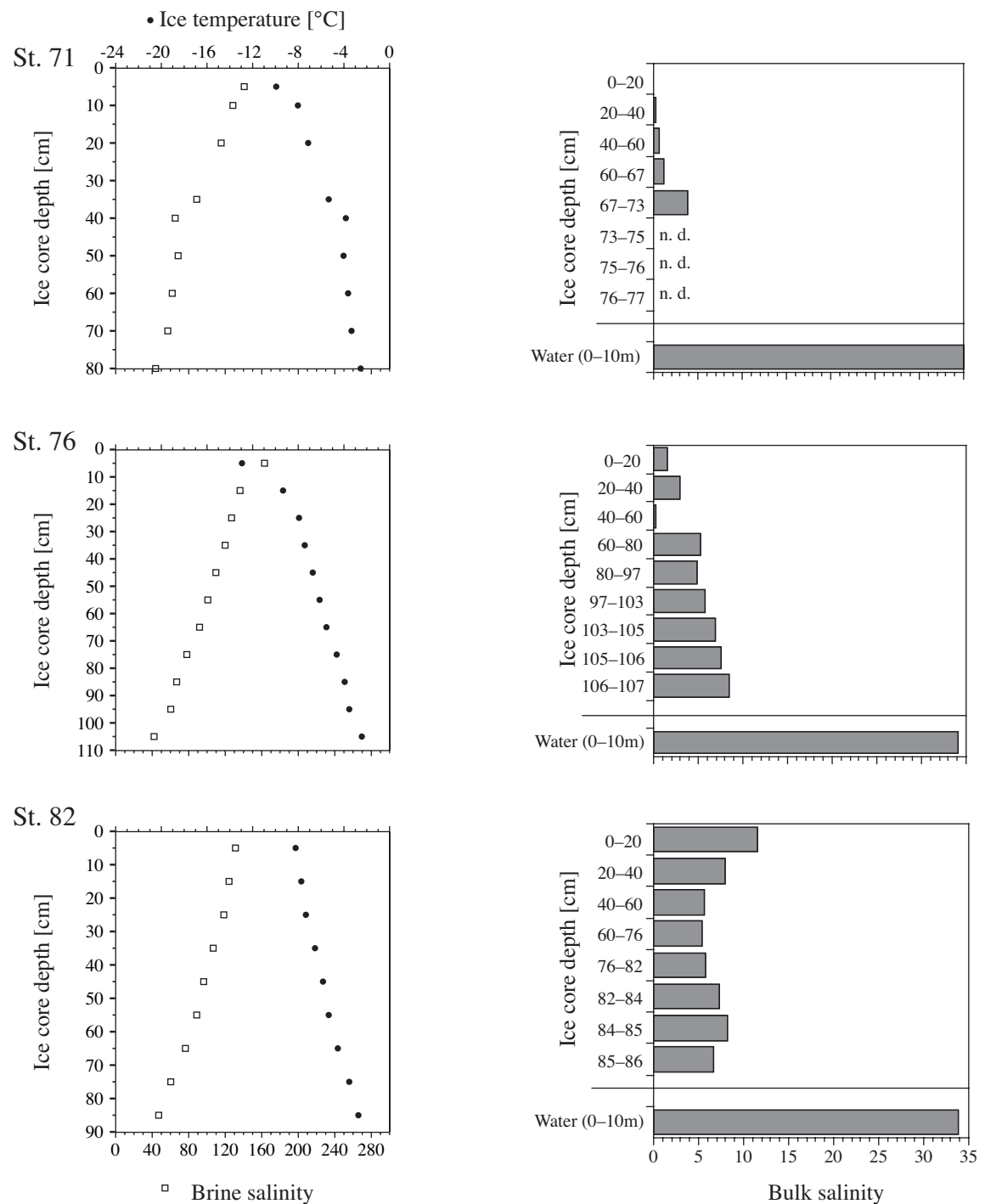


Figure 2.2: Vertical distribution of ice temperature, brine salinity, and bulk salinity in Arctic pack ice and salinity of under-ice water during ARK XIX-1 (stations 71, 76 and 82). The abbreviation “n. d.” means “not determined”.

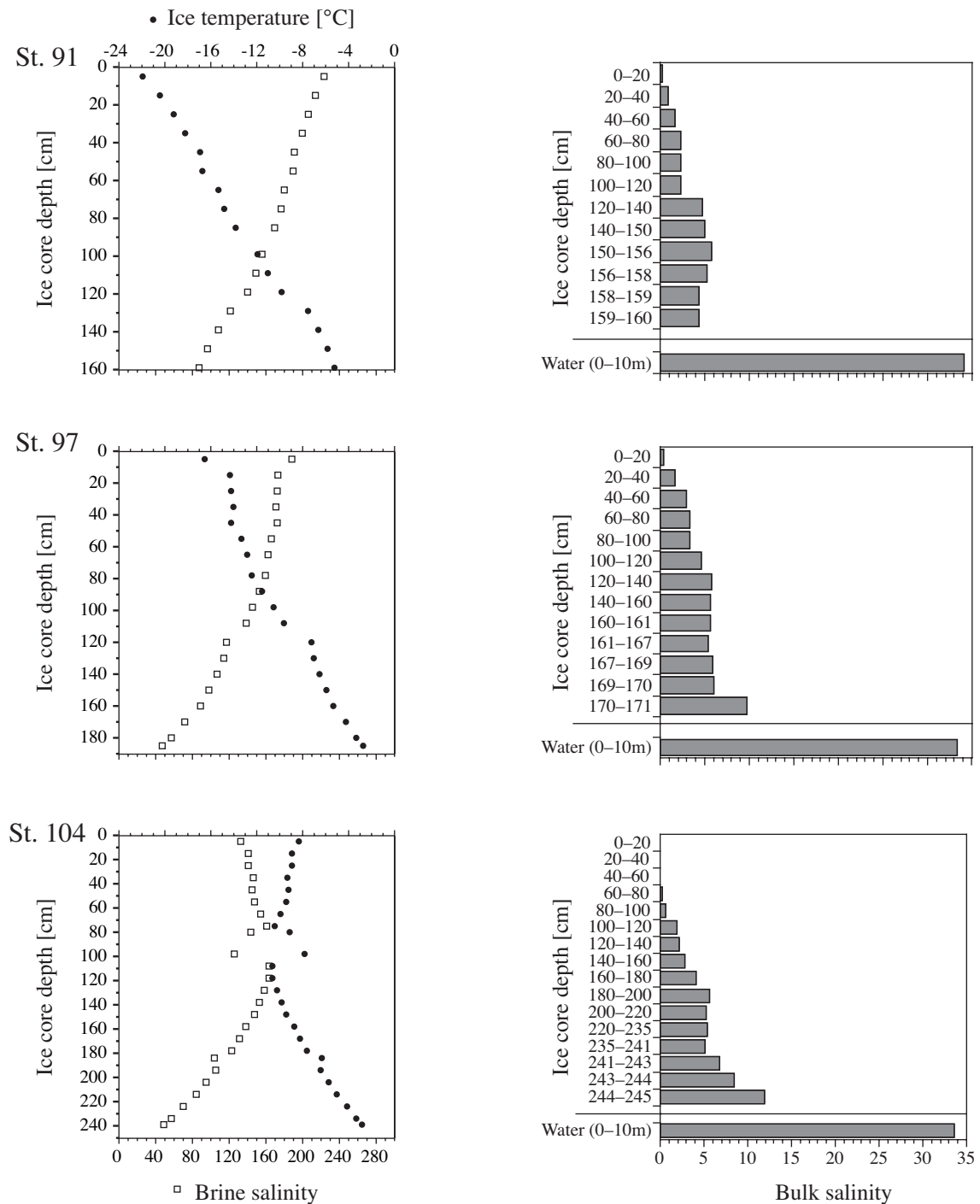


Figure 2.3: Vertical distribution of ice temperature, brine salinity, and bulk salinity in Arctic pack ice and salinity of under-ice water during ARK XIX-1 (stations 91, 97 and 104).

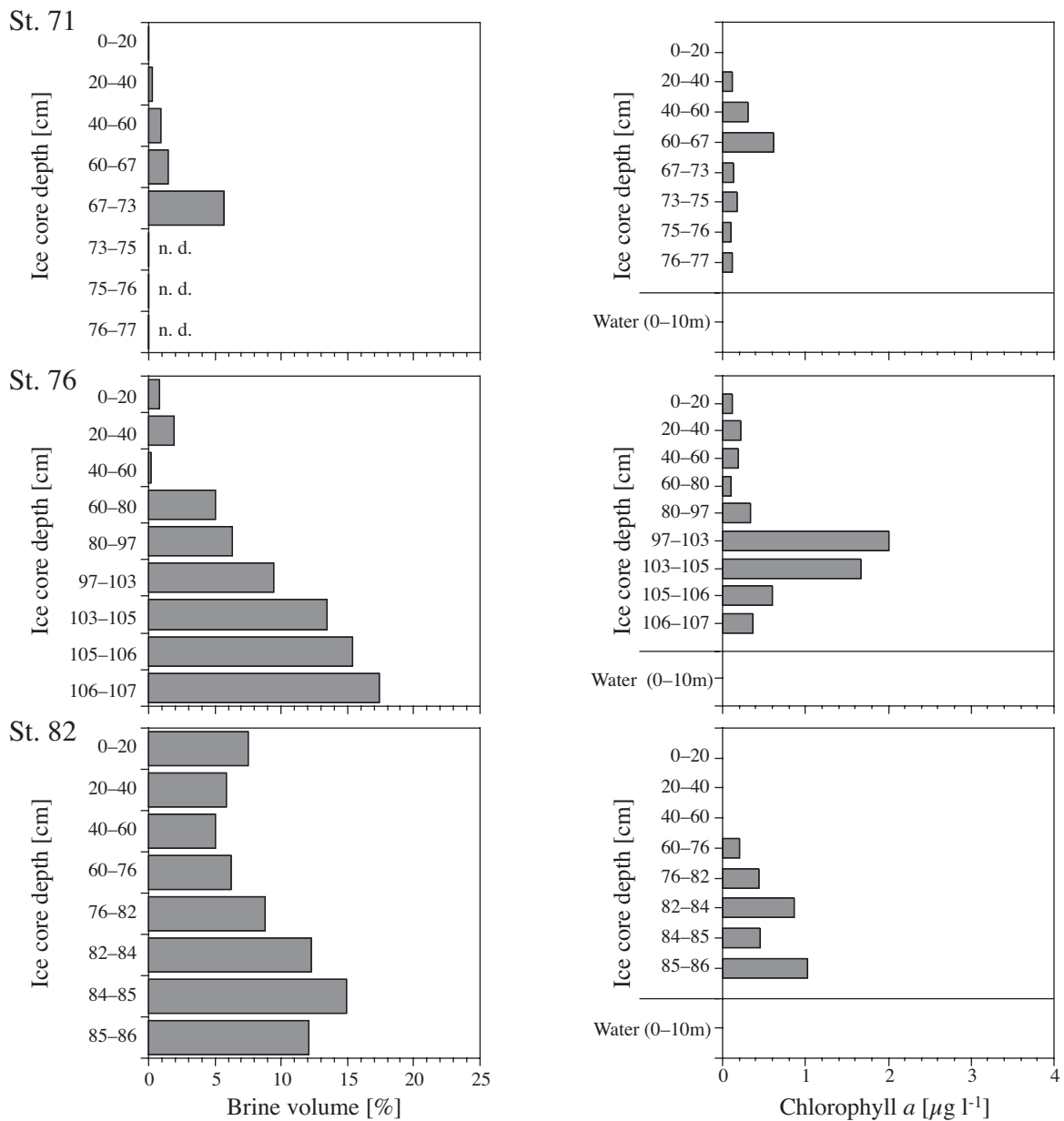


Figure 2.4: Vertical distribution of brine volume and chlorophyll *a* concentration in Arctic pack ice and chlorophyll *a* concentration of under-ice water during ARK XIX-1 (stations 71, 76 and 82). The abbreviation “n. d.” means “not determined”. For chlorophyll *a*, missing bars indicate values below detection limit.

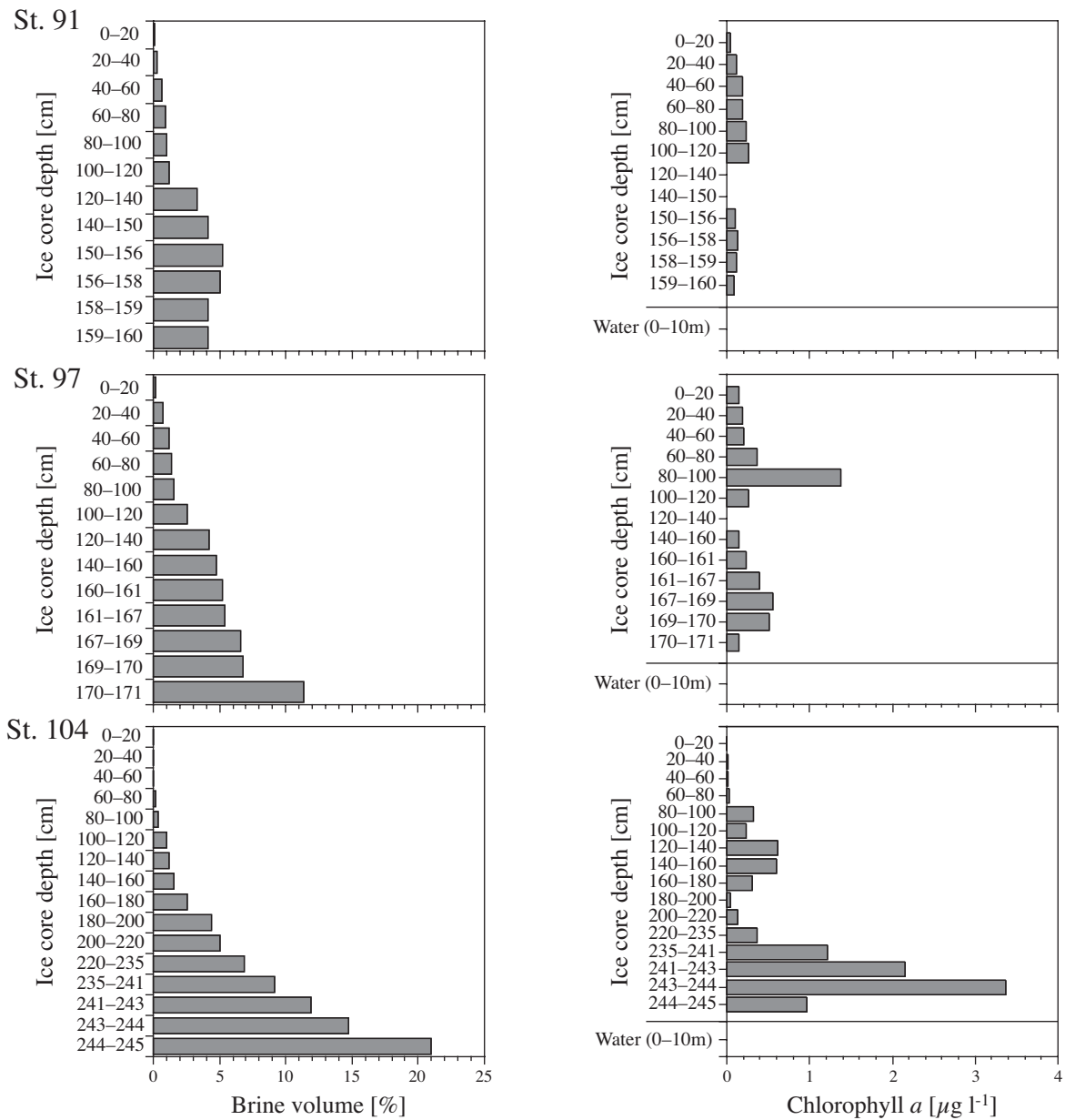


Figure 2.5: Vertical distribution of brine volume and chlorophyll *a* concentration in Arctic pack ice and chlorophyll *a* concentration of under-ice water during ARK XIX-1 (stations 91, 97 and 104). For chlorophyll *a*, missing bars indicate values below detection limit.

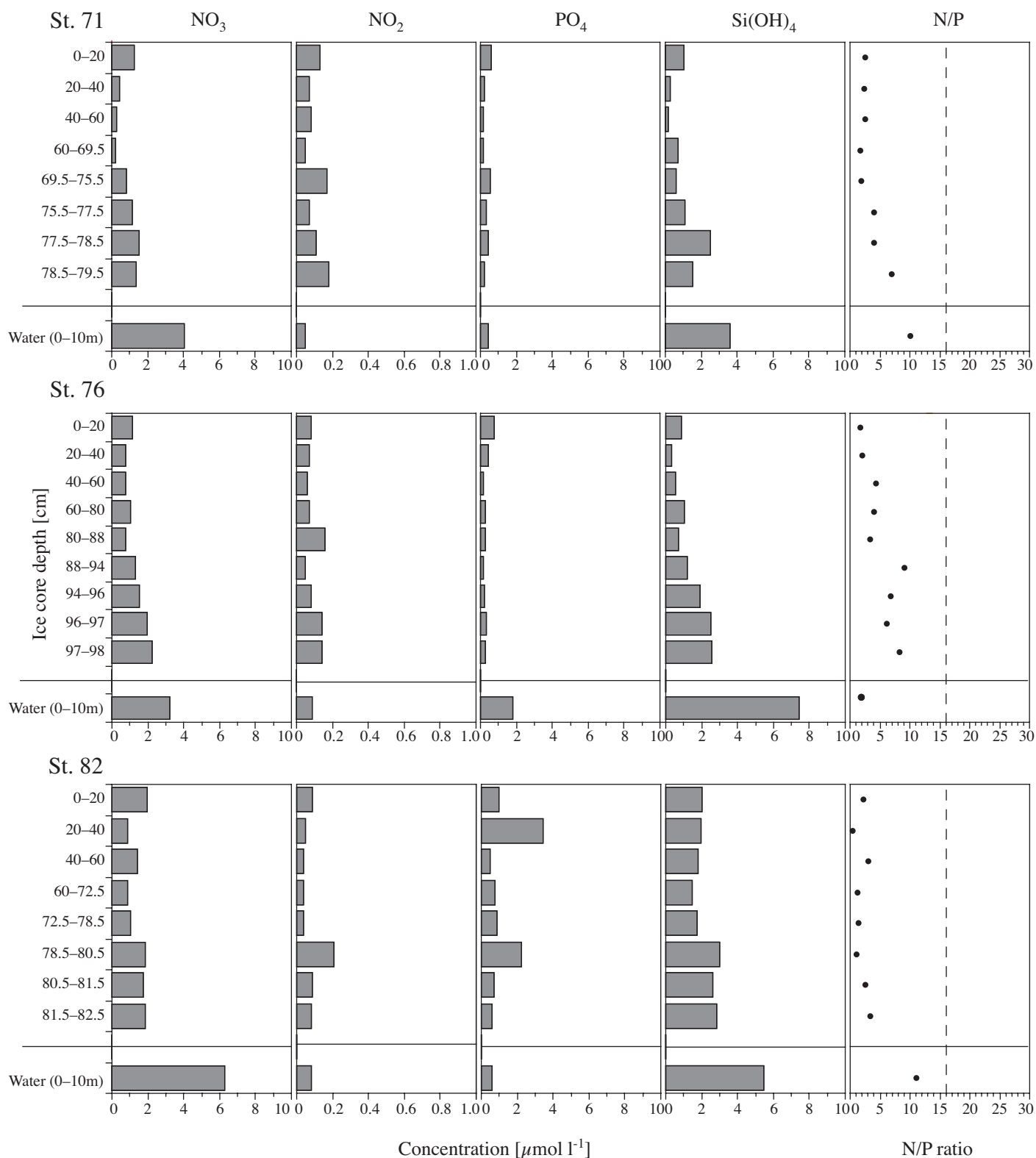


Figure 2.6: Vertical distribution of nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), silicate (Si(OH)_4) and molar N/P ratios in Arctic pack ice and of under-ice water during ARK XIX-1 (stations 71, 76 and 82). Note different scales on x-axes.

2 Physical and biological properties of Arctic pack ice during winter

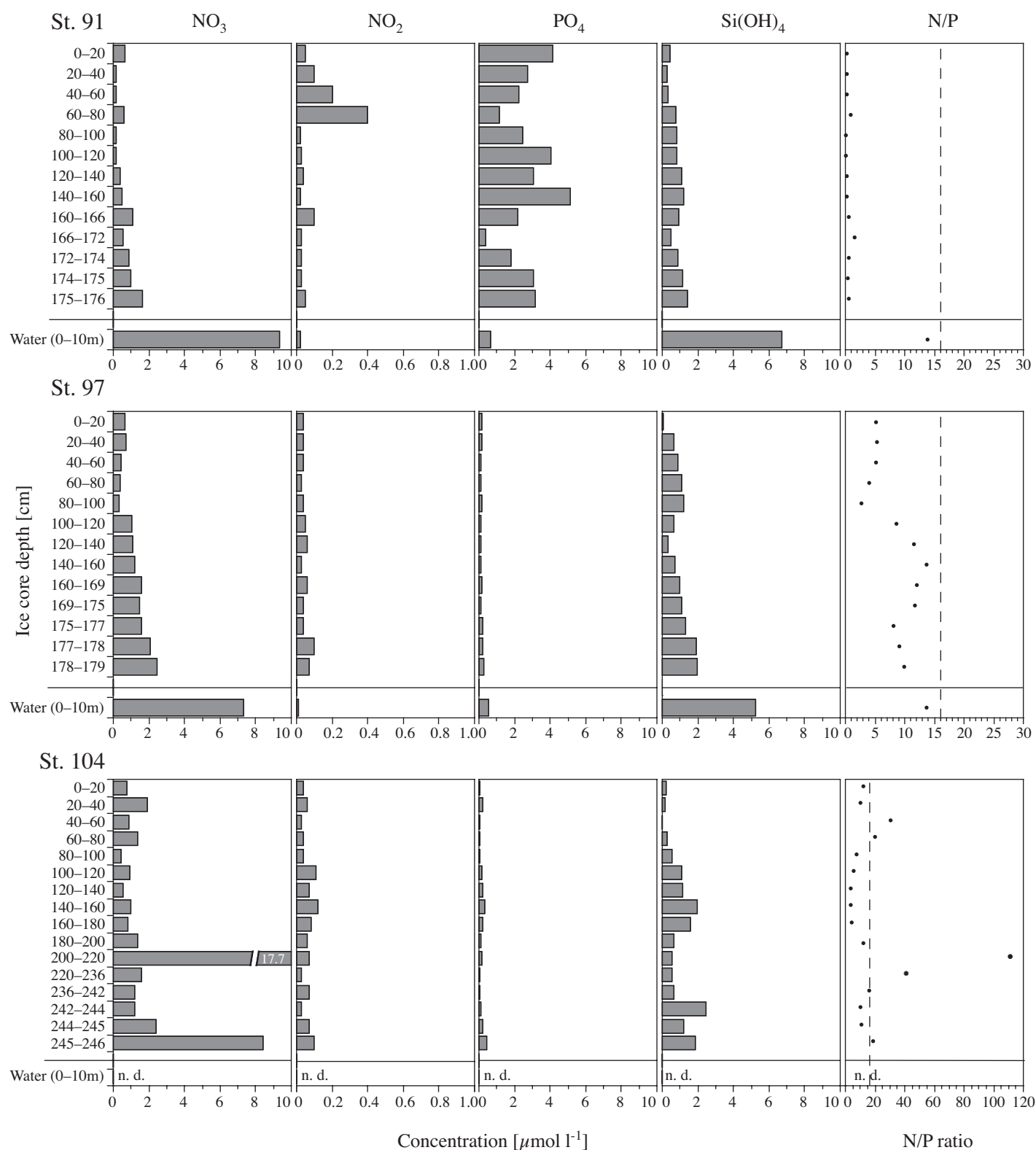


Figure 2.7: Vertical distribution of nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), silicate (Si(OH)_4) and molar N/P ratios in Arctic pack ice and of under-ice water during ARK XIX-1 (stations 91, 97 and 104). The abbreviation “n. d.” means “not determined”. Note different scales on x-axes.

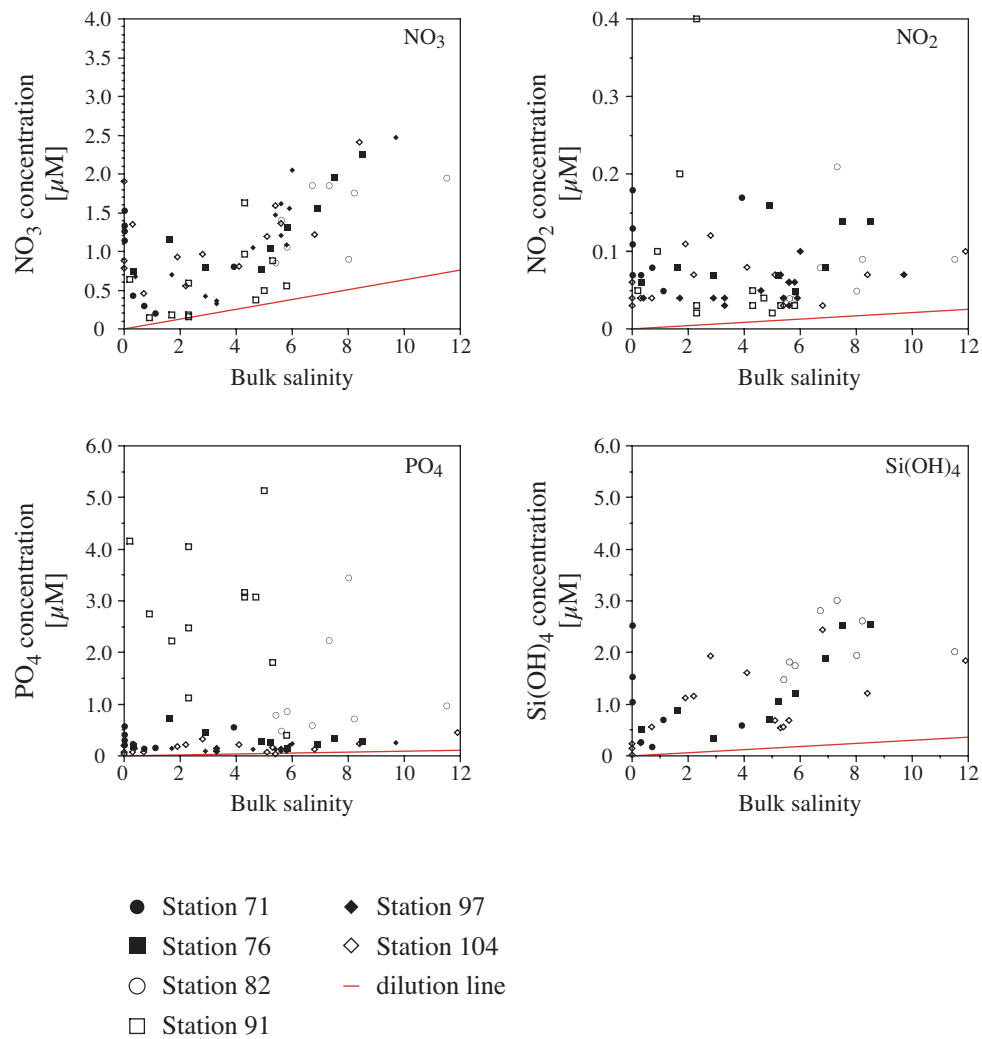


Figure 2.8: Nutrient concentrations as a function of bulk salinity. The dilution line is the nutrient/salinity relationship determined from Arctic surface waters (see text).

