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CRYOPELAGIC FLORA OF THE CHUKCHI, EAST SIBERIAN AND LAPTEV SEAS

Yuri B. OKOLODKOV

Komarov Botanical Institute, USSR Academy of Sciences,
St. Petersburg, 197376, Prof. Popov Str. 2, Russia

Abstract: In the lower layer of young and first-year drifting and fast ice at 125 stations were found more than 120 algal species, the pennate diatoms primarily from the genera *Navicula* (24 species) and *Nitzschia* (20) predominating. The list of species is given. At many stations the ice bloom was observed in 0.2–0.5 cm of the lower layer. Freshwater diatoms and the majority of marine planktonic *Chaetoceros* and *Thalassiosira* species represent the allochthonous element of ice flora. Twenty-five dominant species were revealed, the following being frequent: *Nitzschia frigida*, *N. cylindrus*, *N.* sp. cf. *promare*, *N. grunowii*, *N. delicatissima*, *N. polaris*, *Navicula pelagica* and *N. septentrionalis*.

1. Introduction

Sea-ice flora has been studied since the forties of the 19th century. About 180 algal species have been reported from sea ice of the Laptev, East Siberian and Chukchi seas (CLEVE, 1883; GRAN, 1904; USACHEV, 1946, 1949; BURSA, 1963; FUKUSHIMA, 1965; MEGURO *et al.*, 1966, 1967; HORNER and ALEXANDER, 1972; ALEXANDER *et al.*, 1974; HORNER, 1976, 1977, 1981, 1984, 1985, 1989; OKOLODKOV, 1989, 1990, 1991). Besides,some information on sea-ice algae in the region under research is included in the publications devoted chiefly to the planktonic and benthic microalgae of the Chukchi Sea (MATHEKE and HORNER, 1974; SAITO, 1974; SAITO and TANIGUCHI, 1978; HORNER and SCHRADER, 1982). It should be noted that before our investigations (OKOLODKOV, 1989) any information on sea-ice algae of the East Siberian Sea was absent. The main purpose of the present study was to reveal the species composition and the dominant species. Various questions concerning sea-ice algae have been discussed on the basis of the original materials, too.

2. Materials and Methods

Sea-ice algae were collected mainly by the author of the present article at 125 stations in the Chukchi, East Siberian and Laptev seas during the High-Latitute Aircraft Expeditions of the Arctic and Antarctic Research Institute, Leningrad (Fig. 1, Table 1). Samples were taken with CHEREPANOV's circular ice corer, inside diametre 18 or 22 cm, young ice being sampled in frozen cracks between first-year ice floes. The lower part of a core was detached and placed into a polyethylene jar. After melting the sample was subjected to the preliminary examination. When containing the

