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PRIMARY PRODUCTION, ILLUMINATION AND HYDROGRAPHY IN JØRGEN BRØNLUND FJORD, NORTH GREENLAND

BY

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WITH 12 FIGURES AND 1 TABLE

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Abstract

The data on temperature, salinity, transparency, ice, illumination and primary production gathered during the Fifth Peary Land Expedition to Jørgen Brønlund Fjord in the summer of 1968 are presented and discussed. The fjord is regarded to be rather unique for the area in being free from ice and open to insolation and wave action in a period during the summer and having a restricted contact across a shallow threshold with neighbouring waters, that are largely ice-bound throughout the year. The result is slightly higher temperatures and lower salinities and most certainly greater primary production. Estimated gross production was on the basis of ^{14}C experiments found to be 4.7 g C/m^2/year. Control experiments performed in Disko Fjord, West Greenland indicate that the technique of using a Secchi disc to set the experimental depths yielded results far too low owing to the occurrence of a shallow layer of turbid surface water during most of the summer. Accordingly a yearly production of 7.4–13.7 g/m^2 in Jørgen Brønlund Fjord is rather to be expected.

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BIANCO LUNOS BOGTRYKKERI A/S

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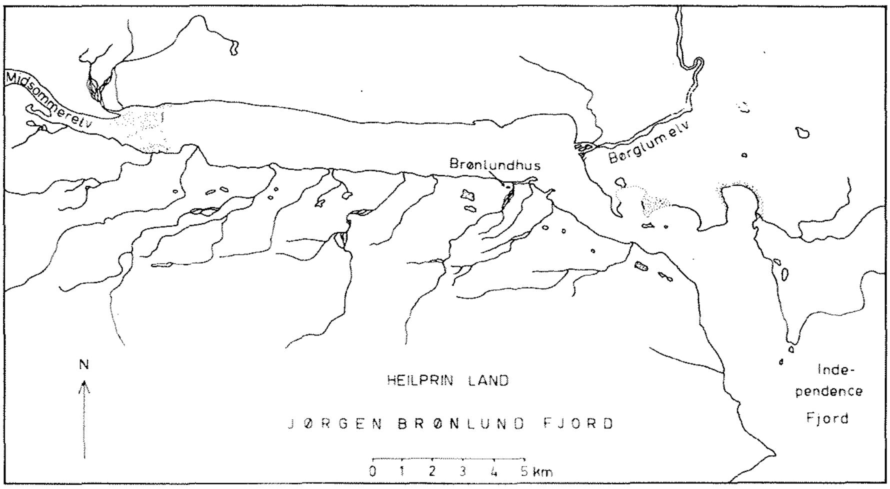

Fig. 1. Map of Jørgen Brønlund Fjord. Redrawn from HØY (1970).

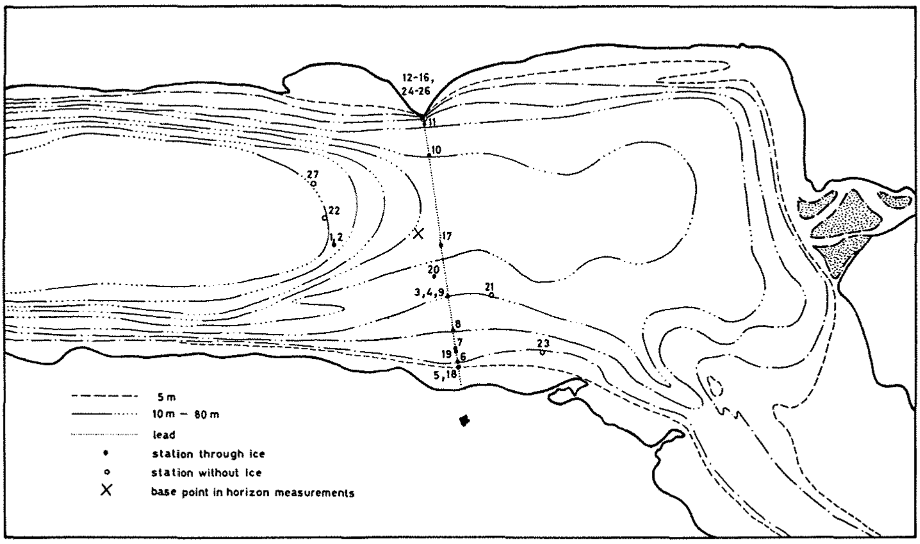

Fig. 2. Map showing the location of all stations.. Redrawn from Høy (1970).

Introduction

During the 5. Peary Land Expedition to Jørgen Brønlund Fjord in the summer of 1968, the author had the opportunity, largely on his own and under rather primitive conditions to carry out marine biological investigations in the fjord between May 30. and August 12. The main objective was to study the primary production in the plankton and the meroplankton and in connection here with the hydrography, of which the first and last will be dealt with here along with a discussion on the effect of ice, turbidity and the low elevation of the sun on the subsurface illumination of the fjord. On working up the material, certain problems concerning the primary production arose and these were sought clarified during a stay at Arctic Station on Disko, West Greenland in 1973–75.

Jørgen Brønlund Fjord (fig. 1) has been described by Just (1970), where he briefly deals with the hydrography and gives an account of the ice conditions, especially with relation to the formation of leads and the final break-up. It is a fjord 30 km long and 1–3 km wide situated at 82°10′N, 30°30′W and running approximately E–W. An 85 m deep inner basin is separated by a 14 m deep threshold from a 50 m deep outer basin, which is directly connected to the deeper Independence Fjord. Tidal fluctuations amount to 40 cm at the most, restricting circulation between the outer and the inner basin, where all investigations were carried out in 1968 (fig. 2).

Material and methods

All water sampling was done with a 1000 ml non toxic insulating water sampler or, on a few occasions, with a simple Meyer water sampler, in which case the temperature could not be measured. The salinity was determined by flotation and the alkalinity for a number of samples by titration. The primary production was measured using the carbon-14 method. The experiments were performed in situ with 50 ml Jena bottles suspended for approximately 12 hours from midnight till noon at 4 depths: immediately beneath the ice or just below the surface of the water and at $^1/_2$, 1 and $1^1/_2$ times Secchi disc depth. At each depth were used 2 light-bottles and 1 dark-bottle. In the period with ice cover all sampling was done with the aid of a hand winch mounted on a pair of skiis, and in the first half of June the gear was worked through holes drilled in the ice with a 22 cm ice drill. Later on, as leads developed across the fjord and the ice elsewhere became less accessible, these were used. After the break-up a raft mounted with the hand winch or a small aluminum boat, both pictured by JUST (1970), was used. The thickness of the ice was regularly measured and the character of the surface was noted in an attempt to judge its ability to reflect light. Meteorological observations were carried out daily at 3-hour intervals from 6 am till midnight. Of interest in connection with the primary production and hydrography is the air temperature, of which the daily means are graphed in fig. 7a. A heliograph recorded the periods of sunshine, which though are not directly applicable to the in situ experiments in the fjord. A station list is found in table 1 and all stations are marked on the map, fig. 2.

