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STUDIES ON BRACKISH WATER PHYTOPLANKTON

Peter H. Campbell

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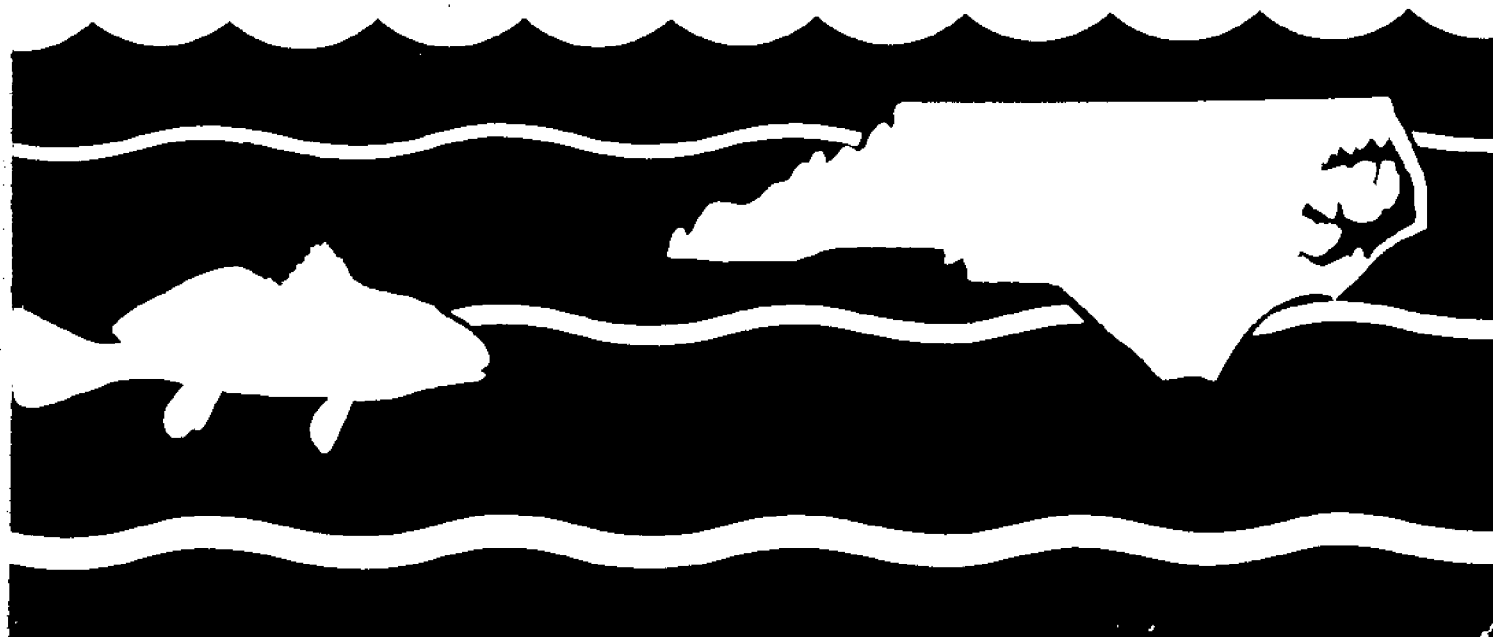

STUDIES ON BRACKISH WATER PHYTOPLANKTON

by
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Department of Botany
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STUDIES ON BRACKISH WATER PHYTOPLANKTON

I. THE PHYTOPLANKTON OF GALES CREEK

WITH EMPHASIS ON

THE TAXONOMY AND ECOLOGY OF ESTUARINE PHYTOFLAGELLATES

by

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Under the direction of

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Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Botany at the University of North Carolina

Chapel Hill

1973

ABSTRACT

The phytoplankton of Gales Creek, a small shallow coastal plain estuary near Morehead City, N. C., was studied for over a year. Special emphasis was placed on determining the species composition and distribution patterns of the phytoflagellates and in measuring environmental factors which may influence the presence and distribution of these species.

Thirty cruises were conducted in 1965-1966 at 2-3 week intervals at 6 stations along the mile length of the estuary. Environmental parameters investigated included temperature, salinity, oxygen, light penetration, pH, and the nutrients nitrate, nitrite, ammonia, total nitrogen, dissolved inorganic phosphate and total phosphorus. Species composition and seasonal distribution were determined qualitatively for diatoms form perserved samples, and quantitatively for phytoflagellates from live samples.

A total of 187 diatom taxa were identified from the estuary. Diatoms exhibited a classic bimodal pattern of seasonal abundance with maxima in spring and autumn.

A total of 152 species of phytoflagellates in 49 genera and 9 classes of algae are described and figured, including 32 species, 4 varieties and 6 combination new to science.

Phytoflagellates dominated the phytoplankton throughout most of the year. The mean yearly standing crop for phytoflagellates was only 5×10^5 cells/liter. Low densities are attributed to low nitrate concentrations and high flushing rate of the estuary. Phytoflagellate seasonal distribution was bimodal with moderate densities in spring and maximum cell concentrations in late summer. A majority of the dominant phytoflagellates were eurythermal and euryhaline species.

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For invaluable advice and suggestions on this work, I am also sincerely grateful to Professor Trygve Braarud and the staff of the Institutt for Marin Biologi, University of Oslo. Special thanks for guidance through the laboratory's world-wide collections of preserved phytoplankton are expressed to Karen Ringdal Gaarder, who aided my study of dinoflagellates and coccolithophorids, and to Grethe Rytter Hasle who guided my examination of the diatoms--including the Gales Creek specimens.

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INTRODUCTION

An estuary is defined by Pritchard (1967) as "a semi-enclosed coastal body of water which has a free connection with the open ocean and within which sea water is measurably diluted with fresh water derived from land drainage". Generally an estuary is a place where the tide of the ocean meets the current of the river.

Shallow well mixed estuaries are found along coast lines with a wide coastal plain, as in the southeastern United States. One form is the bar-built estuary, or lagoon, a shallow embayment cut off from the sea by offshore barrier islands and sand spits, with inlets connecting it to the sea, and receiving fresh water from one or more rivers. Pamlico Sound and Albemarle Sound in North Carolina are the largest examples of this type of estuary in the world.

The other form is the classical estuary known as the drowned river valley or coastal plain estuary. It is typical of the eastern seaboard of the United States, but is found all over the world. With the sea having risen around 100 meters in the 10,000 years since the last glacial period, the valleys of rivers flowing into the sea have become flooded, producing estuaries that range in size from the smallest of river mouths up to such notable examples as Chesapeake Bay and Delaware Bay.

The principal feature of an estuary is the exceeding variability of the environment. Fresh water inflow from land drainage mixes with the salt water inflow from the sea, causing extreme fluctuation in salinity. The shallowness of coastal plain estuaries allows wind action and turbulent currents generated by tide and river flow to greatly influence the circulation. It also promotes heat exchange that permits a rapid fluctuation of water temperature over a wide range. A shallow estuary is also optimal for rapid cycling of nutrients between organic and inorganic phases, with the result that phytoplankton blooms are more frequent and lower in density throughout the year than in most other

aquatic environments. Such properties produce an area of potentially high primary productivity, as evidenced by the substantial fisheries for oysters, crabs, shrimp and fish supported by estuarine systems along the eastern seaboard of the United States. Because of the complexity of the periodically changing parameters in the estuary its population is limited to organisms, including phytoplankton, having a wide range of ecological adaptations.

Investigations on phytoplankton of the North American coast include a number of studies of estuarine phytoplankton; however, these have been largely confined to regions lying to the north of the Carolinas, and include the Bay of Fundy (Gran and Braarud, 1935), the Gulf of Maine (Bigelow, 1926, and Lillick, 1940), the Woods Hole area (Lillick, 1937, and Hulburt, 1965a), Narragansett Bay (Smayda, 1957), Block Island Sound (Riley, 1952), Long Island Sound (Conover, 1956), Moriches Bay and Great South Bay, L. I. (Ryther, 1954), Raritan Bay (Patten, 1962), the Patuxent River, Md. (Morse, 1947), the York River (Fournier, 1966), the James River (Marshall, 1967), and lower Chesapeake Bay (Wolfe, *et al.* 1926, Griffith, 1961, and Patten, *et al.* 1963) and the offshore waters of Chesapeake Bay (Cowles, 1930, Mulford and Norcross, 1971).

Investigations on phytoplankton farther south include offshore work on the Sargasso Sea (Riley, 1957, Hulburt, *et al.* 1960, Hulburt, 1962, Marshall, 1966 and 1968), the Gulf Stream and coastal waters off North Carolina (Hulburt, 1967, and Marshall, 1969a), the Florida Current (Bsharah, 1957), the Caribbean Sea and Gulf of Mexico (Balech, 1967), and inshore studies on Pamlico Sound, N. C. (Hulburt, *et al.* 1970, unpublished, and Bellis, 1971), the Cape Fear estuary (Carpenter, 1971), and brackish water ponds in Morehead City, N. C. (Campbell, 1971). Productivity studies have been conducted on the Beaufort Channel (Williams and Murdoch, 1966) and shallow estuaries near Beaufort, N. C. (Thayer, 1971), and on estuarine waters in Georgia (Ragotzkie, 1959), but other than the work on the brackish water ponds no systematic investigation of estuarine phytoplankton including species descriptions and illustrations exists for the southeastern coast of the United States.

Of these phytoplankton studies on the east coast, few have gone beyond the examination of the diatoms and armored dinoflagellates,

preservable forms normally collected by net hauls. Even so, a number of investigators have noted the significance of nannoplankton richness compared to net plankton (Lohmann, 1911, Harvey, 1950, Miller and Moore, 1953, Wood and Davis, 1956, Rodhe, 1958, Yentsch and Ryther, 1959, Holms and Anderson, 1963), especially in inshore waters (Gross, *et al.* 1947 and 1950). This is readily indicated by the considerable abundance and constancy of unidentified naked microflagellates noted by several authors: densities of up to 10^6 cells/liter from early summer to November in Narragansett Bay (Smayda, 1957); 10^7 cells/liter concentrations from summer in Long Island Sound (Riley, 1952), and the observation that unidentified naked flagellated cells 3-8μ long comprise a major group in coastal Carolina waters (Marshall, 1969a).

The nannoplankton forms recognized to be most important have been the phytoflagellates, yet, except for the armored dinoflagellates, these are the very groups about which the least is known. They are difficult to study because of their motility and failure to preserve adequately with present fixatives. Because the phytoflagellates are distributed through nine different classes of algae, gathering together the pertinant taxonomic references alone is a formidable task. In the absence of systematic work, investigations of the total ecology of the estuaries, so important to an understanding of the productivity of coastal waters, will continue to be hampered or discouraged at a time when estuaries of the southeastern United States are becoming threatened with extinction by the actions of man through coastal development and water pollution.

The decision was therefore made to undertake the investigation of a southern coastal plain estuary unaffected by pollution, with the purpose of determining the species composition of the phytoplankton with special systematic emphasis upon the phytoflagellates, their distribution patterns through the year, and of assessing certain measurable environmental parameters which may be influencing the composition and distribution of these species.

A survey of the estuaries accessible from the Institute of Marine Sciences in Morehead City, N. C., the marine laboratory of the University of North Carolina, led to the selection of Gales Creek, a small natural estuary with a diverse community of phytoflagellates. This estuary was found to be ideal for study by an individual researcher with modest

equipment. The study was begun in 1965 and was continued for almost two years.

GENERAL CHARACTERISTICS

Location and Topography

Gales Creek is a small shallow natural estuary, located 10 miles west of Morehead City in Carteret County, North Carolina. Small tributaries flowing into Gales Creek drain a five square mile low-relief area of Croatan National Forest. The creek then flows into Bogue Sound, a 25-mile long embayment connected with the sea at its eastern extremity through Beaufort Inlet, and at its western end through Bogue Inlet (Fig. 1). The creek enters the sound at a point midway between these two inlets where the sound is over two miles wide.

Saline water from the sound influences the creek to a distance of two kilometers from the mouth, but beyond this the flow of fresh water and the presence of shallow sills in the creekbed normally prevent further salt-water intrusion. Though Gales Creek is part of the much larger estuarine system of Bogue Sound, it is in the creek that one finds the variations in salinity characteristic of classic estuaries. The sound, on the other hand, maintains comparatively higher average salinities and a narrower range of fluctuation in salt concentration throughout the year (Williams, *et al.*, 1967).

The Gales Creek estuary is of classic form, with constricted mouth, broad mixing basin, tapering middle reaches, and headwater region, (Fig. 2). A few hundred meters from the mouth the estuary is further constricted artificially to a bredth of only 27 meters by embankments for a highway bridge. The large mixing basin beyond is over 200 meters broad. From here the estuary is deflected to the west, narrowing to 100 meters in the middle reaches, where it is again deflected north. In the upper reaches where the estuary is less than 10 meters in bredth it is joined by a small creek, the East Prong, its only major tributary. The estuary becomes more constricted and meandering as it arrives in the headwater region, where most of the fresh water enters. Beyond this point the

FIGURE 1

Map indicating the location of Gales Creek on Bogue Sound 10 miles west of Morehead City in Carteret County, North Carolina. Scale 1" = 3 mi.

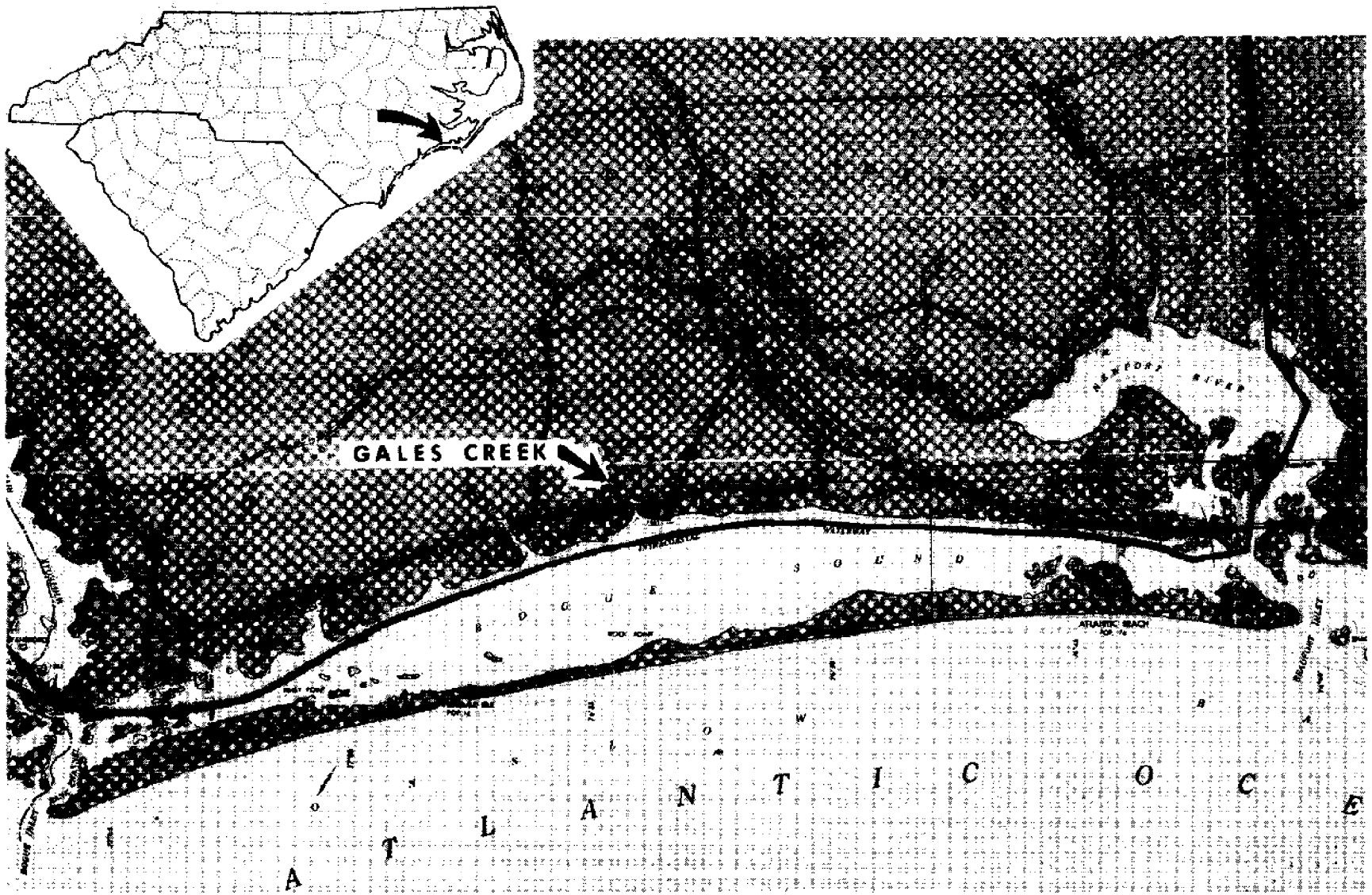
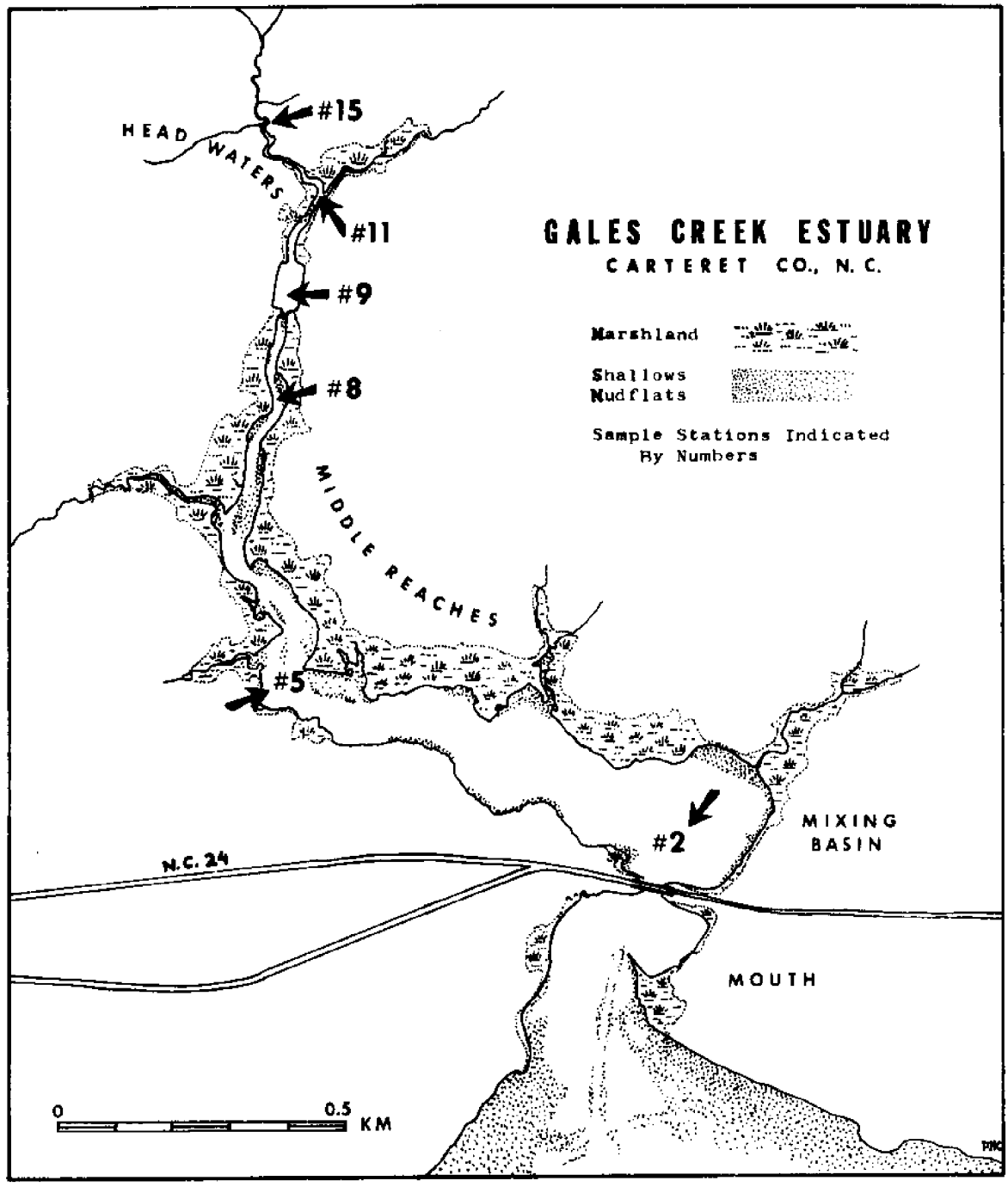

GALES CREEK
ATLANTIC OCEAN

FIGURE 2

Map of the Gales Creek estuary, showing location of the six sampling stations selected for the investigation. Modified from U. S. Coast and Geodetic Survey Map of Salter Path Quadrangle, Carteret County, North Carolina, 1951 edition, and U. S. D. A. aerial photograph BUS-3EE-170, 1-21-64.


GALES CREEK ESTUARY
CARTERET CO., N. C.
Marshland
Shallows
Mudflats
Sample Stations Indicated
By Numbers
#15
#11
#9
#8
#5
#2
HEAD WATERS
MIDDLE REACHES
MIXING BASIN
MOUTH
N.C. 24
0
0.5
KM

stream becomes too narrow and choked by bushes and fallen trees to be navigable by boat.

The open water of Gales Creek covers an area of approximately 217,000 square meters, and is bordered by marshland of somewhat less area. At low tide, extensive mudflats off the mouth and narrow muddy areas along the creek are exposed, though much of the estuary's marsh-grass shoreline is steep enough that tidal fluctuation does not change the shoreline position.

The average depth of Gales Creek is approximately 0.65 meters and the average channel depth is 0.78 meters. Depth measurements coupled with a calculation of the approximate mean tide level has enabled the construction of the depth profiles presented in Fig. 3. In comparison, the average depth of Bogue Sound is 1.5 meters at mean tide. The volume of the estuary at mean tide is estimated to be 140,000 cubic meters.

Of the accessable estuaries near Morehead City, Gales Creek is the only one comparatively free from the influence of man. The others are either built-up with houses, utilized as yacht basins, or surrounded by agricultural land, all sources of possible pollution. While there are a number of houses by Bogue Sound near the mouth of Gales Creek, only a few are presently on the creek itself. It was my hope in selecting this location that this nicely defined natural estuarine system will remain in its relatively unspoiled state for the benefit of future researchers and nature lovers.

Soils and Sediments

Gales Creek cuts through a soil type classified as Klejleon, a moderately well to somewhat poorly drained gray-surfaced sandy soil with little silt or clay in the sand beds which formed the parent material. Surface runoff is slow, with gradients less than 2 or 3%. This soil supports medium-dense open stands of mixed pine and hardwoods. The fresh water creeks flowing into the estuary also drain a somewhat different soil type to the north, the nearly level Lynchburg-rains, a poorly drained gray sandy loam soil with a gradient under 2%, that is derived from beds of sand and clay with little silt. This soil supports the growth of mixed hardwoods. Both of these soils through which Gales

Creek flows have their origin in sedimentary marine deposits which were laid down before the retreat of the sea during the ice ages (Lee, 1955).

After heavy rains, rapid runoff from these sandy soils in the surrounding mixed pine and hardwood areas contributes sand and humus to the estuary. At other times the more steady seepage from the swampy areas provides a continuous supply of water stained orange to brown with humic substances, the "black water" of swamp forests, which contains a variety of dissolved and finely particulate organic matter. Some of the fine particles and dissolved organic compounds precipitate on contacting the salt water in the estuary, and these particles along with larger material washed from the land and marsh settle onto the sandy bottom to form a flocculent ooze which is easily disturbed by currents created by tides, or rapid stream flow. Below the bottom surface, the sediments are usually quite reducing, and as in the richer peaty muds near the marshes, they may emit the odor of hydrogen sulfide when exposed.

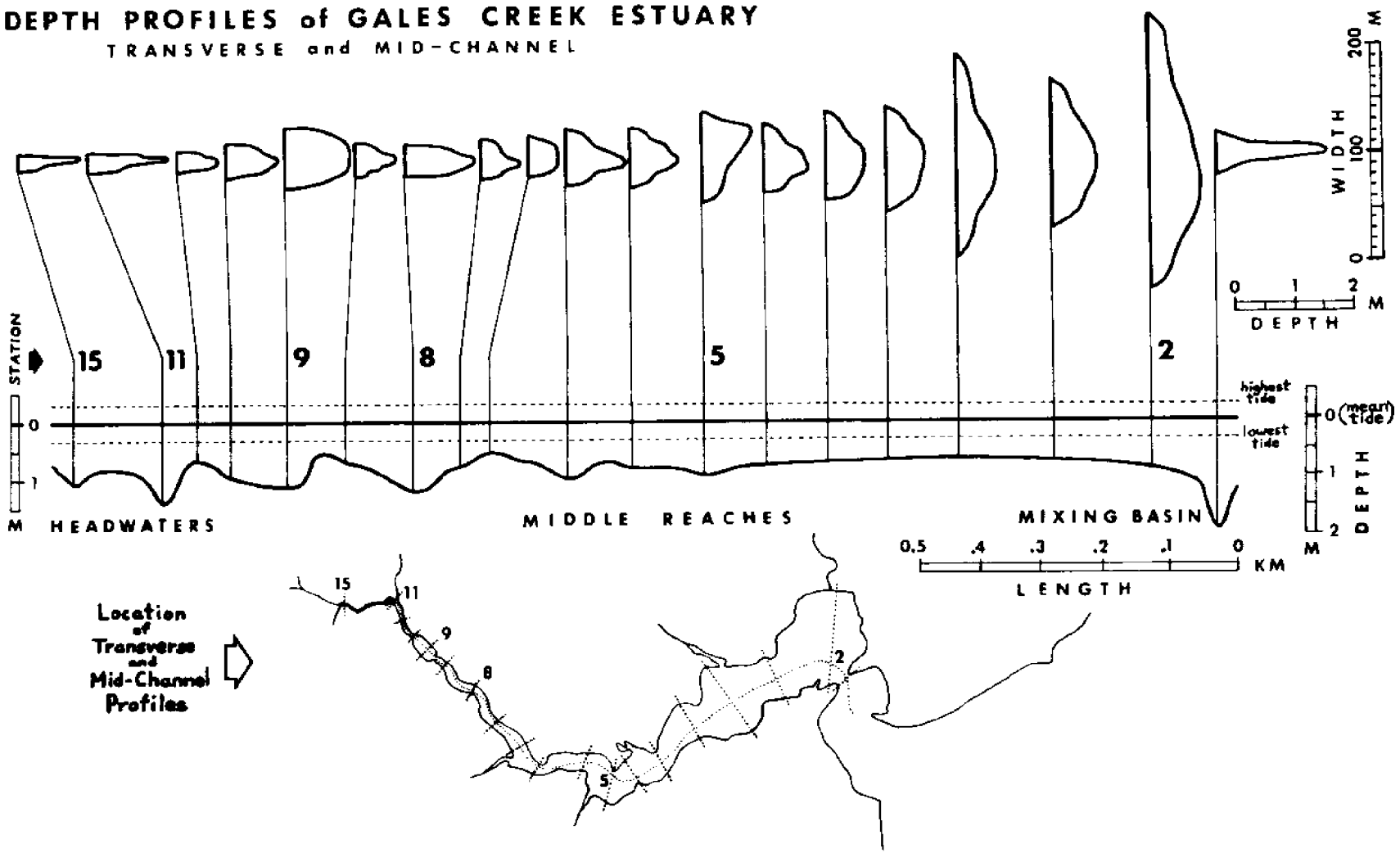
Climate

The Morehead City and Bogue Sound area have a more mild climate than is found inland in Carteret County, for extremes of temperature are dampened by the slower heat exchange of sound and sea. The mean annual temperature in Morehead City is 16.9°C (62.4°F), with the coldest month, January, averaging 6.1°C (43.4°F) and the warmest month, August, averaging 26.2°C (79.1°F). Periods of below-freezing temperatures are usually of short duration, and snow is rare. Only once during the study was Gales Creek found covered by a thin layer of ice, a time when cold weather coincided with high freshwater inflow. (The seasonal variation in air temperature is presented in Fig. 6A.)

The annual precipitation for the area averages 150 cm (59 inches) with the heaviest rainfall normally occurring in late spring and early summer. Generally early spring and autumn are the times of least rainfall, with autumn usually characterized by long periods of clear dry weather. The summer rains are largely in the form of showers which have very local influence. In 1966, the total precipitation was slightly above average at 155.5 cm (61.2 inches) while 1965 had an annual rainfall 1/3 below average, only 98.4 cm (38.7 inches). (The seasonal distribution of precipitation both within one week and within one day

FIGURE 3

Transverse and Mid-channel Depth Profiles for Gales Creek, from the mixing basin to the headwater region. Numbers indicate location of the six sampling stations selected for the investigation. Depths are from mean tide level.