2.4 Discussion

2.4.1 Arctic winter

Although sea-ice sampling during ARK XIX-1 took place in March and April, what might be described as the beginning of spring rather than winter, there are several reasons to consider this cruise as a winter expedition. An explicit definition for the onset and ending of winter is difficult to find as there are different aspects to consider (e.g., calendrical, meteorological, biological). Typical characteristics of the Arctic winter, however, are simpler to define: ice extent reaches the maximum, temperatures decrease far below 0 °C, snow fall occurs and daylight is absent or low. All these characteristics apply to the conditions found during expedition ARK XIX-1, so this cruise was suitable for investigating Arctic pack ice under winter conditions.

Results of the investigation indicate that physical properties of wintertime pack ice are distinctively heterogeneous considering the whole ice thickness. Therefore, for further discussion the upper and the lower part of the ice will be considered separately. The lower part comprises the lowermost 20 cm of the ice, since condition within this portion of the ice seem to be quite similar. The thickness of the upper part depends on total ice thickness, which varied remarkably between the two study areas (78.3 cm to 245.5 cm).

2.4.2 Conditions near the upper surface of the ice

In the upper part of the Arctic pack ice, physical properties in winter clearly differ from those described for other seasons. One of these properties is ice temperature, which is important as it affects brine salinity and brine volume. Both parameters control the structure of the sea-ice habitat (Weissenberger 1992, Krembs et al. 2000).

Since ice temperature in the upper part of the ice is strongly influenced by air temperature, distinct seasonal differences occur. During summer ice temperatures typically decrease with depth and are highest near the surface with values near 0 °C (Friedrich 1997, Gradinger 1998). In winter opposite conditions were found with minimum temperatures of –22 °C at the surface and maximum values of roughly –3 °C near the ice underside. Similar temperature ranges are published for wintertime pack ice (Thomas et al. 1995) and fast ice (Krembs et al. 2002).

Like ice temperature, brine salinity and brine volume in winter differed from those which are typically reported for other seasons (e.g., Eicken et al. 1995, Gradinger et al. 1999). At most stations sampled during ARK XIX-1 the upper part of the ice was characterized by brine salinities close to or exceeding $S = 100$ and brine volumes less or equal to 5%. This latter aspect is of special importance as according to Golden et al. (1998) sea ice becomes impermeable for fluid transport at a brine volume below 5%.

All physical parameters, which seem to be characteristic for the winter situation in the upper part of Arctic pack ice, represent unfavourable conditions for ice algae. Investigations of salinity tolerance of Antarctic ice algae, for example, showed that no cell division occurs that above salinities of $S = 100$ (Bartsch 1989). Measurements of chlorophyll *a* concentrations in the present study also indicate low ice-algal biomasses: values in the uppermost part of the ice were mostly below $0.2 \mu\text{g l}^{-1}$.

2.4.3 Conditions near the ice-water interface

The lowermost 20 cm of the ice are characterized by physical conditions, which are very similar to those reported for other seasons, suggesting a less pronounced seasonality. Ice temperatures ranged between -2.4 °C and -5.2 °C and consequently calculated brine salinities, ranging between 42 and 87, were within the range reported for other seasons (e.g., Gradinger 1998). Also brine volumes were similar to those reported for other seasons. With values ranging between 4% and 21% in the lowermost 20 cm of the ice, brine volume was mostly above 5% and therefore above the threshold for fluid transport (Golden et al. 1998).

Nutrient concentrations in the lowermost 20 cm of the pack ice were comparable or even elevated to results published for other seasons (Gradinger 1998, Mock & Gradinger 1999, Meiners et al. 2003). Furthermore, concentrations were higher than nutrient concentrations reported for Arctic pack ice in winter (Thomas et al. 1995, Melnikov et al. 2002).

Different processes control nutrient concentrations in the ice. Next to physical depletion due to brine loss, biological uptake or regeneration can also change nutrient concentrations in the ice. Dilution curves presenting nutrient/salinity ratios of sea ice and the seawater can be helpful to interpret how variations in the ice are related to these different controlling factors. Generally, if nutrient ions remain in the brine fraction and are only affected by brine loss from ice floes, nutrient/salinity ratios which are characteristic for seawater, should be maintained in the ice (Garrison et al. 1990). Since the exact concentration in the water from which the ice was formed is unknown, dilution curves can only give a rough estimate for concentration processes that have occurred. Nevertheless, they can help to distinguish between physical and biological processes.

Nitrate, nitrite, phosphate and silicate measured during ARK XIX-1 were present in concentrations in excess of those predicted by dilution curves. Thus, this result differs from results published for wintertime sea ice by Thomas et al. (1995) and Garrison et al. (1990), who found nutrient depletion, suggesting biological uptake. The nutrient enrichment found in the present study is explainable by nutrient regeneration during winter and the lack of nutrient-consuming activity, e.g., by ice algae. A previously published study revealed bacterial activity in wintertime sea ice at temperatures down to -20 °C (Junge et al. 2004). Furthermore, the low chlorophyll *a* concentrations in the present study, with most values below $1.0 \mu\text{g chl } a \text{ l}^{-1}$, indicate low standing stocks of ice algae and thus, low nutrient depletion. However, the low molar N/P ratios, with most of the values below 16 (the Redfield-ratio), indicate that nitrogen would be the nutrient limited first.

Control of algal growth is attributed to two factors at different times: during the early stages of spring, the algal bloom in Arctic sea ice is light-limited, while during the later stages it is nutrient-limited (Gosselin et al. 1990, Cota et al. 1991). Although the daylight period already lasted 6 hours at the beginning of the cruise and increased rapidly during the study, light levels in bottom parts of the ice were presumable low as light penetration is drastically affected by the amount of snow cover on the floes (e.g., Bunt & Lee 1970, Sullivan & Palmisano 1981). Snow cover and ice thickness can lead to attenuation

of incident irradiance down to values $< 0.1\%$ beneath the ice (Maykut 1985), and according to these estimates, under-ice irradiance in the present study was at best 8% (for station 71 with an ice thickness of 78 cm and snow cover of 12 cm) but mostly lower than 1%. Since light conditions were not measured during the expedition, the question, whether light levels were already sufficient for a starting ice-algal bloom, remains a matter of speculation. However, the low but detectable chlorophyll *a* concentrations measured during the cruise indicate physiologically intact algal cells. This assumption is also confirmed by preliminary results of HPLC analyses of samples, which were collected during the same expedition (J. Schwarz, pers. comm.).

The results of the present study indicate that physical conditions in the lowermost centimetres of ice should be suitable for other sympagic organisms, such as protozoans and metazoans. It may therefore be of further interest to investigate, whether these organisms take advantage of the moderate conditions for resting in the ice during winter, since strategies of sympagic metazoans for surviving the polar winter are still unknown (Schnack-Schiel 2003).

3 Seasonal variations in distribution patterns and abundances of sympagic meiofauna in Arctic pack ice

3.1 Introduction

Seasonality is very pronounced in the Arctic and consequently Arctic pack ice is subjected to extreme seasonal variations as well. Next to ice extent, which varies between 7×10^6 km² and 14×10^6 km² (Maykut 1985), also physical and chemical properties of the ice differ throughout the year (Gradinger 1998, Thomas et al. 1995) and cause distinct changes in the sea-ice habitat. When the ice cools during winter, the fraction of liquid brine decreases and brine salinity increases (Cox & Weeks 1983, Eicken et al. 2000). Thus, winter sea ice with temperatures below -15 °C near the surface is characterized by brine salinities around 200 and brine volumes $< 1\%$. Furthermore, brine channels become increasingly disconnected with decreasing temperatures (e.g., Weissenberger et al. 1992, Golden et al. 1998). Also light conditions show a distinct seasonal variability, limiting the growth of photoautotrophic organisms. Seasonal changes in solar irradiance, but also ice thickness and snow cover, which can lead to attenuation of incident irradiance down to values $< 0.1\%$ beneath the ice (Maykut 1985), alter light conditions in the ice remarkably during the year.

Several sea-ice studies revealed the existence of a specialized sympagic community, including bacteria, viruses, fungi, algae, protists and metazoans (e.g., Alexander 1980, Carey 1985, Spindler & Dieckmann 1986, Horner et al. 1992, Schnack-Schiel et al. 1998), but reports on physiological limits of temperature, salinity and available space of sea-ice organisms are still rare (Bartsch 1989, Kottmeier & Sullivan 1990, Helmke & Weyland 1995, Spindler 1996, Friedrich 1997, Gradinger & Schnack-Schiel 1998, Krembs et al. 2000, Junge et al. 2004).

Although the processes of initial incorporation of organisms into the ice are already basically known (Garrison et al. 1983, Spindler & Dieckmann 1986, Spindler 1990, Gradinger & Ikävalko 1998), the fate of organisms after incorporation, their winter-survival and subsequent growth are still a matter for speculation. Seasonal dynamics of the pack-ice biota and their survival mechanisms during the winter months are not well understood due to the lack of winter data. While distribution patterns of sympagic meiofauna organisms in pack ice during spring, summer and autumn were already subjects of some studies (e.g., Gradinger et al. 1992, Friedrich 1997, Friedrich & Hendelberg 2001, Nozais et al. 2001), comparatively little is known about wintertime pack ice (Garrison & Close 1993).

During two expeditions in late summer 2002 and winter 2003 with RV "Polarstern", Arctic pack ice and under-ice water were sampled and biotic and abiotic properties were investigated. The aim of this study was to describe seasonal differences in species compo-

sition, abundance and distribution patterns of sympagic metazoans and to place this in the context of abiotic and biotic pack-ice properties. Investigations of species distribution of sympagic metazoans in winter pack ice were expected to provide indications of their seasonal life cycles and overwintering strategies.

3.2 Material and methods

3.2.1 Study area

During two expeditions of the RV “Polarstern” pack ice and under-ice water samples were collected during two different seasons: late summer (September 2002, ARK XVIII-2) and winter (March/April 2003, ARK XIX-1) (for details see: Jokat 2003 and Schauer & Kattner 2004). During the expedition ARK XVIII-2 a total of five stations was sampled in the northern Fram Strait. During the expedition ARK XIX-1 six stations were sampled, which were located in two different areas: (a) in the Storfjord area south of Svalbard, and (b) in the northern Fram Strait. With the exception of one station (station 91), the second half of cruise ARK XIX-1 was in the vicinity of the area, sampled during late summer expedition ARK XVIII-2 (Fig. 3.1). A detailed description of both study areas is given in Chapter 2.

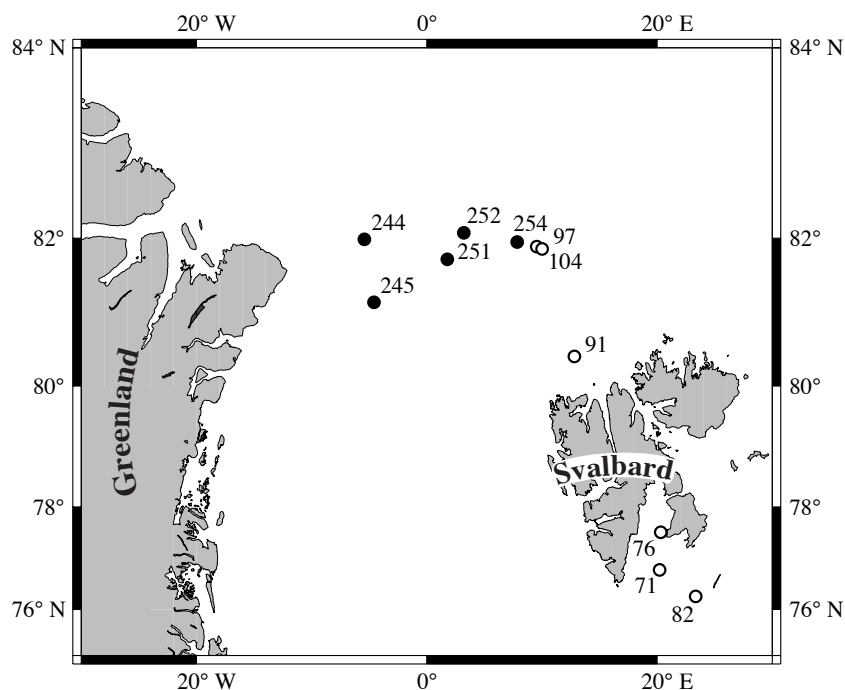


Figure 3.1: Location of sampling sites (indicated by their station numbers) during expeditions ARK XVIII-2 (August/September 2002, filled dots) and ARK XIX-1 (March/April 2003, open dots). Station numbers represent the day of the year.

During the expedition ARK XIX-1, the Storfjord was completely ice-covered and the Storfjord polynya was refrozen and covered by thin ice.

Table 3.1: Ice stations and abiotic data during expeditions ARK XVIII-2 and ARK XIX-1 to the northern Fram Strait (ARK XVIII-2: stations 244–254; ARK XIX-1: stations 91, 97 and 104) and the Storfjord area (ARK XIX-1: stations 71, 76 and 82). Station numbers represent the day of the year.

Station	Date	Latitude	Longitude	Sea ice cover [%]	Ice thickness [cm]	Air temp. [°C]	Snow temp. [°C]	Snow depth [cm]
244	02 Sep 02	81°59.05'N	5°23.90'W	30	200.0	−1.2	−1.0	3.5
245	03 Sep 02	81°11.02'N	4°35.03'W	70	205.0	−3.2	−3.1	2.7
251	09 Sep 02	81°44.38'N	1°47.37'E	100	138.5	−7.2	−7.9	1.0
252	10 Sep 02	82°03.64'N	3°14.69'E	90	250.5	−0.5	−0.5	10.0
254	12 Sep 02	81°57.21'N	7°52.71'E	80	282.0	−2.8	−1.3	6.6
71	12 Mar 03	76°48.65'N	20°13.56'E	100	78.3	−28.5	−19.7	12.0
76	17 Mar 03	77°32.15'N	20°19.83'E	95	102.5	−14.3	−16.4	14.4
82	23 Mar 03	76°16.46'N	23°21.63'E	99	84.3	−19.4	−14.7	18.2
91	01 Apr 03	80°25.95'N	12°49.06'E	100	168.0	−27.4	−26.3	10.2
97	07 Apr 03	81°53.90'N	09°34.12'E	100	175.0	−19.7	−17.8	34.0
104	14 Apr 03	81°52.04'N	10°02.81'E	100	245.5	−2.7	−4.9	9.6

3.2.2 Sampling

At all stations (Table 3.1) four ice cores (denoted A, B, C and D) were drilled with a motor-powered KOVACS ice corer (internal diameter: 9 cm) in areas of non-deformed ice. In order to minimize heterogeneity, all cores were obtained within an area of 1 m². Generally, the uppermost parts of cores A and B were cut into 20 cm segments, while the lowermost 10 cm were cut into 1–6 cm segments to gain higher vertical resolution.

Under-ice water was sampled at all stations through drilled holes using a polyethylene tube (internal diameter: 4 cm) with a valve at one end. The unequipped end was lowered into the water with the valve open. At a depth of 10 m the valve was closed and the tube with the enclosed water was hoisted to the surface. Water samples were released into acid-cleaned plastic cans.

3.2.3 Meteorological conditions and ice thickness

At all stations meteorological conditions were characterized by measuring air and snow temperatures and by determining snow depth. Snow and air temperature were measured with a Testotherm 720 thermometer (measurement accuracy ± 0.2 °C), determination of snow temperature was carried out in a depth of approximately 7 cm. Snow depth was determined from five randomly chosen thickness measurements within the sampling area. Ice thickness was determined as the mean length of core A and B.

3.2.4 Physical and biological ice properties

Core A was used for the determination of ice temperature, bulk salinity, and chlorophyll *a* content. Immediately after drilling, the core was placed into an isolating PVC-pipe,

and ice temperature was measured with a Testotherm 720- thermometer inside small holes, drilled into the core at 5–10 cm intervals. After cutting, the segments were placed into acid-cleaned polyethylene-boxes and melted at 4 °C in the dark. Once melted, bulk salinity was measured with a WTW 190 conductometer. For determination of chlorophyll *a* concentrations melted ice samples were filtered onto Whatman GF/F filters, extracted in 90% acetone, homogenized and analyzed fluorometrically with a Turner Designs 10-AU digital fluorometer according to Evans and O'Reilly (1983). Detection limit of this method was 0.1 $\mu\text{g chl } a \text{ l}^{-1}$. Chlorophyll *a* determination on directly melted ice samples involves the risk of organism loss during ice melting (Garrison & Buck 1986) and thus an underestimation of chlorophyll *a* concentrations, but facilitates the determination of bulk salinity and chlorophyll *a* concentration on the same ice core. Furthermore, this method has been already applied in several Arctic sea-ice studies (e.g. Gradinger 1999b, Mock & Gradinger 1999, Krembs et al. 2001) and therefore allows a comparison of the results.

Based on ice-temperature and bulk-salinity measurements, brine salinity was calculated as a function of ice temperature (Assur 1958), and brine volume was calculated as a function of bulk ice salinity and ice temperature (Frankenstein & Garner 1967, Leppäranta & Manninen 1988).

All methods described above were used on both expeditions. Data on ice thickness, ice temperature, brine salinity, brine volume, chlorophyll *a* concentration as well as meteorological data of ARK XIX-1 are presented in detail in Chapter 2.

3.2.5 Abundance and composition of sympagic meiofauna

Cores B, C and D were used for analyzing composition and abundances of sympagic meiofauna organisms. Core B was completely sawed into 1–20 cm segments, as described above. In order to obtain an extended sample volume, the lowermost 4 cm from cores C and D, cut in the same resolution as the lowermost 4 cm of core B, were used and added to the corresponding segments of core B.

All segments were melted in the dark at 4 °C in addition of 0.2 μm filtered seawater to avoid osmotic stress (Garrison & Buck 1986). Once melted, the samples were concentrated over a 20 μm gauze and fixed with Bouin's solution (1% final concentration) (Lynn 1992). In the home laboratory specimens were sorted into taxa under a stereo microscope (10–50 fold magnification).

3.2.6 Statistics

In order to determine relationships between parameters, non-parametric Spearman-Rank correlation and was used. For testing on significant differences between median values the Mann-Whitney U-test was applied.

3.3 Results

3.3.1 Meteorological conditions and ice thickness

Air and snow temperatures varied considerably during both expeditions (Table 3.1). While air temperatures varied between -0.5 °C and -7.2 °C during summer, winter air temperatures were within a wider range ($\Delta T = 25.8$ °C) and decreased to nearly -30 °C. Snow temperatures in September were similar to air temperatures, except at station 254, where snow temperature was clearly higher than air temperature (Table 3.1). During winter, snow temperatures showed higher deviations from air temperatures: differences between air and snow temperatures reached 8.8 °C (station 71). All sampling sites were snow-covered but during summer, snow depth (mean snow depth: 4.8 cm) was generally lower than during winter (mean snow depth: 16.4 cm).

Ice thickness was highly variable for both expeditions with values ranging between 138.5 and 282.0 cm during September and between 78.3 and 245.5 during March/April (Table 3.1).

3.3.2 Physical and biological ice properties

During late summer, temperature profiles were similar for all stations: ice temperatures were low near the surface, showed maximum values within the uppermost 50 cm and decreased with depth close to -2.0 °C in the lower part of the ice (Fig. 3.2, Fig. 3.3). The bulk ice salinity ranged from $S = 0-4$ and showed vertical gradients with both internal and bottom maxima (Fig. 3.2, Fig. 3.3). Calculated brine salinity generally decreased within the upper centimetres of the ice. Below this layer values increased with depth and showed maximum values near the ice underside (Fig. 3.2, Fig. 3.3). Only at station 251 brine salinity at the ice surface was clearly above values calculated for the ice underside. Profiles of brine volume were variable (Fig. 3.4, Fig. 3.5), and only at stations 244 and 252 brine volume was significantly positively correlated with depth (Spearman-Rank correlation: $p < 0.05$). At all stations brine volumes of the lowermost 10 cm ranged between 3% and 9% . Chlorophyll *a* concentrations were significantly correlated with depth at all stations (Spearman-Rank correlation: $p < 0.05$) and showed maxima in the bottom part of the ice (Fig. 3.4, Fig. 3.5). Maximum chlorophyll *a* concentration was measured at station 244 (67.4 $\mu\text{g chl } a \text{ l}^{-1}$) and lowest concentrations were measured at station 251 with values ranging between 0.1 and 0.9 $\mu\text{g chl } a \text{ l}^{-1}$.

During the winter, ice temperatures were much lower than those measured in late summer and corresponding to this, brine salinity was clearly higher and reached values of $S > 200$ (Table 3.2). Brine volume increased with depth and values ranged between 5% and 15% in the lowermost 10 cm. Chlorophyll *a* concentrations in winter were low at all stations, with a maximum of 3.3 $\mu\text{g chl } a \text{ l}^{-1}$ (Table 3.2). Most of the measured values were below 1.0 $\mu\text{g chl } a \text{ l}^{-1}$. A detailed description of the results of winter expedition is given in Chapter 2.

Depth-integrated chlorophyll *a* concentrations in summer were significantly higher than in winter (Mann-Whitney U-test: $p = 0.03$) (Fig. 3.6).

Table 3.2: Summary of pack-ice properties measured in late summer (ARK XVIII-2, August/September 2002) and winter (ARK XIX-1, March/April 2003). Winter data taken from Chapter 2.

Expedition	Ice temp. [°C]	Brine salinity	Brine volume [%]	Chlorophyll <i>a</i> concentration [$\mu\text{g Chl } a \text{ l}^{-1}$]
ARK XVIII-2	-5.6 to -0.3	5.5 to 93.8	0.0 to 9.9	0.1 to 67.4
ARK XIX-1	-21.9 to -2.4	42.4 to 223.7	0.0 to 21.0	0.0 to 3.3

3.3.3 Abundance and composition of sympagic meiofauna

Vertical distribution patterns of meiofauna organisms are shown in Figures 3.7 and 3.8. During both seasons, maximum abundances found within one ice segment were within the same order of magnitude with maximum values of 317 organisms l^{-1} in late summer (St. 244, Fig. 3.7) and 251 organisms l^{-1} in winter (St. 91, Fig. 3.8). In samples taken during winter, these accumulations were generally restricted to the lowermost 10 cm (Fig. 3.8), while in pack ice sampled during summer organisms frequently occurred above the lowermost 10 cm (Fig. 3.7). During both seasons organism abundances varied considerably between ice stations. During both expeditions organism abundances in under-ice water were lower than those in ice.

Faunistic composition differed distinctively between both seasons (Fig. 3.9). In summertime pack ice, copepods consisting of harpacticoid and cyclopoid as well as some unidentified forms were most abundant and represented 42.7% of the total number of individuals. Rotifers and nematodes formed the next largest fraction within the sea-ice community with 33.4% and 15.6%, respectively. Nauplii (5.3%) and turbellarians (3.0%) were less abundant (Fig. 3.9a).

During winter, composition of sympagic meiofauna was completely different (Fig. 3.9b). Nauplii, which showed a relative abundance of 5.3% during late summer, dominated the community in winter comprising nearly 93% of the fauna. All remaining taxa formed only small fractions (0.1% to 4.1%) of the total number of individuals. Integrated abundances of sea-ice meiofauna were similar for both seasons and varied between 0.6 to 33.5×10^3 organisms m^{-2} in summer and between 3.7 to 24.8×10^3 organisms m^{-2} in winter (Fig. 3.10). Medians for both seasons did not differ significantly (Mann-Whitney U-test).

