Recent sea ice ecosystem in the Arctic Ocean: a review

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Abstract

Recent global warming in the Arctic Ocean predicts shifting of ice-edge to the north, decreasing of sea-ice thickness and surface, and increasing of ice-open areas. This scenario suggests increasing of biological productivity and duration of vegetation period, and intensification of regeneration processes in the sea ice-upper ocean system. However, at present the evidence of impacts of global change on the sea ice ecosystem is sparse or uncertain, though there are fragmentary indications of recent changes. As established now, the biological community response to global change is most likely in the regions, where the sea ice retreat is rather remarkable, e.g., in the region of Beaufort Gyre. Assessment of the recent sea-ice ecosystem dynamic and modeling its potential changes in the Central Arctic Ocean will allow estimating and forecasting potential changes within the sea ice-upper water system and consequent ecological effects on higher trophic levels including birds, marine mammals and benthic organisms.

Introduction

During the last decades, a clear temperature trend towards warming is observed in the Arctic. As a result of warming, the multiyear ice area decreases at least twice, but the seasonal ice area is increasing rapidly exceeding 50% of the Arctic Ocean area in 2007. The ice-cover thickness is also decreased from 3–5 m thick in middle 70th (Busuev 1968; Koerner 1973; Wadhams 1983) to less than 2 m thick in last decade (Perovich et al. 1999; Melnikov 2007, 2008). As a consequence of sea ice melting, a temperature increase and freshening of surface arctic water were also detected (Carmack et al. 1995; Serreze and Maslanik 1997; Morrison et al. 1998; McPhee et al. 1998; etc.) as well as changes in the composition and structure of the sea ice-associated biological communities (Melnikov et al. 1998,

J.C.J. Nihoul and A.G. Kostianoy (eds.), *Influence of Climate Change on the Changing Arctic and Sub-Arctic Conditions*,

2001, 2002; Melnikov 2000; Melnikov and Kolosova 2001). Remarkable changes were occurred in quality and quantity composition of the sea ice biota in comparison to composition in the middle of 70th. So, the total number of sea ice algae in 1975–1982 consists of 172 species (Melnikov 1989) and about 30 species during the last decade (Melnikov 2008). Diatoms were dominated both by species and number in sea ice phytocenoses but recently their domination is decreased and changed by prevalence of other algal groups. Composition of sea ice fauna is also changed: protozoans and sea ice-associated invertebrate animals like acarians, nematodes, turbellarians, rotatorians, copepods and amphipods were numerous in ice of 70th but they are very rare found in ice of last decade and met very often as dead fragments of tintinnides, nematodes, and skins of copepods.

The observed changes allow setting questions related to the response of the sea ice ecosystem to global warming, of which the most important are as follows:

1. How do the physical–chemical properties of sea ice and sea water contacting it change?
2. How does the species composition and structure of biological communities change?
3. What is the dynamics and direction of these processes?

In this review, the main attention will be focused on two major components of the Arctic sea ice cover – multiyear (MY) and seasonal or first year (FY) sea ice as well as the upper ocean system. In this formulation, by the "upper ocean" definition, it means the water of the mixed layer above the pycnocline with a thickness of 0–30 (50) m, whose characteristics and dynamics are interrelated with the sea ice cover.

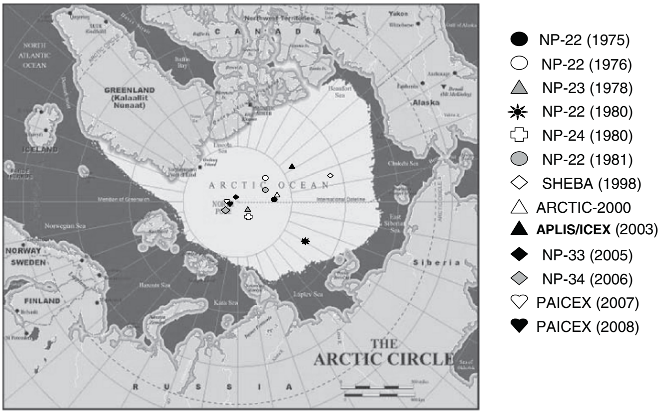

Fig. 1. Map of study areas, where the cryobiological investigations were carried out. Points are the start positions of ice camps drift: North Pole-22 (1975–1981, 83N, 177W); North Pole-23 (1978, 77N, 165E); North Pole-24 (1980, 87N, 125E); SHEBA (1997–1998, 75N, 170W); "Arctic-2000" (2000, 82N, 170E); ARLIS/ICEX (2003, 73N, 148W); North Pole-33 (2005, 85N, 156E); North Pole-34 (2006, 87N, 105E); PAICEX (2007, 89N, 26E) and PAICEX (2008, 89N, 06E).