Hydrography

The inner basin, functionally in itself being a threshold fjord, is greatly influenced, on the one hand, especially in parts of June and July, by the outflow of fresh water from the large Midsommer Elv at the head of the fjord to the west, the somewhat smaller Børglum Elv to the east and a dozen still smaller streams mostly to the south, and on the other hand by tidal movements bringing in water across the shallow threshold area from the cold and salt Independence Fjord, the greater part of which usually stays frozen over all year round. Jørgen Brønlund Fjord in fact differs from most marine areas in the viscinity of North Greenland by being free of ice during a short period – approximately 6 weeks – in the summer. This has a marked effect upon the light conditions in the fjord and upon its hydrography, being open to heating by the sun and stirring by persistent winds. Because of this

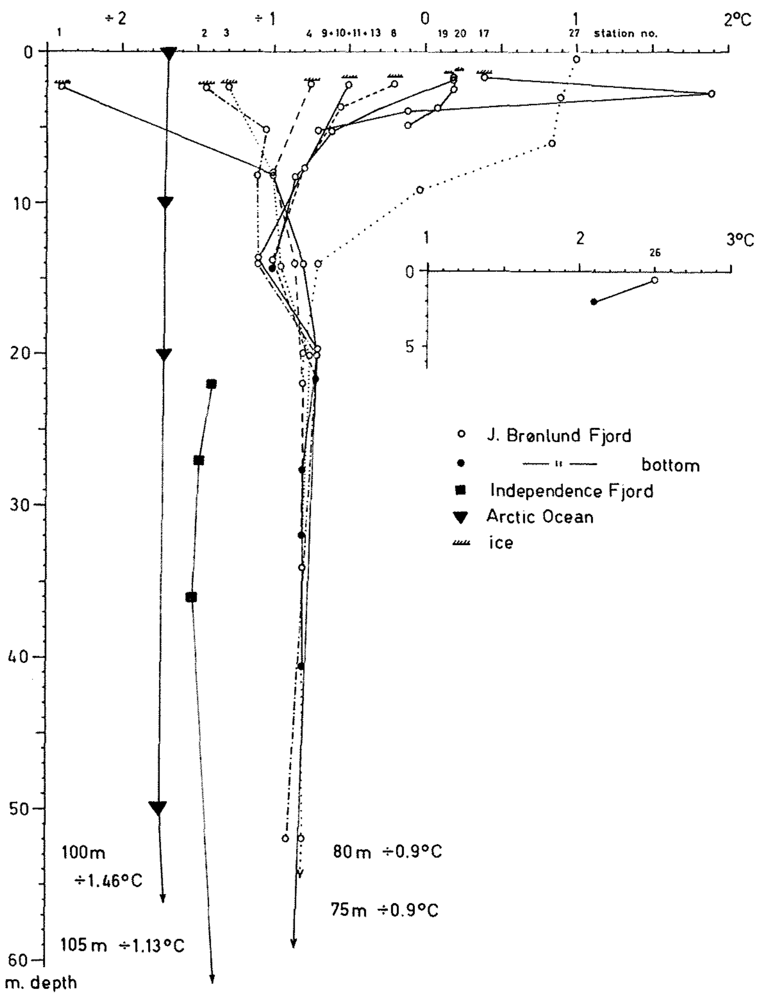

Fig. 3. Temperature profiles from the deepest series on each date of sampling, avoiding shallower bottom readings and stations near shore, + a series from the Independence Fjord (JUST, 1970) and from the Arctic Ocean (SATER, 1971).

and because of the slight interchange with neighbouring waters, this fjord is quite different from adjacent marine areas, both in summer and in winter.

Temperature: According to 4 measurements made by JUST in the Independence Fjord at various depths down to 105 meters, the temperatures of this fjord are markedly different from those of Jørgen Brønlund Fjord (fig. 3). The Independence Fjord showed excessive cooling in the upper at least 40 meters, with the lowest measurement of ÷1.53°C at 36 meters depth on June 3. and possibly a still colder minimum somewhere in the viscinity of this depth. In Jørgen Brønlund Fjord on the

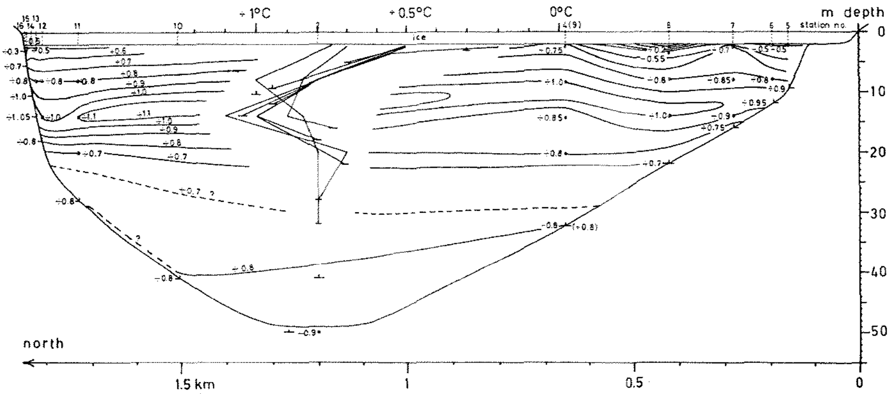

Fig. 4. A cross section of Jørgen Brønlund Fjord showing temperatures measured through the lead (fig. 2) on June 17., 18. and 20. and the corresponding profiles.

other hand all temperatures recorded from below the threshold depth of 14 meters were higher than in the Independence Fjord, namely between ÷0.9°C and ÷0.7°C throughout the summer. Above the threshold depth, measurements from 6 and 12 meters show a persisting minimum layer throughout June somewhere in the viscinity of these depths, an obvious influence from the Independence Fjord. As can be seen in fig. 4, there are variations going across the fjord. The upper 5 meters undergo the greatest fluctuations during the summer. In the beginning of June, the temperatures were as low as in the Independence Fjord, but in the course of the summer, the warming of the upper layers reached the viscinity of 2.5°C and possibly higher. The general warming could in August be ascertained as far down as to the threshold depth of 14 meters.

Salinity: The salinity of Jørgen Brønlund Fjord was likewise different from that of the Independence Fjord, it being somewhat lower at depths greater than 14 meters (fig. 5 & 6). As mentioned above, many streams supply the fjord with plenty of warm–below 5°C–melt water during a period of the summer. Comparing fig. 7a, 7b and 7c will make clear the relation between daily mean air temperature, reduction in ice thickness and dilution of the fjord water. The high correlation between air temperature and the occurrence of surface water of very low salinity is owing to the fact, that precipitation in the summer time is so slight, that it amounts to nothing compared to the snow and ice on land and and fjord ice, the melting of which is governed by insolation and air temperature. The freshening was extensive in the upper few meters, especially in the last week of June and in most of July, and could ultimately be traced down to at least 20 meters. This shows, that a mixing throughout the basin later in the year must have contributed to the making of the generally fresher and warmer water than at like