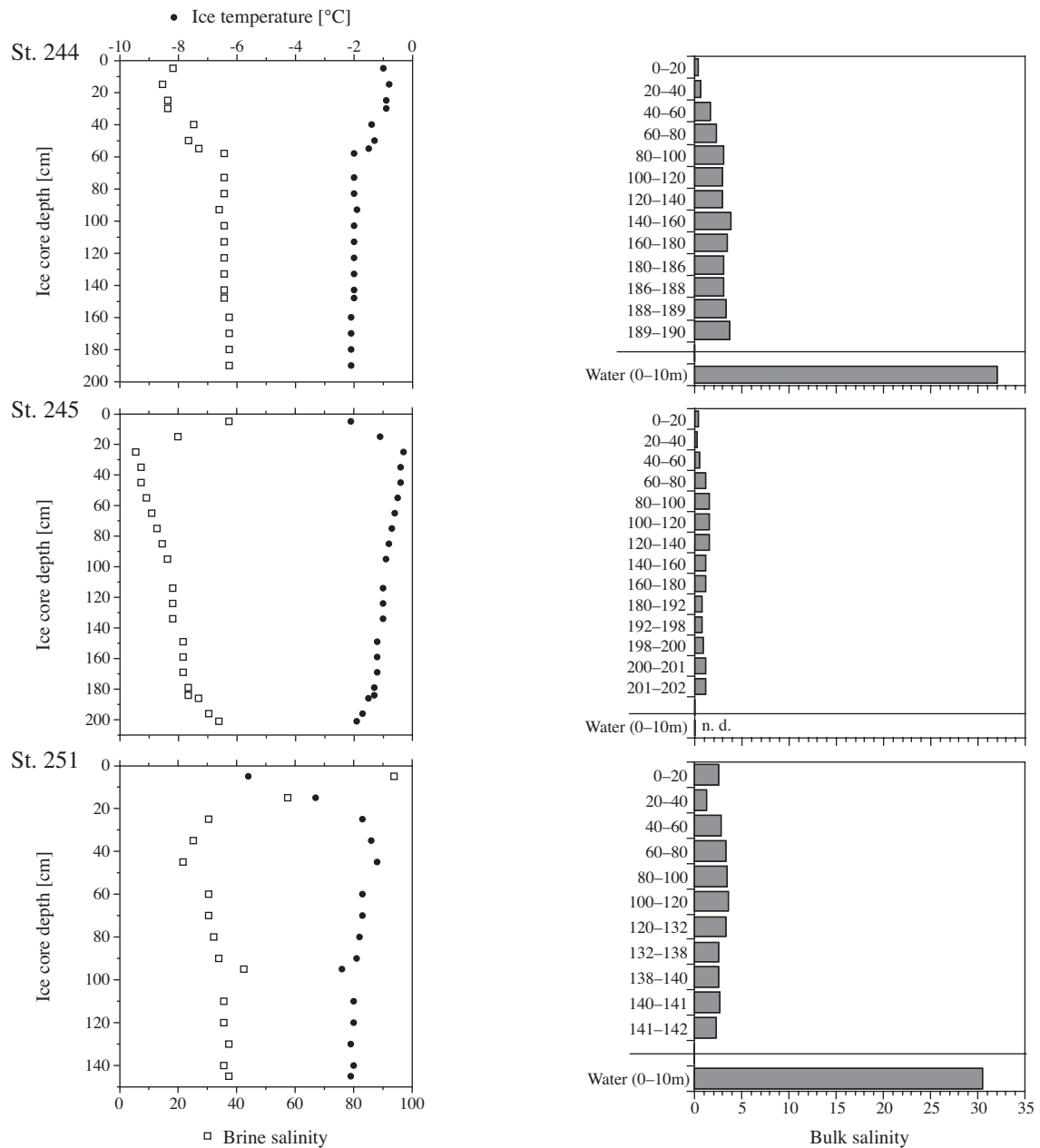


Figure 3.2: Vertical distribution of ice temperature, brine salinity, and bulk salinity in Arctic pack ice and salinity of under-ice water at stations 244, 245 and 251 during late summer (ARK XVIII-2, August/September 2002). The abbreviation “n. d.” means “not determined”.

3 Seasonal variations in distribution patterns and abundances of sympagic meiofauna in Arctic pack ice

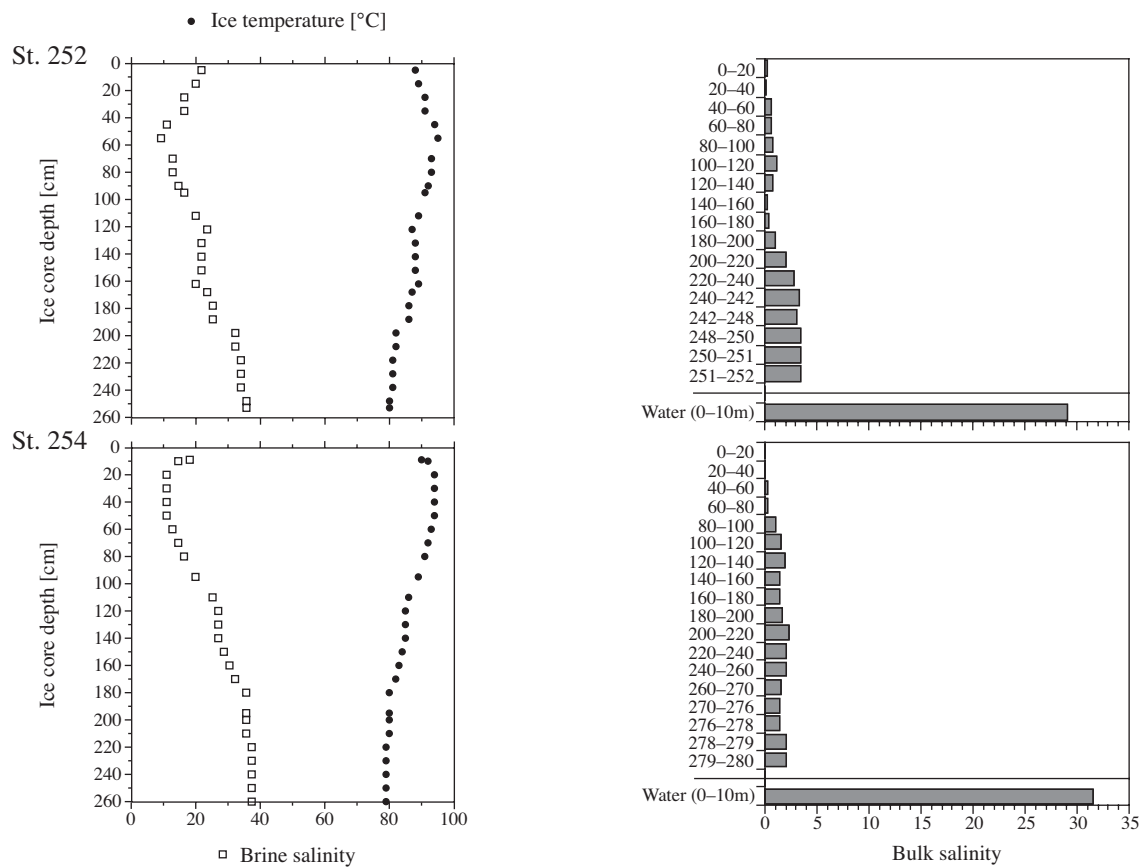


Figure 3.3: Vertical distribution of ice temperature, brine salinity, and bulk salinity in Arctic pack ice and salinity of under-ice water at stations 252 and 254 during late summer (ARK XVIII-2, August/September 2002).

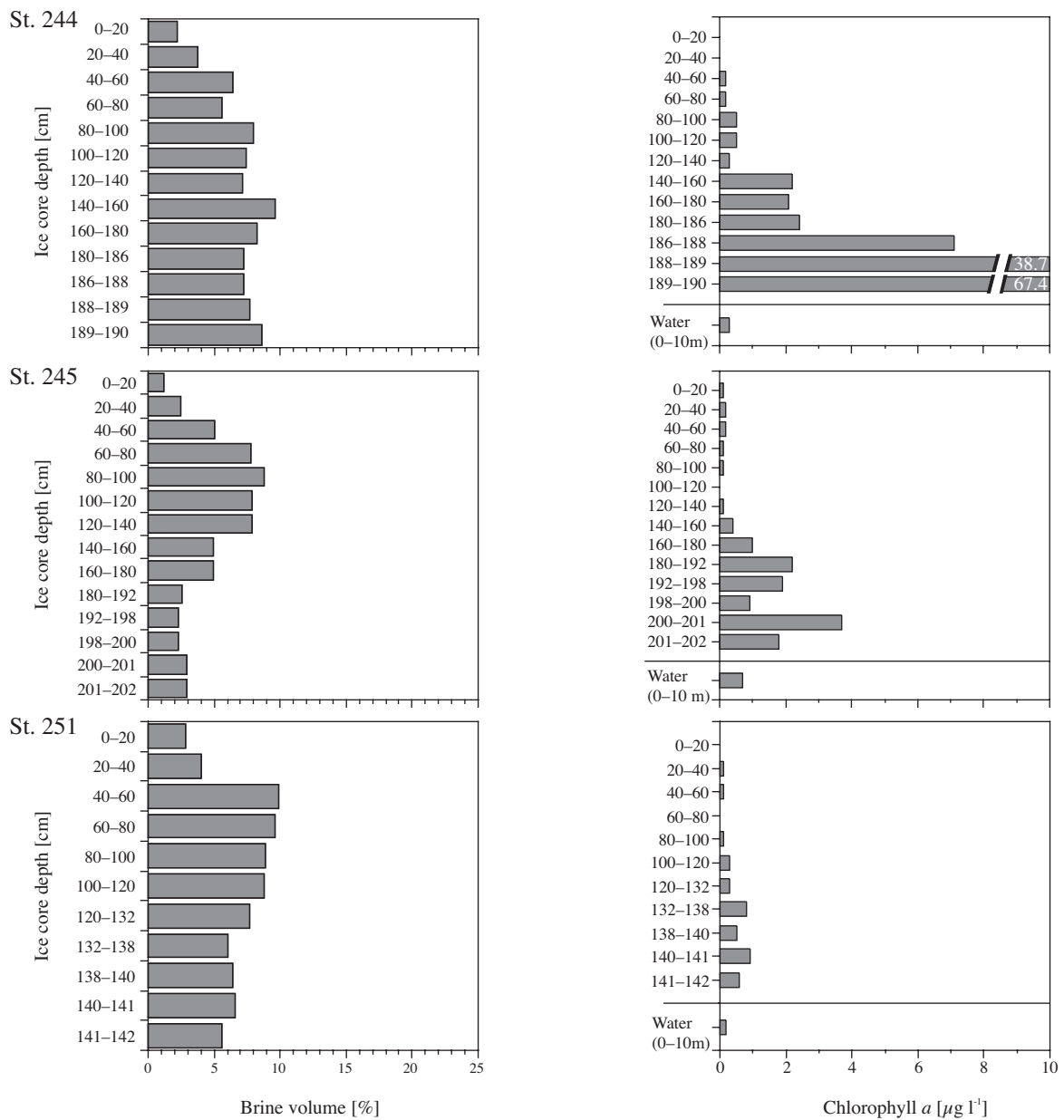


Figure 3.4: Vertical distribution of brine volume and chlorophyll *a* concentrations in Arctic pack ice and chlorophyll *a* concentrations of under-ice water at stations 244, 245 and 251 during late summer (ARK XVIII-2, August/September 2002). For chlorophyll *a*, missing bars indicate values below detection limit.

3 Seasonal variations in distribution patterns and abundances of sympagic meiofauna in Arctic pack ice

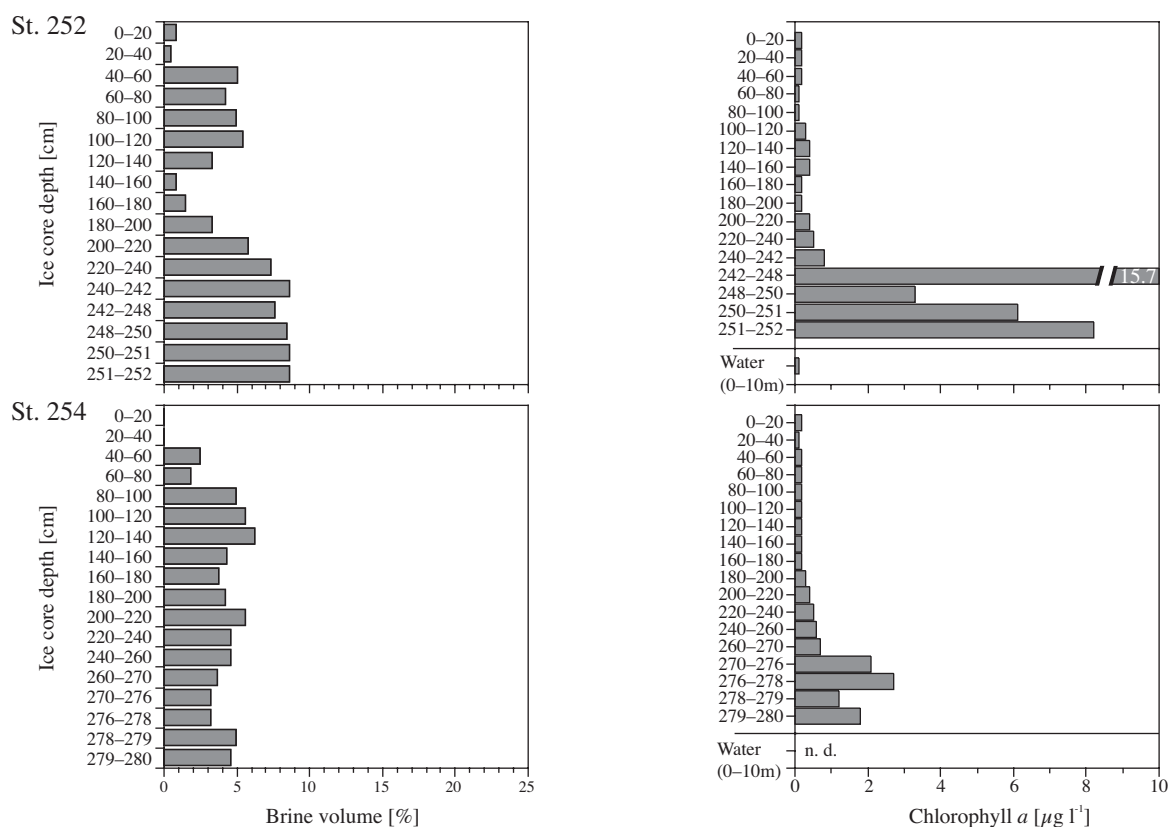


Figure 3.5: Vertical distribution of brine volume and chlorophyll *a* concentrations in Arctic pack ice and chlorophyll *a* concentrations of under-ice water at stations 252 and 254 during late summer (ARK XVIII-2, August/September 2002). The abbreviation “n. d.” means “not determined”. For chlorophyll *a*, missing bars indicate values below detection limit.

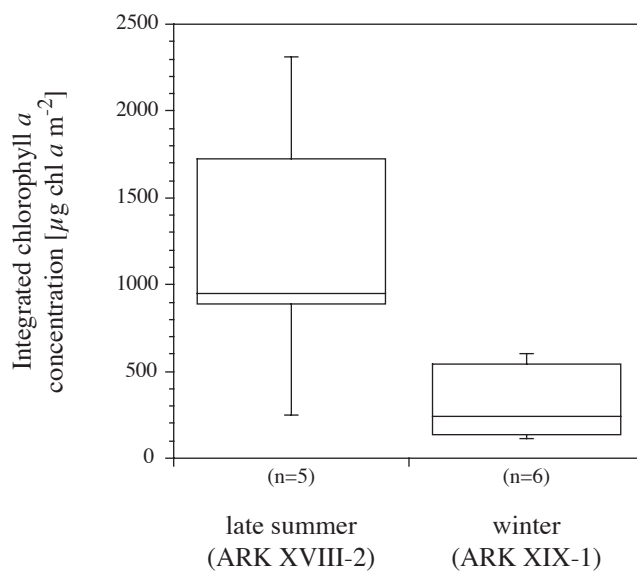


Figure 3.6: Integrated chlorophyll *a* concentrations in Arctic pack ice during late summer (ARK XVIII-2, August/September 2002) and winter (ARK XIX-1, March/April 2003). Box plots show the total data range, the 25–75% quartile range and the median.

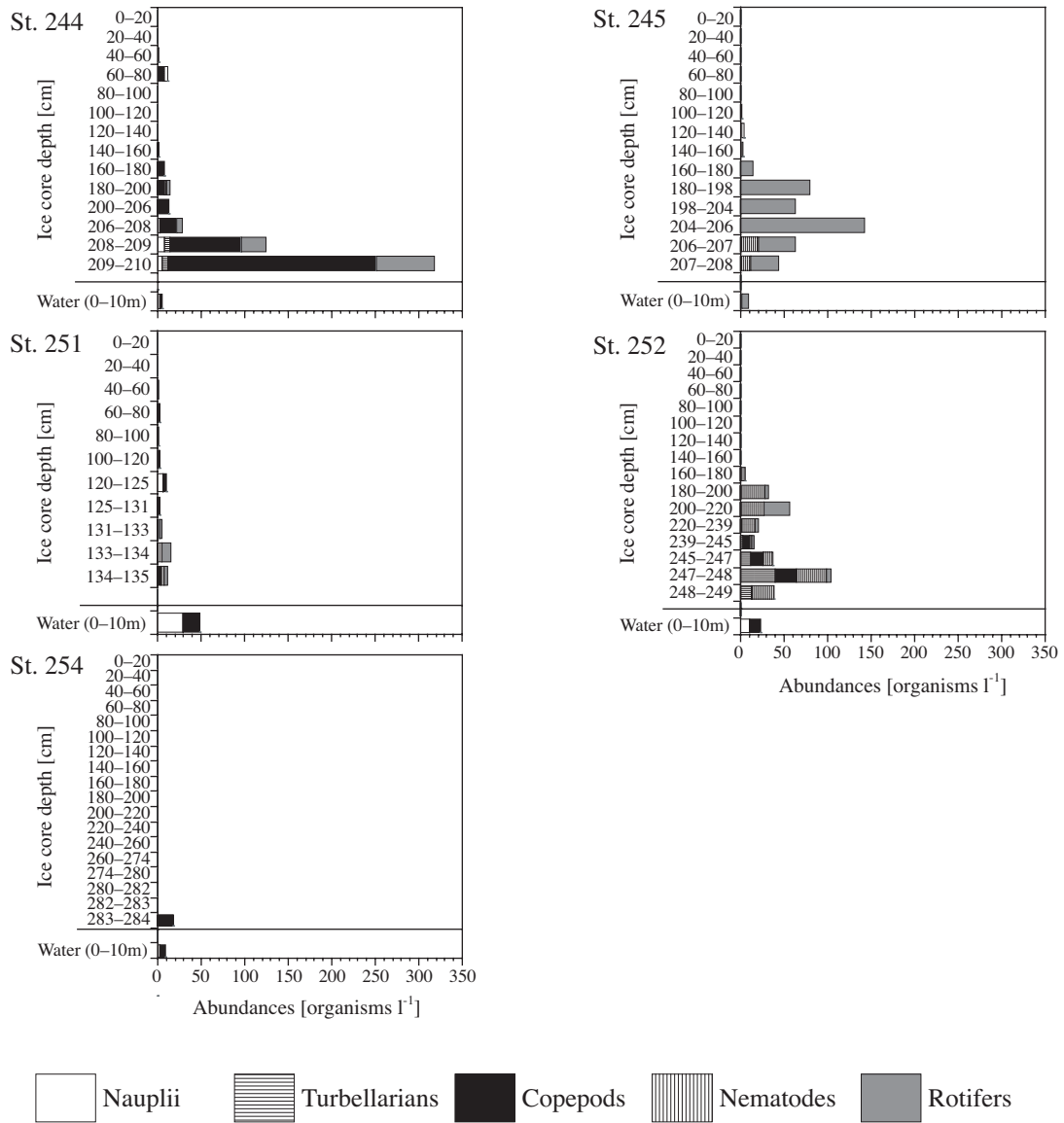


Figure 3.7: Composition, vertical distribution and abundance of sympagic meiofauna organisms in Arctic pack ice during late summer (ARK XVIII-2, August/September 2002).

3 Seasonal variations in distribution patterns and abundances of sympagic meiofauna in Arctic pack ice

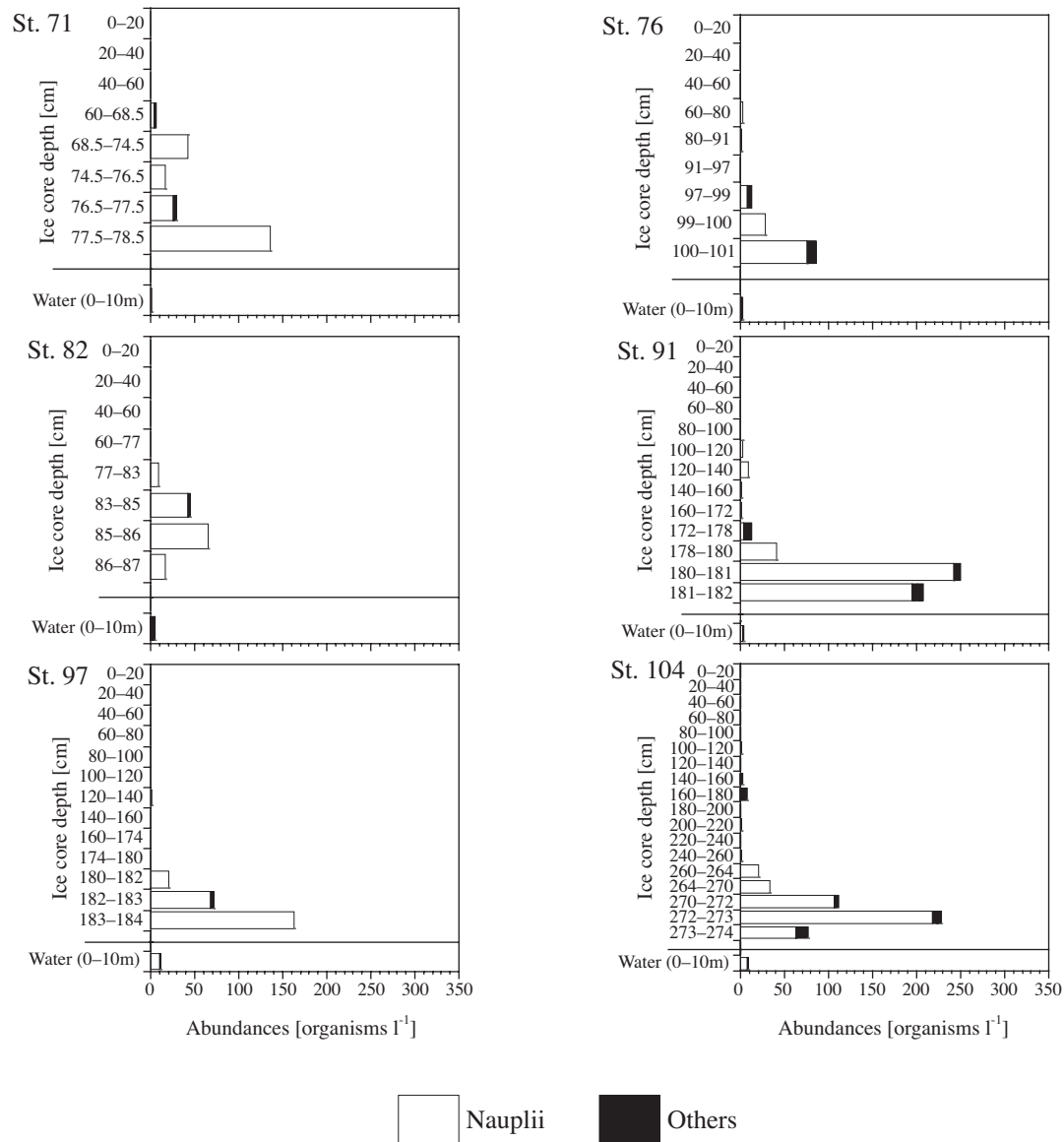


Figure 3.8: Composition, vertical distribution and abundance of sympagic meiofauna organisms in Arctic pack ice during winter (ARK XIX-1, March/April 2003). “Others” includes: turbellarians, copepods, nematodes and rotifers. For detailed composition see Table A5.1–5.7 (Appendix).

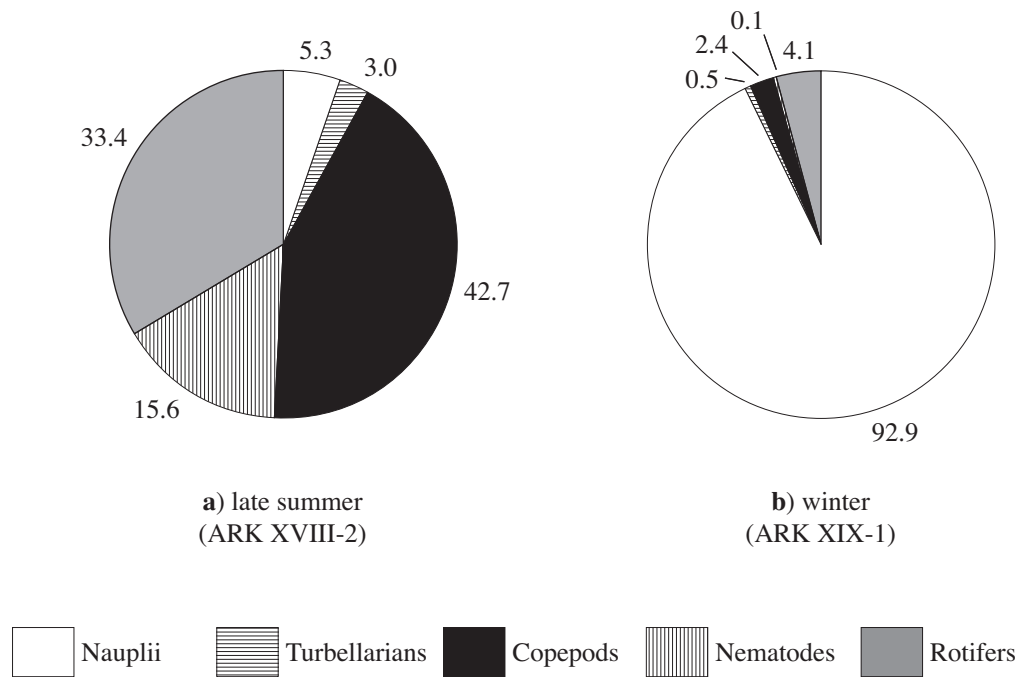


Figure 3.9: Relative contributions (% of total number of individuals) of sympagic meiofauna taxa to total abundances found in Arctic pack ice during (a) late summer (ARK XVIII-2, August/September 2002) and (b) winter (ARK XIX-1, March/April 2003).

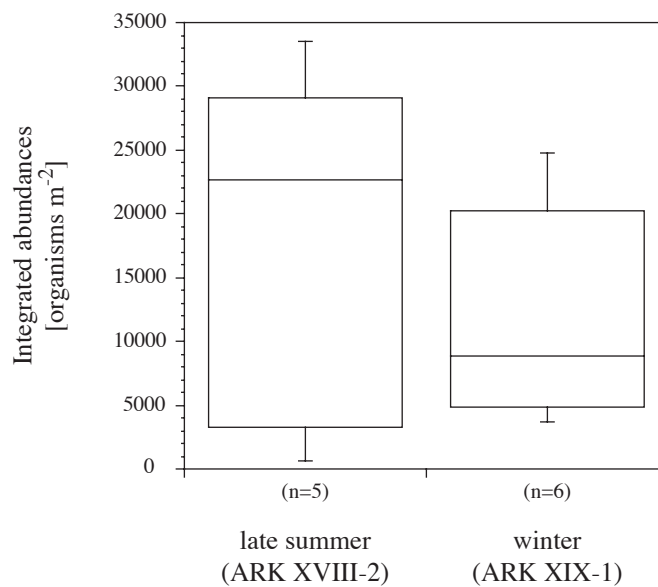


Figure 3.10: Integrated abundances of sympagic meiofauna in Arctic pack ice during late summer (ARK XVIII-2, August/September 2002) and winter (ARK XIX-1, March/April 2003). Box plots show the total data range, the 25–75% quartile range and the median.

