PHYTOPLANKTON IN COASTAL WATERS OF THE ARCTIC OCEAN AT POINT BARROW, ALASKA*

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Introduction

The few published works on the phytoplankton of the Arctic Ocean at the coast of Alaska have dealt mainly with taxonomy (Mann 1926, Allen 1927a, 1927b, 1930; Cupp 1937). Although many investigations have been made in the offshore waters of this region, they have been based mainly on net plankton collections, which are unsuitable for the study of species distribution and succession since many of the nannoplankton forms escape from plankton nets. The sedimentation method (using the reverse microscope) was the main technique used in the present investigation, and this was supplemented by the use of net-caught material. Special attention was paid to the quantitative dynamics of different taxonomic groups of the flagellates that are abundant in the marine environment, although derived from other ecological niches like freshwater ponds on beaches, meltwater ponds on the ice, lagoons, streams, and lakes.

Methods and materials

A Nansen reversible water bottle with thermometer was used for collecting most of the quantitative samples. A small plastic water bottle with a stopper was used in shallow waters of lakes, lagoons, and meltwater ponds on the sea-ice. Three per cent formalin, neutralized with borax, was used for preserving the samples. One hundred millilitres of seawater were stored in plastic vials for quantitative examination. Most of the quantitative samples were taken from the surface except at six stations where plankton was collected from several depths. An Utermöhl reverse microscope was used for quantitative estimation. Samples were sedimented in 5-, 10-, and 25-ml. cylinders, and an 8-power prismatic ocular was used for counting. For closer taxonomic observation an 8-power binocular was used. Rare or unidentifiable forms were transferred with a pipette from the bottom of the sedimentation cylinders and were studied under higher power with a compound microscope. When the nannoplankton was too numerous to be counted in a large volume of water the original seawater samples were mixed with distilled water in the proportion 1:9 for examination. Various

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flagellates and diatoms were grown in mixed cultures at the Arctic Research Laboratory, Barrow and were used for taxonomic identification. To supplement the quantitative samples a number of collections were made using a plankton net of No. 25 silk.

The following references were used for identification: Hustedt (1930) for diatoms, Schiller (1930) and Cupp (1937) for Coccolithineae, Lebour (1925), Schiller (1933, 1937), Kiselev (1950), Wood (1954) and Gaarder (1954) for dinoflagellates, Leegård (1915) for ciliates, Kofoid and Campbell (1929) for tintinnids, Lemmermann (1908), Huber-Pestalozzi (1950), Hollande (1952) and Deflandre (1952) for flagellates.

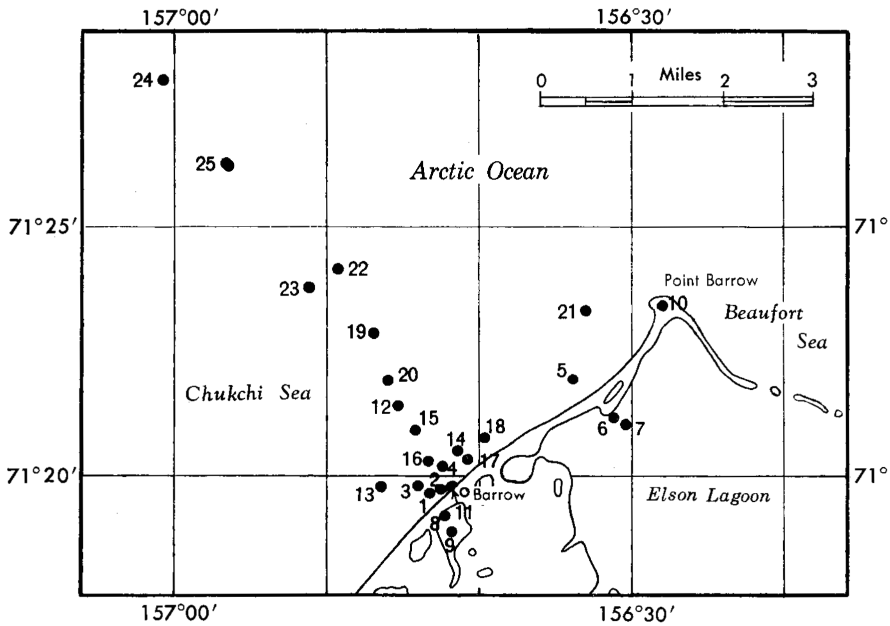

Table 1. Phytoplankton stations in the vicinity of Point Barrow, Alaska, 1954. (See also table of stations in Appendix)

Physical conditions

The flow of Alaskan coastal water tends to follow the contours of the coast, deflecting into Norton Sound, closely hugging the Alaskan side of Bering Strait, deflecting into Kotzebue Sound, continuing north around major promontories and finally flowing north from Point Barrow (LaFond 1954). Entrance of Pacific zooplankton species to the Chukchi and Beaufort seas by this route is shown by Johnson (1956), and that of many Pacific phytoplankton species into the Barrow area was observed in 1954.

The shallowness of the Arctic Ocean off the Alaskan and Canadian coasts strongly influences the type and taxonomic composition of the plankton flora by limiting the number of pelagic species. Strong wind activity during the open-water period complicates proper identification of the water masses and their plankton populations. Although frequent upwelling may favour growth of phytoplankton by supplying nutrients from the bottom, it may also reduce light penetration in the euphotic zone.

Temperature and salinity in the Point Barrow area during the open-water period (Wilimovski 1953a, 1953b, 1954) are rather variable in July and August. Inshore salinity in 1953 varied from 8.77‰ to 24.33‰, in 1954 from 16.33‰ to 30.55‰. Maximum temperature in August 1954 was 10.2°C. Even in the middle of summer water temperature can be as low as 1°C.

MacGinitie (1955) noted that "ice grounds out to a depth of 90 to 100 feet", thus inhibiting faunal development. According to Rex (1955) ice grounding mixes the surface sediments of the bottom perhaps to a depth of 4 to 5 feet thereby destroying stratification, oxygenating the sediment and considerably modifying the environment of the benthic organisms. My own observations show that ice along the Alaskan coast stirs up the surface sediment of the beaches. Even large stones with attached *Alaria* and *Laminaria* were taken up to the beach by the ice. Severe ice conditions delay the development of the microbenthos, which is very sparse and has only a short period of development during the brief period of open water.

Phytoplankton below the ice

Arctic ice is one of the major limiting factors of growth of autotrophic plankton, and according to Braarud and Hope (1952) may delay the spring diatom maximum for many weeks. The two net samples of plankton taken at station 1 Fig. 1 on June 12 (copies of "phytoplankton tables" showing the occurrence of species may be obtained from the author), one close to the ice, the other at a depth of 6 metres, contained mainly *Chlorella salina, Chlorella* sp., *Oocystis* sp., *Scenedesmus bijugatus,* and *Cryptomonas* sp. In contrast to the surface sample, the 6-metre sample contained mostly brackish diatoms, *Navicula* sp., *Nitzschia closterium, Nitzschia* sp., *Synedra* sp., *Grammatophora* sp., and very numerous Chrysomonadineae. Other samples taken approximately 30 to 40 yards from the beach were similar and contained mainly freshwater organisms. These samples, kept under illumination, soon showed flourishing populations of *Massartia asymmetrica, M. glandula, Gymnodinium* sp., *Bodo* sp., *Cryptomonas* sp., and amoebas, not noticed at the time of collecting. Low salinities during the time of melting favour the growth of freshwater and brackish forms. Late spring and summer abundance of euryhaline species is associated with increasing salinities.

Microflora of meltwater pools

When the surface of the arctic ice melts, its microflora gradually changes from a sedentary population to one living in suspension in the small brackish pools. In the middle of June dispersed patches of bacteria and fungi were observed on the surface of the ice. In the course of progressive melting flagellated species of algae and colourless forms became more common. In some pools green patches of *Chlorella salina, Oocystis* sp., and *Ulothrix* sp. were found attached to the bottom. In the middle of July a very large system of shallow pools covered the sea-ice, containing large populations of flagellated organisms and diatoms, as well as some ciliates. These pools and their microflora disappeared when the ice broke up in the coastal area. The microflora of the offshore pack-ice continued its activities until the first autumn frost. The nutritional requirements of the ice-flora are probably supported mainly by nutrients derived from detritus from the tundra and bird and animal faeces. The sand, gravel, and silt in the ice and on its surface come from the sea bottom; they hasten melting of the ice by absorbing more heat than the surrounding ice itself. The peculiar opalescent colour of the water in the pools on the arctic ice is characteristic, but it was not possible to establish whether it was caused by the abundance of *Ochromonas glacialis* or by some chemical properties of the water. The ecosystem of the arctic ice represents the poorest oligohaline type of short duration and is probably of small importance as far as general plankton production in the ocean is concerned. Owing to the physio-chemical continuity of snow and ice, the microflora has cosmopolitan features probably found in any geographical latitude.