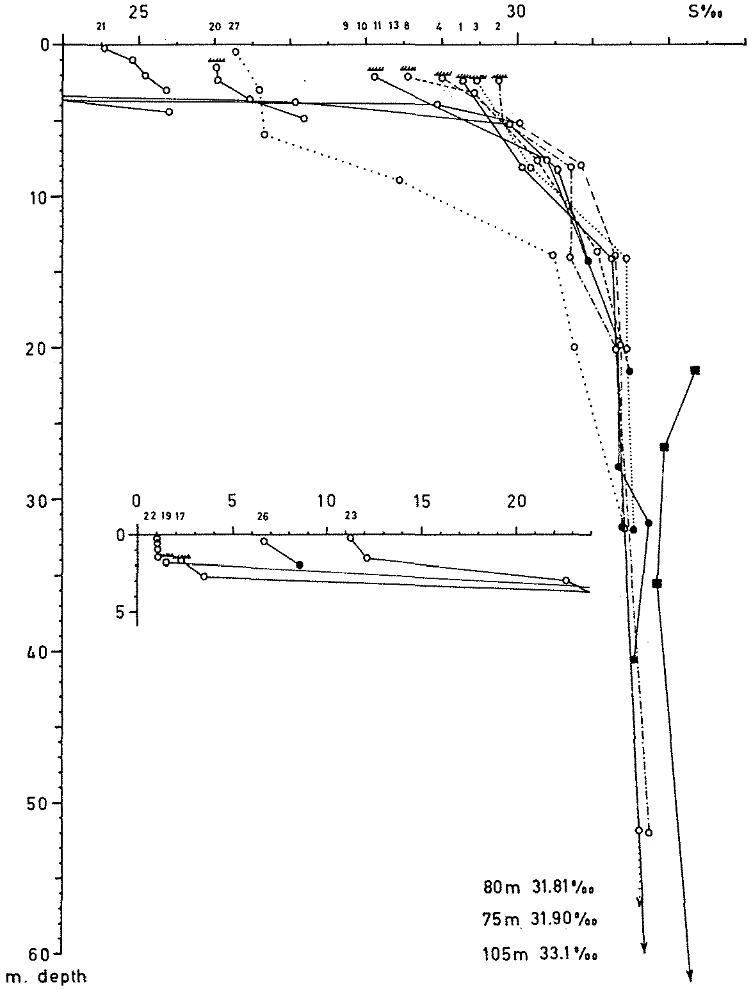

Fig. 5. Salinity profiles from the deepest series on each date of sampling, avoiding shallower bottom readings and stations near shore, + a series from Independence Fjord (JUST, 1970).

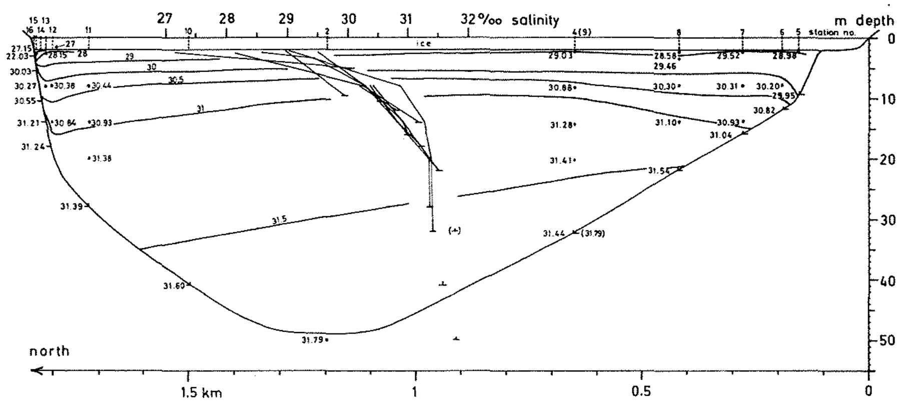

Fig. 6. A cross section of Jørgen Brønlund Fjord showing salinities measured through the lead (fig. 2) on June 17., 18. and 20. and the corresponding profiles.

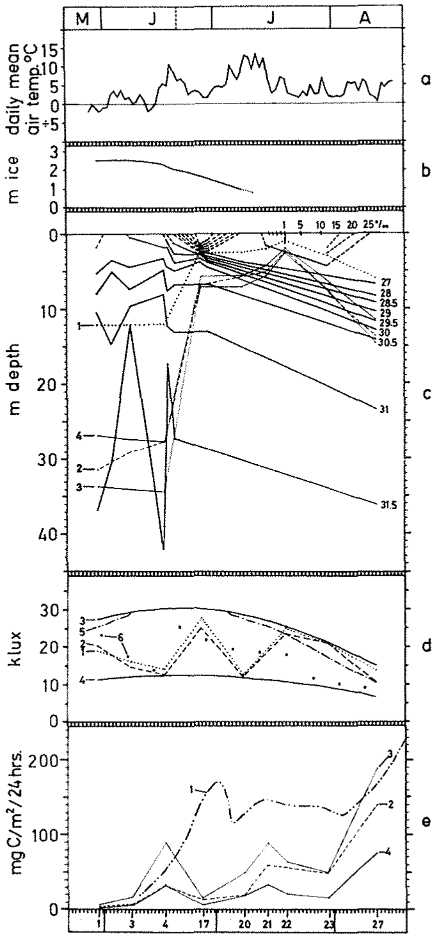

Fig. 7.

a. Daily mean air temperature as calculated from readings every three hours from 6 am till midnight.
b. Ice thickness.
c. Isohalines derived from fig. 5 and the compensation depths found as described in the text for the experiments (2), for maximum (3) and for minimum illumination (4).
d. Mean values of subsurface illumination derived from fig. 11 and 12 for the actual experimental period (1), for the period from midnight till noon on the dates of the experiments (2), for days with maximum (3) and days with minimum surface illumination (4), for days with maximum illumination and shading—at point X in fig. 2—(5) and for each week throughout the summer (6). See the text.
e. Gross primary production at Ogac Lake (McLAREN, 1969) (1), derived from the experiments as described in the text (2) and under conditions of maximum (3) and minimum subsurface illumination (4) as shown in d.

depths in the Independence Fjord. This persistently warmer bottom water of Jørgen Brønlund Fjord may along with the fact, that this fjord for approximately a month and a half each year is free of ice, account for the relatively rich invertebrate fauna of the fjord bottom. The occurrence of the halocline in the upper meters has a marked effect upon the transparency of the water, restricting light to depths primarily inside and above the halocline.

Transparency: The transparency of the water varied greatly in the course of the summer (fig. 7c). The probably highest transparency of the year prevailed in the beginning of June, where the Secchi disc was visible as far down as 12 meters from the under side of the ice. During the melt great quantities of fresh water from land and from the melting sea ice were associated with numerous suspended particles constituting a layer of high turbidity in the upper few meters or less, causing the Secchi disc to disappear as little as 90 cm below the surface in mid July. By August 12. the Secchi disc depth had reached 6 m. Under the given circumstances the Secchi disc proved an inadequate tool for the measurement of transparency in order to estimate the extent of the productive layer, since the turbidity as a result of the high stability of the upper layers was so unevenly distributed from the surface down. A thick turbidity layer could have caused an overestimation of light at greater depths, since the suspended particles tend to sink and accumulate close to pronounced layers of discontinuity, while on the contrary a less extensive layer barely thick enough to blot out the image of the Secchi disc could bring about an underestimation. Then again the light reflected from the suspended particles reduce Secchi disc depth. An entirely different phenomenom may be apt to cause erroneously shallow Secchi disc depths, namely the ability of an abrupt drop in salinity towards the surface to reflect upward irradiance, thus preventing rays reflected by the disc in reaching the surface. This appeared to happen in the last week of June and most of July.