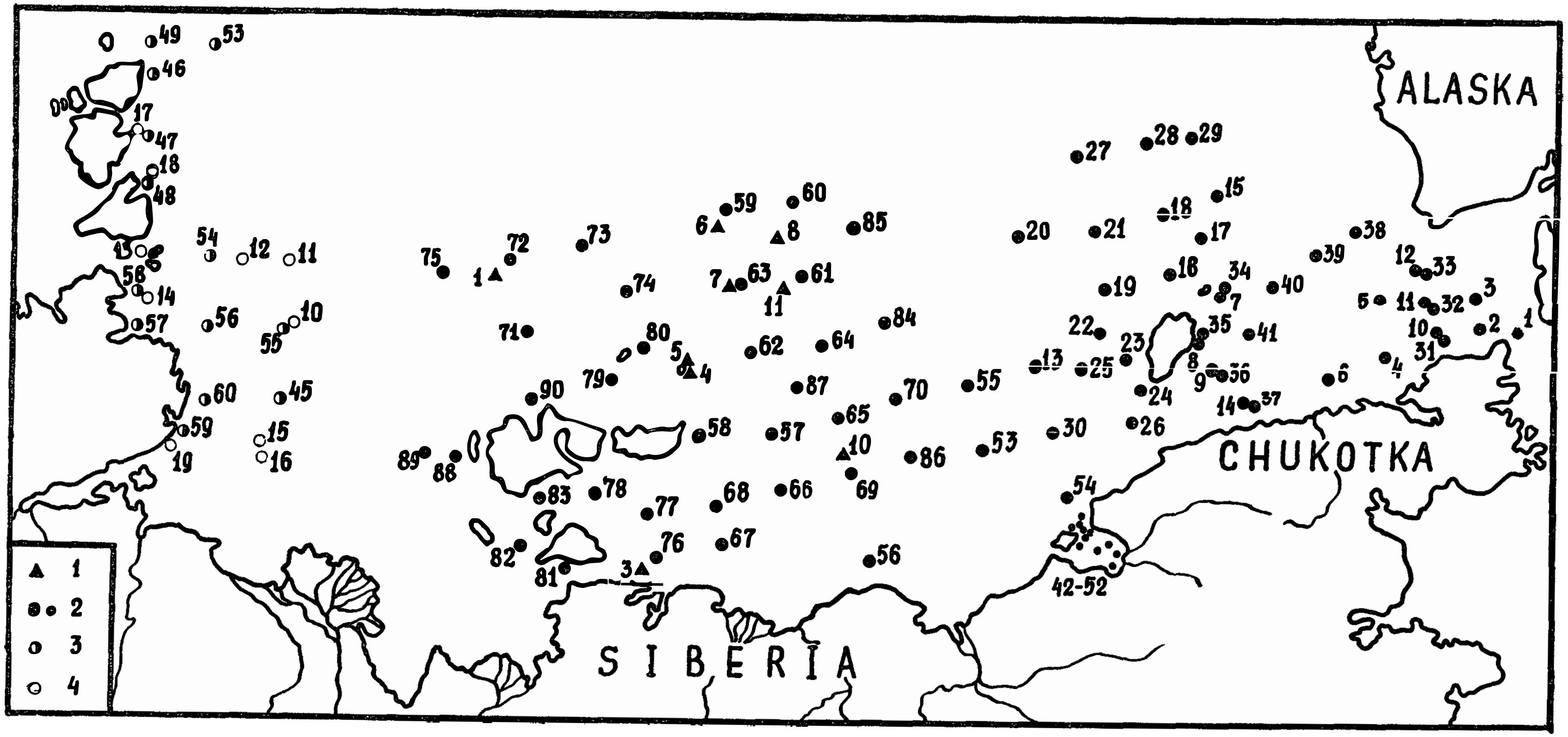

Fig. 1. Cryobiological station locations in the Siberian seas: 1, May 3–23, 1987; 2, March 9–May 19, 1988; 3, May 8–16, 1989; 4, May 10–15, 1990.

Table 1. The 1987–1990 data on the cryobiological stations in the Chukchi, East Siberian and Laptev seas.

Expedition, sampling period	Sampling area	Number of cryobiological stations				
		Total	First-year ice	Young ice	Drifting ice	Fast ice
"North-39", May 3–23, 1987	western East Siberian Sea	10	9	1	7	3
"North-40",	Chukchi Sea	35	14	21	35	—
March 9– May 19, 1988	East Siberian Sea	53	42	11	32	21
	eastern Laptev Sea	4	4	—	2	2
"North-41", May 8–16, 1989	western Laptev Sea	13	11	2	9	4
"North-42", May 10–15, 1990	western Laptev Sea	10	6	4	5	5
	Total:	125	86	39	90	35

flagellate organisms the sample was subdivided into 2 to 4 subsamples. Then they were fixed and stored in 2 to 4 solutions, correspondingly, which are as follows: (1) 2–4% neutralized formaldehyde solution, (2) LUGOL's solution with acetic acid added, (3) mixture consisting of 40% formaldehyde solution 40 ml, 96% alcohol 60 ml, and glycerine 50 ml, (4) 70–75% alcohol. In 1989 some subsamples with the flagellates were fixed with the medical formidrone (its composition: 40% formaldehyde solution 10 g, 95% alcohol 39.5 g, distilled water 50 g, Eau-de-Cologne 0.5 g) and KUZMIN's solution consisting of potassium iodide 10 g, distilled water 50 cm^3, iodine 5 g, 1% chromic acid solution 5 cm^3, concentrated acetic acid 10 cm^3, 40% formaldehyde solution 80 cm^3 (KUZMIN, 1975).

Portions of almost all samples were treated with concentrated hydrogene peroxide and nitric acid when heated directly on slides. The permanent slides prepared in this way were examined more thoroughly with the use of anoptral contrast microscopy MFA-2, LOMO production, Leningrad. Detailed information on the optics employed was published by OKOLODKOV (1989). Algal cells were counted on a slide in a drop of suspension using dark-field microscopy, number of cells being usually no less than 500. A species was considered as the dominant, if its number of cells in a sample was more than 10% of total number. The colour of the lower layer of the ice during ice bloom because of the algae was defined with the use of BONDARTSEV's scale of colours (BONDARTSEV, 1954).

In the present study we use the term "cryobiological" in designation of the community and flora of the lower layer of sea ice, after ANDRIASHEV (1967) and MELNIKOV (1989).

3. Results

3.1. Species composition

The list of the algae found in 1987–1989 in the lower layer of sea ice in the Siberian

Table 2. List of algal species reported from the lower layer of sea ice in the Laptev, East Siberian and Chukchi seas in March-May, 1987–1989.

Taxon	Seas investigated		
	Laptev	East Siberian	Chukchi
1	2	3	4
Bacillariophyta: Pennatophyceae			
Achnanthes taeniata GRUN.	+	+	+
**Amphora coffeaeformis* AG.	–	+	–
**A. holsatica* HUST. var. *holsatica*	+	–	–
A. laevis GREG. var. *laevissima* (GREG.) CL.	+	+	+
**Asterionella formosa* HASS.	+	–	–
**Cocconeis scutellum* EHR. var. *minutissima* GRUN.	–	+	–
Cylindrotheca closterium (EHR.) REIMANN et LEWIN	+	+	+
**Diatoma* sp. cf. *hiemale* (LYNGB.) HEIB. f. *turgidula* KÜTZ. (see Diatom analysis, 1950)	+	–	–
Diploneis litoralis (DONK.) CL. var. *arctica* CL.	+	+	+
D. litoralis var. *clathrata* (OESTR.) CL.	+	+	+
D. oestrupii HUST.	–	+	+
Entomoneis gigantea (GRUN.) POULIN et CARDINAL var. *septentrionalis* POULIN et CARDINAL	+	+	+
E. kjellmanii CL. var. *kjellmanii*	+	+	+
E. kjellmanii var. *kariana* (GRUN.) POULIN et CARDINAL	+	+	+
E. kjellmanii var. *subtilis* (GRUN.) POULIN et CARDINAL	+	+	+
E. kryophila (CL.) OKOL.	+	+	+
E. paludosa (W. SM.) REIM. var. *hyperborea* (GRUN.) POULIN et CARDINAL	+	+	+
**Eunotia pectinalis* (DILLWYN?) RBH. var. *minor* (KÜTZ.) RBH.	+	–	–
Gyrosigma acuminatum (KÜTZ.) RBH.	+	+	+
G. concilians (CL.) OKOL.	+	+	+
G. diaphanum CL.	+	+	–
G. hudsonii POULIN et CARDINAL	+	+	+
G. prolongatum (W. SM.) GRIFFITH et HENFREY var. *prolongatum*	+	–	–
G. tenuissimum (W. SM.) GRIFFITH et HENFREY var. *tenuissimum*	+	–	+
G. tenuissimum var. *hyperborea* (GRUN.) CL.	+	+	–
Haslea crucigeroides (HUST.) SIMONSEN var. *crucigeroides*	+	+	+
H. crucigeroides var. *densestriata* POULIN, CARDINAL et BÉRARD-THERRIAULT	+	+	+
H. kjellmanii (CL.) SIMONSEN	+	+	+
H. vitrea (CL.) SIMONSEN	+	+	+
Navicula algida GRUN.	+	+	+
N. directa (W. SM.) RALFS var. *directa*	+	+	+
N. directa var. *javanica* CL.	–	+	–
N. forcipata GREV. var. *densestriata* A. S.	+	+	+
N. gelida GRUN. var. cf. *radissonii* POULIN et CARDINAL (see POULIN and CARDINAL, 1982b)	+	+	–
N. glacialis (CL.) GRUN. var. *glacialis*	+	+	+
N. glaciei V. H.	+	+	+

