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New Concepts on the Distributions of Zooplankton in the Arctic Ocean – With Comments on the Effect of Climate Change

Kurzfassung

Die Geschichte der Zooplanktonforschung im Nordpolarmeer wird kurz beschrieben. Die räumliche Verteilung und Artzusammensetzung des Zooplanktons ist eng an die Hydrographie gekoppelt, eine besondere Rolle spielt dabei der Einstrom von Atlantikwasser. Die möglichen Auswirkungen eines weiteren Anstiegs der Wassertemperatur und der Rückgang der Eisbedeckung auf das pelagische Ökosystem werden diskutiert.

Abstract

The history of zooplankton research in the Arctic Ocean is reviewed. Qualitative and quantitative distribution are closely related to the hydrography, especially the inflow of Atlantic water. The potential impact of increasing temperatures and sea-ice melting on the pelagic ecosystem is discussed.

Résumé

Dans cet article on fait un tour d'horizon de l'histoire de la recherche du zooplancton dans la mer Arctique. La répartition qualitative et la répartition quantitative sont en rapport direct avec l'hydrographie, notamment avec l'admission d'eau provenant de l'Atlantique. Les effets possibles de l'accroissement des températures et de la fonte des glaces de mer sur l'écosystème pélagique sont discutés.

Keywords

Zooplankton, Arctic Ocean, History

1. History of Zooplankton Research in the Arctic Ocean

The study of Arctic zooplankton is closely coupled with the exploration of the Arctic Ocean. Samples were collected during many exploratory expeditions (Tab. 1). It was not until Nansen's historic voyage across the Arctic at the turn of the 20th century, that the presence of a deep basin was established, thus dispelling the previously held opinions that sea ice covers scattered islands separated by shallow water. Before discovery of the Lomonosov Ridge (1948) the Arctic Ocean was considered as one large central basin. This concept survived up to the late 80s in biology. As most of the manned ice islands drifted in the Canadian Basin, regional sampling was strongly biased. Initial subjects of zooplankton research were species inventory including search for endemic species, and study of the influence of Atlantic and Pacific fauna. Later interest focused on vertical distribution in relation to water masses and seasonal ontogenetic migration, although the number of deep samples was very limited. Trophic relationships, secondary production and the contribution to carbon flux are still only poorly represented. Arctic Ocean for a long time has been considered as a biological desert. Until 1990 biomass maxima between 0.12 and 2g m^{-2} were reported, recent expeditions found up to 9.5 (KOSOBOKOVA & HIRCHE 2000) and 13g m^{-2} (THIBAULT et al. 1999).

2. Modern Concepts of Zooplankton Distribution

Recent studies revealed a close coupling between hydrography, topography and zooplankton distribution. The zooplankton is strongly dominated by copepods (Table 2). There are no endemic species in the Arctic Ocean, instead the fauna shows a close relationship to the North Atlantic deep water fauna, with some Pacific components. Only very few expatriated species were found, which can be used as indicators for Pacific and Atlantic water masses. The similarity in species composition of all four ba-

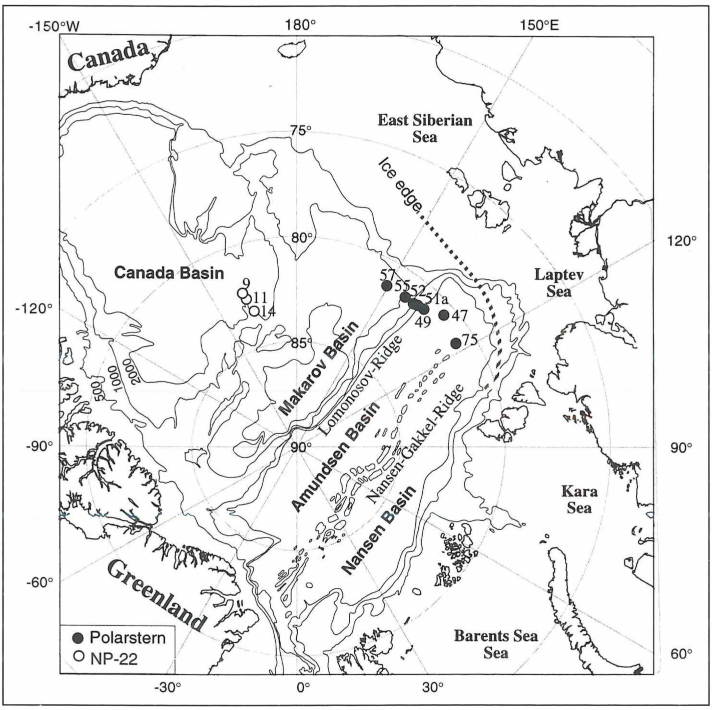

Fig. 1: Map of Arctic with transect across Lomonosov Ridge (57–75) and stations of NP–22 (9–14)

