# *Short Papers and Notes*

## CHLOROPHYLL IN ARCTIC SEA ICE

### Introduction

Four recent papers have discussed unicellular algae growing on or in close association with the sea-ice of the polar regions. Those of Meguro[1], Bunt and Wood[2], and Bunt[3] present qualitative and quantitative information on antarctic ice algae and describe two rather different ecological situations. Meguro's striking colour photographs illustrate a rich flora growing at the interface of snow and ice on broken and drifting ice-floes. Bunt, and Bunt and Wood, on the other hand, describe a rich flora growing on the bottom of solid, unbroken ice fields up to 5 m. thick and with a variable snow cover. Bunt and Wood termed their flora an *epontic* community, and neither Meguro nor Bunt and Wood mention the flora described by the other. They agree that the algae are almost entirely diatoms and, most interestingly, Meguro and Bunt found that the ratio of chlorophyll *a* ($mg/m^3$) to chlorophyll *c* ($mspu/m^3$) is low, about 0.9 to 1.2. They also found chlorophyll *a* concentrations greatly exceeding those normally found in marine phytoplankton populations.

From the Arctic, I reported[4] large chlorophyll concentrations on the bottom of thick, unbroken ice fields covered with 25 cm. of snow. It was noted that the flora must have grown at very low light intensities, as Bunt and Wood also observed, and that the concentrations of chlorophyll declined markedly when light intensities on the ice were artificially or naturally increased.

Further work was done in the Arctic on this subject in 1962 and 1963, and these results, together with some speculations, are presented here.

The samples from the Arctic were collected during the course of the Devon Island Expedition of the Arctic Institute of North America and were taken from the sea-ice of Jones Sound within 200 m. of the shore of Devon Island, N.W.T., at about 75°42′N. The minimum depth of water below the ice in 1961 was about 5 m. and in 1963 was 8 m.

### Methods

Cores of ice were taken with a CRREL (SIPRE) 7.5 cm. diameter ice corer, and the bottoms of cores were sawn off to include all the visually evident chlorophyll. The melted ice was filtered through an HA millipore filter and the pigment was extracted with 5 cc. of 90% acetone for 20 hours, whereupon the sample was centrifuged and the optical density was measured with a Klett colorimeter using a No. 66 filter. I have used a factor of 0.28 ug. chlorophyll *a*/l to convert the Klett readings.

In 1962 *in situ* light measurements were made by freezing a photometer into the ice. It was installed in early March and its distance below the surface of the ice was 170 cm. In suspending the photometer it was necessary to guess what the thickness of the ice would be in May and June, the time of the expected maximum of chlorophyll development. The ice in the previous year was about 165 cm. thick in June but in 1962 the ice reached a thickness of 180 cm. on 1 June; thus the photometer did not measure light at the bottom of the ice. Nevertheless, the values are, at worst, maximum values, and since the light extinction of the ice itself was found to be fairly low, the values are probably close to those incident to the algae. The light readings were made within half an hour of local noon and were accompanied by readings of a surface photometer.

### Results

The chlorophyll values are listed in Table 1 and the light readings are shown in Table 2. The collection of samples with a CRREL corer depends upon sharp blades. Unfortunately these were not available in 1962 and only one or two samples were obtained that could be considered roughly quantitative. Therefore there are few chlorophyll values that can be related directly to the light measurements.

It is necessary to emphasize that the Chlorophyll values can only be considered as semi-quantitative. There are several reasons for this. Bunt emphasized the very fragile nature of the under-surface of sea-ice and described his difficulties in obtaining quantitative samples. The same condition undoubtedly occurs in the Arctic, and it is unlikely that the corer collects all the ice within its cutting diameter. Further, sections had to be cut from the core as far as pigments were visible; thus it is quite possible that some pigment was not included in the samples. Finally, the concentrations are calculated on the basis of the amount of water filtered and it is possible that some water that did not contain pigments was filtered. This is probably true of the 1961 values which should then be rather larger. These sources of error will of course cause the actual chlorophyll concentrations to be underestimated. The figures listed can therefore be considered minimum values and the light readings maximum values.

