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Quantitative Composition, Distribution, Community Structure and Standing Stock of Sea Ice Microalgae in the Canadian Arctic

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ABSTRACT. One hundred and ninety-six (196) species of microalgae were identified from the annual shore-fast sea ice samples collected from the Canadian Arctic between November and June in the years 1971 to 1978. The diatoms were represented by 189 species (21 centric and 168 pennate), the flagellates by three species, the dinoflagellates and chrysophytes by two species each. There were no blue-green algae. Species composition and distribution are tabulated. The dominant species of the microalgal communities in the bottom of the ice different from those found elsewhere in the ice.

The sea ice microalgal communities and standing stock started to develop in late fall at the time of ice formation. They grew very slowly through the winter months, exponentially increased in early spring, reached a peak just prior to the thaw period in late spring or early summer, and declined rapidly in summer as ice melting occurred. Standing stock was greatest at the bottom of the sea ice, where it was one to two orders of magnitude larger than in other parts of the ice column, and 50 to 500 times greater than in the phytoplankton in the underlying waters. The ice communities consisted mainly of diatoms with a great majority of pennate forms. Large numbers of species and cells of diatoms were found at the bottom of the sea ice. Dinoflagellates, flagellates and chrysophytes occurred in relatively low numbers except in a few cases when ice blooms were observed. During May most of the sea ice microalgal blooms occurred in the bottom of the ice except for *Phaeocystis pouchetii*, which occurred elsewhere in the ice.

Environmental factors controlling standing stock, growth and distribution of sea ice microalgae are discussed.

RÉSUMÉ. Cent quatre-vingt seize (196) espèces d'algues microscopiques ont été identifiées à partir d'échantillons prélevés dans l'Arctique canadien sur la banquise côtière annuelle entre novembre et juin, de 1971 à 1978. Les diatomées y étaient représentées par 189 espèces (21 de forme centrique et 168 de forme pennée), les flagellés par trois espèces, les dinoflagelés et les chrysophytes par deux espèces chacune. Les algues bleues ne comptaient aucun représentant. La composition et la distribution de espèces ont été mises en tableaux. Les espèces dominantes des communautés d'algues microscopiques que l'on retrouve dans la couche inférieure de la glace différaient de celles recontrées ailleurs dans la glace.

Les communautés d'algues microscopiques de glace de mer et le stock *in situ* ont commencé à se constituer à la fin de l'automne, lors de la formation des glaces. Ils se sont développés très lentement durant les mois d'hiver, augmentant de façon exponentielle tôt le printemps pour atteindre un sommet tout juste avant la période de dégel, à la fin du printemps ou au début de l'été et puis décroître rapidement en été avec la fonte des glaces. Le stock *in situ* atteignait un maximum dans la couche inférieure de la glace de mer et dépassait par un ou deux ordres de grandeur les valeurs trouvées dans les autres parties de la colonne de glace; il était de 50 à 500 fois supérieur à celui du phytoplancton présent dans les sous-jacentes. Les communautés de glace se composent surtout de diatomées, la grande majorité étant de forme pennée. Un grand nombre d'espèces et de cellules de diatomées dans la couche inférieure de la glace. Les dinoflagellés, flagellés et chrysophytes se retrouvent en nombre relativement restreint à part quelques rares occasions lorsque des blooms d'algues microscopiques ont été observés dans la glace. Durant le mois

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de mai, c'est dans la couche inférieure de la glace marine que se produisent la plupart des blooms d'algues microscopiques à l'exception de *Phaeocystis pouchetii* dont le bloom se prouit ailleurs dans la glace.

Des facteurs de l'environnement pouvant contrôler les stocks *in situ*, la croissance et la distribution des algues microscopiques de la glace marine sont discutés.

Traduit par l'auteur.

INTRODUCTION

Sea ice covers 26 million km^2 of the earth's surface. Of this, about 10 million km^2 lie in the Arctic (Coachman and Aagaard, 1974). Two distinct communities of microalgae exist in the polar sea ice. The first is the snow community in the Antarctic studied by Meguro (1962), which is derived from seawater penetrating into the interstices of the snow which piles on the surface of the ice; the microalgae are entrapped and frozen compacted on the top of the ice. The second is the epontic community described by Bunt and Wood (1963) in the Antarctic and by Meguro *et al.* (1967) in the Arctic, in which the microalgae are attached to ice crystals and in the interstitial water of the ice matrix formed at the bottom surface of the sea ice. During late winter through spring and early summer, colored bands ranging from brownish-green, greenish-brown, yellow-brown, brown, dark brown, to red are commonly seen in the arctic sea ice, especially in the bottom layers (Gran, 1904; Apollonio, 1961; Bursa, 1961; Meguro *et al.*, 1966; 1967; Alexander *et al.*, 1974; McRoy and Goering, 1976; Grant and Horner, 1976). These bands are caused by the pigments of microalgae with different proportions of diatoms, green flagellates, dinoflagellates and chrysophytes growing on, or trapped within, the ice. It has been recognized that the sea ice microalgae play an important role as primary producers in the arctic marine ecosystem (Meguro *et al.*, 1966; 1967; Horner and Alexander, 1972; Alexander, 1974; McRoy and Goering, 1974; Clasby *et al.*, 1976). They may directly provide a potential food source for grazing zooplankton (English, 1961; Apollonio, 1965; Alexander *et al.*, 1974), euphausiid shrimp, fish fry, glacial and polar cod (Andriashev, 1968; Ackley *et al.*, 1979), and they may indirectly supply food through zooplankton consumers (fishes) to fish-eating species of mammals and birds (Horner, 1976; McConnaughey and McRoy, 1979).

The composition of the arctic ice flora was reported by Ehrenberg (1853) from Assistance Bay, Hingston Bay and Melville Bay; Dickie (1878) from the region between Smith Sound and Robeson Channel; Cleve and Grunow (1880) from the Kara Sea; Cleve (1883; 1884; 1896; 1898; 1899; 1900) from Cape Wankarema, Discovery Bay, Baffin Bay and Davis Strait, Franz Joseph Land, between Greenland and Spitsbergen, and north of Jan Mayen Island; Gran (1897; 1904) from Karajak Fjord and the Arctic Ocean; Østrup (1895) from the east coast of Greenland; and Usachev (1938; 1949) from the Kara and Laptev seas. All of this information was obtained from drifting, broken ice-floes or samples taken from ice upturned in the path of ice-breakers. None of it was quantitatively evaluated samples for species composition. Recently, Alexander *et al.* (1974) used a SIPRE ice corer to take samples from solid, unbroken sea ice at Barrow, Alaska and quantitatively analyzed the samples from the bottom of ice cores for species

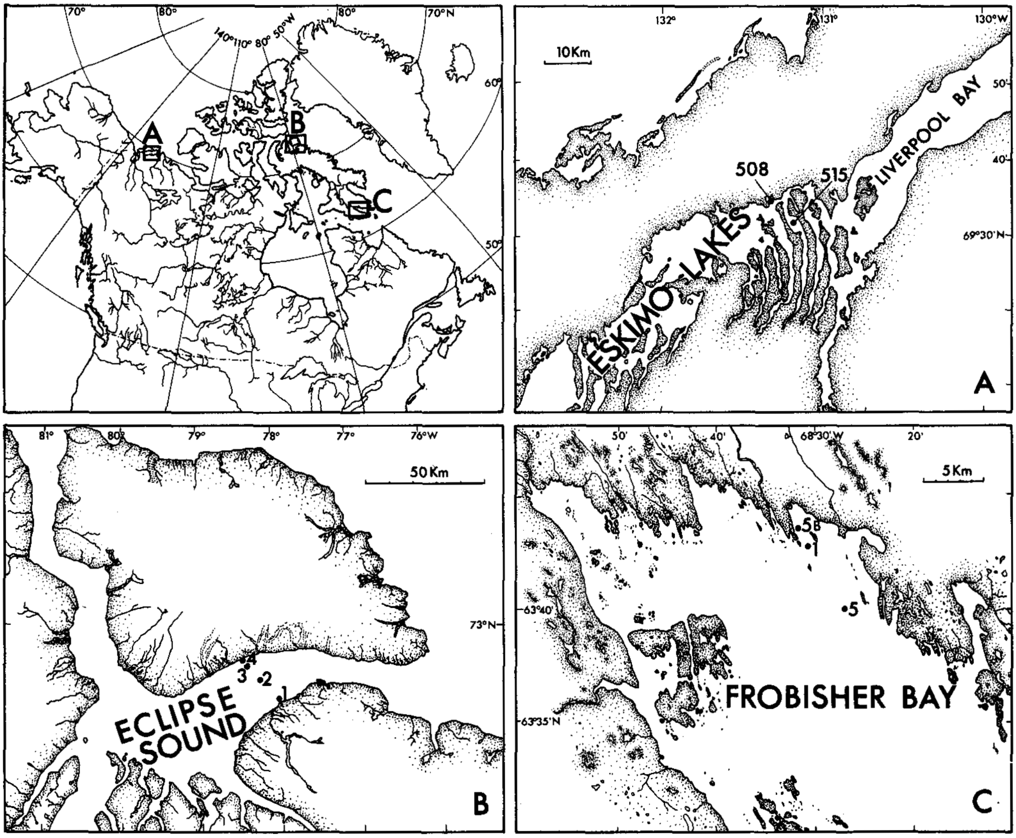

FIG. 1. Station locations in the Canadian Arctic. The collecting sites, A, B, and C indicated in the map at upper left are illustrated in greater detail in the other three maps.

composition and standing stock. The development and composition of the epontic community in the vicinity of Barrow have been studied by Meguro *et al.* (1966; 1967), Horner and Alexander (1972) and Horner (1976; 1977). However, very little is known concerning qualitative and quantitative species composition and spatial distribution of sea ice microalgae in the Canadian Arctic. The objective of this paper is to investigate the quantitative composition, vertical distribution and standing stock of microalgae in the Canadian arctic sea ice, and to explore some environmental factors controlling their distribution.