DEPTH PROFILES of GALES CREEK ESTUARY
TRANSVERSE and MID-CHANNEL
STATION
15
11
9
8
5
2
WIDTH
200 M
100
0
0 1 2 M
DEPTH
highest tide
0 (mean tide)
lowest tide
1
2
DEPTH
M
HEADWATERS
MIDDLE REACHES
MIXING BASIN
0.5 .4 .3 .2 .1 0 KM
LENGTH
Location of Transverse and Mid-Channel Profiles
15
11
9
8
5
2

before the time of sampling is presented in Fig. 5A.) All rainfall data were recorded by the weather station in Morehead City. No doubt some discrepancies exist between precipitation occurring there and at the creek, especially at times of summer thundershower activity.

The prevailing winds are from the northeast in September and October, from the northwest in November, December and February, and from the southwest during the remainder of the year. Wind velocities are higher than those found inland, and often have strong effects on water level and currents in broad shallow Bogue Sound. Gales Creek is less affected being protected by surrounding vegetation.

Tides and Currents

The water level in Gales Creek is a product of the combined influences of runoff from surrounding lands, winds blowing across shallow Bogue Sound, and the tides.

Tidal impulses occur twice a day, and enter Bogue Sound through Beaufort Inlet and Bogue Inlet, each a distance of about 13 miles from the mouth of Gales Creek, but with the greater influence being exerted from the broader Beaufort Inlet end. The sea water off these inlets is around $35^{o}/oo$ salinity, while the average for Bogue Sound off Gales Creek during the study was $28.6^{o}/oo$ salinity.

The mean range of tidal fluctuation at Morehead City, located near Beaufort Inlet, is 0.85 meters, while at Bogue Inlet it is only 0.67 meters. Spring tide ranges are 1.04m to the east and 0.79m to the west. The tide is delayed 1/2 hour at Bogue Inlet from that at Morehead City (U.S. Coast and Geodetic Survey, 1966).

During the study, Gales Creek exhibited a mean tidal fluctuation of around 0.3m with no observed single fluctuation exceeding 0.4m. The tide cycle was normally delayed about three hours from that at the inlets. This lag could be strongly affected by the direction and velocity of the wind, and sometimes was delayed up to five hours.

The difference between the highest high tide observed and the lowest low tide recorded during the study was about 0.7m due to the effects of wind action on Bogue Sound. Steady winds with an easterly component tend to pile water up against the more constricted western end

of the sound, raising the water level in this area. Strong winds blowing across the 2 1/4 miles of open shallow water towards the mouth of Gales Creek pile water into the creek itself, thereby also raising the base level of the tides. Winds blowing in opposite directions from these to some extent have the opposite effect of lowering the base level of the creek water. Another contributing factor is flooding from run-off after heavy percipitation. During one cruise, the continuing creek runoff from a 6.5 cm rainfall the previous day was enough to add 5 cm to the normal height of the high tide.

Flushing Rate

The calculated volume of water exchanged during a tidal fluctuation of 0.3 m in the creek is approximately 60,000 m^3. With total volume of the estuary only 140,000 m^3, this makes an exchange ratio of 0.43. Ketchum, 1954, states that local plankton populations can maintain themselves where exchange ratios are 0.5 or less, but populations at this level must double with each tide cycle in order to stay constant. In such a situation, only the fastest growing species would be expected to survive as endemic species, while the rest of the plankton community would relfect introduction from sound and sea. Gales Creek, however, has a narrow mouth and a rather narrow channel in the upper reaches protected from the wind by surrounding vegetation. Both tide- and wind-induced circulation are consequently lessened, and the decreased mixture of waters up- and down-stream was evidenced by the high degree of stratification normally found in the water column in the upper reaches (Fig. 9). It is primarily the water in the mixing basin portion that is regularly exchanged with the tide. In times of high runoff, the upper reaches may be completely flushed, but otherwise water masses in these regions merely move back and forth and are only partially mixed with sound water at each tidal exchange.

Added to this is another factor of biological significance, the retention of water masses in "pools" between shallow sills in the upper reaches (Fig. 3), where denser more saline water below 0.5 m is exchanged only during heavy runoff. One such area was the result of an uncompleted Boy Scout swimming hole project which created a basin

100 m x 1 1/2 m deep in the upper middle reaches of the creek (Station 9 in Figure 2). Under these conditions, there is apparently enough retention time for significant communities of plankton to remain established despite the high calculated exchange ratio.

Benthic Organisms

During the colder months, there were no conspicuous growths of macroscopic algae on the muddy bottom of the estuary. When the water in the lower reaches was clear, it revealed only large expanses of mud with scattered castings from various infauna and different sized holes created by blue crabs. A few small scattered clumps of oyster shells were found near the margins of the mouth and mixing basin regions.

In warmer months, growth of certain benthic algae common in Bogue Sound also occurred in the lower regions of the estuary. Most of these were unattached and drifted about the muddy bottom with the currents. They probably represent either fragments or whole plants which have been introduced from the sound by wind and tidal currents.

The dominant benthic alga encountered in the summer was *Gracilaria verrucosa* (Huds.) Papenf. Other common species included, in approximate order of abundance, *Hypnea musciformis* (Wulf.) Lamour., *Dictyota dichotoma* (Huds.) Lamour., *Ectocarpus siliculosus* (Dillw.) Lyngbye, *Laurencia poitei* (Lamour.) Howe, *Codium decorticatum* (Woodw.) Howe, *Ulva lactuca* L., *Chaetomorpha* sp., *Rhizoclonium riparium* (Roth.) Harvey, and *Lyngbya confervoides* Ag.

Benthic diatoms mixed with sand grains and detrital particles were found in the surface layer of bottom sediments from the lower regions of the estuary during most of the year. Thin diatom layers also occurred on algae, oyster shells, submerged marsh vegetation, and other detritus. These diatoms may become disturbed by water currents and appear in phytoplankton samples.

Beds of the submerged aquatic *Halodule beaudettei* (Den Hartog) Den Hartog, and its relative, *Zostera marina* L., the eel grass, are found in Bogue Sound off the mouth of Gales Creek, but do not appear in Gales Creek.

Marsh Vegetation

The gradient in salinity from fresh water in the headwaters to saline water at the mouth of Gales Creek is reflected in the marsh vegetation flooded by these waters at high tide.

In the headwater region, a freshwater creek marsh type of vegetation is present which includes *Cladium jamaicense* Crantz (saw grass), *Setaria magna* Grisebach (marsh foxtail grass), and a few individuals of *Typha anuistifolia* L. (narrow-leaved cattail) growing along with *Erianthus giganteus* (Walter) Muhl. (giant beard grass) and species of *Panicum*, *Andropogon*, and *Polygonum*. This vegetation becomes replaced in the upper middle reaches by extensive areas of the black rush, *Juncus roemerianus* Scheele, the dominant species of brackish marshes in the South. This black rush zone extends to the mixing basin area but is found progressively further back from the creek where flooding by saline water is infrequent. Mixed with the black rush was *Aster tenuifolius* L., patches of *Scirpus americanus* Persoon (chair-maker's rush), and *Fimbristylis spadicea* (L.) Vahl. At slightly higher elevations in the black rush zone a variety of plants may constitute a definite shrub zone, including *Iva frutescens* L. (marsh elder), *Baccharis halimifolia* L. (silverling), *Myrica cerifera* L. (wax myrtle) and *Hibiscus moscheutos* L. (rose mallow).

In the middle reaches *Spartina alterniflora* Loisel. (salt-water cordgrass) first begins to appear in patches just along the banks, but from the lower middle reaches to the mouth of the estuary this species becomes a continuous and widening band forming the saltwater marsh between the creek and the black rush zone. Both the saltwater and brackish marsh build up a black organic peaty substratum which is reducing in nature and may smell of hydrogen sulfide when disturbed.

In the region of the mouth peat accumulation is prevented by the exposure of the marsh to tidal currents and waves. On the sandy substrata found here the zonation begins with the saltwater cordgrass from the low tide level, and, moving up through the marsh, is replaced by *Distichlis spicata* (L.) Greene (saltmarsh grass) along with *Spartina patens* (Ait.) Nuhl. (saltmeadow cordgrass) and in some cases *Borrichia frutescens* (L.)DC. (sea oxeye daisy). Beyond the range flooded by normal sound tides are usually found marsh elder, wax myrtle, silverling and other shrubs.

On the higher land along the estuary, backing up the shrub zones of either the saltwater, brackish water, or fresh water marshes, are found many typical species of coastal plain and maritime forests in the South, such as *Nyssa sylvatica* var. *biflora* (Walter) Sargent (black gum), *Liquidambar styraciflua* L. (sweet gum), *Acer rubrum* L. (red maple), *Persea borbonia* (L.) Sprengel (red bay), *Magnolia virginiana* L. (sweet bay), *Ilex vomitoria* Aiton (yaupon), *Ilex opaca* Aiton (holly), *Quercus lyrata* Walter (overcup oak), *Quercus stellata* Wang. (post oak), *Quercus laurifolia* Michaux (laurel oak), and *Juniperus virginiana* L. (red cedar). The most conspicuous tree species, however, is *Pinus taeda* L. (loblolly pine). Most of the area around the creek is part of Croatan National Forest, but shows evidence of logging for pine, and though the hardwoods appear to be filling in around the creek, many large pines still remain standing above the hardwood understory.

MATERIALS AND METHODS

Field Methods

The preliminary surveys of Bogue Sound estuaries during spring and summer of 1965 included sampling from the shores of Gales Creek. In August, 1965, purchase of a shallow-draft 9-foot aluminum jon boat and 3 hp. outboard motor made "cruises" up the estuary possible. The creek was charted, measured for depth (see Fig. 3), and locations for 15 preliminary sampling stations were selected. Temperature and salinity measurements were begun at this time using an Industrial Instruments RS-5 conductivity-measuring electrodeless salinometer with thermister. Secchi disc depths were also recorded, and water samples were taken for the determination of species composition and distribution of phytoflagellates.

In September, 1965, plankton net hauls were added to these activities. A #20 net was used, and hauls lasted 10 minutes. One haul was made on each cruise from the lower middle reaches to the mixing basin area.

Acidity measurements in the field using pH paper were unsuccessful in brackish water, so beginning in October pH measurements were made in the laboratory. The collecting of samples for nutrient and chlorophyll analysis was also begun in October.

In December, six of the original 15 stations were chosen for further study. These were #2 in the mixing basin, #5, 8 and 9 in the middle reaches, and # 11 and 15 in the headwater region (Fig. 2). The station at the mouth was eliminated because at times data collecting was made very hazardous by waves off the sound threatening to inundate the boat. Oxygen readings were begun in December using a Yellow Springs Instruments polarographic electrode.

To assure that all measurements and samples were taken from the same stratum of the water column, the salinometer probe with temperature

sensor, the oxygen electrode, and a plastic tube with a screened opening for drawing up water samples were mounted to terminate together at the end of a long pole bearing short crosspieces at 0.1m intervals. The pole could then be hung vertically on another pole lying across the boat's gunwales which made possible the collecting of data and samples at 0.1m intervals from surface to bottom. Water was drawn up the tube and into 250 ml sample jars with a suction hand pump (Fig. 4). Enough water was drawn through the tube and discarded with each sampling to ensure that only water from the desired depth filled the sample jar.

The use of this compound probe provided an immediate picture of temperature, salinity, and oxygen stratification at each station. From this information, the most promising depths for plankton sampling were selected, which normally consisted of a surface sample, a near-bottom sample, and one or two samples in between.

Experimentation with a number of methods for determining plankton standing crop resulted in the development of a method which enabled both identification and enumeration of phytoflagellates in each water sample. This method was first applied on Cruise #8 in December, 1965.

With all hydrographic sampling methods thus established, the study was continued for one year, with cruises normally spaced at intervals of 2 to 3 weeks. A total of 29 cruises were made, with one added sampling taken without hydrographic data in April, 1967. Cruise dates and data collected during each cruise are presented in Table 1. Field equipment used for the study is illustrated in Fig. 4. A summary of the methods used in the field is presented below:

Summary of Field Methods

Cruises -- 29 separate sampling trips were conducted at approximately bi-weekly intervals, between August 1965 and November 1966.

Stations -- Six stations, positioned along the estuary from the mising basin to the headwater region, were occupied on each cruise whenever possible.

Table 1

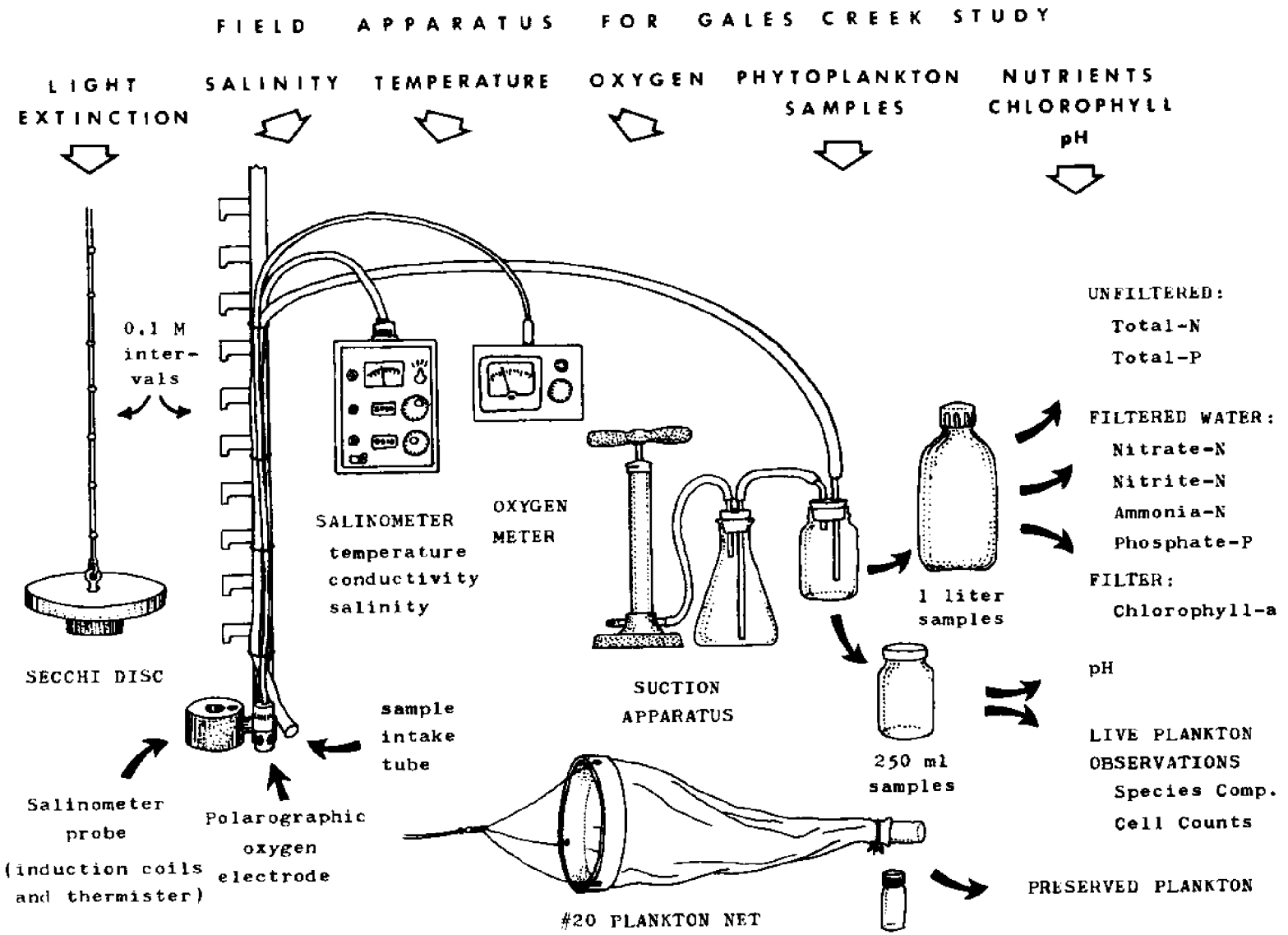
DATES OF GALES CREEK CRUISES

+ = Salinity & Temperature
* = Net Plankton Tow
n = Nutrient Samples
c = Cell Counts
o = Oxygen
G = Glutaraldehyde Preserved Samples
S = Statistical Sampling
D = Diel Study

Cruise Designation							Date		Season
A.							Mar. 6,	1965	Winter
B.							Mar. 12,	"	"
C.	+						Apr. 12,	"	Spring
D.							Jul. 5,	"	Summer
E.	+						Jul. 19,	"	"
1.	+						Aug. 6,	"	"
2.	+						Aug. 12,	"	"
3.	+	*					Sep. 24,	"	Autumn
4.	+	*	n				Oct. 7,	"	"
5.	+	*	n				Oct. 14,	"	"
6.	+	*					Oct. 27,	"	"
7.	+	*					Nov. 11,	"	"
8.	+	*	n	o	c		Dec. 14,	"	"
9.	+	*	n	o	c		Jan. 7,	1966	Winter
10.	+	*	n	o	c		Feb. 1,	"	"
11.	+	*	n	o	c		Feb. 15,	"	"
12.	+		n	o	c		Mar. 4,	"	"
13.	+		n	o	c		Mar. 19,	"	"
14.	+	*		o	c	G	Mar. 31,	"	Spring
15.	+	*	n	o	c		Apr. 15,	"	"
16.	+		n				May 3,	"	"
17.	+	*		o	c		May 23,	"	"
18.	+	*	n	o	c		Jun. 8,	"	"
19.	+	*	n	o	c		Jun. 29,	"	Summer
20.	+		n	o	c		Jul. 18,	"	"
21.	+			o	c	S	Jul. 26,	"	"
22.	+			o	c		Aug. 3,	"	"
23.	+	*	n	o	c		Aug. 17,	"	"
24.	+	*	n	o	c		Aug. 31,	"	"
25.	+	*	n	o	c		Sep. 25,	"	Autumn
26.	+	*		o	c	D	Sep. 30,	"	"
27.	+			o	c		Oct. 14,	"	"
28.	+	*	n	o	c		Nov. 6,	"	"
29.	+	*	n	o	c		Nov. 26,	"	"
30.					c		Apr. 10,	1967	Spring

FIGURE 4

Field apparatus for Gales Creek Study. Illustration of equipment used for collection of data from the estuary.


FIELD APPARATUS FOR GALES CREEK STUDY
LIGHT EXTINCTION
SALINITY
TEMPERATURE
OXYGEN
PHYTOPLANKTON SAMPLES
NUTRIENTS
CHLOROPHYLL
pH
0.1 M intervals
SECCHI DISC
SALINOMETER
temperature
conductivity
salinity
OXYGEN METER
SUCTION APPARATUS
1 liter samples
250 ml samples
sample intake tube
Salinometer probe
(induction coils and thermister)
Polarographic oxygen electrode
#20 PLANKTON NET
UNFILTERED:
Total-N
Total-P
FILTERED WATER:
Nitrate-N
Nitrite-N
Ammonia-N
Phosphate-P
FILTER:
Chlorophyll-a
pH
LIVE PLANKTON OBSERVATIONS
Species Comp.
Cell Counts
PRESERVED PLANKTON

Hydrographic Sampling

Temperature -- Measured at 0.1m intervals to bottom at each station, using thermister in salinometer probe.

Salinity -- Measured at 0.1m intervals to bottom at each station, using a conductivity-measuring salinometer.

Oxygen -- Measured at 0.1m intervals to bottom at each station using a Y. S. I. polarographic oxygen electrode.

Light -- Secchi disc depth was measured at each station, extinction coefficients were then calculated and the depth of 1% incident light (compensation point) calculated.

pH -- Measured from live plankton water samples as soon as possible at laboratory.

Nutrients and Chlorophyll -- Four 1-liter water samples were collected in polyethylene jugs at the following stations: a.) in mixing basin (#2), next to bottom, for nutrients entering from the sound; b.) in the headwaters (#15), at the surface, for nutrients flowing in with fresh water; c.) at surface and d.) next to bottom in upper middle reaches (#9), for nutrients from marsh and estuary. Samples were taken to the Institute of Marine Sciences in Morehead City where 500 ml of each sample were Millipore filtered to collect chlorophyll-containing cells, and the 500 ml filtered portion, a 250 ml unfiltered portion (both in polyethylene bottles) and the Millipore filter from each sample was stored at freezing temperatures for future analysis.

Biological Sampling

Plankton Net Sample -- One 24 cm-diameter #20 plankton net sample (average pore size 67x58 μ) was taken by towing for 10 minutes at slowest outboard motor speed between stations #5 and #2. Plankton was collected in a 12 ml vial and preserved with borax-neutralized formalin.

Live Plankton Samples -- Three or four 250 ml samples between surface and bottom were drawn by suction hand pump at each station. Jars were capped, kept cool and transported to Chapel Hill for plankton species enumeration, cell counts and culturing.

Laboratory Methods

Nutrients: Equipment and proceedures for seawater analysis were those used and, in some cases, modified by Dr. William Woods at the Institute of Marine Science in Morehead City for his studies on coastal waters of North Carolina. Gales Creek nutrient samples were analyzed under his guidance in his laboratory. An outline of the methods and reagents used is presented with his permission in Appendix A. All the methods are colorimetric and involve absorbency measurements using a Beckman DU spectrophotometer with 1 cm or 5 cm cells.

Nitrite-nitrogen was determined from the filtered water samples by the diazotization method of Rider with Mellon (1946). The same method was used for *nitrate-nitrogen* analysis after first reducing the nitrate to nitrite as described by Mullin and Riley (1955). Though treatments precipitated out most humic substances, values for nitrate and nitrite in more heavily tannin-stained samples may have been high due to absorbence by the yellow-brown water in the wavelengths used for the analyses.

Ammonia-nitrogen was separated from the samples by steam distillation and developed for colorometric measurement according to T. P. Riley's (1953) method with modifications as recommended by Crowther and Large (1956). *Total nitrogen* determination involved a micro-Kjeldahl digestion, modified from Woods (1965), in which organic nitrogen from the unfiltered water samples was converted to ammonia and assayed. The methods for determining ammonia and total nitrogen were the least satisfactory analyses. However, a method which does not yield the high blanks and rather erratic results experienced here was not yet available at the time of this study.

Inorganic phosphate was determined from filtered samples by the ascorbic acid methods of Greenfield and Kalber (1954) with slight modifications by Woods (see Appendix A). Unfiltered samples were digested with perchloric acid according to Hansen and Robinson (1953) and, with all organic phosphorus converted to phosphate, this was then developed as in the preceeding method to yield *Total Phosphorus*.

Organic nitrogen is assumed to be the difference between total nitrogen and the sum of nitrate, nitrite, and ammonia nitrogen, while organic phosphorus is assumed to be the difference between total phosphorus and phosphate phosphorus. No attempt was made to differentiate

between the soluble and particulate forms of organic nitrogen and organic phosphorus.

pH: As soon as water samples for plankton analysis arrived at the laboratory, pH was measured with a Fisher Accumet pH meter.

Chlorophyll: Millipore filters containing particulate matter filtered from 500 ml of sample water were dried by freezing, then extracted in 5 ml of 90% acetone according to Creitz and Richards (1955) from absorbency measurements made with a Beckman DU spectrophotometer. Chlorophyll concentrations were calculated according to the method of Richards with Thompson (1952).

Net Plankton: Borax-buffered formalin-preserved net plankton samples were cleared and prepared as permanent mounts on slides for determination of diatom species and their seasonal distribution. Preparation and identification of diatoms was carried out at the Institut for Marin Biologi, University of Oslo, under the guidance of G. R. Hasle. The method of preparation is provided in Appendix B.

Live Plankton: A 40 ml aliquot was drawn from each well shaken 250 ml sample, placed in a conical centrifuge tube, and concentrated by centrifugation at 825 g for 10-15 minutes. The supernatant was then carefully drawn off, and the phytoplankton resuspended in the remaining drop. The drop was then transferred to a clean slide, spread and stirred, and covered with a square 22 mm coverslip. With the right sized drop, about 0.05 ml, the sample always spread just to the edge of the coverslip.

The slide was then examined live for phytoflagellates under a Zeiss GFL compound microscope equipped with phase contrast, surveying the slide and counting large species at 125x, and using selected transects to count moderate sized species at 500x and small species at

1250x. The higher magnifications were also used for careful identification and measurement of all species. From knowing the number of fields of view across the coverslip for each objective, the number of transects counted, and the original volume of sample concentrated under the coverslip, the number of cells/liter in the original sample was calculated. Measurements and colored drawings of each species were kept on 3 x 5 cards for quick reference, and photographs were taken using tri-X film and a Zeiss strobe attachment for exposures at 1/1000 sec. to prevent blurring of moving cells and flagella.

Cultures: Sterile solutions of a modified soil-water-extract medium, Føyn's Erd-Schreiber (Provasoli, McLauchlin and Droop, 1957), were innoculated with varying aliquots of plankton-containing water from the live samples, and these crude cultures grown in 10°C and 20°C constant temperature rooms under fluorescent lights. Cultures were periodically examined and transfers made of interesting species.

Discussion of Plankton Examination Methods

The method finally developed for combined phytoflagellate species determinations and cell counts was arrived at only after experimenting with a number of different techniques.

Utermöhl's (1931) sedimentation method using an inverted microscope (Lund, Kipling and Le Cran, 1958) is only satisfactory for preservable plankton such as the larger diatoms and armoured dinoflagellates. The same may be said for Holmes' (1962) method using a molecular filter, which involves killing and fixing a plankton sample with formalin or Lugol's solution and then filtering, followed by washing, dehydrating, staining with fast green, clearing, and finally mounting the molecular filter on a slide as a permanent mount. Gales Creek microflagellates prepared by this method lost most of their identifying structures when killed, while the stain concealed other details and the multiple filtrations further damaged the delicate cells.

There is still no fixative which preserves all species of phytoplankton in their natural form. Formalin, Lugol's solution, osmic acid

and glutraldehyde all caused enough distortion of cells to make identification impossible, especially in small unarmoured dinoflagellates where position of girdle and sulcus is very important for classification. At present the only way to work with delicate phytoflagellates taxonomically is with living material. This imposes great restrictions on such studies as the samples must be observed within a reasonable time after collection before too many of the cells have begun to die.

Ballantine (1953) compared a number of methods for concentrating living cells and concluded that the most satisfactory one was centrifugation. She found that the great majority of cells were sedimented after 15 minutes at 358 g, and the results from counting were comparable to other less rapid and more complex methods.

Because some plankton samples from Gales Creek were often rather low in cell concentrations, 40 ml centrifuge tubes rather than the usual 12 ml tubes were used. It was found that a percentage of the centrifuged cells would not get transferred because they had become stuck to the sides of the centrifuge tube or the transferring pipette, and a smaller percentage would be lost in the discarded supernatant. For some extreme examples, a sample of *Olisthodiscus* with an average cell volume of 700 μ^3 which was centrifuged only 10 minutes at 670 g left 11.5% of the cells in the supernatant and 17.5% on the sides of the tube, and comparable figures for a *Hemiselmis* sample with average cell volume of 40 μ^3 were 17.5% and 26%. This problem of adherance to the glass surfaces is not overcome by longer centrifugation time and will always give an error on the low side in standing crop estimates, with the error being greater for smaller cells.

Estimating phytoflagellate standing crop by live cell counts is also made difficult because the cells in the samples are usually quite motile. Methods for immobilizing the cells (F.W. Jane, 1942), such as use of menthol crystals, glycerin, or methyl cellulose, were rated unsatisfactory for the Gales Creek study because some delicate species tended to drop their flagella when they came in contact with these foreign substances. Use of vital stains was also found of little value in the study because most of the species were pigmented forms.

The use of constant volume plankton chambers for estimation of cell concentrations, such as the rectangular chambered Sedgewick-Rafter cell, the smaller circular-chambered Palmer cell, or the haemocytometer, all

have the distinct disadvantage of not permitting oil-immersion examination of small cells because of too great a chamber depth.

The only method found to be at all satisfactory in working with phytoflagellates was also the simplest - to place a concentrated plankton sample on a slide under a square coverslip and observe the plankton under the compound microscope as the slide slowly dried out. First the cells were observed in the freely motile state under low power, then as the decreasing volume became more restrictive to flagellate movement the undistorted general morphology of the cells was noted with the high-dry lense. Then while the coverslip pressed down to completely immobilize the cells, distort them, and often cause them to lose their flagella, surface structures such as scales or periplast ornaments, and internal organelles such as plastids, nucleus, pyrenoids, stigma and other bodies could be observed in greater detail with the oil immersion objective.