This review is based on materials obtained in Arctic Ocean expeditions (Fig. 1): North Pole (NP) drifting stations (1975–1982); SHEBA (Surface Heat Budget of the Arctic Ocean), 1997–1998; “Arctic-2000”; ICEX (Ice Camp Expedition), 2003; NP-33 and 34, 2004–2006; PAICEX (PanArctic Ice Camp Expedition), 2007–2008, as well as on the data available from literature sources. The main focus will be done on comparison of data obtained at the North Pole stations during the period of the middle 70th which is considered as a pre-melting period of sea ice cover in the Arctic Ocean and steady-stable existence of sea ice ecosystem, and on data from SHEBA expedition in 1997–1998 and last decade expeditions when observed an intensive melting sea ice and degradation of sea ice ecosystem.

Sea ice extent and thickness

In the middle of 70th the total extent of sea ice area in the Arctic Ocean varies from a minimum of about 6.9 million square kilometer in September to a maximum of about 8.3 million square kilometer in March (Atlas 1980) and within this ocean, the multi-year sea ice is a key dominant environmental feature. According to the data of ice satellite observations in 1973–1976 (NASA 1987), the MY ice occupied up to

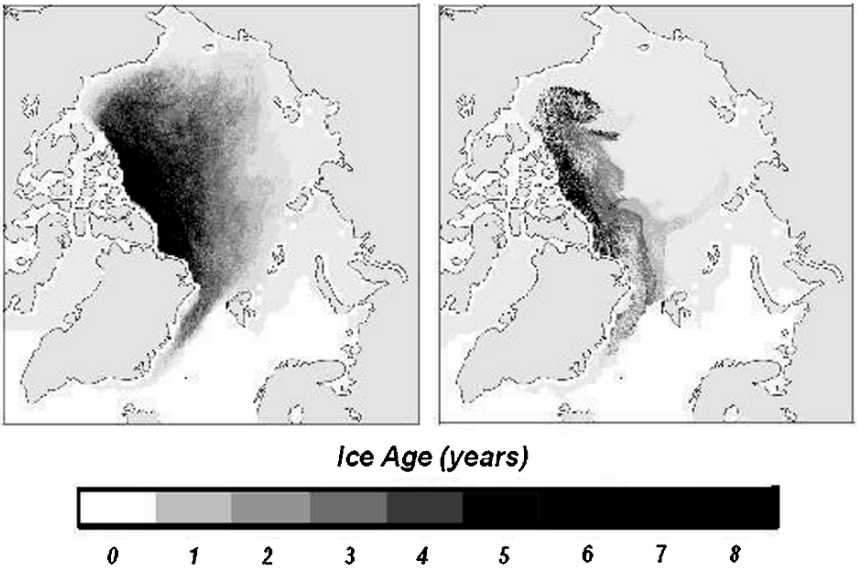

Fig. 2. Arctic Sea ice age and extent in February 2008 (right) compared to the average for 1985–2000 (left). The area and thickness of sea ice that survives the summer has been declining over the past decade. Whereas perennial ice used to cover 50–60% of the Arctic, it covered less than 30% in 2008—down 10% from 2007. The ice that remains is also getting younger. In the mid- to late 1980s, over 20% of Arctic sea ice was at least six years old; in February 2008, just 6% ice was six years old or older (Source: http://nsidc.org/data/seaice_index/n_plot.html).

80% of the Arctic Basin area and interannual variability of this area does not exceed 2% (Carsey 1982). In that pre-melting period, the seasonal ice occupies 6–17%, and ice-free water is 3–24%, respectively, depending on space and time.

The observations during the last decade have recorded a significant decrease of the sea ice extent (Fig. 2) from 7 to 5.32 million square kilometer and 4.14 million square kilometer for September 2000, 2005 and 2007, correspondingly, that is to be melting faster than predicted by any of the 18 computer models used by the Intergovernmental Panel on Climate Change (Stroeve et al. 2007). Two facts are primarily of interest: (1) the ice edge has been significantly displaced northward approximately by 2–3°, which confirms satellite information about the ice cover area decrease (Cavaliere et al. 1997), and (2) the sea ice thickness has noticeably changed. According to data of different authors who carried out ice thickness measurements in the Arctic Basin in the 1960s, the mean equilibrium thickness of non-deformed ice in the Amerasian sub-basin comprised about 3 m (Busuev 1968; Koerner 1973; Wadhams 1983). Based on data obtained at NP-22 and AIDJEX ice stations that drifted in the Beaufort Gyre in 1975–1976, the ice thickness after summer melting was 2–3 m (Melnikov 1989; McPhee et al. 1998). Twenty years later in October 1997 during the ice camp SHEBA expedition in the same region of the Beaufort Gyre the average ice thickness was 1.5 m. PAICEX observations during the IPY in the North Pole region shown that the average ice thickness was 177.1 cm ± 13.2 (n = 133) and 181.4 cm ± 13.3 (n = 203) in April 2007 and 2008, correspondingly (Table 1) (Melnikov 2007, 2008a). The occurrence of seasonal ice was increased from 37% in 2007 to 68% in 2008 (group of ice 180– 200 cm thick), but the multiyear ice (group of ice 240–300 cm) in April 2008 was not met at all by 203 direct thickness measurements along 23 km transect (Fig. 3).