MATERIALS AND METHODS

The sea ice microalgal samples were collected with a 7.5-cm SIPRE ice corer from the top to the bottom of the ice at stations 508 and 515 in the Eskimo Lakes during late fall and spring of the years 1972 to 1974; at stations 1, 2, 3, and 4 in Eclipse Sound during March and May of the years 1976 and 1977; and at stations 1, 5 and 5B in Frobisher Bay during late fall and spring of the years 1971 to 1973, 1977 and 1978 (Fig. 1). The length of the ice core was measured, and various parts of the core were cut with a fine-toothed meat saw. The ice samples were placed in clean plastic containers, and then thawed in the laboratory at room temperature. One set of the samples from the Eskimo Lakes (Grainger *et al.*, 1977) and Frobisher Bay (Grainger, 1971) was used for the analyses of salinity, nutrients and pigments. The other set of samples was used for species identification and enumeration, and was immediately preserved with formalin at a final concentration of 2%, neutralized with calcium carbonate in Boston round polyethylene bottles.

The preserved sea ice microalgae were quantitatively analyzed for species composition and standing stock. The techniques for preparing permanent slides of cleaned diatoms for species identification were described by Foy and Hsiao (1976). Sea ice microalgae were identified with the aid of a Leitz phase-contrast compound microscope. All samples were thoroughly shaken to suspend cells. Subsamples of 10mL (except for those taken from the bottom of the ice cores which, because of the dense concentrations of cells there, were only 1mL) were pipetted into a Zeiss 10-mL phytoplankton sedimentation chamber. The cells were allowed to settle for 12-24 hours, and were counted with the aid of a Leitz inverted microscope at a magnification of 500x. The cells in an area equivalent to 89 microscope fields were counted. They were indentified to species when possible, otherwise to higher taxonomic levels or groups. The microalgae described here were mostly collected from 10 cm long ice cores, taken from near the top surface, the middle and the bottom surface of the ice. Total cell counts and chlorophyll *a* were used to estimate the standing stock of sea ice microalgae. The integrated standing stock was used as the standard value for seasonal and regional comparisons. Chlorophyll *a* was analyzed in the field with a spectrophotometric technique following the method of Strickland and Parsons (1972).

RESULTS

Species Composition, Distribution and Abundance

A total of 196 species in 46 genera of microalgae was identified from the Canadian arctic sea ice (Table 1). Among them, the diatoms were represented by 189 species (21 centric and 168 pennate), the flagellates by three species, the dinoflagellates and chrysophytes by two species each. No blue-green algae were found in this study. Eleven, 24 and 44 species of microalgae were found exclusively in the Eskimo Lakes, Eclipse Sound and Frobisher Bay, respectively; 51 species were observed in more than one region, and 68 species occurred in all three regions. Of the 68 species of sea ice microalgae commonly distributed in these regions, the 18 most frequently encountered were *Amphiprora kjellmanii* var. *kariana*, *A. kjellmanii* var. *striolata*, *Amphora laevis* var. *laevissima*, *Cylindrotheca closterium*, *Gomphonema exiguum* var. *pachycladum*, *Navicula directa*, *N. quadripedis*, *Nitzschia cylindrus*, *N. frigida*, *N. gruendleri*, *N. hybrida*, *N. laevissima*, *N. tergestina*, *N. polaris*, *Pinnularia quadratarea* var. *stuxbergii*, *Pleurosigma clevei*, *P. stuxbergii* and *Thalassiosira nordenskioldii*.

Most species of ice flora were distributed at the bottom of the sea ice, while eight species (*Chaetoceros fragilis*, *Fragilaria pinnata*, *Licmophora gracilis*, *Navicu-*

Table 1. Species composition and vertical distribution[1] of sea ice microalgae in the Canadian Arctic

Sea ice microalgae	Eclipse Sound Station				Eskimo Lakes Station		Frobisher Bay Station		
	1	2	3	4	508	515	5	5B	1
Diatoms									
Centric									
Biddulphia aurita (Lyngbye) Brébisson et Godey								b	
Chaetoceros borealis Bailey					b	b		t b	
C. decipiens Cleve	t								
C. fragilis Meunier							t	t	t
C. furcellatus Bailey							mb	t B	t
C. septentrionalis Östrop					tmB		tmB	tmB	m
Coscinodiscus kuetzingii var. *glacialis* Grunow						b		t b	
C. lacustris var. *septentrionalis* (Grunow) Rattray								b	
C. polyacanthus Grunow *in* Cleve et Grunow								m	
Coscinosira oestrupii Ostenfeld							tmb	tmb	
Eucampia Ehrenberg				b					
Melosira arctica (Ehrenberg) Dickie *in* Pritchard	b	B	b		b		mB	tmb	
Porisira glacialis (Grunow) E. Jørgensen	b								
Rhizosolenia alata Brightwell	B								
R. hebetata var. *subacuta* Grunow							b		
Thalassiosira bioculatus (Grunow) Ostenfeld	B								
T. bioculatus var. *exigua* (Grunow) Hustedt					b		t b	tm	
T. decipiens (Grunow) E. Jørgensen							tm	tm	
T. gravida Cleve	b	B	b	b	B		tmb	tm	
T. nordenskioldii Cleve	B	b	b	b	B		B	B	
Triceratium arcticum Brightwell	b			b	tm	b	tm	tmb	
T. nobile Witt					t				
Pennate									
Achnanthes delicatula (Kützing) Grunow *in* Cleve et Grunow					b		t	B	
A. minutissima Kützing					m				
A. taeniata Grunow *in* Cleve et Grunow					B		t B	mB	
Amphipleura rutilans (Trentepohl) Cleve					t			b	
Amphiprora concilians Cleve	b				b		tmB	mB	

A. gigantea var. *septentrionalis* (Grunow *in* Cleve et Grunow) Cleve	B	B	b	B			tmB	tmB	
A. kjellmanii Cleve *in* Cleve et Grunow	B				m				
A. kjellmanii var. *kariana* (Grunow *in* Cleve et Grunow) Cleve	B	B	B	B	t B		B	mb	
A. kjellmanii var. *striolata* (Grunow *in* Cleve et Grunow) Cleve	B	B	B	B	tmB	b	tmB	tmB	mB
A. kryophila Cleve	B	B	B	B	mb		mB	tmB	mB
Amphora angusta var. *ventricosa* (Gregory) Cleve	b								
A. eunotia Cleve	B	b		B			mb	B	
A. exsecta Grunow *in* Schmidt et al			b				tmB	t b	
Amphora laevis var. *laevissima* (Gregory) Cleve	B	B	B	B	B		tmB	mB	tmB
A. laevissima var. *minuta* Cleve		b	b				mB	mB	
A. proteus Gregory					t			B	t
Bacillaria paradoxa Gmelin *in* Linnaeus	b	b		B	b		tmb	mb	
Caloneis brevis (Gregory) Cleve								b	
C. kryophila (Cleve) Cleve	b	b	b	b	tmb	B	mB	mb	
C. liber (Wm. Smith) Cleve	b				b				
C. obtusa (Wm. Smith) Cleve	b								
C. semiinflata (Östrup) Boyer					b		b	b	
Cocconeis costata Gregory							t B	t b	
C. placentula var. *euglypta* (Ehrenberg) Grunow							t		
C. scutellum Ehrenberg							t	t b	
C. scutellum var. *parva* Grunow *in* van Heurck							tmb	tmB	t
C. scutellum var. *stauroneiformis* Rabenhorst							t b	tmB	
Cylindrotheca closterium (Ehrenberg) Reimann et Lewin	t B	B		B	tmB		tmB	TmB	tmb
Diploneis didyma (Ehrenberg) Ehrenberg								b	
D. incurvata (Gregory) Cleve								b	
D. lineata (Donkin) Cleve					m		mb	tmb	
D. litoralis var. *arctica* Cleve	b		b	b	tmB	b	tmB	tmB	m
D. litoralis var. *clathrata* (Östrup) Cleve		b							
D. smithii (Brébisson *in* Wm. Smith) Cleve					t b			t b	
D. vacillans (Schmidt *in* Schmidt et al) Cleve								b	
Eunotia Ehrenberg							t		
Fragilaria pinnata Ehrenberg					t				
Gomphonema exiguum Kützing		b					b		
G. exiguum var. *pachycladum* (Brébisson *in* Brébisson et Godey) Cleve	B	b	B	B	tmB	B	tmB	tmB	tmB