3.4 Discussion

As pack-ice sampling was carried out not only during two different seasons, but also in two different locations, regional variability next to seasonal variability has to be taken into account. Half of the winter stations (71, 76, and 82) were distinctively separated from sampling sites investigated during late summer. Nevertheless, the faunal composition of winter stations 91, 97 and 104, which were close to the summer stations, was similar to the other winter stations and thus, differences in meiofaunal composition are explainable rather by seasonal than by regional differences.

Despite the strong seasonality, which is characteristic for the Arctic, changes in physical properties of Arctic pack ice within the lowermost centimetres of the ice are comparatively small. Even in winter, conditions in this portion of the ice are very similar to those described for other seasons (see Chapter 2). Therefore, the lowermost part of the ice seems to offer suitable physical conditions for sympagic meiofauna organisms throughout the whole year. However, meiofaunal investigations show that the composition of sympagic meiofauna organisms in winter differs clearly from situation in summer. Next to physical conditions, food availability could be a controlling factor for biological development within the ice. Although investigations of chlorophyll *a* concentrations indicate the existence of ice algae already during March and April, pigment concentrations were comparatively low.

In the present study total depth-integrated abundances of meiofauna ranged between 0.6 and 33.5×10^3 organisms m^{-2} in summer and between 4.8 and 24.8×10^3 organisms m^{-2} in winter. Thus, the results differ considerably from those found during a non-seasonal investigation of sympagic meiofauna, carried out during the SHEBA ice-camp drift in the Canadian Basin of the Arctic Ocean in 1997/1998 (Melnikov et al. 2002). The SHEBA ice samples were characterized by the complete absence of living sympagic fauna. However, other pack-ice studies revealed higher meiofauna abundances than found in the present study (e.g., Friedrich 1997, Gradinger 1999a) but since protozoans, which comprise 29% to 67% of the total sympagic meiofauna in other studies (Gradinger et al. 1991, Gradinger 1999a), were not included in the present study, comparisons are difficult to perform. Summer abundances of nauplii (0.5×10^3 organisms m^{-2}) are comparable to those reported by Gradinger et al. (1999) (0.2×10^3 organisms m^{-2}), whereas winter abundances (11×10^3 organisms m^{-2}) are elevated by a factor of 50.

Faunistic composition differed distinctively between the two seasons. In late summer, sympagic meiofauna assemblage was dominated by copepods and rotifers, and thus, differs from data for the central Arctic Ocean given by Gradinger (1999a). Pack ice investigated in this study was dominated by nematodes and rotifers, and crustaceans contributed only 5% to total abundance. During winter, composition changed completely and the sea-ice community consisted almost exclusively of copepod nauplii. This observation corresponds with results of a winter pack-ice study in the Antarctic, in which naupliar stages of copepods were the only metazoans detected in the winter-ice assemblage (Garrison & Close 1993).

Harpacticoid and cyclopoid copepods are typical sympagic metazoans in the Arctic

(Kern & Carey 1983, Grainger & Mohammed 1986, Carey 1992), but the knowledge about their life cycles in the ice is as yet incomplete. Carey (1992) supposes that harpacticoid copepods develop and grow but do not reproduce in fast ice of the shallow southwestern Beaufort Sea. While this mechanism may occur in nearshore fast ice, where harpacticoid copepods can easily recruit to the ice from the benthos and an interexchange between both habitats is possible, the situation will presumably differ for offshore pack ice, which is separated from the sea floor by a deep water column. Nozais et al. (2001) presume that the high abundance of nauplii, found in pack ice of the northern Baffin Bay during April and May, is explainable by ice copepods reproducing actively at the bottom surface of the ice during spring. Egg-carrying copepod females were detected several times within Arctic pack ice sampled in Fram Strait (H. Schünemann, unpubl. data), indicating that reproduction and breeding occurs in this habitat. Friedrich (1997) also found all developmental stages of harpacticoid copepods (e.g., *Halectinosoma finmarchicus*, *Tisbe furcata*) in the pack ice of the Transpolar Drift, and supposes that these species are autochthonous. In Antarctic pack ice a similar life cycle has been described for the harpacticoid *Drescheriella glacialis* (Schnack-Schiel et al. 1998), whose development is completely connected with the sea ice.

In order to explain the domination of nauplii in the winter assemblage with nearly 93%, while other typical organisms (e.g., nematodes, turbellarians) are extremely rare, it is necessary to focus on factors, which may influence the occurrence of sympagic organisms. Structural analyses of the ice provide information about the ice texture, which influences small-scale distribution and abundance of sympagic organisms. However, data on ice-texture of the sampled ice floes are not available, but the determination of abiotic ice parameters facilitates the description of environmental conditions within the sea-ice habitat. Especially brine salinity and brine volume are considered to be controlling physical factors for the distribution of sympagic metazoans (Krembs et al. 2000, Gradinger 2001, Meiners et al. 2002).

Since air temperature directly influences brine salinity (Assur 1958), brine salinity is very variable especially in the upper part of the ice and reacts very sensitive to seasonal changes in air temperatures. Arctic and the Antarctic studies indicate the wide adaptability of sea-ice algae and the highly variable response of their growth rates to changing salinities (Kirst & Wiencke 1995, Zhang et al. 1999). Experimental investigations show that sea-ice nematodes, which tolerate a wide salinity range from 5–100 for at least a few days, are characterized by the greatest salinity tolerance of all investigated meiofauna organisms (Friedrich 1997). Arctic sea-ice turbellarians show salinity tolerances from 5–65 and furthermore survive temperatures down to -6°C (Friedrich 1997). In the present study nematodes and single specimens of turbellarians were found in wintertime ice cores.

Regarding the restricted space-availability in the ice, sea-ice turbellarians and rotifers appear to be well-adapted to extreme conditions. Krembs et al. (2000) reveal the ability of rotifers and turbellarians to penetrate narrow passages in the ice, which are 57% and 60%, respectively, of their body diameter. Hence, these organisms are characterized by a high degree of flexibility that facilitates adaptations to changing environmental conditions.

However, ice temperature, brine salinity and brine volume in the lowermost part of the ice did not differ distinctively between summer and winter, as it is shown in the present

study. Hence, neither salinity nor temperature or space, appear to be limiting factors. Only chlorophyll *a* concentrations differed significantly between summer and winter.

Sea-ice microalgae face total darkness for a period of up to six months during polar winters (Palmisano & Sullivan 1985), and although they are assumed to survive the polar winter by means of energy storage and reduction of cellular metabolism (Palmisano & Sullivan 1982, Gradinger 1998, Zhang et al. 1998), chlorophyll *a* concentrations were very low during winter, with most of the values below $1.0 \mu\text{g chl } a \text{ l}^{-1}$ (see Chapter 2). Similar results of chlorophyll *a* concentrations in Arctic winter pack ice were measured during the SHEBA ice-camp drift (Melnikov et al. 2002). Since ice algae are probably used as food source by sympagic metazoans (Grainger & Hsiao 1990, Norrman & Andersson 1994, Janssen & Gradinger 1999), chlorophyll *a* is an indicator for food-conditions and might be a limiting factor for the occurrence of sympagic metazoans in winter. The lack of ice algae may, therefore, explain the low abundances of herbivores and possibly also the high abundances of nauplii, since it is supposed that non feeding naupliar stages exist (S. Seifried, pers. communication). Another possible overwintering strategy for herbivorous crustaceans is the accumulation and use of storage lipids, as it has been shown for copepod nauplii below Baltic sea ice (Werner & Auel 2004).

The question, how and where other sympagic metazoans survive the polar winter, remains unclear. The idea that organisms leave the ice during winter and accumulate in the underlying water-column was neither confirmed by sampling the under-ice water beneath the ice in the present study nor by under-ice water sampling conducted with a pumping system during the winter expedition ARK XIX-1 (Werner, in press). The inclusion of organisms in the ice during winter with subsequent death is also unlikely since no remains of copepods or other organisms were found in the sampled ice. Although bacterial activity occurs at extremely low temperatures (Junge et al. 2004), some traces of “skeletons” would have been expected.

As pointed out by Garrison & Close (1993), a variety of overwintering strategies, for example the production of resting stages, is imaginable for ice-associated organisms. Furthermore, it seems possible that the small standing stock of overwintering meiofauna organisms, which was found in the wintertime ice, is sufficient to be multiplied to summer levels by active reproduction during the spring ice-algal bloom. New local colonization of the sea ice at the beginning of spring seems most unlikely, since several sympagic meiofauna organisms are rather of benthic origin (such as turbellarians, nematodes and most harpacticoid copepods), and a local recruitment of benthic metazoans over several thousand metres of water depth seems to be impossible (Brierley & Thomas 2002).

4 Regional variability of pack-ice habitat and sympagic meiofauna in the central Arctic Ocean

4.1 Introduction

Nearly the whole area of the central Arctic Ocean is ice-covered all year, and also its marginal seas are ice-free for less than three months each year (Parkinson 1992). Large amounts of sea ice formed over the shallow Arctic shelves, are transported across the central basin and are exported primarily through Fram Strait, and to lesser degrees, through the Barents Sea and the Canadian Archipelago (Gordienko 1958, Colony & Thorndike 1984, Pfirman et al. 1997, Pfirman et al. 2004).

Several studies investigating the sympagic meiofauna of pack ice have been conducted in the marginal seas of the Arctic Ocean, like the Barents, Laptev and Greenland Seas or the Canadian Archipelago (Gradinger et al. 1992, Friedrich 1997, Gradinger et al. 1999, Friedrich & Hendelberg 2001, Nozais et al. 2001). Pack ice investigations in the central basin of the Arctic Ocean, however, are comparatively scarce (Wheeler et al. 1996, Melnikov 1997, Gradinger 1999a, Melnikov et al. 2002).

The expedition ARK XVII-2 with the icebreaking RV “Polarstern” (August–October 2001) offered the opportunity to sample and investigate pack ice in the central Arctic Ocean. The scope of this study was to study abiotic and biotic properties of pack-ice habitat as well as the sympagic meiofauna, and to describe possible regional differences along a transect across the eastern Arctic Basin. Furthermore, the results facilitate the assessment of temporal changes in the Arctic pack-ice habitat occurring within one decade, since comparable pack-ice investigations in the same study area were already carried out exactly ten years before (Gradinger 1999a,b).

4.2 Material and methods

4.2.1 Study area

The material for the present study was collected during the expedition ARK XVII-2 of the RV “Polarstern” in August and September 2001 (Thiede 2002). Pack ice and under-ice water were sampled in the central Arctic Ocean along a transect following Gakkel Ridge from northeast off Greenland to the central part of the eastern Arctic Basin (Fig. 4.1).

With an area of 9.5×10^6 km², the Arctic Ocean is the largest land-locked sea in the world. Besides a small number of restricted openings, the principal connection to the adjacent seas is the Fram Strait, located between Greenland and Spitsbergen (Rey 1982). In the central part, the Arctic Ocean consists of two deep basins, separated by the Lomonosov Ridge: the Eurasian Basin towards Europe and the Canadian Basin towards

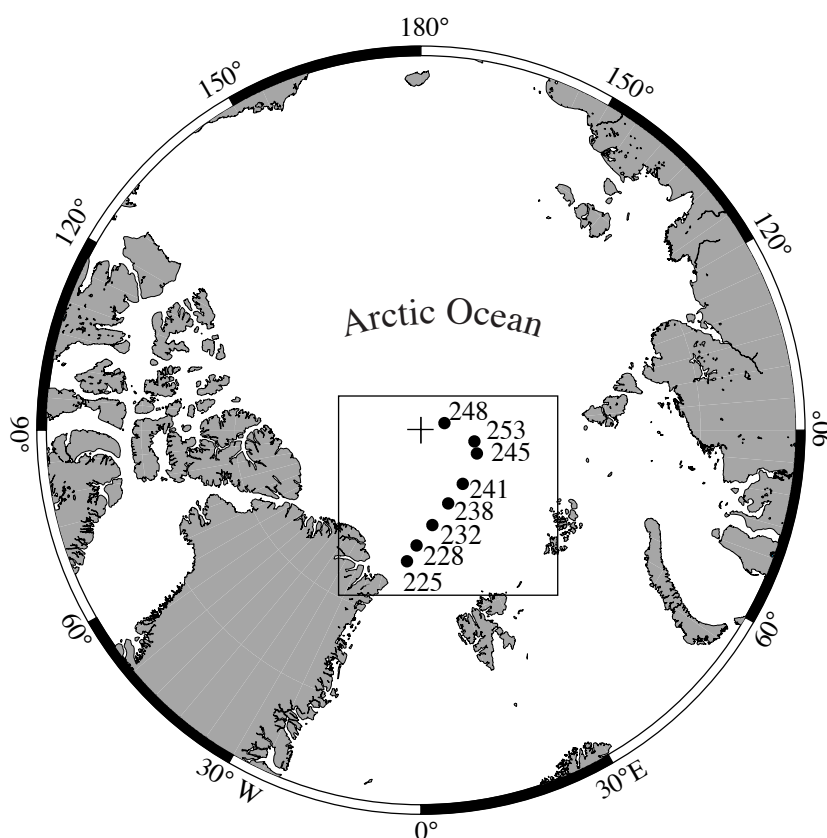


Figure 4.1: Location of the stations sampled in the central Arctic Ocean during expedition ARK XVII-2 (August–October 2001). Station numbers represent the day of the year. The marked area defines the detail of the map presented in Figure 4.5.

North America. Both basins are further subdivided into smaller basins. The Alpha Rise divides the Canadian Basin into the Canada Basin and the Marakov Basin. The Eurasian Basin comprises the Amundsen Basin and the Nansen Basin, separated by the Gakkel Ridge, which is the most northern part of the Atlantic middle-oceanic ridge.

The marginal seas surrounding the central part of the Arctic Ocean extend over narrow shelves on the North American side of the Arctic Ocean (50–90 km), and over very broad shelves on the Eurasian side (> 800 km). Although the five marginal seas (Barents, Kara, Laptev, East Siberian, and Chukchi Sea) cover an area of almost 36% of the area of the Arctic Ocean, they contain only 2% of its water mass (Coachman & Aagaard 1974). These shallow areas, in particular the Siberian shelves, are the principal sea-ice production zones of the Arctic (e.g., Colony & Thorndike 1985, Pfirman et al. 1997).

Ice motion in the Arctic primarily follows two major drift systems: (1) the Transpolar Drift, which transports sea ice from the western side of the basin across the pole and through the Fram Strait, and (2) the Beaufort Gyre, a clockwise gyre in the Beaufort Sea region. The sea ice of the Beaufort Gyre can remain in the Arctic basin for 2.5–30 years, while the ice involved in the Transpolar Drift Stream generally leaves the basin after 2–3 years (Colony & Thorndike 1985). However, the boundaries between the two systems

Table 4.1: Location and meteorological data of ice stations during the expedition ARK XVII-2 (August–October 2001) to the central Arctic Ocean. Station numbers represent the day of the year.

Station	Date	Latitude	Longitude	Ice thickness [cm]	Air temp. [°C]	Snow temp. [°C]	Snow depth [cm]
225	13 Aug 01	82°54.04'N	06°11.61'W	349	0.0	−0.1	10.2
228	16 Aug 01	83°47.45'N	02°11.96'W	160	−0.6	−0.2	4.6
232	20 Aug 01	84°51.08'N	06°40. 04'E	206	−3.6	−0.1	4.6
238	26 Aug 01	85°47.95'N	20°11.00'E	132	0.0	−0.1	6.2
241	29 Aug 01	86°19.74'N	37°46.03'E	230	−0.5	−0.2	2.0
245	02 Sep 01	86°45.02'N	67°18.31'E	185	−4.8	−0.5	16.2
248	05 Sep 01	88°40.95'N	106°19.47'E	212	−3.5	−2.1	2.6
253	10 Sep 01	87°03.41'N	78°16.99'E	205	−3.3	−2.1	6.6

are not distinct and ice drifting at the periphery of one system can be incorporated into the other.

4.2.2 Sampling

Meteorological properties at all sampling sites were recorded. For the measurement of air and snow temperature, a Testotherm 720 thermometer (measurement accuracy ± 0.2 °C) was used. Snow depth was determined from five randomly chosen thickness measurements within the sampling area.

For the investigations of ice properties at each station (Table 4.1), four ice cores (denoted A, B, C and D) were drilled with a motor-powered KOVACS ice corer (internal diameter: 9 cm) in areas of non-deformed ice. In order to minimize heterogeneity, all cores were drilled within an area of 1 m². After drilling, ice thickness was determined as the mean length of core A and B.

Under-ice water was sampled at all stations through drilled holes using a polyethylene tube (internal diameter: 4 cm) with a valve at one end. The unequipped end was lowered into the water with the valve open. At a depth of 10 m the valve was closed and the tube with the enclosed water was hoisted to the surface. Water samples were released into acid-cleaned plastic cans.

4.2.3 Physical and biological ice properties

Core A was used for determination of ice temperature, bulk salinity, and chlorophyll *a* content. Immediately after drilling, the core was placed into an isolating PVC-pipe, and ice temperature was measured with a Testotherm 720 thermometer inside small holes, drilled into the core at 5–10 cm intervals. Afterwards, the uppermost part of core A was cut into 20 cm segments, while the lowermost 10 cm were cut into 1–6 cm segments to ensure higher depth resolution. After cutting, the segments were placed into acid-cleaned polyethylene-boxes and melted at 4 °C in the dark. Once melted, bulk salinity was measured with a WTW 190 conductometer. For determination of chlorophyll *a*

concentration melted ice samples were filtered onto Whatman GF/F filters, extracted in 90% acetone, homogenized and analyzed fluorometrically with a Turner Designs 10-AU digital fluorometer according to Evans and O'Reilly (1983). Detection limit of this method was $0.1 \mu\text{g chl } a \text{ l}^{-1}$. Based on ice-temperature and bulk-salinity measurements, brine salinity was calculated as a function of ice temperature (Assur 1958), and brine volume was calculated as a function of ice bulk salinity and ice temperature (Frankenstein & Garner 1967, Leppäranta & Manninen 1988).

In order to gain information about the age of the ice, third-order polynomials were fitted to bulk salinity profiles (Eicken 1991).

4.2.4 Abundance and composition of sympagic meiofauna

Cores B, C and D were used for analyzing composition and abundance of sympagic meiofauna organisms. Core B was completely sawed into 1–20 cm segments, as described for core A. In order to gain an extended sample volume, the lowermost 4 cm from cores C and D, cut in the same resolution as the lowermost 4 cm of core B, were used and added to the corresponding segments of core B.

All segments were melted in the dark at $4 \text{ }^\circ\text{C}$ by addition of $0.2 \mu\text{m}$ filtered seawater to avoid osmotic stress (Garrison & Buck 1986). Once melted, the samples were concentrated over a $20 \mu\text{m}$ gauze and fixed with Bouin's solution (1% final concentration) (Lynn 1992). In the home laboratory, specimens were sorted into taxa under a stereo microscope (10–50 fold magnification).

4.2.5 Statistical evaluation

Similarities between the samples (stations) in term of faunistic composition were examined by non-parametric classification and ordination techniques (Clarke & Warwick 1994). For classification, a hierarchical agglomerative clustering was chosen, based on the Bray-Curtis similarity index. This method yields a dendrogram. The calculations for the community analysis were conducted using the programme PRIMER (Clarke & Warwick 1994). In order to determine relationships between parameters, non-parametric Spearman Rank-correlation was applied using the programme JMP.

4.3 Results

4.3.1 Sampling sites

During the cruise northward across the eastern Arctic basin, differences in meteorological conditions of the sampled ice floes were small (Table 4.1). Air and snow temperatures were always at or below $0 \text{ }^\circ\text{C}$ and showed minimum values of $-4.8 \text{ }^\circ\text{C}$ and $-2.1 \text{ }^\circ\text{C}$, respectively. All sampled ice floes were snow-covered with snow depths of 2.6–16.2 cm.

4.3.2 Physical and biological ice properties

Ice thickness at all stations north of 83° N ranged between 132 cm and 230 cm (Table 4.1) and was considerably higher at station 225 (349 cm). Mean thickness of all sampled ice floes was 205.4 cm. In all sampled ice cores bulk salinities were below 5, and fitted third-order polynomials showed similar shapes with lowest values in the upper part of the ice and increasing salinities with depth (Fig. 4.2). However, at stations 228, 238, 245 and 248 interior maxima occurred, while the other stations showed highest bulk salinities near the ice underside (Fig. 4.2).

Ice temperature, brine salinity, brine volume and chlorophyll *a* concentrations in the upper 25%, the interior 50% and the lower 25% of the ice showed differences between, but similar values within the sections at all stations (Fig. 4.3).

Ice temperatures ranged between -0.3 and -2.2 °C. They were highest in the upper part of the ice and decreased with depth. Variability in the upper 25% was 1.4 °C, in the interior 50% 1.8 °C and in the lower 25% of the ice 1.5 °C (Fig. 4.3).

Brine salinities showed opposite conditions with lowest values in the upper 25% of the ice and increasing brine salinities with ice depths. Median values of salinity were at 11.0, 23.5 and 32.2 for the upper, the interior and the lower part of the ice, respectively (Fig. 4.3). Highest variation within one section was found in the interior 50% of the ice with a range of nearly 32 (5.5–37.4).

Brine volume was lowest in the upper part of the ice (median: 2%), and showed no vertical gradient in the underlying parts of the ice (medians: 8.6% and 9.0% for the interior and the lower section of the ice, respectively). Within both lowermost sections, brine volume was mostly above 5% (Fig. 4.3).

Chlorophyll *a* concentrations in the upper 25% and the interior 50% of the ice were generally below $0.5 \mu\text{g l}^{-1}$, but their medians differ significantly (Mann-Whitney U-test, $p = 0.042$). With the exception of a few outliers, measured chlorophyll *a* concentrations of both sections were within very small ranges (Fig. 4.3). In the lower 25% of the ice, chlorophyll *a* concentrations differed significantly from those measured in the uppermost two sections. Median concentration was $1.9 \mu\text{g chl } a \text{ l}^{-1}$ and the maximum exceeded $59 \mu\text{g chl } a \text{ l}^{-1}$ (station 238).

Integrated pigment concentrations in the Arctic pack ice ranged between 0.5 and 2.7 $\text{mg chl } a \text{ m}^{-2}$ with a median of $1.4 \text{ mg chl } a \text{ m}^{-2}$ (Fig. 4.4).

4.3.3 Abundance and composition of sympagic meiofauna

A total of five taxa of sympagic meiofauna were found in the ice samples, with rotifers and copepods (harpacticoids and cyclopoids) being most abundant followed by nematodes, turbellarians and nauplii. Rotifers and copepods were found in all ice samples, but only at one station (station 232) all five taxa occurred simultaneously (Fig. 4.5). No correlation between meiofauna abundance and chlorophyll *a* concentration was found for any of the five taxa (Spearman-Rank correlation: $p > 0.05$). As observed for physical and biological ice properties, the sympagic meiofauna did not reveal any differences between the sampling sites, neither in terms of abundance nor in composition (Fig. 4.5). Total

abundances varied between 13.8×10^3 organisms m^{-2} (stations 248 and 245) and 46.7×10^3 organisms m^{-2} (station 232).

Meiofauna abundances in the under-ice water (0–10 m) ranged between 3.9 and 9.8 organisms l^{-1} and, thus, were far below those observed in the lowermost 10 cm of the ice (0–1033.3 organisms l^{-1}). At all stations, the under-ice water fauna consisted mainly of rotifers, copepods and nauplii, while nematodes and turbellarians each occurred only at one station and in very low numbers (Fig. 4.6).

The community structure examined by non-parametric classification, was remarkably homogeneous for all stations. With the exception of station 225, the stations showed a similarity of 70% (Bray-Curtis Similarity), as shown by the dendrogram (Fig. 4.7).

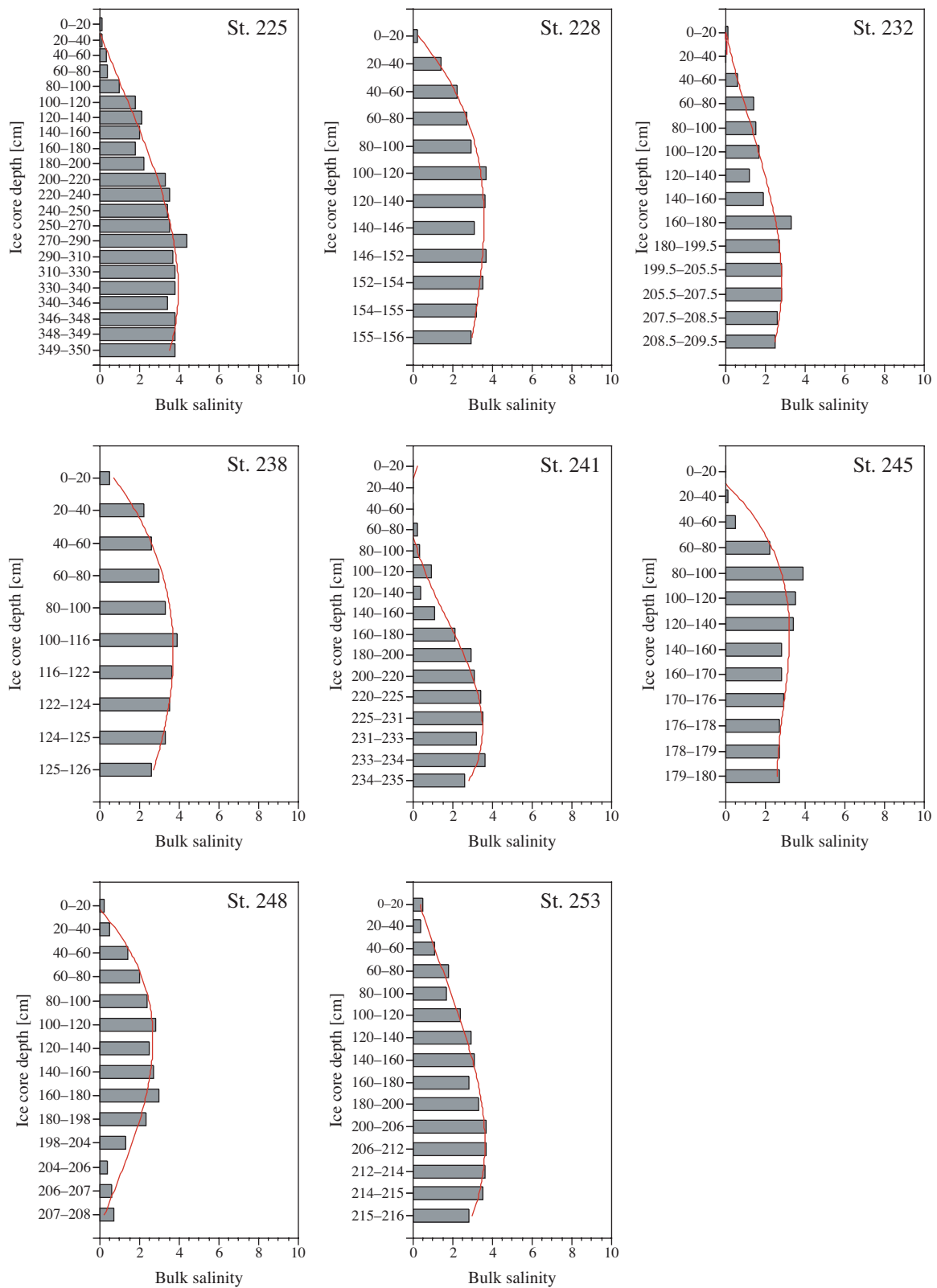


Figure 4.2: Vertical profiles of bulk salinity and fitted third-order polynomials of ice cores sampled during ARK XVII-2 (August–October 2001).