It must be mentioned that the concentrations listed in my previous note[4] are low values. They were reported as micrograms per liter when they should have been listed as micrograms per core sample. The correct 1961 values are included in Table 1.

Since the algae develop as an interface flora, it is more meaningful to consider the quantity of chlorophyll on an aereal basis. This raises the question of the exact thickness of the chlorophyll band in the ice, and again reduces the reliability of quantitative measures. Nevertheless, Table 1 include values for chlorophyll $a/m^2$ for those samples that were taken from normal, snow-covered sea-ice and appeared most reliable upon collection.

The table also includes indications of the depth of snow and the ice thickness.

**Table 1.** Chlorophyll *a* concentrations from sea-ice, Jones Sound, 1961-63.

| *Date* | *μg/1* | *mg./m²* | *snow (cm.)* | *ice (cm.)* |
|---|---|---|---|---|
| *1961* | | | | |
| 4 June | 307 | 10.6 | 23 | 165 |
| | 383 | | | |
| 5 " | 645 | 23.0 | 24 | |
| 6 " | 229 | | 23 | |
| 7 " | 495 | 17.9 | 20 | |
| 9 " | 325 | 11.6 | 21 | |
| 10 " | 123 | | cleared* | |
| | 107 | | cleared* | |
| 11 " | 380 | 13.2 | 20 | |
| | 114 | | cleared* | |
| 12 " | 639 | 23.0 | 18 | |
| | 133 | | cleared* | |
| 13 " | 283 | 9.5 | 17 | |
| | 65 | | cleared* | |
| 16 " | 99 | | cleared† | |
| 20 " | 114 | | no snow, melt puddles on ice | |
| | 196 | | " " " | |
| 23 " | 30 | | " " " | |
| 26 " | 59 | | " " " | |
| 27 " | 58 | | " " " | |
| | 39 | | " " " | |
| *1962* | | | | |
| 9 April | 186 | | 0 | 210 |
| 30 " | 297 | | 13 | 165 |
| *1963* | | | | |
| 11 May | 596 | 9.6 | 10 | 190 |
| | 194 | 3.0 | 20 | |
| 14 " | 1460 | 23.0 | 10 | |
| | 610 | 9.5 | | |
| 20 " | 582 | 9.4 | 10 | |
| | 720 | 11.5 | | |
| 22 " | 638 | 10.0 | 10 | |
| | 686 | 11.0 | 12 | |
| | 525 | 8.5 | 19 | |
| 31 " | 438 | 7.8 | 0 | |
| | 775 | 12.6 | 0 | |
| | 571 | 9.3 | 10 | |
| 1 June | 453 | 7.0 | 12 | |
| | 1205 | 19.6 | 12 | |
| 4 " | 369 | | cleared†† | |
| | 545 | 9.0 | 10 | |
| 6 " | 121 | | cleared†† | |
| | 552 | 9.0 | 11 | |
| 7 " | 762 | 12.0 | 10 | |
| 12 " | 178 | | cleared†† | |
| | 323 | | 10, melting | |

*area artificially cleared of snow on 3 June.
†area artificially cleared of snow on 10 June.
††area artificially cleared of snow on 1 June.

## Discussion

The chlorophyll values are very high when expressed on a volumetric basis. They average at least an order of magnitude larger than the largest concentrations found in rich coastal diatom blooms and are at least two orders of magnitude larger than concentrations in open sea water.[5]