Table 2. (*continued*).

1	2	3	4
N. imperfecta Cl.	+	+	+
N. impexa Hust.	+	+	–
N. kariana Grun. var. *detersa* (Grun.) Grun.	+	+	+
N. kariana var. *frigida* (Grun.) Cl.	+	+	+
N. kryokonites Cl. var. *kryokonites*	+	–	–
N· kryokonites var. *semiperfecta* Cl.	+	+	+
N. kryophila (Cl.) Poulin et Cardinal	+	+	+
N. novadecipiens Hust.	+	+	–
N. obtusa Cl.	+	+	+
N. oestrupii Cl.	+	+	+
N. pelagica Cl.	+	+	+
N. septentrionalis (Grun.) Gran	+	+	+
N. sibirica (Grun.) Cl.	+	+	+
N. solitaria Cl.	+	+	–
N. superba Cl. var. *superba*	+	+	+
N. superba var. *elliptica* Cl.	+	+	+
N. superba var. *subacuta* Gran	+	+	+
N. transitans Cl. var. *transitans*	+	+	+
N. transitans var. *asymmetrica* (Cl.) Cl.	+	+	+
N. transitans var. *derasa* (Grun.) Cl.	+	+	+
N. transitans var. *erosa* (Cl.) Cl.	–	+	+
N. transitans var. *incudiformis* (Grun.) Cl.	–	+	+
N. trigonocephala Cl. var *depressa* Oestr.	+	+	+
N· trigonocephala var. *depressa* f. *minor* Oestr.	+	+	+
N· valida Cl. et Grun. var. *valida*	+	+	+
N. valida var. *minuta* Cl.	+	+	+
N. vanhoeffenii Gran	+	+	+
Nitzschia angularis W. Sm.	+	+	+
N. arctica Cl.	+	+	+
N. brebissonii W. Sm. var. *borealis* (Grun.) Cl.	+	+	+
N. cylindrus (Grun.) Hasle	+	+	+
N. delicatissima Cl.	+	+	+
N. distans var. *erratica* Cl.	+	+	+
N. frigida Grun.	+	+	+
N. gelida Cl. et Grun.	+	+	+
N. grunowii Hasle	+	+	+
N. hybrida Grun.	+	+	+
N. kryophila Cl.	–	+	–
N. laevissima (Grun.) Grun.	+	+	+
N. lanceolata W. Sm. var. *pygmaea* Cl.	+	+	+
N. lanceolata var. *pygmaea* f. *costata* Okol.	+	–	–
Navicula pellucidula Hust.			
N· polaris (Grun.) Grun.	+	+	+
N. scabra Cl.	+	+	+
N. seriata Cl.	+	+	+
N. wankaremae Cl.	+	+	+
N. sp. cf. *grunowii* Hasle (see Hasle and Medlin, 1990)	+	+	–
N. sp. cf. *promare* Medlin (see Medlin and Hasle, 1990)	+	+	+
N. sp. cf. *vidovichii* Grun. (see Diatom analysis, 1950)	+	+	+
Pinnularia ambiqua Cl.	+	+	+

Table 2. (*continued*).