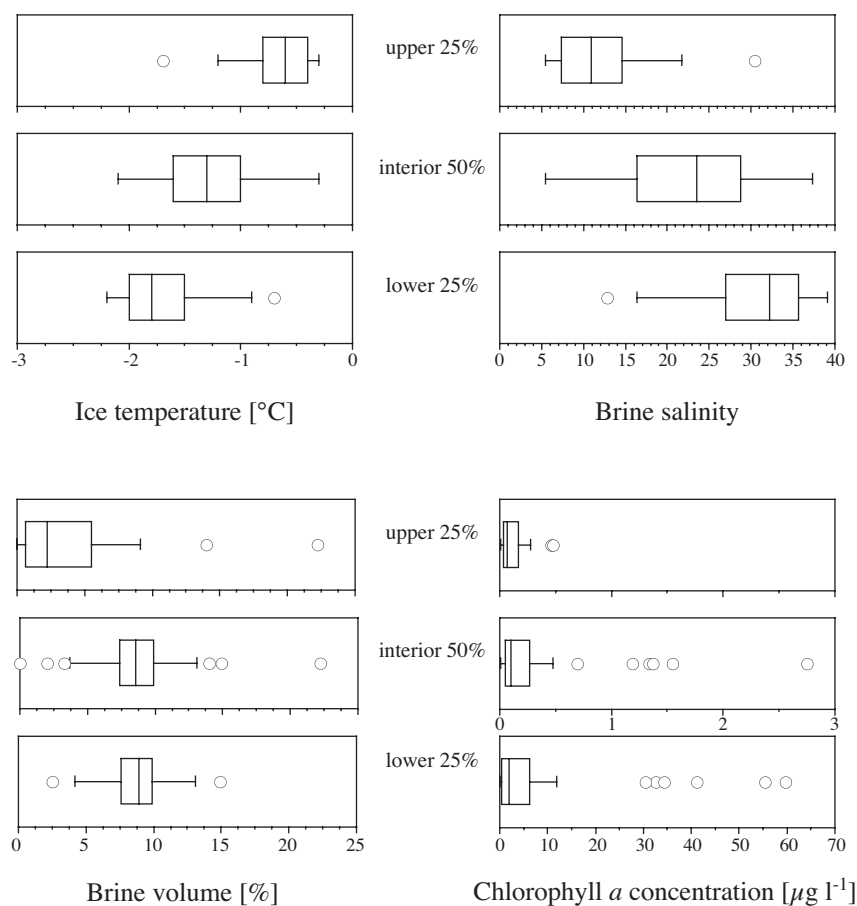


Figure 4.3: Ice temperature, brine salinity, brine volume and chlorophyll *a* concentration in three depth intervals of the ice cores: upper 25%, interior 50% and lower 25%. Box plots show the total data range, the 25–75% quartile range and the median. Single data points are marked as outliers when they are above/below a value of $V = UQ + 1.5 \times IQD$ or $V = LQ - 1.5 \times IQD$ (UQ is the upper quartile, LQ is the lower quartile, IQD is the interquartile distance).

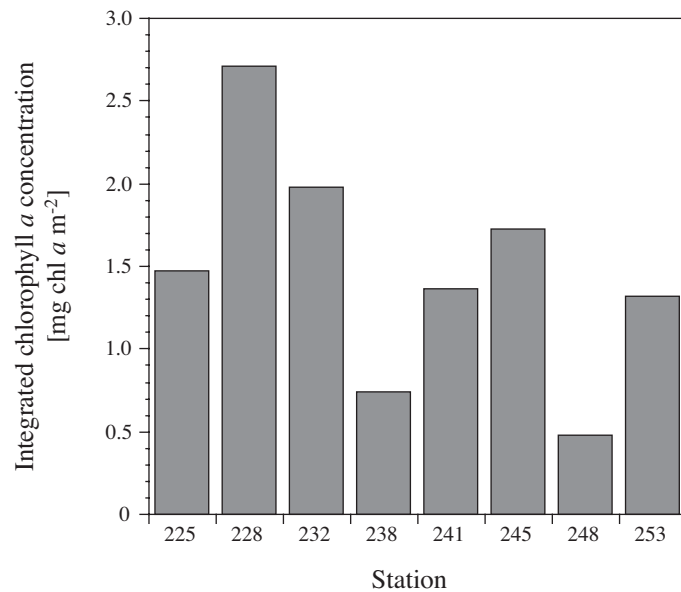


Figure 4.4: Integrated chlorophyll *a* concentration at ice stations sampled during expedition ARK XVII-2 (August–October 2001).

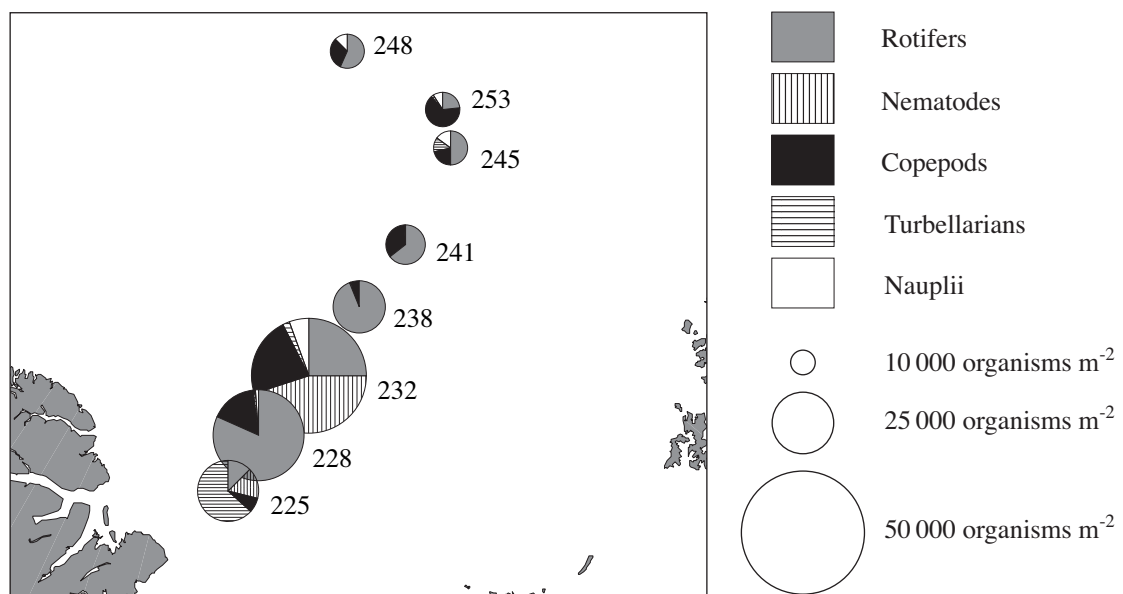


Figure 4.5: Abundance and composition of the sympagic meiofauna for all pack ice stations (indicated by their station numbers) sampled during the expedition ARK XVII-2 (August–October 2001). Sizes of the circles correspond to total abundances. The detail of the map corresponds to the outlined area in Figure 4.1.

4 Regional variability of pack-ice habitat and sympagic meiofauna in the central Arctic Ocean

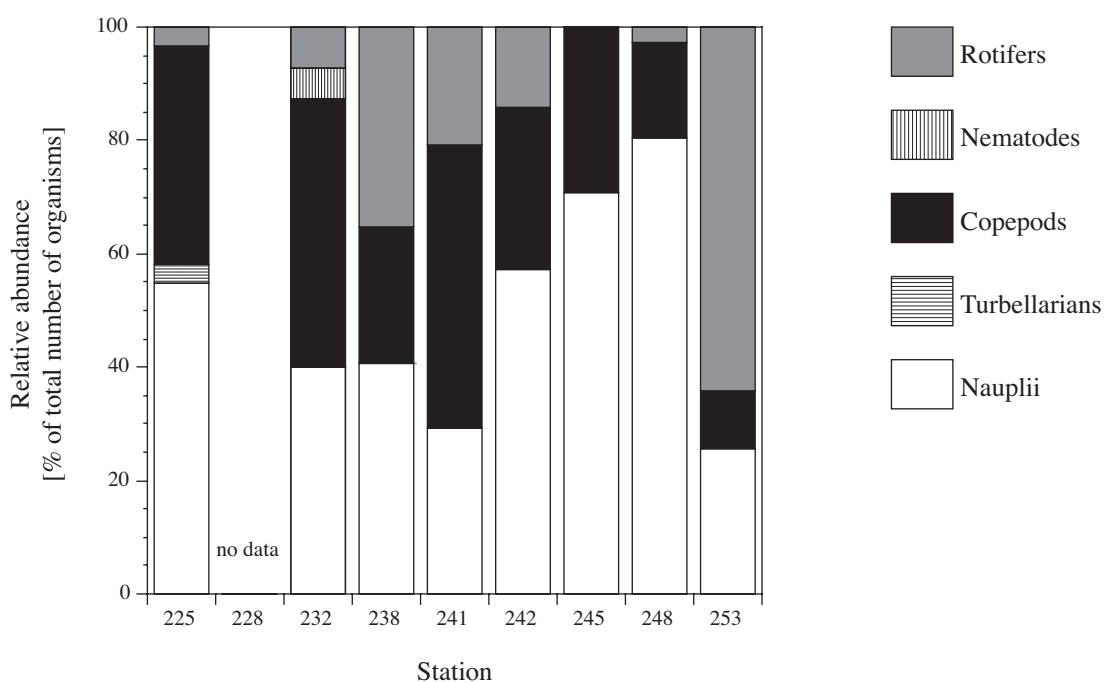


Figure 4.6: Relative abundance (% of total number of individuals) of meiobenthic taxa in the under-ice water (0–10 m beneath the ice). No data are available for station 228.

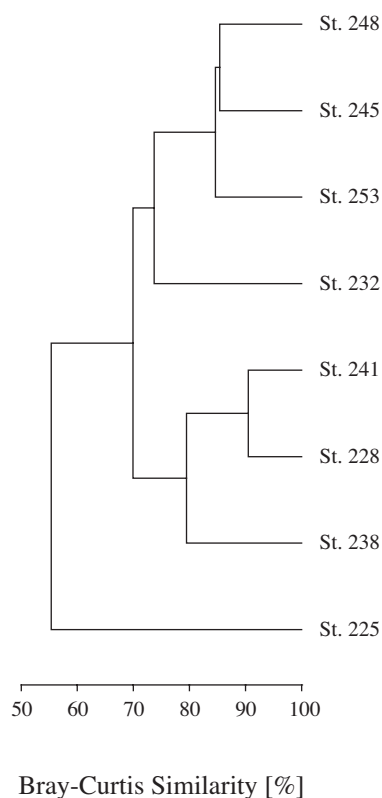


Figure 4.7: Cluster dendrogram based on abundance of meiobenthic taxa showing the classification of all sampled stations in the central Arctic Ocean during ARK XVII-2 (August–October 2001).

4.4 Discussion

During the expedition ARK XVII-2 pack ice between Greenland and the North Pole was sampled along a transect, which extends over approximately 850 km. Despite this broad regional coverage, investigations of the ice floes did not reveal any spatial trends, neither in terms of physical and biological ice properties nor in colonization patterns of sympagic meiofauna organisms. Similar results are already published for ice algae and under-ice algae in the central Arctic Ocean. Studies on diatom species distribution indicated no discernable geographic variation over a long distance either (Booth & Horner 1997). The pronounced uniformity found in the present study indicates that all sampled ice floes originated presumably from the same geographic area, where they have been formed at the same time. Analyses of the ice structure revealing uniform textures for all pack-ice samples also confirmed the uniformity of the sampled ice floes (C. Haas, unpubl. data). Due to prevailing drift patterns and the estimated ice age of two years (C. Haas, pers. comm), the possibility of initial different ice levelled by uniform environmental conditions during the ice drift seems to be unlikely.

All sampling sites were located within the Transpolar Drift. Several studies have already shown that this large-scale drift system basically transports sea ice from the ice-forming shelves of the Laptev and East Siberian Seas across the North Pole and further south along the east coast of Greenland (e.g., Colony & Thorndike 1985, Nürnberg et al. 1994, Pfirman et al. 1997). However, the ice drift can vary to a certain degree, and a recently published study indicates that within the last decades the sources of ice exported to Fram Strait shifted from dominance of the Kara Sea and Severnaya Zemlya to the New Siberian Islands, East Siberian Sea, and Chukchi Sea (Pfirman et al. 2004). During the expedition ARK XVII-2, the course of the Transpolar Drift was without any distinct anomalies, but a pronounced westward drift had predominated before (C. Haas, pers. comm.). With the exception of station 225, all sampled ice floes were therefore probably formed in and transported out of the Kara and Laptev Seas into the sampling area. It is likely that the strong westward drift, occurring in summer 2001, intensified this transport. According to the definition of Eicken (1991) and Eicken et al. (1995), bulk salinities and fitting third-order polynomials to bulk-salinity profiles indicated that all ice floes had survived at least one summer melting. Therefore, they were formed in autumn/winter of the previous year. Bulk salinities ($S < 5$) were comparatively low for second-year ice, but are explainable by strong ablation that occurred in summer 2001 (Haas et al. 2002).

The origin of station 225 seems to differ from those of the other sampled ice floes. With a thickness of 350 cm, the floe was considerably thicker than the others, and the faunistic composition underscores the discrepancy between station 225 and the other stations. Possibly, this ice floe drifted north off Greenland and thus, was entrained in a branch of the Beaufort Gyre before.

During a previous expedition, carried out from August to October 1991, pack ice in the central Arctic Ocean was investigated exactly ten years before (Fütterer 1992). Despite shortcomings due to a limited number of observations, identical methods applied for both expeditions, facilitates the assessment of temporal changes of the sea-ice habitat within one decade. This aspect is of special interest for the decade between 1991 and

2001, since there are several studies discussing changes in Arctic sea-ice thickness and dynamics, especially for the 1990s (Rothrock et al. 1999, Wadhams & Davis 2000, Tucker et al. 2001, Rothrock et al. 2003).

Comparisons between the results of pack-ice investigations in 1991 and 2001 revealed a decreasing in ice thickness over this period. With a mean ice thickness of 260 cm in 1991 (Gradinger 1999a), the sampled ice floes were on average 55 cm thicker than measured in 2001 (mean ice thickness: 205 cm). Integrated pigment concentrations measured in 2001 agreed exactly with those published for 1991 (Gradinger 1999b). Medians were 1.4 mg chl *a* m⁻² both in 1991 and in 2001. Therefore, there are no implications for an increasing ice algal biomass, despite lower ice thicknesses and thus, possibly improved light conditions within the ice.

Integrated meiofaunal abundances were similar for both years. Since Gradinger (1999a) includes ciliates in his study, which contribute with 53% to total abundance, abundances of sympagic metazoans, excluding ciliates, could only be estimated. Assuming that the mean integrated meiofauna abundance in 1991 was 40×10^6 organisms m⁻², of which 21×10^6 organisms m⁻² were ciliates (53%), total integrated abundance of sympagic metazoans in 1991 was approximately 19×10^6 organisms m⁻². This is within the same range observed in 2001 (median: 16×10^6 organisms m⁻²). The faunistic composition, however, shifted from the dominance of nematodes and rotifers in 1991 (Gradinger 1999a) to rotifers and copepods in 2001. The high contribution of rotifers in the present study agrees with results published for pack ice in the Laptev and Barents Seas (Friedrich 1997), and thus, confirms the assumption that the ice floes, sampled during ARK XVII-2, originated from these areas. The similarity of integrated meiofauna abundance and algal biomass in 1991 and 2001 contradicts the results presented by Melnikov et al. (2002). Sea-ice investigations during the SHEBA ice camp drift (October 1997 to October 1998) revealed a decrease of ice diatoms in terms of species number and cell abundance and the absence of any living sympagic meiofauna. Comparing the results with data of the NP-22 ice camp (1974/1975), the authors relate the distinct changes in composition and structure of the sea-ice community to the increased melting of the sea-ice cover of the previous decades. The results of the present study, however, indicate that the changes found by Melnikov et al. (2002) may characterize rather a local feature than a generally trend. Due to different sampling techniques, a qualitative comparison between observations by Melnikov et al. 2002 and the present study is not possible.

Furthermore, the faunistic composition of the ice floes sampled during ARK XVII-2 provides implications for overwintering strategies of the sympagic meiofauna. The occurrence of organisms, which are rather of benthic origin, e.g., nematodes, turbellarians, harpacticoid copepods, is only explainable by initial incorporation during the ice formation over the shallow Siberian shelves. During the initial ice formation both inorganic sediment particles and biological particles like algae are incorporated in the ice (e.g., Ackley et al. 1987, Spindler & Dieckmann 1986, Reimnitz et al. 1993, Grossmann & Dieckmann 1994, Gradinger & Ikävalko 1998) by different mechanisms (Spindler 1994). Once enclosed into the ice (in autumn or the beginning of winter), the organisms are transported far off the shallow shelf areas and have to survive the following winter (see Chapter 2). Since in the present study benthic organisms occurred in pack ice, which

already “survived” one winter, and a newly colonization of the ice by benthic forms over water depths of more than 3000 m is unlikely, it seems plausible that the small standing stock of organisms remaining in the ice during winter is multiplied to summer levels by active reproduction in spring. The results of pack-ice investigations during the winter expedition ARK XIX-1 (see Chapter 3) confirm this assumption.

5 Conclusions and outlook

5.1 Seasonal variability in the Arctic pack-ice habitat and of the sympagic meiofauna

The results of the present work demonstrate distinct seasonal changes in the composition of the sympagic meiofauna between winter and late summer (see Chapter 3). Nauplii, which contributed only a small fraction of the total meiofauna in late summer (5.3%), dominated the community in winter, comprising 92.9%. The other taxa (copepods, nematodes, turbellarians, rotifers) accounted only for the remaining 7.1% in winter, whereas during summer they contributed to the main fraction with 94.7%.

Extreme variations in atmospheric conditions, especially in air temperature, cause strong seasonal changes of ice temperature, brine salinity and brine volume in the upper part of the ice. Compared to summer data, ice temperatures in the present study decreased by approximately 10 °C, brine salinities increased by a factor of 5–6 and brine volumes were generally less than 2% in winter and approximately 5% during summer. Nevertheless, the absence of many actively overwintering sympagic meiofauna organisms in the pack ice is obviously not explainable by unsuitable physical conditions in the upper part of the ice, since the sympagic meiofauna typically accumulates in the lowermost decimetres of the ice (Horner et al. 1992). This part of the ice is characterized by more moderate physical conditions even in winter (Chapter 2). Water temperature mainly controls the ice temperature near the ice underside. The under-ice water temperature is comparatively stable during the year and thus, shows no strong seasonal variability (Werner & Gradinger 2002, Werner, in press). Like ice temperature, seasonal variability of brine salinity and brine volume in this horizon is less pronounced than in the upper part of the ice.

Therefore, abiotic factors, which generally control the distribution of sympagic meiofauna organisms (Krembs et al. 2000, Gradinger 2001, Meiners et al. 2002), generate suitable living conditions for sympagic organisms even in wintertime pack ice. However, the completely different composition of this community in winter indicates the lack of an essential factor facilitating an active overwintering for all meiofauna taxa. The low food availability, indicated by very low chlorophyll *a* concentrations measured in winter, may be this limiting factor. Chlorophyll *a* concentrations, with values mostly below 1.0 µg l⁻¹, were significantly lower than in late summer. Nauplii, which are known to have non-feeding stages (S. Seifried, pers. comm.), possibly can cope with this low food availability and thus, may have an advantage over the other sympagic taxa.

The faunistic investigations of the ice cores sampled in winter showed that despite the recognizable dominance of nauplii, single individuals of the other meiofauna taxa occurred. This result implicates that possibly single individuals are sufficient to be multiplied to summer levels by active reproduction during the spring ice-algal bloom. Further-

more, the production of resting stages may represent a possible overwintering strategy. This possibility to survive poor environmental conditions is, for example, known for monogonont rotifers (Westerheide & Rieger 1996).

The hypothesis of single individuals or resting stages maintaining the population of sympagic meiofauna organisms during winter is also supported by faunistic investigations of different multi-year ice floes, sampled in the central Arctic Ocean (see Chapter 4) and the northern Fram Strait (Chapter 3) during summer. Due to water depths of more than 3000 m in the central Arctic Ocean and mostly more than 1300 m in the northern Fram Strait, local recruitment of organisms of benthic origin (e.g., nematodes, turbellarians, harpacticoid copepods) is most unlikely. Thus, these organisms must have been already incorporated during ice formation, which presumably happened in both cases over the shallow Siberian shelves. However, since many organisms of these groups were found in off-shore pack ice, which already had “survived” one winter, the sympagic meiofauna must have been maintained over the winter season. The occurrence of the ice nematode species *Theristus melnikovi*, *Cryonema crassum* sp. n. and *C. tenue* sp. n. in pack ice (Tchesunov & Riemann 1995, Friedrich 1997) indicates that overwintering of some sympagic organisms generally takes place. These species seem to be confined to the sea-ice habitat as they have never been found in sediments. Their autochthonous life cycles implicate that overwintering in the sea ice habitat must be possible.

Although no evidence was found in the present study, the production of resting stages represents a further possibility for organisms to survive poor environmental conditions during winter. Rotifers are known to produce resting-eggs when environmental conditions deteriorate (Westerheide & Rieger 1996), and several studies revealed the occurrence of rotifer (resting) eggs in sea ice (Norrman & Andersson 1994, Friedrich 1997, Friedrich & De Smet 2000, Werner & Auel 2004). In case of the present study, this strategy seems to be unlikely, since rotifer resting-eggs, if abundant in wintertime pack ice samples, would have been detected due to their conspicuous appearance. However, it cannot be completely excluded that single eggs were overlooked, and that these single eggs may function as some kind of “seed” in the beginning spring.

5.2 Regional variability in the Arctic pack-ice habitat and of the sympagic meiofauna

The results of the present work indicate that regional variability in the Arctic pack ice habitat and of the sympagic meiofauna is comparatively small. The investigations of structure and properties of pack ice sampled along a transect of more than 850 km in the central Arctic Ocean revealed a high uniformity of all samples. Furthermore, the community structure of the sympagic meiofauna showed a similarity of 70% (Bray-Curtis Similarity) (Chapter 4) and thus, indicated no distinct regional variations.

This result of high geographical uniformity is also confirmed by the examination of similarity in terms of faunistic composition for all ice floes sampled for the present study (ARK XVII-2, ARK XVIII-2 and ARK XIX-1). The multi-dimensional scaling (MDS) ordination shows a distinct separation into only two groups (Fig. 5.1). With the excep-

tion of one station (station 254), all late summer stations sampled in the central Arctic Ocean and the Fram Strait (ARK XVII-2 and ARK XVIII-2) are combined in one central group. This indicates a high homogeneity in the community structure across a geographically large area of nearly 1000 km extension. However, the stations, which were sampled in the Fram Strait during winter (stations 91, 97 and 104), are combined in one group with the other wintertime samples (stations 71, 76 and 82), although these were geographically separated in the Storfjord area. Thus, the ordination indicates that seasonal variability in the present study is much more pronounced than regional variability of the sympagic meiofauna in Arctic pack ice.

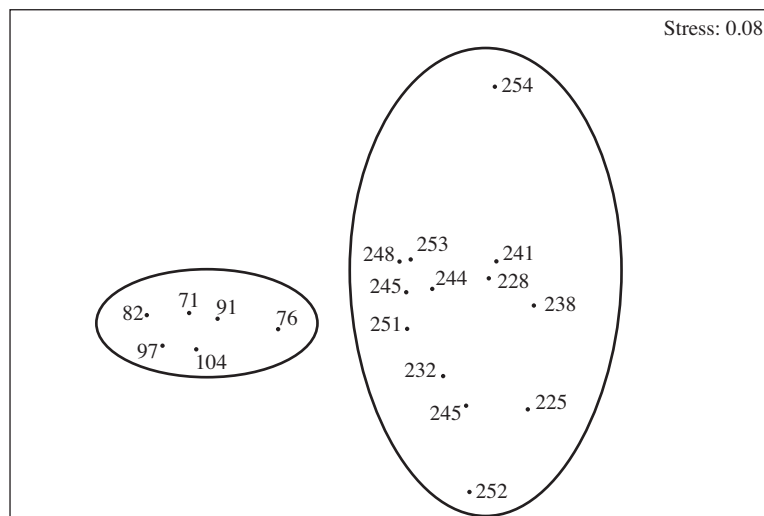


Figure 5.1: Ordination of all stations (indicated by their station numbers) of the sympagic meiofauna from the central Arctic Ocean (ARK XVII-2), northern Fram Strait (ARK XVIII-2, ARK XIX-1) and the Storfjord area (ARK XIX-1). Stations are plotted in two dimensions using multi-dimensional scaling (MDS). Axis scales are arbitrary.

5.3 Outlook

In order to attain a more detailed understanding of the ecology and physiology of sympagic meiofauna organisms, and to assess their significance for the complete sea-ice community, future sea-ice studies should include the following:

- Detailed investigations of organism incorporation into new-forming pack ice in the shallow shelf areas of the Arctic Ocean could clarify whether sympagic meiofauna assemblages found in pack ice far off the production zones change or are maintained during the drift of the ice.
- Classification of the organisms to species level would be crucial to identify autochthonous and allochthonous life cycles of the organisms.