sins indicates effective mixing processes. Two major gradients describe the regional distribution of zooplankton in the Arctic Ocean, both related to the circulation patterns. According to recent hydrographic studies, Atlantic water enters the Arctic Ocean through Fram Strait and over the Barents and Kara Shelves (RUDELS et al. 1994). It is trapped in a boundary current running counterclockwise along the perimeter of the Arctic Ocean (AAGAARD 1989). Recirculating branches of the Atlantic water are deflected where mid ocean ridges meet the Eurasian Shelf like the Nansen-Gakkel Ridge (ANDERSON et al. 1989), the Lomonosov Ridge (AAGAARD 1989; ANDERSON et al. 1989), and the Alpha-Mendeleev Ridge (RUDELS et al. 1994). This inflow advects a large zooplankton biomass from the Greenland and Barents Seas (HIRCHE & MUMM 1992; MUMM et al. 1998). Recent calculations of the transport through Fram Strait of 1.6 Sv (Fahrbach pers. comm.) would result in an export of 315.360 or 31.536.000 to carbon year^{-1}, assuming a zooplankton concentration of 0.01 or 1 g C m^{-3}. Vice versa, in the Barents and Greenland Seas and in Baffin Bay, Polar water is overlaying the Atlantic waters and Arctic fauna is exported south. Intensive exchange processes take also place with other marginal seas. Thus in the Kara Sea and Laptev Sea, Arctic water masses including Arctic fauna are advected on-shelf and penetrate under the riverine formed waters far into the mouths of the rivers. In turn, estuarine species are drifting away from the rivers in the wake of the riverine waters.

Gradient 1 describes the biomass and relative species composition from the basin margins to their centres, reflecting the dynamics of the Atlantic inflow. The inner basins are inhabited by an autochthonous community of low biomass (ca. 1 g m^{-2}) consisting mainly of meso- and bathypelagic copepods, while along the margins in the centre of the boundary current an allochthonous community of mostly Atlantic species is found with much higher biomass, dominated by the large herbivorous copepods *Calanus hyperboreus*, *C. glacialis* and *C. finmarchicus*. The former 2 species have multi-annual life cycles, *C. hyperboreus* eventually up to six years, and can starve for many months. So far this community is tracked in the Nansen Basin on the Barents shelf slope (HIRCHE & MUMM 1992) and off the Laptev Shelf (KOSOBOKOVA et al. 1998). In addition, a transect from the Amundsen Basin across the Lomonosov Ridge to the Makarov Basin (KOSOBOKOVA & HIRCHE 2000) showed a strong gradient in biomass along the transect, with a pronounced peak (9.5 g dry weight m^{-2}) in the core of Atlantic water over the ridge, and minima over the deep basins (Figures 1, 2). According to the circulation of the boundary current, maxima are also expected on the margins of the Canada Basin and in recirculation branches over the Alpha-Mendeleev Ridge. The reduction of Atlantic species in the inner basins suggests that the allochthonous community is dependent on advection.

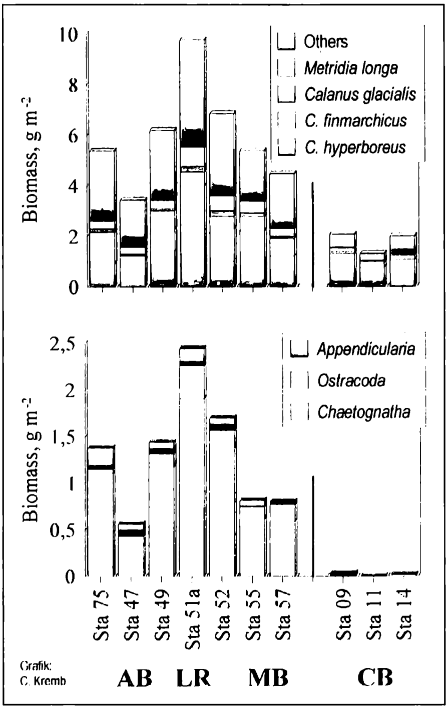

Fig. 2: Distribution of total biomass and portion of large copepods (a) and other taxa (b) in different basins of the Arctic Ocean (station locations in Fig. 1; modified from KOSOBOKOVA & HIRCHE 2000)