Two pools on the sea-ice, stations 2 (June 30) and 3 (July 9), showed very similar populations of microflora. The total number of species in the first pool consisted of 3 pennate diatoms, 13 freshwater green algae, 1 chrysomonadinean, 1 colourless flagellate, and some unidentified ciliates. The second pool contained 1 brackish diatom, 10 species of freshwater green algae and a single chrysomonadinean. Other pools on the ice examined in late August also contained some marine plankton species, which entered the pools through deep perforations in the ice. These were the diatoms *Achnantes taeniata, Fragillaria oceanica, Navicula* sp. and *Chaetoceros wighami.*

Elson Lagoon

The long narrow strip of Barrow Peninsula separates Elson Lagoon from the Chukchi Sea. Arctic water enters the lagoon from the east through several channels, Eluitkak Pass, Ekilkruak Entrance, and others yet unnamed, situated between Barrow Peninsula, Doctor and Tapkaluk Islands. The average depth of the lagoon is about 8 feet. The sand and gravel covering the floor of the lagoon favour the growth of benthic algae, *Ulva* sp., *Enteromorpha* sp., *Cladophora* sp., *Sphacelaria* sp., and *Lithoderma* sp., which are attached to the surface of small stones. The large influx from many streams dilutes the lagoon water, in which freshwater, brackish and euryhaline organisms are mixed.

Elson Lagoon commonly varies slightly in temperature owing to wind and current effects. The oxygen values were uniformly near saturation through the summer (Wohlschlag 1955, personal communication). Elson Lagoon waters are well aerated, owing to its shallowness and to wind effects. The high oxygen content could be produced by photosynthetic activities of autotrophic plankton, benthic algae, and the microflora that cover the bottom of the lagoon as a dense brown crust. Local plankton populations of Elson Lagoon are protected by several islands from immediate mixing with the phytoplankton of the Beaufort Sea. Rare in the net hauls in the Arctic Ocean stations, *Goniaulax catenata, Chaetoceros wighami,* and *Ch. socialis* were common in Elson Lagoon. Grazing effectiveness in the lagoon is increased by large numbers of bottom animals. The water of the lagoon is dark, because it flows through the bogs and carries large quantities of humic acids and detritus, washed in from the tundra. The phytoplankton collected on August 14, station 14, showed 8,930 diatoms, 1,280 dinoflagellates, 10,900 unindentified flagellates, with *Polytomella* species dominant, and 400 ciliates per litre. The same locality on August 23 showed an increase of *Polytomella* species and some tiny holozoic flagellates, up to 82,400 cells per litre, 5,280 diatoms, 1,340 dinoflagellates and 160 ciliates per litre. Since the ice of Elson Lagoon melts earlier than that in the ocean, these observations represent the decreasing phase in phytoplankton production in the lagoon. Its maximum probably had occurred in the middle of July.

Surface temperatures obtained from Dr. Wohlschlag (private communication 1955) were: July 31, 6.67°C; August 14, 10.83°C; August 17, 8.89°C; September 8, 7.78°C; September 9, 7.22°C.

The leads in the sea-ice

The leads in the ice of the neritic area near Barrow start to open at the beginning of May, and may last until the inshore waters are cleared of ice. The length of the leads varies from several feet to many miles. Life activities begin to accelerate about 2 months earlier in the leads than in the ice-covered areas. Direct exposure to sunlight and contact with air may favour phototactic migration of flagellates from under-ice darkness. These movements attract zooplankton and larger animals, including pteropods and medusae, which swarm in the leads.

Small populations of phytoplankton are found in early summer; considerably larger populations are observed later in the summer in spite of intensive grazing by zooplankton. The lead examined on June 18 (station 4) showed a population of phytoplankton comprising 13 species, among which tiny flagellates numbered 10,500 cells per litre. The lead opposite "Duck Camp" (station 5) had more abundant phytoplankton (23 species) and large dominant populations of *Nitzschia closterium* (60,500 cells per litre), *Goniaulax tamarensis* (15,800) and *Polytomella* sp. (39,400). The total number of diatoms was 77,500, of flagellated groups 58,700, and of ciliates 200 cells per litre. This is a large population, which may provide food for various types of zooplankton grazers.

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The lake west of Barrow

Prescott (1953) made an ecological study of the algae, and measured temperature, pH, and oxygen of this lake. A narrow connection between the lake and the Arctic Ocean allowed sea-water to enter the lake during storms. When a small causeway was built over the outlet (July, 1954) the water exchange between the ocean and the lake was cut off, with a resulting decrease in salinity.

The phytoplankton populations of the lake were rather unstable in their composition, and after storms many marine diatoms, dinoflagellates, and zooplankton were found in the lake for a few days and then disappeared. All *Ceratium* sp. swept into the lake were dead, or only empty membranes were found. *Peridinium pellucidum, P. finlandicum,* and *Peridinium* sp. had deteriorated little and seldom lost their motility. Either no, or very slight, deterioration and rejection of flagella was noticed in *Goniaulax tamarensis* and *Massartia asymmetrica.* It was also observed that the samples collected from the sandy or muddy surface of the lake bottom, after the lake was free of ice (end of June), contained *Amphidinium fusiforme* (Martin, 1929). This lake had a green belt of diatoms and filamentous algae including large populations of *Chlamydomonas, Oocystis, Polytomella,* and *Cryptomonas* sp. The green algae were most abundant near the northern end of the lake.

The phytoplankton at stations 7, 8 and 9, which were situated at the entrance to the lake and in the middle of it, shows a striking difference in composition compared with that at the inshore stations. This plankton had 2,440 and 2,840 diatoms and large populations of small autotrophic flagellates, which were represented by 53,660 and 160,340 individuals per litre (dinoflagellates are included in that number). The plankton station at the mouth of the lake contained mixed populations of brackish and freshwater species including rare euryhaline forms. *Cryptomonas* sp. and *Ochromonas* sp. were also quite common in the net and in sedimentation cylinders.

Three weeks after the connection between the ocean and the lake had been cut off by the causeway, the composition of the phytoplankton had changed drastically. Most of the marine dinoflagellates, including *Amphidiniopsis kofoidi* Woloszynska, the discovery of which in this lake was the first arctic find, disappeared completely. The large populations of *Pyramimonas grossi* (Parke, 1949) mixed with other species of the same genus and *Polytomella* became dominant over other freshwater flagellate species.

Nuwuk Pond

On the gravel spit that forms the "point"of Point Barrow are several ponds. The largest of these is called Nuwuk Pond. It is about 750 feet in greatest dimension, its northwest margin lying some 200 feet from the sea. Salinity tested on July 7, 1952, was 2.45‰ (Mohr, 1953). A sulfide mud covers the bottom of the deeper parts of the pond. Algae, *Enteromorpha, Ulothrix, Oscillatoria,* diatoms, Tintinnidae and Foraminifera were collected in 1952 (Mohr, *et al.,* 1961).

Nuwuk Pond (station 10) showed highly oligotrophic features. Phytoplankton samples taken on August 24 contained few species, mostly diatoms of freshwater origin. The total population taken a few metres from the margin of the pond contained per litre: *Navicula* sp., 120 cells; *Massartia* sp., 80; *Cryptomonas* sp., 100; *Bodo* sp., 1,000; unidentified cysts 3,200; *Mastigameba* sp., 2,400; and a non-planktonic *Saccharomyces* sp. Since the ice melts sooner in the pond than in the sea, it is possible that the phytoplankton maximum in the pond occurs earlier than the end of July, as has been supposed. *Bodo bacillariophagus* n. sp. described below, and some naked forms of dinoflagellates were also observed. The small ponds, which have sandy bottoms, contained fairly abundant populations of *Amphidinium* sp., which were not found along the beach of the Arctic Ocean.