**Table 2.** Light penetration through snow and ice in Jones Sound, N.W.T., 1962.

| *Date* | *Sky* | *Surface* *µ-amps* | *Surface* *foot-candles* | *170 cm.* *µ-amps* | *170 cm.* *foot-candles* | *Snow cm.* |
|---|---|---|---|---|---|---|
| 21 March | Bright | 2380 | 595 | 14.8 | 3.7 | 8 |
| 25 " | " | 2800 | 700 | 16.4 | 4.1 | 8 |
| 7 April | " | 4200 | 1050 | 17.8 | 4.5 | 8 |
| 20 " | " | 4200 | 1050 | 22.3 | 5.6 | 8 |
| 30 " | " | 4600 | 1150 | 44.0 | 11.0 | 13 |
| 8 May | " | 6200 | 1550 | 58.0 | 14.5 | 13 |
| 22 " | Total uniform overcast | 5680 | 1420 | 92.0 | 23.0 | Wind-packed |
| 1 June | Total, thick uniform overcast | 4640 | 1160 | 108.0 | 27.1 | 15 Some deterioration |
| 4 " | Bright | 6880 | 1718 | 175.0 | 43.0 | Soft & wet |
| 9 " | Uniform overcast | 4400 | 1100 | 700.0 | 175.0 | No snow |
| 12 " | Bright | 6720 | 1680 | 960.0 | 240.0 | Melt puddles on ice |
| 16 " | " | 6400 | 1600 | 860.0 | 215.0 | " " |
| 29 " | Uniform overcast | 4400 | 1100 | 500.0 | 125.0 | " " |

Meguro's value for chlorophyll *a* (0.67 mg/1) compares very well with the arctic values, and Bunt's values are also in this high range of concentration even though his population grew under ice at least twice as thick as the arctic ice.

The variability that is obvious in Table 1 is undoubtedly due in part to the inherent inadequacy of my collecting technique. It may also be caused in part by local variations in the depth of the snow cover, and it may further result from unequal grazing by amphipods. In 1961 the bottom of one core was completely covered by very small, probably newborn, amphipods that were rather firmly attached to the ice, and were undoubtedly feeding on the algae. This phenomenon was observed only once.

My previous note raised the question of the amount of light at the bottom of the ice and indicated that the algae are adapted to very low light intensities. Bunt found a mean light intensity of around 8 foot-candles in his sampling zone, indicating extreme "shade" characteristics. The photometric values in Table 2, as stated previously, may be higher than the values reaching the algal layer. They are also undoubtedly higher than the intensities in 1961 and 1963 since the snow cover in 1962 was rather less than in the other years. The marked increase in light values after the snow melted (compare 1 and 9 June) indicates the high extinction coefficient of snow. It is probably safe to say that an intensity of less than 20 foot-candles reached the bottom of the ice in 1962 at the time of the maximum chlorophyll development. In 1961, since the snow was about twice as deep, probably no more than 10-15 foot-candles reached the algal population. Dr A. E. Collin[6] found no more than 10 foot-candles penetrating 23 cm. of snow and 2.3 m. of sea-ice on 24 May 1961, at 79° N., with a surface intensity of 1450 foot-candles.

The volumetric concentrations in Table 1 are generally lower in 1961 than in 1963. As indicated above, this may be simply a reflection of the fact that more water per sample on the average was filtered in 1961. The method of calculating the aereal values, however, makes the values for the 2 years comparable. These data then suggest that the concentrations were higher in 1961 and I am inclined to believe that this was a real difference resulting from deeper snow in the earlier year.

Thomas[7] presented light absorption coefficients of snow and ice which show a marked decrease of absorption toward the shorter wave lengths. Strickland[8] indicated that chlorophyll c is at least 6 times as efficient as chlorophyll *a* in absorbing blue light, and in this connection it is pertinent that both Meguro and Bunt show that their algal populations contain roughly twice as much chlorophyll c as do planktonic diatoms[9]. The ratios of the ice pigments evidently are adapted to maximum absorption of blue light penetrating the snow and ice.

The arctic work in 1961 showed a marked decline in chlorophyll with increased light. This was again observed in 1963 (Table 1), and in the Antarctic Bunt and Wood reported "that a sudden increase in under-ice illumination . . . appeared to be related at least in part, to the loss of the epontic community coincident with the deterioration in the lower layers of the sea-ice". Undoubtedly some of the decline is attributable to physical changes in the ice, but it is highly likely also that a relatively high light intensity would cause considerable bleaching of pigments in such markedly "shade" organisms. The exact fate of the ice algae is not clear. There was no chlorophyll in the water below the arctic ice that could be related to the ice plants, and whether the cells drop off the ice or remain attached in a bleached state is not known. It was previously noted that the bottom of the ice retained its characteristic appearance when the algae disappeared during the snow melt. This suggests that the algae did not melt off the ice.