Sea ice microalgae	Eclipse Sound Station				Eskimo Lakes Station		Frobisher Bay Station		
	1	2	3	4	508	515	5	5B	1
G. Groenlandicum Östrup	b	b	b	B			mB	B	t B
Grammatophora angulosa Ehrenberg								t	
C. arctica Cleve								b	
G. hamulifera Kützing								b	
Gyrosigma fasciola (Ehrenberg) Cleve					t			b	
Hantzschia weyprechtii Grunow *in* Cleve et Grunow	b		b	b			B	b	
Licmophora dalmatica (Kützing) Grunow					t b				
L. gracilis (Ehrenberg) Grunow					t				
L. gracilis var. *anglica* ützing) Peragallo et Peragallo								B	
L. hyalina (Kützing) Grunow	b								
Navicula algida Grunow	b	b	b	b	b	b	mb	B	
N. cancellata Donkin	b	b			t			t	
N. cluthensis Gregory							*t*		
N. cluthensis var. *pagophila* Grunow					mb	b	mb	t b	
N. crassirostris Grunow *in* Cleve et Grunow	b	b	b		tmB		tmb	tmB	
N. crucigeroides Hustedt	B	b	b	B	b		tmB	tmB	b
N. decipiens O'Meara	b	b	b	b	tmb	b	t B	mB	
N. digitoradiata (Gregory) Ralfs *in* Pritchard	b	b	b	b			tmB	tmB	tmb
N. directa (Wm. Smith) Ralfs *in* Pritchard	B	B	B	B	tmB	b	tmB	tmB	mb
N. directa var. *javanica* Cleve							mB	b	
N. directa var. *subtilis* (Gregory) Cleve		b							
N. forcipata Greville		b			t b		tmb	tmb	
N. gastrum (Ehrenberg) Kützing	B		b				t B	b	
N. gelida Grunow		b	b	b	mb		tmb	tmB	
N. glacialis (Cleve) Grunow	B	b	b	b	b		t b	B	
N. granii (E. Jørgensen) Gran	B	B							
N. imperfecta Cleve			b				mB	mB	
N. kariana Grunow *in* Cleve et Grunow	b				t B		t b	mB	
N. kariana var. *detersa* Grunow *in* Cleve et Möller	b		b	b			mb	b	
N. kjellmanii (Cleve *in* Cleve et Grunow) Cleve	b	b	b	b	B	b	mB	tmB	mb
N. lineola Grunow								mb	
N. lyra var. *atlantica* Schmidt								b	
N. marina Ralfs *in* Pritchard	b	b	b	b	mb		mb	tmB	b
N. novadecipiens Hustedt	b		b	b	b		mb	tmb	
N. obtusa (Cleve *in* Cleve et Möller) Cleve				b			t b	b	

N. oestrupi Cleve	b			B	t b		t b	mb	
N. pellucida Karsten								b	
N. perlucens Östrup					b				
N. pygmaea Kützing							m		
N. quadripedis Cleve-Euler	B	B	B	B	tmB		tmB	B	B
N. recurvata Gran	b	b	b	b	t b		tmB	tmB	
N. salinarum Grunow *in* Cleve et Möller							t		
N. siberica (Grunow *in* Cleve et Möller) Cleve	b	b	b	B			b	b	
N. solitaria Cleve					b		b	b	
N. spicula (Hickie) Cleve					b		mb		
N. stuxbergii var. *subglabra* Östrup					mb		b	m	
N. subinflata Grunow *in* Cleve et Möller	b				tm		tm	mb	
N. superba Cleve	B	b	B	b	b		tmB	b	
N. superba var. *crassa* (Östrup) Gran	b			b	t		mB	mb	
N. superba var. *elliptica* Cleve							b	b	
N. superba var. *subacuta* Gran	b		B	B			B	B	m
N. transfuga Grunow *in* Cleve								t	
N. transfuga var. *plagiostoma* (Grunow *in* Cleve et Möller) Cleve								b	
N. transfuga var. *septentrionalis* Östrup							b	b	
N. transitans Cleve	B	B	b	b	tmb		tmB	mB	b
N. transitans var. *derasa* (Grunow *in* Cleve et Grunow) Cleve	b	b	b	b	b		tmb	mb	
N. transitans var. *erosa* (Cleve) Cleve	b	b	b	b	b		t B	b	
N. transitans var. *incudiformis* (Grunow *in* Cleve) Cleve	B	b	b	b	b		tmb	mb	
N. trigonocephala Cleve	B	b	b	b	t		t B	tmB	
N. trigonocephala var. *contracta* Östrup							mb	b	
N. trigonocephala var. *depressa* Östrup	b	b	b	b	b		tmb	mb	
N. valida Cleve et Grunow	b	b	b	b	tmb	b	tmB	mb	
N. valida var. *minuta* Cleve	b	b	b	b	b		tmB	tmB	
Nitzschia acicularis (Kützing) Wm. Smith							tm	tmB	
N. acuminata (Wm. Smith) Grunow					b				
N. angularis Wm. Smith	B	B						m	
N. angulata Hasle	b								
N. brebissonii var. *borealis* Grunow *in* Cleve et Möller	b						tmB	mB	
N. curta (Van Heurck) Hasle	t								
N. cylindrus (Grunow) Hasle	t B	B	B	B	tmB	b	tmB	TMB	tmB
N. delicatissima Cleve	b								
N. diaphana Cleve					tmB		tmB	mB	

Sea ice microalgae		Eclipse Sound Station			Eskimo Lakes Station		Frobisher Bay Station		
	1	2	3	4	508	515	5	5B	1
N. distans var. *erratica* Cleve	B	B	B	b	b		mB	mB	B
N. frigida Grunow *in* Cleve et Grunow	B			B	mB		mB	mB	B
N. gelida Cleve et Grunow in Cleve et Möller	t				mB		mB	mB	B
N. gruendleri Grunow *in* Cleve	B	b	B	B	mB		tmB	mB	
N. grunowii Hasle	b	b	b	b				B	B
N. hybrida Grunow *in* Cleve et Grunow	B	B	B	B	tmB	b	tMB	tmB	m
N. laevissima Grunow *in* Cleve et Möller	B	b	B	B	tmB		tmB	tmB	mB
N. lanceolata var. *pygmaea* Cleve	B								
N. lecointei Van Heurck	b	b	b	b	b	b	mb	mb	tm
N. linearis (Agardh) Wm. Smith	b				B		B	B	B
N. lineata Hasle	B	b	b	b					
N. longissima (Brébisson *in* Kützing) Grunow	b							tmB	
N. marginulata Grunow *in* Cleve et Möller		b							
N. obliquecostata (Van Heurck) Hasle			b						
N. polaris Grunow *in* Cleve et Möller	B	B	B	B	tmB	B	tmB	tmB	tmB
N. seriata Cleve	tmB		B	B	tb		tmB	mB	
N. tergestina (Kützing) Ralfs *in* Pritchard	b			B	B		mB		
Pinnularia ambigua Cleve	b	b	b	b	b		b	b	
P. quadratarea (Schmidt) Cleve					b		tm	mb	
P. quadratarea var. *bicontracta* (Östrup) Heiden *in* Schmidt et al	b	b	b	b	tmB	B	tmB	mB	b
P. quadratarea var. *bicuneata* Heiden et Kolbe	b				m		tmB	mb	
P. quadratarea var. *constricta* (Östrup) Heiden *in* Schmidt et al	b	b	b	b	tmB	B	tmB	tmB	
P. quadratarea var. *cuneata* (Östrup) *in* Schmidt et al								m	
P. quadratarea var. *densestriata* Cleve					b	b	b		
P. quadratarea var. *leptostauron* Cleve	b				b		tmb	mb	
P. quadratarea var. *maxima* (Östrup) Boyer		b			b		b	b	
P. quadratarea var. *minima* (Östrup) Boyer	b	b	b	b	b	b	b	mb	
P. quadratarea var. *stuxbergii* (Cleve *in* Cleve et Grunow) Cleve	b	B	b	B	t B	b	tmB	tmb	mb
P. quadratarea var. *subconstricta* (Östrup) Heiden *in* Schmidt et al					b		m	m	
P. quadratarea var. *subcontinua* (Cleve) Cleve					b	b	b	mb	
Plagiogramma staurophorum (Gregory) Heiberg							t b	b	