By placing a small enough concentrate of a known volume under the coverslip, about .05 ml, the water spreads just to the edge of the coverslip, and from this known area of a known volume a calculation of the number of cells per unit volume may be made for each species at the same time the species are examined and identified. Normal procedure using this method with a slide of Gales Creek material was to count three transects near the center of the coverslip with low power magnification for larger species while cells were actively moving, and one transect directly down the center at high dry magnification for smaller species as cells slowed down, while examining all new forms in detail with oil immersion objectives. This usually occupied about one hour's time for each slide, with counts facilitated by use of a seven-tab laboratory counter for the most abundant species.

In samples with an abundance of particulate organic matter stirred up from the bottom or washed into the estuary from runoff, some of the phytoplankters certainly must have been obscured and therefore not counted.

One problem of using a simple microscope slide in making counts on a concentrated sample is the error introduced by non-random distribution of the cells when the whole slide is not counted. It was felt, however, that the somewhat higher counts which would result from transects in the central portion of the coverslip would compensate for loss

of plankton on the surface of the centrifuge tube and transferring pipette.

Another possible source of error is that estimates of cell number made while the cells are still motile may be too high because the same flagellates get counted several times. On the other hand, some sensitive species, as soon as they stop moving, may drop their flagella, die and disintegrate to such a condition that they are no longer identifiable, which then results in too low estimates of cell number. Differences between cell estimates before and after loss of motility were as much as 42% in an *Olisthodiscus* and 62% in a *Hemiselmis* sample over a period of a half hour. Thus the longer a cell count takes, the lower the calculated cell number per unit volume may be for the same aliquot.

Changes in cell number in the samples prior to the time of examination is also an important source of error in standing crop determination. Samples from Gales Creek were normally transported back to the University 180 miles away and counts begun the next day. Since the processes involved in preparation and examination normally required around an hour and a half for each sample, the complete cruise collection would take three days to study even if fatigue or other commitments did not intervene. At different times of the year, selected samples were counted over five day periods to determine the degree of change in cell numbers. 14 species gave an average decrease in density of 78% in 5 days due to death, with the greatest decrease at 99.8% for a *Gyrodinium* species, while 6 species showed an average increase in cell number of 200% due to growth in the sample jars, with the greatest increase at 400% for *Hemiselmis*. After five days many species died out completely in the samples, so it was very important to complete counts before this much time elapsed after collection. Thus with present methods there was no way to avoid the possibility of errors in standing crop determinations with as much as ±100% or more of the original sample cell densities.

In addition to these possible sources of error in examining the samples, there is also the further problem of how accurately and precisely these samples represent the natural densities in the estuary.

Some motile phytoflagellates from Gales Creek demonstrated movement rates of as much as a centimeter per minute. With the estuary's shallowness and often high degree of stratification the plankton could

readily become clumped and layered at favorable locations in the water mass. How much variation this resulting patchiness could produce in the calculations was tested by examining sets of four samples collected at 8-minute intervals from each of three different depths at one station (#5 on cruise 21). Coefficients of variability (standard deviation divided by the mean, expressed as a percentage) were calculated from salinity, temperature and oxygen values in these samples, as well as for the eight most abundant phytoflagellate species present. The average coefficient of variability of the eight phytoflagellates was 86.8, a very high value when compared to the average coefficients of variability for the physical parameters measured from the same sample, which was only 12.5. As an extreme example of this variable microdistribution, an *Eutreptia* species obtained in four samples from near the lower limit of the fresh water layer varied from 0 to 3000 cells per liter.

Over longer periods of time during the day, even larger variations would be expected because of the combined effects of phytoflagellate mobility, cellular reporduction and changing of water masses with tidal flow. During a diel study (cruise 26) single samples from the same station and depth taken at 3-hour intervals showed a few cases of rather large fluctuations in cell numbers. Examples over 3-hour periods during the night include a 340% increase in a *Chroomonas* count, from 32,000 to 108,000 cells per liter, and an 875% increase in a *Gyrodinium* count from 800 to 7000 cells per liter. In both cases, the counts dropped back to near the original values after another 3-hour period.

The problem of patchiness of plankton has been discussed by Cassie (1963) and Wiebe and Holland (1968). Bainbridge (1957) states that concentrated patches of diatoms or flagellates may sometimes occur giving densities 20 times the normal level. Hasle (1954) concluded from her work that the ordinary method for determining plankton density with one sample at each station or depth is satisfactory when the counting results are treated critically, taking into account the possible uneven distribution in nature and the error of the counting method.

In the Gales Creek study the combined sources of possible error from patchiness, death or growth in the sample jars, loss of cells and

non-random distribution resulting from the concentrating and counting methods were such as to suggest that differences in cell counts below the level of a power of ten are too small to be significant when comparing live phytoflagellate samples.

RESULTS AND DISCUSSION

Hydrographic Characteristics of Gales Creek

Temperature: Average water temperatures for each cruise normally corresponded rather closely with the air temperatures at the time of sampling. Average monthly water temperatures were close to the average monthly air temperatures recorded by the U.S. Weather Bureau at Morehead City, though the estuary tended to be a few degrees warmer (Fig. 5A). In deeper bodies of water such a close paralleling of water and air temperatures would not occur, but here the shallowness of the estuary and sound combine with wind- and tide-generated currents to promote rapid heat exchange. Thus the estuary would provide little escape for organisms from the cold of winter, where water temperatures went as low as 3°C in February, or heat of summer, where temperatures reached as high as 34°C in June, giving a water temperature range of 31°C for the year. For an organism to be indigenous to the estuary, it would either have to be eurythermic or utilize a resistant dormant resting stage in its life cycle.

From late autumn to early spring, temperatures averaged aroung 15°C, rising through the spring to an average between 25°C and 30°C from late spring through the summer to early autumn, then decreasing rather quickly in the autumn to the cold season average around 15°C. The lowest average temperatures occurred in early February, the highest in August. The average range of temperatures encountered during any cruise was 5.5°C.

A slight thermocline was sometimes evident, corresponding to the sharp density gradient that frequently occurred between fresh surface water and brackish bottom water. The surface water responded more readily to changes in air temperature and sunlight than bottom water, so when the salinity density gradient was great enough the surface water

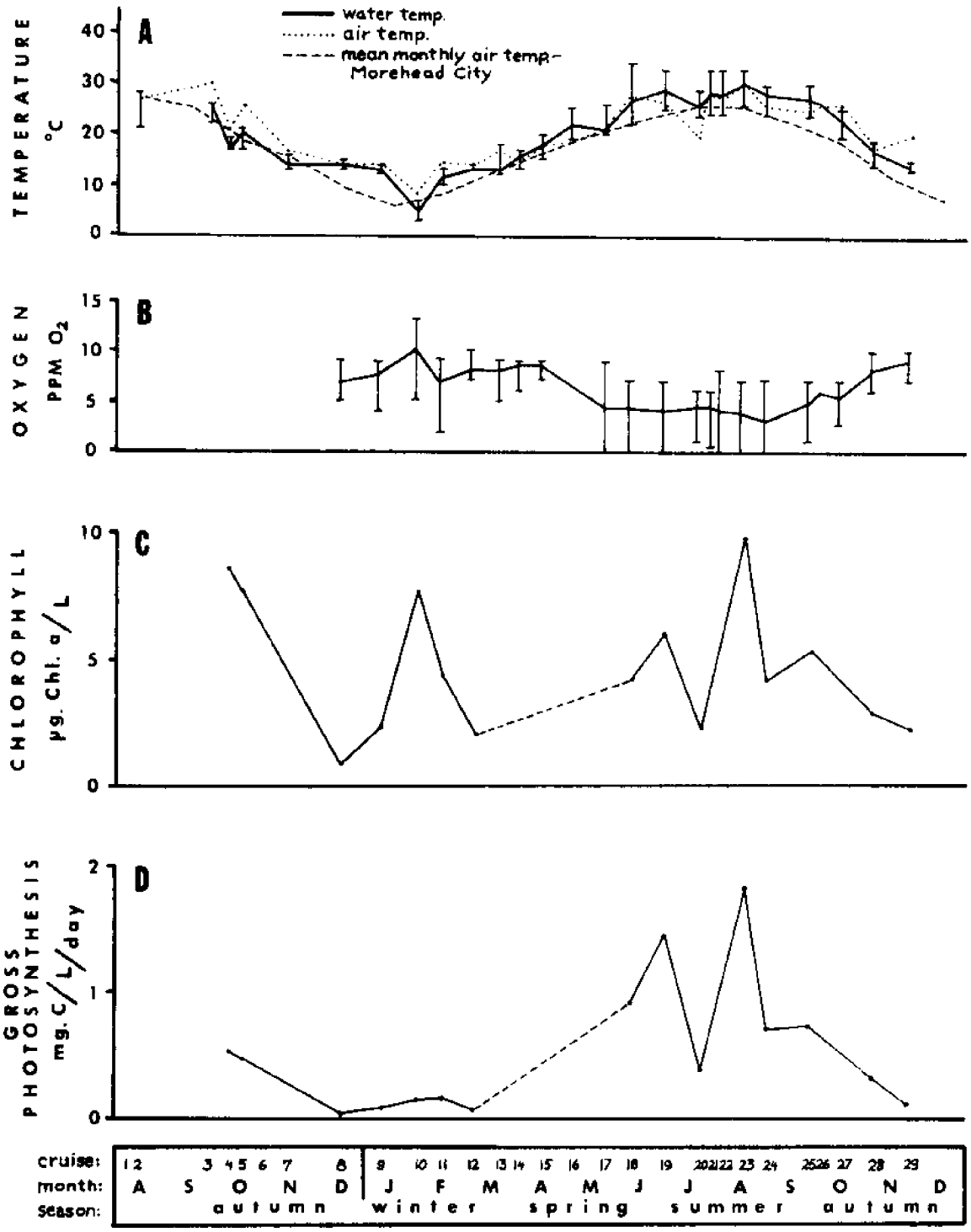
FIGURE 5

A. Seasonal variation of temperature. Average water temperature for each cruise is plotted, with brackets indicating range of temperatures encountered. Also included are plots of the average air temperature for each cruise and the mean monthly air temperature recorded from Morehead City, 10 miles east of Gales Creek.

B. Seasonal variation of Oxygen concentrations. Average oxygen concentration for each cruise is plotted, with brackets indicating range of concentrations encountered.

C. Seasonal variation of average chlorophyll concentrations. Dotted line indicates missing set of samples.

D. Seasonal variation of gross photosynthesis values calculated from chlorophyll and temperature data according to the formula of Williams and Murdock (1966).


A
water temp.
air temp.
mean monthly air temp-
Morehead City
TEMPERATURE °C
40
30
20
10
0
B
OXYGEN PPM O_2
15
10
5
0
C
CHLOROPHYLL µg. Chl. a/L
10
5
0
D
GROSS PHOTOSYNTHESIS mg. C/L/day
2
1
0
cruise: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
month: A S O N D J F M A M J J A S O N D
season: autumn winter spring summer autumn

could be either warmer or cooler than the more slowly responding water beneath.

Salinity: The salinity range in Gales Creek was from 37°/oo to fresh water. Bottom water in the mixing basin, which usually reflected the influence of Bogue Sound, presented the highest salinities recorded in the creek. Here values were from 37°/oo in September to a low of 20°/oo during heavy runoff in July, with an annual average of 28.6°/oo. At the head of the creek the average surface water salinity was only 1.4°/oo, and no surface water measurement exceeded 6°/oo, due to continuous freshwater inflow at the headwaters.

When a value greater than 1°/oo was obtained at the surface in the headwater region, it was still possible to observe a thin layer of tannin-stained fresh water lying above the clearer higher salinity water below, forming a layer too shallow to measure with the salinometer probe. A surface effect on the probe causes slightly higher conductivity readings, so "surface" salinity measurements have actually been for a depth of around 0.05 meters.

Average salinities calculated for each cruise (Fig. 6C) indicate the relative influence of the two sources of water, fresh from runoff and saline from sound and sea. After heavy rains in the summer, the average salinity was as low as 3.4°/oo, while during the dry autumn it was as high as 33°/oo. Seasonal averages were 26.7°/oo in autumn, 12.5°/oo in winter, 20.6°/oo in spring and 15.8°/oo in summer, indicating that in winter and summer the estuary was most influenced by fresh water runoff, while during the dry autumn sound waters dominated, with the spring presenting an intermediate condition.

In spring and fall, the bottom of the creek is almost continually exposed to saline waters of 20°/oo or higher, even in the headwater region where saltwater lies beneath the freshwater surface layer. During most of the winter, and at certain times in summer, runoff from heavy precipitation is great enough to introduce fresh water onto the surface of the mixing basin; when the runoff is this great the flushing effect is strong enough to expose the bottom of the estuary in the headwater regions to fresh water (Figures 7 and 8). This alternate exposure of the bottom to fresh and salt water is undoubtedly a major factor responsible for the apparent absence of benthic flora and fauna in the upper regions of the estuary.

In the headwater region, the fresh water inflow always formed a surface layer with a sharp halocline (salinity gradient) between it and the brackish estuarine water beneath, except in those instances in which runoff was so heavy that all brackish water in the head region had been flushed out (e.g., January, March and July). The halocline was normally so sharp that the headwater station (#15) had an average salinity change of 17.8°/oo over only 0.1 meter difference in depth. The amount of water runoff is reflected in the depth of the halocline (Fig. 6B), and therefore correlated well with the graph for the average salinity of the estuary (Fig. 6C). Agreement with the precipitation data from the U.S. Weather Bureau in Morehead City is not quite so clear, and may be the result of patchiness in rainfall distribution (Fig. 6A).

The halocline decreased in depth with distance from the head region. Compared to the halocline depth at station #5 during times of heavy freshwater inflow, the halocline was approximately 0.1m shallower at station #11, another 0.1m shallower at #9, 0.2m less at #8, and another 0.2m less from station #5 to the mixing basin, #2. With exposure to stronger wind and tide currents, the halocline was sometimes lost due to mixing. This was generally the case in the lower regions of the creek, but sometimes also occurred in the more sheltered upper reaches. Fig. 9 presents the stratification conditions found at the six stations on a cruise in August where a strong southwesterly wind had disturbed the sharp and slowly rising halocline in the lower portion of the estuary.

Because of the strong salinity stratification in Gales Creek, most samples obtained from the estuary were either from polyhaline waters (18-30°/oo) or from oligohaline waters (0.5-5°/oo) with relatively few samples from mesohaline salinities in between. This distribution is readily seen in Fig. 10, where the 324 water samples from cruise 9 to cruise 29 are plotted for salinity and temperature.

Oxygen: Oxygen concentrations in Gales Creek varied from a maximum of 13 ppm to a minimum of 0 ppm. From late spring to early autumn the average for the creek was under 5ppm, while from late autumn to early spring the average was around 8 ppm (Fig. 5B). Values were normally highest in the surface fresh water layer, dropping sharply in the halocline to lower values in the underlying more saline water. During the warmer period of the year from late spring to the end of summer, oxygen

FIGURE 6

A. Seasonal variation of precipitation within one week and within one day of sampling cruises. Data from Morehead City weather station, 10 miles east of the estuary.

B. Seasonal variation in halocline depth, the sharp gradient between the surface fresh water layer and underlying brackish water, at station #15, in the headwater region.

C. Seasonal variation in salinity. The average salinity from all samples on each cruise is plotted, with brackets indicating the salinity range for each cruise.

D. Seasonal variation in the average depth at which 1% incident light was calculated to have occurred, using Secchi disc depth data from all stations on each cruise. Stippled areas indicate where calculated depth was less than depth of bottom.

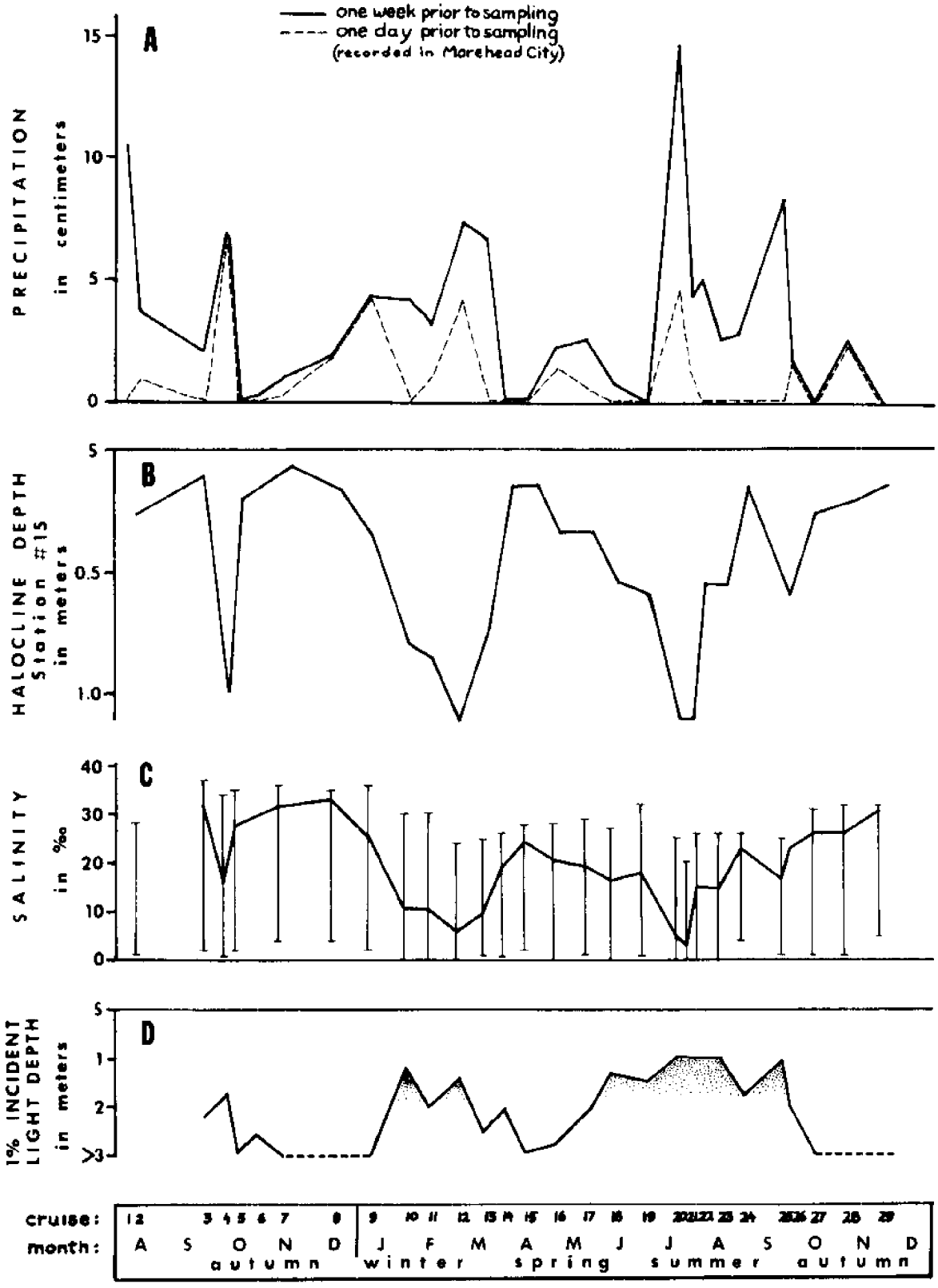

A
one week prior to sampling
one day prior to sampling
(recorded in Morehead City)
PRECIPITATION
in centimeters
15
10
5
0
B
HALOCLINE DEPTH
Station #15
in meters
5
0.5
1.0
C
SALINITY
in ‰
40
30
20
10
0
D
1% INCIDENT
LIGHT DEPTH
in meters
5
1
2
>3
cruise:
month:
A S O N D
autumn
J F M A M J
winter
spring
J A S O N D
summer
autumn

FIGURE 7

Seasonal variation in positions of surface water isohalines down the length of the estuary.

Note that in winter and summer runoff was great enough to introduce fresh water into the surface of the mixing basin.

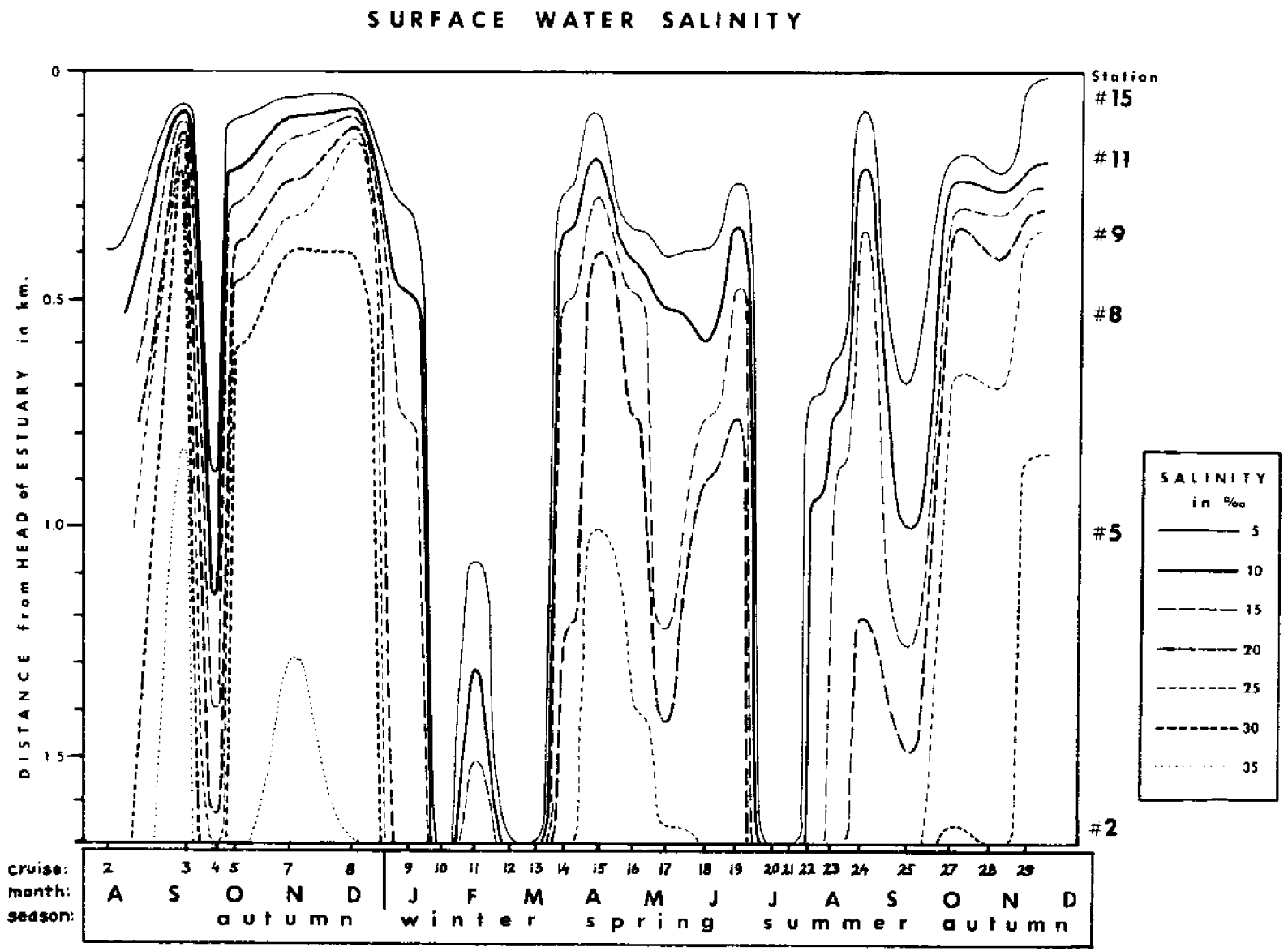

SURFACE WATER SALINITY
DISTANCE from HEAD of ESTUARY in km.
0
0.5
1.0
1.5
Station
#15
#11
#9
#8
#5
#2
SALINITY in ‰
5
10
15
20
25
30
35
cruise:
month:
season:
2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 27 28 29
A S O N D J F M A M J J A S O N D
autumn winter spring summer autumn

FIGURE 8

Seasonal variation in positions of bottom water isohalines down the length of the estuary. Enclosed areas indicate pockets of higher salinity bottom waters.

Note that in winter and summer fresh water from runoff was great enough to extend to the bottom in the headwater region.

BOTTOM WATER SALINITY

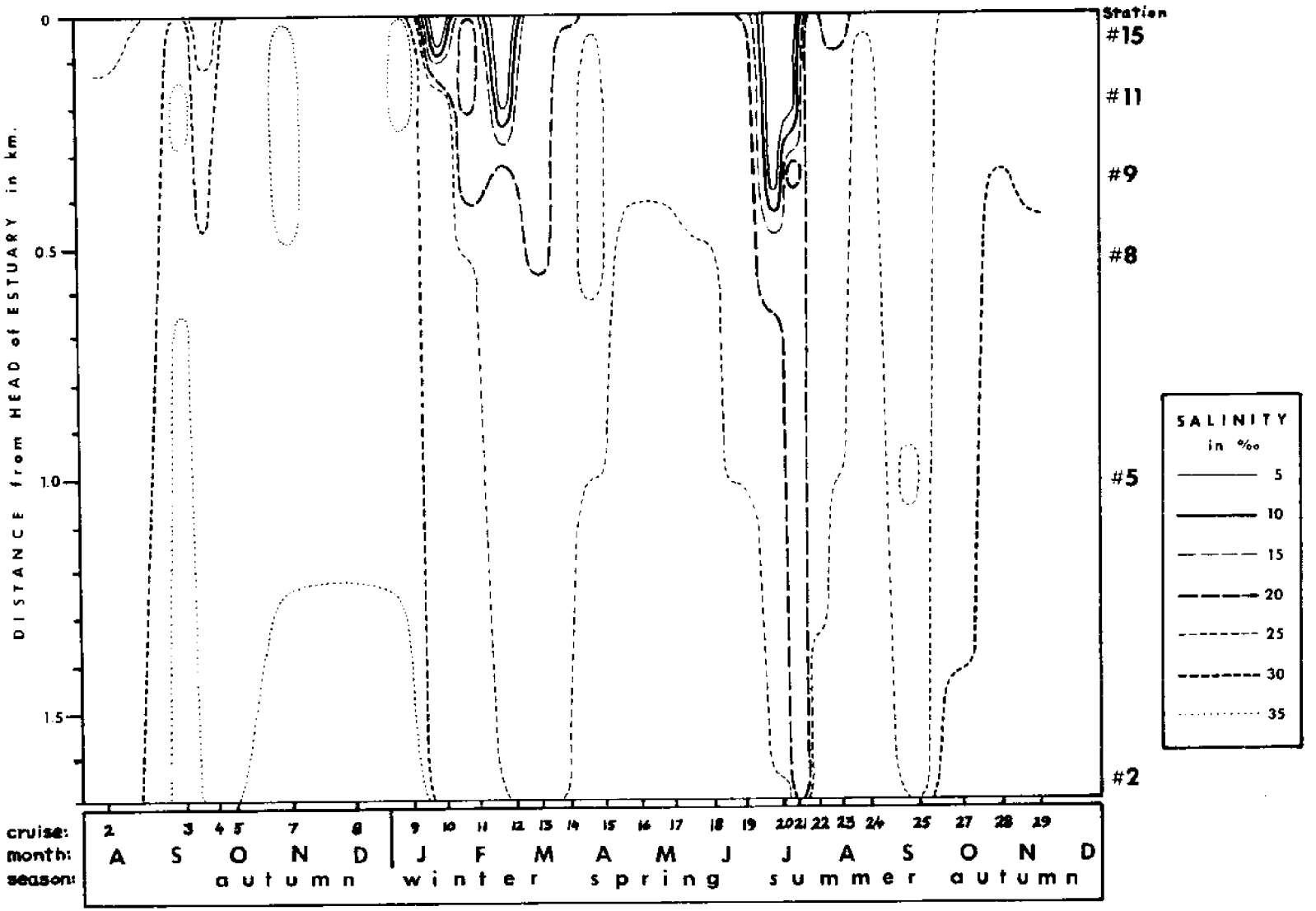


FIGURE 9

Salinity and oxygen depth profiles for each station on a representative cruise, #23 (August 17, 1966). Salinities are indicated by solid lines, oxygen concentrations by dashed lines. Also included is an indication of the depth of 1% incident light at each station calculated from Secchi disc data.