The inshore plankton stations

The inshore plankton stations were taken mostly at the surface, chiefly opposite the site of the Arctic Research Laboratory, 71°19′45″ N. 156°40′50″ W., usually a few hundred yards from the beach. On some occasions plankton stations were located at a distance of 2 miles from the coast. The inshore hydrographical conditions were very unstable because of surface drift; wind action stirred up enormous quantities of organic and mineral detritus to such an extent that after storms the water was milky, and quantitative plankton assessments were often impossible. At the end of July plankton at the inshore stations is still in its initial phase of restoration after the breakup of the ice and the winter minimum. The freshwater species of green algae and diatoms were much more common in the close inshore belt of water than in the offshore area. The flagellated groups included holozoic and holophytic species, which were especially difficult to distinguish because of the detritus in the inshore water. They were represented by populations of Coccolithophorideae, *Polytomella, Pyramimonas,* and some unidentified forms, estimated at between 1,000 and 27,000 cells per litre. Bentic diatoms (*Navicula* sp., *Licmophora* sp. and *Melosira arenaria*) were common in this area though only in small numbers not exceeding hundreds.

The copepods from the inshore stations were packed with various dinoflagellates, especially *Goniaulax tamarensis* and *Gymnodinium* sp., while diatoms were rare. The dinoflagellates are selectively grazed by plankton crustaceans. Throughout the whole season of open water along the arctic coast, *G. tamarensis* was found frequently. It produced temporary thin cysts, as well as thick membraned cysts, which allow the organisms to survive and adapt to the changing salinity and temperature conditions in the inshore areas. Later observations at stations 11, 12, 14, and 15, show the increase of *G. tamarensis* populations and related species. The *Chaetoceros* group, usually common and numerous in neritic waters, was observed in the inshore water in small quantities only, or was absent entirely at most plankton stations.

The offshore plankton stations

The phytoplankton stations located from 2 to about 10 miles from the Barrow coast were seldom occupied, since the area was mostly covered by pack-ice even in late summer, and practically no ice-free pelagic waters existed in the Barrow region. Stations located within 2 or 3 miles of the coast showed increased numbers of typical marine diatoms and decreased populations of the freshwater or brackish green flagellates so abundant close to the beach. Stations 11 and 13 to 18 harboured large populations of Rotatoria (1,820 per litre), ciliates, naupli (520 per litre) and velligers which obviously reduced the phytoplankton populations. *Nitzschia closterium* reached its summer climax represented by 78,500 cells per litre at the surface of station 20. At station 20 there were 45,000 *Leptocylindrus danicus* and 28,000 *Goniaulax tamarensis,* which possibly represented the annual maxima for both species. It is remarkable that *Dinobryon balticum* occurred in the large number of 98,000 cells per litre, which means that this freshwater organism is physiologically well adapted to conditions in the Arctic Ocean. A small diatom, *Chaetoceros subtilis,* was found to number 30,000 cells per litre. It had not been reported previously from the inshore waters of the Arctic.

All plankton stations situated more than 3 miles from the coast showed that large pelagic species *Chaetoceros atlanticus, Ch. concavicornis,* and *Ch. eibeni* become more numerous with increasing distance from the shore. The benthic and neritic diatoms decreased in number at the offshore stations. Johnson (1956) observed a diatom bloom near Point Barrow. I did not see any bloom in 1954.

Two offshore plankton stations (22 and 23), taken nearly 5 miles off the Barrow coast on August 15 and 29, showed some increase in the *Chaetoceros* group, among which *Ch. gracilis* reached a maximum of 38,340 cells per litre, whereas *Ch. atlanticus, Ch. compressus, Ch. debilis, Ch. laciniosus,* and *Ch. eibeni* occurred in smaller numbers, totalling 82,620 cells per litre.

N. closterium and Navicula sp. were found in smaller populations (4,000 and 5,300 cells per litre) than at the inshore stations. The mixture of benthic diatoms was still noticed. *Sceletonema costatum,* rare in the Barrow area, was found as only 2,000 cells per litre. *Ceratium arcticum* occurred as 440 cells per litre, despite the lateness of the season. The other dinoflagellates, though present in net samples, occurred in small quantities in the sedimentation cylinders. Station 21, taken at the end of August, shows an evident decrease of phytoplankton species in all groups, approaching the autumn minimum. Whereas the populations of Coccolithophoridineae and some unidentified flagellates were, with 126,000 cells per litre, still large in the middle of August, at the end of the month they diminished to 39,600 cells. The quantity of phytoplankton at the surface was observed to change within a few hours. In calm weather higher surface plankton concentrations were found, but after even small storms, as a result of vertical dispersal from euphotic to dysphotic layers and over larger volumes of water smaller concentrations were found. It is a matter for future research to establish the value of plankton dispersal coefficients by wind and water currents.

Station 24, occupied on August 14, 10 miles off the Barrow coast, shows a broad similarity to station 23 (August 29), 5 miles off Barrow. There are, however, differences in the taxonomic composition, and benthic elements disappear from the plankton. *Chaetoceros compressus,* rare at other stations, occurred as a population of 14,200 cells per litre, *Ch. laciniosus* as 5,600. The phytoplankton populations of this station had been greatly reduced by a large number of ciliates, of which 720 per litre were found at the surface.

Station 25, situated 8 miles off the Barrow coast, was occupied on September 7. In spite of the lateness of the season, the net sample contained 46 species of diatoms, various dinoflagellates, and other flagellated groups previously not observed at other stations. It is probable that the even dispersal of small populations of diatoms and dinoflagellates from the surface to 40 metres depth is a result of current activity, which is very strong in this area. The maximum of *Thalassionema nitzschioides* occurred at 20 metres depth, *Thalassiosira gravida,* an important phytoplankton producer, had its maximum of 1,480 cells per litre at 10 metres depth.

All *Ceratium* populations, from the surface to 40 metres depth, occurred in large numbers. Unidentified flagellates numbered 27,000 cells per litre at the surface, with the maximum at 5 metres, and their number gradually diminished with increasing depth. It is not possible to evaluate the phytoplankton productivity of the offshore belt, based on only two stations, with no information on the previous history of the water masses and their organisms. The available observations allow the conclusion, however, that in spite of the high northern latitude and adverse ice conditions, the biomass of plankton diatoms is sufficiently great for the winter survival of zooplankton.

Taxonomy of new and rare species

CHRYSOMONADINEAE

Ochromonas glacialis n. sp. (Fig. 2).

Cells are broadly rounded anteriorly, where two flagella of unequal length emerge. Single olive-green chromatophores, or two, were changing their position within the cell. Holozoic individuals are common. Bacteria are ingested with an elongated food vacuole rapidly appearing at the base of the longer flagellum; this happens when the organism is attached to the substrate by a short hyaline stalk. The undigested food particles were removed by the motile individuals from the excretory vacuole formed posteriorly. This morphologically highly variable organism moves very fast along an irregular spiral pathway. Dimensions of holophytic forms: length from 5 to 10 μ, breadth from 4 to 6 μ; of holozoic forms: length from 5 to 8 μ, breadth from 4 to 6 μ. It was common in meltwater pools on the surface of the ice, from June to July, 1954. It was kept for 2 months in mixed culture enriched with nitrates and phosphates, in the Arctic Research Laboratory at Barrow.

flagellum is stretched forward and performs fast undulatory movements. The species is highly variable morphologically, changing its shape from a spherical to an elongated form while moving. Some individuals may reject their flagella, become spherical and remain motionless. The nucleus is spherical and subcentral. Nutritional requirements are highly specialized.

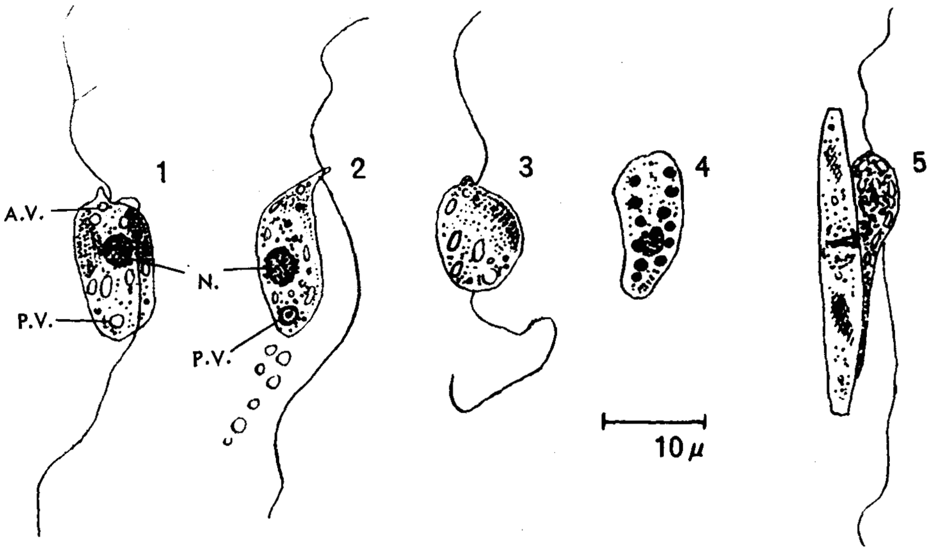

Fig. 7. *Bodo bacillariophagus* n. sp. (1) ventral view, showing anterior vacuole (A.V.), nucleus (N.), and posterior vacuole (P.V.), the dotted areas showing blue-pinkish plasts; (2) side view, showing flagella, nucleus and posterior vacuole; (3) an almost subspherical form, not compressed dorso-ventrally; (4) an individual after rejection of flagella following staining with cresyl blue, the vacuole stained with dark-blue globules; (5) individual attached to a diatom ingests nuclear content with the thin haustorium inserted through the raphe. All observed *in vivo*. *Camera lucida*, 43 × 25.