The ice: In May and the first week of June the ice maintained its greatest thickness of $2^1/_2$ meters and not till about June 20. did it start melting from below. The thickness was reduced to approximately 1 meter by July 11., when strong westerly winds opened up the entire fjord. During the melting period the appearance of the ice underwent striking changes. These must have been of some importance to the illumination beneath the ice and thus to the primary production. Therefore the following brief description.

Fig. 8 schematically illustrates some of the changes, that took place. Already on May 30. the ice proved quite soft and porous and, when boring holes into it, water filled the cavity already at the water line.

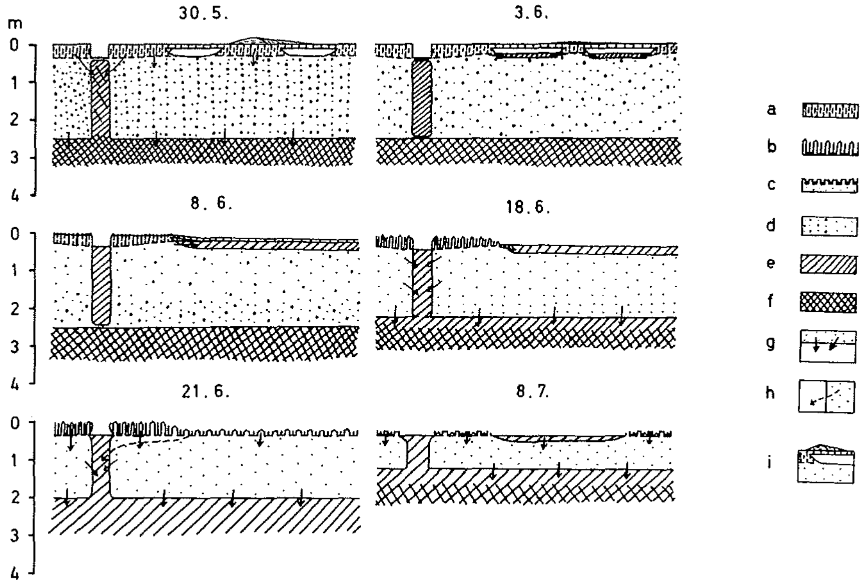

Fig. 8. Vertical sections of the fjord ice at various dates. See text. From June 21. onward the lower surface is progressively undulating—not shown.

a. Smooth ice enholding bubbles of air.
b. Snow-like ice.
c. Snow-like ice soaked in water.
d. Porous ice below the water-line enholding a stronger (left) and a weaker (right) brine.
e. Fresh water.
f. Salt water.
g. Seeping and melting out of the brine.
h. Melt water running off.
i. A snow drift on smooth ice enholding bubbles of air and a larger air-filled cavity.

The surface was smooth and free from snow except for some few small and dirty drifts. Close to the surface were a great many air bubbles and there were larger airfilled spaces, all making the ice extremely intransparent. As illustrated for June 3. and June 8., the drifts soon disappeared and the large cavities gradually spread and became filled with melt-water. Where there were no such cavities, especially next to the leads, which formed across the fjord, and where the ice stood upon the bottom, the upper strata became progressively more air-filled, sometimes aquiring an appearance like crusted snow. This surface ultimately became very snow-like, consisting entirely of white, perpendicular, closely set needles of ice several inches in length, often forming beautifull patterns. But by June 17. nearly the entire surface of the ice had gradually come to consist of large ice-covered lakes only broken by the leads and bordered by narrow bands of snow-like ice. The following day, June 18., the ice-lakes were entirely free from ice. The leads and the

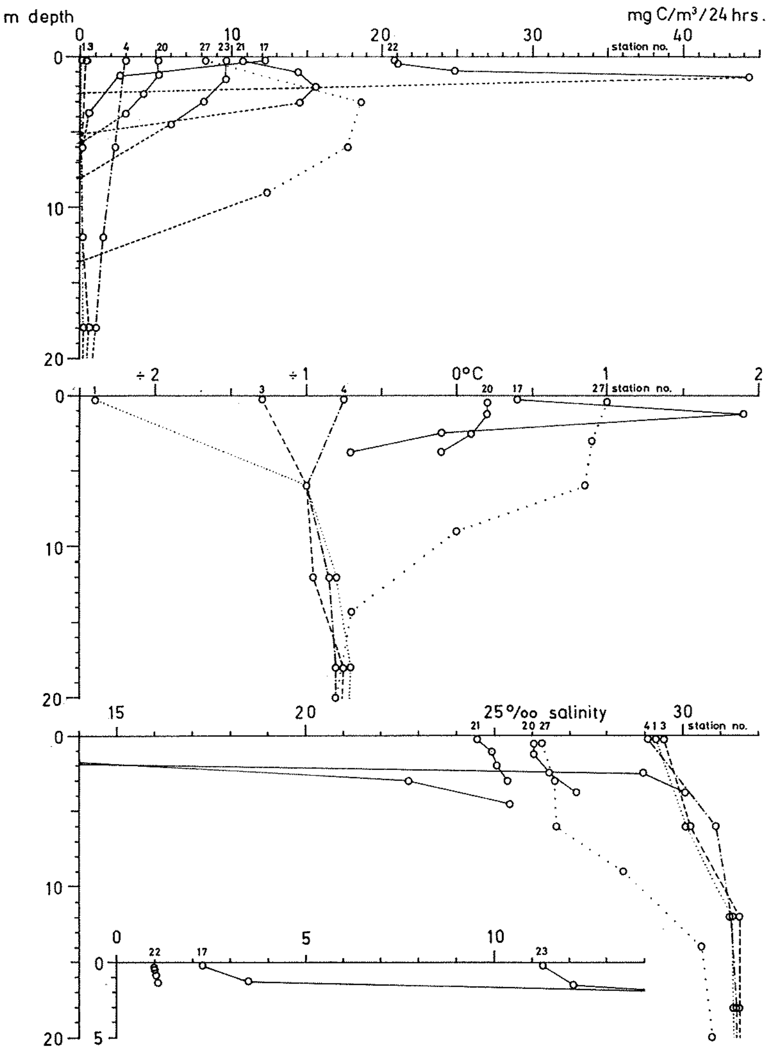

Fig. 9. Profiles showing gross primary production and the corresponding temperatures and salinities. The extent of the productive layer was found as described in the text.

holes bored through the ice had previous to June 20. largely been closed at the bottom next to the salt water of negative temperatures beneath the ice, indicating, that the under-side of the ice also must have been frozen tight. In any event, during the night between June 20. and June 21. all water suddenly left the surface of the ice, probably as a result of the appearance of water of positive temperatures immediately beneath the ice, thawing this and allowing melt-water to seep down through the ice. The entire surface was soon transformed into a field of