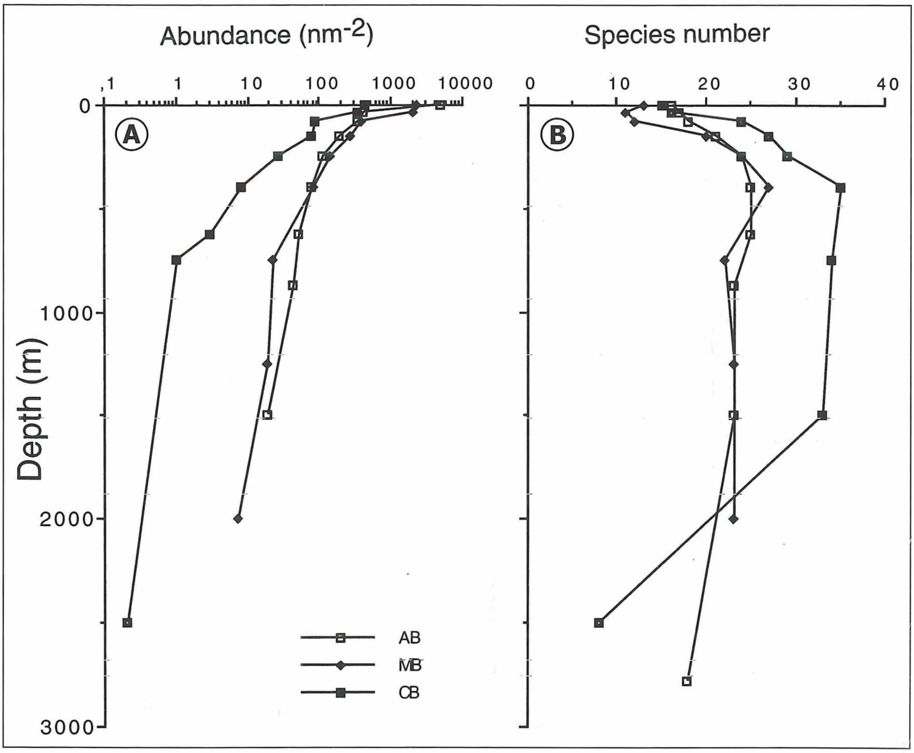

Fig. 3: Vertical summer distribution of zooplankton abundance (A) and species number (B) in the Amundsen (AB), Makarov (MB) and Canada Basins (CB) of the Arctic Ocean. Note the maxima of species number in the Atlantic layer. (Data from KOSOBOKOVA & HIRCHE 2000)

Tab. 1: History of Zooplankton Research in the Arctic Ocean (s.d. = sampling depth)

1893–1896	Fram (s.d. 300m)
1931	Nautilus 82°30' (HARDY 1936)
1935–1937	USSR Ice breakers Sedov (-85°N), Sadko, F. Lidtke (s.d. 500m)
1937	Ice Islands NP–1 (2nd International Polar Year)
1950–1978	Ice Islands NP 2–23; from NP–2 first deep samples (s.d. 300m; BRODSKY & NIKTIN 1955)
1950, 1951	USCGC Burton Island (JOHNSON 1956, HAN & KAN 1961)
1952–1958	Ice Island T–3 "Fletcher Island" (s.d. 3000m; MOHR 1959)
1957–1958	Ice Island Alpha: Canadian and Eurasian Basin (JOHNSON 1963, MINODA 1967, HOPKINS 1969)
1961	USS Seadragon (nuclear powered submarine) (s.d. 200m; GRICE 1962)
1980	Ymer 82°N (s.d. 500m, 2000m; GROENDAHL & HERNROTH 1986)
1987	Polarstern 86°N (s.d. 500m; HIRCHE & MUMM 1992)
1991	Oden/Polarstern North Pole (s.d. 500m; HANSEN 1993)
1995	Polarstern Transect across Lomonosov Ridge (s.d. close to bottom; KOSOBOKOVA & HIRCHE 2000)
1996	Arctic Ocean Section (s.d. 500m; THIBAULT et al. 1999)