Bodo bacillariophagus attaches itself to the moving diatoms, *Navicula* sp., which lose their own independent motility and are carried along by *Bodo*. The attacking flagellate extends its delicate haustorium through the raphe into the diatom and ingests the nucleoplasm. It was observed that the chromatophores and protoplasm are not touched by *Bodo*. After a few minutes, *Bodo* separates itself from the diatom and swims freely. Diffused blue-pinkish plast-like pigment concentration was seen in some individuals of this flagellate. Staining with cresyl blue, 0.5 per cent solution, produces dark blue coloration of globules within the protoplasm. Flagella are rejected. Excretion of undigested food takes place posteriorly and, rather remarkably, in the form of small bubbles. Cell length is from 8 to 19 μ, breadth from 6 to 9 μ. The species was found in Nuwuk Pond, near Point Barrow, Alaska, and on the Arctic Ocean beach. It was very rare, and was found from July to September.

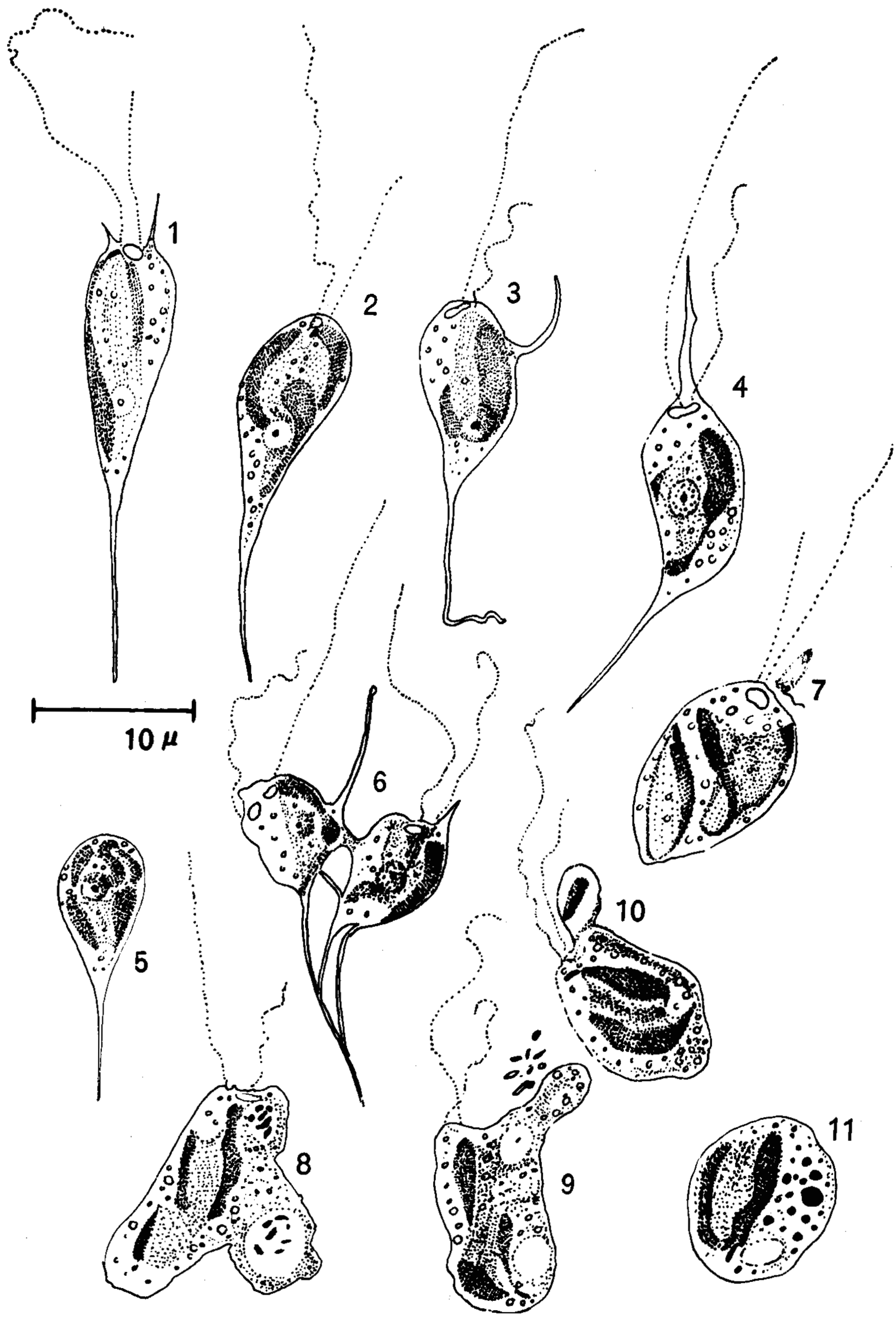

Fig. 3. *Ochromonas pearyi* n. sp. (1-4) sedentary individuals, with flagella, stigma, food vacuole, chromatophores, and apical protoplasmatic extensions; (5) sedentary individual after rejection of flagella; (6) division of a sedentary individual; (7) ingestion of food (small holozoic flagellates); (8) digestion of food in the food vacuole; (9) rejection of undigested food remnants from the vacuole; (10) extended vacuole immediately after capture of flagellates; (11) palmelloidal phase of *Ochromonas* stained with cresyl blue. *Camera lucida,* oil immers., 95 × 25.

Amphidiopsis kofoidi Woloszynska (Fig. 4 and 5).

Polymorphic *A. kofoidi,* discovered in the Baltic by Woloszynska (1928), is a rare species. This second known locality on the Alaskan coast is widely separated from that in the Baltic Sea. According to Woloszynska, many arctic dinoflagellates were introduced into the Baltic when an Arctic-Baltic connection existed

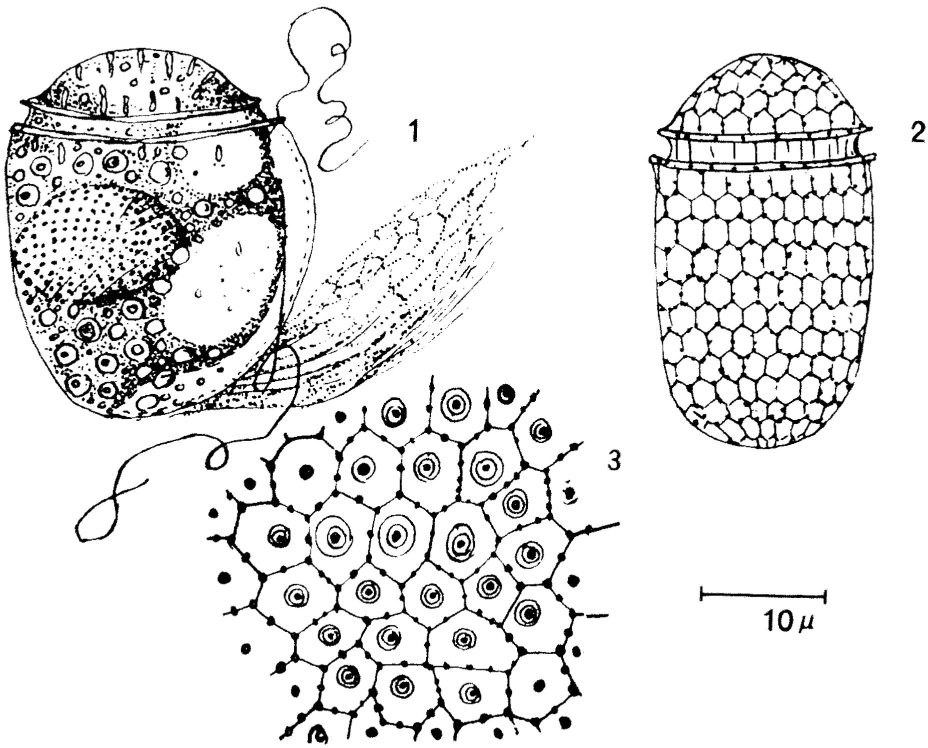

Fig. 4. *Amphidiniopsis kofoidi* Woloszynska. (1) lateral view, reticulate surface membrane detached from the sulcus after treatment with cresyl blue, with nucleus, two food vacuoles, anterior and longitudinal flagella; (2) dorsal view, showing reticulate membrane surface; (3) hexagonate membrane plates of the surface membrane lamella; showing homogeneous and heterogeneous inclusions within the reticulate plates, stained with weak lugol solution; and homogeneous spherical inclusions within the sutures of the small hexagonate plates. *Camera lucida,* oil immers., 95 × 25.