Pleurosigma angulatum (Quekett) Wm. Smith	b	B	b	B					
P. antarcticum Heiden et Kolbe	b				b		tmB	mB	
P. clevei Grunow *in* Cleve et Grunow	b	b	b	B	B	b	mB	tmB	m
P. cuspidatum (Cleve) H. Peragallo		b	b				mb	B	
P. elongatum var. *karianum* (Grunow *in* Cleve et Grunow) Cleve	b			b			B	t b	
P. longum Cleve		b		B					
P. marinum Donkin		b							
P. stuxbergii Cleve et Grunow	b	b	b	B	mB		tmB	t B	mB
P. stuxbergii var. *minor* Grunow		B	b	b	mb		tmB	tmB	
P. stuxbergii var. *rhomboides* (Cleve *in* Cleve et Grunow) H. Peragallo			b						
Rhabdonema arcuatum (Lyngbye) Kützing							b	t b	
R. minutum Kützing							t b	B	
Stenoneis inconspicua var. *baculus* (Cleve *in* Cleve et Möller) Cleve			b	b	mb		tmB	mb	B
Surirella japonica A. Schmidt *in* Schmidt et al					b				
S. oestrupi Gran					t				
Synedra camtschatica var. *finnamarchica* Cleve et Grunow								b	
S. hyperborea Grunow							t		
S. hyperborea var. *rostellata* Grunow								t	
S. pulchella (Ralfs) Kützing								b	
S. tabulata (Agardh) Kützing	B				tmb		t b	t B	
S. tabulata var. *fasciculata* (Kützing) Hustedt							t	tmb	
S. tabulata var. *obtusa* (Pantocsek) Hustedt					t				
Tabellaria fenestrata (Lyngbye) Kützing	b								
T. flocculosa (Roth) Kützling								b	
Trachyneis aspera (Ehrenberg) Cleve		b	b	b				t b	
Tropidoneis maxima (Gregory) Cleve					mb		tmB	tmB	
T. maxima var. *dubia* (Cleve et Grunow) Cleve	b	b	b	b				b	
Dinoflagellates									
Goniaulax catenata Kofoid					tmB	b			
Gymnodinium Stein					b				
Peridinium Ehrenberg	b	b			b		B	b	
Prorocentrum ovalis Rampi				b			b	t b	
Flagellates									
Chlamydomonas ballenyana Kol et Flint				b					

Sea ice microalgae	Eclipse Sound Station				Eskimo Lakes Station		Frobisher Bay Station		
	1	2	3	4	508	515	5	5B	1
Euglena geniculata Dujardin	B								
E. proxima Dangeard							B		
Unidentified green flagellates					tmB	B	tmB	tmB	B
Chrysophytes									
Chloridella glacialis Kol	B								
Phaeocystis pouchetii (Hariot) Lagerheim							T	TM	

[1] T, t, M, m, B and b indicate the top, middle and bottom of the sea ice. Capital letters indicate dominant species (more than 100,000 cells per litre), while lower case letters simply show presence in particular layers. Estimated cell numbers, dates of collections and portions of ice core sampled are given in detail in Hsiao (1979a, b, c).

la cluthensis, N. salinarum, N. transfuga, Synedra hyperborea and *S. hyperborea* var. *rostella*) occurred only at the top of the sea ice. Notably there were 17 species (*Chaetoceros septentrionalis, Amphiprora kjellmanii* var. *striolata, Cylindrotheca closterium, Diploneis litoralis* var. *arctica, Gomphonema exiguum* var. *pachycladum, Navicula crassirostris, N. directa, N. quadripedis, N. transitans, N. valida, Nitzschia cylindrus, N. diaphana, N. hybrida, N. laevissima, N. polaris, Pinnularia quadratarea* var. *bicontracta* and *P. quadratarea* var. *constricta*) scattered throughout the entire thickness of the sea ice both in the Eskimo Lakes and in Frobisher Bay, while only four species (*Achnanthes minutissima, Navicula pygmaea, Pinnularia quadratarea* var. *cuneata* and *Coscinodiscus polyacanthus*) inhabited exclusively the middle of the sea ice. The species composition and distribution of microalgae in the Canadian arctic sea ice are presented in detail in Hsaio (1979a, b, c).

The vertical distribution of dominant species of microalgae in the Eskimo Lakes, Eclipse Sound and Frobisher Bay is listed in Table 1. Highest counts of diatoms were found at the top of the ice at station 5B in Frobisher Bay in late May, with the greatest number of *Nitzschia cylindrus* the dominant species, occurring as 1.45 × 10^5 cells/L. In the middle of the ice at station 5 in Frobisher Bay in late May *Nitzschia hybrida* was dominant, as 1.45 × 10^5 cells/L. In the bottom of the ice at station 4 in Eclipse Sound in late May, *Nitzschia frigida* was dominant, comprising 193.07 × 10^5 cells/L. The most abundant flagellate found was an unidentified green flagellate with 1.45 × 10^4 cells/L in the top of the ice in early February and 6.16 × 10^4 cells/L in the middle of the ice at station 5B in Frobisher Bay in late May, and with 5.44 × 10^5 cells/L from the bottom of the ice at station 5 in Frobisher Bay in mid-May. Among euglenoid flagellates, the most abundant was *Euglena proxima,* with 2.18 × 10^5 cells/L, encountered only in the bottom of the ice at station 5 in Frobisher Bay in mid-and late-May. *Phaeocystis pouchetii,* with 2.03 × 10^5 cells/L in the top of the ice and with 3.52 × 10^5 cells/L in the middle of the ice occurred at station 5B in Frobisher Bay in late May, but not in the bottom of the ice. *Chloridella glacialis,* with 29.73 × 10^5 cells/L, was obtained only from the bottom of the ice at station 1 in Eclipse Sound in mid-May, and showed there the highest counts of chrysophytes found. *Goniaulax catenata,* in quantities of 3.3 × 10^3, 7.3 × 10^3 and 1120 × 10^3 cells/L was found, respectively, in the top, middle and bottom of the ice at station 508 in the Eskimo Lakes in late May. It was the most abundant dinoflagellate.

Community Structure

The ice flora of the Eskimo Lakes was dominated by the diatom community in all but three samples out of 34, followed by dinoflagellates and flagellates. No chrysophytes were found in this region (Table 2). The largest numbers of species and cells of diatoms were found in the bottom of the sea ice,while the dinoflagellates and flagellates were rare and scattered through the entire thickness of the ice. Diatoms comprised more than 95.1% of the microalgae in the sea ice of Eclipse Sound (Table 3). A small number of species and cells of dinoflagellates and chrysophytes occasionally formed communities at the bottom of the sea ice. Ice diatoms appeared to be the largest community in the ice flora of Frobisher

Table 2. Standing stock and community structure of sea ice microalgae in the Eskimo Lakes

Station No.	Date	Sea ice thickness (cm)	Ice section from top to bottom (cm)	Chl. a (mg/m^3)	Total sea ice microalgae (cells/litre)	Diatoms		Flagellates		Dinoflagellates	
						%*	No.**	%*	No.**	%*	No.**
508	17 Mar 72	157	0-10	trace	373,492	35.0(†C11.7 §P23.3)	16(†C1 §P15)	0	0	65.0	spp.
			147-157	3.14	3,952,558	74.3(C11.0 P63.3)	41(C2 P39)	0	0	25.7	1 + spp.
	18 May 72	191	0-10	trace	58,017	43.8(C12.5 P31.3)	2(C0 P2)	0	0	56.2	spp.
			35-45	2.49	119,662	57.6(C 6.1 P51.5)	9(C1 P8)	0	0	42.4	spp.
			70-80	3.30	250,200	82.6(C 4.4 P78.2)	9(C0 P9)	0	0	17.4	spp.
			105-115	2.27	340,856	93.6(C 0 P93.6)	11(C0 P11)	0	0	6.4	spp.
			140-150	1.71	319,101	95.4(C 3.4 P92.0)	16(C1 P15)	0	0	4.6	spp.
			181-191	5.95	41,157,370	94.9(C 4.8 P90.1)	45(C3 P42)	0.6	spp.	4.5	1 + spp.
	24 Nov 72	50	0-10	trace	39,887	72.7(C 9.1 P63.6)	2(C0 P2)	0	0	27.3	spp.
			40-50	1.18	485,906	97.0(C 1.5 P95.5)	16(C1 P15)	0	0	3.0	spp.
	23 Feb 73	141	0-10	0.23	58,015	75.0(C12.5 P62.5)	8(C1 P7)	6.3	spp.	18.7	spp.
			35-45	0.60	108,784	36.7(C 3.3 P33.4)	5(C0 P5)	0	0	63.3	spp.
			70-80	0.36	108,784	60.0(C 6.7 P53.3)	11(C1 P10)	6.7	spp.	33.3	spp.
			105-115	0.65	170,427	89.4(C 6.4 P83.0)	15(C1 P14)	2.1	spp.	8.5	spp.
			131-141	0.84	333,604	79.3(C25.0 P54.3)	17(C3 P14)	2.2	spp.	18.5	1 + spp.
508	19 May 73	169	0-10	0.50	616,442	96.5(C24.7 P71.8)	32(C4 P28)	0	0	3.5	spp.
			35-45	0.32	268,333	94.6(C 5.4 P89.2)	18(C2 P16)	0	0	5.4	spp.
			70-80	1.24	504,035	95.7(C 0.7 P95.0)	26(C1 P25)	0.7	spp.	3.60	spp.
			105-115	1.28	504,031	90.6(C 4.3 P86.3)	28(C2 P26)	0	0	9.4	spp.
			159-169	57.02	35,174,140	99.2(C 4.3 P94.9)	61(C2 P59)	0	0	0.8	spp.
	2 Mar 74	143	0-10	0.11	130,539	91.7(C19.4 P72.3)	10(C0 P10)	0	0	8.3	spp.
			35-45	0.47	130,540	77.8(C 0 P77.8)	9(C0 P9)	0	0	22.2	spp.
			70-80	0.23	116,035	87.5(C 0 P87.5)	9(C0 P9)	0	0	12.5	spp.
			105-115	0.44	181,306	90.0(C 2.0 P88.0)	8(C0 P8)	0	0	10.0	spp.
			133-143	0.45	217,566	90.0(C 6.7 P83.3)	16(C3 P13)	0	0	10.0	spp.
	24 May 74	203	0-35	0.38	112,408	64.5(C12.9 P51.6)	8(C1 P7)	12.9	spp.	22.6	1 + spp.
			35-70	0.10	145,044	72.5(C 5.0 P67.5)	9(C1 P8)	7.5	spp.	20.0	1 + spp.
			70-105	trace	232,073	62.5(C 4.7 P57.8)	7(C2 P5)	17.2	spp.	20.3	1 + spp.
508			105-140	trace	203,064	67.9(C 3.6 P64.3)	7(C1 P6)	0	0	32.1	spp.
			140-175	0.05	250,203	85.5(C15.9 †P69.6)	39(C2 P37)	1.5	spp.	13.0	spp.
			175-193	0.24	591,060	93.3(C 8.0 P85.3)	29(C2 P27)	0.6	spp.	6.1	1 + spp.
			193-203	22.28	29,491,884	95.7(C 6.2 P89.5)	33(C3 P30)	1.8	spp.	2.5	1 + spp.
515	1 Mar 74	144	139-144	0.23	112,408	87.1(C22.6 P64.5)	14(C2 P12)	0	0	12.9	1 + spp.
	25 May 74	186	181-186		29,154,648	97.6(C 2.7 P94.9)	15(C1 P14)	1.0	spp.	1.4	1 + spp.