Gradient 2 describes differences between basins. While the relative composition of zooplankton is similar in the Nansen, Amundsen and Makarov Basins, in the Canada Basin the abundances were at least one order of magnitude lower at each depth (Fig. 3), and biomass was lower by a factor of 2 or 3 in a historical data set from NP-22 (KOSOBOKOVA & HIRCHE 2000; Fig. 2). The portion of copepods was increased due to a dramatic decrease of non-copepod zooplankton in the Canada Basin. Within the copepods, the complete absence of the Atlantic indicator species *Calanus finmarchicus* is noteworthy. Appendicularians have almost disappeared, and the biomass of chaetognaths was less than half of the Eurasian Basins (Fig. 2). The low biomass observed in the Canada Basin, and especially the decrease in its allochthonous components, is explained by the fact, that this basin is relatively more isolated from the Atlantic inflow and has a much longer renewal time than the other basins (SWIFT et al. 1997). Eventually food conditions there are also more severe.

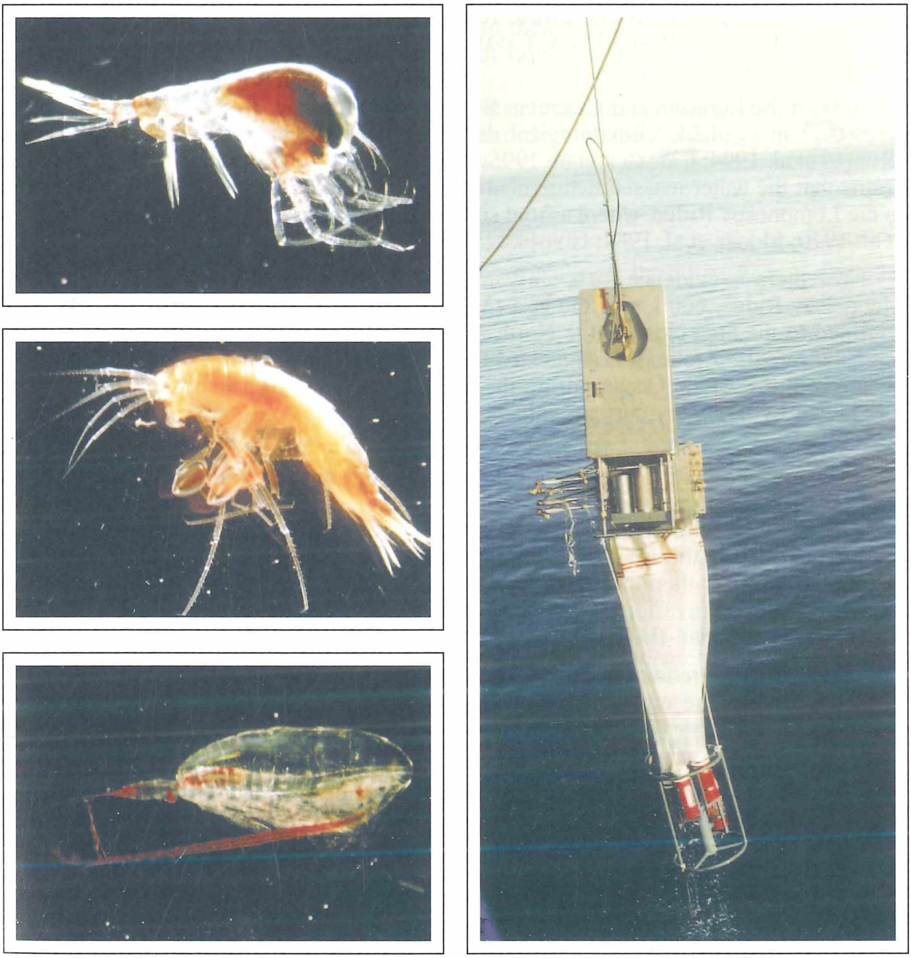

Fig. 4: Two mesopelagic amphipods (left up and left centre) and the dominant copepod *Calanus hyperboreus* (left down) from the Arctic Ocean. The modern multiple opening-closing net (right) allows to sample 5 depth strata in one hawl.