Bunt's work[3] and mine in the Arctic show that these algal growths are clearly separated in time from the normal phytoplankton bloom. The water below the arctic ice remains low in cell counts and light extinction coefficients, and high in nutrient concentrations.

There is doubt about the extent of the distribution of ice algae through the arctic seas. It is very likely that the plants occur on all one-year-old ice on the periphery of the Arctic Ocean, and I have found them in large quantities in June on young winter ice on northern Ellesmere Island at the edge of the Arctic Ocean. The degree of their occurrence on the thick, old ice of the Arctic Ocean itself, however, is uncertain. English[10], on Drifting Station Alpha, observed "films of organic matter, composed of diatoms, bacteria, and detritus . . . on the bottom and sides of ice floes". He also found amphipods grazing along the bottom and sides of floes but he concluded that "those organic inclusions must be infrequent and of small significance in the economy of the ocean". Tibbs[11], on Arlis II, "found no evidence of (amphipods) obtaining food embedded in the ice" and the same authors reported that "cores of the floe ice were essentially devoid of microscopic organisms", but they recognize the possibility of patchy distribution of organisms. The work in Jones Sound demonstrates the seasonal occurrence of the algae and that the plants probably are not visually obvious after the snow melts.

The present data do not permit an estimate of the seasonal variations of the amount of chlorophyll on the arctic ice on which the plants do occur. In view of the fragile nature of rapidly growing sea-ice, it is unlikely that adequate data in the early spring can be obtained using a CRREL corer, and in March and early April 1962, no chlorophyll was found on snow-covered sea-ice. The expedition glaciologist, R. M. Koerner, found chlorophyll on 24 March under 7 ft. of ice in an inlet. There was practically no snow on this ice and it received a little weak sunlight for only about four hours a day at that time. He again found chlorophyll in that spot on 9 April. On the more typical, offshore, snow-covered sea-ice, chlorophyll was first found on 20 April with an incident light intensity on the algae of about 5 foot-candles. The chlorophyll probably reaches a maximum concentration in late May or early June, and by mid-June it must decline as the snow melts. There is, then, a period of about 7 weeks in which chlorophyll is present in very high concentrations on arctic sea-ice peripheral to the Arctic Ocean, and such a concentrated source of *potential* food for a rather long period of time should offer optimum feeding conditions to arctic marine browsers. It is clearly of greater *potential* significance than the phytoplankton as a source of primary production in the Arctic.

Weeks and Lee[12] estimate that 16 million sq. km. of sea-ice exist each year in the northern hemisphere. Ignoring the area of the Arctic Ocean ($14x10^6$ $km^2$: Sverdrup *et al.*[13]) for which the extent of the ice algae is uncertain, it can be estimated that a *standing crop* of at least 10-12 mg./m.$^2$ or 25x10$^6$ kg. Chl. *a* exists during about two months. A conservative carbon to chlorophyll ratio of 30:1 suggests a standing crop of 750x10$^6$ kg. C on the ice.[14] There is no quantitative information on the actual utilization of this food but since it is found at high concentrations throughout the spring and disappears as a result of increased light intensities, it is probable that little of it is assimilated into a higher trophic level.

It is unlikely that the algal growth described by Meguro[1] occurs to any significant extent in the Arctic since it is evidently dependent upon a snow layer remaining on broken sea-ice. The below-freezing air temperatures of the Antarctic permit this, but it is normal in the Arctic for the snow cover to melt and disappear before the ice breaks. There are apparently no reports of such a development in arctic ice, nor have I seen it while observing sea-ice in five different regions of the north.

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Mr. A. S. Bursa, Arctic Unit, Fisheries Research Board of Canada, has kindly examined preserved samples from the ice and has identified over 60 species of algae, of which diatoms are dominant. Mr. Bursa expects to prepare a separate report on the results of his examination.

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[15]The Devon Island Expedition received financial and material support from many sources. These are listed in Arctic, 14: 252-265.

**Corrigendum (Radiocarbon Dating, Barrow, Alaska)**

*Arctic*, Vol. 18, No. 1, page 36. Footnote to second column of Table 1 — *Age*[1] *(yrs. B.P.)* — should read: ". . . no corrections are made for new half life or *1950* reference year."