A. kofoidi was observed *in vivo,* and stained with 0.5 per cent cresyl blue. Over 150 living and many preserved cells were examined. Ingested food greatly influenced the external shape of the cells. Large diatoms and *Gymnodium* that had been ingested deformed them so much that they looked like other organisms. The cell-membrane of *A. kofoidi* consists of three layers. The surface (outermost) layer is very thin, with delicate hexagonal reticulation. The middle layer is much thicker and the plate sutures can be distinguished in it. The innermost layer is fused with the protoplasm. The homogeneous and heterogeneous spherical amyloid inclusions are embedded in all membrane layers.

Description of the membrane plates

Differences in the arrangement and shape of the membrane plates in Baltic and Alaskan *A. kofoidi* are not sufficiently large to allow their

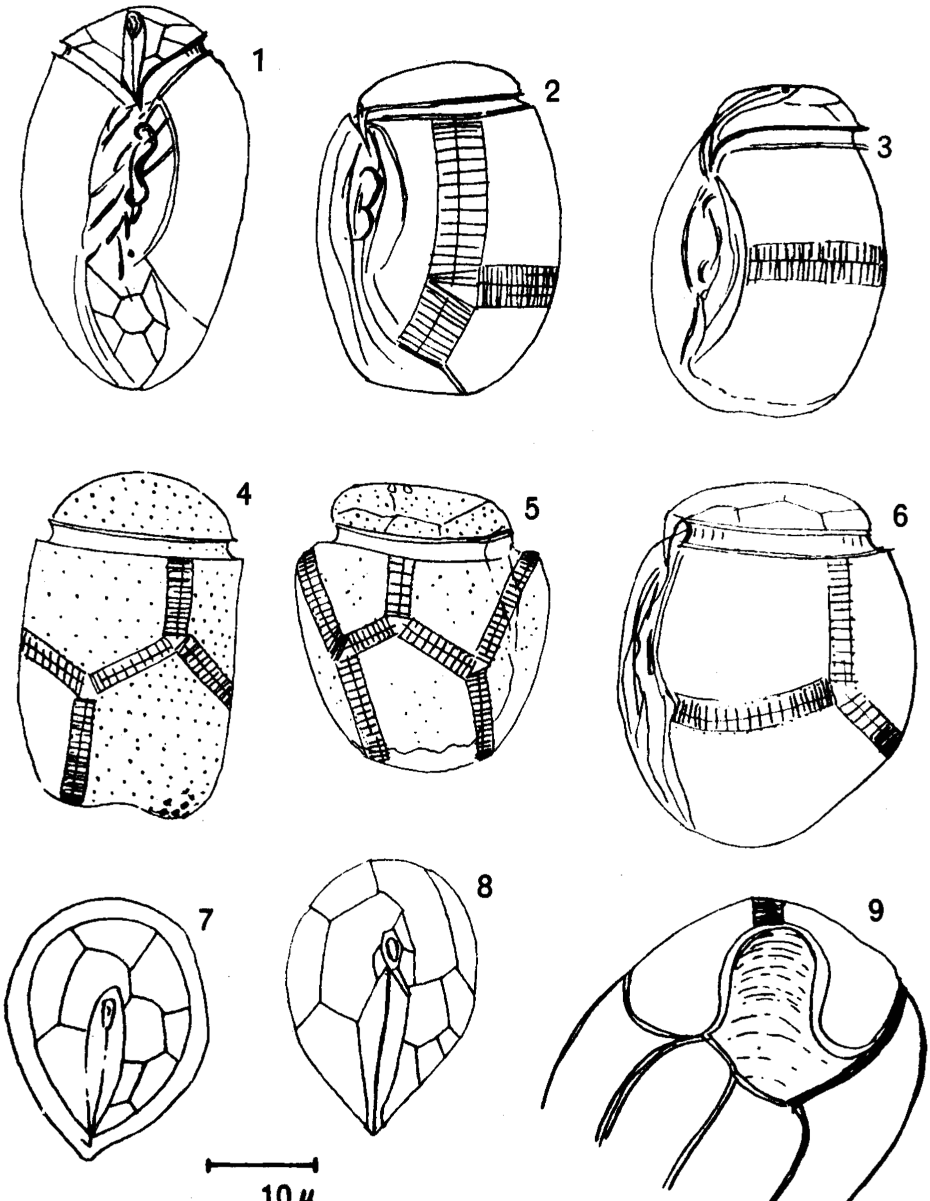

Fig. 5. *Amphidiniopsis kofoidi* Woloszynska. (1) ventral view of the epicone plate arrangement, sulcal area and antapical hexagonate plate with six additional side plates; (2) side view; (3) cell with reduced number of plates; (4) plates in dorsal view; (5) dorsal view of short individual; (6) individual on its left side showing plate arrangement; (7, 8) front view of the apex with previously undescribed small plate within the apex; (9) antapical view of the sulcus. *Camera lucida,* oil immers., 95 × 25.

separation into two forms. It has, however, to be considered that Woloszynska based her formula for the plates on only two empty thecas, whereas the Alaskan dinoflagellate is described from more than 150 living and preserved cells. Although the formula for the membrane plates given by Woloszynska for the Baltic form applies to the Alaskan also, the latter shows 3′, 7″, 5‴, 2⁗ as well. However, many thecas possessed more variable numbers of plates, which reflects intra-specific variability of *A. kofoidi* in general. This refers particularly to the newly described antapical sulcus platelets (Fig. 5, No. 1). The modified plate formula of *A. kofoidi,* including the varying counts of membrane plates, could be written as: 3′ to 5′, 7″ to 9″, 5‴, 2⁗, plus G.

Cell dimensions for the Baltic specimens (from Woloszynska 1928) are length, 30 to 40 μ, epicone width 15 to 22 μ and hypocone width from 18 to 25 μ. In Alaska length is from 25 to 40 μ, breadth of epicone from 14 to 20 μ and breadth of hypocone from 20 to 28 μ. Occurrence in the Baltic is recorded as Debki at Piasnica, in the neritic plankton; very rare, taken in May and October. In Alaska it was taken in a brackish lake west of Barrow Base in July.

DINOFLAGELLATAE

Gymnodinium alaskensis n. sp. (Fig. 6).

The body is ellipsoidal, flattened dorso-ventrally. The ventral surface is slightly concave, the dorsal convex. The girdle is displaced about one width, the sulcus extending from apex to antapex. The transverse flagellum completely encircles the body; the longitudinal flagellum is one-and-a-half times longer than the length of the cell. The shallow sulcus becomes wider where it meets the girdle. The longitudinal flagellum emerges below the acute notch of the hypocone; it opens widely at the antapex. The girdle is deeper than the sulcus. The large spherical or subspherical nucleus is close to the apex, with well-marked beaded chromosomes. The plasma is filled with spherical bodies of starch; those that are close to the membrane surface, or within the membrane, are arranged in longitudinal rows. Movement is slow, with rotation along the short axis of the cell. Chromatophores are long, ribbon-shaped, with acute ends brown green or brown yellow. Large crystals of cubic shape were observed in most individuals to form a regular ring or to be dispersed close to the membrane surface. Two forms of this species were observed: (a) epicone twice as long as hypocone; (b) epicone slightly longer than hypocone. Both forms have their largest diameter within the girdle. In both forms the girdle is deeply cut. Palmella stages were observed. Staining with 0.5 per cent cresyl blue in water solution shows three distinct layers within the palmelloidal mucilage with numerous darker transverse radii. In form (a) cell length is from 40 to 54 μ, breadth from 30 to 35 μ. Small individuals of 28 to 31 μ were observed. The species was taken in a lake to the west of the Barrow Base, between July and September, 1954. It occurred in both brackish and freshwater parts of the lake.