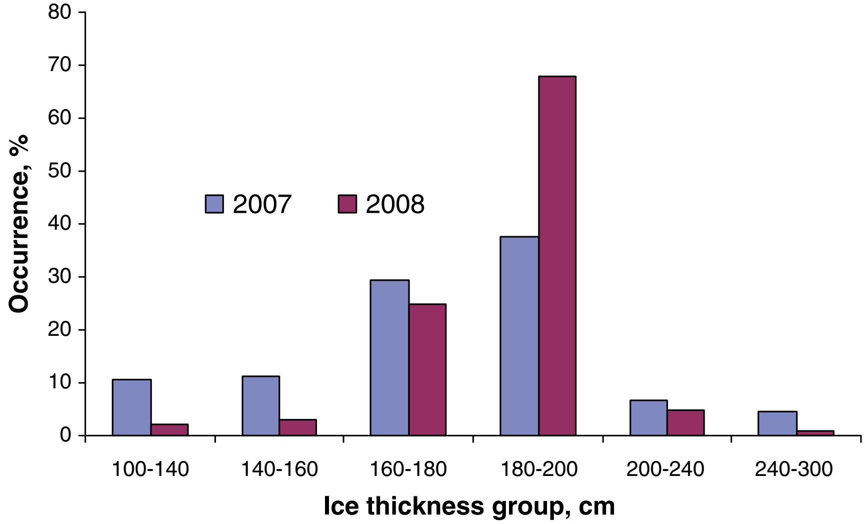

Fig. 3. Occurrence of ice thickness size groups in the North Pole area. Data from observations at PAICEX 2007 and 2008 (Melnikov 2007, 2008).

Table 1. Average sea ice thickness in the nearby North Pole area (PAICEX, April 2007 and 2008).

Direction	Number of measurements	Distance (m)	Average thickness (cm) Ice	Snow
Ice thickness profiles "PAICEX", April 2007				
West	25	4,000	174	24
East	28	3,400	181	26
South	31	4,700	185	24
North	36	4,000	170	26
Total	119	16,100	178	25
Ice thickness profiles "PAICEX", April 2008				
West	40	4,200	185	6
East	51	4,800	182	6
South	52	7,100	181	4
North	60	6,400	179	5
Total	203	22,500	182	5

Physical-chemical variables

The thickness and salinity are main physical factors accentuating differences between MY and FY ice. It is common knowledge that the older ice is the thicker and the fresher it is, and vice versa. Salinity values reflect a typical vertical distribution characteristic of seasonal ice within 5–8 ‰ through the whole ice mass in ice as thick as 180–200 cm and perennial ice within values varying from 0.1–0.5‰ in the upper layer to 2–3‰ in the lower layer in ice as thick as 240–300 cm (Fig. 4). The reason for a lower salinity of the MY ice consists in that this ice recurrently passed the ice melting stage. In the result of intravolumetric melting, the porosity is intensified so that the brine cells are being diluted with the melt water drain downward by the force of gravity, thereby promoting more active rejection of the salts. In winter, the salinity of the MY ice increases in comparison with the ice salinity in summer by the growth of a new ice layer with the increased salinity from beneath which increases the salinity of the entire thickness of the MY ice on the whole. The reason for a higher salinity of FY ice consists in that, from one hand, at the initial moment of ice formation, some salts are retained in the intercrystalline spaces, therefore high salinity values are observed in the upper layers and, from another hand, this ice is formed in winter and it has not passed the summer melting stage.