Table

station	date	true local time for the C-14 experiments	bottom depth in m	sample depth in m	thickness of ice in cm : fig. 7b	temperature in °C : fig. 3+4+9	total salinity in ‰ : fig. 5+6+9	sigma t	Secchi disc depth in m : fig. 7c1
1......	30.5.		75	0.2	250	÷ 2.4	29.30	23.45	12
1......	"	00:40–	"	6	"	÷ 1.0	30.10	24.15	"
1......	"	12:40	"	12	"	÷ 0.8	31.30	25.2	"
1......	"		"	18	"	÷ 0.7	–	–	"
1......	"		"	73	"	÷ 0.9	31.90	25.6	"
2......	3.6.		75	0.2	250	÷ 1.45	29.78	23.9	12
2......	"		"	3	"	÷ 1.05	29.84	23.9	"
2......	"		"	6	"	÷ 1.1	30.75	24.7	"
2......	"		"	12	"	÷ 1.1	30.75	24.7	"
2......	"		"	18	"	÷ 0.7	31.36	25.2	"
2......	"		"	50	"	÷ 0.9	31.79	25.55	"
3......	8.6.		30	0.2	250	÷ 1.3	29.50	23.6	12
3......	"	02:30–	"	6	"	÷ 1.0	30.21	24.25	"
3......	"	14:30	"	12	"	÷ 0.95	31.50	25.3	"
3......	"		"	18	"	÷ 0.75	31.50	25.3	"
3......	"		"	30	"	÷ 0.8	31.60	25.4	"
4......	17.6.		30	0.2	230	÷ 0.75	29.03	23.3	12
4......	"	03:00–	"	6	"	÷ 1.0	30.88	24.8	"
4......	"	16:30	"	12	"	÷ 0.85	31.28	25.2	"
4......	"		"	18	"	÷ 0.8	31.41	25.3	"
4......	"		"	30	"	÷ 0.8	31.44	25.3	"
5......	18.6.		7.5	0.2	200	÷ 0.5	28.98	22.45	–
5......	"		"	7.5	"	÷ 0.9	29.95	24.0	–
6......	"		10	÷ 1	"	0.1	0.7	0.4	–
6......	"		"	÷ 0.2	"	0.1	0.9	0.7	–
6......	"		"	0.2	"	÷ 0.5	–	–	–
6......	"		"	6	"	÷ 0.8	30.20	24.2	–
6......	"		"	10	"	÷ 0.95	30.82	24.8	–

1.

cpm for bottles in			a ÷ c	$\frac{c}{a} \cdot 100$ %	primary production / 24 hrs in		mean compensation depth in m 1 = $\frac{20}{7}$ · Secchi disc depth 2 as fig. 7c2 3 as fig. 7c3 4 as fig. 7c4	mean subsurface illumination in klux 1 as fig. 7d1 2 as fig. 7d2 3 as fig. 7d3 4 as fig. 7d4
light a	light b	dark c			mgC/m^3 experimental : fig. 9	mgC/m^2 1, 2, 3 and 4 with illuminations & compensation depths 1, 2, 3 and 4 respectively: fig. 7e		
1.7	1.4	1.2	0.5	70.6	0.05	1: 4.27	1: 34.3	1: 18.0
1.0		0.3	0.7	30.0	0.07	2: 4.19	2: 31.4	2: 20.27
1.9	1.1	0.5	1.4	26.3	0.14	3: 6.05	3: 33.55	3: 27.45
3.0	2.9	0.6	2.4	20.0	0.24	4: 1.97	4: 26.8	4: 11.25
4.5	2.9	0.9	3.6	20.0	0.36	1: 9.62	1: 34.3	1: 16.2
2.0		1.0	1.0	50.0	0.09	2: 6.91	2: 29.0	2: 14.9
2.3		1.1	1.2	47.8	0.12	3: 16.42	3: 34.0	3: 29.5
7.9		1.8	6.1	22.8	0.60	4: 5.19	4: 27.35	4: 12.0
35.9	21.8	2.1	33.8	5.85	2.96	1: 42.26	1: 34.3	1: 14.2
29.8	4.3	4.1	25.7	13.77	2.26	2: 33.28	2: 27.55	2: 12.35
20.0	4.6	3.9	16.1	19.50	1.41	3: 88.65	3: 34.25	3: 30.4
16.1		5.4	10.7	33.7	0.95	4: 33.28	4: 27.55	4: 12.35

(continued)

Table 1.

station	date	time for C-14 exp.	bottom depth in m	sample depth in m	ice in cm	temperature in °C	total salinity in ‰	sigma t	Secchi disc depth in m
7......	18.6.		14	0.5	200	÷0.7	29.52	23.7	–
7......	"		"	6	"	÷0.85	30.31	24.3	–
7......	"		"	12	"	÷0.9	30.93	24.9	–
7......	"		"	14	"	÷0.75	31.04	25.0	–
8......	"		20	0.5	"	÷0.2	28.58	22.8	–
8......	"		"	1.5	"	÷0.55	29.46	23.6	–
8......	"		"	6	"	÷0.8	30.30	24.3	–
8......	"		"	12	"	÷1.0	31.10	25.05	–
8......	"		"	20	"	÷0.7	31.54	25.4	–
9......	20.6.		30	30	"	÷0.8	31.79	25.55	–
10.....	"		39	39	"	÷0.8	31.60	25.45	–
11.....	"		26	6	"	÷0.8	30.44	24.45	–
11.....	"		"	12	"	÷1.1	30.93	24.9	–
11.....	"		"	18	"	÷0.7	31.38	25.25	–
11.....	"		"	26	"	÷0.8	31.39	25.25	–
12.....	"		16	6	"	÷0.8	30.38	24.4	–
12.....	"		"	12	"	÷1.1	30.84	24.8	–
12.....	"		"	16	"	÷0.8	31.24	25.2	–
13.....	"		12	0.5	"	÷0.5	28.15	22.6	–
13.....	"		"	6	"	÷0.8	30.27	24.25	–
13.....	"		"	12	"	÷1.05	31.21	25.15	–
14.....	"		8.5	8.5	"	÷1.0	30.55	24.55	–
15.....	"		3.5	0.5	"	÷0.5	27.15	21.75	–
15.....	"		"	3.5	"	÷0.7	30.03	24.0	–
16.....	"		1	1	"	÷0.3	22.03	17.7	–
17.....	27.6.		45	0.2	170	0.4	2.26	1.75	2.5
17.....	"	03:10–	"	1.25	"	1.9	3.46	2.8	"
17.....	"	15:10	"	2.5	"	÷0.1	28.96	23.3	"
17.....	"		"	3.75	"	÷0.7	30.05	24.0	"
18.....	29.6.		7	2.5	150	÷0.3	29.34	23.5	2.5
18.....	"		"	7	"	÷0.8	30.30	24.3	"

(Continued)

cpm for bottles in			a÷c	$\frac{c}{a} \cdot 100$ %	primary production / 24 hrs in		mean compensation depth in m	mean subsurface illumination in klux
light a	light b	dark c			mgC m³	mgC/m²		
125.8	62.8	3.3	122.5	2.62	12.10	1: 14.00	1: 7.15	1: 27.7
31.9	17.2	6.8	25.1	21.3	2.50	2: 12.48	2: 6.87	2: 25.0
4.4	2.7	7.5	÷3.1	–	–	3: 15.57	3: 7.13	3: 30.2
10.4	3.8	5.0	5.4	48.0	0.53	4: 5.97	4: 5.73	4: 12.3