SALINITY AND OXYGEN PROFILES FOR GALES CREEK
CRUISE # 23, AUGUST 17, 1966

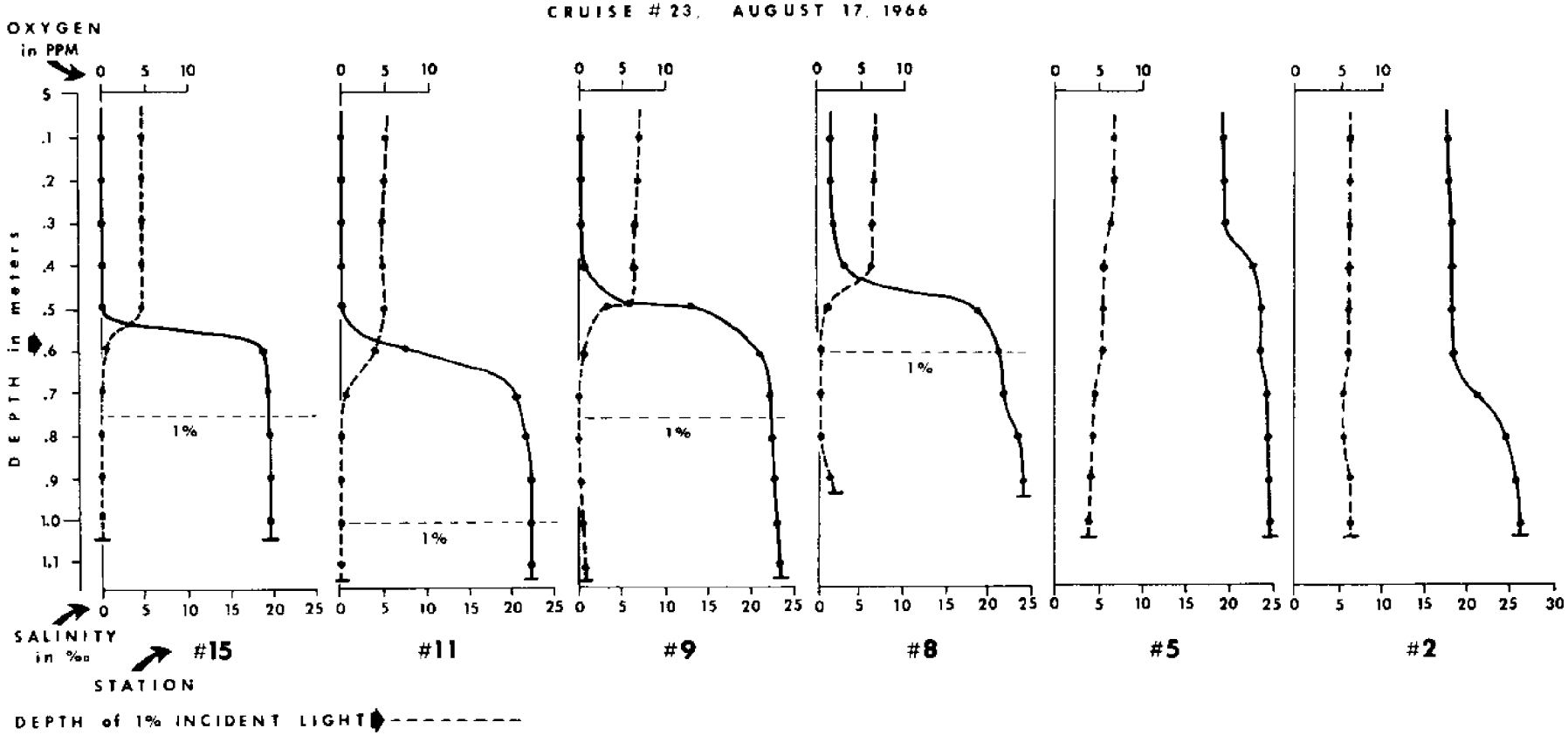
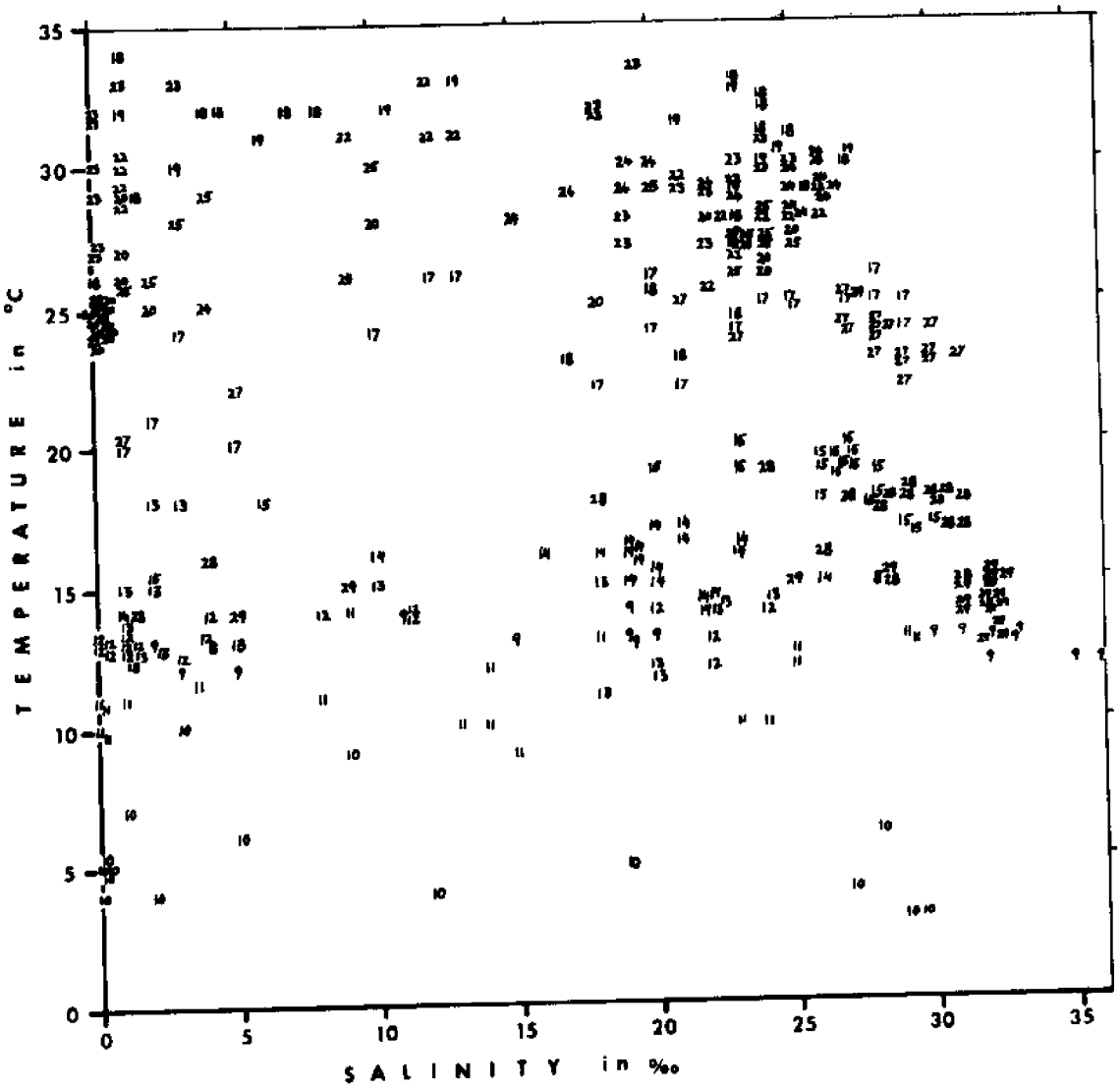


FIGURE 10

Plot of the temperature-salinity distributions for 324 water samples from cruise 9 to cruise 29, with each sample indicated by cruise number. Warmer samples appear towards the top and higher salinity samples appear towards the right.

TEMPERATURE — SALINITY DISTRIBUTIONS
for 324 SAMPLES by cruise numbers



was often completely depleted by biological metabolism in the lower depths at the upper stations on the creek (Fig. 9). Here deeper pools protected from strong tidal influence by shallower down-stream areas of the creek could retain denser haline waters long enough that they became stagnant. However, oxygen was present at all times of the year in bottom waters from the lower middle reaches to the mixing basin. Benthic organisms observed in the estuary appeared to be limited to those regions where continued water corculation prevented complete oxygen depletion.

Light: On each cruise, a secchi disc was used to determine roughly the degree of light extinction at stations along the creek. Shallower secchi disc depths were recorded in winter and summer, reflecting the greater turbidity of the creek during these seasons due to greater freshwater runoff carrying quantities of dissolved and particulate organic matter. This turbidity generally decreased towards the mouth where the influx of clearer sound water was greater. Though the water was less turbid in the spring than in summer or winter, only in the late autumn was the creek clear enough that the secchi disc could be seen at most stations when resting on the bottom.

The compensation depth is the point where on the average, plankton photosynthesis just balances respiration. This normally occurs at a depth where the light intensity is reduced to approximately 1% of that at the surface (Yentsch, 1962). Calculations of the depth of 1% surface radiation ($Z_{1\%}$ = 2.5 x Secchi disc Depth) in Gales Creek revealed that in water next to the bottom at the upper stations photosynthetic rates could have been below the compensation point during some of the winter and summer cruises (Fig. 6D). These calculations must be considered tentative, however, because to obtain accurate light extinction values from secchi disc depth measurements, the water column must be uniform and unstained, and neither of these characteristics held true for Gales Creek.

Fluctuation of the average depth for 1% incident light over the year showed a direct relationship of turbidity to the volume of fresh water runoff entering the estuary, and an inverse relationship to the fluctuation of average salinity. In the summer, the water masses calculated to be below compensation depth were also anoxic, and could

therefore present definite stress for heterotrophic as well as autotrophic aerobes.

Transmission spectra on brown-stained unfiltered water samples showed terminal absorption in the shorter wavelengths without any maxima. According to Burt (1955a) this indicates that the controlling median radius of particles in suspension did not exceed 0.6μ. These humic substances apparently are present in a continuous gradation from dissolved compounds through colloidal suspensions to fine particulate matter, with coarser particles in earlier stages of degradation abundant at times of heavy fresh water runoff or strong bottom currents.

pH: The presence of excess alkaline radicals, such as the carbonates, serves to buffer salt water against great changes in pH. The pH of sea water, with an average salinity of $35^{o}/oo$, is generally very stable, ranging between 8.1 and 8.3. In less buffered brackish water and unbuffered fresh water, pH is more variable. The expected relationship between salinity and pH was observed in Gales Creek (Fig. 11). In polyhaline waters ($18\text{-}30^{o}/oo$), the pH ranged between 7.6 and 8.2 generally, reflecting the influence of introduced sea water. In mesohaline waters ($5\text{-}18^{o}/oo$), pH varied between 7.0 and 7.9, and in oligohaline waters ($0.5\text{-}5^{o}/oo$) was usually between 6.7 and 7.7. Occasional heavy influxes of fresh water resulted in pH levels as low as 5.6 (cruise 12) and 6.3 (cruise 18). Since most of the carbon dioxide dissolved in waters of pH 6.5 to 8.5 is present as bicarbonate ion, it was assumed that a good reserve of CO_2 for photosynthesis was present in all the brackish water situations encountered.

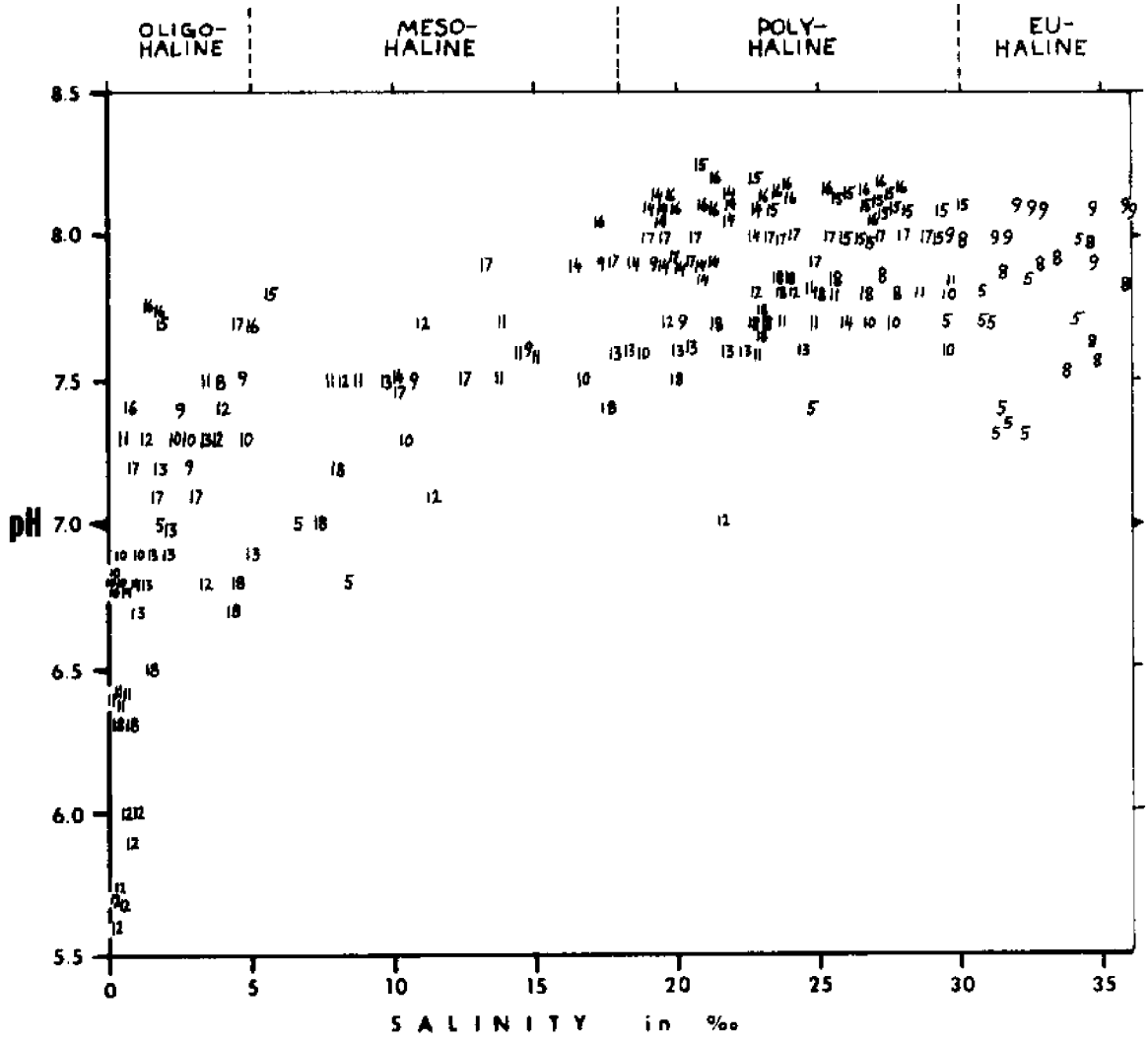
These pH measurements should not be considered firm figures. In the time from collection to when these samples were measured at the laboratory, significant changes in dissolved carbon dioxide concentrations, and therefore pH, might have taken place, due to exchange with the air or biological activity. In future investigations, where possible, pH measurements should be made in the field to insure greater reliability of the data.

The slightly acid nature of the runoff was due to humic acid materials contributed from the surrounding forest soils and swamps. As these waters meet the saline water from the sound, the humic substances become coagulated and the pH shifts to slightly alkaline. These coagulated

FIGURE 11

Plot of the pH-salinity distributions for 213 water samples from cruise 5 to cruise 18, with each sample indicated by cruise number. More acidic samples appear to the bottom and more saline samples appear towards the right.

pH — SALINITY DISTRIBUTIONS for SAMPLES
by cruise numbers



particles contribute to the flocculent ooze on the bottom so easily disturbed by currents.

Chlorophyll-a: Concentrations ranged from undetectable to 18.71 µg/l. Values were low in December, increased to a peak in February, then diminished again by the end of winter. The samples from March to May were lost so data are not available for this period. Increasing chlorophyll-a concentrations were obtained through the summer, except for one depression during heavy runoff in July. The maximum was reached in August, then values dropped back to the low levels of autumn. The mean from October to March was 3.89 µg/l, while the mean from June to September was 5.39 µg/l, values which were slightly lower than those obtained by Patten *et al.* (1963) for Chesapeake Bay. Seasonal distribution of average chlorophyll-a values for the creek is illustrated in Fig. 5C.

These data were used along with water temperature measurements and day length information from the U.S. Coast and Geodetic Survey Tide Tables (1966) to calculate the possible gross photosynthesis such chlorophyll concentrations in plankton could yield, according to the formula of Williams and Murdock (1966), and the curve derived therefrom is presented in Fig. 5D. It is apparent from this curve that the winter peak in chlorophyll-a concentration probably did not signify any parallel increase in productivity by the phytoplankton, because of low light levels and low temperatures at that time of year.

Chlorophyll concentrations can provide an estimate of the autotrophic plankton standing crop at specific times. How well these concentrations correlate with the seasonal distribution of average total phytopfagellate cell counts may be seen by comparing Fig. 5D with Fig. 14B. The correlation is positive but changes in cell densities are much greater than those of chlorophyll concentrations. This discrepancy possibly reflects the disproportionate emphasis placed on small cells when using cell counts as a measure of standing crop.

Nutrients

Very little literature is available concerning the distribution and fluctuation of nutrients in waters along the eastern shores of the United States. Riley and Conover (1956) studied the chemical

oceanography of Long Island Sound, and Ryther (1954) investigated 12 polluted bays along the Long Island shore. Ketcham (1967) investigated phosphorus distribution in the New York Bight. Ryther and Dunstan (1971) studied the distribution of inorganic nitrogen and phosphorus in several of the same Long Island bays, the New York Bight, and coastal waters of the eastern seaboard as far south as Cape Hatteras. Phosphates and nitrates were studied in Chesapeake Bay at the mouth of the Patuxent River by Newcombe *et al.* (1939) and Newcomb and Lang (1939). The York River was investigated for ammonia nitrogen by Patten and Lacey (1961). A transect of Chesapeake Bay off the York River was examined for one year by Patten *et al.* (1963) for dissolved and absorbed orthophosphate, dissolved and particulate organic phosphorus, and nitrate nitrogen.

All of these bodies of water studied are of much greater size than Gales Creek, and of these only Chesapeake Bay, 300 miles to the north, is of classical estuarine form. With so many conditions being different, only general comparisons can be made between these studies and data from Gales Creek. Nutrient studies on the Pamlico River, Pamlico Sound, and Bogue Sound in North Carolina are in progress, and Thayer (1971) presented nitrogen and phosphorus values for shallow estuaries near Beaufort, N.C. The rest of these studies have yet to be published, and there is no similar estuarine study available for any other part of the southeastern coast.

Nutrient sampling from Gales Creek consisted, whenever possible, of four samples from each cruise, collected from the surface water in the headwater region, surface water from the middle reaches, water next to the bottom also in the middle reaches, and water next to the bottom in the mixing basin. It was hoped that such sampling might reveal whether various nutrients were being supplied by stream, by sound, or by generation within the estuary itself by the process of biochemical circulation as described by Redfield (1955). However, the actual concentrations of the various nutrients studied often showed little apparent relationship to each other. Great variability in concentrations was recorded between stations and between cruises for the same station. Thus the data obtained were not in most cases consistant enough to support any conclusions as to the possible source of the nutrients. The discussions of nutrient fluctuations has therefore been confined primarily to

averages for the estuary as a whole. All values are in microgram-atoms per liter.

Nitrate-nitrogen: The range in concentrations for this fraction of the total nitrogen in Gales Creek was from non-measurable to 6.84 µg-At/l, almost exactly the same range obtained by Patten *et al.* (1963) in Chesapeake Bay, but higher than Thayer (1971) reported for waters around Beaufort, N.C. Values were quite low in mid autumn and from late winter through spring to early summer, with an average of less than 0.5 µg-At/l in November and from March to July. Winter values were somewhat higher, averaging between 1.0 and 1.5 µg-At/l. Values increased in mid-summer to averages around 3 µg-At/l, with the highest concentrations recorded in samples from near the bottom. Seasonal distribution of average nitrate-nitrogen values for the creek is presented in Fig. 12C, while the complete data is plotted in Appendix C, Fig. 1B.

Nitrite-nitrogen: This nutrient ranged in concentration from undetectable to 5.89 µg-At/l, with lowest average figures occurring in mid autumn. Values from late winter to early summer were higher than those for nitrate, but were still below 1 µg-At/l, while in the winter the figures were slightly higher. The highest average values, up to 3 µg-At/l, occurred in the latter part of the summer. Here they paralleled the nitrate concentrations, where the highest levels were also reached in the bottom samples. Fig. 12B presents the average seasonal distribution, while complete data are plotted in Appendix C, Fig. 1A.

In comparison, the highest value obtained for Chesapeake Bay and the Patuxent River (Newcombe *et al.*, 1939) was only 0.6 µg-At/l, and only 0.5 µg-At/l from waters around Beaufort, N.C., (Thayer, 1971).

Ammonia-nitrogen: Ammonia concentrations ranged from non-measurable to an extraordinary 19.09 µg-At/l. This peak was recorded at a time soon after a portion of the upper middle reaches of the creek was being excavated to create a swimming area for the local Boy Scouts, a project which was later discontinued. This disruption of the marsh areas along the creek in early February resulted in great amounts of organic material in various states of decomposition being washed into the estuary. Evidence of this was the increased turbidity at that time. By mid-February when the next cruise occurred, the ammonia level had jumped to this remarkable peak in the bottom waters at the middle reaches, most likely the result of bacterial action on the excess

introduced organic matter. Within a month, ammonia concentrations had dropped to the lowest average level for the year, under 1 µg-At/1. There was no increase in phytoflagellate concentrations during this period, but there was a great deal of heavy fresh water runoff. Probably the excess ammonia was physically removed from the estuary by flushing, rather than by biological activity.

Concentrations were low through spring and also in the latter part of autumn, averaging around 1 µg-At/1. Averages were high through the summer. The highest peak occurring under natural conditions was 8.49 µg-At/1 in July from a bottom sample taken just before the largest phytoflagellate bloom in the estuary occurred. Further statements about ammonia concentrations are difficult to make from the data because of the great variability between stations and samples. Average seasonal fluctuations of ammonia are presented in Fig. 12A, with complete data graphed in Appendix C, Fig. 2A.

Summer values for ammonia nitrogen in upper Chesapeake Bay and the Patuxent River also reached 8 µg-At/1 (Newcombe *et al.*, 1939). In the lower York River the highest recorded value was 4.95 µg-At/1 with a mean near 2 µg-At/1 (Patten and Lacey, 1961). The highest value for Beaufort waters (Thayer, 1971) was 4.30 µg-At/1.

Total Nitrogen: This determination includes the dissolved forms of inorganic nitrogen along with both dissolved and particulate organic nitrogen. The range was from non-measurable to 65.8 µg-At/1. Fluctuation in total nitrogen correlated rather well with the amount of fresh water runoff flowing into the creek and with the turbidity of the estuary. There was a peak in winter, a broader peak from the middle of spring through summer into early autumn, and low concentrations in late autumn and early spring. The peak in winter was enhanced in early February by the introduction of excess organic detritus from the marsh due to excavation of the creek mentioned above. Dissolved and particulate organic nitrogen contribute a much greater portion to the total nitrogen concentration in the estuary than do ammonia, nitrite, and nitrate, as shown in Fig. 13A. Complete total-nitrogen data are graphed in Appendix C, Fig. 2B.

Further analysis would need to be carried out to determine what proportion of this organic nitrogen is supplied to the estuary as dissolved and colloidal compounds rather than as suspended particulate

FIGURE 12

A. Seasonal distribution of dissolved *ammonia-nitrogen* concentrations, measured in microgram-atoms of nitrogen per liter. Average ammonia concentrations are plotted, with brackets indicating the range in sample concentrations from each cruise. (Complete data graphed in Fig. 2A of Appendix C.)

B. Seasonal distribution of dissolved *nitrite-nitrogen* concentrations, in microgram-atoms of nitrogen per liter. Average concentrations are plotted in the manner of the above graph. (Complete data graphed in Fig. 1A of Appendix C.)

C. Seasonal distribution of average dissolved *nitrate-nitrogen* concentrations in microgram-atoms of nitrogen per liter, plotted in the manner of the above graphs. (Complete data graphed in Fig. 1B of Appendix C.)

D. Seasonal distribution of average dissolved *phosphate-phosphorus* concentrations, measured in microgram-atoms of phosphorus per liter, plotted in the manner of the above graphs. (Complete data graphed in Fig. 3A of Appendix C.)

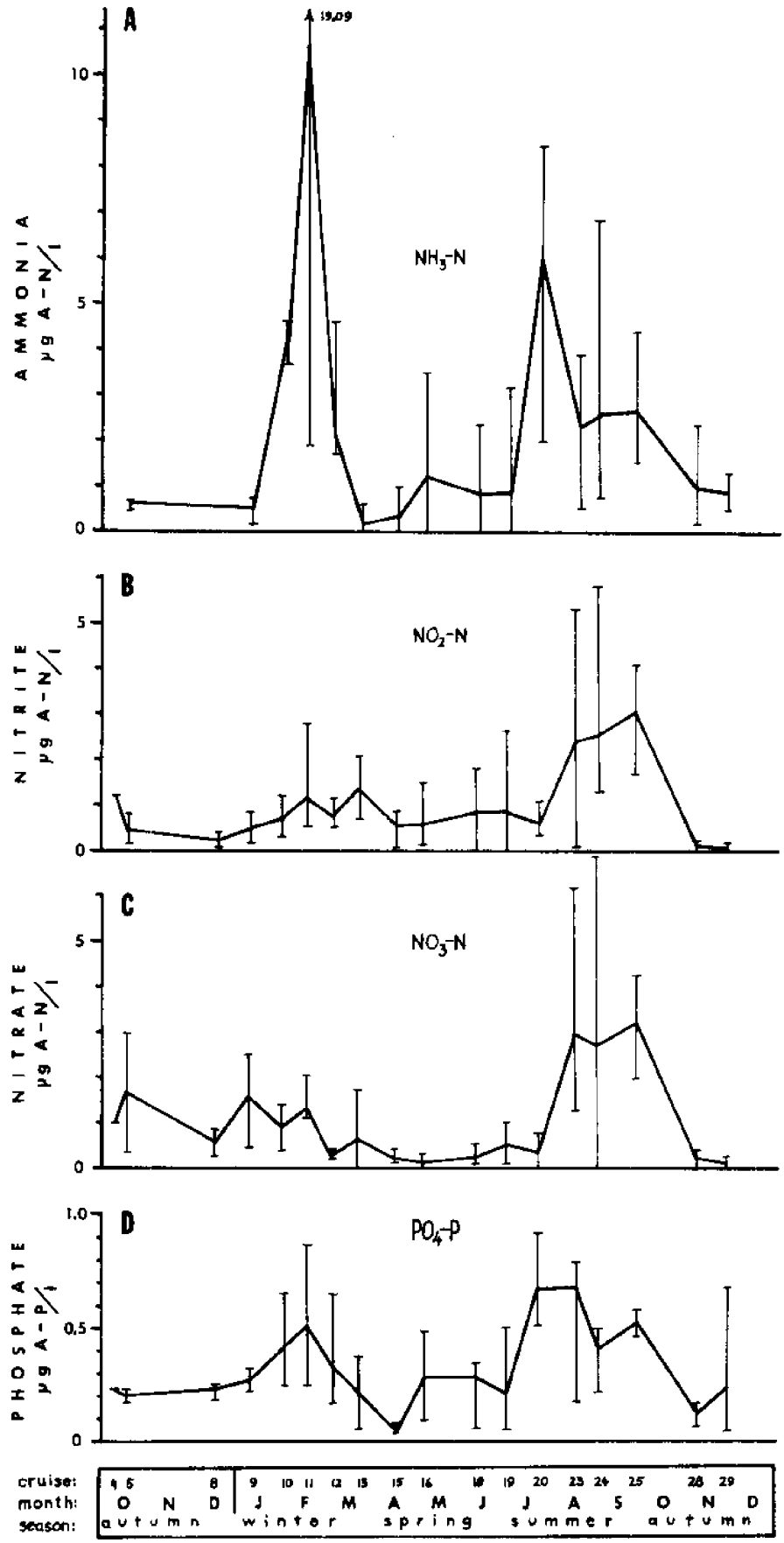
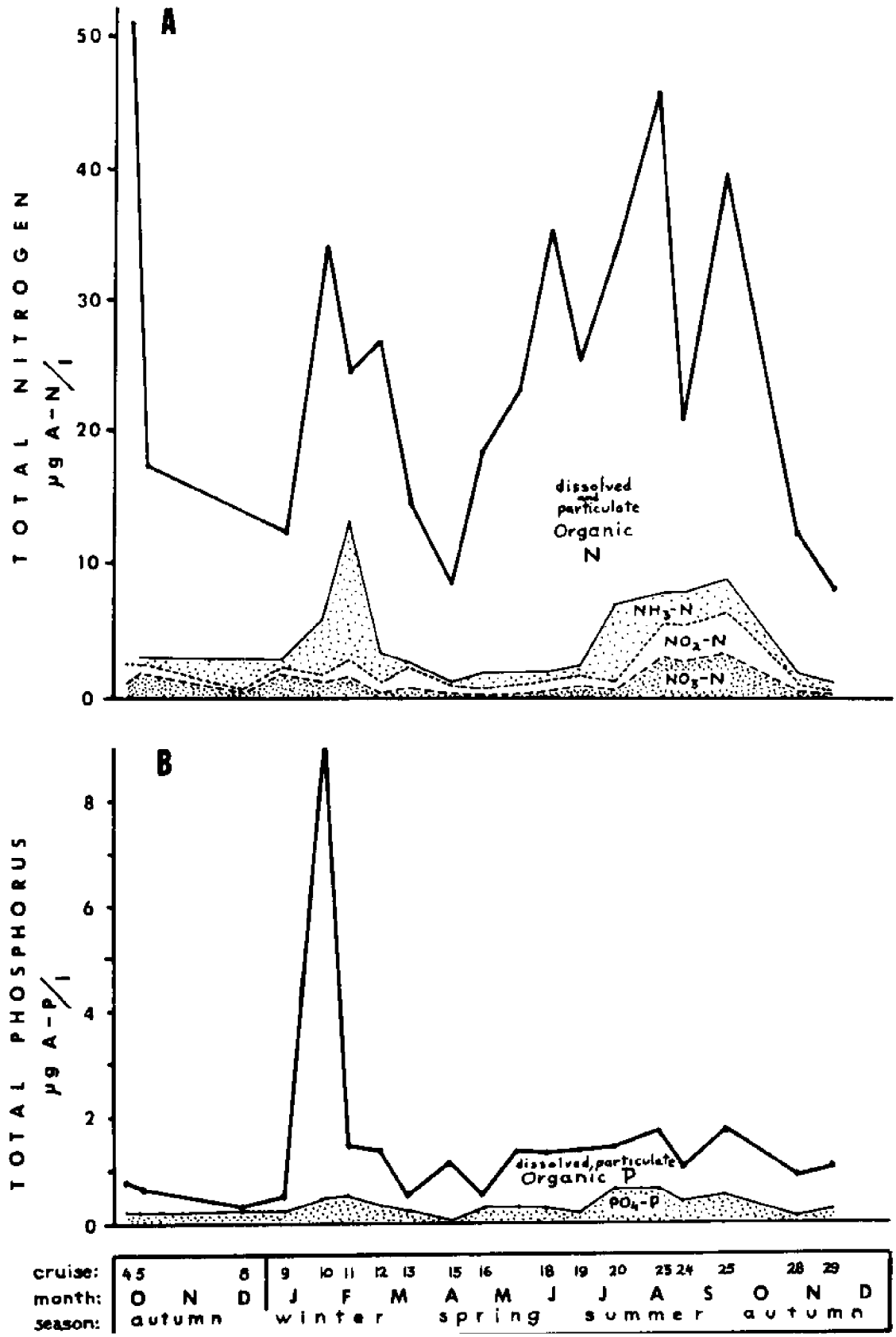

A
19.09
10
5
0
AMMONIA
µg A-N/l
NH3-N
B
5
0
NITRITE
µg A-N/l
NO2-N
C
5
0
NITRATE
µg A-N/l
NO3-N
D
1.0
0,5
0
PHOSPHATE
µg A-P/l
PO4-P
cruise: 4 5 8 9 10 11 12 13 15 16 18 19 20 23 24 25 28 29
month: O N D J F M A M J J A S O N D
season: autumn winter spring summer autumn

FIGURE 13

A. Seasonal distribution of average *total nitrogen* concentrations, consisting of dissolved and particulate organic and inorganic nitrogen fractions, measured in microgram-atoms of nitrogen per liter. The portions comprising dissolved ammonia-, nitrite- and nitrate-nitrogen are indicated within the graph area. (Complete data graphed in Fig. 2B of Appendix C.)