1	2	3	4
P. polaris HEIDEN	–	+	+
P. quadratarea (A. S.) CL. var. *quadratarea*	+	+	+
P. quadratarea var. *bicontracta* (OESTR.) HEIDEN	+	+	+
P. quadratarea var. *bicuneata* HEIDEN et KOLBE	–	+	+
P. quadratarea var. *capitata* HEIDEN	+	+	+
P. quadratarea var. *constricta* (OESTR.) HEIDEN	+	+	+
P. quadratarea var. *constricta* f. *interrupta* HEIDEN	–	+	+
P. quadratarea var. *cuneata* OESTR.	–	+	–
P. quadratarea var. *dubia* HEIDEN	–	–	+
P. quadratarea var. *leptostauron* (GRUN.) CL.	+	+	+
P. quadratarea var. *maxima* (OESTR.) BOYER	+	+	+
P. quadratarea var. *minor* (OESTR.) HEIDEN	+	+	+
P. quadratarea var. *patrickae* POULIN et CARDINAL	–	+	–
P. quadratarea var. *subglabra* (OESTR.) POULIN et CARDINAL	–	+	+
P. semiinflata (OESTR.) GRAN var. *semiinflata*	+	+	+
P. semiinflata var. *decipiens* (CL.) GRAN	+	+	+
Plagiotropis maxima (GREG.) POULIN et CARDINAL	+	+	+
Pleurosigma clevei GRUN.	+	+	+
P. stuxbergii CL. et GRUN. var. *stuxbergii*	+	+	+
P. stuxbergii var. *minor* GRUN.	+	+	+
P. stuxbergii var. *rhomboides* (CL.) CL.	+	+	+
P. sp. cf. *delicatulum* W. SM. (see CARDINAL *et al.*, 1986)	+	+	–
Pseudogomphonema arcticum (GRUN.) MEDLIN	+	–	–
P. groenlandicum (OESTR.) MEDLIN	+	+	+
P. kamtschaticum (GRUN.) MEDLIN	+	–	–
P. septentrionale (OESTR.) MEDLIN	+	+	+
**Rhabdonema minutum* KÜTZ.	–	+	–
Stauroneis anceps EHR. var. *hyalina* BRUN et PERAG.	–	+	–
S. anceps var. *subcapitata* OESTR.	–	+	–
S. pellucida var. *cuneata* OESTR.	+	–	–
S. pellucida var. *pleurosigmoidea* OESTR.	+	+	–
S. sp. cf. *radissonii* POULIN et CARDINAL (see POULIN and CARDINAL, 1982a)	–	+	–
Stenoneis inconspiqua GREG. var. *baculus* (CL.) CL.	+	+	+
S. obtuserostrata (HUST.) POULIN	+	+	–
Surirella septentrionalis OESTR.	–	+	–
**S.* sp. cf. *ovata* KÜTZ. (see Diatom analysis, 1950)	–	+	–
**Synedra* sp. cf. *acus* KÜTZ. (see Diatom analysis, 1950)	–	+	–
S. sp. cf. *hyperborea* GRUN. var. *rostellata* GRUN. (see Diatom analysis, 1950)	+	+	–
Pennatophyceae gen. sp. 1 (solitary cells with stauros and numerous intercalary bands, length 36–49 μm; Fig. 2)	+	+	+
Pennatophyceae gen. sp. 2 (cells united in ribbon colonies with free apices and numerous intercalary bands, length 33–53 μm, breadth 2 μm; Fig. 3)	+	+	+
Bacillariophyta: Centrophyceae			
**Aulacosira* sp.	+	+	–
**Chaetoceros cinctus* GRAN	–	–	+

Table 2. (continued).

1	2	3	4
**C. compressus* LAUD.	+	+	+
**C. concavicornis* MANGIN	−	+	−
**C. decipiens* CL.	−	+	−
C. furcellatus BAIL.	−	−	+
C. holsaticus SCHÜTT	−	+	+
C. wighamii BRIGHT.	+	+	−
**Coscinodiscus subtilis* EHR.	−	+	−
Detonula confervacea (CL.) GRAN	−	+	−
Gonioceros septentrionale (OESTR.) ROUND	+	+	+
Melosira arctica (EHR.) DICKIE	+	+	+
M. moniliformis (O. MÜLL.) AG. var. *subglobosa* GRUN.	+	+	−
Odontella aurita (LYNGB.) AG.	−	+	−
**Paralia sulcata* EHR.	−	+	−
Porosira glacialis (GRUN.) JÖRG.	+	+	+
**Thalassiosira antarctica* COMB.	−	−	+
**T. gravida* CL.	−	−	+
T. hyperborea (GRUN.) HASLE var. *hyperborea*	+	+	+
T. hyperborea var. *septentrionalis* (GRUN.) HASLE	−	+	−
**T. nordenskioeldii* CL.	−	+	+
**T.* sp. cf. *decipiens* (GRUN.) JÖRG. (see MAKAROVA, 1988)	−	−	+
**T.* sp. cf. *kryophila* (GRUN.) JÖRG. (see MAKAROVA, 1988)	−	−	+
Dinophyta			
**Cochlodinium* sp. cf. *brandtii* WULFF (see DODGE, 1982)	+	−	−
Ebria sp. cf. *tripartita* EHR. (see GEMEINHARDT, 1930)	−	+	+
Gymnodinium sp. cf. *punctatum* POUCHET (see SCHILLER, 1933)	−	+	−
**Protoperidinium pallidum* (OSTF.) BALECH	−	+	−
Dinophyta gen. sp. 1 (thecate, length 22–34 μm, breadth 9–12 μm)	+	+	+
Dinophyta gen. spp.	+	+	+
Chrysophyta			
Dictyocha speculum EHR. var. *speculum*	−	+	−
**D. speculum* var. *septenarius* (EHR.) JÖRG.	−	+	−
*Craspedomonadales gen. sp.	−	+	−
Euglenophyta			
Euglena spp.	+	+	−
Eutreptiella spp.	+	+	−
Lepocinclis ovum (EHR.) MINK. var. *butschlii* (LEMM.) CONRAD	−	+	−
Xanthophyta			
Characiopsis sp.	−	−	+
Chlorophyta			
Chlorophyta gen. sp. (solitary oval cells, length 17–24 μm, breadth 14–20 μm, with numerous parietal chloroplasts, without flagella)	−	+	−
Algae of unknown systematic position (Fig. 4)	+	+	+

* indicates single finding of a species during an expedition.
+, present; −, absent.