(continued)

Table 1.

station	date	time for C-14 exp.	bottom depth in m	sample depth in m	ibe in cm / wind in knots	temperature in °C	total salinity in ‰	sigma t	Secchi disc depth in m
19.....	29.6.		13	0.5	150	0.2	1.5	1.2	2.5
19.....	"		"	2.5	"	÷0.3	27.08	21.65	"
19.....	"		"	4	"	÷0.6	29.91	23.95	"
19.....	"		"	7	"	÷0.85	30.56	24.5	"
19.....	"		"	13	"	÷1.0	31.00	25.0	"
20.....	8.7.		35	0.5	100	0.2	26.04	20.85	2.5
20.....	"	02:20–	"	1.25	"	0.2	26.06	20.85	"
20.....	"	14:20	"	2.5	"	0.1	26.48	21.2	"
20.....	"		"	3.75	"	÷0.1	27.19	21.7	"
21.....	14.7.		30	0.2	16	–	24.54	–	2
21.....	"	02:20–	"	1.0	"	–	24.91	–	"
21.....	"	14:20	"	2	"	–	25.08	–	"
21.....	"		"	3	"	–	25.36	–	"
22.....	19.7.		80	0.2	7	–		–	0.9
22.....	"	02:30–	"	0.45	"	–		–	"
22.....	"	14:30	"	0.9	"	–	1–1.1	–	"
22.....	"		"	1.35	"	–		–	"
23.....	30.7.		10	0.2	9	–	11.30	–	3
23.....	"	02:00–	"	1.5	"	–	12.10	–	"
23.....	"	14:00	"	3	"	–	22.73	–	"
23.....	"		"	4.5	"	–	25.40	–	"
24.....	"		0.5	0.5	"	1.55	7.26	5.8	–
25.....	"		1	0.5	"	2.4	7.09	5.7	–
25.....	"		"	1	"	1.9	7.25	5.8	–
26.....	"		2	0.5	"	2.5	6.62	5.35	–
26.....	"		"	2	"	2.1	8.54	6.9	–
27.....	12.8.		80	0.5	7	1.0	26.27	20.95	6
27.....	"		"	3	"	0.9	26.60	21.25	"
27.....	"		"	6	"	0.85	26.66	21.3	"
27.....	"		"	9	"	0.0	28.46	22.8	"
27.....	"		"	14	"	÷0.7	30.51	24.5	"
27.....	"		"	20	"	÷0.8	30.80	24.8	"
27.....	"		"	32	"	÷0.8	31.47	25.3	"
27.....	"		"	52	"	÷0.8	31.66	25.45	"
27.....	"		"	80	"	÷0.9	31.81	25.55	"

* Here correction has been made for the effect issued by wave action upon surface film transmissior

(Continued)

cpm for bottles in			a÷c	$\frac{c}{a} \cdot 100$ %	primary production / 24 hrs in		mean compensation depth in m	mean subsurface illumination in klux
light a	light b	dark c			mgC/m³	mgC/m²		
53.7	52.2	2.6	51.1	4.84	5.06	1: 21.05	1: 7.15	1: 12.8
54.5	43.6	2.8	51.7	5.14	5.12	2: 18.58	2: 5.72	2: 12.21
44.3	41.2	2.8	41.5	6.32	4.11	3: 47.91	3: 7.05	3: 28.65
30.1	22.2	0.5	29.6	1.66	2.94	4: 17.77	4: 5.66	4: 11.75
114.2	94.8	6.7	107.5	5.87	10.65	1: 64.11	1: 5.71	1: 19.0
153.2	150.7	8.7	144.5	5.68	14.30	2: 57.17	2: 5.13	2: 18.8
168.8	149.0	12.5	156.3	7.40	15.50	3: 87.35	3: 5.58	3: 27.2
158.8		12.2	146.6	7.68	14.49	4: 31.33	4: 4.46	4: 11.25
218.0	184.9	8.4	209.6	3.85	20.73	1: 65.11	1: 2.57	1: 25.2
230.0	219.0	8.7	231.3	3.78	21.00	2: 55.80	2: 2.44	2: 23.7
259.0	250.0	8.0	251.0	3.09	24.75	3: 62.08	3: 2.48	3: 25.6
454.0	412.0	7.1	446.9	1.57	44.24	4: 20.68	4: 1.98	4: 10.6
100.7	90.9	9.2	91.5	9.14	9.58	1: 51.52	1: 8.57	1: 21.2
104.9	97.1	8.2	96.7	7.82	9.57	2: 49.56*	2: 8.05*	2: 21.6*
91.3	60.3	8.2	83.1	8.98	8.13	3: 48.82	3: 7.95	3: 21.4
62.8	62.0	3.3	59.5	5.25	5.95	4: 16.13	4: 6.06	4: 8.0
86.8	78.8	3.8	83.0	4.38	8.22	1: 194.88	1: 17.14	1: 13.9
190.3	183.7	2.2	188.1	1.15	18.60	2: 139.64	2: 13.53	2: 11.6
182.2	169.4	3.5	178.7	1.92	17.65	3: 187.25	3: 14.54	3: 15.0
127.2	125.7	2.6	124.6	2.05	12.30	4: 74.62	4: 11.49	4: 6.7

dazzling white snow-like ice. From then on the ice quickly diminished in thickness and the surface gradually became uneven, as the layer of snow-like ice thinned out finally becoming wet throughout, and puddles formed all over the surface.

The effect of this sequence of events upon illumination is difficult to evaluate, but the general result was a gradual reduction in the reflective action of the ice culminating and ending abruptly on June 21., when the resulting snow-like surface probably effectuated the most thorough block to in-coming light. From then on the thinning and soaking of the ice made for another gradual bettering of the subsurface light conditions.

Thus the light conditions under sea ice are governed not only by the well known effect of snow cover as well as the thickness of the ice, but also by the condition of the ice, which varies greatly during the course of the thawing period, especially in the subzero waters of the ice-bound Arctic, as seems supported by the results of the measurements of primary production dealt with in the following.

Primary production and illumination

Results: Fig. 9 shows the gross production in mg C/m^3/day as found in the 9 experiments performed. Of the two light bottles used in each case the one yielding the highest value was used, since in some instances light bottle values were almost as low as or even lower than the dark bottle value (table 1). These low values must be ascribed to leakage from the experimental bottles, since in some cases the tops vere quite loose an even dropped off on retrieval. On June 27. persistent low values most certainly arose from the fact, that no phototrophic organisms survived in the boundary layer between the fresh surface water and the salt water beneath.

The dark fixation amounted to between 1.15 $^0/_0$ and 70 $^0/_0$ of that of the light bottles at the same depth, the largest percentage occurring at times of lowest production and never exceeding 1.24 mg C/m^3/day. The greatest dark fixations prevailed in the period of high turbidity, on June 27. exceeding 10 $^0/_0$ at the deeper levels.