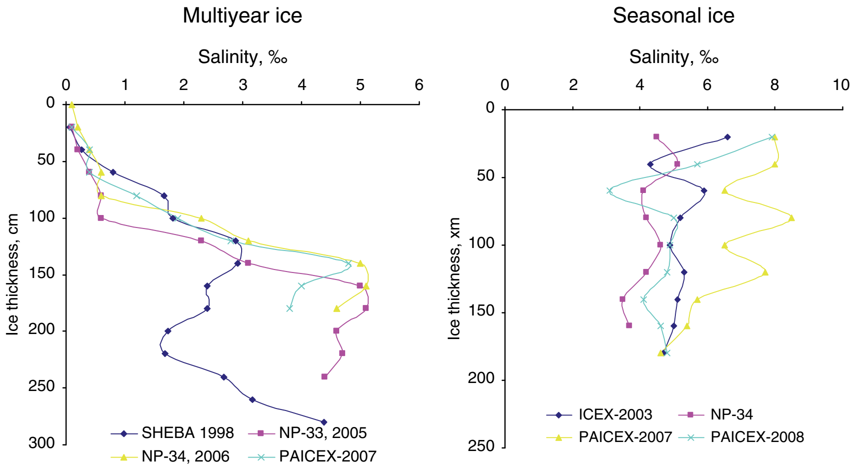

Fig. 4. Vertical distribution of salinity in multiyear and seasonal sea ice thickness for the period 1998–2008 in the Central Arctic Ocean.

Physical and chemical variables of the MY and FY are presented in Table 2. Mean SHEBA values of the MY ice salinity are about half those of NP-22, but the FY values are twice as high. The most curious feature of the SHEBA ice samples is very low concentrations of silicate in the MY and FY sea ice, an order of magnitude less than at the NP-22: 3.76 μM/l and 2.18 μM/l in the MY and FY ice at the NP-22, and 0.40 μM/l and 0.28 μM/l at the SHEBA, respectively. The main feature of chlorophyll *a* concentrations in the ice cores is the two-fold decrease in SHEBA multi-year ice compared to NP-22, and three-fold increased chlorophyll *a* concentrations in first-year ice. Such a large discrepancy can be caused by a loss of silicate with melt water due to its active export from ice to the underlying sea water as a result of active intra-volumetric ice melting in the summertime at SHEBA station while at NP-22 such strong melting was not observed. The loss of silicate with melt water can in turn be a cause for a significant decrease in the numbers of diatoms (main silicate consumers during photosynthesis), which we observed at SHEBA station and did not observe at NP-22. The main peculiarity in the distribution of chlorophyll *a* in the MY and FY ice strata is its twofold decrease in MY ice at SHEBA and a threefold increase in FY ice as compared with a similar concentration of chlorophyll *a* in ice at NP-22. Throughout winter, the concentration of chlorophyll *a* under m^2 of MY ice at SHEBA station did not experience any significant changes. From October to February, the concentrations varied within 0.3–0.5 mg/m^2. In March, the concentration has increased to a value of 1.2 mg/m^2 (spring maximum of alga blooming) and then comprised again the values observed in winter. A noticeable increase of chlorophyll *a* concentration was observed in summer in July–August when its concentration has increased to 2 mg/m^2 (summer maximum). In autumn (September), the concentration of chlorophyll

Table 2. Summary of ice thickness, date of sampling and position, physical and chemical variables of MY and FY ice cores at the NP-22 and SHEBA ice camps. Data are mean ±1SD.