B. Seasonal distribution of average *total phosphorus* concentrations, consisting of dissolved and particulate organic and inorganic phosphorus fractions, measured in microgram-atoms of phosphorus per liter. The portion comprising dissolved phosphate-phosphorus is indicated within the graph area. (Complete data graphed in Fig. 3B of Appendix C.)


A
TOTAL NITROGEN
µg A-N/l
50
40
30
20
10
0
dissolved and particulate Organic N
NH3-N
NO2-N
NO3-N
B
TOTAL PHOSPHORUS
µg A-P/l
8
6
4
2
0
dissolved, particulate Organic P
PO4-P
cruise: 4 5 6 9 10 11 12 13 15 16 18 19 20 25 24 25 28 29
month: O N D J F M A M J J A S O N D
season: autumn winter spring summer autumn

matter, though some phytoflagellates are capable of utilizing the latter by phagocytosis as a source of nitrogen.

Dissolved Phosphate-Phosphorus: This fraction varied from a low of 0.043 µg-At/l in April to a peak of 0.93 µg-At/l in July. Average figures presented in Fig. 12D show a peak in winter at 0.5 µg-At/l, then an early spring minimum followed by somewhat higher levels near 0.3 µg-At/l until summer when concentrations rose to maximum averages near 0.7 µg-At/l, dropping in late summer and autumn to levels similar to late spring. The seasonal curve from surface samples in the headwater region appears to correlate well with the amount of fresh water runoff, but the other curves fluctuate too erratically to draw any conclusions about the possible source of the phosphate. These curves are presented in Appendix C, Fig. 3A.

In Chesapeake Bay concentrations were comparably low, with means between 0.2 and 0.4 µg-At/l except for higher summer peaks and maxima in autumn as high as 2.26 µg-At/l, more than double the maximum values of Gales Creek (Patten, *et al.*, 1963). In waters around Beaufort, N.C., concentrations ranged from undetectable to a relatively high 1.46 µg-At/l (Thayer, 1971).

Total Phosphorus: This fraction contains both dissolved and particulate organic and inorganic phosphorus. Figures ranged from a minimum of 0.19 µg-At/l in December to a peak of 4.25 µg-At/l in August. At the time of the excavation for a swimming hole mentioned above, a maximum figure of 21.74 µg-At/l was recroded. Once digging ceased, the concentrations dropped to average values (around 1 µg-At/l for spring). Late spring and summer values ranged between 1 and 2 µg-At/l in bottom water samples and below 1 µg-At/l in surface samples, both dropping slightly in autumn. These values are similar to those obtained by Patten *et al.* (1963) for Chesapeake Bay, where the low levels were also recorded in the autumn. Average figures are graphed in Fig. 13B. The complete curves are given in Appendix C, Fig. 3B, where it may be observed that the phosphorus is more often concentrated in the bottom waters of the estuary.

Nitrate:Phosphate Ratio: More important than absolute concentrations of nitrogen or phosphorus is the relative abundance of these atoms. Phytoplankton organisms are said to deplete nitrogen and phosphorus from sea water in a ratio generally comparable to the atomic

ratio of nitrogen and phosphorus in their cells, or approximately 20:1, according to Yentsch (1962) though Ryther and Dunstan (1971) state that the ratios may range from 3:1 to 30:1, with 5:1 to 15:1 being most commonly encountered. In the open sea, the nitrate:phosphate ratio is generally given as 15:1, while in coastal and estuarine waters it is often lower (Raymont, 1963).

In Gales Creek, the ratio varied from a minimum of 0.23:1 in March to a maximum of 28.8:1 in August with a very low average that fluctuated between 1:1 and 6:1 from mid-autumn through winter to early spring, then remained near 1.6:1 until early summer, finally rising to a peak averaging about 10:1 in late summer. The yearly Nitrate:Phosphate average for the estuary was a low 3.75:1. The curve for the average ratios is presented in Fig. 14A, with the complete data graphed in Appendix C, Fig. 3C. From these data it would appear that the low concentrations of nitrate could be an important limiting factor for phytoplankton in Gales Creek. This would agree with the conclusion of Ryther and Dunstan (1971) that nitrogen is the critical limiting factor to algal growth and eutrophication in coastal marine waters.

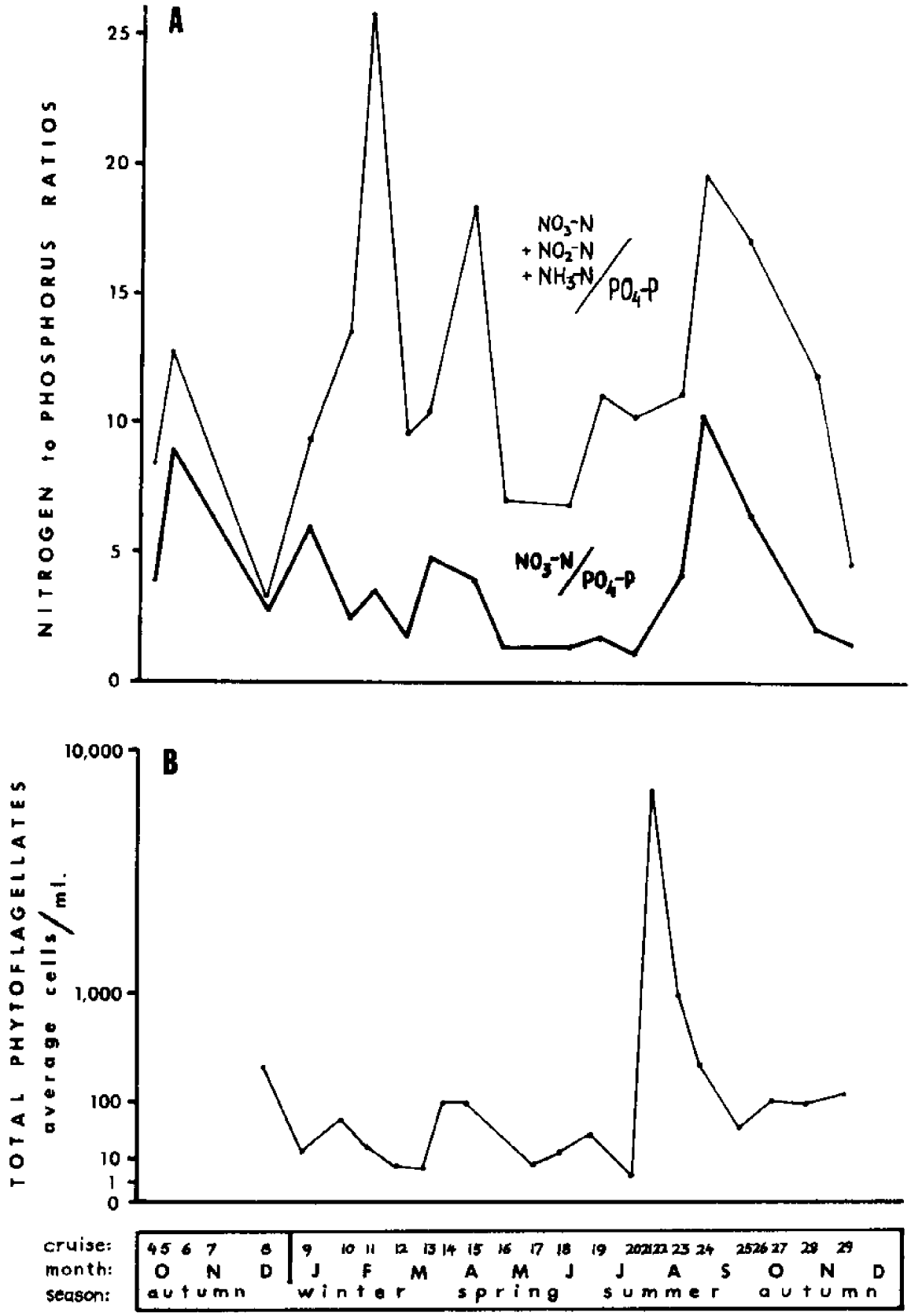
Various studies in the past on nitrogen uptake by algae have shown that many phytoplanktors can also utilize nitrite and ammonia as well as nitrate, and that when ammonia is present it is often preferred over nitrate as the nitrogen source (Provasoli, 1958). If all the analysed sourses of dissolved inorganic nitrogen in Gales Creek are taken together in relation to dissolved inorganic phosphorus, the Nitrogen:Phosphorus ratio for the estuary still comes out low but are not as extremely small as when nitrate is considered alone. These average ratios, presented in Fig. 14A, fluctuated between 3:1 and 26:1, with lower values in late autumn and late spring. The maximum average value occurred after the digging disturbance in February, though two other peaks with values near 20:1 occurred in early spring and in late summer.

It should be recognized that none of these figures for nutrient concentrations disclose anything about the turnover rates of the various compounds. This would be most important to investigate, for in autumn and spring, when absolute nutrient concentrations are lowest, plankton cell concentrations were not also diminished. Thus, depending on both turnover rates and the metabolic versatility of particular

FIGURE 14

A. Seasonal distribution of average *nitrogen to phosphorus ratios*. Plotted are both nitrate to phosphate and nitrate-nitrite-ammonia to phosphate ratios. (Complete data on nitrate to phosphate ratios graphed in Fig. 3C of Appendix C.)

B. Seasonal distribution of average *total phytoflagellate concentrations*, measured in cells per milliliter, using Lohmann's (1908) spheric curves formula for obtaining the vertical axis. (Complete data graphed in Fig. 15.)


A
NITROGEN to PHOSPHORUS RATIOS
25
20
15
10
5
0
NO_3-N + NO_2-N + NH_3-N / PO_4-P
NO_3-N / PO_4-P
B
TOTAL PHYTOFLAGELLATES average cells/ml.
10,000
1,000
100
10
1
0
cruise: 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
month: O N D J F M A M J J A S O N D
season: autumn winter spring summer autumn

phytoplankton species in utilizing available nitrogen sources, nitrogen may in some cases prove not to be so important a limiting factor in Gales Creek. This is certainly an area open for further study.

A factor not investigated was vitamin B_{12}, an important requirement for many algal flagellates and diatoms. It should not, however, be a limiting factor, since even the open sea is considered by Droop (1957) to have more than sufficient B_{12} vitamin available for the plankton crops normally encountered.

Discussion of Hydrography

From the information presented above it is evident that this estuarine environment possesses a high degree of variability. In fact, there was usually found to be more variation at and between stations on a single cruise than in averages between cruises.

Several factors studied stand out as probably being the most influencial in the estuary, ones to which phytoplankton species maintaining themselves in the estuary must be adapted. Most obvious of these is salinity, since water samples ranged from oligohaline to polyhaline on every cruise, and during periods of heavy fresh water runoff oligohaline waters could be found at every station along the creek. This influence was proportional to the degree of local precipitation, which also influenced the turbidity of the creek. This, in turn, increased the possibility of creating aphotic zones in deeper parts of the estuary which would cause further stress for autotrophic organisms. The stratification of the water column caused by the salinity-induced density gradient combined with warm summer temperatures and biological activity in the bottom waters often created anoxic conditions a stress for heterotrophic aerobes in both plankton and benthon.

The low levels of nitrate-nitrogen in relation to available phosphate-phosphorus would have an important limiting effect on those phytoplankton species unable to utilize ammonia or nitrite, though all three sources of nitrogen were low enough in late autumn and late spring to be of limiting effect for those species not also capable of utilizing

organic nitrogen sources. In general, total phytoflagellate cell numbers appeared to vary directly with the concentration of these nutrients.

There was no appearance of an organic nitrogen breakdown sequence of the type described by Barnes (1957) in which a high influx of organic nitrogen is subjected to autolytic or bacterial decomposition with graded release first of ammonia, later nitrite, and finally nitrate over a period of several months. The apparent absence of this sequence is readily explained by the overwhelming influence on the estuary of rapid tidal exchange, with a ratio of 0.43, plus the occasional flushing effect of heavy fresh water runoff. These influences would allow little time for biological influences to occur before the water in the estuary was completely exchanged, which in most cases was a time shorter than that between sampling cruises. It would appear, then, that the phytoplankton community merely responds to the rapidly fluctuating physical and chemical factors acting in Gales Creek, and normally has little effect upon modifying this environment through depletion or augmentation of nutrients.

Net Plankton Samples - The Diatoms of Gales Creek

(Class Bacillariophyceae)

Information on the presence and abundance of diatoms in Gales Creek is limited to 20 formalin-preserved samples collected by a #20 plankton net from the lower reaches and mixing basin area from October of 1965 to November of 1966.

From a calculation of the amount of water passing through the net during a 10 minute tow, and from the resulting concentration of plankton gathered, it was estimated that the seeming abundance of diatoms present in a drop of preserved sample was actually concentrated from at least 10 times as much water as the drop concentrated by centrifugation from a corresponding live sample. Thus, for the most part, qualitative measurements of diatom densities presented here reflect a one degree lower order of magnitude in abundance than those found for the phytoflagellates. The determination of dominance in these net samples was subjective, but occasional counts made during observation of phytoflagellates in live samples when diatom densities were notably significant provide some indication of the relative importance of the maximum net diatom concentrations in comparison to densities attained by the phytoflatellates.

The diatoms exhibited two periods of population maxima, in spring and in autumn, the classical bimodal pattern of seasonal abundance so often described for net forms (Wolfe, *et al.*, 1926; Cowles, 1930; Morse, 1947).

Abundant Species: Nine species of diatoms were abundant in the spring, and four of these were abundant again in the autumn. Two species were abundant in both summer and autumn, and eight more species were abundant only in the autumn. Two species were abundant in winter.

These five groupings of abundant species are presented below, and maximum cell counts for dominant diatom species observed in equivalent live samples are provided in parentheses:

Spring

Skeletonema costatum (51.2 cells/ml; 3290 cells/ml in middle reaches)
Chaetoceros subsecundus
Gyrosigma balticum
Nitzschia longissima
Nitzschia closterium

Spring and Autumn

Chaetoceros lorenzianus, *Chaetoceros teres* (13 cells/ml)
Melosira moniloformis (3 cells/ml)
Eupodiscus radiatus

Summer and Autumn

Coscinodiscus granii (0.8 cells/ml)
Chaetoceros sp.

Autumn

Chaetoceros curvisetus (23 cells/ml)
Rhizosolenia calcar-avis
Rhizosolenia imbricata var. *shrubsolei*
Cerataulina bergoni
Rhabdonema adriaticum
Striatella unipunctata
Licmophora hastata
Amphipleura rutilans

Winter

Asterionella japonica (13.8 cells/ml)
Chaetoceros aff. *costatus*

The spring bloom occurred in two pulses, an earlier *Skeletonema* and *Melosira* peak in March and April followed by a later bloom of several *Chaetoceros* species in May and June. The autumn bloom was strong with the species enduring through the season in 1965, but in 1966 the relative density of the bloom was less, and two dominants of the previous autumn, *Rhizosolenia calcar-avis* and *Cerataulina bergoni*, were absent. The lower densities may have been the product of greater grazing pressure by zooplankton the second autumn. A greater proportion of copepods, nauplei, trochophores, and other larvae were present in the samples from winter, summer and the second autumn, and from late spring through the summer the net plankton was dominated by the loricate

tintinnid ciliate *Favella panamensis*. However, Williams (1965) states that in the inshore areas he studied near Beaufort, N.C., grazing by zooplankton never controlled the abundance of phytoplankton, so other factors may also be involved.

As in many east coast estuaries, the species attaining the most significant cell concentrations was *Skeletonema costatum*. This is a neritic form widely distributed in seas throughout the world (Cupp, 1943), and of special importance in colder waters (Braarud, 1945). Smayda (1957) has indicated that it is the dominant form in Narragansett Bay; Patten, *et al.* (1963), note its significance in Chesapeake Bay; and Hulburt, *et al.* (1963), in Pamlico Sound. Smayda (1957) concluded that this species is primarily adapted for exploitation of semi-enclosed areas by its rapid division rate (Braarud, 1945) and exogenous vitamin B_{12} requirement (Droop, 1955).

Characteristic Species: A number of diatom species, including some of the more abundant forms listed above, appeared fairly consistantly in the samples, and must therefore be considered well adapted to either Gales Creek or to adjacent Bogue Sound from which they would then become periodically introduced. Those diatoms recorded in at least half the 20 plankton net hauls are listed below as the species most characteristic of the estuary:

Melosira moniliformis
Melosira sulcata
Coscinodiscus granii
Eupodiscus radiatus
Rhizosolenia imbricata var. *shrubsolei*
Chaetoceros lorenzianus
Chaetoceros teres
Synedra hennedyana
Diploneis smithii var. *pumila*
Gyrosigma balticum
Navicula salinarum
Rhopalodia musculus
Denticula hustedtii
Bacillaria paradoxa
Nitzschia compressa
Nitzschia lanceola
Nitzschia panduriformis
Nitzschia frustulum var. *subsalina*
Nitzschia sigma

Nitzschia longissima
Surirella febigerii

Taxonomy: Identified in these preserved net samples was a total of 187 diatom taxa, of which 49 were centric diatoms and 138 were pennate diatoms. In terms of number of taxa identified, the Bacillariophyceae was the most important class of phytoplankton present in Gales Creek, with more species than the combined total of all phytoflagellate groups, which was 152 species. These 187 diatom species are presented with references and seasonal distribution in Table 2.

A number of the taxa observed did not readily fit any described species in the literature available, and considering that Hustedt (1955) was able to describe 89 new species in but two mud samples obtained from the beach near Beaufort, N.C., it would appear that many more new species are yet to be discovered in Carolina estuarine waters.

Of these 187 species 38% were also listed by Mulford (1962) for the York River, lower Chesapeake Bay and adjacent offshore waters, and 22% were recorded by Patten, *et al.* (1963), for lower Chesapeake Bay, the nearest large body of water systematically studied for diatoms.

Of all the other phytoplankton organisms known to be present in the estuary, only isolated appearances of six of the larger species of dinoflagellates, along with an equal number of blue-green algal species (Cyanophyceae) occurred in the net samples. This well demonstrates the inadequacy of net sampling. Thus future studies of the Bacillariophyceae should involve plankton samples concentrated by centrifugation to ensure accurate counts of all species and observations on the many smaller species missed by net sampling. Future investigations should also consider the benthic diatom layer, which because of the shallowness of these estuaries, must also play an important part in biological production.

It is hoped that the seasonal data and taxonomic information presented in Table 2 will help provide impetus for these much needed basic systematic studies of the Bacillariophyceae in coastal Carolina, where at present so little work has been done.

Table 2

THE DIATOMS OF GALES CREEK

(Class Bacillariophyceae)

A list of the taxa recorded in 20 preserved net samples, including seasonal distribution (v = spring, s = summer, a = autumn, w = winter) and degree of abundance (- = rare, + = numerous, * = dominant), with modern references wherever possible.

	SPECIES	SEASON: v	s	a	w
1.	*Melosira nummuloides* (Dillw.) C.A.Ag. Hust., 1930, Kiesel. 1, p. 231, f. 95	-		+	+
2.	*Melosira moniliformis* (Müll.) Ag. Hust., 1930, Kiesel. 1, p. 236, f. 98	*	+		+
3.	*Melosira sulcata* (Ehr.) Kütz. Hust., 1930, Kiesel. 1, p. 276, f. 118-9	+	+	+	+
4.	*Stephanopyxis palmeriana* (Grev.) Grun. Hust., 1930, Kiesel. 1, p. 308, f. 147			+	
5.	*Skeletonema costatum* (Grev.) Cl. Hust., 1930, Kiesel. 1, p. 311, f. 149	*	+		+
6.	*Cyclotella caspia* Grun. Hust., 1930, Kiesel. 1, p. 347, f. 177		+		
7.	*Coscinodiscus concinnus* W. Sm. Peragallo, 1908, p. 424, pl. 115, f. 12			-	
8.	*Coscinodiscus granii* Gough Hust., 1930, Kiesel. 1, p. 436, f. 237	+	*	*	-
9.	*Coscinodiscus asteromphalus* Ehr. Hust., 1930, Kiesel. 1, p. 452, f. 250	-		+	
10.	*Actinoptychus taeniatus* Hust. Hust., 1955, p. 7, pl. 1, f. 1,2	-	-	-	
11.	*Actinoptychus adriaticus* var. *balearica* Grun V. H. Syn., 1885, pl. 121, f. 2	-			
12.	*Actinoptychus splendens* (Shadb.) Halfs. Hust., 1930, Kiesel. 1, pl 478, f. 265	-			-
13.	*Eupodiscus radiatus* Bailey Hendey, 1964, p. 97, pl. 23, f. 3	+	-	-	+
14.	*Aulacodiscus argus* (Ehr.) A. Schmidt Hust., 1930, Kiesel. 1, p. 503, f. 281			-	
15.	*Leptocylindrus danicus* Cl. Hust., 1930, Kiesel. 1, p. 558, f. 319			-	
16.	*Guinardia flaccida* (Castr.) Per. Hust., 1930, Kiesel. 1, p. 562, f. 322		-	+	
17.	*Rhizosolenia stolterfothii* Per. Hust., 1930, Kiesel. 1, p. 578, f. 329		-	+	

Table 2 (continued)

SPECIES	SEASON: v	s	a	w
18. *Rhizosolenia imbricata* var. *shrubsolei* (Cl.) Schr. Hust., 1930, Kiesel. 1, p. 584, f. 332			+	+
19. *Rhizosolenia hebetata* f. *semispina* (Hensen) Gran Hust., 1930, Kiesel. 1, p. 592, f. 338	+	+	+	
20. *Rhizosolenia calcar-avis* M. Schultze Hust., 1930, Kiesel. 1, p. 592, f. 339	+		*	
21. *Rhizosolenia alata* f. *indica* (Per.) Ost. Hust., 1930, Kiesel. 1, p. 602, f. 346			+	-
22. *Bacteriastrum delicatulum* Cl. Hust., 1930, Kiesel. 1, p. 612, f. 353		+	+	-
23. *Chaetoceros eibenii* Grun. Hust., 1930, Kiesel. 1, p. 653, f. 369			-	
24. *Chaetoceros peruvianus* Brightwell Hust., 1930, Kiesel. 1, p. 671, f. 379-80			-	
25. *Chaetoceros lorenzianus* Grun. Hust., 1930, Kiesel. 1, p. 679, f. 385	*	+	*	-
26. *Chaetoceros teres* Cl. Hust., 1930, Kiesel. 1, p. 681, f. 386	*	+	*	
27. *Chaetoceros compressus* Lauder Hust., 1930, Kiesel. 1, p. 684, f. 388	-	-	+	
28. *Chaetoceros didymus* Ehr. Hust., 1930, Kiesel. 1, p. 688, f. 390	-		+	
29. *Chaetoceros constructus* Gran Hust., 1930, Kiesel. 1, p. 694, f. 395			+	
30. *Chaetoceros affinis* Lauder Hust., 1930, Kiesel. 1, p. 695, f. 396	-		+	
31. *Chaetoceros affinis* var. *willei* (Gran) Hust. Hust., 1930, Kiesel. 1, p. 697, f. 398			+	
32. *Chaetoceros* aff. *costatus* Pav. Cupp, 1943, p. 127, f. 79	-		+	+
33. *Chaetoceros* cf. *brevis* Schütt Cupp, 1943, p. 129, f. 82	+			
34. *Chaetoceros* cf. *subsecundus* (Grun.) Hust. Hust., 1930, Kiesel. 1, p. 709, f. 404	*		+	
35. *Chaetoceros curvisetus* Cl. Hust., 1930, Kiesel. 1, p. 737, f. 426	-	+	*	
36. *Chaetoceros pseudocurvisetus* Mangin Hust., 1930, Kiesel. 1, p. 739, f. 427			+	
37. *Chaetoceros debilis* Cl. Hust., 1930, Kiesel. 1, p. 740, f. 428	+	+	-	
38. *Chaetoceros muelleri* Lem. Hust., 1930, Kiesel. 1, p. 756, f. 439	+			

Table 2 (continued)