* Percentage of total sea ice microalgae

** Number of species

† C = Centric diatoms

§ P = Pennate diatoms

Table 3. Standing stock and community structure of sea ice microalgae in Eclipse Sound

Station No.	Date	Sea ice thickness (cm)	Ice section from top to bottom (cm)	Total sea ice microalgae (cells/litre)	Diatoms		Flagellates		Chrysophytes		Dinoflagellates	
					%*	No.**	%*	No.**	%*	No.**	%*	No.**
1	15 May 76	182	181-182	62,736,113	95.1(†C11.6 §P 83.5)	72(†C7 §P65)	0.2	1	4.7	1	0	0
	20 May 76	196	195-196	91,664,798	100.0(C 4.0 P 96.0)	57(C4 P53)	0	0	0	0	0	0
	27 May 76	193	192-193	110,700,616	99.9(C 1.9 P 98.0)	52(C4 P48)	0	0	0	0	<0.1	spp.
	21 Mar 77	124	0-1	28,000	100.0(C57.1 P 42.9)	6(C1 P5)	0	0	0	0	0	0
			61-62	4,000	100.0(C 0 P100.0)	1(C0 P1)	0	0	0	0	0	0
			123-124	29,000	100.0(C 0 P100.0)	10(C1 P9)	0	0	0	0	0	0
2	17 May 76	193	192-193	25,808,366	99.8(C13.5 P86.3)	56(C3 P53)	0	0	0	0	0.2	spp.
	18 May 76	193	192-193	2,349,764	100.0(C 3.3 P96.7)	56(C3 P53)	0	0	0	0	0	0
	24 May 76	192	191-192	11,631,363	100.0(C 3.4 P96.6)	56(C2 P54)	0	0	0	0	0	0
3	18 May 76	—	bottom 1 cm	62,491,490	100.0(C 1.8 P98.2)	69(C3 P66)	0	0	0	0	0	0
4	18 May 76	216	215-216	127,319,753	100.0(C 1.8 P98.2)	64(C2 P62)	0	0	0	0	0	0
	25 May 76	217	216-217	160,229,950	99.9(C 1.3 P98.6)	65(C3 P62)	0	0	0	0	<0.1	spp.

* Percentage of total sea ice microalgae
** Number of species
† C = Centric diatoms
§ P = Pennate diatoms

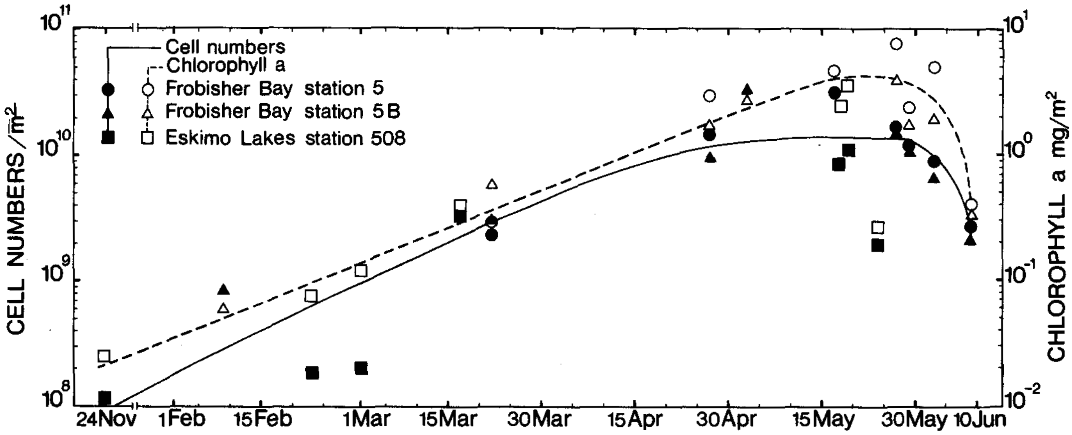

FIG. 2. Standing stock of sea ice microalgae in the Canadian Arctic.

Bay except for one sample (out of 54) dominated by chrysophytes (Table 4). Dinoflagellates frequently occurred with small numbers of species and cells. Flagellates formed the smallest community.

Generally, the ice flora of the Canadian Arctic consisted mainly of diatoms which were largely composed of pennate forms. Dinoflagellates, flagellates and chrysophytes were fewer in numbers of species and cells.

Standing Stock

The standing stock results, as measured by both chlorophyll *a* and cell counts, are presented in Tables 2-5 and Figure 2. The cell numbers in Canadian arctic sea ice varied from 3.99×10^4 cells/L in the top of the ice in late November to 4.12×10^7 cells/L in the bottom of the ice in mid-May at station 508 in the Eskimo Lakes; from 4.0×10^3 cells/L in the middle of the ice in late March at station 1 to 1.6×10^8 cells/L in the bottom of the ice in late May at station 4 in the Eclipse Sound; and from 5.8×10^4 cells/L in the top of the ice at station 5B in late April to 7.2×10^7 cells/L in the bottom of the ice in early May at station 1 in Frobisher Bay. Chlorophyll *a* ranged from a trace amount (undetected by spectrophotometer) in the top of the ice in late November to 57.02 mg/m³ in the bottom of the ice in mid-May at station 508 in the Eskimo Lakes, and from 0.19 mg/m³ in the top of the ice at station 1 in early May to 300.55 mg/m³ in the bottom of the ice in late May at station 5 in Frobisher Bay. The greatest numbers of cells and concentrations of chlorophyll *a* were found near the bottom of the sea ice.

Integrated standing stock, in terms of cell numbers and chlorophyll *a* per m² over the whole ice column, showed that the standing stock started to build up from the time the ice formed in late fall. From initial values of 1.05×10^8 cells/m² with chlorophyll *a* 0.023 mg/m², there was a slow but steady increase through the winter months, followed by a dramatic increase in early spring. Maximum levels of 3.42×10^{10} cells/m², with a chlorophyll *a* value 7.58 mg/m² were reached in late spring, and thereafter declined rapidly as ice melting occurred in early summer (Fig. 2).