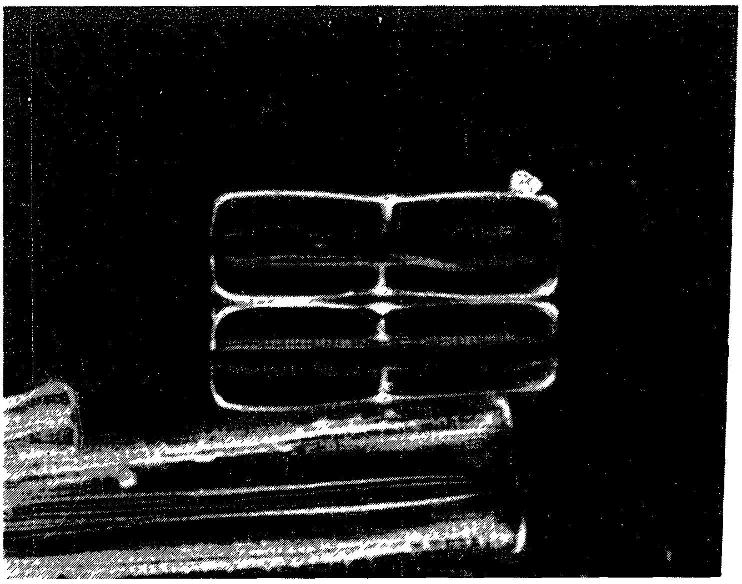

Fig. 2. Pennatophyceae gen. sp. 1 (× 1000, permanent slide).

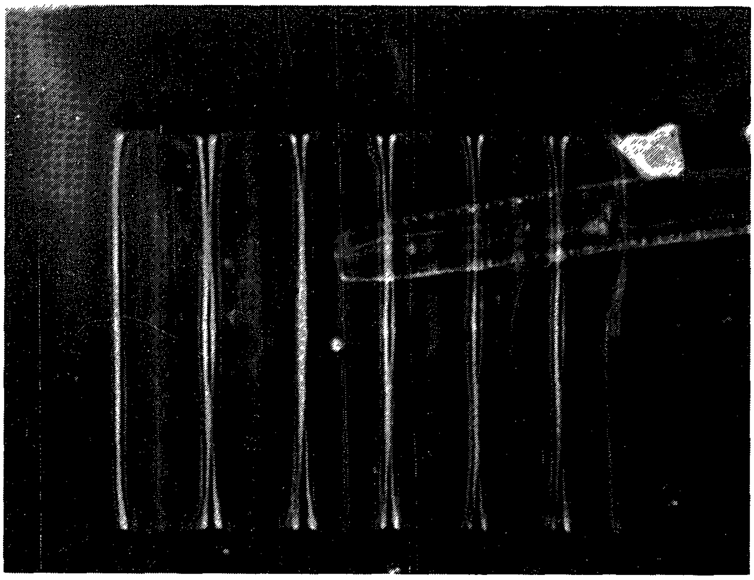

Fig. 3. Pennatophyceae gen. sp. 2 (× 1000, permanent slide).

seas under study is given in Table 2. It is corrected and supplemented by taking into account new materials in addition to the published ones (OKOLODKOV, 1989, 1990, 1991). In total, 119 algal species have been identified including 89 pennate diatoms, 22 centric diatoms, 4 dinoflagellates, 2 chrysophytes, 1 euglenoid and 1 xanthophyte. Besides, 2 pennate diatoms, about 10 dinoflagellates and 5 euglenoids are unidentified and some algal species are of unknown taxonomic position. About half the pennate diatom species belongs to the genera *Navicula* (24 species) and *Nitzschia* (20). In general, among the diatoms prevail the pennates (88%).

Table 3. The quantitative characteristics of sea-ice algae in the lower layer of drifting ice of the Chukchi Sea in March–April, 1988.

Station number	Date	Ice age	Ice thick-ness (cm)	Snow cover (cm)	Number of cells in litre of melted ice	Dominant species and percentage of prevalence
1	2	3	4	5	6	7
1	March 9	young	75	5	2.3×10^6	*Nitzschia cylindrus* (37)
2	March 9	first-year	105	15	3.4×10^4	*Nitzschia frigida* (34)
3	March 9	first-year	108	18	3.4×10^4	*Nitzschia frigida* (18), *N. cylindrus* (18)
4	March 10	first-year	120	11	1.2×10^5	*Nitzschia frigida* (39)
5	March 10	young	55	12	7.9×10^4	*Nitzschia frigida* (21)
6	March 10	first-year	155	18	6.0×10^3	*Chaetoceros holsaticus* (20), *Cylindrotheca closterium* (15)
7	March 12	first-year	170	8	2.1×10^4	*Thalassiosira hyperborea* (17), *Nitzschia frigida* (15), *Entomoneis kjellmanii* (12)
8	March 12	first-year	105	8	1.2×10^5	*Thalassiosira hyperborea* (24), *Nitzschia frigida* (15)
9	March 12	young	10	15	1.6×10^4	*Nitzschia arctica* (28), *Achnanthes taeniata* (14)
10	March 13	young	9	35	4.0×10^3	*Nitzschia grunowii* (16), *N. frigida* (14), *Thalassiosira hyperborea* (11)
11	March 13	first-year	146	10	1.5×10^4	*Chaetoceros furcellatus* (16)
12	March 13	first-year	110	3	1.4×10^7	*Nitzschia frigida* (27), *N. arctica* (17)
14Y	March 15	young	45	4	4.1×10^4	*Nitzschia arctica* (15)
14F	March 15	first-year	90	4	4.8×10^6	*Nitzschia cylindrus* (33), *N. delicatissima* (25), *Thalassiosira hyperborea* (14)
15	March 17	first-year	147	10	3.0×10^6	*Nitzschia frigida* (32)
16	March 17	young	25	10	1.9×10^4	*Nitzschia* spp. (32)
17	March 25	young	92	10	5.5×10^4	*Cylindrotheca closterium* (28), *Nitzschia frigida* (18)
18	March 25	young	55	5	1.5×10^3	no dominant species
19	March 25	young	93	15	2.4×10^4	*Nitzschia frigida* (17), *Cylindrotheca closterium* (16)
20	March 26	young	43	10	5.5×10^3	Dinophyta gen. sp. 1 (25)
21	March 26	young	40	7	7.4×10^2	*Nitzschia* spp. (90)
27	April 4	first-year	220	no data	1.1×10^5	*Nitzschia frigida* (40), *Navicula directa* (19)
28	April 4	young	56	6	2.0×10^4	Dinophyta gen. sp. 1 (50), *Nitzschia frigida* (25)
29	April 4	young	73	0	1.5×10^5	Chlorophyta gen. sp. (21), *Cylindrotheca closterium* (13), *Nitzschia frigida* (11), Dinophyta gen. sp. 1 (11)
31	April 6	young	45	5	1.3×10^6	*Nitzschia cylindrus* (57), *Navicula pelagica* (22)
32	April 6	young	42	4	1.9×10^6	*Nitzschia cylindrus* (70)