	SPECIES	SEASON: v	s	a	w
39.	*Chaetoceros* sp., (with similarities to *C. brevis*, *C. affinis* and *C. laciniosus*)	+	*	*	
40.	*Ditylum brightwellii* (West) Grun. Hust., 1930, Kiesel. 1, p. 784, f. 457-9			-	
41.	*Lithodesmium undulatum* Ehr. Hust., 1930, Kiesel. 1, p. 789, f. 461			+	
42.	*Triceratium favus* Ehr. Hust., 1930, Kiesel. 1, p. 798, f. 462-3		-	-	
43.	*Triceratium reticulum* Ehr. Hust., 1930, Kiesel. 1, p. 823, f. 485-6			-	
44.	*Triceratium alternans* Bail. Hust., 1930, Kiesel. 1, p. 825, f. 488	-			
45.	*Biddulphia rhombus* f. *trigona* Hust. Hust., 1930, Kiesel. 1, p. 843, f. 498	+		-	
46.	*Biddulphia sinensis* Grev. Hust., 1930, Kiesel. 1, p. 837, f. 493			+	
47.	*Biddulphia aurita* (Lyngb.) Breb. & Godey Hust., 1930, Kiesel. 1, p. 846, f. 501	-		-	+
48.	*Cerataulina bergonia* Peragallo Hust., 1930, Kiesel. 1, p. 869, f. 517			*	
49.	*Hemiaulus sinensis* Grev. Hust., 1930, Kiesel. 1, p. 875, f. 519			-	
50.	*Rhabdonema adriaticum* Kutz. Hust., 1959, Kiesel. 2, p. 23, f. 552	+	-	*	+
51.	*Rhabdonema crassum* Hendey Hendey, 1964, p. 172, pl. 26, f. 8-10				-
52.	*Striatella unipunctata* (Lyng.) Ag. Hust., 1959, Kiesel. 2, p. 32, f. 560	+	-	*	+
53.	*Grammatophora marina* (Lyng.) Kutz. Hust., 1959, Kiesel. 2, p. 43, f. 569	+	+		+
54.	*Grammatophora oceanica* (Ehr. 1854 e.p.) Grun. Hust., 1959, Kiesel. 2, p. 45, f. 573	+	-	+	+
55.	*Licmophora abbreviata* Ag. Hust., 1959, Kiesel. 2, p. 66, f. 590			-	
56.	*Licmophora hastata* Mereschkowsky Hust., 1959, Kiesel. 2, p. 72, f. 599			*	-
57.	*Licmophora debilis* (Kutz.) Grun Hust., 1959, Kiesel. 2, p. 73, f. 602	-			
58.	*Plagiogramma rhombicum* Hust. Hust., 1955, p. 11, pl. 4, f. 25-27	-			-
59.	*Plagiogramma staurophorum* (Greg.) Heiberg Hust., 1959, Kiesel. 2, p. 110, f. 635	-	-		-

Table 2 (continued)

	SPECIES	SEASON: v	s	a	w
60.	*Dimerogramma minor* var. *nana* (Greg.) V. H. Hust., 1959, Kiesel. 2, p. 119, f. 641	-	-	-	-
61.	*Glyphodesmis distans* (Greg.) Grun. Hust., 1959, Kiesel. 2, p. 125, f. 647	-	-	-	
62.	*Opephora martyi* Heribaud Hust., 1959, Kiesel. 2, p. 135, f. 654	-		-	-
63.	*Opephora pacifica* (Grun.) Petit Hust., 1955, p. 13, pl. 4, f. 47	+	-	+	-
64.	*Trachysphenia acuminata* Per. Hust., 1955, p. 14, pl. 4, f. 52			-	
65.	*Raphoneis surirella* (Ehr.) Grun. Hust., 1959, Kiesel. 2, p. 173, f. 679a-c	-			-
66.	*Raphoneis surirella* var. *australis* Petit Hust., 1959, Kiesel. 2, p. 174, f. 679d			-	
67.	*Synedra hennedyana* Greg. Hust., 1959, Kiesel. 2, p. 222, f. 713	+	-	+	-
68.	*Synedra gaillonii* (Bory) Ehr. Hust., 1959, Kiesel. 2, p. 195, f. 690	-			
69.	*Synedra laevigata* Grun. Hust., 1959, Kiesel. 2, p. 213, f. 706		-		
70.	*Synedra crystallina* (Ag.) Kutz. Hust., 1959, Kiesel. 2, p. 232, f. 719	-		-	-
71.	*Synedra formosa* Hantzsch Hust., 1959, Kiesel. 2, p. 233, f. 720	-		-	-
72.	*Synedra tabulata* (Ag.) Kutz. Hust., 1959, Kiesel. 2, p. 218, f. 710b	-		+	+
73.	*Asterionella japonica* Cl. Hust., 1959, Kiesel. 2, p. 254, f. 734	+	-		+
74.	*Cocconeis disculoides* Hust. Hust., 1955, p. 17, pl. 5, f. 8-11, pl. 7, f. 8	-		-	-
75.	*Cocconeis heteroidea* Hantzsch Hust., 1959, Kiesel. 2, p. 356, f. 811			-	+
76.	*Cocconeis scutellum* Ehr. Hust., 1959, Kiesel. 2, p. 337, f. 790	+	-	-	+
77.	*Achnanthes orientalis* Hust. Hust., 1959, Kiesel. 2, p. 390, f. 838	-	-	+	-
78.	*Achnanthes tenera* Hust. Hust., 1955, p. 17, pl. 5, f. 22-25	-		-	
79.	*Achnanthes lanceolata* (Breb.) Grun. Hust., 1959, Kiesel. 2, p. 408, f. 863		-	-	-
80.	*Achnanthes bervipes* var. *intermedia* (Kutz.) Cl Hust., 1959, Kiesel. 2, p. 425, f. 877d			-	

Table 2 (continued)

	SPECIES	SEASON: v	s	a	w
81.	*Achnanthes longipes* Ag. Hendey, 1951, p. 42, pl. 1, 2, 3	-		-	
82.	*Mastogloia angulata* Lewis Hust., 1959, Kiesel. 2, p. 465, f. 855	-			
83.	*Mastogloia crucicula* (Grun.) Cl. Hust., 1955, p. 19, pl. 6, f. 12		-		-
84.	*Mastogloia smithi* Thwaites Hust., 1959, Kiesel. 2, p. 502, f. 928a	-	-	-	-
85.	*Mastogloia* cf. *baldjikiana* Grun. Hust., 1959, Kiesel. 2, p. 550, f. 981	-		+	-
86.	*Mastogloia pumila* (Grun.) Cl. Hust., 1959, Kiesel. 2, p. 553, f. 983			-	
87.	*Mastogloia mauritiana* Brun Hust., 1959, Kiesel. 2, p. 563, f. 995	-			
88.	*Mastogloia pusilla* Grun. Peragallo, 1908, p. 38, pl. 6, f. 36-37	-	-		-
89.	*Mastogloia pusilla* var. *linearis* Ostrup Hust., 1959, Kiesel. 2, p. 569, f. 1002d				-
90.	*Mastogloia exigua* Lewis Hust., 1959, Kiesel. 2, p. 569, f. 1003	-		-	-
91.	*Mastogloia* cf. *tenuis* Hust. Hust., 1959, Kiesel. 2, p. 570, f. 1004			-	-
92.	*Diploneis suborbicularis* (Greg.) Cl. Hust., 1959, Kiesel. 2, p. 612, f. 1026b	-			
93.	*Diploneis smithi* (Breb.) Cl. Hust., 1959, Kiesel. 2, p. 647, f. 1051	-	-	+	-
94.	*Diploneis smithi* var. *pumila* (Grun.) Hust. Hust., 1959, Kiesel. 2, p. 650, f. 1052d,e	+	-	+	+
95.	*Diploneis gruendleri* (A.S.) Cl. Hust., 1959, Kiesel. 2, p. 702, f. 1084	-	-	-	
96.	*Diploneis splendida* (Greg.) Cl. Hust., 1959, Kiesel. 2, p. 712, f. 1089	+	-	-	+
97.	*Amphipleura rutilans* (Trent.) Cl. Hust., 1959, Kiesel. 2, p. 720, f. 1093		+	*	
98.	*Frustulia rhomboides* var. *saxonica* (Rabh.) DeToni Hust., 1959, Kiesel. 2, p. 729, f. 1099a			-	
99.	*Frustulia interposita* (Lewis) Cl. Patrick, 1966, p. 305, pl. 22, f. 5	-	-		
100.	*Gyrosigna exilis* (Grun.) Patrick Patrick, 1966, p. 322, pl. 24, f. 4	-	-	-	-
101.	*Gyrosigna peisonis* (Grun.) Hust. Hust., 1955, p. 34, pl. 10, f. 5	-	-	+	

Table 2 (continued)

	SPECIES	SEASON: v	s	a	w
102.	*Gyrosigma balticum* (Ehr.) Rabh. Hust., 1930, Bacill., p. 224, f. 331	+	-	+	-
103.	*Donkinia recta* (Donkin) Grun. ex V. H. Hendey, 1964, p. 251, pl. 35, f. 7			-	
104.	*Pleurosigma affine* Grun Peragallo, 1908, p. 162, pl. 32, f. 3			-	
105.	*Pleurosigma strigosum* W. Sm. Smith, 1853, p. 64, pl. 21, f. 203	-	-	+	
106.	*Pleurosigma salinarum* Grun. Patrick, 1966, p. 333, pl. 27, f. 2	-	-		
107.	*Navicula amphipleuroides* Hust. Hust., 1955, p. 30, pl. 5, f. 33-34	+	+	-	-
108.	*Navicula pygmaea* Kutz. V. H. Syn., 1885, p. 94, pl. 10, f. 7	-	-	-	-
109.	*Navicula* cf. *forcipata* Grev. Hust., 1955, p. 22, pl. 7, f. 12	+		-	-
110.	*Navicula subforcipata* Hust. Hust., 1964, Kiesel. 3, p. 533, f. 1569	+	-	-	
111.	*Navicula nummularia* Grev. Hust., 1964, Kiesel. 3, p. 527, f. 1566	-	-		
112.	*Navicula pseudony* Hust. Hust., 1955, p. 23, pl. 8, f. 11	-	-	-	-
113.	*Navicula clavata* Greg. Hendey, 1964, p. 212, pl. 35, f. 13	-			-
114.	*Navicula subcarinata* (Grun.) Hendey Hendey, 1951, p. 50, pl. 10, f. 2-3			-	-
115.	*Navicula mutica* var. *tropica* Hust. Patrick, 1966, p. 456, pl. 42, f. 4			-	
116.	*Navicula granulata* Bail. Hendey, 1951, p. 49, pl. 12, f. 2	+	-	-	+
117.	*Navicula sovereignae* Hust. Hust., 1955, p. 25, pl. 8, f. 18-19		-		
118.	*Navicula heufleri* var. *leptocephala* (Breb. ex Grun.) Patrick, 1966, p. 515, pl. 49, f. 7		-		
119.	*Navicula* cf. *halophila* (Grun.) Cl. Patrick, 1966, p. 467, pl. 44, f. 4		-	-	
120.	*Navicula liber* var. *linearis* Grun. Peragallo, 1908, p. 72, pl. 9, f. 8-10			-	
121.	*Navicula salinarum* Grun. Hust., 1955, p. 27, pl. 7, f. 25	+	+	+	+
122.	*Navicula* cf. *notha* Patrick Patrick, 1966, p. 528, pl. 50, f. 10-11		-	-	

Table 2 (continued)

	SPECIES	SEASON: v	s	a	w
123.	*Navicula symmetrica* Patrick Patrick, 1966, p. 513, pl. 49, f. 2		-		
124.	*Navicula* cf. *tripunctata* var. *schizonemoides* (V.H.) Patrick, 1966, p. 514, pl. 49, f. 4	+	-	+	+
125.	*Navicula powellii* Lewis Peragallo, 1908, p. 78, pl. 14, f. 6	-	-		
126.	*Navicula* cf. *quadriseriata* Cl. et Grun. Peragallo, 1908, p. 79, pl. 14, f. 12				-
127.	*Navicula* cf. *circumtexta* Meist. ex Hust. Patrick, 1966, p. 442, pl. 39, f. 3	+	-	-	
128.	*Navicula yarrensis* Grun. Hust., 1955, p. 32, pl. 9, f. 2	+	-	+	
129.	*Navicula subsalina* var. *major* V. H. Peragallo, 1908, p. 76, pl. 10, f. 7	-	-	-	-
130.	*Stauroneis salina* W. Smith Hust., 1930, Bacill., p. 258, f. 414	+	-		-
131.	*Stauroneis amphioxys* Greg. Hendey, 1964, p. 219, pl. 37, f. 13-14				-
132.	*Stauroneis anceps* f. *linearis* (Ehr.) Cl. Hust., 1930, Bacill., p. 256, f. 407				-
133.	*Trachyneis aspera* var. *minuta* Per. Peragallo, 1908, p. 150, pl. 29, f. 7			-	
134.	*Tropidoneis seriata* Cl. Hust., 1955, p. 37, pl. 12, f. 1	+	-	-	-
135.	*Tropidoneis lepidoptera* Greg. Peragallo, 1908, p. 188, pl. 39, f. 3-7	+	-		
136.	*Amphiprora alata* (Ehr.) Kutz. Hendey, 1964, p. 253, pl. 39, f. 14-16	+	-	-	+
137.	*Amphora tenerrima* Aleem & Hust. Hust., 1955, p. 39, pl. 14, f. 15	-	-	-	-
138.	*Amphora* cf. *exigua* Greg. Peragallo, 1908, p. 230, pl. 50, f. 30-31	+	-	+	-
139.	*Amphora* cf. *macilenta* Greg. Wood, 1961, p. 689, pl. 54, f. 141		-	-	
140.	*Amphora bigibba* Grun. Hust., 1955, p. 40, pl. 14, f. 25		-	-	
141.	*Amphora* cf. *laevissima* var. *perminuta* Grun. Peragallo, 1908, p. 221, pl. 49, f. 10			-	
142.	*Amphora ovalis* Kutz V. H. Syn., 1885, p. 59, pl. 1, f. 1	-		-	-
143.	*Amphora ovalis* var. *affinis* Grun. Peragallo, 1908, pl. 44, f. 18	+	+		-

Table 2 (continued)

	SPECIES	SEASON: v	s	a	w
144.	*Amphora mexicana* A. S. A. S. Atlas, 1874- , pl. 27, f. 49	+	-		
145.	*Amphora* cf. *ostrearia* Breb. V. H. Syn., 1885, p. 55, pl. 1, f. 25	+	-	+	+
146.	*Amphora angusta* Greg. Peragallo, 1908, p. 231, pl. 50, f. 37	-	-		
147.	*Amphora ventricosa* Greg. Hendey, 1951, p. 70, pl. 9, f. 6	-	-	-	
148.	*Rhopalodia musculus* (Kutz.) O. Müll. Hust., 1930, Bacill., p. 392, f. 745	+	+	-	-
149.	*Rhopalodia gibberula* var. *protracta* Grun Hust., 1930, Bacill., p. 391, f. 743	+	-	+	-
150.	*Denticula* cf. *hustedtii* Simonsen & Kanaya S. & K., 1961, p. 501, pl. 1, f. 19	+	+	-	-
151.	*Bacillaria paradoxa* Gmel. Hust., 1930, Bacill., p. 396, f. 755	+	+	+	-
152.	*Nitzschia compressa* (Bail.) Boyer Wood, 1961, p. 694, pl. 55, f. 174	+	+	+	+
153.	*Nitzschia tryblionella* var. *victoriae* Grun. Hust., 1930, Bacill., p. 399, f. 758	-	-	-	-
154.	*Nitzschia tryblionella* var. *debilis* (Arnott) A. Mayer. Hust., 1930, Bacill., p. 399, f. 759		-		
155.	*Nitzschia circumsuta* (Bail.) Grun. Hust., in A.S. Atlas, 1874- , pl. 330, f. 1	-	-		
156.	*Nitzschia acuminata* (W. Smith) Grun. Hust., 1930, Bacill., p. 401, f. 764	+	-	-	-
157.	*Nitzschia hungarica* Grun. Hust., 1930, Bacill., p. 401, f. 766		-		
158.	*Nitzschia marginulata* Grun. Peragallo, 1908, p. 270, pl. 70, f. 14	+			
159.	*Nitzschia lanceola* Grun. Hust., 1955, p. 44, pl. 15, f. 23	+	-	+	-
160.	*Nitzschia silicula* Hust. Hust., 1955, p. 44, pl. 16, f. 19-20	-	-		
161.	*Nitzschia panduriformis* var. *minor* Grun. Peragallo, 1908, p. 269, pl. 70, f. 6			-	
162.	*Nitzschia panduriformis* var. *continua* Grun. V. H. Syn., 1885, p. 172, pl. 58, f. 6	+	+	+	-
163.	*Nitzschia brittoni* Hagelst. Hust., 1955, p. 46, pl. 15, f. 7-8	-		-	
164.	*Nitzschia marginata* Hust. Hust., 1955, p. 46, pl. 16, f. 11-12			+	

Table 2 (continued)

	SPECIES	SEASON: v	s	a	w
165.	*Nitzschia* cf. *balatonis* Grun. V. H. Syn., 1885, pl. 57, f. 28				-
166.	*Nitzschia fonticola* Grun. V. H. Syn., 1885, pl. 69, f. 15-19		-	-	
167.	*Nitzschia frustulum* var. *subsalina* Hust. Hust., 1930, Bacill., p. 415, f. 796	+	-	+	-
168.	*Nitzschia frustulum* var. *perpusilla* (Rabh.) Grun. Hust., 1930, Bacill., p. 415	-			-
169.	*Nitzschia proxima* Hust. Hust., 1955, p. 46, pl. 16, f. 13		-		
170.	*Nitzschia grossestriata* Hust. Hust., 1955, p. 46, pl. 16, f. 8-10	+	-	-	
171.	*Nitzschia pulchella* Per. Peragallo, 1908, p. 282, pl. 72, f. 21			-	-
172.	*Nitzschia* cf. *obtusa* W. Smith Hust., 1930, Bacill., p. 422, f. 817a-c			-	
173.	*Nitzschia obtusa* var. *scalpelliformis* Grun. Hust., 1930, Bacill., p. 422, f. 817d	-	-		-
174.	*Nitzschia filiformis* (W. Sm.) Hust. Hust., 1930, Bacill., p. 422, f. 818a,b	-	+	-	-
175.	*Nitzschia valida* Cl. & Grun. Peragallo, 1908, p. 289, pl. 79, f. 3		-		
176.	*Nitzschia sigma* (Kutz.) Smith V. H. Syn., 1885, pl. 65, f. 7	+	+	+	-
177.	*Nitzschia sigma* var. *habirshawii* Febiger Peragallo, 1908, pl. 74, f. 6	-	-		
178.	*Nitzschia sigma* var. *rigida* (Kutz.) Grun. Peragallo, 1908, pl. 74, f. 9		-		-
179.	*Nitzschia brevirostris* Hust. Hust., 1955, p. 48, pl. 16, f. 21		-		
180.	*Nitzschia longissima* (Breb.) Ralfs. Cupp, 1943, p. 200, f. 154	*	+	-	+
181.	*Nitzschia closterium* W. Smith Hust., 1955, p. 48, pl. 16, f. 16-18	*	+	-	
182.	*Campylodiscus echeneis* Ehr. Hust., 1930, Bacill., p. 449, f. 875	-	-		-
183.	*Surirella gemma* (Ehr.) Dutz Hendey, 1951, p. 76, pl. 8, f. 10	+	-	+	-
184.	*Surirella febigerii* Lewis A. S. Atlas, 1874- , pl. 20, f. 9	+	-	+	-
185.	*Surirella praeclara* A. S. Hust., 1955, p. 48, pl. 3, f. 1	+	-	+	

Table 2 (continued)

SPECIES	SEASON: v	s	a	w
186. *Surirella recedens* A. S. Hust., 1955, p. 48, pl. 3, f. 2	-		+	
187. *Surirella inducta* A. S. Hust., 1955, p. 48, pl. 3, f. 3		-		

Live Plankton Samples - The Phytoflagellates of Gales Creek

Information on the phytoflagellates of Gales Creek comes from the 481 water samples collected on 35 occasions between March 1965 and April 1967. The main body of taxonomic information was obtained through live identification and enumeration of species from 336 samples collected at several depths from the six stations on each cruise from December 1965 to November 1966.

Phytoflagellates appeared to be the dominant plankton throughout most of the year in terms of standing crop, measured by cell numbers. Only in certain periods of spring and autumn were phytoflagellate densities noticeably secondary to diatom densities, even though in terms of taxa represented the diatoms were the most important group of plankton in the creek.

The yearly average for total phytoflagellate density in Gales Creek was 5×10^5 cells/liter, only 1/4 the average of total nonnoplankton from Beaufort Channel given by Williams & Murdoch (1966) and from the areas east and north of Morehead City given by Thayer (1971), and only 1/10 the average for Narragansett Bay reported by Smayda (1957). Though part of the explanation for the lower average density in Gales Creek compared to these other areas may be that diatom densities were not also included, it is also likely to be the product of the strong flushing rate of the estuary combined with the influence of low nitrogen.

Seasonal distribution of phytoflagellate densities is shown in fig. 14B to have a moderate spring peak, a late summer maximum pulse with strong densities continuing into autumn, and minimum concentration in late winter and late spring-early summer. Fig. 15 shows that this bimodal distribution was manifested largely in the middle reaches of the estuary, where the greatest cell densities of the study also occurred. The smallest fluctuations in phytoflagellate densities occurred in the mixing basin, where the strong effect of tidal mixing and exchange with higher salinity sound waters has dampened the spring

and summer pulses. The greatest fluctuations in cell concentrations occurred in the headwater region, where flushing by periodically heavy freshwater runoff often resulted in very low plankton densities.

The number of phytoflagellate species per sample ranged from 1 to 28, with greater numbers of species appearing in the higher salinity samples, and the fewest species in surface freshwater runoff samples or samples from stagnant anoxic bottom waters in the "pools" from the upper reaches.

Distribution by Class: The phytoflagellates were comprised of nine classes of algae. Seasonal distribution of these nine classes is summarized in fig. 16.

The Dinophyceae dominated the phytoflagellates with 76 species of dinoflagellates. This group was well represented all year, exhibiting a bimodal distribution similar to that of the diatoms, with the maximum peak in April and strong concentrations through autumn, but with the secondary peak occurring in August.

The second most important class, the Cryptophyceae, with 12 species of cryptomonads, was also represented all year, but attained peak concentrations only in late summer and autumn, with no spring peak.

The Prasinophyceae, with 14 species, developed strong concentrations from late summer through to early spring with peak densities in autumn, while the Chlorophyceae, with 10 species, was represented all months but May and developed peak densities in August and November. The 16 species in the Chrysophyceae placed this class second to the Dinophyceae in number of taxa, but they were of low average concentrations throughout the year, as were the 8 species of the Haptophyceae and the 9 species of the Euglenophyceae. Three species of uncertain systematic position though presently placed in the Xanthophyceae, attained bloom concentrations in some spring and late summer-early autumn samples, and thus have given this class a bimodal distribution.

Characteristic Species: Because of the large number of cruises, samples and cell densities being worked with, it was necessary to quantify the intuitive rankings of the dominant and abundant phytoflagellates and group them into their important seasonal associations.

FIGURE 15

Graphs showing the seasonal distribution of total phytoflagellate concentrations from surface, middle, and bottom depths at each of the six stations. Concentrations, measured in cells per liter, are plotted against a logarithmic scale to show details where densities were low.

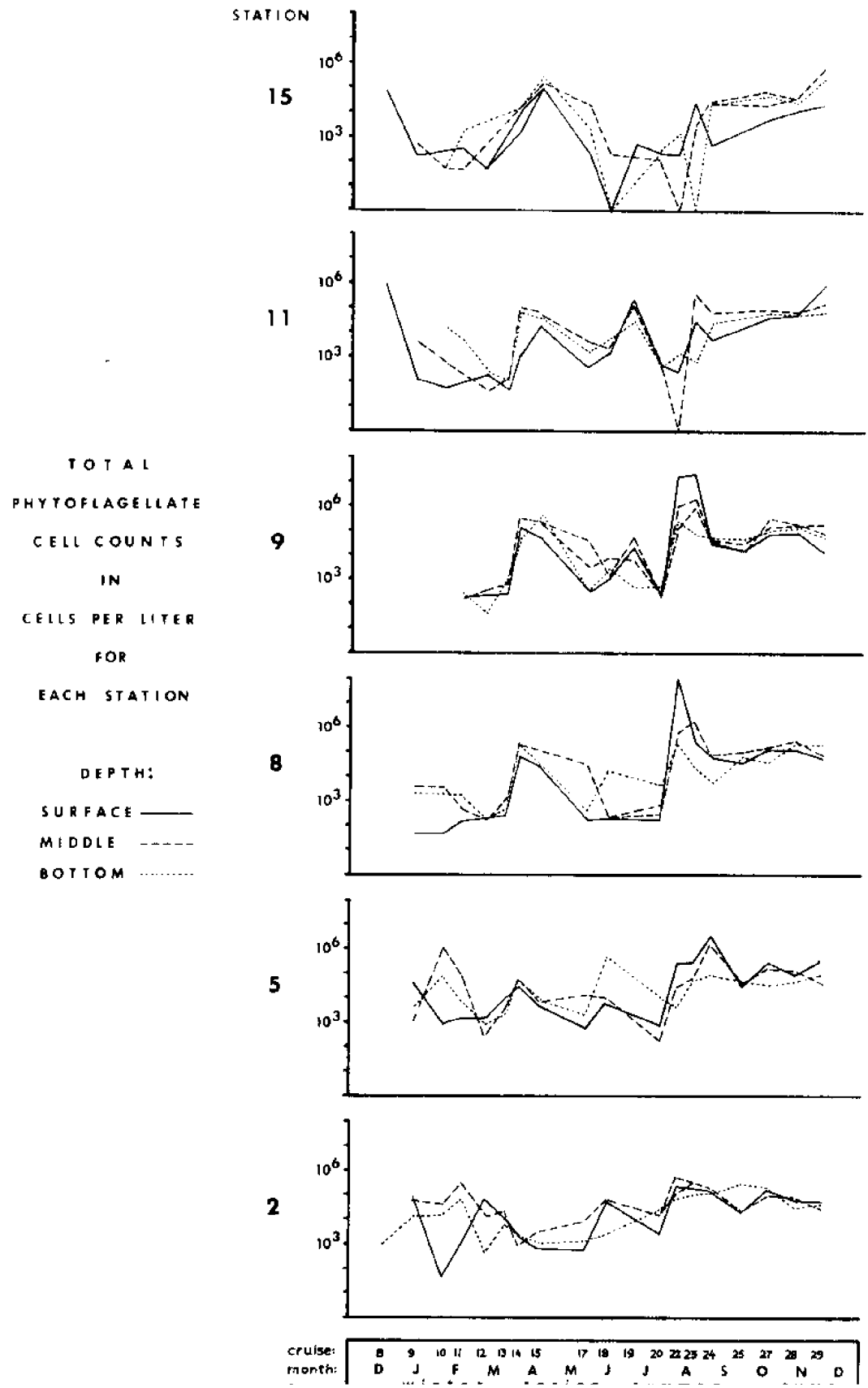
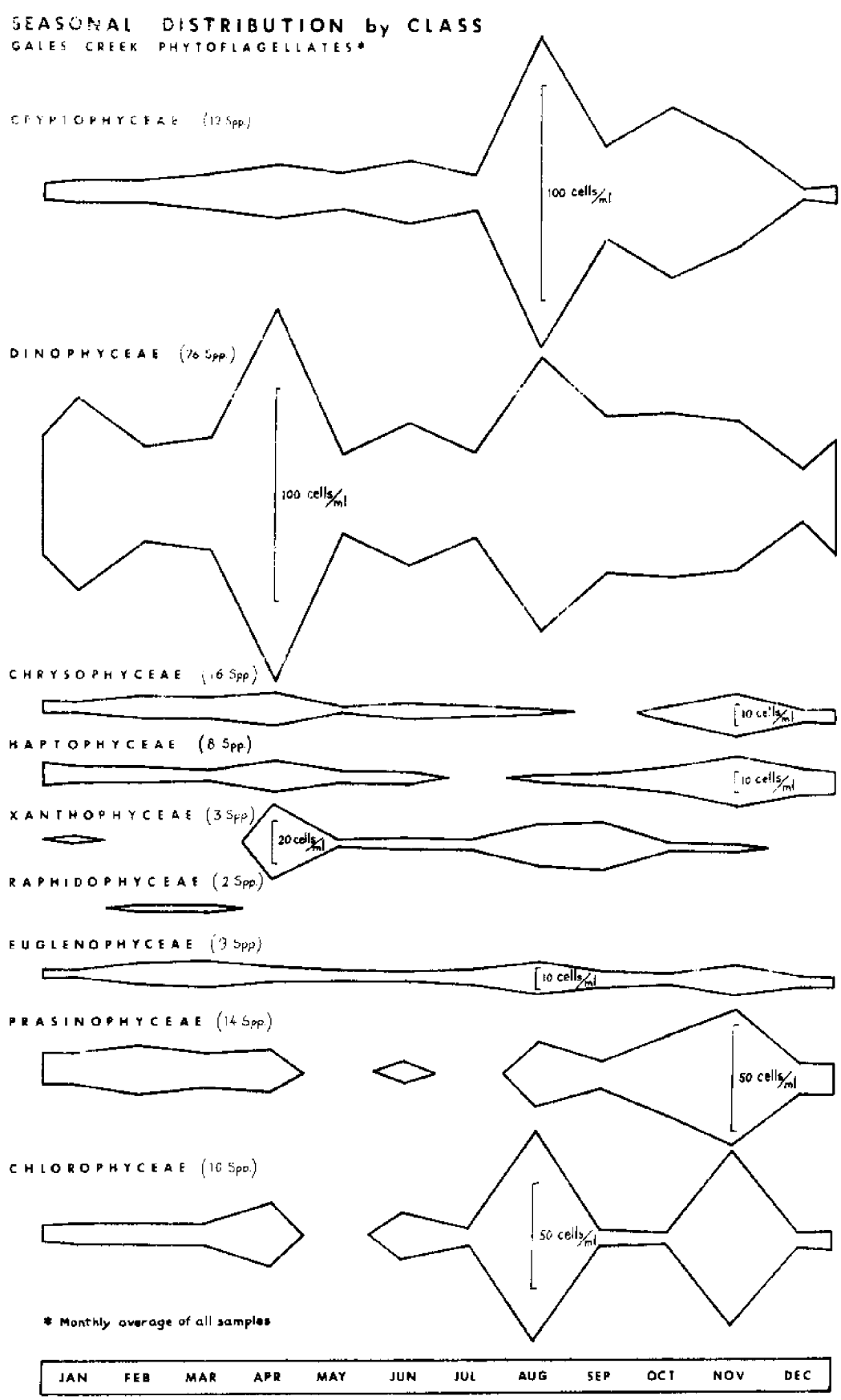

STATION
15
11
9
8
5
2
10^6
10^3
TOTAL PHYTOFLAGELLATE CELL COUNTS IN CELLS PER LITER FOR EACH STATION
DEPTH:
SURFACE
MIDDLE
BOTTOM
cruise: 8 9 10 11 12 13 14 15 17 18 19 20 22 23 24 25 27 28 29
month: D J F M A M J J A S O N D

FIGURE 16

Graphs of the seasonal distribution of the phytoflagellates by taxonomic class. Plotted concentrations, measured in cells per milliliter, represent monthly averages from all water samples collected. The number of species representing each class is indicated in parentheses.