Core #	Thick (cm)	Sampling date	Latitude	Longitude	Salinity (‰)	Silicate (μM/l)	Chl *a* (μg/l)
			NP-22, multi-year ice				
1	404 (11)	15 Feb 80	77° 53'N	153° 49'E	2.02±1.69	6.1±2.11	0.45±0.44
2	350 (9)	11 Mar 80	78° 17'N	153° 35'E	2.42±1.43	2.6±0.53	0.23±0.18
3	163 (5)	31 Mar 80	78° 21'N	153° 07'E	5.60±2.14	3.51±4.05	0.18±0.22
4	199 (6)	01 Apr 80	78° 22'N	153° 01'E	5.07±0.48	2.21±0.43	0.09±0.01
5	162 (5)	04 Apr 80	78° 22'N	152° 30'E	5.52±0.86	3.93±0.5	0.06±0.04
6	339 (11)	18 Apr 80	78° 35'N	151° 52'E	3.17±0.56	3.2±1.33	0.61±0.34
7	211 (4)	20 Apr 80	78° 39'N	151° 48'E	4.86±4.21	4.68±2.39	0.24±0.18
				Mean:	4.09±1.62	3.76±1.62	0.35±0.20
			NP-22, first-year ice				
1	104 (3)	23 Jan 80	77° 40'N	154° 99'E	0.99±0.09	1.90±0.69	0.05±0.01
2	114 (4)	01 Feb 80	77° 48'N	153° 54'E	0.84±0.19	ND	ND
3	129 (4)	26 Feb 80	78° 05'N	154° 36'E	0.88±0.22	1.98±0.33	0.09±0.07
4	167 (4)	28 Feb 80	78° 07'N	153° 54'E	1.28±0.25	2.67±0.70	0.06±0.03
				Mean:	0.99±0.19	2.18±0.57	0.06±0.03
			SHEBA, multi-year ice				
1	244 (10)	27 Oct 97	75° 17'N	143° 31'W	ND	ND	0.12±0.08
2	235 (12)	12 Nov 97	76° 09'N	146° 26W'	1.43±0.96	0.12±0.16	0.24±0.19
3	185 (9)	28 Nov 97	75° 07'N	147° 33'W	1.67±1.08	0.16±0.14	0.09±0.15
4	216 (11)	10 Dec 97	75° 44'N	150° 25'W	2.16±1.36	ND	0.31±0.53
5	178 (9)	29 Dec 97	75° 17'N	149° 59'W	2.62±1.60	0.72±0.43	0.13±0.05
6	177 (9)	12 Jan 98	74° 51'N	150° 25'W	2.97±1.87	0.74±0.37	0.11±0.05
7	260 (13)	27 Jan 98	74° 51'N	155° 38'W	2.10±1.30	0.46±0.27	0.31±0.32
8	281 (14)	18 Feb 98	74° 54'N	157° 50'W	2.55±1.58	0.35±0.22	0.05±0.04
9	417 (21)	09 Mar 98	75° 28'N	160° 18'W	2.08±0.95	0.08±0.05	0.17±0.13
10	287 (15)	29 Apr 98	75° 57'N	166° 13'W	2.50±2.02	0.45±0.37	0.09±0.09
11	291 (14)	25 May 98	76° 24'N	167° 11'W	0.94±0.50	0.56±0.18	0.11±0.13
				Mean:	2.10±1.32	0.40±0.24	0.16±0.16
			SHEBA, first-year ice				
1	62 (6)	19 Oct 97	75° 20'N	144° 29'W	0.41±0.19	ND	0.20±0.07
2	66 (6)	27 Oct 97	75° 17'N	143° 31'W	0.58±0.32	ND	0.46±0.50
3	77 (7)	11 Nov 97	76° 09'N	146° 23'W	1.74±0.89	0.08±0.01	0.13±0.10
4	79 (8)	26 Nov 97	76° 13'N	147° 43'W	3.03±1.85	0.36±0.27	0.41±0.25
5	116 (6)	12 Dec 97	75° 41'N	150° 44'W	2.42±1.54	ND	0.14±0.09
6	95 (9)	27 Dec 97	77° 17'N	149° 57'W	2.86±1.56	0.44±0.26	0.10±0.11
7	137 (7)	11 Jan 98	74° 53'N	150° 12'W	2.86±1.62	0.45±0.19	0.05±0.02
8	150 (8)	24 Jan 98	74° 38'N	153° 25'W	3.42±1.99	0.14±0.05	0.06±0.04
9	132 (7)	16 Feb 98	74° 53'N	157° 50'W	3.31±1.58	0.11±0.03	0.13±0.07
10	171 (9)	09 Mar 98	75° 28'N	160° 18'W	3.39±1.75	0.05±0.03	0.12±0.08
11	142 (7)	29 Apr 98	75° 57'N	166° 13'W	ND	0.25±0.09	0.18±0.16
12	138 (7)	25 May 98	76° 24'N	167° 11'W	ND	0.67±0.28	0.20±0.16
				Mean:	2.4±1.33	0.28±0.13	0.18±0.13

a has dropped to the values recorded during the previous autumn period, i.e. about 0.4 mg/m^2. The revealed chlorophyll *a* dynamics reflects the winter and summer stage of succession of ice flora where 17 species of the group of Bacillariophyta, 5 – Dynophyta and by 1 species, correspondingly, from the groups of Silicoflagellatae, Chlorococcales and Chrysophyta were recorded. Among the diatoms, *Cylinrotheca* *closterium*, *Leptocylindrus minimus*, *Navicula vanhoeffenii* and *Nitzscia neofrigida* dominated 57 (63% of the numbers of cells) and among Chrysophyta – *Groenlandiella brevispina* (31%).

Sea ice biota

Vertical distribution. The species composition of the sea-ice communities is not uniform. Within the sea ice thickness it was found out the strict vertical zonation in their distribution within the sea-ice thickness.