The graphs for temperature, as far as they are available, and for salinity are also shown in fig. 9 and fig. 7e shows the production per m^2 down to the compensation depth found as described below. Assuming the average respiration loss to be 8 $^0/_0$ of the possible production on June 21., the yearly production in the resulting productive period of 150 days (fig. 10) amounts to only 4.7 g C/m^2.

If one is to rely on the values for subsurface illumination found on the basis of the Secchi disc measurements, the productive zone seems

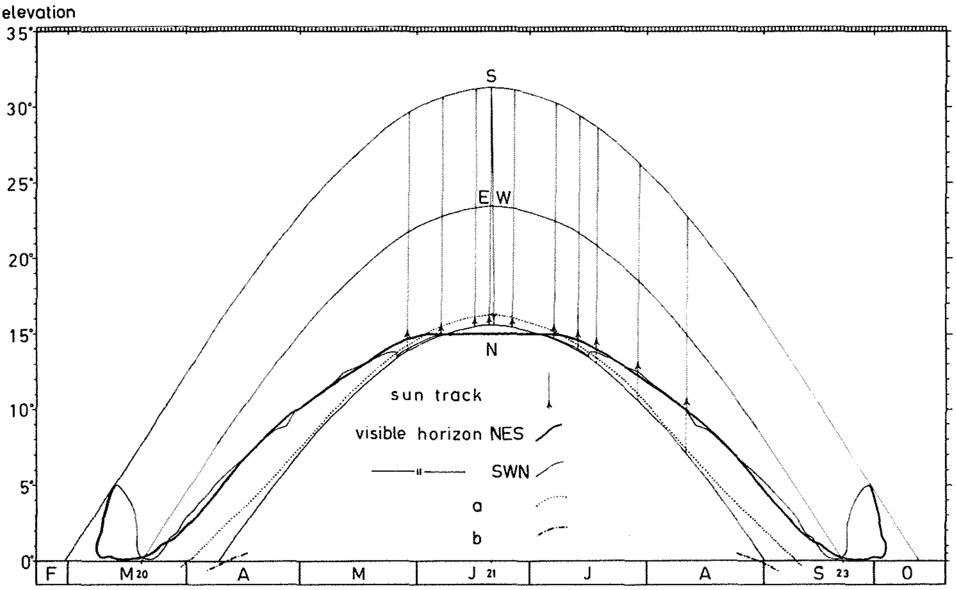

Fig. 10. The amplitude described by the sun above the horizon in the period with sun is shown by lines representing the altitude of the sun, when it is north, east or west and south respectively, and the positions of the dates, when the C-14 experiments were performed, are marked by their respective sun tracks. The visible horizon is seen from point X in fig. 2. a is a strictly theoretical curve derived to estimate the extent of the productive period by assuming respiration to be 8 % of the production at noon on a sunny day in mid summer and production to be proportional to illumination. The computation is thus a simple subtraction of these 8 % from the average illumination at any time through 24 hours with sun. b represents the ends of a like curve but for cloudy conditions. The illuminations are derived from fig. 11 and 12.

throughout most of the summer to have been limited to the upper 5 to 10 meters or less, only in the first half of June and by mid August going noticeably deeper. In fact, the ^{14}C experiments show, that production was restricted to the fresh or diluted surface water and to the persisting intermediate halocline, not coming into contact with the bottom water, presumeably rich in nutrients, until mid August, where vertical mixing had extended the halocline to a depth of more than 20 meters. The supply of vital nutrients in the surface layer seems to have been depleated by the end of July, whereas production on August 12. implies, that a slight replenishment of nutrients from below has commenced.

Having the values for production in 4 depths only, chosen as mentioned above, the results did not show the nature of production in the lower part of the euphotic zone. To compensate for this an attempt was made at estimating the extent of the euphotic layer. This was done by assuming the mean illumination in mid summer with a cloudless sky to

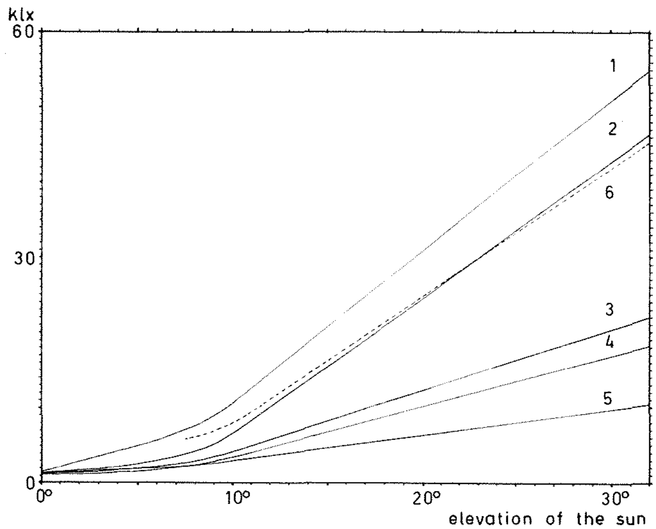

Fig. 11. These curves represent surface illumination with (3) and without clouds (1) and subsurface illumination with (4) and without clouds in calm weather (2) and without clouds but with a 4 Beaufort wind blowing (6). 5 represents subsurface light derived from diffuse light in clear wheather.

be an optimal condition, where the extent according to STEEMANN NIELSEN (1958) should be 20/7 times the Secchi disc depth. Using the heliograph measurements and insolation values and cloud transmission given by DIGBY (1960) from Sørgat and ÅNGSTRØM (1933) from Sveanor, as well as surface film transmission given by DIGBY and reflection by BURT (1954) and ANDERSON (1954), all dependent on the elevation of the sun (fig. 11), the mean sub-surface illumination was with the aid of fig. 12 found for each of the experimental periods. These did not always run from midnight till noon and correction was made for this. A correction was also made for the effect of wave action on July 30. amounting to +2 $^0/_0$ (COX & MUNK, 1956) (fig. 7d).

In the calculations of sub-surface illumination the effect of the ice has been disregarded. It can however be assumed, as mentioned earlier, that light conditions gradually reached their best on June 21., which at least is not contradicted by the relatively high production under the conditions of low insolation on June 17. On June 27. a low production in spite of the more favourable conditions of insolation coincided with the highly reflecting snow-like surface of the ice, while the slightly higher production on July 8. in spite of the very poor illumination coincided with the thinning of the ice and its surface being wet and the ice dark.