Crustacea	96.6% abundance
Copepoda	95.5
Ostracoda	0.9
Amphipoda	0.15
Others	3.4% abundance
Appendicularia	1.4
Chaetognatha	1.3

Tab. 2: Composition of zooplankton taxa (Eurasian Basin). Caveat: only relatively small nets used

3. Climate and Zooplankton in the Arctic Ocean

New observations show that the Arctic Ocean is not a quiescent environment remaining in a quasi-steady state, but that it exhibits as large a variability as other regions of the ocean. Thus microwave remote sensing data have revealed a decrease in the extent of sea-ice (PARKINSON & CAVALIERI 1989), which in recent years has accelerated (JOHANNESSEN et al. 1995).

In both the Eurasian and Canadian Basins the Atlantic layer shows higher temperatures than in available climatological data as a result from inflow of Atlantic waters (RUDELS et al. 1994; CARMACK et al. 1995; MACDONALD 1996). From past investigations it seems that the water mass structure characteristic of the Canadian Basin extended fully to the Lomonosov Ridge, where a front separated the two hydrographic domains (KINNEY et al. 1970; MOORE et al. 1983; GORSHKOV 1983).

Now there is evidence for a shift in this front from the Lomonosov Ridge to the Mendeleev Ridge, 600 km to the east (MCLAUGHLIN et al. 1996). Pacific water is more confined to the area close to the North American continent allowing Atlantic water to reach far into the Arctic. It is suggested that this warming and water mass transition has occurred in the Arctic Ocean during the 90s, with a rapid propagation of the temperature signal by boundary currents into at least three of the four major basins (CARMACK et al. 1995).

These changes in the intensity of the Atlantic inflow and their effect especially on the Makarov Basin should have strong influence on zooplankton biomass and distribution. Indeed, as in the hydrographic data (RUDELS et al. 2000), there was no indication for a front east of the Lomonosov Ridge in the zooplankton either (KOSOBOKOVA & HIRCHE 2000). It is therefore very likely that the recent invasion of warm water was associated with an invasion of Atlantic zooplankton, which may have replaced the poor stock of the Canadian Basin.

This implies a tremendous increase of zooplankton carbon considering the size of this basin. Also, the unusual biomass peak on the Lomonosov Ridge observed by KOSOBOKOVA & HIRCHE (2000) may be indication for increased advective intensity, eventually in combination with good growth conditions for the advected fauna underway.

Which ecological consequences are to be expected from further increase of temperature and sea-ice melting in the Arctic Ocean?

Increased temperatures may lead to:

- a regime shift in the advection community. The expatriated, however very abundant copepod *Calanus finmarchicus* may reproduce successfully and thus compete with the larger congeners *C. hyperboreus* and *C. glacialis*.
- establishment of Atlantic predator populations (e.g. cod) in the region of Atlantic inflow. Thus the warming from the 1920s up to the late 30s was followed by a northward migration of cod along the west coast of Greenland.

Increased melting of sea ice may:

- increase primary production due increased stratification and light availability
- hamper vertical mixing and thus the supply of nutrients during the growth season
- lengthen the growth season which in turn may
- increase the turnover of calanoid copepod populations
- modify the trophic relationships, as they are the main metazoan consumers of microalgal biomass and the primary trophic link between plankton and vertebrates (fish, birds, marine mammals).
- modify the vertical flux of biogenic carbon in the Arctic, as they produce large, fast-sinking faecal pellets that in some instance can accelerate the vertical flux of particulate organic carbon.

Many fields of zooplankton research in the Arctic Ocean such as trophodynamics, transformation of organic matter etc. are still in their infancy. More complete data sets from synoptic transects through all basins with sampling down to bottom covering all seasons in combination with experimental work on trophodynamics are needed to assess interannual variability in zooplankton distribution and to determine whether autotrophic and heterotrophic processes are balanced, or if the Arctic is a net source or sink for organic carbon.

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