Table 4. Standing stock and community structure of sea ice microalgae in Frobisher Bay

Station No.	Date	Sea ice thickness (cm)	Ice section from top to bottom (cm)	Chl. a (mg/m^3)	Total sea ice microalgae (cells/litre)	Diatoms		Flagellates		Chrysophytes		Dinoflagellates	
						%*	No.**	%*	No.**	%*	No.**	%*	No.**
5	27 Apr 71	158	0-10	1.11	141,418	74.4(†C33.4 §P41.0)	16(†C4 §P12)	0	0	0	0	25.6	spp.
			35-45	2.51	203,064	80.4(C 5.4 P75.0)	21(C4 P17)	0	0	0	0	19.6	spp.
			70-80	0.85	369,862	97.1(C 2.0 P95.1)	33(C2 P31)	0	0	0	0	2.9	spp.
			105-115	1.93	525,790	95.2(C 8.3 P86.9)	45(C4 P41)	0	0	0	0	4.8	spp.
			148-158	252.76	65,452,910	98.7(C 6.3 P92.4)	76(C5 P71)	0.5	1 + spp.	0	0	0.8	spp.
	27 May 71	160	0-8	1.09	638,205	97.7(C13.6 P84.1)	17(C2 P15)	0.6	spp.	0	0	1.7	spp.
			37-45	0.31	431,510	90.8(C 8.4 P82.4)	20(C1 P19)	2.5	spp.	0	0	6.7	spp.
			72-80	0.66	848,521	97.9(C 9.8 P88.1)	32(C3 P29)	0	0	0	0	2.1	spp.
			107-115	0.19	1,127,732	98.4(C 9.3 P89.1)	61(C4 P57)	0	0	0	0	1.6	spp.
			152-160	300.55	68,172,560	98.8(C 8.2 P90.6)	62(C3 P59)	0.5	spp.	0	0	0.7	spp.
	3 June 71	159	151-159	189.72	51,238,206	97.9(C 7.2 P90.7)	64(C4 P60)	1.1	spp.	0	0	1.0	spp.
	9 June 71	158	150-158	68.31	41,810,086	99.6(C 4.9 P94.7)	55(C4 P51)	0	0	0	0	0.4	spp.
	17 May 72	191	0-10	—	275,588	22.4(C 1.3 P21.1)	24(C3 P21)	0	0	50.0	1	27.6	spp.
			181-191	—	35,137,878	97.0(C 6.1 P90.9)	65(C2 P63)	2.2	1	0	0	0.8	spp.
	22 Mar 73	168	0-10	0.33	587,434	92.6(C28.4 P64.2)	37(C7 P30)	0	0	0	0	7.4	spp.
			35-45	0.21	431,507	92.5(C 5.1 P87.4)	36(C2 P34)	0.8	spp.	0	0	6.7	spp.
			70-80	0.33	551,168	89.5(C 8.6 P80.9)	49(C4 P45)	0	0	0	0	10.5	spp.
			105-115	0.34	645,447	89.3(C 7.3 P82.0)	47(C4 P43)	0	0	0	0	10.7	spp.
			140-150	1.98	1,486,720	97.3(C 3.2 P94.1)	57(C2 P55)	0.5	spp.	0	0	2.2	spp.
			158-168	52.15	14,113,127	97.9(C 2.6 P95.3)	68(C3 P65)	0	0	0	0	2.1	1 + spp.
	29 May 73	195	0-8	1.23	844,888	84.6(C 9.9 P74.7)	39(C4 P35)	0	0	3.9	1	11.5	spp.
			36-44	0.71	1,047,957	87.9(C10.4 P77.5)	43(C4 P39)	2.8	spp.	2.4	1	6.9	spp.
			106-114	0.62	1,664,399	89.1(C 3.7 P85.4)	59(C4 P55)	0.9	spp.	6.1	1	3.9	spp.
			141-149	1.10	1,653,528	82.2(C 4.4 P77.8)	53(C3 P50)	0.5	spp.	15.8	1	1.5	spp.
			187-195	95.63	43,079,256	98.4(C 7.7 P90.7)	80(C4 P76)	0.5	spp.	0	0	1.1	spp.
5B	27 Apr 71	163	0-10	9.29	221,194	98.4(C13.1 P85.3)	18(C3 P15)	0	0	0	0	1.6	spp.
			35-35	3.95	58,016	62.5(C31.2 P31.3)	13(C2 P11)	12.5	spp.	0	0	25.0	spp.
			70-80	0.61	348,111	94.8(C 2.1 P92.7)	35(C4 P31)	0	0	0	0	5.2	spp.
			105-115	2.35	525,791	89.6(C 7.6 P82.0)	46(C3 P43)	0	0	3.5	1	6.9	spp.
			153-163	94.32	38,205,643	99.6(C10.3 P89.3)	79(C4 P75)	0.2	spp.	0	0	0.2	spp.
	27 May 71	166	0-8	2.53	957,309	99.2(C 8.3 P90.9)	27(C2 P25)	0	0	0	0	0.8	spp.
			37-45	0.82	627,326	94.2(C12.1 P82.1)	22(C3 P19)	0.6	spp.	0	0	5.2	spp.
			72-80	0.68	902,913	98.8(C12.5 P86.3)	36(C2 P34)	0	0	0	0	1.2	spp.
			107-115	0.96	1,493,978	99.3(C13.8 P85.5)	54(C5 P49)	0	0	0	0	0.7	spp.
			158-166	133.77	54,429,262	98.0(C 3.3 P94.7)	61(C1 P60)	1.2	spp.	0	0	0.8	spp.
	3 June 71	160	152-160	54.3	16,027,804	97.3(C 5.0 P92.3)	49(C2 P47)	2.7	spp.	0	0	0	0
	9 June 71	158	150-158	14.73	12,075,246	96.7(C 4.8 P91.9)	51(C2 P49)	0.9	spp.	0	0	2.4	spp.

Station No.	Date	Sea ice thickness (cm)	Ice section from top to bottom (cm)	Chl. a (mg/m^3)	Total sea ice microalgae (cells/litre)	Diatoms		Flagellates		Chrysophytes		Dinoflagellates	
						%*	No.**	%*	No.**	%*	No.**	%*	No.**
	9 Feb 72	145	0-8	—	68,895	42.1(C31.6 P10.5)	2(C1 P1)	21.1	spp.	0	0	36.8	spp.
			137-145	—	1,174,876	94.2(C12.0 P82.2)	29(C3 P26)	1.5	spp.	0	0	4.3	spp.
	22 Mar 73	181	0-10	0.48	496,784	73.0(C16.8 P56.2)	16(C3 P13)	0	0	0	0	27.0	spp.
			35-45	0.19	663,586	82.0(C16.9 P65.1)	15(C1 P14)	0	0	0.5	1	17.5	spp.
			70-80	0.53	757,862	87.6(C18.7 P68.9)	40(C5 P35)	0	0	0	0	12.4	spp.
			105-115	0.70	797,750	90.9(C25.0 P65.9)	51(C6 P45)	0	0	0	0	9.1	spp.
			140-150	0.48	924,662	95.7(C12.9 P82.8)	51(C7 P44)	0	0	0	0	4.3	spp.
			171-181	12.19	12,249,270	97.0(C 7.2 P89.8)	67(C2 P65)	0	0	0	0	3.0	1 + spp.
	29 May 73	200	0-8	1.62	576,558	50.3(C12.0 P38.3)	23(C6 P17)	0.6	spp.	35.3	1	13.8	1 + spp.
			36-44	1.25	823,137	91.2(C34.8 P56.4)	35(C7 P28)	0	0	1.3	1	7.5	1 + spp.
			106-114	1.79	1,519,359	67.3(C10.0 P57.3)	60(C7 P53)	4.1	spp.	23.1	1	5.5	spp.
			141-149	1.63	1,171,247	96.0(C12.1 P83.9)	47(C5 P42)	0	0	0	0	4.0	1 + spp.
			192-200	56.15	37,531,170	99.0(C 7.7 P91.3)	74(C3 P71)	0	0	0	0	1.0	spp.
	23 Mar 77	180	175-180	-	7,397,448	96.0(C 6.4 P89.6)	57(C5 P52)	2.0	spp.	0	0	2.0	spp.
1	3 May 78	185	0-5	0.19	576,556	95.0(C39.0 P56.0)	10(C1 P9)	0	0	0	0	5.0	spp.
			90-95	1.06	765,119	97.2(C 4.8 P92.4)	19(C1 P18)	0	0	0	0	2.8	spp.
			180-185	108.40	72,270,116	98.9(C 2.1 P96.8)	24(C0 P24)	0.8	spp.	0	0	0.3	spp.