Still following STEEMANN NIELSEN (1958), the compensation depths defining the position of the deepest end of the production curves of

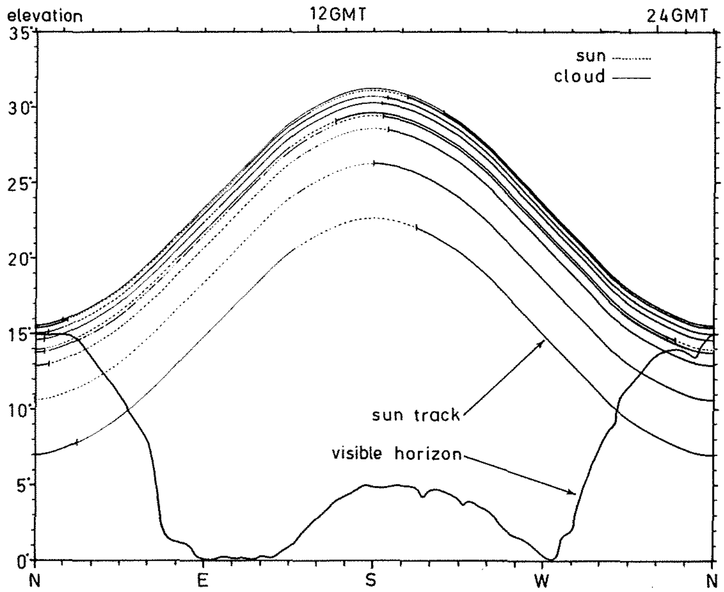

Fig. 12. The visible horizon is seen from point X in fig. 2. The sun tracks are from the dates on which the nine C-14 experiments were performed. From below they represent stations 27, 23, 22, 21, 1, 20, 3, 17 and 4 respectively. "Sun" and "cloud" represent the record made by the heliograph.

fig. 9, were found by raising the theoretical optimal curve found with the Secchi disc depth measured in each case to a depth proportional to the mean sub-surface illumination from midnight till noon on the experimental dates (fig. 7c).

In order to get a rough idea of the boundaries for variation in production, the sub-surface illumination under clear and overcast conditions respectively was calculated (fig. 7d). The resulting production was found, assuming it to be proportional to the illumination and ignoring the question of nutrition (fig. 7e). This would give a yearly production of 7.1 and 1.8 g C/m^2 in the resulting productive periods of 160 days and 140 days respectively with a respiration loss as mentioned above.

Fig. 7d also shows the effect of shadowing at point X on fig. 2 by the mountains to the north. These mountains always cast a shadow down upon the fjord around midnight. In mid summer the shadow reaches $^3/_4$ to 1 kilometer out from the northern shore, and for only 2 to $2^1/_2$ months does it fail to reach the southern shore. The experiments, though, were largely performed out of the shade, only three having been shaded for a short time.

Discussion: As mentioned, the technique of using a Secchi disc to determine the experimental depths must have been a major cause for error, since the experiments hereby often were wholly or partly restricted to the upper layers of fresh water, giving results of questionable value owing to a possible missing of deeper lying marine layers of production. This actually seems more or less to have been the case throughout the period with the persisting layer of turbidity from the last week of June till the beginning of August. It was most pronounced on July 19., where production was greatest at the deepest level and the experiment was confined entirely to the fresh-water layer.

McLaren (1969) in his study of Ogac Lake, a land-locked fjord with clear water, found production in the summer to be confined not only to the upper strata associated with the halocline but also to a deeper lying distinct concentration of phytoplankton.

In order to clarify, whether this could also be the case in a fjord with a turbid surface layer and to clear up the question of production in Jørgen Brønlund Fjord as far as possible, without having to go there again, a series of measurements with a photometer was done in the upper reaches of the inner part of Disko Fjord, West Greenland, a locality having much the same characteristics of turbidity as Jørgen Brønlund Fjord. At the same time in situ ^{14}carbon experiments using set depths of 0, 2.5, 5, 10, 15, 20, 30, 40 and 50 m were performed on 15 occasions in the open water period and twice beneath the ice in the spring.

The light measurements showed, that the densely turbid surface layer often was confined to the upper few decimeters or meters barely surpassing the Secchi disc depth and having water of much greater transparency immediately beneath it.

The production experiments from Disko Fjord showed, that a technique as that used in Jørgen Brønlund Fjord as opposed to the one used in Disko Fjord would have necessitated appreciable corrections – of more than +15 $^0/_0$ – of results, almost exclusively as a result of very shallow Secchi disc depths – 1.65 m or less. It was almost exclusively productivity found close to or at least indistinguishable from the surface layer of production, that would have been missed by the technique used in Jørgen Brønlund Fjord. Experiments, where Secchi disc depths were of a magnitude as those encountered in Jørgen Brønlund Fjord, showed a need for corrections of from ÷3.2 $^0/_0$ to 235 $^0/_0$, in absolute measure being from ÷5 to 285 mg C/m^2/day. On three occasions only, in spring and early summer, did deeper layers of production call for major corrections of from 30.5 $^0/_0$ to 1422 $^0/_0$, one being the largest to be made in both relative and absolute measure being from 8 to 325 mg C/m^2/day.

Transferring these results to the situation in Jørgen Brønlund Fjord makes probable a yearly production of from 7.4 to 13.7 g C/m^2 with the major corrections falling in the last week of June and the first half of July, roughly the period of greatest turbidity. Supporting this are growth-curves for pelagic bivalve larvae in Jørgen Brønlund Fjord showing greatest increment during the first three weeks of July.

In any event it is substantiated, that primary production in Jørgen Brønlund Fjord was greater, than the experiments there showed, most probably being about 8–10 g C/m²/year. On the other hand, it is evident, that production is greatly impaired by the layer of more or less turbid water covering the fjord prior to the break-up and through much of the open water period.

Resumé

The results of investigations on temperature, salinity, transparency, illumination, ice and primary production of Jørgen Brønlund Fjord done during the 5. Peary Land Expedition from May 30. to August 12, 1968 have been presented.

The fjord is in part a threshold fjord having an inner basin 85 m deep, a threshold area with a minimum depth of 14 m and an outer basin adjacent to the much deeper Independence Fjord. Circulation across the threshold is restricted, the tidal fluctuation being 40 cm at the most. This and the fact, that the fjord is free from ice for about two months each year and thus can be heated by the sun and is open to the mixing effect of the almost constantly blowing winds–in mid August traceable down to about 20 m–makes the hydrography distinct from that of the Independence Fjord, which in most years is largely covered with ice throughout the summer. Sub-threshold temperatures are 0.23–0.75°C warmer and salinities are 0.3–1.5 ‰ less than outside the threshold, where temperatures are close to those of the Arctic Ocean. A cold intermediate layer at threshold depth indicating an influx across the threshold underlies a warmer, at the surface at times fresh layer reaching 2.5°C.

Secchi disc measurements varied from 12 m in May over 90 cm in mid July to 6 m by mid August.

The $2^1/_2$ m thick fjord ice first thawed from the surface and from June 20. and on also from beneath finally breaking up on July 12. at a thickness of 1 m. The transparency of the ice was greatly affected by the melting in the upper strata and by the chance for the melt water to escape from the surface leaving this very snow-like and highly reflecting. This happened over night, when the ice commenced to thaw from beneath.

The primary production measured with ^{14}C by in situ experiments setting the depths according to Secchi disc measurements varied from 4.19 to 139.6 mg C/m²/day. The estimated yearly production was 4.7 g C/m², the highest possible being 7.1 g and the least being 1.8 g under clear and over-cast conditions respectively. The occurrence of a turbid surface layer caused the experimental depths set according to Secchi disc measurements to be too small. Additional experiments done

in Disko Fjord, West Greenland make probable, that yearly production rather should be 7.4–13.7 g/m^2. In all event it is evident, that production is greatly impaired by the surface layer of high turbidity blocking out the light.

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