SEASONAL DISTRIBUTION by CLASS
GALES CREEK PHYTOFLAGELLATES*
CRYPTOPHYCEAE (12 Spp.)
100 cells/ml
DINOPHYCEAE (76 Spp.)
100 cells/ml
CHRYSOPHYCEAE (16 Spp.)
10 cells/ml
HAPTOPHYCEAE (8 Spp.)
10 cells/ml
XANTHOPHYCEAE (3 Spp.)
20 cells/ml
RAPHIDOPHYCEAE (2 Spp.)
EUGLENOPHYCEAE (3 Spp.)
10 cells/ml
PRASINOPHYCEAE (14 Spp.)
50 cells/ml
CHLOROPHYCEAE (16 Spp.)
50 cells/ml
* Monthly average of all samples
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

Species selected as characteristic of each season were those present in over 15 samples and which either averaged over 5 cells/ml from all samples in which they were present, or were present at a frequency greater than 40% in all samples from one cruise. 37 characteristic species were established by this method.

It was possible to group these species into 11 different seasonal distributions, out of the total of 15 possible combinations that could occur with four seasons. The significance of the autumn pulse is emphasized by the presence of 24 of the characteristic species in this season as compared to 19 in summer, 16 in spring, and only 7 in winter.

The 11 associations of characteristic phytoflagellates are presented in Table 3, with the dominant species indicated by asterisks. Illustrations of the species comprising these seasonal associations are provided in Figures 17 to 21.

Table 3

CHARACTERISTIC PHYTOFLAGELLATE ASSOCIATIONS

(Frequency = Frequency of presence in samples from one cruise: 1 = 0-20%, 2 = 21-40%, 3 = 41-60%, 4 = 61-80%, 5 = 81-100%.)

(Dominants = Species which attained an average density of over 25 cells/ml and over 60% frequency in samples from an entire season.)

ASSOCIATION SPECIES	GREATEST DENSITY Cells/ml	GREATEST FREQUENCY 1-5	DOMINANTS **
SPRING (Fig. 17)			
Prorocentrum minimum	206	5	**
Gymnodinium aureolum	41	5	
Nephrochloris salina	69	4	
Amphidinium crassum	44	4	
Cryptomonas pseudobaltica	26	4	
Peridinium brevipes	19	4	
Gymnodinium nelsoni	3.8	4	
Cryptomonas testacea	440	3	
SPRING & SUMMER (Fig. 18)			
Olisthodiscus carterae var. *olivaceus*	81,000	5	**

ASSOCIATION

SPECIES	GREATEST DENSITY Cells/ml	GREATEST FREQUENCY 1-5	DOMINANTS **
SPRING & AUTUMN (Fig. 18)			
Pavlova gyrans var. *simplex*	38	5	
SPRING, SUMMER & AUTUMN (Fig. 18)			
Chroomonas minuta var. *apyrenoidosa*	219	5	**
Gyrodinium pellucidum	140	4	
Gyrodinium dominans			
Chroomonas amphioxeia	33	4	
SUMMER (Fig. 19)			
Chlamydomonas sp. b	244	2	
Gymnodinium roseostigma	66	1	
SUMMER & AUTUMN (Fig. 19)			
Hemiselmis virescens	1,200	5	**
Chroomonas caroliniana			
Calycomonas ovalis	63	5	
Pyramimonas micron	128	4	
Pyramimonas torta	83	3	
Gymnodinium galesianum	20	3	
Chlamydomonas sp. a	10,120	2	
SUMMER, AUTUMN & WINTER (Fig. 21)			
Katodinium rotundatum	1,550	5	**
Eutreptia viridis	42	4	
Eutreptia lanowii			
Euglena proxima			
AUTUMN (Fig. 20)			
Heteromastix pyriformis	20	5	
Chrysochromulina minor	540	4	
Chrysochromulina kappa			
Gymnodinium danicans	76	4	
Tetraselmis gracilis	250	3	
Tetraselmis maculata	52	1	
Pyramimonas pluioculata	26	1	
WINTER (Fig. 21)			
Pyramimonas grossii	13	1	
WINTER & SPRING (Fig. 21)			
Heterocapsa triquetra	643	5	**
ALL YEAR (Fig. 21)			
Chalmydomonas vectensis	11,880	4	**

FIGURE 17

Characteristic Phytoflagellate Associations
of Gales Creek

for Spring:

(Cryptophyceae)

Cryptomonas pseudobaltica Butcher

Cryptomonas testacea sp. nov.

(Dinophyceae)

Prorocentrum minimum (Pavillard) Schiller

Amphidinium crassum Lohmann

Gymnodinium nelsoni Martin

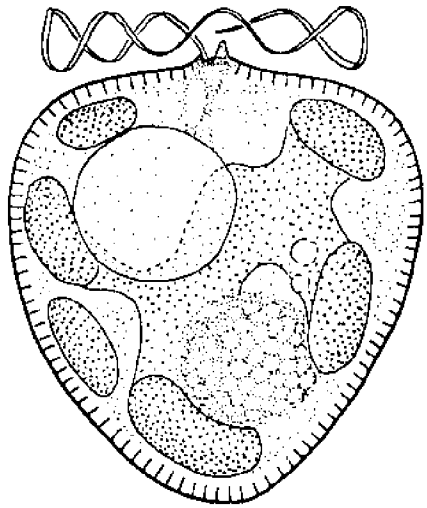
Gyrodinium aureolum Hulburt

Peridinium brevipes Paulsen

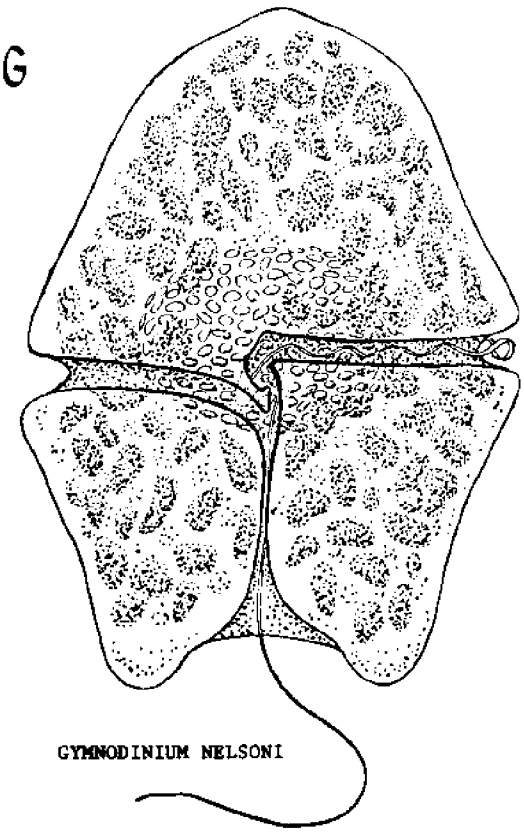
(Xanthophyceae)

Nephrochloris salina Carter

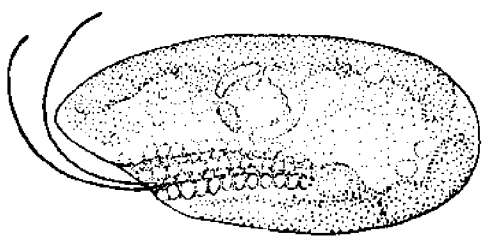
SPRING



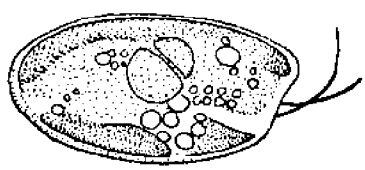
PROROCENTRUM MINIMUM



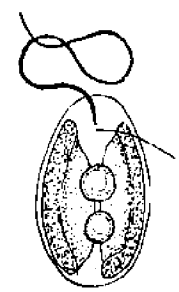
GYMNODINIUM NELSONI



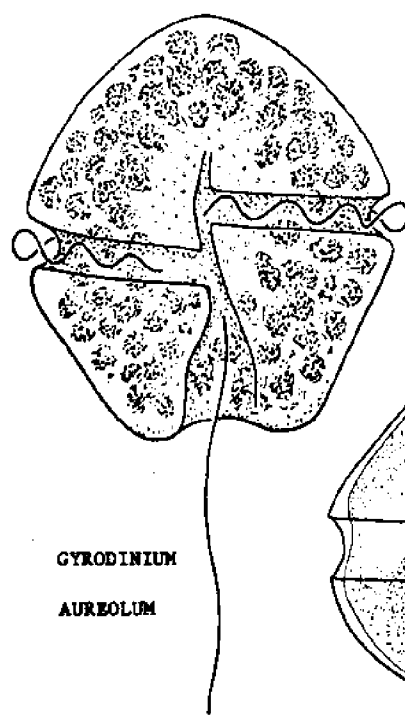
CRYPTOMONAS TESTACEA



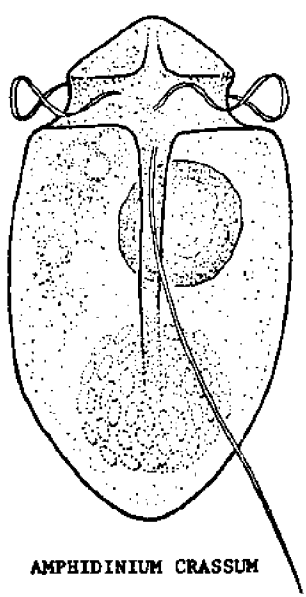
CRYPTOMONAS PSEUDOBALTICA



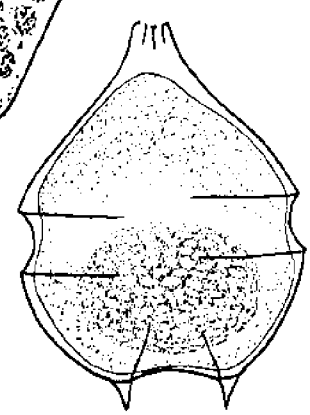
NEPHROCHLORIS SALINA



GYRODINIUM AUREOLUM



AMPHIDINIUM CRASSUM



PERIDINIUM BREVIPES

FIGURE 18

Characteristic Phytoflagellate Associations
of Gales Creek

for Spring and Summer:

(Xanthophyceae)

Olisthodiscus carterae var. *olivaceus* var. nov.

for Spring, Summer and Autumn:

(Cryptophyceae)

Chroomonas minuta var. *apyrenoidosa* Hulburt

Chroomonas amphioxeia (Conrad) Butcher

(Dinophyceae)

Gyrodinium pellucidum (Wulff) Martin

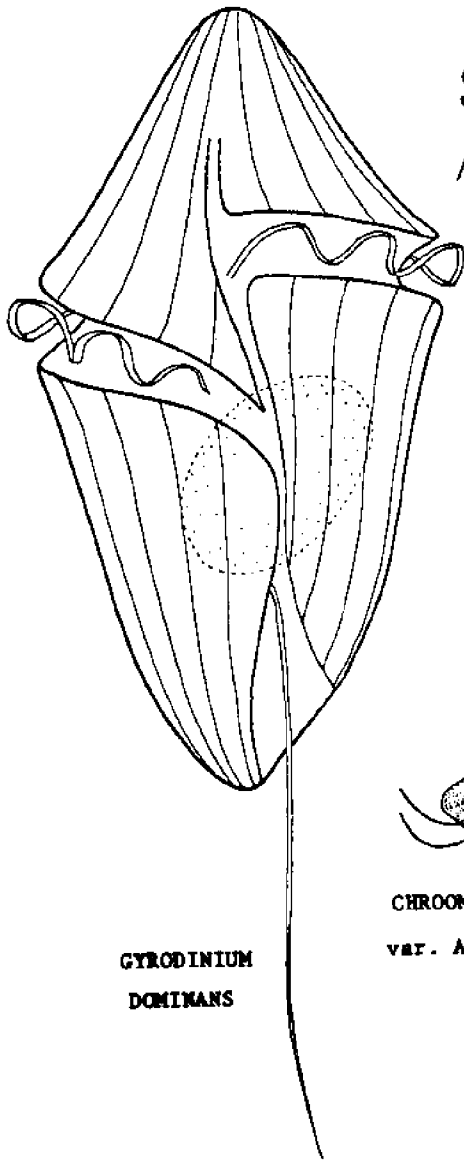
Gyrodinium dominans Hulburt

for Spring and Autumn:

(Chrysophyceae)

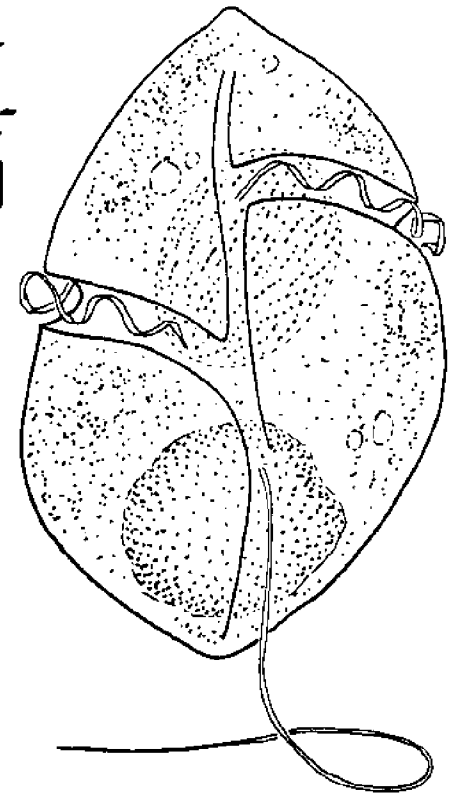
Pavlova gyrans var. *simplex* var. nov.

SPRING-
SUMMER-
AUTUMN

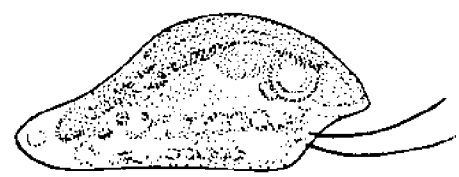


GYRODINIUM
DOMINANS

CHROOMONAS MINUTA
var. APYRENOIDOSA

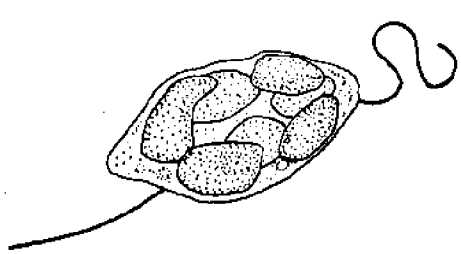


GYRODINIUM PELLUCIDUM



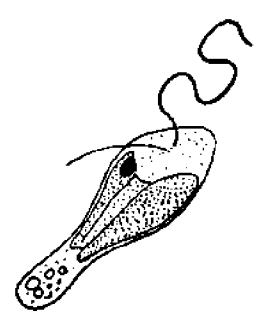
CHROOMONAS AMPHIOXEIA

SPRING-SUMMER



OLISTHODISCUS CARTERAE var. OLIVACEUS

SPRING-AUTUMN



PAVLOVA GYRANS var. SIMPLEX

FIGURE 19

Characteristic Phytoflagellate Associations
of Gales Creek

for Summer:

(Dinophyceae)

Gymnodinium roseostigma sp. nov.

(Chlorophyceae)

Chlamydomonas sp. "b"

for Summer and Autumn:

(Cryptophyceae)

Hemiselmis virescens Droop

Chroomonas caroliniana sp. nov.

(Dinophyceae)

Gymnodinium galesianum sp. nov.

(Chrysophyceae)

Calycomonas ovalis Wulff

(Prasinophyceae)

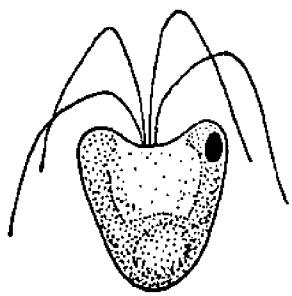
Pyramimonas torta Conrad & Kufferath

Pyramimonas micron Conrad & Kufferath

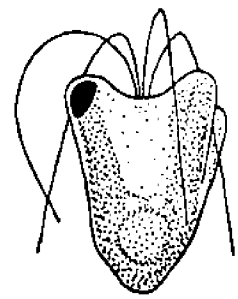
(Chlorophyceae)

Chlamydomonas sp. "a"

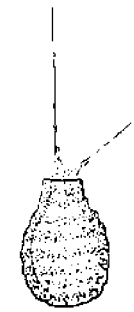
SUMMER-AUTUMN



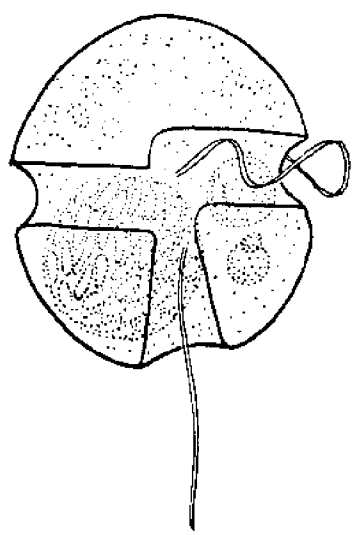
PYRAMIMONAS MICRON



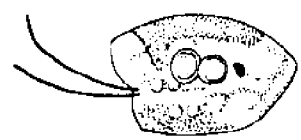
PYRAMIMONAS TORTA



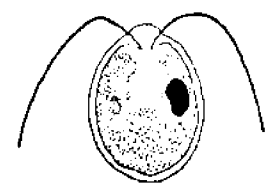
CALYCOMONAS OVALIS



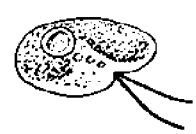
GYMNODINIUM GALESIANUM



CHROOMONAS CAROLINIANA

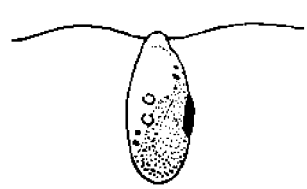


CHLAMYDOMONAS sp. "a"

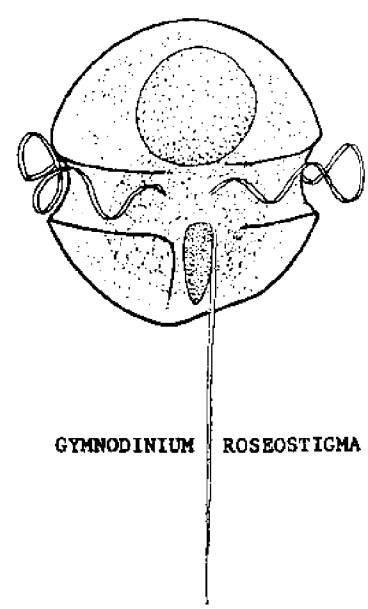


HEMISELMIS VIRESCENS

SUMMER



CHLAMYDOMONAS sp. "b"



GYMNODINIUM ROSEOSTIGMA

FIGURE 20

Characteristic Phytoflagellate Associations
of Gales Creek

for Autumn:

(Dinophyceae)

Gymnodinium danicans sp. nov.

(Chrysophyceae)

Chrysochromulina minor Parke & Manton

Chrysochromulina kappa Parke & Manton

(Prasinophyceae)

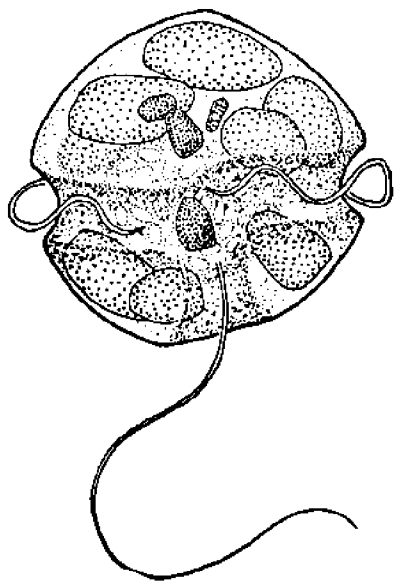
Heteromastix pyriformis (Carter) Manton

Pyramimonas plurioculata Butcher

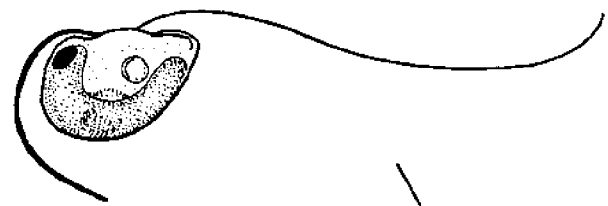
Tetraselmis gracilis (Kylin) Butcher

Tetraselmis maculata Butcher

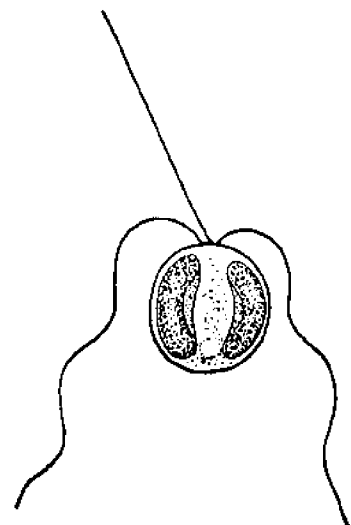
AUTUMN



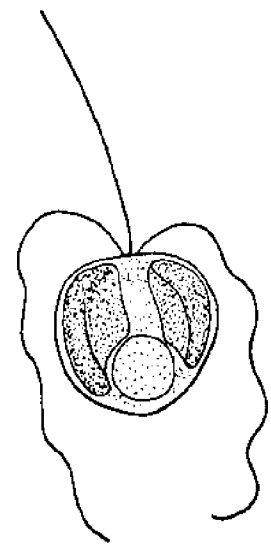
GYMNODINIUM DANICANS



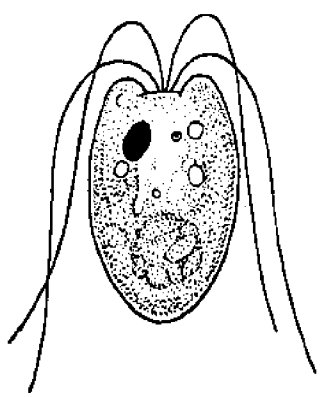
HETEROMASTIX PYRIFORMIS



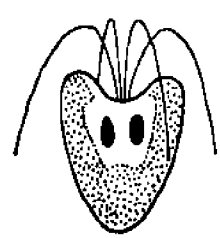
CHRYSOCHROMULINA MINOR



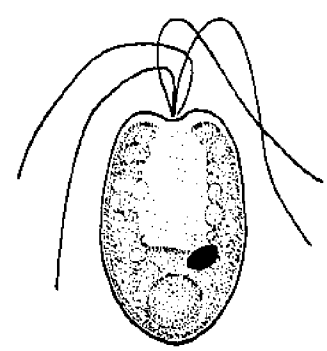
CHRYSOCHROMULINA KAPPA



TETRASELMIS GRACILIS



PYRAMIMONAS PLURIOCULATA



TETRASELMIS MACULATA

FIGURE 21

Characteristic Phytoflagellate Associations
of Gales Creek

for Summer, Autumn and Winter:

(Dinophyceae)

Katodinium rotundatum (Lohmann) Fott

(Euglenophyceae)

Eutreptia viridis Perty

Eutreptia lanowii Steuer

Euglena proxima Dangeard

for Winter:

(Prasinophyceae)

Pyramimonas grossii Parke

for Winter and Spring:

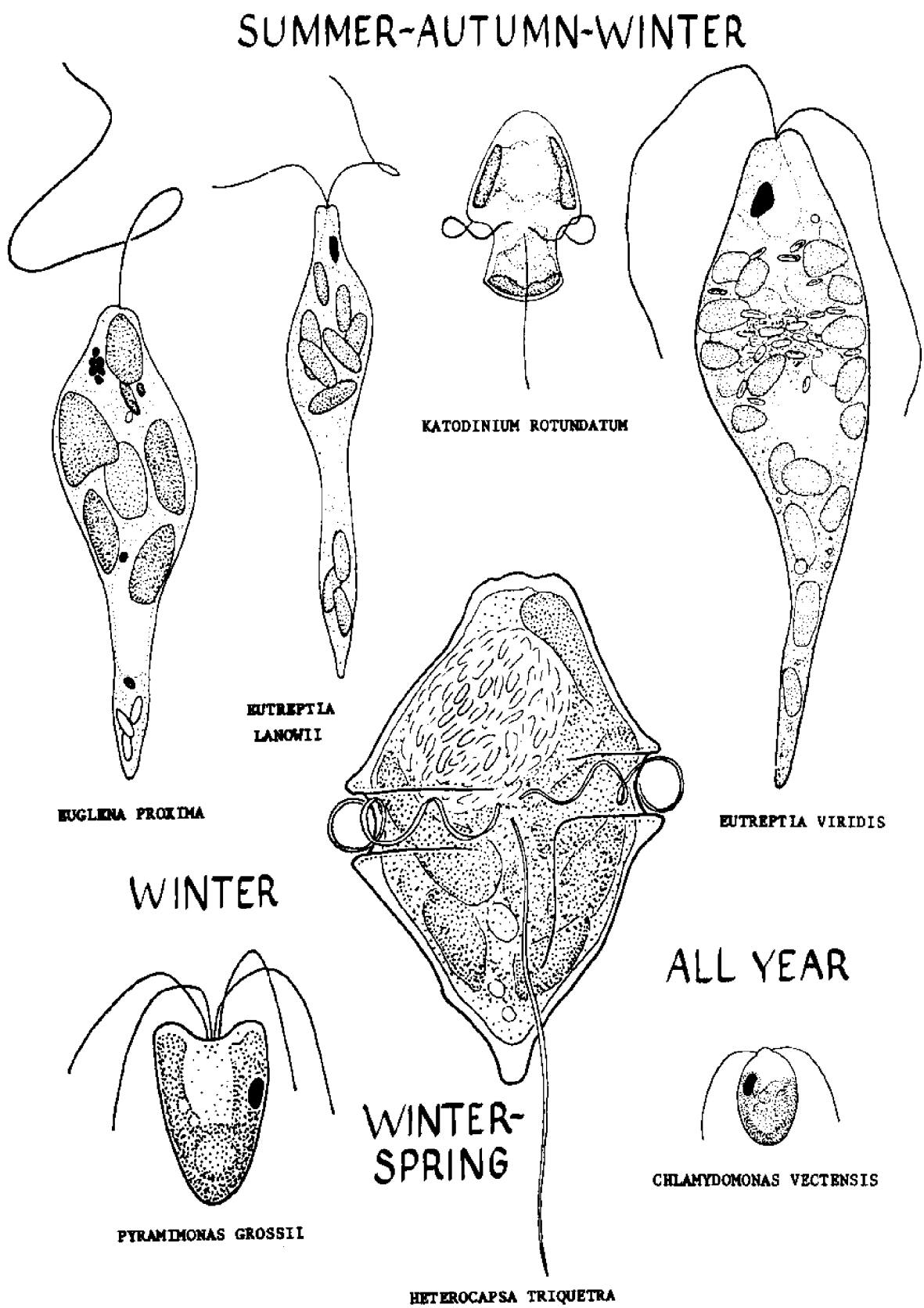
(Dinophyceae)

Heterocapsa triquetra (Ehrenberg) Stein

for All Year:

(Chlorophyceae)

Chlamydomonas vectensis Butcher


SUMMER-AUTUMN-WINTER
KATODINIUM ROTUNDATUM
EUTREPTIA LANOWII
EUGLENA PROXIMA
EUTREPTIA VIRIDIS
WINTER
ALL YEAR
WINTER-SPRING
PYRAMIMONAS GROSSII
CHLAMYDOMONAS VECTENSIS
HETEROCAPSA TRIQUETRA

The most important spring dominant, *Prorocentrum minimum*, has been recorded as a species distributed evenly through the year in Pamlico Sound (Hulburt, *et al.*, 1970), and as an autumn dominant in lower Chesapeake Bay (Patten, *et al.*, 1963). *Katodinium rotundatum*, strongly dominant from summer to winter in Gales Creek, was reported to give summer red water in Raritan Bay (Patten, 1961, 1962) and in the York River (Patten, *et al.*, 1963) where it was dominant in summer and autumn. It was also a most abundant species in Pamlico Sound, growing better in winter (Hulburt, *et al.*, 1970). The "gymnodinioid arrowhead" attaining 10^4 cells/l concentrations from June to November in Narragansett Bay (Smayda, 1957) may have been this species. *Pyramimonas* species were recorded as summer and autumn dominants in lower Chesapeake Bay (Patten, *et al.*, 1963) as they were in Gales Creek. Another species abundant in summer and autumn in Gales Creek, *Calycomonas ovalis*, was one of the species evenly distributed through the year in Pamlico Sound (Hulburt, *et al.*, 1970). *Heterocapsa triquetra*, dominant from late winter to early spring, was also a most abundant species in Pamlico Sound, growing better in winter (Hulburt, *et al.*, 1970), and was reported dominant in spring and summer in lower Chesapeake Bay (Morse, 1947; Patten, *et al.*, 1963), and dominant in summer and autumn in the York River (Fournier, 1966). But while most of the dominant species in Gales Creek appear to be common estuarine forms, the organism which attained the highest concentrations of any species in the creek is a newly described variety, *Olisthodiscus carterae* var. *olivaceus*, which reached 8 x 10^7 cells/liter in August.

unpublished manuscript

The three successional stages described by Margalef (1960) - first rapidly increasing small species, then medium sized diatoms, finally more free-swimming species with lower potential increase - were not observed to occur in Gales Creek, probably because the rapid flushing rate of the estuary would not allow a body of water to remain intact long enough for exhaustion of nutrients and accumulation of metabolites and inhibitors to occur.