The bottom sea-ice surface is colonized by the cryopelagic algae formed mass aggregations of benthic- and plankto-benthic types as well as by the algae developed on the under-ice platelets. Diatoms are the most abundant species with a domination of *Melosira arctica*, *Chaetoceros karianus*, *Gomphonema exiguum* (benthic type), *Fragilaria striatula*, *Comphonema kamtschaticum*, *Navicula vanhoeffenii*, *Nitzschia sigma* (plankto-benthic type), and *Navicula kariana*, *N. spicula*, *Gomphonema exiguum* (cryophilic microphytobenthos type). It was found out the very high resemblance between the species composition of all algae communities developed in this biotope. Cryopelagic fauna count the 48 species with a domination of *Arthropoda* (81% of the total species number). There are distinguished two dominant and one secondary ecological groups: (1) the autochthonous fauna including 12 species (*Amphipoda* – 6 species, *Copepoda* – 2, *Mysidacea* – 1, *Polychaeta* – 1, and *Osteichtyes* – 2), (2) the allochthonous fauna including 9 species of *Copepoda*, and (3) the group of the xenocryobiontic fauna. The list of algae developed in the sea-ice interior consists of 171 species (*Bacillariophyta* – 148 species, *Chlorophyta* – 20, *Silicoflagellatae* – 2, *Dinophyta* – 1, and *Cyanophyta* – 1). The obvious predominance of the pennate (136 species or 89% of all diatoms) compared with the centric (12 species or 11%) diatoms is the main peculiarity of the sea-ice flora. The existence of the fresh-water green algae (*Chlorophyta*) is a second peculiarity of the sea-ice phytocoenosis. Two different floristic communities develop independently within the sea-ice interior: (1) the fresh-water algae community of the upper layers and (2) the sea algae community of the lower layers. Cryointerstitial faunistic community consists of two ecological groups: (1) the autochthonous fauna (*Nematoda*, *Turbellaria*, *Acarina*, and *Protozoa*) and (2) the allochthonous fauna represented by juvenil amphipods *Apherusa glacialis* and juvenil harpacticoid copepods *Tisbe furcata*. Animals of both groups occupy the lower layer of the sea ice. Habitants of the upper sea-ice surface are mainly represented by the freshwater green algae (*Chlorophyta*) between which *Chlamydomonas nivalis* and *Ancylonema nordenskioeldii* dominate. Representatives of other groups (*Cyanobacteria*, *Chrysophyta*, and *Fungy*) are subdominant. Diatoms, which are abundant on the bottom sea-ice surface and within the sea-ice interior, do not develop in this biotope. Invertebrate fauna was not observed.

Flora. The total list of ice algae identified at NP-22 and SHEBA stations numbers 102 taxa among which 84 species or 76% of the total numbers were revealed at NP-22 station while at SHEBA – only 26 species or 23%, respectively (Table 3; Melnikov et al. 2001). The dominance of marine diatoms over the other groups of algae is the most important feature of the sea ice phytocenoses of NP-22. Freshwater algae (mainly from the group of Chlorophyta) were observed at NP-22 only in melt water of puddles developing in the summer period at the upper surface of multiyear ice or in the upper sections of this ice. The most important feature of the phytocenoses of multiyear and first-year ice of SHEBA station is a significant dominance of freshwater algae of the Pyrrophyta and Chlorophyta groups over the marine diatom algae with the former being distributed over the vertical strata of both multiyear and first-year ice.

Fauna. The most important and curious characteristic of sea ice from SHEBA station is a complete absence of interstitial fauna. Whereas in the multiyear ice strata of NP-22, such groups as Tintinnoidea, Acarina, Nematoda, Turbellaria, Copepoda and Amphipoda in numbers of tens of thousands individuals per square meter were noted (Table 4; Melnikov 1989) there was not a single living individual from the enumerated groups in the ice samples from SHEBA station (Melnikov et al. 2001). In all investigated samples, single shells of dead foraminifers, fragments of tintinnides and nematodes, and skins of copepods were detected.

Table 3. Number of algal species presents within sea ice interior in samples collected from the ice camps NP-22 (winter 1979–1980) and SHEBA (winter 1997–1998), Beaufort Gyre, Canadian Basin of the Arctic Ocean.

Taxon	NP-22	SHEBA
Bacillariophyta	79	18
Dinophyta	NO	5
Chrysophyta	NO	1
Chlorophyta	NO	1
Silicoflagellatae	5	1

NO – not observed.

Table 4. Species number of fauna associated with the sea ice interior in samples from the ice camps NP-22 (winter 1979–1980) and SHEBA (winter 1997–1998), Beaufort Gyre, Canadian Basin of the Arctic Ocean.

Taxon	NP-22	SHEBA
Protozoa	3	NO
Foraminifera	1	1
Acarina	1	NO
Nematoda	2	NO
Turbellaria	1	NO
Harpacticoida	1	NO
Amphipoda	1	NO

NO – not observed.

A comparative analysis of data obtained at NP-22 and SHEBA allows to make the following conclusions:

- Populations of ice diatom algae identified in all types of sea ice during the SHEBA station drift have low numbers both in respect of the numbers of species and the numbers of cells;
- Freshwater algae identified earlier at NP-22 only within the upper surface of multiyear sea ice are currently distributed throughout the entire sea ice strata (SHEBA);
- Populations of invertebrates such as nematodes, copepods, amphipods and turbellarian dominating both by the numbers and the biomass in the multiyear ice strata during the NP-22 station drift (1979–1980) were not observed at all in sea ice samples in the SHEBA expedition (1997–1998).