The protoplasm of living *G. alaskensis,* when treated with a 0.5 per cent boiling solution of mercury chloride, shrinks centrally, except for the numerous perpendicular threads of protoplasm, which have a greater consistency. These threads are fixed to the spherical amyloid bodies visible within the membrane. These are not trichocysts as described by Biechler (1952) in other dinoflagellates.

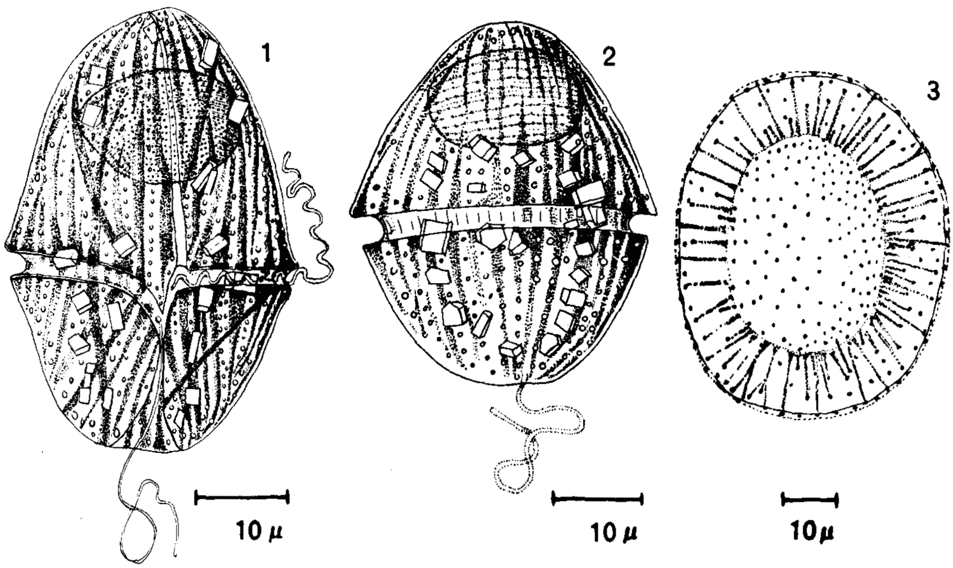

Fig. 6. *Gymnodinium alaskensis* n. sp. (1) ventral view of long form, showing chromatophores, nucleus, and anterior and longitudinal flagellum; (2) dorsal view of short form in which chromatophores, nucleus, and crystals are arranged in a circle; (3) after treatment with mercury chloride (5 per cent solution) the protoplasm has shrunk, except for the protoplasmatic threads that are attached to he membrane. The dark points on the surface belong to the threads and are partly embedded in the cell membrane. *Camera lucida,* oil immers., 95 × 25 (1 and 2), 43 × 10 (3).

G. alaskensis is most common on the bottom of small ponds and brackish lagoons. It is related to *G. placidum* Herdm. which lives in the sands at Port Erin, Isle of Man (Herdman 1921). It differs, however, from the European species in: (a) the presence of cubic crystals in the protoplasm; (b) the acute notch of the epicone; and (c) the absence of a streaky appearance.

BODONIDAE

Bodo bacillariophagus n. sp. (Fig. 7).

The cell is elongate, wide in dorso-ventral view, narrow in side view. Anterior part of cell is elongated into a proboscis-like extension starting from the shallow gullet in which the small spherical trichocysts are located. Two or three food vacuoles of unequal size were observed in motile specimens. The longitudinal flagellum, two-and-one-half times longer than the body, is dragged behind while the cell is moving forward. The shorter flagellum is stretched forward and performs fast undulatory movements. The species is highly variable morphologically, changing its shape from a spherical to an elongated form while moving. Some individuals may reject their flagella, become spherical and remain motionless. The nucleus is spherical and subcentral. Nutritional requirements are highly specialized.

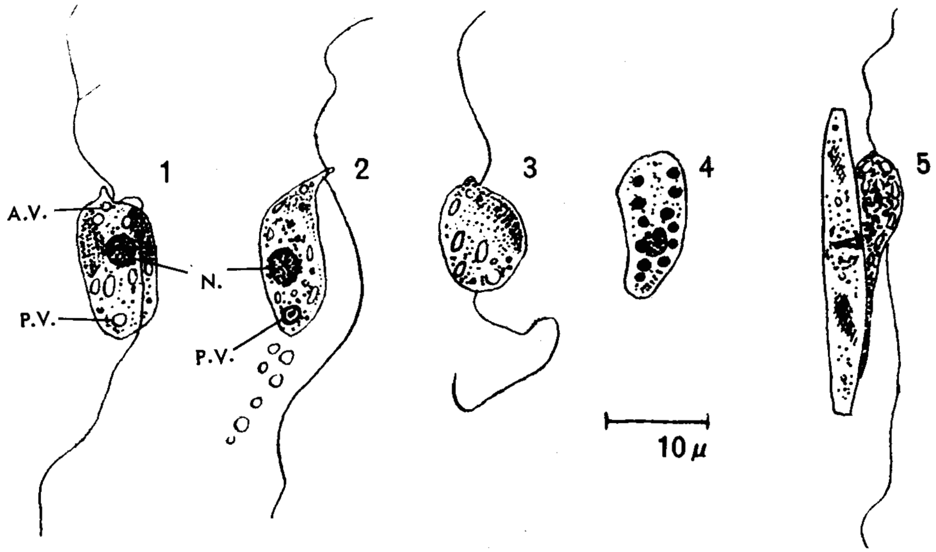

Fig. 7. *Bodo bacillariophagus* n. sp. (1) ventral view, showing anterior vacuole (A.V.), nucleus (N.), and posterior vacuole (P.V.), the dotted areas showing blue-pinkish plasts; (2) side view, showing flagella, nucleus and posterior vacuole; (3) an almost subspherical form, not compressed dorso-ventrally; (4) an individual after rejection of flagella following staining with cresyl blue, the vacuole stained with dark-blue globules; (5) individual attached to a diatom ingests nuclear content with the thin haustorium inserted through the raphe. All observed *in vivo*. *Camera lucida*, 43 × 25.

Bodo bacillariophagus attaches itself to the moving diatoms, *Navicula* sp., which lose their own independent motility and are carried along by *Bodo*. The attacking flagellate extends its delicate haustorium through the raphe into the diatom and ingests the nucleoplasm. It was observed that the chromatophores and protoplasm are not touched by *Bodo*. After a few minutes, *Bodo* separates itself from the diatom and swims freely. Diffused blue-pinkish plast-like pigment concentration was seen in some individuals of this flagellate. Staining with cresyl blue, 0.5 per cent solution, produces dark blue coloration of globules within the protoplasm. Flagella are rejected. Excretion of undigested food takes place posteriorly and, rather remarkably, in the form of small bubbles. Cell length is from 8 to 19 μ, breadth from 6 to 9 μ. The species was found in Nuwuk Pond, near Point Barrow, Alaska, and on the Arctic Ocean beach. It was very rare, and was found from July to September.

BACILLARIOPHYCEAE (CENTRICAE)

Chaetoceros decipiens Cleve forma *barrowensis* n.f. (Fig. 8).

Cells are from 10 μ wide, in broad girdle view four-cornered. Chains are usually short, from three to ten cells long, straight and flattened. Aperture is narrow, with flat or slightly undulating surface of the opposite cell wall. The terminal set is long and widely opened. The valvar surface of the apical axis is wide. From the surface of the apical axis emerge cone-shaped threads of mucilage differentiated into cortex and axis intensively absorbing cresyl brilliant blue.