- Pack-ice studies in spring and early summer would be necessary to prove if a small standing stock of sympagic organisms remaining in the ice during winter is multiplied to typical summer abundances by active reproduction. If so, rapidly increasing abundances should be detectable during these seasons.
- Additional winter pack-ice studies are required to scrutinize the results of the present winter investigation and to complete the understanding of seasonal cycles and possible overwintering strategies.
- Since small-scale distribution and abundance of sea-ice organisms can also depend on ice structure, future investigations have to include structural analyses of the sea ice.
- Until now, there is little information about the feeding behaviour of sympagic heterotrophs and their grazing impact. Therefore, quantitative and qualitative experimental studies of ingestion rates and food selection of sympagic meiofauna organisms are pertinent to identify trophic interactions within the sea ice food-web.
- Analyses of physiological adaptations of sympagic metazoans to the ice environment are still absent but fundamental for the understanding of survival mechanisms.

Due to the complexity of the different approaches, multidisciplinary research including taxonomists, ecologists, physiologists and physicists is of great importance to fully understand the decisive processes in the sea-ice habitat.

6 References

- Ackley SF, Dieckmann G, Shen HT (1987) Algal and foram incorporation into new sea ice. *EOS* 68:1736
- Alexander V (1980) Interrelationships between the seasonal sea ice and biological regimes. *Cold Reg Sci Technol* 2:157–178
- Andriashev AP (1968) The problem of the life community associated with the Antarctic fast ice. In: Currie RI (ed) *Symposium on Antarctic Oceanography*. Scott Polar Res Inst, Cambridge, pp 147–155
- Assur A (1958) Composition of sea ice and its tensile strength. *Nat Res Council Publ* 598:106–138
- Bartsch A (1989) Die Eisalgenflora des Weddellmeeres (Antarktis): Artenzusammensetzung und Biomasse sowie Ökophysiologie ausgewählter Arten. Doctoral thesis. Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, *Ber Polarforsch* 63, 110 pp
- Booth BC, Horner RA (1997) Microalgae on the Arctic Ocean Section, 1994: species abundance and biomass. *Deep-Sea Res II* 44(8):1607–1622
- Brierley AS, Thomas DN (2002) The ecology of Southern Ocean pack ice. *Adv Mar Biol* 43:171–278
- Bunt JS, Lee CC (1970) Seasonal primary production in Antarctic sea ice at McMurdo Sound in 1967. *J Mar Res* 28:304–320
- Carey Jr AG (1985) Marine ice fauna: Arctic. In: Horner RA (ed) *Sea ice biota*. CRC Press, Boca Raton, Florida, pp 173–190
- Carey Jr AG (1992) The ice fauna of the shallow southwestern Beaufort Sea, Arctic Ocean. *J Mar Syst* 3:225–236
- Carey Jr AG, Montagna PA (1982) Arctic sea ice faunal assemblage: first approach to description and source of the underice meiofauna. *Mar Ecol Prog Ser* 8:1–8
- Chengalath R (1985) The Rotifera of the Canadian Arctic sea ice, with description of a new species. *Can J Zool* 63:2212–2218
- Clarke KR, Warwick RM (1994) *Change in marine communities: an approach to statistical analysis and interpretation*. Natural Environment Research Council, Plymouth, 144 pp

- Coachman LK, Aagaard K (1974) Physical oceanography of Arctic and Subarctic seas. In: Herman Y (ed) Marine geology and oceanography of the Arctic seas. Springer Verlag, New York, pp 1–72
- Colony R, Thorndike AS (1984) An estimate of the mean field of Arctic sea ice motion. *J Geophys Res* 89(C6):10623–10629
- Colony R, Thorndike AS (1985) Sea ice motion as a drunkard's walk. *J Geophys Res* 90(C1):965–974
- Comiso JC (2003) Large-scale characteristics and variability of the global sea ice cover. In: Thomas DN, Dieckmann GS (eds) Sea ice – an introduction to its physics, chemistry, biology and geology. Blackwell Science Ltd, Oxford, pp 112–142
- Cota GF, Legendre L, Gosselin M, Ingram RG (1991) Ecology of bottom ice algae: I. Environmental controls and variability. *J Mar Syst* 2:257–277
- Cox GFN, Weeks WF (1983) Equations for determining the gas and brine volumes in sea-ice samples. *J Glaciol* 29(102):306–316
- Ehrenberg CG (1841) Ein Nachtrag zu dem Vortrage über Verbreitung und Einfluß des mikroskopischen Lebens in Süd- und Nordamerika. *Monatsber Dtsch Akad Wiss* 1841:202–207
- Eicken H (1991) Quantifizierung von Meereiseigenschaften: automatische Bildanalyse von Dünnschnitten und Parametrisierung von Chlorophyll- und Salzgehaltsverteilungen. Doctoral thesis. Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, *Ber Polarforsch* 82, 105 pp
- Eicken H (2003) From the microscopic, to the macroscopic, to the regional scale: growth, microstructure and properties of sea ice. In: Thomas DN, Dieckmann GS (eds) Sea ice – an introduction to its physics, chemistry, biology and geology. Blackwell Science Ltd, Oxford, pp 22–81
- Eicken H, Bock C, Wittig R, Miller H, Poertner H-O (2000) Magnetic resonance imaging of sea-ice pore fluids: methods and thermal evolution of pore microstructure. *Cold Reg Sci Technol* 31(3):207–225
- Eicken H, Lensu M, Leppäranta M, Tucker III WB, Gow AJ, Salmela O (1995) Thickness, structure, and properties of level summer multiyear ice in the Eurasian sector of the Arctic Ocean. *J Geophys Res* 100(C11):22697–22710
- Evans CA, O'Reilly JE (1983) A handbook for the measurement of chlorophyll *a* in net plankton and nanoplankton. SCAR/Biomass Handbook 9, 44 pp
- Frankenstein G, Garner R (1967) Equations for determining the brine volume of sea ice from -0.5°C to -22.9°C . *J Glaciol* 6(48):943–944

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- Friedrich C (1997) Ökologische Untersuchungen zur Fauna des arktischen Meereises. Doctoral thesis. Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Ber Polarforsch 246, 211 pp
- Friedrich C, De Smet WH (2000) The rotifer fauna of Arctic sea ice from the Barents Sea, Laptev Sea and Greenland Sea. *Hydrobiologia* 432:73–89
- Friedrich C, Hendelberg J (2001) On the ecology of Acoela living in the Arctic Sea ice. *Belg J Zool* 131(Supplement 1):213–216
- Fütterer DK (1992) ARCTIC '91: the expedition ARK-VIII/3 of RV "Polarstern" in 1991. Alfred-Wegener Institut für Meeres- und Polarforschung, Bremerhaven, Ber Polarforsch 107, 267 pp
- Garrison DL, Buck KR (1986) Organism losses during ice melting: a serious bias in sea ice community studies. *Polar Biol* 6(4):237–239
- Garrison DL, Close AR (1993) Winter ecology of the sea ice biota in Weddell Sea pack ice. *Mar Ecol Prog Ser* 96(1):17–31
- Garrison DL, Ackley SF, Buck KR (1983) A physical mechanism for establishing algal populations in frazil ice. *Nature* 306(5941):363–365
- Garrison DL, Close AR, Gordon LI (1990) Nutrient concentrations in Antarctic pack ice during the austral winter. In: Ackley SF, Weeks WF (eds) *Sea ice properties and processes – Proceedings of the W.F. Weeks Sea Ice Symposium*. U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory, Hanover, pp 35–39
- Golden KM, Ackley SF, Lytle VI (1998) The percolation phase transition in sea ice. *Science* 282(5397):2238–2241
- Gordienko PA (1958) Arctic ice drift. *Proceedings of the conference on Arctic Sea Ice*. National Academy of Sciences, Washington, DC, pp 210–220
- Gosselin M, Legendre L, Therriault J-C, Demers S (1990) Light and nutrient limitation of sea-ice microalgae (Hudson Bay, Canadian Arctic). *J Phycol* 26:220–232
- Gosselin M, Legendre L, Therriault J-C, Demers S, Rochet M (1986) Physical control of the horizontal patchiness of sea-ice microalgae. *Mar Ecol Prog Ser* 29(3):289–298
- Gradinger R (1998) Environmental controls of Arctic pack ice algal composition and development – a synopsis. Habilitation thesis. University of Kiel, Kiel, 82 pp
- Gradinger R (1999a) Integrated abundance and biomass of sympagic meiofauna in Arctic and Antarctic pack ice. *Polar Biol* 22(3):169–177

- Gradinger R (1999b) Vertical fine structure of the biomass and composition of algal communities in Arctic pack ice. *Mar Biol* 133(4):745–754
- Gradinger R (2001) Adaptation of Arctic and Antarctic ice metazoa to their habitat. *Zoology* 104:339–345
- Gradinger R, Ikävalko J (1998) Organism incorporation into newly forming Arctic sea ice in the Greenland Sea. *J Plankt Res* 20(5):871–886
- Gradinger R, Schnack-Schiel SB (1998) Potential effect of ice formation on Antarctic pelagic copepods: salinity induced mortality of *Calanus propinquus* and *Metridia gerlachei* in comparison to sympagic acoel turbellarians. *Polar Biol* 20(2):139–142
- Gradinger R, Friedrich C, Spindler M (1999) Abundance, biomass and composition of the sea ice biota of the Greenland Sea pack ice. *Deep-Sea Res II* 46(6–7):1457–1472
- Gradinger R, Spindler M, Henschel D (1991) Development of Arctic sea-ice organisms under graded snow cover. In: Sakshaug E, Hopkins CCE, Øritsland NA (eds) *Proceedings of the Pro Mare Symposium on Polar Marine Ecology*, Trondheim, 12–16 May 1990. *Polar Res* 10(1), pp 295–307
- Gradinger R, Spindler M, Weissenberger J (1992) On the structure and development of Arctic pack ice communities in Fram Strait: a multivariate approach. *Polar Biol* 12(8):727–733
- Grainger EH, Hsiao SIC (1990) Trophic relationships of the sea ice meiofauna in Frobisher Bay, Arctic Canada. *Polar Biol* 10:283–292
- Grainger EH, Mohammed AA (1986) Copepods in Arctic sea ice. In: Schriever G, Schminke HK, Shih C-T (eds) *Proceedings second international conference on copepoda*. National museum of Canada, Ottawa, pp 303–310
- Grainger EH, Mohammed AA (1990) High salinity tolerance in sea ice copepods. *Ophelia* 31(3):177–185
- Grainger EH, Mohammed AA, Lovrity JE (1985) The sea ice fauna of Frobisher Bay, Arctic Canada. *Arctic* 38:23–30
- Grossmann S, Dieckmann GS (1994) Bacterial standing stock, activity, and carbon production during formation and growth of sea ice in the Weddell Sea, Antarctica. *Appl Environ Microbiol* 60(8):2746–2753
- Haarpaintner J, Gascard J-C, Haugan PM (2001) Ice production and brine formation in Storfjorden, Svalbard. *J Geophys Res* 106(C7):14001–14013
- Haas C, Schünemann H, Kubas G, Scheltz A, Bareiss J (2002) Salinity, density and texture of ice cores. In: Thiede J (ed) *Polarstern ARKTIS XVII/2 cruise report: AMORE 2001*. *Ber Polarforsch Meeresforsch* 421, p 76

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- Harder M (1996) Dynamik, Rauigkeit und Alter des Meereises in der Arktis – Numerische Untersuchungen mit einem großskaligen Modell. Doctoral thesis. Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Ber Polarforsch 203, 126 pp
- Helmke E, Weyland H (1995) Bacteria in sea ice and underlying water of the eastern Weddell Sea in midwinter. *Mar Ecol Prog Ser* 117:269–287
- Hooker JD (1847) The botany of the Antarctic voyage of H. M. Discovery ships Erebus and Terror in the years 1839–1843. I. Flora Antarctica. J. Cramer, Weinheim, pp 503–519
- Horner R, Ackley SF, Dieckmann GS, Gulliksen B, Hoshiai T, Legendre L, Melnikov IA, Reeburgh WS, Spindler M, Sullivan CW (1992) Ecology of sea ice biota. 1. Habitat, terminology, and methodology. *Polar Biol* 12(3–4):417–427
- Horner RA (1985a) Sea ice biota. CRC press, Boca Raton, 215 pp
- Horner RA (1985b) History of ice algal investigations. Sea ice biota. CRC Press Inc, Boca Raton Florida, pp 1–19
- Hoshiai T, Tanimura A, Watanabe K (1987) Ice algae as food of an Antarctic ice-associated copepod, *Paralabidocera antarctica* (I. C. Thompson). *Proc NIPR Symp Polar Biol* 1:105–111
- Janssen HH, Gradinger R (1999) Turbellaria (Archoophora: Acoela) from Antarctic sea ice endofauna – examination of their micromorphology. *Polar Biol* 21(6):410–416
- Jokat W (2003) The expedition ARKTIS XVIII/2 of RV “Polarstern” in 2002. Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Ber Polarforsch Meeresforsch 449, 63 pp
- Junge K, Eicken H, Deming JW (2004) Bacterial activity at –2 to –20°C in Arctic wintertime sea ice. *Appl Environ Microbiol* 70(1):550–557
- Kern JC, Carey Jr AG (1983) The faunal assemblage inhabiting seasonal sea ice in the nearshore Arctic Ocean with emphasis on copepods. *Mar Ecol Prog Ser* 10:159–167
- Kirst GO, Wiencke C (1995) Ecophysiology of polar algae. *J Phycol* 31:181–199
- Kottmeier ST, Sullivan CW (1990) Bacterial biomass and production in pack ice of Antarctic marginal ice edge zones. *Deep-Sea Res* 37(8):1311–1330
- Krembs C, Eicken H, Junge K, Deming JW (2002) High concentrations of exopolymeric substances in Arctic winter sea ice: implication for the polar ocean carbon cycle and cryoprotection of diatoms. *Deep-Sea Res I* 49(12):2163–2181

- Krembs C, Gradinger R, Spindler M (2000) Implications of brine channel geometry and surface area for the interaction of sympagic organisms in Arctic sea ice. *J Exp Mar Biol Ecol* 243:55–80
- Krembs C, Mock T, Gradinger R (2001) A mesocosm study of physical-biological interactions in artificial sea ice: effects of brine channel surface evolution and brine movement on algal biomass. *Polar Biol* 24(5):356–364
- Lange MA, Ackley SF, Wadhams P, Dieckmann GS, Eicken H (1989) Development of sea ice in the Weddell Sea. *Ann Glaciol* 12:92–96
- Leppäranta M, Manninen T (1988) The brine and gas content of sea ice with attention to low salinities and high temperatures. *Finn Inst Mar Res Intern Rep* 2:1–14
- Loeng H (1991) Features of the physical oceanographic conditions of the Barents Sea. In: Sakshaug E, Hopkins CCE, Øritsland NA (eds) *Proceedings of the Pro Mare Symposium on Polar Marine Ecology*, Trondheim, 12–16 May 1990. pp 5–18
- Lynn DH (1992) Protargol staining. In: Lee JJ, Soldo AT (eds) *Protocols in protozoology*. Society of Protozoologists, Lawrence, pp C-4.1–C-4.8
- Lytle VI, Ackley SF (1996) Heat flux through sea ice in the western Weddell Sea: convective and conductive transfer processes. *J Geophys Res* 101(C4):8853–8868
- Lønne OJ, Gulliksen B (1991a) On the distribution of sympagic macro-fauna in the seasonally ice covered Barents Sea. *Polar Biol* 11:457–469
- Lønne OJ, Gulliksen B (1991b) Sympagic macro-fauna from multiyear sea-ice near Svalbard. *Polar Biol* 11:471–477
- Maykut GA (1985) The ice environment. In: Horner RA (ed) *Sea ice biota*. CRC Press, Boca Raton, Florida, pp 21–82
- Maykut GA, Grenfell TC (1975) The spectral distribution of light beneath first-year sea ice in Arctic Ocean. *Limnol Oceanogr* 20:554–563
- Meiners K, Fehling J, Granskog MA, Spindler M (2002) Abundance, biomass and composition of biota in Baltic sea ice and underlying water (March 2000). *Polar Biol* 25(10):761–770
- Meiners K, Gradinger R, Fehling J, Civitarese G, Spindler M (2003) Vertical distribution of exopolymer particles in sea ice of the Fram Strait (Arctic) during autumn. *Mar Ecol Prog Ser* 248:1–13
- Melnikov IA (1997) *The Arctic sea ice ecosystem*. Overseas Publishers Association, Amsterdam, 204 pp

-
- Melnikov IA, Kolosova EG, Welch HE, Zhitina LS (2002) Sea ice biological communities and nutrient dynamics in the Canada basin of the Arctic Ocean. *Deep-Sea Res I* 49(9):1623–1649
- Michel C, Nielsen TG, Nozais C, Gosselin M (2002) Significance of sedimentation and grazing by ice micro- and meiofauna for carbon cycling in annual sea ice (northern Baffin Bay). *Aquat Microb Ecol* 30:57–68
- Mock T, Gradinger R (1999) Determination of Arctic ice algal production with a new *in situ* incubation technique. *Mar Ecol Prog Ser* 177:15–26
- Norges Sjøkartverk (1990) Den norske los – Arctic pilot, Farvannsbeskrivelse, sailing directions, travellers' guide, Svalbard-Jan Mayen. 7th edition. Norwegian Hydrographic Service and Norwegian Polar Institute, Stavanger, Norway, 433 pp
- Norrman B, Andersson A (1994) Development of ice biota in a temperate sea area (Gulf of Bothnia). *Polar Biol* 14:531–537
- Nozais C, Gosselin M, Michel C, Tita G (2001) Abundance, biomass, composition and grazing impact of the sea-ice meiofauna in the North Water, northern Baffin Bay. *Mar Ecol Prog Ser* 217:235–250
- Nürnberg D, Wollenburg I, Dethleff D, Eicken H, Kassens H, Letzig T, Reimnitz E, Thiede J (1994) Sediments in Arctic sea ice: implications for entrainment, transport and release. *Mar Geol* 119(3–4):185–214
- Palmisano AC, Sullivan CW (1982) Physiology of sea ice diatoms. I. Response of three polar diatoms to a simulated summer-winter transition. *J Phycol* 18:489–498
- Palmisano AC, Sullivan CW (1985) Growth, metabolisms, and dark survival in sea ice microalgae. In: Horner RA (ed) *Sea ice biota*. CRC Press, Boca Raton, Florida, pp 131–146
- Palmisano AC, Beeler SooHoo J, Moe RL, Sullivan CW (1987) Sea ice microbial communities. VII. Changes in under-ice spectral irradiance during the development of Antarctic sea ice microalgal communities. *Mar Ecol Prog Ser* 35(1):165–173
- Parkinson CL (1992) Spatial patterns of increases and decreases in the length of the sea ice season. *J Geophys Res* 97(C9):14377–14388
- Pfirman S, Haxby WF, Colony R, Rigor I (2004) Variability in Arctic sea ice drift. *Geophys Res Lett* 31: L16402 doi:10.1029/2004GLO200063
- Pfirman SL, Colony R, Nürnberg D, Eicken H, Rigor I (1997) Reconstructing the origin and trajectory of drifting Arctic sea ice. *J Geophys Res* 102(C6):12575–12586

- Poltermann M (2001) Arctic sea ice as feeding ground for amphipods – food sources and strategies. *Polar Biol* 24(2):89–96
- Reimnitz E, Clayton JR, Kempema EW, Payne JR, Weber WS (1993) Interaction of rising frazil with suspended particles: tank experiments with application to nature. *Cold Reg Sci Technol* 21:117–135
- Rey L (1982) The Arctic Ocean: a ‘Polar Mediterranean’. In: Rey L (ed) *The Arctic Ocean*. John Wiley & Sons, New York, pp 3–38
- Rothrock DA, Yu Y, Maykut GA (1999) Thinning of the Arctic sea-ice cover. *Geophys Res Lett* 26(23):3469–3472
- Rothrock DA, Zhang J, Yu Y (2003) The Arctic ice thickness anomaly of the 1990s: a consistent view from observations and models. *J Geophys Res* 108(C3): 3083 doi:10.1029/2001JC001208
- Schauer U, Kattner G (2004) The expedition ARKTIS XIX/1 a,b and XIX/2 of the Research Vessel “Polarstern” in 2003. Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Ber Polarforsch Meeresforsch 481, 190 pp
- Schnack-Schiel SB (2003) The macrobiology of sea ice. In: Thomas DN, Dieckmann GS (eds) *Sea ice – an introduction to its physics, chemistry, biology and geology*. Blackwell Science Ltd, Oxford, pp 211–239
- Schnack-Schiel SB, Dieckmann GS, Gradinger R, Melnikov IA, Spindler M, Thomas DN (2001) Meiofauna in sea ice of the Weddell Sea (Antarctica). *Polar Biol* 24(10):724–728
- Schnack-Schiel SB, Thomas D, Dahms H-U, Haas C, Mizdalski E (1998) Copepods in Arctic sea ice. *Antarct Res Ser* 73:173–182
- Schweitzer PN (1995) Monthly average polar sea-ice concentration: U.S. Geological Survey Digital Data Series DDS-27. U.S. Geological Survey, Reston, Virginia
- Spies A, Brockmann UH, Kattner G (1988) Nutrient regimes in the MIZ of the Greenland Sea in summer. *Mar Ecol Prog Ser* 47:195–204
- Spindler M (1990) A comparison of Arctic and Antarctic sea ice and the effects of different properties on sea ice biota. In: Bleil U, Thiede J (eds) *Geological history of the polar oceans: Arctic versus Antarctic*. Kluwer Academic Publ., Netherlands, pp 173–186
- Spindler M (1994) Notes on the biology of sea ice in the Arctic and Antarctic. *Polar Biol* 14(5):319–324
- Spindler M (1996) On the salinity tolerance of the planktonic foraminifer *Neogloboquadrina pachyderma* from Antarctic sea ice. *Proc NIPR Symp Polar Biol* 9:85–91

-
- Spindler M, Diekmann GS (1986) Distribution and abundance of the planktic foraminifer *Neogloboquadrina pachyderma* in sea ice of the Weddell Sea (Antarctica). *Polar Biol* 5(3):185–191
- Spindler M, Dieckmann GS, Lange MA (1990) Seasonal and geographic variations in sea ice community structure of the Weddell Sea, Antarctica. In: Kerry KR, Hempel G (eds) *Antarctic ecosystems: ecological change and conservation*. Springer-Verlag, Berlin, Heidelberg, pp 129–135
- Sullivan CW, Palmisano AC (1981) Sea-ice microbial communities in McMurdo Sound. *Antarct J US* 16(5):126–127
- Swadling KM, Gibson JAE, Ritz DA, Nichols PD (1997) Horizontal patchiness in sympagic organisms of the Antarctic fast ice. *Antarct Sci* 9(4):399–406
- Tchesunov AV, Riemann F (1995) Arctic sea ice nematodes (Monhysteroidea) with descriptions of *Cryonema crassum* gen. n., sp. n. and *C. tenue* sp. n. *Nematol* 41:35–40
- Thiede J (2002) Polarstern ARKTIS XVII/2 Cruise report: AMORE 2001 (Arctic Mid-Ocean Ridge Expedition). Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Ber Polarforsch Meeresforsch 421, 397 pp
- Thomas DN, Lara RJ, Eicken H, Kattner G, Skoog A (1995) Dissolved organic matter in Arctic multi-year sea ice during winter: major components and relationship to ice characteristics. *Polar Biol* 15(6):447–483
- Tucker WBIII, Weatherly JW, Eppler DT, Farmer LD, Bentley DL (2001) Evidence for rapid thinning of sea ice in the western Arctic Ocean at the end of the 1980s. *Geophys Res Lett* 28(14):2851–2854
- Wadhams P, Davis NR (2000) Further evidence of ice thinning in the Arctic Ocean. *Geophys Res Lett* 27(24):3973–3975
- Weeks WF, Ackley SF (1986) The growth, structure and properties of sea ice. In: Untersteiner N (ed) *The Geophysics of sea ice*. Plenum Press, New York, pp 9–164
- Weissenberger J (1992) Die Lebensbedingungen in den Solekanälchen des antarktischen Meereises. Doctoral thesis. Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Ber Polarforsch 111, 159 pp
- Weissenberger J, Dieckmann GS, Gradinger R, Spindler M (1992) Sea ice: a cast technique to examine and analyze brine pockets and channel structure. *Limnol Oceanogr* 37(1):179–183
- Werner I (in press) Living conditions, abundance and biomass of under-ice fauna in the Storfjord area (western Barents Sea, Arctic) in late winter (March 2003). *Polar Biol*

- Werner I, Auel H (2004) Environmental conditions and overwintering strategies of planktonic metazoans in and below coastal fast ice in the Gulf of Finland (Baltic Sea). *Sarsia* 89(2):102–116
- Werner I, Gradinger R (2002) Under-ice amphipods in the Greenland Sea and Fram Strait (Arctic): environmental controls and seasonal patterns below the pack ice. *Mar Biol* 140(2):317–326
- Westerheide W, Rieger R (1996) *Spezielle Zoologie – Teil 1: Einzeller und Wirbellose Tiere*. Gustav Fischer Verlag, Stuttgart, 909 pp
- Wettlaufer JS (1991) Heat flux at the ice-ocean interface. *J Geophys Res (c Oceans)* 96(C4):7215–7236
- Wheeler PA, Gosselin M, Sherr E, Thibault D, Kirchman DL, Benner R, Whitley TE (1996) Active cycling of organic carbon in the central Arctic Ocean. *Nature* 380:697–699
- Wiktor J, Szymelfenig M (2002) Patchiness of sympagic algae and meiofauna from the fast ice of North Open Water (NOW) Polynya. *Pol Polar Res* 23(2):175–184
- World Meteorological Organization (1970) WMO Sea-ice nomenclature. WMO/OMM/BMO Rep 259(TP145)
- Zhang Q, Gradinger R, Spindler M (1998) Dark survival of marine microalgae in the High Arctic (Greenland Sea). *Polarforschung* 65(3):111–116
- Zhang Q, Gradinger R, Spindler M (1999) Experimental study on the effect of salinity on growth rates of Arctic-sea-ice algae from the Greenland Sea. *Boreal Environ Res* 4(1):1–8

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Appendix

Tables A1.1–1.5: Vertical profiles of sea-ice temperature and brine salinity for all stations sampled during expeditions ARK XVII-2 (August–October 2001), ARK XVIII-2 (August/September 2002) and ARK XIX-1 (March/April 2003).