The changes revealed in the composition and structure of the communities inhabiting sea ice could be probably attributed to increasing melting of the ice cover for the last two decades. I consider several factors determining these changes among which the most important are the following: 1) draining of fresh melt water through the ice strata; 2) accumulation of freshwater under the ice; and 3) formation of a sharp pycnocline in 25–30 m depths weakening vertical water mixing. Ie suppose that the modern “upper ocean – sea ice” ecosystem modifies due to these acting factors from a typically marine to brackish-water ecological system.

Discussion and conclusions

The sea-ice cover of the Arctic Ocean is a multi-component natural complex comprising the ice layers which differ from each other in the age, thickness, mobility and other features. The main component of the sea-ice cover in the central deep-sea Arctic Basin is represented by the MY ice which dominates over the ice of other age groups in respect to the area and volume. The FY ice which is formed mainly in winter in open water on the area of the Arctic Seas after summer ice melting partially compensates for the loss of the ice during its drift from the Arctic Basin into the Northern Atlantic Ocean regions. The young ice and ice-free areas (ponds, cracks, polynyas, and leads) comprise a small area of the basin.

It is well known that the arctic sea ice is a fine and sensitive climate indicator: the warmer it is the more intense is melting and vice versa, the colder it is, the more intense and stronger is the growth of its thickness. At that climatic and hydrological level, the sea-ice cover is a stable natural formation. The main reason for its stability consists in the existence of a thin stratified surface layer precluding the contact of the sea ice with warm Atlantic water. The mechanism regulating the average equilibrium thickness as well as the peculiarities of the large-scale ice circulation, and the system maintaining the equilibrium sea-ice budget contribute to the stability of the ice cover in the geographical scales of the ocean.

The observations during the last two decades have recorded a significant decrease of the ice cover area and thickness in the Arctic Ocean due to global climate warming in the Northern hemisphere. How does it influence the species composition and structure of sea ice ecosystems?

Studies carried out over the past decade revealed appreciable changes in the qualitative and quantitative composition of the biota in the Arctic sea-ice compared to the composition in the mid-1970s. The total list of ice algae identified for the period of 1975–1982 comprises 172 taxa (Melnikov 1989) and about 30 species identified in 1997–2008 (Melnikov et al. 2002; Melnikov 2005, 2008b). The prevalence of sea diatoms was a significant feature of sea ice phytocoenosis in the 1970s, and their domination greatly decreased in the past decade, while other groups are growing in importance. The ice fauna composition has changed as well. Such mass representatives of protozoans and invertebrates as foraminifers, tintinninids, mites, nematodes, turbellarians, rotifers, copepods, and amphipods inhabiting the ice mass in the 1970s (Melnikov 1989) were rarely encountered in the past decade or were found as individual body fragments of these organisms. To appreciate the causes of the revealed differences, we must take a closer look at the composition and dynamics of the Arctic Ocean recent sea-ice cover, as well as at peculiarities of the formation and function of the MY and FY sea-ice ecosystems.

Under conditions of a stable climate, perennial sea ice represents an integral ecological system stable in time with a constant species composition of the flora and fauna (Melnikov 1989). The system stability persists due to average equilibrium thickness supported by summer ice thawing from above and winter compensation ice growth from below (Zubov 1945). This property, which can be referred to as sea ice cover homeostasis, the ability to retain its average equilibrium thickness, is of great ecological significance. It is expressed in the fact that the vertical structure of biological communities inhabiting it persists due to the action of two flows in different directions: (1) the motion of the crystalline structure from the bottom upwards due to thermodynamic ice thawing and ice formation, (2) the passive and/or active counter motion of organisms from the top down. In winter, ice grows from below on existing ice, the thickness of which after summer thawing is preserved at 2 m, and organisms, which inhabit these layers building-up from below, reside in conditions of mild temperatures close to the seawater temperature (about –2°C), which promotes their survival in the winter period. The balanced relationship between regions of perennial ice production and evacuation from the basin, as well as peculiarities of ice circulation along with mechanisms maintaining a constant species composition of ice organisms within the vertical crystalline structure, determines the stability of the perennial ice ecosystem in the Arctic Ocean.