Table 3. (continued).

1	2	3	4	5	6	7
33	April 6	young	4	3	1.5×10^4	*Nitzschia cylindrus* (33), *N. frigida* (30)
34	April 7	young	42	3	1.4×10^5	*Nitzschia cylindrus* (32), *N. grunowii* (13)
35	April 7	first-year	130	3	1.4×10^7	*Nitzschia frigida* (21)
36	April 7	first-year	90	3	7.4×10^7	*Navicula pelagica* (26), *Nitzschia* sp. cf. *promare* (17), *N. frigida* (15), *Navicula septentrionalis* (11)
37	April 7	young	55	3	1.2×10^7	*Nitzschia cylindrus* (60), *N. frigida* (17)
38	April 8	first-year	120	3	4.4×10^8	*Nitzschia frigida* (50)
39	April 8	young	25	8	2.7×10^5	*Nitzschia grunowii* (59), *N. frigida* (16)
40	April 8	young	61	3	3.1×10^6	*Nitzschia grunowii* (32), *N. cylindrus* (23)
41	April 8	young	15	no data	1.7×10^4	*Nitzschia frigida* (53)

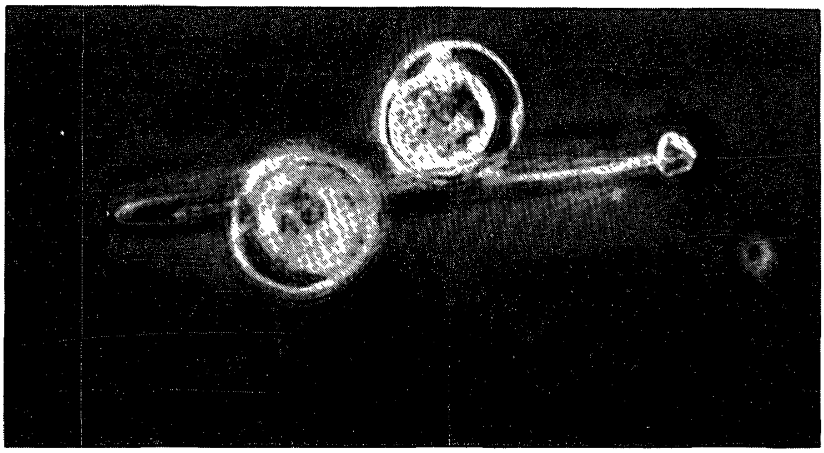

Fig. 4. Algae gen. sp., attached to Nitzschia frigida *(× 1000, water mount).*

3.2. Concentration of the algae and the dominant species

The maximum concentrations of the algae were in the lower layer of ice cores, judging from the visual observation. The earliest ice bloom was noted visually on March 9 and 13, 1988 at Stns. 1 and 12 in the Bering Strait and Chukchi Sea. At the rest stations in the region mentioned during the survey from March 9 to April 8, 1988 we have not seen coloured ice excluding St. 36 in the Long Strait and St. 38 in the eastern Chukchi Sea on April 7 and 8. The subsequent survey of the East Siberian and eastern Laptev seas continued from March 25 to May 19, 1988 (only St. 13 was worked earlier, on March 15). In 1988 slightly or moderately coloured ice was noticed at Stns. 22, 30, 53–55, 57, 61, 64, 65, 69–73, 76, 79, 82 and 84–88. Intensively coloured ice was found at Stns. 24, 47, 49, 58, 67, 74, 75, 78, 80, 89 and 90. Among 35 stations

Table 4. List of the species prevailing numerically in the lower layer of the ice of the East Siberian and Laptev seas in March–May, 1987–1990.