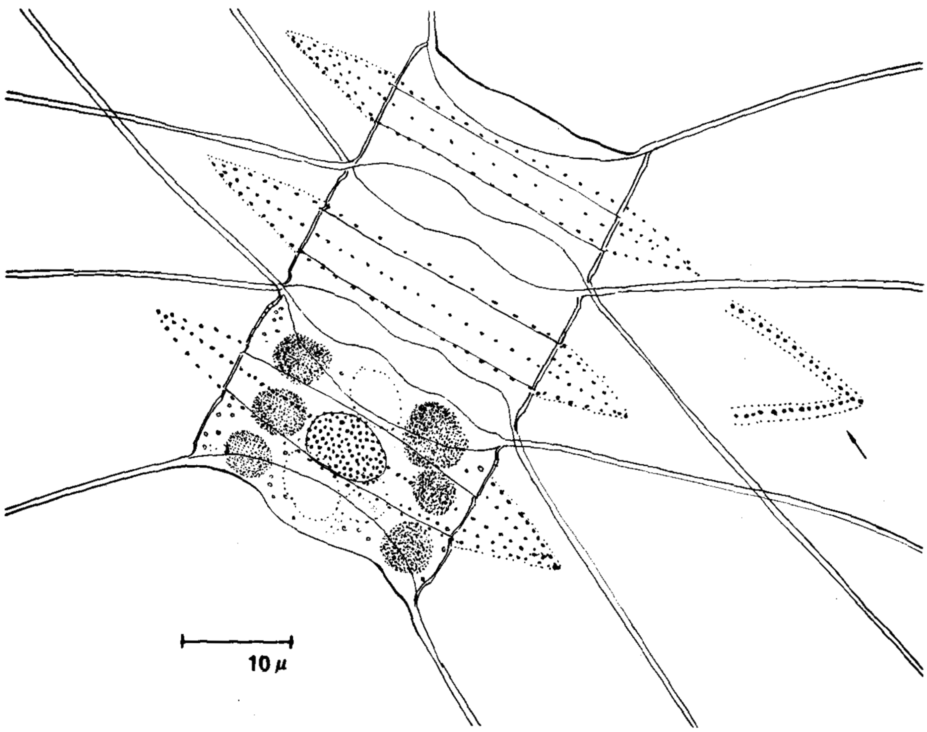

Fig. 8. *Chaetoceros decipiens* Cleve forma *barrowensis* n. f. in broad girdle view. The cone-shaped mucoid threads emerge through the cell membrane. The arrow shows a mucuous thread in which the cortex and small globular inclusions are seen. Stained *in vivo* with cresyl blue (0.5 per cent solution). *Camera lucida,* oil immers., 95 $\times$ 25.

The mucus threads emerge through the minute membrane pores visible after incineration. Cushing (1953 and 1955) demonstrated these pores in his electron microphotographs. The mucoid threads occurred rarely, otherwise all observed chains of *Ch. decipiens* show features identical with those given by Hustedt (1930) and Cupp (1943).

Summary

The living material in fresh- and salt-water starts from an inorganic solution used by autotrophs for growth of protoplasm, which passes through

the digestive systems of animals, and is decomposed by bacteria into inorganic elements again. Since water and its elements interact with the physiological activities of phytoplankton in the course of yearly changes, studies on plankton production and its ecology in open arctic water, coastal lagoons and lakes constitute an integral part of oceanography and limnology.

The arctic ice acts as a main limiting factor by inhibiting metabolic activities for from 9 to 11 months and thus creates an ecological niche for cryobionts and organisms living in the meltwater pools on the ice. The ice subsurface constitutes another typical arctic niche. It serves as a second sea floor for attachment of many endemic arctic diatoms, mainly pennate forms and to some extent Centricae from benthos and plankton. The biogeographical distribution, duration and alternation of planktonic diatoms is determined by ice conditions. Six different interlocking ecological niches and cycles, each containing a well-defined population, can be distinguished.

1. *The phytoplankton cycle below the ice.*

Phytoplankton taken by net immediately below the ice contained *Chlorella salina* and *Oocystis, Scenedesmus, Ochromonas* and *Bodo* spp. Samples taken at a depth of 6 metres below the ice contained mostly diatoms.

2. *The microflora of the meltwater pools.*

The microflora of the meltwater pools on the ice consists mainly of the freshwater green algae and flagellates, initially found on the ice surface (cryobionts) as conspicuous brown-green patches. When the ice breaks the microflora of the pools is mixed with marine waters and plankton.

3. *The phytoplankton cycle in the coastal and offshore leads.*

Phytoplankton activities begin in coastal leads while the rest of the water, covered by ice, is still cut off from sunlight energy. A single lead, which had opened close to the shore at Barrow by June 18, swarmed with zooplankton. Its phytoplankton consisted of 12 diatom species, among them *Goniaulax tamarensis* with 2,900 cells per litre. The lead examined on July 8, situated 2.5 miles from the coast, showed a population of diatoms of 77,520 cells, with a prominent maximum for *Nitzschia closterium* of 60,500 cells per litre.

The offshore phytoplankton stations, situated more than 3 miles from the beach, showed fewer benthic and neritic species than were found inshore. The phytoplankton populations in this area decrease towards the north. The pelagic diatoms *Chaetoceros decipiens, Ch. atlanticus, Ch. eibeni,* and *Ch. lorenzianus* were common. The neritic pattern of phytoplankton composition observed in calm weather in this area changed after a few days of northerly winds, with the appearance of pelagic *Gymnodinium lohmanni, Gyrodinium* sp., *Goniaulax monospina, Polykrikos* sp. and other species drifting towards the coast. It is noteworthy that no rapid decrease in the quantity of phytoplankton was observed in late summer, and that the large number of 46 species was still found in the net haul sample 8 miles offshore on September 7. In spite of the advanced date *Ceratium* species reached at this time its maximum of 400 cells per litre.

4. *The phytoplankton cycle in lagoons and lakes along the shore.*

Elson Lagoon, owing to its separation from the Arctic Ocean and its shallowness, has an autochthonous population of *Chaetoceros wighami, Ch. socialis, Goniaulax catenata,* freshwater and bentic diatoms.

The lagoon, situated on the west side of Barrow Base, is populated with freshwater Phytomonadina, occasionally mixed with phytoplankton swept by storms from the ocean into the lagoon. As a result of sudden changes of salinity and osmotic pressure, many animals are plasmolysed.

Nuwuk Pond, an oligotrophic, brackish lake on Point Barrow Peninsula, contained small populations of nannoplankton when examined in September.

5. *The phytoplankton cycle of the inshore waters.*

The phytoplankton of a strip of water extending for up to 3 miles from the beach fluctuates greatly in quantity and composition. The rapidly changing temperatures and salinities of this area, and its large amount of detritus, are not favourable for the growth of plankton, which is represented chiefly by the freshwater *Phytomonadina,* benthic diatoms.

6. *The benthic microflora of sandy and muddy sites.*

Diatoms, flagellated organisms, and blue-green algae, which make up the populations in these habitats, have been listed in the appendix but have not been investigated ecologically.

It is characteristic for the whole coastal area of Point Barrow that the diatoms *Thalassiosira* and *Coscinosira,* which occur usually in large quantities and form an important part of the biomass, were found only in very small numbers at a few stations, or were absent. *Chaetoceros atlanticus, Ch. concavicornis, Ch. decipiens,* and *Ch. lorenzianus* were common in net samples but poorly represented in the sedimentation cylinders. The neritic form *Nitzschia closterium* was most common in the area, reaching maxima of 30,000 to 78,000 cells per litre. *Leptocylindrus danicus* occurred also in the rather high number of 45,000 cells per litre.

Goniaulax tamarensis, Massartia rotundata, and *M. asymmetrica* were common at most inshore stations, *G. tamarensis* showing a maximum of 28,000 cells per litre in August. *Peridinium pellucidum, P. pallidum, P. breve, Protoceratium reticulatum, Dinophysis,* and *Ceratium* were common in offshore samples. Some species that are rare in the Barrow area, such as *Goniaulax diegenensis,* may come via the Chukchi Sea and its populations probably originate in the North Pacific.

Although the taxonomic record (see Appendix) comprises 90 species of diatoms, 79 species of dinoflagellates, 19 species belonging to different minor flagellate groups, 12 algae and 18 ciliates, including the new species *Gymnodinium alaskensis, Chaetoceros decipiens* f. *barrowensis, Ochromonas pearyi, O. glacialis* and *Bodo bacillariophagus,* this list is still far from complete. To complete it would require many years of research carried out continuously by specialists studying the occurrence of species in relation to ice conditions and water currents.

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Appendix

Table 1. Phytoplankton stations in the vicinity of Point Barrow, Alaska, 1954.