* Percentage of total sea ice microalgae

** Number of species

† C = Centric diatoms

§ P = Pennate diatoms

The standing stock of sea ice microalgae in the Eskimo Lakes, Eclipse Sound and Frobisher Bay was almost always dominated by species of pennate diatoms and had cell numbers greater than 1 million per litre (Hsiao 1979a, b, c). *Navicula quadripedis, Nitzschia cylindrus, N. polaris* and *N. frigida* were commonly found in these 3 regions. Other dominant species in both Eclipse Sound and Frobisher Bay were *Amphiprora kjellmanii* var. *striolata, Amphora laevis* var. *laevissima, Gomphonema exiguum* var. *pachycladum, Nitzschia hybrida* and *N. seriata.* Other abundant species occurring only in Eclipse Sound included *Amphiprora kryophila, Bacillaria paradoxa, Navicula granii, Nitzschia angularis, N. laevissima, N. tergestina* and *N. lineata.* Species occurring only in Frobisher Bay were *Achnanthes taeniata, Navicula transitans, Cylindrotheca closterium, Nitzschia distans* var. *erratica, N. grunowii* and *Rhabdonema minutum.*

DISCUSSION

There were 196 species of microalgae found in the Canadian arctic sea ice with 189 species of diatoms making up the greatest cell abundance, and fewer species and a lesser abundance of flagellates, dinoflagellates and chrysophytes. Usachev (1949) listed 142 species of diatoms but few dinoflagellates, flagellates or green algae from the ice in the Kara and Laptev seas. He designated 24 (three centric and 21 pennate) diatom species as typical cryophiles. All these typical cryophiles except *Fragilaria islandica* were also found in the Canadian arctic sea ice. Meguro *et al.* (1966; 1967) found 24 species of pennate diatoms, but no other algae, in the bottom of arctic sea ice off the Point Barrow area, Alaska. Nineteen of them, except *Gomphonema exiguum* var. *arctica, Navicula gracilis* var. *inaequalis, Nitzschia lavuensis, Pinnularia quadratarea* var. *capitata* and *Stenoneis inconspicua,* also commonly occurred in the sea ice of the Canadian Arctic. The pennate diatoms *Nitzschia frigida* and *Navicula marina* were the most abundant species in the ice microalgal community in the Chukchi Sea at Barrow (Horner and Alexander, 1972; Clasby *et al.,* 1976), but were not found in areas farther from shore (Meguro *et al.,* 1966; 1967). These species were commonly dominant in this study. Other dominant species of diatoms are listed in Table 1 which includes all the species found by Horner and Alexander (1972).

In most samples (101 out of 105), the diatom community overwhelmingly exceeded the dinoflagellates, flagellates and chrysophytes. On only three occasions did the dinoflagellates exceed more than 50% of the total microalgal population in the top of the ice at station 508 in the Eskimo Lakes. In only one case did the chrysophytes exceed 50% of the populations in the top of the ice at station 5 in Frobisher Bay. Diatoms consisted largely of pennate forms in all three areas studied in the Canadian arctic sea ice, while centric forms formed only a small percentage of the total population except for two (out of 105) samples. In these, centric forms were 14.2% and 21.1% more numerous than pennates in the top of the ice at stations 5B and 1 in Frobisher Bay and in Eclipse Sound, respectively. Allen (1971) stated that small pennate diatoms principally represented the ice community at high latitudes. Horner and Alexander (1972) found only pennate diatoms occurring in Chukchi sea ice. Later, Horner (1976) observed several species of *Chaetoceros* and *Thalassiosira,* centric diatoms, occurring in an ice microalgal community dominated by pennate diatoms and small flagellates, in the sea ice at Barrow. Grant and Horner (1976) collected *Coscinodiscus lacustris* from ice in the nearshore Beaufort Sea. Of the diatoms identified in the sea ice samples from the Eskimo Lakes, Eclipse Sound and Frobisher Bay, the order of importance of the genera of pennate diatoms, in terms of standing stock, were *Navicula, Nitzschia* and *Pinnularia*. Centric diatom genera of lesser importance included *Chaetoceros* and *Thalassiosira*. Next to the diatoms in abundance and importance were the dinoflagellates represented by *Goniaulax catenata,* the flagellates by *Euglena proxima* and unidentified green flagellates, and the chrysophytes by *Chloridella glacialis* and *Phaeocystis pouchetii*. Species other than diatoms were not found commonly at Barrow (Horner and Alexander, 1972). In the Antarctic, most of the sea ice microalage were diatoms (Bunt and Wood, 1963; Buinitsky, 1968).

The sea ice microalgal communities developed from late fall at the time of the ice formation, through the winter, and increased rapidly in spring until the ice disappeared. The melting fast ice promoted the growth of microalgae by increasing available light, nutrients and low-salinity water (McRoy and Goering, 1974; Grainger, 1977; Tsurikov and Vedernikov, 1979), with maximum standing stock being reached just prior to the thaw period. The dominant species of microalgae in the bottom of the ice differed from those found in the top and middle. The shade-adapted microalgae grew well in a very small amount of light energy reaching to the bottom of the sea ice after being almost completely absorbed by snow cover, sea ice and flora lying above (Tsurikov and Vedernikov, 1979). The growth was inhibited by the higher light intensities in the upper layer as a result of photo-oxidation of photosynthetic algal pigments, particularly as the overlying snow melted (Apollonio, 1961; Bunt, 1964; Burkholder and Mandelli, 1965; Tsurikov and Vedernikov, 1979).

The standing stock of microalgae in the top of the ice increased from 4.0×10^4 cells/L with a trace amount of chlorophyll *a* in late November to 9.6×10^5 cells/L with chlorophyll *a* 2.53 mg/m^3 in late May; in the middle of the ice it increased from 1.09×10^5 cells/L with chlorophyll *a* 0.36 mg/m^3 in late February to 3.41×10^5 cells/L with chlorophyll *a* 2.27 mg/m^3 in mid-May; in the bottom ice it increased from 2.17×10^5 cells/L with chlorophyll *a* 0.45 mg/m^3 in early March to 6.82×10^7 cells/L with chlorophyll *a* 300.55 mg/m^3. Concentrations varied greatly depending upon the time of year, station locations and portions of the ice core sampled. The integrated standing stock found in the sea ice increased in quantity from 1.05×10^8 cells/m^2 with chlorophyll *a* 0.023 mg/m^2 in November to 3.42×10^{10} cells/m^2 with chlorophyll *a* 7.58 mg/m^2 in late May. Such standing stock was comparable to the amount found in the arctic sea ice of Jones Sound, N.W.T. (Apollonio, 1961; 1965), at Point Barrow, Alaska (Meguro *et al.*, 1966; 1967; Alexander *et al.*, 1974), and in the Bering Sea (McRoy and Goering, 1974), and in the Antarctic fast ice (Buinitsky, 1977), but it was at least one to two orders of magnitude greater than that of phytoplankton in the underlying waters (Hsiao, 1979c), and also higher than that of phytoplankton blooms in some productive seas of the northern hemisphere (Bursa, 1961; Thórdardóttir, 1973; Throndsen and Heimdal, 1976; Hsiao *et al.*, 1977; Hsiao and Trucco, 1980). Standing stock, consisting mostly of species of *Navicula* and *Nitzschia*, with *Navicula quadripedis* and *Nitzschia frigida* being the most abundant, was low in late fall through winter, increased in early spring to blooms in late spring or early summer, and then declined as the sea ice melted.

Live microalgae within seasonal shore-fast ice in the study areas lasted eight to nine months a year, starting from newly formed sea ice in late October that thickened through the winter months to about 2 m by early June. Microalgal cells were present in the ice from the time it formed, but they were few in number and scattered through the entire thickness of the ice so that no visible layer of organisms was present. By late March a relatively large population existed in the ice and by late April or May a thin layer was visible on the bottom of the ice. The number of cells increased and the layer developed colored bands ranging from greenish-brown to dark brown, concentrated in approximately the bottom 2 cm.

The bottom ice layer of 1-2 cm was relatively soft, and consisted of a relatively loosely aggregated matrix of large, platelet ice crystals oriented vertically in which many micro- and mega-fissures were encased; within these fissures were brine solutions and air pockets (Pounder, 1965; Meguro *et al.*, 1967). The sea ice in nature is virtually never in an equilibrium state and most of its physical properties depend on the brine content (Pounder, 1965). The brine content varies with time because of both temperature and salinity changes. The ice-air interface (top of the ice) is colder than the bottom of the ice sheet, which is fixed at the freezing point of the seawater. Because of diffusion, the concentration of brine within the cell is uniform and of a salinity to match the mean temperature of the ice surrounding the cell. Hence at the warmer end the brine is too concentrated and will dissolve ice to reduce its concentration. At the colder end more ice freezes to increase the brine concentration, and the net effect is to move the entire cell of brine along the gradient in the direction of higher temperature. In a sea ice cover the brine migration acts in the same direction as brine drainage so that the two effects are additive. Both processes take place slowly during the winter months. Brine drainage is quite rapid when the ice approaches its melting point during the warmer months of spring and summer (Pounder, 1965).

A high nutrient content occurs in the brine pockets and fissures in which the microalgae live and form colonies. The brine is in a quasi-crystalline (ice-like) state and acts as a strong biological stimulant to algal growth (Buinitsky, 1977). Thus the bottom layer was the main area of distribution and had the largest quantity of microalgae. The numbers of microalgae varied from 2.18×10^5 to 1.6×10^8 cells/L. In contrast, the top ice layer was relatively thick, dense, compact and hard because its temperature was colder than the bottom ice resulting in brine cells, cut off from each other and from the sea, that decreased in size to smaller diameters or even migrated downward to the bottom. Salinity and nutrients subsequently declined. The cell numbers ranged between 2.8×10^4 and 9.57×10^5 cells/L, and were ten to a hundred times fewer than the bottom ones.