Species	Year and station numbers
Achnanthes taeniata	1987: 3af; 1989: 58Faf
Chaetoceros holsaticus	1988: 46af
Cylindrotheca closterium	1988: 13ad, 25yd, 50af
Navicula glaciei	1988: 85ad
N. pelagica	1987: 3af; 1988: 67af, 68af, 69ad, 70yd, 76af, 78af, 83af, 89ad; 1989: 45ad; 1990: 14af, 16yd, 17af
N. septentrionalis	1988: 47af, 79ad; 1989: 45ad; 1990: 12ad, 13af, 14af, 17af, 18af
N. sibirica	1988: 84ad, 87ad
N. vanhoeffenii	1988: 68af, 72ad, 90ad; 1989: 47af
Nitzschia arctica	1988: 23ad, 81af
N. cylindrus	1987: 4af, 8ad, 9ad, 10ad, 11ad; 1988: 25yd, 26yd, 30yd, 46af, 49af, 50af, 60ad, 62ad, 65ad, 66ad, 70yd, 73ad, 79ad, 80af, 87ad; 1989: 53ad; 1990: 11yd, 12ad, 13af
N. delicatissima	1987: 5af, 6ad, 7ad, 9ad, 11ad; 1988: 30yd, 60ad, 66ad; 1989: 53ad, 54ad
N. frigida	1987: 3af; 1988: 13ad, 22ad, 24ad, 42af, 45af, 46af, 47af, 49af, 50af, 51af, 53ad, 54yd, 57yd, 64ad, 67af, 68af, 69ad, 70yd, 74yd, 78af, 80af, 81af, 83af, 86ad, 88af, 89ad, 90ad; 1989: 45ad, 47af, 48ad, 49ad, 53ad, 54ad, 55ad, 56ad, 57af, 59ad, 60ad; 1990: 10ad, 11yd, 12ad, 14af, 16yd, 17yd, 18af, 19af
N. grunowii	1987: 1yd; 1988: 55ad, 71yd, 72ad; 1989: 49ad, 54ad, 56ad, 57af, 58Yyd
N. polaris	1988: 23ad, 58af, 75ad, 81af; 1990: 15yd, 16yd, 19af
N. sp. cf. *grunowii*	1988: 80af; 1990: 10yd
N. sp. cf. *promare*	1988: 53ad, 55ad, 57yd, 59yd, 64ad, 67af, 69ad, 71yd, 72ad, 79ad, 80af; 1989: 48ad, 49ad, 53ad, 54ad, 57af, 58Yyd; 1990: 10yd, 11yd, 14af, 17af
Pleurosigma stuxbergii	1988: 84ad
Pseudogomphonema septentrionale	1988: 24ad
Thalassiosira hyperborea	1988: 13ad, 61ad; 1989: 46af
Gymnodinium sp. cf. *punctatum*	1987: 5af

Small letters behind ciphers indicate the age and type of ice: y, young; a, annual (first-year); d, drifting; f, fast.

with coloured layer, in 30 cases we dealt with first-year ice of thickness up to 203 cm, and in 5 cases with young ice of 43–80 cm thickness in frozen cracks between ice floes. As a rule, the lower layer of 0.2 to 0.5 cm was coloured greyish-brown (in Latin: argillaceus, the colour b4 after BONDARTSEV's scale), in several cases nicotianus, d7 and in one case rufescens, zh2. Sometimes coloured layer thickness reached 3.0 to 3.5 cm, *e.g.* at St. 58 (April 25, ice thickness 200 cm, snow cover 4 cm) and St. 89 (May 18, ice thickness 99 cm, snow cover 2 cm) near the New Siberian Islands.

The quantitative characteristics of the algae were studied more thoroughly in the Chukchi Sea in March–April, 1988 (Table 3). The concentration of the algae in March did not exceed 7.9×10^4 cells/l at 15 stations from a total of 21, the maximum number of cells being found at St. 12. In the first decade of April the concentration at 10 of 14 stations was no more than 3.1×10^6 cells/l. The maximum number was registered at St. 38. The average number was 1.2×10^6 cells/l in March and 3.4×10^7 cells/l in early April.

In Table 4 are presented the data on the dominant species in the ice of the East Siberian and Laptev seas. As seen in Tables 3 and 4, a total of 25 dominant species have been revealed. More frequently encountered abundant species are *Nitzschia frigida*, *N. cylindrus*, *N.* sp. cf. *promare*, *N. grunowii*, *N. delicatissima*, *N. polaris*, *Navicula pelagica* and *N. septentrionalis*. They all are the colonial pennate diatoms. Among 10 species represented by solitary cells, *Pseudogomphonema septentrionale* is the only epiphyte.

4. Discussion

The results of the present investigation show that the species composition of sea-ice algae of the cryobiological community in different seas has much in common (Table 2). The differences between them are conditioned chiefly by isolated findings of the allochthonous species of freshwater origin. In addition, it is similar to a great extent to the Wankarema community named by GRAN (1904) after the Cape Wankarema situated on the shore of the Chukchi Sea and designated for certain complex of algal species. GRAN supposed the community to be characteristic of the Cape Wankarema, Arctic Ocean (north of the Laptev Sea), Greenland and western Norwegian seas. NANSEN and CLEVE believed that the diatoms in northern Siberia and eastern Greenland are directly connected with one another through ice drift across the central Arctic Ocean (GRAN, 1904). Dealing with only the samples from the Laptev, East Siberian and Chukchi seas, *i.e.* from the region with the Wankarema community, it is impossible to resolve definitely the problem concerned.

As a rule, most of the algae occurred every year. The composition of the dominant species is rather constant in the sampling area, on the whole, and the composition does not seem to be related with certain age and type of ice (Table 4).