By contrast, seasonal ice is a dependent ecosystem unstable with time, the lifetime of which is determined by a complex of environmental factors, the temperature being regarded as the most significant among them. Seasonal ice formation begins in open water at a low air temperatures. In the course of formation of first layers, planktonic organisms in the water at the moment are mechanically entrained into the ice crystalline structure of the lower growing layer. As the qualitative and quantitative composition of plankton in water is poor in the autumn–winter period, the amount of organisms entrained in ice appears to be small. Those organisms, which were mechanically entrained into ice, appear under conditions of intense cooling since the surface is in contact with air, the temperature of which decreases down to minus 30–40° C, and some of them survive but most of the organisms die because of sharp cooling. It is likely that because of this some isolated cells of algae and protozoans, as well as individual representatives of invertebrates, mechanically captured into the ice structure during its growth in winter are found in the ice mass in the spring period during the maximal ice development. In the autumn period, conditions for the formation of what is called infiltration ice may emerge at a low air temperature and intense snow accumulation on the ice. When the ice is thin and the snow weight becomes substantial relative to the weight of the ice, the ice appears to be submerged below the sea level, so that seawater along with cells of planktonic algae rises through the capillary system to the ice–snow boundary. As snow is a good heat insulator and light is still sufficient for photosynthesis to proceed, favorable conditions are created in this layer for alga development. The biomass of algae and concentration of the organic matter synthesized by them exceed in this layer by many times the same parameters in water below the ice. Such ice was encountered for the first time during the expedition "Arctic-2000" at the icebreaker *Akademik Fedorov* in the Canadian sector of the Arctic Ocean at 82°N and 170°W in September 2000 (Melnikov 2004). The formation of infiltration ice is a typical Antarctic phenomenon (Buinitskii 1973), and direct testimony to further development of infiltration ice in the Arctic Ocean is unavailable nowadays. However, it may be inferred that the phenomenon would continue in the future in view of the growing role of seasonal ice and increasing snowfall in the Arctic regions.

In comparing mechanisms for the formation of sea ice of these two types, it may be concluded that the main cause of the differences revealed between the composition of biological sea ice communities in the 1970s and the last decade is that the two MY and FY sea-ice ecosystems considered and compared were different in the structure and function. Indeed, in the first case, the constant species composition of algae and the invertebrate fauna was maintained by mechanisms forming the average equilibrium thickness, as well as by processes of colonization and evolution of organisms within the vertical crystalline structure of ice. Predominant were benthic-type algae adapted to dwelling in a solid substrate and capable of moving in narrow intercrystalline spaces of ice. In the second case, the species composition of the ice flora was formed directly from water and mainly represented by typical planktonic forms making up long chains from cells and mainly evolving in the lower layer of ice or on its lower surface (Melnikov 1989).

Hence, two MY and FY ice ecosystems different in composition and function coexist in the recent Arctic sea-ice cover As the share of the first ecosystem is dynamically decreasing and the share of the second ecosystem is simultaneously increasing, a gradual reorganization in the ecosystem of the Arctic Ocean pelagic region is taking place at present. If such a dynamics is retained, it may be inferred that in the course of time the marine Arctic regions will gain features of the marine Antarctic regions. Indeed, the sea ice cover in the Southern Ocean disappears in summer and reappears in winter. Seasonal ice predominates and occupies more than 80% of the sea-ice cover area for eight months, whereas perennial ice occupies less than 20% of the area (NASA 1987). Seasonal ice develops in the Southern Ocean north of 70°S. There is no long polar night at these latitudes and light is sufficient for maintaining photosynthesis of the ice flora (Melnikov 1998). The total organic material of the Antarctic regions is produced mainly by phytoplankton in summer and partially by the flora of infiltration ice in winter. By contrast, the whole Arctic sea-ice cover is located north of 70°N, and all the biological communities evolve under more severe conditions. In central regions constantly covered with sea ice, the total organic production is combined from the production created by algae of perennial ice (>90%) and production of algae of seasonal ice and phytoplankton, which account for less than 10% (Melnikov 1989). The phytoplankton organic production makes up 97–99% in regions where seasonal ice predominates, for instance, in Arctic seas, which become free of ice in summer (Subba Rao and Platt 1984). At present, the function of the pelagic ecosystem in the central regions of the Arctic Ocean is being rearranged and is passing into conditions of seasonal development of the sea-ice cover; therefore, organic production by phytoplankton should be growing and the contribution of the sea ice flora should be decreasing. Such a cycle of evolution may result in reorganization of the whole lower trophic structure of the ocean and, probably, may affect all higher chains of the trophic structure, fishes, birds, and mammals included.

Recent decreasing of sea ice extent and thickness is not a fact of the complete disappearance of sea ice cover in the Arctic Ocean. In fact, it observes a reduction of MY ice surface that it leads to increasing of ice-free areas where FY ice is formed in winter. Now we observe the intensive process in reconstruction of sea-ice cover from domination of MY ice onto domination of seasonal ice. If this dynamic will be continued the Arctic Ocean will be getting similar to the Southern Ocean where seasonal ice is a dominant component reaching more 80% of its surface (NASA 1983), by another words, in time marine Arctic is getting more features of marine Antarctic.

Acknowledgments

This research was supported by the Russian Foundation for Basic Research (grant #08-05-00219).

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