No.	*Date*	*Location*
1	June 12	below the ice, west of Barrow Base; (a) immediately below the ice, (b) 6 metres below the ice
2	June 30	meltwater ponds on the ice, west of Barrow Base
3	July 9	meltwater ponds on the ice, west of Barrow Base
4	June 18	lead 0.5 mile northwest of the Arctic Research Laboratory
5	July 8	lead opposite "Duck Camp". 2.5 miles off shore
6	Aug. 14	Elson Lagoon
7	Aug. 23	Elson Lagoon
8	July 28	entrance of lake southwest of Barrow Base
9	July 28	centre of lake southwest of Barrow Base
10	Aug. 24	Nuwuk Pond
11	July 22	beach near the Arctic Research Laboratory
12	July 24	2 miles off shore at Barrow Village
13	July 24	beach near Barrow Village
14	Aug. 6	0.5 mile off shore at Barrow Base
15	Aug. 9	1.5 mile off shore at Barrow Base
16	Aug. 13	0.5 mile off shore at Barrow Base
17	Aug. 19	400 yards off shore at Barrow Base
18	Aug. 18	a few hundred yards off shore at the Arctic Research Laboratory
19	Aug. 14	3.5 miles off shore at Barrow Base
20	Aug. 15	2.5 miles off shore at Barrow Base
21	Aug. 18	2.5 miles off shore at Barrow Base
22	Aug. 19	5 miles off shore at Barrow Base
23	Aug. 29	5 miles off shore at Barrow Base
24	Aug. 14	10 miles off shore at Barrow Base
25	Sep. 7	8 miles off shore at Barrow Base

Phytoplankton species and ciliates found in the vicinity of Point Barrow, Alaska in 1954

DIATOMS

Achnantes taeniata Grunow
Amphiprora hyperborea Gran
Asterionella kariana Grunow
A. gracillima Heib.
Attheia decora West
Bacteriosira fragilis Gran
Bellerochea malleus Van Heurck
Biddulphia aurita Brebisson and Godey
Cerataulina bergoni Peragallo
Chaetocerus atlanticus Cleve
Ch. borealis Bailey
Ch. concavicornis Gran
Ch. convolutus Castracane
Ch. compressus Lauder
Ch. constrictus Gran
Ch. curvisetus Cleve
Ch. decipiens Cleve
Ch. debilis Cleve
Ch. densus Cleve
Ch. eibeni Grunow
Ch. furcellatus Bailey
Ch. didymus Ehrenberg
Ch. mitra Cleve
Ch. gracilis Schütt
Ch. lorenzianus Grunow
Ch. laciniosus Schütt
Ch. teres Cleve
Ch. septentrionalis Oestrup
Ch. socialis Lauder
Ch. subtilis Cleve
Ch. subsecundus Cleve
Ch. wighami Brightwell
Chaetoceros sp.
Coscinosira polychorda Gran
Coscinodiscus concinnus Smith
C. iridis Ehrenberg
C. grani Gouch
C. excentricus Ehrenberg
C. marginatus Ehrenberg
C. lineatus Ehrenberg
C. radiatus Ehrenberg
Coscinodiscus sp.
Cyclotella sp.
Eucampia zodiacus Ehrenberg
Fragillaria cylindrus Grunow
F. crotonensis Kitton
F. oceanica Cleve
Fragillaria sp.
Gyrosigma spenceri Cleve
Grammatophora marina Kützing
Grammatophora sp.
Isthmia nervosa Kützing
Leptocylindrus danicus Cleve
Licmophora abbreviata Agardh
Melosira arenaria Moore
M. arctica Dickie
M. nummuloides Agardh
Melosira sp.
Navicula distans Smith
N. vanhoffeni Gran
N. grani (Jörgensen) Gran

Nitzschia closterium Smith
N. delicatissima Cleve
N. seriata Cleve
N. lineola Gran
N. frigida Grunow
Nitzschia sp.
Porosira glacialis Jörgensen
Pleurosigma sp.
Pinnularia debesi Hustedt
Rhabdonema arcuatum Kützing
Rhizosolenia alata Brightwell
Rh. styliformis Brightwell
Rh. hebetata Gran
Sceletonema costatum Cleve
Stephanopyxis nipponica Gran and Yendo
Plagiogramma sp.
Actinoptychus undulatus Ralfs
Actinoptychus sp.
Asterolampra sp.
Thalassiosira bioculata Ostenfeld
Th. gravida Cleve
Th. hyalina Gran
Th. rotula Meunier
Th. subtilis Gran
Thalassiosira sp.
Thalassionema nitzschioides Grunow
Thalassiothrix frauenfeldti Grunow
Th. longissima Cleve and Grunow
Synedra sp.

DINOFLAGELLATES

Amphidinium sp.
Ceratium arcticum Cleve
C. bucephalum Cleve
C. longipes Gran
C. macroceros Cleve
C. tripos (Müller) Nitzsche
C. lineatum Cleve
C. fusus (Ehrenberg) Dujardin
Ceratium sp.
Dinophysis acuminata Claparede and Lachmann
D. acuta Ehrenberg
D. grani Paulsen
D. islandica Paulsen
D. norvegica Claparede and Lachmann
Amphidinium klebsi Kofoid and Swezy
A. operculatum Claparede
A. extensum Wulff
A. fusiformis Martin
Amphidinium sp.
Massartia asymmetrica Schiller
M. rotundata Schiller
M. glandula Schiller
Massartia sp.
Cochlodinium sp.
Gymnodinium abbreviatum Kofoid and Swezy
G. alaskensis n. sp.
Gymnodinium sp.
Polykrikos kofoidi Chatton
Polykrikos sp.
Blepharocysta sp.
Cladopyxis sp.

CYSTS OF DINOFLAGELLATES

Amphidiniopsis kofoidi Woloszynska
Thecadinium ebriolum Herdman
Thecadinium sp.
Glenodiniopsis sp.
Glenodinium lenticula Schiller-Biecheler
Goniodoma pseudogoniaulax Biecheler
Goniaulax dimorpha Biecheler
G. catenata Kofoid
G. digitale Kofoid
G. polyedra Stein
G. polygramma Stein
G. tamarensis Lebour
G. spinifera Diesing
G. diegenensis Kofoid
G. scrippsae Kofoid
G. triacantha Jörgensen
Goniaulax sp.
Oxytoxum sp.
Peridinium minusculum Pavillard
P. achromaticum Levander
P. cerasus Peters and Smith
P. conicum Ostenfeld
P. crassipes Kofoid
P. curvipes Ostenfeld
P. depressum Bailey
P. divergens Ehrenberg
P. leonis Pavillard
P. pallidum Ostenfeld
P. pellucidum Schütt
P. subinerme Paulsen
P. subcurvipes Lebour
P. trochoideum Lemmermann
P. triquetrum Lebour
P. grani Ostenfeld
P. brevipes Paulsen
P. roseum Paulsen
P. finlandium Paulsen
P. mite Pavillard
Protoceratium reticulatum Bütschli
Protoceratium sp.
Phalacroma rotundatum Kofoid and Michener
Phalacroma sp.

FLAGELLATES, ETC.

Dinobryon pellucidum Levander
Dinobryon sp.
Pheocystis poucheti Lagerheim
Coccolithus huxleyi Kamptner
Coccolithus sp.
Distephanus speculum Haeckel
Stichococcus sp.
Chlorella salina Butcher
Chlorella sp.
Characiopsis sp.
Ankistrodenus falcatus Ralfs
Dactylococcus infusionum Naegeli
Scenedesmus quadricauda Brebisson
S. obliquus Kützing
S. acuminatus Chodat
S. bijugatus (Turp.) Kützing
Scenedesmus sp.
Scotiella nivalis (Chod.) Fritsch
Trachelomonas sp.
Maesotenium sp.
Merismopedia sp.

CYSTS

Pyramimonas sp.
Ochromonas pearyi n. sp.
O. glacialis n. sp.
Ochromonas sp.
Cryptomonas sp.
Polytomella sp.

Ulothrix sp.
Oocystis lacustris Chodat
O. solitaria
Oocystis sp.
Bicoeca sp.
Codonosiga sp.
Polytomellophagus sp.
Bodo *bacillariophagus* n. sp.
Bodo sp.
Mastigameba sp.
Trochiscia sp.
Englena sp.

CILIATES

Laboea acuminata Leegård
L. reticulata Leegård
L. strobila Lohmann
L. conica Lohmann
Leprotintinnus pellucidus Cleve
Lohmanniella oviformis Leegård
Mesodinium rubrum Lohmann
Didinium sp.
Ptychocyclis urnula Brandt
P. obtusa Kofoid and Campbell
P. arctica Kofoid and Campbell
Tintinnus acuminatus Claparede and Lachmann
Tintinnopsis beroidea Stein
T. parvula Jörgensen
T. karajakensis Brandt
Tintinnopsis sp.
Stenosomella sp.
Acanthosomella norvegica Jörgensen
Other unidentified Ciliates