Table 5. Standing stock and community structure of sea ice microalgae and phytoplankton in the underlying water in Frobisher Bay

Station No.	Date	Sea ice thickness (cm)	Sample type	Chl. a (mg/m^3)	Total cell Nos./litre	Diatoms		Flagellates		Dinoflagellates	
						%*	No.**	%*	No.**	%*	No.**
5B	23 Mar 77	180	Ice core bottom 5cm	—	7,397,448	96.0(†C 6.4 §P89.6)	57(†C5 §P52)	2.0	spp.	2.0	spp.
			Surface water	—	37,109	95.4(C 8.6 P86.8)	7(C2 P5)	0.6	spp.	4.0	spp.
1	3 May 78	185	Ice core top 5cm	0.19	576,556	95.0(C 3.9 P56)	10(C1 P9)	0	0	5.0	spp.
			Ice core middle 5cm	1.06	765,119	97.2(C 4.7 P92.5)	19(C1 P18)	0	0	2.8	spp.
			Ice core bottom 5cm	108.40	72,270,116	98.9(C 2.1 P96.8)	14(C0 P14)	1.4	spp.	0.3	spp.
			Surface water	2.12	1,958,141	100.0(C 0.9 P99.1)	8(C0 P8)	0	0	0	0
			5m	0.32	184,932	98.0(C31.4 P66.6)	4(C0 P4)	2.0	spp.	0	0
			10m	0.29	170,426	93.6(C14.9 P78.7)	4(C0 P4)	0	0	6.4	spp.
			15m	0.42	105,156	100.0(C10.3 P89.7)	3(C0 P3)	0	0	0	0
			20m	0.22	105,156	100.0(C34.5 P65.5)	4(C1 P3)	0	0	0	0
			25m	0.31	76,147	100.0(C19.1 P80.9)	5(C0 P5)	0	0	0	0

* Percentage of total sea ice microalgae
** Number of species
† C = Centric diatoms
§ P = Pennate diatoms

Nutrients were always sufficient to support the growth of microalgae in the ice of the Eskimo Lakes and Frobisher Bay (Grainger, 1975; 1977; 1979). They were also plentiful in ice in other areas of the Arctic (Meguro *et al.*, 1967; Oradovskiy, 1972; Alexander, 1974) and in the Antarctic (Oradovskiy, 1974; Buinitsky, 1977). These nutrients were possibly supplied from desaltation of sea ice, exchange with seawater under the ice, and *in situ* regeneration due to the active microbial populations (Meguro *et al.*, 1967; Alexander *et al.*, 1974). Microalgae entrapped over winter in persistent ice due to freezing of seawater could remain viable for long periods in the dark without an external additional carbon source (Bunt and Lee, 1972). Rodhe (1955) demonstrated that microalgae had the dual ability of auto-and hetero-trophic growth to enable them to survive the extended darkness of winter by assimilating dissolved organic substances or extracellular products synthesized during growth in the previous light period. Recently, Mel'nikov and Pavlov (1978) found that organic carbon concentrations were higher in ice than in water in the Arctic Basin. They supported Rodhe's observation that dissolved and suspended organic carbons in ice seem to play an important role in the survival of microalgae during the polar winter.

The sea ice microalgae grew and spread in the continuously low temperature, variable salinities and a quite remarkable set of light fields, together with spatially and temporally variable and discontinuous physical-chemical conditions. Unfortunately, the temperature of sea ice was not measured in this study. Minimal surface seawater temperatures under the ice in the Eskimo Lakes, Eclipse Sound and Frobisher Bay during winter months were -1.2°C, -1.6°C and -1.7°C, respectively, whereas the air temperatures were between -20°C and -30°C. Most arctic environments have a comparable temperature regime in the winter months. Meguro *et al.* (1967) found that the temperature of the microhabitat in the brine cells within 5 cm of the bottom sea ice was stable at about -1.75°C in ice 2 m thick at Point Barrow, Alaska. They concluded that this microhabitat was neither a closed frozen system to supply nutrients nor a completely inactive biochemical environment owing to the extremely low temperature.

Ice formation and melting affect the salinity and available nutrients (Grainger, 1977). The salinity at the bottom of the ice ranged from 2‰ to 10‰ in Frobisher Bay and Eskimo Lakes. Microalgae were potentially exposed to high ranges of salinities up to 45‰ in the brine cells near the bottom of the sea ice in winter in the Barrow area (Meguro *et al.*, 1967), and to very low salinities as early summer melt water mixed with the surface water producing a range of 0.5‰ to 7‰, averaging about 4‰ in Frobisher Bay (Grainger, 1977). Grant and Horner (1976) reported that arctic ice diatoms were able to grow in a wide range of salinities between 5‰ and 60‰, and tolerate well the brine-cell salinities. Meguro *et al.* (1967) suggested that salinity was probably the most important factor limiting the upper extent of the microalgae in the sea ice. However, with low summer salinities below 5‰ resulting from prolonged periods of melting ice, the pigmentation of Antarctic ice diatoms changed from the normal yellow-brown to pale bluish-green (Whitaker, 1977), and was probably not the major cause of the disappearance of the ice microalgal bloom (Grant and Horner, 1976). Apollonio (1965) found that the loss of the epontic community was more closely related to a marked increase in light intensity within the ice as the overlying snow melted and shade-adapted ice microalgae could not tolerate the higher light intensities.

During the ice period, in late autumn and early spring the sun is low on the horizon and the days are short, while winter months are essentially sunless. From late spring onwards, day length increases and in summer the sun remains overhead 24 hours daily while the sea is still covered with about 2 m of ice and often snow as well. The effect of light on life processes is indeed significant. Sea ice is itself a strongly scattering medium and is definitely not a homogeneous material. It is commonly illuminated by natural sunlight at a very low angle. Moreover, the cloudy conditions which often prevail in the polar regions result in further diffusion and scattering of the available light. Light transmission through *in situ* sea ice is determined not only by its intensity, angle of incidence, surface reflection, snow cover and ice conditions but also by the biological activities of epontic communities. It is a widely held veiw that the photic zone extends to the depth at which illumination has fallen to 1% of its value at the surface. Many of the sea ice microalgae are able to make slow but effective growth at intensities several orders of magnitude lower than this. Their ranges may be extended further still if provided with appropriate organic substrates.

Light intensity under the ice in Frobisher Bay measured by Grainger (1979) was less than 5 ft-c in January and March with the snow cover between 3 and 45 cm, while surface light was about 770 ft-c. In late April and May, with the snow cover about the same as earlier, surface light reached as high as 1300 ft-c and the light under the ice increased to between 5 and 10 ft-c. At this period a colored layer of microalgae appeared at the bottom of the ice. Grainger (1977) also indicated that the maximum ice flora activity probably occurred at between about 10 and 50 ft-c, before loss by melting began. In June the snow cover on the ice disappeared, whereas light beneath the ice rose to between 50 and 75 ft-c. Apollonio (1965) reported that light intensity reaching the bottom of the ice in Jones Sound near Devon Island was less than 20 ft-c at the time of the maximum chlorophyll development, while English (1961) considered the compensation intensity for microalgae recovered from beneath arctic pack ice to lie between 20 and 200 ft-c. Clasby *et al.* (1973) indicated that the minimum light requirement for primary productivity of arctic sea ice microalgae was about 6 ft-c. In the Antarctic, the sea ice microalgae were light saturated at 100 ft-c, photosynthesis inhibited at 1100 ft-c and compensation intensity was about 2.5 to 7 ft-c (Bunt, 1964; 1968). Apparently light is the primary limitation to the development of the epontic community in polar waters. Buinitsky (1968) found that sea ice microalgae absorb radiation passing through the ice and thereby promote the more rapid melting and breakup of the ice. A sudden marked increase in under-ice illumination would damage the epontic community coincident with deterioration in the lower layers of the sea ice.

Sea ice is a very favorable medium for the existence and development of microalgae (Buinitsky, 1977). Under favorable conditions, the microalgae start to grow from where they are trapped. They are distributed in different ways in the ice. Most frequently they form horizontal layers at the bottom of the arctic sea ice. This is possibly due to the fact that the largest brine drainage channels are located near the bottom of the ice and extend downward to the ice-water interface. They also show horizontal migration in these layers (Lake and Lewis, 1970; Eide and Martin, 1975). In the Antarctic sea ice, some microalgal populations form as individual patches which are irregularly distributed throughout the entire ice thickness, and as clearly outlined horizontally elongated "strings", "veins" or "trunks" (Buinitsky, 1968). Sometimes these types of strings, veins and trunks run vertically and/or obliquely riddling the ice from its lower to its upper surface. It is clear that the microalgal distribution and growth in the sea ice are probably determined by the orientation and length of fissures and capillary drainage channels that riddle the ice as well as by available nutrients and light. The movement of microalgae in the ice is closely associated with the mechanism of brine migration.

The peak of the sea ice microalgal bloom takes place about late May or early June just before the sea ice melts and erodes away. In mid-June ice melting then begins and continues until the sea is free of fast ice soon after mid-July. The rapid disappearance of the Microalgal layer is probably caused by a combination of melting ice, which results in low salinity and increased light intensity, and brine drainage along with tidal currents that wash away the soft bottom ice.

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