Tables A2.1–2.4: Vertical profiles of sea-ice bulk salinity, brine volume and values for under-ice water salinity for all stations sampled during expeditions ARK XVII-2 (August–October 2001), ARK XVIII-2 (August/September 2002) and ARK XIX-1 (March/April 2003).

Tables A3.1–3.4: Vertical profiles of sea-ice chlorophyll *a* concentration and values for under-ice water chlorophyll *a* concentration for all stations sampled during expeditions ARK XVII-2 (August–October 2001), ARK XVIII-2 (August/September 2002) and ARK XIX-1 (March/April 2003).

Tables A4.1–4.2: Vertical profiles of sea-ice nutrient concentration (NO_3 , NO_2 , $\text{Si}(\text{OH})_4$, PO_4) and values for under-ice water nutrient concentration for all stations sampled during expedition ARK XIX-1 (March/April 2003).

Tables A5.1–5.7: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water for all stations sampled during expeditions ARK XVII-2 (August–October 2001), ARK XVIII-2 (August/September 2002) and ARK XIX-1 (March/April 2003).

Table A1.1: Vertical profiles of sea-ice temperature and brine salinity at stations 225, 228 and 232 (ARK XVII-2, August–October 2001).

	Ice core depth [cm]	Temperature [°C]	Brine salinity		Ice core depth [cm]	Temperature [°C]	Brine salinity
ARK XVII-2 St. 225	5	-0.4	7.34	ARK XVII-2 St. 228	5	-0.4	7.34
	15	-0.3	5.51		20	-0.5	9.16
	25	-0.3	5.51		30	-0.5	9.16
	35	-0.4	7.34		40	-0.7	12.77
	45	-0.5	9.16		50	-0.9	16.36
	55	-0.6	10.97		60	-1.0	18.15
	65	-0.6	10.97		70	-1.2	21.70
	75	-0.7	12.77		80	-1.3	23.46
	80	-0.7	12.77		85	-1.3	23.46
	90	-0.9	16.36		89	-1.3	23.46
	95	-1.0	18.15		99	-1.2	21.70
	100	-1.0	18.15		109	-1.3	23.46
	110	-1.3	23.46		114	-1.6	28.72
	115	-1.4	25.22		124	-1.7	30.46
	125	-1.5	26.97		134	-1.7	30.46
	135	-1.4	25.22		144	-1.8	32.19
	145	-1.6	28.72		154	-1.9	33.92
	150	-0.9	16.36		164	-1.9	33.92
	160	-1.8	32.19		169	-2.0	35.64
	170	-1.7	30.46				
	180	-1.6	28.72				
	185	-1.7	30.46	St. 232	5	-0.4	7.34
	190	-1.5	26.97		15	-0.3	5.51
	195	-2.0	35.64		25	-0.3	5.51
	200	-2.0	35.64		35	-0.3	5.51
	210	-2.0	35.64		45	-0.3	5.51
	220	-2.1	37.36		55	-0.5	9.16
	230	-2.0	35.64		65	-0.7	12.77
	240	-1.9	33.92		75	-0.8	14.57
	250	-2.0	35.64		85	-0.9	16.36
	260	-1.9	33.92		95	-1.0	18.15
	270	-1.8	32.19		122	-1.3	23.46
	280	-2.0	35.64		132	-1.4	25.22
	285	-2.0	35.64		142	-1.4	25.22
	290	-2.2	39.07		152	-1.2	21.70
	300	-2.1	37.36		162	-1.2	21.70
	310	-2.1	37.36		172	-1.5	26.97
	320	-2.1	37.36		182	-1.7	30.46
	325	-2.1	37.36		192	-1.8	32.19
	335	-2.0	35.64		202	-1.8	32.19
	345	-1.8	32.19		212	-1.9	33.92
	350	-2.0	35.64				

Table A1.2: Vertical profiles of sea-ice temperature and brine salinity at stations 238, 241, 245 and 248 (ARK XVII-2, August–October 2001).

	Ice core depth [cm]	Temperature [°C]	Brine salinity		Ice core depth [cm]	Temperature [°C]	Brine salinity
ARK XVII-2 St. 238				ARK XVII-2 St. 245			
	5	-0.7	12.77		5	-0.8	14.57
	20	-0.5	9.16		15	-0.7	12.77
	25	-0.4	7.34		25	-0.8	14.57
	40	-0.8	14.57		45	-1.2	21.70
	50	-1.2	21.70		55	-1.2	21.70
	60	-1.2	21.70		88	-1.5	26.97
	70	-1.3	23.46		93	-1.6	28.72
	80	-1.3	23.46		103	-1.7	30.46
	90	-1.1	19.92		113	-1.8	32.19
	95	-1.3	23.46		123	-1.8	32.19
	95.5	-1.7	30.46		133	-1.9	33.92
	105.5	-1.8	32.19		138	-1.9	33.92
	115.5	-1.7	30.46		148	-2.0	35.64
	120.5	-1.7	30.46		158	-1.9	33.92
					168	-2.1	37.36
					178	-2.2	39.07
St. 241							
	10	-0.3	5.51		188	-2.1	37.36
	20	-0.3	5.51		193	-2.1	37.36
	30	-0.3	5.51	St. 248			
	40	-0.3	5.51		5	-1.7	30.46
	55	-0.4	7.34		10	-1.7	30.46
	70	-0.3	5.51		20	-1.1	19.92
	80	-0.4	7.34		30	-1.1	19.92
	90	-0.4	7.34		40	-1.2	21.70
	95	-0.5	9.16		50	-0.9	16.36
	121	-0.5	9.16		60	-0.9	16.36
	131	-0.5	9.16		70	-1.0	18.15
	141	-0.7	12.77		80	-1.1	19.92
	151	-0.8	14.57		90	-1.2	21.70
	161	-1.0	18.15		95	-1.2	21.70
	171	-1.1	19.92		108	-1.4	25.22
	181	-1.2	21.70		118	-1.5	26.97
	191	-1.3	23.46		128	-1.5	26.97
	201	-1.3	23.46		138	-1.4	25.22
	214	-1.7	30.46		148	-1.5	26.97
	224	-1.7	30.46		158	-1.6	28.72
	234	-1.6	28.72		168	-1.4	25.22
					178	-1.4	25.22
					188	-1.1	19.92
					198	-0.9	16.36
					208	-0.7	12.77

Table A1.3: Vertical profiles of sea-ice temperature and brine salinity at station 253 (ARK XVII-2, August–October 2001) and stations 244, 245 and 251 (ARK XVIII-2, August/September 2002).

	Ice core depth [cm]	Temperature [°C]	Brine salinity		Ice core depth [cm]	Temperature [°C]	Brine salinity
ARK XVII-2 St. 253				ARK XVIII-2 St. 245			
	15	-0.8	14.57		5	-2.1	37.36
	25	-1.1	19.92		15	-1.1	19.92
	35	-0.7	12.77		25	-0.3	5.51
	45	-0.7	12.77		35	-0.4	7.34
	50	-0.6	10.97		45	-0.4	7.34
	60	-0.8	14.57		55	-0.5	9.16
	70	-0.9	16.36		65	-0.6	10.97
	80	-1.0	18.15		75	-0.7	12.77
	90	-1.1	19.92		85	-0.8	14.57
	95	-1.1	19.92		95	-0.9	16.36
	108.5	-1.5	26.97		114	-1.0	18.15
	118.5	-1.5	26.97		124	-1.0	18.15
	128.5	-1.6	28.72		134	-1.0	18.15
	138.5	-1.7	30.46		149	-1.2	21.70
	148.5	-1.8	32.19		159	-1.2	21.70
	158.5	-1.6	28.72		169	-1.2	21.70
	168.5	-1.8	32.19		179	-1.3	23.46
	178.5	-1.8	32.19		184	-1.3	23.46
	208	-2.0	35.64		186	-1.5	26.97
	218	-2.0	35.64		196	-1.7	30.46
	228	-2.1	37.36		201	-1.9	33.92
	238	-2.1	37.36				
ARK XVIII-2 St. 244				St. 251			
	5	-1.0	18.15		5	-5.6	93.79
	15	-0.8	14.57		15	-3.3	57.48
	25	-0.9	16.36		25	-1.7	30.46
	30	-0.9	16.36		35	-1.4	25.22
	40	-1.4	25.22		45	-1.2	21.70
	50	-1.3	23.46		60	-1.7	30.46
	55	-1.5	26.97		70	-1.7	30.46
	58	-2.0	35.64		80	-1.8	32.19
	73	-2.0	35.64		90	-1.9	33.92
	83	-2.0	35.64		95	-2.4	42.47
	93	-1.9	33.92		110	-2.0	35.64
	103	-2.0	35.64		120	-2.0	35.64
	113	-2.0	35.64		130	-2.1	37.36
	123	-2.0	35.64		140	-2.0	35.64
	133	-2.0	35.64		145	-2.1	37.36
	143	-2.0	35.64				
	148	-2.0	35.64				
	160	-2.1	37.36				
	170	-2.1	37.36				
	180	-2.1	37.36				
	190	-2.1	37.36				

Table A1.4: Vertical profiles of sea-ice temperature and brine salinity at stations 252 and 254 (ARK XVIII-2, August/September 2002) and stations 71, 76 and 82 (ARK XIX-1, March/April 2003).

	Ice core depth [cm]	Temperature [°C]	Brine salinity		Ice core depth [cm]	Temperature [°C]	Brine salinity
ARK XVIII-2				ARK XVIII-2			
St. 252				St. 254 (continued)			
	5	-1.2	21.70		195	-2.0	35.64
	15	-1.1	19.92		200	-2.0	35.64
	25	-0.9	16.36		210	-2.0	35.64
	35	-0.9	16.36		220	-2.1	37.36
	45	-0.6	10.97		230	-2.1	37.36
	55	-0.5	9.16		240	-2.1	37.36
	70	-0.7	12.77		250	-2.1	37.36
	80	-0.7	12.77		260	-2.1	37.36
	90	-0.8	14.57	ARK XIX-1			
	95	-0.9	16.36	St. 71			
	112	-1.1	19.92		5	-9.9	141.2
	122	-1.3	23.46		10	-8.0	128.8
	132	-1.2	21.70		20	-7.1	116.0
	142	-1.2	21.70		35	-5.3	89.2
	152	-1.2	21.70		40	-3.8	65.6
	162	-1.1	19.92		50	-4.0	68.8
	168	-1.3	23.46		60	-3.6	62.4
	178	-1.4	25.22		70	-3.3	57.5
	188	-1.4	25.22		80	-2.5	44.2
	198	-1.8	32.19	St. 76			
	208	-1.8	32.19		5	-12.9	163.5
	218	-1.9	33.92		15	-9.3	136.7
	228	-1.9	33.92		25	-7.9	127.4
	238	-1.9	33.92		35	-7.4	120.3
	248	-2.0	35.64		45	-6.7	110.2
	253	-2.0	35.64		55	-6.1	101.3
St. 254					65	-5.5	92.3
	10	-0.8	14.57		75	-4.6	78.4
	20	-0.6	10.97		85	-3.9	67.2
	30	-0.6	10.97		95	-3.5	60.8
	40	-0.6	10.97		105	-2.4	42.5
	50	-0.6	10.97	St. 82			
	60	-0.7	12.77		5	-8.2	131.6
	70	-0.8	14.57		15	-7.7	124.6
	80	-0.9	16.36		25	-7.3	118.9
	9	-1.0	18.15		35	-6.5	107.2
	95	-1.1	19.92		45	-5.8	96.8
	110	-1.4	25.22		55	-5.3	89.2
	120	-1.5	26.97		65	-4.5	76.8
	130	-1.5	26.97		75	-3.5	60.8
	140	-1.5	26.97		85	-2.7	47.5
	150	-1.6	28.72				
	160	-1.7	30.46				
	170	-1.8	32.19				
	180	-2.0	35.64				

Table A1.5: Vertical profiles of sea-ice temperature and brine salinity at stations 91, 97 and 104 (ARK XIX-1, March/April 2003).

	Ice core depth [cm]	Temperature [°C]	Brine salinity		Ice core depth [cm]	Temperature [°C]	Brine salinity
ARK XIX-1 St. 91				ARK XIX-1 St. 104			
	5	-21.9	223.7		5	-10.1	142.8
	15	-20.4	214.3		15	-11.1	150.3
	25	-19.2	206.6		25	-11.0	149.5
	35	-18.2	200.0		35	-10.4	145.0
	45	-16.9	191.4		45	-10.2	143.5
	55	-16.7	190.0		60	-9.9	141.2
	65	-15.3	180.4		70	-9.3	136.7
	75	-14.8	176.9		85	-9.9	141.2
	85	-13.8	169.9		95	-9.8	140.5
	99	-11.9	156.2		105	-9.4	137.4
	109	-11.0	149.5		115	-9.2	135.9
	119	-9.8	140.5		125	-9.0	134.3
	129	-7.5	121.7		135	-8.6	131.2
	139	-6.6	108.7		145	-8.5	130.5
	149	-5.8	96.8		153	-8.2	131.6
	159	-5.2	87.7		163	-7.7	124.6
St. 97					173	-7.3	118.9
	5	-16.5	188.7		183	-6.9	113.1
	15	-14.3	173.4		193	-6.3	104.3
	25	-14.2	172.7		203	-5.8	96.8
	35	-14.0	171.3		213	-5.1	86.1
	45	-14.2	172.7		223	-4.5	76.8
	55	-13.3	166.3		230	-3.7	64.0
	65	-12.8	162.7		240	-2.8	49.2
	78	-12.4	159.8				
	88	-11.5	153.2				
	98	-10.5	145.8				
	108	-9.6	139.0				
	120	-7.2	117.4				
	130	-7.0	114.5				
	140	-6.5	107.2				
	150	-5.9	98.3				
	160	-5.3	89.2				
	170	-4.2	72.0				
	180	-3.3	57.5				
	185	-2.7	47.5				

Table A2.1: Vertical profiles of sea-ice bulk salinity, brine volume and values for under-ice water salinity at stations 225, 228, 232, 238 and 241 (ARK XVII-2, August–October 2001). Brine volume calculated according to Frankenstein & Garner (1967) and Leppäranta & Manninen (1988). n.d. = not determined.

	Ice core depth [cm]	Bulk salinity	Brine volume [%]		Ice core depth [cm]	Bulk salinity	Brine volume [%]
ARK XVII-2				ARK XVII-2			
St. 225				St. 232 (continued)			
	0–20	0.1	1.2		120–140	1.2	4.2
	20–40	0.1	1.2		140–160	1.9	7.8
	40–60	0.3	2.5		160–180	3.3	11.7
	60–80	0.4	2.8		180–199.5	2.7	7.4
	80–100	1.0	5.5		199.5–205.5	2.8	7.7
	100–120	1.8	6.8		205.5–207.5	2.8	7.3
	120–140	2.1	6.9		207.5–208.5	2.6	6.8
	140–160	2.0	11.0		208.5–209.5	2.5	6.5
	160–180	1.8	5.2		Water (0–10m)	32.4	
	180–200	2.2	7.2	St. 238			
	200–220	3.3	8.1		0–20	0.5	3.1
	220–240	3.5	8.6		20–40	2.2	22.2
	240–250	3.4	8.4		40–60	2.6	10.7
	250–270	3.5	9.1		60–80	3.0	11.4
	270–290	4.4	10.8		80–100	3.3	14.9
	290–310	3.7	8.6		100–116	3.9	10.7
	310–330	3.8	8.9		116–122	3.6	10.5
	330–340	3.8	9.3		122–124	3.5	10.2
	340–346	3.4	9.4		124–125	3.3	9.6
	346–348	3.8	10.5		125–126	2.6	7.6
	348–349	3.8	9.9		Water (0–10m)	32.5	
	349–350	3.8	9.9	St. 241			
	Water (0–10m)	32.2			0–20	0.0	0.0
St. 228					20–40	0.0	0.0
	0–20	0.2	2.5		40–60	0.0	0.0
	20–40	1.4	14.0		60–80	0.2	3.3
	40–60	2.2	12.1		80–100	0.3	3.7
	60–80	2.7	11.1		100–120	0.9	9.0
	80–100	2.9	11.0		120–140	0.4	4.0
	100–120	3.7	13.1		140–160	1.1	6.8
	120–140	3.6	10.5		160–180	2.1	9.4
	140–146	3.1	9.0		180–200	2.9	11.0
	146–152	3.7	9.7		200–220	3.1	9.6
	152–154	3.5	9.1		220–225	3.4	9.9
	154–155	3.2	8.3		225–231	3.5	10.2
	155–156	2.9	7.6		231–233	3.2	9.9
	Water (0–10m)	n. d.			233–234	3.6	11.1
St. 232					234–235	2.6	8.0
	0–20	0.1	1.2		Water (0–10m)	31.9	
	20–40	0.0	0.0				
	40–60	0.6	7.5				
	60–80	1.4	8.7				
	80–100	1.5	7.4				
	100–120	1.7	7.6				

Table A2.2: Vertical profiles of sea-ice bulk salinity, brine volume and values for under-ice water salinity at stations 245, 248 and 253 (ARK XVII-2, August–October 2001) and stations 244 and 245 (ARK XVIII-2, August/September 2002). Brine volume calculated according to Frankenstein & Garner (1967) and Leppäranta & Manninen (1988). n.d. = not determined.

	Ice core depth [cm]	Bulk salinity	Brine volume [%]		Ice core depth [cm]	Bulk salinity	Brine volume [%]
ARK XVII-2				ARK XVII-2			
	St. 245				St. 253 (continued)		
	0–20	0.0	0.0		214–215	3.5	8.6
	20–40	0.1	0.6		215–216	2.8	6.9
	40–60	0.5	2.0		Water (0–10m)	32.1	
	60–80	2.2	8.4		ARK XVIII-2		
	80–100	3.9	12.9		St. 244		
	100–120	3.5	9.6		0–20	0.4	2.2
	120–140	3.4	8.9		20–40	0.7	3.8
	140–160	2.8	6.9		40–60	1.7	6.4
	160–170	2.8	6.9		60–80	2.3	5.6
	170–176	2.9	6.4		80–100	3.1	8.0
	176–178	2.7	6.0		100–120	3.0	7.4
	178–179	2.7	6.0		120–140	2.9	7.1
	179–180	2.7	6.0		140–160	3.9	9.6
	Water (0–10m)	32.6			160–180	3.5	8.2
	St. 248				180–186	3.1	7.2
	0–20	0.2	0.6		186–188	3.1	7.2
	20–40	0.5	2.2		188–189	3.3	7.7
	40–60	1.4	7.7		189–190	3.7	8.6
	60–80	2.0	9.9		Water (0–10m)	32.0	
	80–100	2.4	9.9		St. 245		
	100–120	2.8	9.9		0–20	0.4	1.2
	120–140	2.5	8.2		20–40	0.2	2.5
	140–160	2.7	8.9		40–60	0.5	5.0
	160–180	3.0	10.6		60–80	1.1	7.8
	180–198	2.3	10.3		80–100	1.6	8.8
	198–204	1.3	8.0		100–120	1.6	7.9
	204–206	0.4	2.5		120–140	1.6	7.9
	206–207	0.6	4.2		140–160	1.2	4.9
	207–208	0.7	4.9		160–180	1.2	4.9
	Water (0–10m)	27.0			180–192	0.8	2.6
	St. 253				192–198	0.8	2.3
	0–20	0.5	3.1		198–200	0.9	2.3
	20–40	0.4	2.2		200–201	1.1	2.9
	40–60	1.1	9.1		201–202	1.1	2.9
	60–80	1.8	9.9		Water (0–10m)	n. d.	
	80–100	1.7	7.6				
	100–120	2.4	7.9				
	120–140	2.9	9.0				
	140–160	3.1	8.5				
	160–180	2.8	7.7				
	180–200	3.3	8.6				
	200–206	3.7	9.1				
	206–212	3.7	9.1				
	212–214	3.6	8.8				

Table A2.3: Vertical profiles of sea-ice bulk salinity, brine volume and values for under-ice water salinity at stations 251, 252 and 254 (ARK XVIII-2, August/September 2002) and stations 71, 76 and 82 (ARK XIX-1, March/April 2003). Brine volume calculated according to Frankenstein & Garner (1967) and Leppäranta & Manninen (1988). n.d. = not determined.

Ice core depth [cm]	Bulk salinity	Brine volume [%]	Ice core depth [cm]	Bulk salinity	Brine volume [%]
ARK XVIII-2			ARK XVIII-2		
St. 251			St. 254 (continued)		
0–20	2.6	2.8	240–260	2.0	4.6
20–40	1.3	4.0	260–270	1.6	3.7
40–60	2.8	9.9	270–276	1.4	3.2
60–80	3.3	9.6	276–278	1.4	3.2
80–100	3.4	8.9	278–279	2.1	4.9
100–120	3.6	8.8	279–280	2.0	4.6
120–132	3.3	7.7	Water (0–10m)	31.5	
132–138	2.6	6.0			
138–140	2.6	6.4	ARK XIX-1		
140–141	2.7	6.6	St. 71		
141–142	2.3	5.6	0–20	0.0	0.0
Water (0–10m)	30.5		20–40	0.3	0.3
			40–60	0.7	0.9
St. 252			60–67	1.1	1.5
0–20	0.2	0.8	67–73	3.9	5.7
20–40	0.1	0.5	73–75	n. d.	n. d.
40–60	0.6	5.0	75–76	n. d.	n. d.
60–80	0.6	4.2	76–77	n. d.	n. d.
80–100	0.8	4.9	Water (0–10 m)	35.0	
100–120	1.1	5.4			
120–140	0.8	3.3	St. 76		
140–160	0.2	0.8	0–20	1.6	0.8
160–180	0.4	1.5	20–40	2.9	1.9
180–200	1.0	3.3	40–60	0.3	0.2
200–220	2.1	5.8	60–80	5.2	5.0
220–240	2.8	7.3	80–97	4.9	6.3
240–242	3.3	8.6	97–103	5.8	9.4
242–248	3.1	7.6	103–105	6.9	13.5
248–250	3.4	8.4	105–106	7.5	15.4
250–251	3.5	8.6	106–107	8.5	17.4
251–252	3.5	8.6	Water (0–10 m)	34.1	
Water (0–10m)	29.1				
			St. 82		
St. 254			0–20	11.5	7.5
0–20	0.0	0.0	20–40	8.0	5.9
20–40	0.0	0.0	40–60	5.6	5.0
40–60	0.3	2.5	60–76	5.4	6.2
60–80	0.3	1.8	76–82	5.8	8.8
80–100	1.0	4.9	82–84	7.3	12.3
100–120	1.6	5.6	84–85	8.2	14.9
120–140	1.9	6.2	85–86	6.7	12.1
140–160	1.4	4.3	Water (0–10 m)	33.8	
160–180	1.4	3.8			
180–200	1.7	4.2			
200–220	2.3	5.6			
220–240	2.0	4.6			

Table A2.4: Vertical profiles of sea-ice bulk salinity, brine volume and values for under-ice water salinity at stations 91, 97 and 104 (ARK XIX-1, March/April 2003).

	Ice core depth [cm]	Bulk salinity	Brine volume [%]		Ice core depth [cm]	Bulk salinity	Brine volume [%]
ARK XIX-1				ARK XIX-1			
St. 91				St. 104			
	0–20	0.2	0.1		0–20	0.0	0.0
	20–40	0.9	0.3		20–40	0.0	0.0
	40–60	1.7	0.6		40–60	0.0	0.0
	60–80	2.3	0.9		60–80	0.3	0.2
	80–100	2.3	1.0		80–100	0.7	0.4
	100–120	2.3	1.2		100–120	1.9	1.0
	120–140	4.7	3.3		120–140	2.2	1.2
	140–150	5.0	4.1		140–160	2.8	1.6
	150–156	5.8	5.2		160–180	4.1	2.6
	156–158	5.3	5.0		180–200	5.6	4.4
	158–159	4.3	4.1		200–220	5.3	5.0
	159–160	4.3	4.1		220–235	5.4	6.9
	Water (0–10 m)	34.1			235–241	5.1	9.2
					241–243	6.8	11.9
					243–244	8.4	14.7
					244–245	11.9	21.0
					Water (0–10 m)	33.6	
St. 97							
	0–20	0.4	0.2				
	20–40	1.7	0.7				
	40–60	2.9	1.2				
	60–80	3.3	1.4				
	80–100	3.3	1.6				
	100–120	4.6	2.6				
	120–140	5.8	4.2				
	140–160	5.6	4.8				
	160–161	5.6	5.2				
	161–167	5.4	5.4				
	167–169	5.9	6.6				
	169–170	6.0	6.8				
	170–171	9.7	11.4				
	Water (0–10 m)	33.3					

Table A3.1: Vertical profiles of sea-ice chlorophyll *a* concentration and values for under-ice water chlorophyll *a* concentration at stations 225, 228, 232, 238 and 241 (ARK XVII-2, August–October 2001). n.d. = not determined.

Ice core depth [cm]	Chlorophyll <i>a</i> concentration [$\mu\text{g l}^{-1}$]	Ice core depth [cm]	Chlorophyll <i>a</i> concentration [$\mu\text{g l}^{-1}$]
ARK XVII-2		ARK XVII-2	
St. 225		St. 232 (continued)	
0–20	0.3	140–160	0.7
20–40	0.0	160–180	0.8
40–60	0.0	180–199.5	2.1
60–80	0.0	199.5–205.5	3.9
80–100	0.0	205.5–207.5	4.5
100–120	0.0	207.5–208.5	6.3
120–140	0.0	208.5–209.5	55.5
140–160	0.0	Water (0–10m)	n. d.
160–180	0.0		
180–200	0.0		
200–220	0.0	St. 238	
220–240	0.1	0–20	0.1
240–250	0.1	20–40	0.0
250–270	0.1	40–60	0.1
270–290	0.2	60–80	0.1
290–310	0.2	80–100	0.2
310–330	1.0	100–116	0.3
330–340	1.5	116–122	0.5
340–346	4.4	122–124	0.8
346–348	9.4	124–125	2.1
348–349	11.8	125–126	59.7
349–350	32.6	Water (0–10m)	0.3
Water (0–10m)	0.3	St. 241	
St. 228		0–20	0.0
0–20	0.2	20–40	0.0
20–40	0.1	40–60	0.0
40–60	0.1	60–80	0.0
60–80	0.1	80–100	0.1
80–100	1.6	100–120	0.1
100–120	0.4	120–140	0.4
120–140	4.3	140–160	0.3
140–146	4.2	160–180	0.3
146–152	6.9	180–200	0.5
152–154	9.3	200–220	1.0
154–155	9.7	220–225	2.7
155–156	34.4	225–231	4.0
Water (0–10m)	n. d.	231–233	8.8
		233–234	11.4
		234–235	30.3
St. 232		Water (0–10m)	0.8
0–20	0.1		
20–40	0.1		
40–60	0.0		
60–80	0.0		
80–100	0.1		
100–120	0.1		

Table A3.2: Vertical profiles of sea-ice chlorophyll *a* concentration and values for under-ice water chlorophyll *a* concentration at stations 245, 248 and 253 (ARK XVII-2, August–October 2001) and stations 244 and 245 (ARK XVIII-2, August/September 2002).