Special attention should be paid to the freshwater and brackish-water species. The experience of the use of sea-ice algae as biological indicators of ice origin in the Arctic seas is restricted primarily to the investigations of CLEVE (1898) and USACHEV (1938, 1946, 1949). Like CLEVE and USACHEV, we consider freshwater algae to be a witness in favour of the idea that ice was formed in a river mouth or, at least, in the neighbourhood of the river. Single findings of freshwater species *Asterionella formosa*, *Aulacosira* sp., *Diatoma* sp. cf. *hiemale* f. *turgidula* and *Eunotia pectinalis* var. *minor* in young ice of the western Laptev Sea at St. 58 in 1989 may be explained by the river influence. Isolated frustules of freshwater diatoms were discovered in 1988 in the East Siberian Sea at Stns. 42 (*Synedra* sp. cf. *acus*) and 84 (*Aulacosira* sp.). Brackish-water algae are assumed to mark the fluvial flow in the coastal regions. Its influence on algal species composition in sea ice was noted in 1989 in the western Laptev Sea at Stns. 46 and 58–60, where brackish-water species *Amphora holsatica* and *Melosira moniliformis* var. *subglobosa* were found. The latter species occurred in 1988 in the East Siberian Sea at Stns. 55 and 68. Besides, almost complete absence of algal cells at St. 82 in the eastern Laptev Sea in 1988 is believed to be conditioned by insignificant salinity below the ice (22‰). The range of 22–26‰ is known to be the zone of critical salinity or β-horohalinicum, within which some of the biological characteristics are changed and transformations of the physico-chemical properties of sea water take place (VINOGRADOV, 1986; KHLEBOVICH, 1989).

Apart from freshwater and brackish-water diatoms mentioned above, we attribute to the allochthonous element the following species: brackish-water-marine form *Amphora coffeaeformis*, marine benthic forms *Cocconeis scutellum* var. *minutissima* and *Rhabdonema minutum*, marine planktonic-benthic forms *Odontella aurita* and *Paralia sulcata*, marine planktonic forms *Chaetoceros cinctus*, *C. compressus*, *C. concavicornis*, *C. decipiens*, *Coscinodiscus subtilis* and *Thalassiosira* species, excepting *T. hyperborea*. The rest diatoms can be regarded as autochthonous and, thus, characteristic of the Arctic sea ice in the area studied.

GRAN as early as in 1904 distinguished the group of species that occurred in both the ice and water column, consisting of 9 species, some of them (*Melosira arctica*, *Nitzschia cylindrus* and *N. grunowii*) predominating in both habitats. HORNER (1981) and HORNER and SCHRADER (1982) mentioned 2 species developing in a great number in the Arctic sea ice as well as in water, *N. cylindrus* and *N. grunowii*. *N. grunowii* was shown to accompany drifting ice and to produce phytoplankton bloom in the Kara Sea (KOLTSOVA and ILJASH, 1982). Taking into account the dominant species of spring phytoplankton bloom in the East Siberian and Chukchi seas (SHIRSHOV, 1936, 1937), *Achnanthes taeniata* should be added to the species listed.

The group of species under discussion is closely related with the problem of seasonal occurrence. Seasonal characteristics were established for several species as phytoplankton organisms. The following ones were considered as "early-spring" or "spring" in the Siberian seas: *Nitzschia cylindrus*, *N. grunowii* and *Achnanthes taeniata* (SHIRSHOV, 1937), *Nitzschia delicatissima* (USACHEV, 1949) and *N. frigida* (OKOLODKOV, 1987). It was demonstrated that they were the dominant species in our samples (Tables 3 and 4). Spring phytoplankton bloom in the Chukchi and East Siberian seas occurs from mid-July to mid-August (SHIRSHOV, 1936, 1937; OKOLODKOV, 1987, 1988; GALKINA *et al.*, in press), some of the species mentioned being among the prevailing forms, while the "biological spring" in sea ice has been observed in April–May in all the Siberian seas (OKOLODKOV, 1989, 1990, 1991, and unpublished data on the Kara Sea). Although the data on ice algae and phytoplankton sampled in June–July are absent, there is a reason to suppose that the interval between spring blooms in the ice and water column can be about 3 to 3.5 months.

The role of epiphytic species in a sea-ice algal community was usually underestimated. In our samples 10 species were recorded as epiphytes of the colonial pennate diatoms, some of them prevailing in number. The most important epiphytic forms are *Gonioceros septentrionale*, species of the genus *Pseudogomphonema* MEDLIN (=pro parte *Gomphonema* AG.), *Synedra* sp. cf. *hyperborea* var. *rostellata* and the species of unknown taxonomic position represented by globular cells, 14–23 μm in diametre, attached more often to *Nitzschia* and *Entomoneis* species.

Rare occurrence of the resting stages of the algae in our samples agrees with the data of other authors on the Arctic sea ice. We observed the diatom resting spores and the valves of their parent cells belonging to *Chaetoceros cinctus*, *C. compressus*, *C. furcellatus* and *Thalassiosira antarctica*. Taking into consideration the findings of the resting spores of *Chaetoceros affinis* LAUD., *C. diadema* (EHR.) GRAN and empty spores of *Thalassiosira gravida* (?) in the Arctic sea ice (PORETZKY, 1939; HORNER, 1976), one may conclude that it is a biotope for surviving the neritic planktonic diatoms. The resting spores are supposed to be a component of the cryobiological community, at least, at the moment of their inclusion into the ice from below, not depending on the ice layer where the spores had been found.

Thus, the algae of the cryobiological community in the Arctic sea ice are represented by benthic and planktonic-benthic species of primarily pennate diatoms, by the epiphytes (mainly diatoms) attached to them, and by resting spores of neritic planktonic species. The structure described is peculiar to Arctic first-year and young fast and drifting undeformed sea ice, *i.e.* beyond the limits of the hummocks. In the central Arctic Ocean, in the zone of the multi-year hummocked ice, *Melosira arctica* is the most abundant species (MELNIKOV and BONDARCHUK, 1987; MELNIKOV, 1989).

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