Ice core depth [cm]	Chlorophyll <i>a</i> concentration [$\mu\text{g l}^{-1}$]	Ice core depth [cm]	Chlorophyll <i>a</i> concentration [$\mu\text{g l}^{-1}$]
ARK XVII-2		ARK XVII-2	
St. 245		St. 253 (continued)	
0–20	0.3	214–215	11.5
20–40	0.2	215–216	41.1
40–60	0.5	Water (0–10m)	5.0
60–80	2.8		
80–100	1.2	ARK XVIII-2	
100–120	1.3	St. 244	
120–140	1.4	0–20	0.1
140–160	1.0	20–40	0.1
160–170	1.5	40–60	0.2
170–176	2.0	60–80	0.2
176–178	1.8	80–100	0.5
178–179	1.8	100–120	0.5
179–180	4.1	120–140	0.3
Water (0–10m)	0.3	140–160	2.2
		160–180	2.1
		180–186	2.4
		186–188	7.1
St. 248		188–189	38.7
0–20	0.2	189–190	67.4
20–40	0.2	Water (0–10m)	0.3
40–60	0.5		
60–80	0.2		
80–100	0.1		
100–120	0.1	St. 245	
120–140	0.2	0–20	0.1
140–160	0.2	20–40	0.2
160–180	0.4	40–60	0.2
180–198	0.0	60–80	0.1
198–204	2.1	80–100	0.1
204–206	0.3	100–120	0.1
206–207	0.2	120–140	0.1
207–208	0.3	140–160	0.4
Water (0–10m)	0.2	160–180	1.0
		180–192	2.2
		192–198	1.9
St. 253		198–200	0.9
0–20	0.1	200–201	3.7
20–40	0.0	201–202	1.8
40–60	0.1	Water (0–10m)	0.7
60–80	0.1		
80–100	0.1		
100–120	0.1		
120–140	0.1		
140–160	0.2		
160–180	0.3		
180–200	1.6		
200–206	1.5		
206–212	2.4		
212–214	5.1		

Table A3.4: Vertical profiles of sea-ice chlorophyll *a* concentration and values for under-ice water chlorophyll *a* concentration at stations 91, 97 and 104 (ARK XIX-1, March/April 2003).

	Ice core depth [cm]	Chlorophyll <i>a</i> concentration [$\mu\text{g l}^{-1}$]		Ice core depth [cm]	Chlorophyll <i>a</i> concentration [$\mu\text{g l}^{-1}$]
ARK XIX-1			ARK XIX-1		
	St. 91			St. 104	
	0–20	0.0		0–20	0.0
	20–40	0.1		20–40	0.0
	40–60	0.2		40–60	0.0
	60–80	0.2		60–80	0.0
	80–100	0.2		80–100	0.3
	100–120	0.3		100–120	0.2
	120–140	0.0		120–140	0.6
	140–150	0.0		140–160	0.6
	150–156	0.1		160–180	0.3
	156–158	0.1		180–200	0.0
	158–159	0.1		200–220	0.1
	159–160	0.1		220–235	0.4
	Water (0–10m)	0.0		235–241	1.2
				241–243	2.1
				243–244	3.4
				244–245	1.0
				Water (0–10m)	0.0
	St. 97				
	0–20	0.2			
	20–40	0.2			
	40–60	0.2			
	60–80	0.4			
	80–100	1.4			
	100–120	0.3			
	120–140	0.1			
	140–160	0.1			
	160–161	0.2			
	161–167	0.4			
	167–169	0.6			
	169–170	0.5			
	170–171	0.2			
	Water (0–10m)	0.0			

Table A4.1: Vertical profiles of sea-ice nutrient concentration (NO_3 , NO_2 , $\text{Si}(\text{OH})_4$, PO_4) and values for under-ice water nutrient concentration at stations 71, 76 and 82 (ARK XIX-1, March/April 2003).

Ice core depth [cm]	NO_3 [$\mu\text{mol l}^{-1}$]	NO_2 [$\mu\text{mol l}^{-1}$]	$\text{Si}(\text{OH})_4$ [$\mu\text{mol l}^{-1}$]	PO_4 [$\mu\text{mol l}^{-1}$]
ARK XIX-1				
St. 71				
0–20	1.27	0.13	1.04	0.58
20–40	0.44	0.07	0.27	0.23
40–60	0.30	0.08	0.18	0.15
60–69.5	0.21	0.05	0.70	0.16
69.5–75.5	0.81	0.17	0.60	0.56
75.5–77.5	1.14	0.07	1.07	0.31
77.5–78.5	1.53	0.11	2.53	0.41
78.5–79.5	1.34	0.18	1.53	0.22
Water (0–10m)	4.06	0.05	3.62	0.41
St. 76				
0–20	1.16	0.08	0.89	0.74
20–40	0.79	0.07	0.34	0.45
40–60	0.75	0.06	0.53	0.19
60–80	1.05	0.07	1.06	0.28
80–88	0.77	0.16	0.71	0.29
88–94	1.31	0.05	1.21	0.15
94–96	1.55	0.08	1.89	0.24
96–97	1.96	0.14	2.53	0.35
97–98	2.25	0.14	2.55	0.29
Water (0–10m)	3.22	0.09	7.41	1.82
St. 82				
0–20	1.95	0.09	2.02	0.97
20–40	0.90	0.05	1.96	3.46
40–60	1.41	0.04	1.83	0.49
60–72.5	0.85	0.04	1.48	0.79
72.5–78.5	1.06	0.04	1.76	0.86
78.5–80.5	1.86	0.21	3.01	2.24
80.5–81.5	1.76	0.09	2.63	0.73
81.5–82.5	1.86	0.08	2.82	0.59
Water (0–10m)	6.29	0.08	5.49	0.58

Table A4.2: Vertical profiles of sea-ice nutrient concentration (NO_3 , NO_2 , $\text{Si}(\text{OH})_4$, PO_4) and values for under-ice water nutrient concentration at stations 91, 97 and 104 (ARK XIX-1, March/April 2003). n.d. = not determined.

Ice core depth [cm]	NO_3 [$\mu\text{mol l}^{-1}$]	NO_2 [$\mu\text{mol l}^{-1}$]	$\text{Si}(\text{OH})_4$ [$\mu\text{mol l}^{-1}$]	PO_4 [$\mu\text{mol l}^{-1}$]
ARK XIX-1				
St. 91				
0–20	0.64	0.05	0.43	4.15
20–40	0.15	0.10	0.25	2.74
40–60	0.18	0.20	0.35	2.23
60–80	0.59	0.40	0.77	1.13
80–100	0.16	0.02	0.81	2.47
100–120	0.18	0.03	0.80	4.04
120–140	0.37	0.04	1.08	3.07
140–160	0.50	0.02	1.21	5.13
160–166	1.09	0.10	0.94	2.16
166–172	0.56	0.03	0.50	0.40
172–174	0.88	0.03	0.86	1.80
174–175	0.97	0.03	1.13	3.07
175–176	1.63	0.05	1.44	3.16
Water (0–10m)	9.34	0.02	6.73	0.68
St. 97				
0–20	0.67	0.04	0.07	0.14
20–40	0.70	0.04	0.63	0.14
40–60	0.42	0.04	0.90	0.09
60–80	0.36	0.03	1.12	0.10
80–100	0.32	0.04	1.22	0.14
100–120	1.05	0.05	0.64	0.13
120–140	1.08	0.06	0.32	0.10
140–160	1.20	0.03	0.71	0.09
160–169	1.61	0.06	1.01	0.14
169–175	1.47	0.04	1.08	0.13
175–177	1.56	0.04	1.32	0.20
177–178	2.05	0.10	1.90	0.24
178–179	2.47	0.07	1.95	0.26
Water (0–10m)	7.34	0.01	5.27	0.54
St. 104				
0–20	0.78	0.04	0.23	0.07
20–40	1.90	0.06	0.14	0.20
40–60	0.88	0.03	0.02	0.03
60–80	1.35	0.04	0.26	0.07
80–100	0.46	0.04	0.57	0.07
100–120	0.93	0.11	1.12	0.19
120–140	0.55	0.07	1.16	0.21
140–160	0.97	0.12	1.94	0.33
160–180	0.81	0.08	1.61	0.21
180–200	1.36	0.06	0.68	0.12
200–220	17.70	0.07	0.54	0.16
220–236	1.59	0.03	0.56	0.04
236–242	1.19	0.07	0.68	0.08
242–244	1.22	0.03	2.44	0.13
244–245	2.41	0.07	1.21	0.24
245–246	8.43	0.10	1.85	0.46
Water (0–10m)	n. d.	n. d.	n. d.	n. d.

Table A5.1: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water at stations 225 and 228 (ARK XVII-2, August–October 2001). n.d. = not determined.

Ice core depth [cm]	Rotifers [organisms l ⁻¹]	Nematodes [organisms l ⁻¹]	Copepods [organisms l ⁻¹]	Turbellarians [organisms l ⁻¹]	Nauplii [organisms l ⁻¹]
ARK XVII-2					
St. 225					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	1.0	0.0	0.0	0.0
120–140	0.0	0.0	1.1	0.0	0.0
140–160	0.0	0.0	0.0	0.0	0.0
160–180	n. d.	n. d.	n. d.	n. d.	n. d.
180–200	0.0	2.0	0.0	0.0	0.0
200–220	0.0	1.7	0.0	0.0	0.0
220–240	0.0	4.6	0.0	0.0	0.0
240–260	0.0	0.0	0.0	0.0	0.0
260–280	0.0	3.5	0.0	0.9	0.0
280–300	0.0	2.7	0.0	2.7	0.0
300–320	1.0	1.0	0.0	20.8	0.0
320–338	6.5	0.0	0.0	25.8	0.0
338–344	13.5	5.4	0.0	51.4	0.0
344–346	10.2	6.8	0.0	16.9	0.0
346–347	66.7	66.7	66.7	366.7	0.0
347–348	100.0	66.7	300.0	566.7	0.0
Water (0–10m)	0.1	0.0	1.5	0.1	2.2
St. 228					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.9	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	1.0	0.0	0.0	0.0	0.0
100–120	1.0	0.0	0.0	0.0	0.0
120–140	1.0	0.0	0.0	0.0	0.0
140–154	1.4	0.0	0.0	0.0	0.0
154–160	8.8	0.0	0.0	0.0	0.0
160–162	35.1	0.0	2.7	0.0	0.0
162–163	111.5	0.0	3.8	0.0	0.0
163–164	568.0	0.0	148.0	8.0	8.0
Water (0–10m)	n. d.	n. d.	n. d.	n. d.	n. d.

Table A5.2: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water at stations 232, 238 and 241 (ARK XVII-2, August–October 2001).

	Ice core depth [cm]	Rotifers [organisms Γ^{-1}]	Nematodes [organisms Γ^{-1}]	Copepods [organisms Γ^{-1}]	Turbellarians [organisms Γ^{-1}]	Nauplii [organisms Γ^{-1}]
ARK XVII-2						
St. 232						
	0–20	0.0	0.0	0.0	0.0	0.0
	20–40	0.0	0.0	0.0	0.0	0.0
	40–60	0.0	0.0	0.0	0.0	0.0
	60–80	0.0	0.0	0.0	0.0	0.0
	80–100	0.0	0.0	0.0	0.0	0.0
	100–120	0.0	0.0	0.0	0.0	0.0
	120–140	0.0	0.9	0.9	0.0	0.0
	140–160	16.2	29.5	2.9	0.0	0.0
	160–180	7.5	49.5	0.0	0.0	0.0
	180–193	11.9	47.8	0.0	0.0	0.0
	193–199	14.3	37.1	11.4	0.0	0.0
	199–201	26.3	18.4	23.7	0.0	0.0
	201–202	37.5	8.3	45.8	0.0	4.2
	202–203	82.6	4.3	169.6	26.1	65.2
	Water (0–10m)	0.5	0.3	3.0	0.0	2.5
St. 238						
	0–20	0.0	0.0	0.0	0.0	0.0
	20–40	0.0	0.0	0.0	0.0	0.0
	40–60	0.0	0.0	0.0	0.0	0.0
	60–80	3.8	0.0	0.0	0.0	0.0
	80–100	14.3	0.0	0.0	0.0	0.0
	100–120	7.0	0.0	2.0	0.0	0.0
	120–127	25.8	0.0	0.0	0.0	0.0
	127–133	44.4	0.0	3.2	0.0	0.0
	133–135	48.5	0.0	6.1	0.0	0.0
	135–136	57.9	0.0	0.0	0.0	0.0
	136–137	265.0	5.0	10.0	0.0	0.0
	Water (0–10m)	3.3	0.0	2.3	0.0	3.8
St. 241						
	0–20	0.0	0.0	1.4	0.0	0.0
	20–40	0.0	0.0	1.1	0.0	0.0
	40–60	0.0	0.0	0.0	0.0	0.0
	60–80	0.0	0.0	0.0	0.0	0.0
	80–100	0.0	0.0	0.0	0.0	0.0
	100–120	0.0	0.0	0.0	0.0	0.0
	120–140	0.0	0.0	0.0	0.0	0.0
	140–160	13.6	0.0	0.0	0.0	0.0
	160–180	1.8	0.0	0.0	0.0	0.0
	180–200	5.6	0.0	1.1	0.0	0.0
	200–215	10.3	0.0	10.3	0.0	0.0
	215–221	30.6	0.0	19.4	0.0	0.0
	221–223	24.2	0.0	21.2	0.0	0.0
	223–224	26.3	0.0	26.3	5.3	0.0
	224–225	52.6	0.0	21.1	0.0	0.0
	Water (0–10m)	1.2	0.0	2.9	0.0	1.7

Table A5.3: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water at stations 245, 248 and 253 (ARK XVII-2, August–October 2001).

	Ice core depth [cm]	Rotifers [organisms l ⁻¹]	Nematodes [organisms l ⁻¹]	Copepods [organisms l ⁻¹]	Turbellarians [organisms l ⁻¹]	Nauplii [organisms l ⁻¹]
ARK XVII-2						
St. 245						
	0–20	0.0	0.0	0.0	0.0	0.0
	20–40	0.0	0.0	0.0	0.0	0.0
	40–60	0.0	0.0	0.0	0.0	0.0
	60–80	0.0	0.0	0.0	0.0	0.0
	80–100	8.9	0.0	0.0	0.0	0.0
	100–120	6.2	0.0	0.0	0.0	0.0
	120–140	4.9	0.0	2.0	0.0	0.0
	140–160	8.9	0.0	4.4	0.0	0.0
	160–180	10.2	0.0	2.0	1.0	1.0
	180–186	3.3	0.0	0.0	20.0	0.0
	186–188	3.6	0.0	21.4	14.3	32.1
	188–189	8.3	0.0	33.3	0.0	8.3
	189–190	28.6	0.0	14.3	14.3	28.6
	Water (0–10m)	0.0	0.0	1.8	0.0	4.3
St. 248						
	0–20	0.0	0.0	0.0	0.0	0.0
	20–40	0.0	0.0	0.0	0.0	0.0
	40–60	18.0	0.0	1.0	0.0	0.0
	60–80	4.8	0.0	0.0	0.0	0.0
	80–100	7.3	0.0	0.0	0.0	0.0
	100–120	1.1	0.0	0.0	0.0	0.0
	120–140	2.8	0.0	1.9	0.0	10.2
	140–160	1.0	0.0	1.9	0.0	0.0
	160–180	3.6	0.0	3.6	0.0	0.0
	180–200	6.0	0.0	7.0	0.0	0.0
	200–205	11.5	0.0	3.8	0.0	0.0
	205–211	0.0	0.0	27.6	0.0	0.0
	211–213	5.9	0.0	5.9	0.0	0.0
	213–214	0.0	0.0	7.1	0.0	0.0
	214–215	0.0	0.0	0.0	0.0	0.0
	Water (0–10m)	0.1	0.0	0.7	0.0	3.3
St. 253						
	0–20	0.0	0.0	0.0	0.0	0.0
	20–40	0.0	0.0	0.0	0.0	0.0
	40–60	0.0	0.0	0.0	0.0	0.0
	60–80	0.0	0.0	0.0	0.0	0.0
	80–100	0.0	0.0	0.0	0.0	0.0
	100–120	0.0	0.0	0.0	0.0	0.0
	120–140	0.0	0.0	0.0	0.0	0.0
	140–160	5.3	0.0	1.1	0.0	0.0
	160–180	0.0	0.0	0.0	0.0	0.0
	180–183	0.0	0.0	50.0	0.0	0.0
	183–189	8.6	0.0	20.0	0.0	0.0
	189–191	5.6	0.0	22.2	2.8	2.8
	191–192	29.6	0.0	111.1	0.0	7.4
	192–193	58.3	0.0	166.7	8.3	50.0
	Water (0–10m)	6.3	0.0	1.0	0.0	2.5

Table A5.4: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water at stations 244, 245 and 251 (ARK XVIII-2, August/September 2002).

Ice core depth [cm]	Rotifers [organisms Γ^{-1}]	Nematodes [organisms Γ^{-1}]	Copepods [organisms Γ^{-1}]	Turbellarians [organisms Γ^{-1}]	Nauplii [organisms Γ^{-1}]
ARK XVIII-2					
St. 244					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.9	0.0	0.9
60–80	0.0	0.0	3.8	1.3	6.3
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	0.0	0.0	0.0	0.0
120–140	0.0	0.0	0.0	0.0	0.0
140–160	0.0	0.0	1.8	0.0	0.0
160–180	1.0	0.0	7.1	0.0	0.0
180–200	3.6	2.4	8.3	0.0	0.0
200–206	0.0	0.0	12.3	0.0	0.0
206–208	6.5	0.0	19.5	0.0	2.2
208–209	28.5	0.0	82.1	7.1	7.1
209–210	65.7	0.0	240.7	5.5	5.5
Water (0–10m)	0.0	0.0	1.6	0.0	3.2
St. 245					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	0.0	0.9	0.0	0.0
120–140	0.0	0.0	0.0	2.6	0.9
140–160	0.0	0.0	0.0	1.7	0.9
160–180	13.5	0.0	0.0	0.0	0.0
180–198	79.2	0.0	0.0	0.0	0.0
198–204	62.3	0.0	0.0	0.0	0.0
204–206	142.9	0.0	0.0	0.0	0.0
206–207	41.5	20.7	0.0	0.0	0.0
207–208	31.3	11.7	0.0	0.0	0.0
Water (0–10m)	6.8	0.0	1.5	0.2	0.0
St. 251					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.9	0.0	0.0	0.0	0.0
60–80	0.0	0.0	2.9	0.0	0.0
80–100	0.9	0.0	0.9	0.0	0.0
100–120	0.0	0.0	0.9	0.0	1.7
120–125	0.0	0.0	3.3	0.0	6.5
125–131	0.0	0.0	2.6	0.0	0.0
131–133	2.5	0.0	2.5	0.0	0.0
133–134	10.7	5.3	0.0	0.0	0.0
134–135	3.7	3.7	3.7	0.0	0.0
Water (0–10m)	0.0	0.0	19.5	0.0	29.1

Table A5.5: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water at stations 252 and 254 (ARK XVIII-2, August/September 2002).

Ice core depth [cm]	Rotifers [organisms l ⁻¹]	Nematodes [organisms l ⁻¹]	Copepods [organisms l ⁻¹]	Turbellarians [organisms l ⁻¹]	Nauplii [organisms l ⁻¹]
ARK XVIII-2					
St. 252					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	0.0	0.0	0.0	0.0
120–140	0.0	0.0	0.0	0.0	0.0
140–160	0.0	0.0	0.0	0.0	0.0
160–180	0.0	4.8	0.0	0.0	0.0
180–200	4.0	28.3	0.0	0.0	0.0
200–220	29.2	27.5	0.0	0.0	0.0
220–239	4.2	14.4	1.7	0.0	0.0
239–245	2.5	2.5	7.4	2.5	0.0
245–247	0.0	11.7	14.1	11.7	0.0
247–248	4.9	34.6	24.7	39.6	0.0
248–249	0.0	25.2	0.0	12.6	0.0
Water (0–10m)	0.0	0.0	13.2	0.0	10.0
St. 254					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	0.0	0.0	0.0	0.0
120–140	0.0	0.0	0.0	0.0	0.0
140–160	0.0	0.0	0.0	0.0	0.0
160–180	0.0	0.0	0.0	0.0	0.0
180–200	0.0	0.0	0.0	0.0	0.0
200–220	0.0	0.0	0.0	0.0	0.0
220–240	0.0	0.0	0.0	0.0	0.0
240–260	0.0	0.0	0.0	0.0	0.0
260–274	0.0	0.0	0.0	0.0	0.0
274–280	0.0	0.0	0.0	0.0	0.0
280–282	0.0	0.0	0.0	0.0	0.0
282–283	0.0	0.0	0.0	0.0	0.0
283–284	0.0	0.0	18.0	0.0	0.0
Water (0–10m)	0.0	0.0	6.7	0.0	3.0

Table A5.6: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water at stations 71, 76, 82 and 91 (ARK XIX-1, March/April 2003).

Ice core depth [cm]	Rotifers [organisms Γ^{-1}]	Nematodes [organisms Γ^{-1}]	Copepods [organisms Γ^{-1}]	Turbellarians [organisms Γ^{-1}]	Nauplii [organisms Γ^{-1}]
ARK XIX-1					
St. 71					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–68.5	2.2	0.0	0.0	0.0	4.3
68.5–74.5	0.0	0.0	0.0	0.0	42.2
74.5–76.5	0.0	0.0	0.0	0.0	17.0
76.5–77.5	0.0	0.0	3.7	0.0	25.9
77.5–78.5	0.0	0.0	0.0	0.0	136.5
Water (0–10m)	0.0	0.0	0.0	0.0	0.8
St. 76					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.6	0.0	0.0	0.0	2.5
80–91	0.0	0.0	0.0	0.0	1.6
91–97	0.0	0.0	0.0	0.0	0.0
97–99	5.3	0.0	0.0	0.0	7.9
99–100	0.0	0.0	0.0	0.0	28.5
100–101	9.5	0.0	0.0	0.0	75.9
Water (0–10m)	0.0	0.0	1.2	0.0	1.0
St. 82					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–77	0.0	0.0	0.0	0.0	0.0
77–83	0.0	0.0	0.0	0.0	9.0
83–85	0.0	0.0	3.0	0.0	42.0
85–86	0.0	0.0	0.0	0.0	65.1
86–87	0.0	0.0	0.0	0.0	16.0
Water (0–10m)	0.0	0.2	4.8	0.0	0.6
St. 91					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	0.0	0.0	0.0	2.6
120–140	0.0	0.0	0.0	0.0	8.8
140–160	0.0	0.0	0.0	0.0	0.8
160–172	0.0	0.0	0.0	0.0	1.8
172–178	8.8	0.0	0.0	0.0	4.4
178–180	0.0	0.0	0.0	0.0	41.2
180–181	8.6	0.0	0.0	0.0	242.0
181–182	6.9	0.0	0.0	6.9	194.4
Water (0–10m)	0.0	0.0	0.9	0.0	2.6

Table A5.7: Vertical distribution of the abundance of rotifers, nematodes, copepods, turbellarians and nauplii in sea ice and under-ice water at stations 97 and 104 (ARK XIX-1, March/April 2003).

Ice core depth [cm]	Rotifers [organisms l ⁻¹]	Nematodes [organisms l ⁻¹]	Copepods [organisms l ⁻¹]	Turbellarians [organisms l ⁻¹]	Nauplii [organisms l ⁻¹]
ARK XIX-1					
St. 97					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	0.0	0.0	0.0	0.0
120–140	0.0	0.0	0.0	0.0	1.8
140–160	0.0	0.0	0.0	0.0	0.0
160–174	0.0	0.0	0.0	0.0	0.0
174–180	0.0	0.0	0.0	0.0	0.0
180–182	0.0	0.0	0.0	0.0	19.9
182–183	0.0	0.0	0.0	4.0	67.7
183–184	0.0	0.0	0.0	0.0	163.2
Water (0–10m)	0.0	0.0	1.1	0.0	9.9
St. 104					
0–20	0.0	0.0	0.0	0.0	0.0
20–40	0.0	0.0	0.0	0.0	0.0
40–60	0.0	0.0	0.0	0.0	0.0
60–80	0.0	0.0	0.0	0.0	0.0
80–100	0.0	0.0	0.0	0.0	0.0
100–120	0.0	0.0	0.0	0.0	1.5
120–140	0.0	0.0	0.0	0.0	0.0
140–160	0.0	0.0	2.7	0.0	0.0
160–180	0.0	0.0	7.5	0.0	0.0
180–200	0.0	0.0	0.0	0.0	0.0
200–220	0.0	0.0	0.0	0.0	1.9
220–240	0.0	0.0	0.0	0.0	0.0
240–260	0.0	0.0	0.0	0.0	0.9
260–264	0.0	0.0	0.0	0.0	21.2
264–270	0.0	0.0	0.0	0.0	32.9
270–272	3.2	0.0	1.6	0.0	106.4
272–273	0.0	5.2	0.0	5.2	218.2
273–274	0.0	0.0	13.9	0.0	62.5
Water (0–10m)	0.0	0.0	1.0	0.0	8.3

Lebenslauf

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Erklärung

Hiermit erkläre ich, dass die vorliegende Dissertation – abgesehen von der Beratung durch meine akademischen Lehrer – nach Inhalt und Form meine eigene Arbeit ist. Sie wurde keiner anderen Stelle im Rahmen eines Prüfungsverfahrens vorgelegt. Dies ist mein erster Promotionsversuch.

Kiel, im September 2004