Biomass: Standing crop of phytoflagellates in this study has been measured by cell counts. This might be said to place a disproportionate emphasis on the smaller-celled specimens, where the total biomass on a number of small cells may actually be less than a few cells of a larger

species. The importance of these plankton species to grazing herbivores is certainly more a function of the total cell carbon they provide than of their numbers.

To give some perspective to the numerical data on the phytoflagellates, the average cell volumes of the 37 characteristic species in the estuary have been calculated by measuring the water displacement of clay scale models. These species have been arranged in Table 4 in order of decreasing volume, where it may be seen that one cell of the largest species, *Gymnodinium nelsoni* , is equivalent in volume to 2000 cells of the smallest species, *Heteromastix pyriformis*.

Since there are no large central vacuoles in these species, as there are in the diatoms, these cell volumes may be considered plasma volumes. The calculated total plasma volume of the largest cell concentration achieved by each characteristic species is included in the table, along with the carbon equivalent for each of these concentrations, calculated with Strathman's (1967) figure for the ratio between cell carbon and plankton cell volume of 0.11 picograms/μ^3. Mullen, *et al.* (1966), found that cells of smaller species had more carbon per unit cell volume than larger species, and the five non-diatom species they studied ranged from 0.26 to 0.06 picograms/μ^3, so the figures in the table might be in error by a factor of 2 or more.

Table 4 shows the importance, in terms of biomass, of the larger third of the characteristic species. The 230 cells/ml of *Heterocapsa triquetra*, for instance, could have contained more carbon than the approximately 12,000 cells/ml of *Chlamydomonas vectensis*. Over 2/3 of the characteristic species, however, were under 1500 μ^3 in volume and 20 μ in length. Smaller cell size provides a greater proportion of surface to volume, which can enable more rapid uptake of nutrients and permit a more rapid metabolism and growth of these smaller species when advantageous conditions appear in the estuary. Thus use of cell volume in calculating standing crop may overemphasize the importance of the larger species.

It must be remembered that biomass, whether calculated by number of cells or volume of plasma, still represents an instantaneous quantity of organisms, and does not include the time factor concerned with the development of the crop. In an estuary where tidal currents are continually diluting the plankton populations, low standing crops do not necessarily

Table 4

MAXIMUM BIOMASS OF CHARACTERISTIC SPECIES OF GALES CREEK PHYTOFLAGELLATES

(In order of decreasing volume)

SPECIES in order of decreasing cell volume	Average Cell Volume (μ^3)	Greatest Density Achieved (cells/ml)	Total Biomass Volume (μ^3/ml)	Biomass Carbon Equivalent (µg C/liter)
1. *Gymnodinium nelsoni*	50,000	3	150,000	16.5
2. *Gyrodinium aureolum*	8,700	21	180,000	19.8
3. *Peridinium brevipes*	5,200	16	83,000	9.1
4. *Gyrodinium pellucidum* 5. *Gyrodinium dominans*	3,600	108	390,000	42.8
6. *Heterocapsa triquetra*	2,900	230	667,000	73.5
7. *Prorocentrum minimum*	2,500	206	515,000	56.6
8. *Euglena proxima*	2,400	2	4,800	0.5
9. *Amphidinium crassum*	1,500	44	66,000	7.3
10. *Gymnodinium danicans*	1,500	76	114,000	12.5
11. *Eutreptia viridis* 12. *Eutreptia lanowii*	1,400	60	84,000	9.2
13. *Cryptonomas testacea*	1,250	440	550,000	60.5
14. *Gymnodinium galesianum*	1,170	20	23,400	2.6
15. *Olisthodiscus carterae* var. *olivaceus*	700	81,000	56,500,000	6220
16. *Gymnodinium roseostigma*	460	66	30,500	3.4
17. *Cryptomonas pseudobaltica*	440	2	980	0.1
18. *Tetraselmis gracilis*	420	249	105,000	11.5

Table 4

(continued)

(In order of decreasing volume)

	SPECIES in order of decreasing cell volume	Average Cell Volume (μ^3)	Greatest Density Achieved (cells/ml)	Total Biomass Volume (μ^3/ml)	Biomass Carbon Equivalent (µg C/liter)
19.	*Pyramimonas torta*	380	83	31,500	3.5
20.	*Chroomonas amphioxeia*	230	33	7,600	0.8
21.	*Katodinium rotuandatum*	190	1,548	295,000	32.5
22.	*Tetraselmis maculata*	120	61	7,300	0.8
23.	*Pyramimonas grossii*	110	13	1,430	0.2
24.	*Pyramimonas plurioculata*	100	26	2,600	0.3
25.	*Nephrochloris salina*	70	69	4,800	0.5
26.	*Chrysochromulina minor*	65	590	38,400	4.2
27.	*Chrysochromulina kappa*				
28.	*Pavlova gyrans* var. *simplex*	60	38	22,380	0.3
29.	*Pymamimonas micron*	50	128	6,400	0.7
30.	*Chlamydomonas* sp. "a"	50	10,120	505,000	55.5
31.	*Chlamydomonas vectensis*	50	11,880	595,000	65.5
32.	*Chroomonas minuta* var. *apyrenoidosa*	45	219	9,900	0.1
33.	*Hemiselmis virescens*	40	1,200	48,000	5.3
34.	*Chroomonas caroliniana*				
35.	*Chlamydomonas* sp. "b"	35	244	8,500	0.9
36.	*Calycomonas ovalis*	30	63	1,900	0.2
37.	*Heteromastix pyriformis*	25	20	500	0.05

mean a low rate of production. What is really important for the ecosystem is the rate at which the densities of populations in the community are produced, and future studies should include such measurements.

Taxonomy of Gales Creek Phytoflagellates

The nine classes of phytoflagellates in Gales Creek consisted of 152 species distributed in 49 genera. 102 of these species were previously described, while 32 species, 4 varieties, and 6 combinations are new to science. All taxa, previously described or new, are presented here with descriptions and figures based on the Gales Creek material. Systematic arrangement primarily follows the classification based on Christensen (1962) used by Parke & Dixon (1968).

(Class Cryptophyceae)

Hemiselmis virescens Droop

(pl. 1, f. 1 a-b, pl. 22, f. 1-3)

Hemiselmis virescens Droop, 1955b, p. 238, f. 7-11; Butcher, 1967, p. 17, pl. 1, f. 8, pl. 14, f. 1.

Cells small, body asymmetric, generally bean-shaped in lateral view, laterally compressed, elliptical in dorsal view. Length 4-6μ, width 2-4μ. Furrow short and shallow, running at an angle across the middle of the depressed ventral surface, lined with a few trichocysts. Flagella 2, sub-equal, about body length, inserted in the ventral depression but directed anteriorly.

Chromatophore single, greenish-blue, parietal, covering 1/2-2/3 the cell surface. Round pyrenoid-like refractive body present, usually in the posterior portion of the cell. No stigmatic granules or vacuoles observed.

Rock pools from Scotland and England.

Gales Creek: At lower magnifications used in counting, this species was not distinguished from *Chroomonas caroliniana* sp. nov.,

so the following data covers both species: Present all year, abundant in summer and autumn; euryhaline, from 0 to 33°/oo salinity; observed in 140 samples.

This blue bean-shaped organism differs from the similar small species *Chroomonas caroliniana* sp. nov., with which it was counted, in the more ventral insertion of the flagella in the more laterally angled short ventral furrow. Droop's description includes mention of 1-3 reddish stigmatic grains, which were not observed in the Gales Creek material, but Butcher describes these as inconspicuous, they are not shown in his illustrations, and they were not observed in the live type culture personally examined at Mary Parke's laboratory in Plymouth.

Studies: Pigments--Allen, et al. (1959); O hEocha & Raftery (1959); Riley & Segar (1969). Vitamin requirements--Provasoli (1963). Fatty acids--Beach, et al. (1970).

Chroomonas caroliniana sp. nov.
(Pl. 1, f. 2 a-b)

Cells small, body asymmetric, dorsiventrally compressed, variable in shape but in general elliptical in ventral view, anteriorly obliquely truncate and posteriorly rounded, dorsal surface convex and ventral surface straight or concave in lateral view. Length 5-9-(12) μ, width 3.5-6-(8) μ, thickness 2.5-4 μ. Ventral furrow indistinct, lined with one or two rows of 2-4 trichocysts which extend to slightly beyond the middle of the cell. Flagella 2, sub-equal, between 1/2 and 3/4 the body length, inserted in the anterior end of the ventral depression.

Chromatophore single, greenish-blue, a lobed parietal mantle covering the dorsal and lateral surfaces of the cell. Stigma a small elongate orange granule positioned against the inner side of the middle or more posterior portion of the chromatophore. One or two spherical refractive pyrenoid or pyrenoid-like bodies present in the central or posterior portion of the cell.

Gales Creek: At lower magnifications used for counting, this species was not distinguished from *Hemiselmis virescens* Droop, described above, so the following data covers both species: Present all year, abundant in summer and autumn; euryhaline, from 0 to 33°/oo salinity, greatest numbers in August (775-1200 cells/ml) in oligohaline water; observed in 140 samples.

This organism differs from the blue bean-shaped cells of *Hemiselmis virescens* Droop in the more anterior insertion of the flagella in a more longitudinal ventral furrow, and from *Chroomonas baltica* (Büttner) Carter, the other blue-pigmented cryptomonad in Gales Creek, in the smaller size and presence of an orange stigma.

Chroomonas vectensis Carter (1937) is a brackish water species of similar size but which lacks both the stigma and definite dorsi-ventral compression of the body. The weakly pigmented stigma of the Gales Creek material could be overlooked because of masking by the blue-green chromatophore. Material from Woods Hole classified by Hulburt (1965a) as *C. vectensis* is illustrated with a lack of detail that suggests the possibility that a stigma may have been overlooked, for his organisms appear to exhibit the same general contours and definite dorsi-ventral compression found in the Gales Creek specimens.

Chroomonas coerulea (Geitler) Skuja (1948), described first as *Cryptomonas coerulea* by Geitler (1922) from fresh water, is similar in size and form, but the stigma is adjacent to the ventral margin away from the chromatophore, and the body is only slightly compressed laterally. A similar species, *Chroomonas rosenbergae* Huber-Pestalozzi (1950), collected from fresh water and described from agar cultures by Rosenberg (1944) but incorrectly ascribed by him to *C. nordstedtii* Hansgirg, also has a stigma, but it is carmine red and more deeply positioned in the cell, and the shape of the body is more ovoid with apparently little if any compression. Anterior contractile vacuoles described for these fresh water species were absent in the Gales Creek organisms.

Chroomonas mesostigmatica Butcher (1967), examined in detail by Dodge (1969) is from brackish water, but it is uncompressed, has a

definite pyrenoid which is positioned posteriorly and ventrally, and its central stigma is comprised of a mass of carotin grains.

Chroomonas baltica (Buttner) Carter
(pl. 1, f. 3 a-b, pl. 22, f. 4)

Chroomonas baltica (Büttner) Carter, 1937, p. 55, pl. 8, f. 6-8; Butcher, 1967, p. 23, pl. 1, f. 16. *Cyanomonas baltica* Buttner, 1911, p. 129, f. 9. *?Cryptomonas* sp. Dangeard, 1910, p. 212.

Cells moderate in size, body asymmetric, dorsiventrally compressed, somewhat irregular in shape but in general varying from slightly ovoid to slightly obovoid in ventral view, obliquely truncate anteriorly and posteriorly rounded, dorsal surface more convex than the ventral surface in lateral view. Length 11-18μ, width 6-10μ. Ventral furrow and gullet indistinct, 1/2 body length, extending slightly beyond middle of cell, lined with two rows of trichocysts. Flagella 2, sub-equal, about 2/3 the body length, inserted in the anterior portion of the ventral groove.

Chromatophore single, greenish-blue, a lobed parietal mantle covering most of the dorsal and lateral surfaces. Stigma absent. Vacuole sometimes observed near apex. Two round refractive pyrenoid-like bodies, though sometimes one or three, placed in the posterior-central portion of the cell.

Kiel Harbor, Germany; Isle of Wight, England; Belgium.

Gales Creek: Rare, in winter and early spring; from 15 to 33°/oo salinity; observed in 23 samples.

Apparently the only difference separating this species from *Chroomonas nordstedtii* Hansgirg (1885), as described and illustrated in Skuja (1948), is that *C. baltica* is a brackish water species. In Gales Creek its salinity range was between 15 and 33°/oo but the Isle of Wight type locality ranged between 1 and 4°/oo. Carter (1937) and Butcher (1967) do not appear to have considered the close similarity of Hansgirg's freshwater species. If future comparison should reveal that these two species are in fact identical, then Hansgirg's name

must take precedence. *Chroomonas caroliniana* sp. nov. differs from this species mainly in its smaller size and possession of an orange stigma.

Chroomonas minuta (Skuja), comb. nov., var. *apyrenoidosa* Huburt
(pl. 1, f. 4 a-f, pl. 22, f. 5-6)

Cells small, body lenticular to somewhat obovoid, obliquely truncate anteriorly, acute or narrowly rounded posteriorly, dorsal surface convex, ventral surface straight, widest portion just anterior to the middle of the cell. Length 4-8-(10)μ, breadth 3-5μ. Ventral surface lined with 1 or 2 rows each of 2 to 5 trichocysts, extending 1/2 to 3/4 the body length. Flagella 2, equal, about 2/3 the cell length, inserted on the ventral obliquity.

Chromatophore single, from pale reddish-brown to brownish-yellow in color, dorsal in position and usually extending almost the full length of the cell. A spherical refractive granule is often present anteriorly.

Woods Hole, Mass.

Gales Creek: Absent in winter, abundant in summer and autumn with up to 219 cells/ml in August; euryhaline, from 1 to 32°/oo salinity; observed in 71 samples.

This organism is similar to the freshwater form *Rhodomonas minuta* var. *nannoplanktonica* Skuja (1948), but lacks a pyrenoid. It often resembles a miniature *Chroomonas amphioxeia* (Conrad) Butcher (1967), a species with which it is probably closely related, as cells in the overlapping size range were sometimes difficult to tell apart when both species were present in Gales Creek.

Since the genus *Rhodomonas* basically differs from *Cryptomonas* and *Chroomonas* only in its red color, and since color is so variable in these genera, Butcher (1967) feels that it must be ignored as a generic character, and so he considers *Rhodomonas* a superfluous genus. Those species with a rudimentary gullet or a simple furrow lined with just two rows of small trichocysts he places in *Chroomonas*, and those with a

complex furrow-gullet system lined with three or more rows of trichocysts he places in *Cryptomonas*.

Chroomonas amphioxeia (Conrad) Butcher
(pl. 1, f. 5 a-e, pl. 22, f. 7-9)

Chroomonas amphioxeia (Conrad) Butcher, 1967, p. 31; *Rhodomonas amphioxeia* Conrad, 1939b, p. 2, f. 3-6; Hulburt, 1965a, p. 92, pl. 3, f. 9-12.

Cells moderate in size, body obovoid to lenticular, greatest width somewhat forward of center, slightly compressed laterally, somewhat ob-chordate in cross-section; dorsal surface convex, ventral surface flattened, anterior end obliquely truncate, posterior end acute or drawn out in a rounded tip. Length 8.5-15-(18)μ, breadth 5-10μ. Ventral furrow shallow, beginning anteriorly and extending from 1/2 to 3/4 the length of the ventral side, lined with 2 longitudinal rows of 4 to 10 trichocysts each. Flagella equal, about 1/2 the body length, inserted on the anterior-ventral obliquity.

Chromatophore single, reddish-brown to yellowish-brown, positioned against the dorsal surface, extending almost the full length of the cell but only partially covering the sides. Pyrenoid absent, though sometimes a bulge from the underside of the chromatophore at its greatest point of arc has a somewhat pyrenoid-like appearance. A spherical refractive body is often present anteriorly, other refractive granules sometimes scattered through the cytoplasm.

Belgium; Woods Hole.

Gales Creek: Rare in winter, abundant in April and from August to November; euryhaline, from 1 to 33°/oo salinity; observed in 125 samples.

In shape, size and color, the Gales Creek material was very similar to Hulburt's, though trichocyst areas were not usually as large as he illustrates. Discrimination became difficult when smaller

specimens of *C. amphioxeia* overlapped in size with the largest cells of *C. minuta* var. *apyrenoidosa* Hulburt (1965a) also present in the estuary.

Cryptomonas pseudobaltica Butcher
(pl. 1, f. 6 a-i, pl. 22, f. 10-12)

Cryptomonas pseudobaltica Butcher, 1967, p. 44, pl. 6, f. 2; *Rhodomonas baltica* sensu Zimmerman, 1923, p. 285, f. 1a; 1925, pl 4, pl. 1, f. 1a-d; Carter, 1937, p. 54, pl. 8, f. 4-5; non Karsten, 1898, p. 15, pl. 1, f. 8-12.

Cells moderate in size, body only slightly compressed, elliptical to somewhat ovoid in ventral view, obliquely truncate anteriorly, rounded posteriorly. Length 9-16μ, width 5.5-12μ. Periplast rigid, bearing a double series of oblique striations. Ventral furrow wide and flat in the anterior portion of the ventral surface, the margins gradually overlapping and closing to form a deeper gullet which extends to about the center of the body or somewhat beyond; Trichocysts lining the furrow-gullet varying greatly in number but often appearing to lie in four longitudinal rows. Flagella 2, sub-equal, about 2/3 the body length, inserted anteriorly in the furrow.

Chromatophore single, parietal, with two lateral lobes joined dorsally in the region of the pyrenoid, color varying from red to reddish-brown to yellowish-brown. Large round pyrenoid usually discernable centrally, outlined by starch platelets; various refractive granules and globules scattered through the cytoplasm.

Baltic Sea; English coast.

Gales Creek: Present all year but never in any concentrations; euryhaline, from 0 to 32°/oo salinity; observed in 85 samples.

Karsten's description of *Rhodomonas baltica* includes no mention of pyrenoid or trichocysts, thereby leaving the identity of this form questionable. Butcher therefore erects a new species for Zimmerman's more completely described organism, and on the basis of its 3 or more

trichocyst rows places it in *Cryptomonas*, having eliminated the genus *Rhodomonas* as being superfluous.

Butcher's description gives the size range recorded by Zimmerman (18-30μ x 5-8μ) but the material Butcher illustrates is smaller--the same general size as reported by Carter (12.5μ x 7μ x 6μ), which was also the average size of the Gales Creek material.

The structure of the ventral furrow, usually difficult to discern, appeared in one favorable instance under careful light microscope examination to become gradually deepened and overlapped by one of the furrow margins while extending down the body of the cell, as shown in plate 1, fig. h, i.

In culture, the Gales Creek material was observed to exhibit two phenomena reported by Zimmermann (1923): a negative phototaxis, and a change in chromatophore color from red in weak light to shades of reddish or even yellowish brown in brighter light. The red color also disappeared as the cultures aged; the cells became greenish-yellow and filled with starch granules.

Cryptomonas salina Wislouch (1924) is almost identical to *C. pseudobaltica*, but according to Butcher it only has 2 rows of trichocysts, and on this basis it is reclassified *Chroomonas salina* (Wislouch) Butcher (1967). *Rhodonomas rubra* Geitler (1922), not mentioned by Butcher, has a slightly larger size range (13-20μ x 8-10μ) but otherwise appears identical to the above species, and is illustrated with only 2 rows of trichocysts. If this fresh water organism is indeed the same as *C. salina*, also first described from fresh water, then Geitler's name must take precedence over Butcher's combination when transferred to the proper genus: *Chroomonas rubra* (Geitler) comb. nov.

Hulbert (1965a) describes *Cryptomonas salina* from Woods Hole, but his illustrations indicate the presence of 3 and 4 rows of trichocysts, which suggests that in fact he was observing the same species found in Gales Creek, *C. pseudobaltica*. Carter (1937) reported both red *R. baltica* and brown *C. salina* from a brackish pond on the Isle of Wight, but her *R. baltica* was only found in the winter when light intensities are low, and her *C. salina* illustrations appear to indicate more than two rows of trichocysts, so perhaps they were both merely different color forms of *C. pseudobaltica*.

Cryptomonas pseudobaltica is very similar to 3 other species recently described from cultures isolated by Mary Parke and which I had an opportunity to observe in Plymouth, England.

C. maculata Butcher (1967), is described as having straighter sides, a more narrow outline, and a pyrenoid absent or not well marked by starch sheathes. The cells were slightly larger and more compressed than described, possessed a thinly starch-ensheathed pyrenoid and striated periplast not mentioned by Butcher, but were generally more elongate than the Gales Creek material, though some individual specimens from Gales Creek were very similar in shape. *C. reticulata* Lucas (1968) appeared in ventral view as it does in Lucas' photographs, very similar to cells photographed from Gales Creek, but though the Lucas culture had cells much more compressed in lateral view than described, they did exhibit a ventrilaterally curved posteriority which was never observed in my material, and his cells were also of a somewhat larger size (20μ x 10μ). *C. calceiformis* Lucas (1968) is illustrated as having a very short gullet, but cells observed in the culture possessed trichocyst areas over 1/3 the body length. The cells were also somewhat larger than described and were more rounded posteriorly, and in general were very similar to the *C. maculata* culture, being somewhat more elongate than *C. pseudobaltica.*

These species were each described from vigorous clonal cultures. As the cultures age the average cell size increases, and various other deviations from the described forms appear. Given the variation in conditions in the natural environment identification of these forms in the field should prove to be very difficult, if indeed these are all separate species and not just sub-specific variations isolated as clones in culture.

Cryptomonas cf. *rostrella* Lucas
(pl. 2, f. 8 a-c)

Cryptomonas rostrella Lucas, 1968, p. 537, f. 1a, 2, 3.

Cells moderate to large in size, laterally compressed, variable in shape with forms which may be elliptical, obovoid, fusiform or sub-rectangular, over twice as long as broad, anterior end obliquely truncate,

posterior end broadly to acutely rounded, ventral and dorsal contours straight to convex. Length 16-20 μ, breadth 7-10 μ, thickness 5-7.5 μ. Trichocyst area moderately narrow, extending 2/5 to 3/5 the length of the cell. Flagella 2, equal, over half the length of the cell.

Chromatophore single, parietal, covering all sides of the cell though sometimes indented somewhat posteriorly, reddish- to yellowish-brown. Stigma moderately small, variously shaped, red to orange in color, lying next to the ventral margin slightly posterior to the middle of the cell. Pyrenoid single, dorsal and central or somewhat posteriorly positioned, covered with starch plates.

Roscoff, France.

Gales Creek: Rare, in autumn and early spring; euryhaline, from 1 to 33°/oo salinity; observed in 9 samples.

A number of individual organisms of somewhat different form have been grouped together here because of their similarity in size, coloration, and possession of a stigma and single starch-sheathed pyrenoid. The form most often encountered, however, is that shown in Fig. 8a. This differs from Lucas' more anteriorly rostrate and posteriorly tapering type illustration (Fig. 1a), but is similar to cells in his photographs (Figs. 2 and 3). The Gales Creek cells were mostly smaller than the minimum dimensions given by Lucas. He described his species from a clonal culture and not from field material, so I am assuming a greater variation of the species in nature which allows me to tentatively place these Gales Creek forms under *C. rostrella* until more observations are made on both the species and these forms. (I am also tentatively placing here a larger form, 33μ x 15μ in size with an orange stigma, shown in pl. 2, fig. 8d and pl. 22, fig. 13.)

Cryptomonas stigmatica Wislouch (1924) is the only other stigma-possessing species similar in size, form and color to the Gales Creek material, but it differs in the possession of two pyrenoids. None of the Gales Creek specimens showed this distinguishing character, though *C. stigmatica* has been reported on the east coast from Woods Hole by Hulburt (1965a).

Cryptomonas testacea sp. nov.
(pl. 2, f. 9 a-d, pl. 22, f. 14-16)

Cells large, body elliptical but occasionally somewhat ovoid or obovoid, body 2 to 3 times as long as broad, somewhat compressed laterally, with dorsal and ventral contours only slightly convex or sometimes straight, anterior end obliquely emarginate, anterior tip acute or rounded, posterior contour broadly rounded or tapering and more narrowly rounded. Length 17-25 μ, breadth 7-12 μ, thichness 6-9 μ. Gullet moderately broad, extending posteriorly usually beyond the middle of numerous trichocysts. Flagella 2, slightly exceeding half the body length, inserted anterior-ventrally in the mouth of the gullet.

Chromatophores two, reddish-brown in color, though sometimes of a more brownish-yellow hue, positioned laterally but with one often extending more toward the dorsal surface, the other more toward the ventral. Pyrenoid single, though occasionally two may be present, round or somewhat elliptical, large, lying dorsally in the middle of the cell, outlined by ensheathing starch plates; the presence of the pyrenoid(s) may be difficult to determine if the starch plates are not present. Stigma absent. Assimilate granules and globules usually scattered along the chromatophores and clustered posteriorly.

Gales Creek: Present in spring and autumn with some abundance in April; from 1 to 28°/oo salinity; observed in 32 samples.

This species was first tentatively classified as *Cryptomonas rufescens* Skuja (1939) the description of which indeed fit the Gales Creek specimens rather well, including the large elliptical sometimes shelled dorsal pyrenoid. But in his 1956 publication, Skuja states that *C. rufescens* actually does not have a pyrenoid, but instead 1 or 2 "elliptical bodies" are to be found in the middle of the cell. From Skuja's figures in both publications, it would appear that these elliptical bodies could not easily be mistaken for typical pyrenoids.

Another reddish-brown species of the same size, *Cryptomonas cuprea* Skuja (1956) is more cylindrically elongate, with a more diagonally directed gullet and more obliquely truncate anterior contour, and though lacking a typical pyrenoid, also possesses 1 or 2 "elliptical bodies" as

in *C. rufescens*. Both of these species were described from lakes in Sweden.

Cryptomonas stigmatica Wislouch, as described by Hulburt (1965a), from brackish water in the Woods Hole vicinity, is similar in size, shape, and coloration to the Gales Creek material, but differs in possessing the striking characters of a lunate red stigma and two pyrenoids which proliferate large sub-hemispherical starch bodies.

Cryptomonas ovata Ehrenberg
(pl. 2, f. 11 a-b, pl. 22, f. 17-18)

Cryptomonas ovata Ehrenberg, 1838, p. 41; Pascher & Lemmermann, 1913, p. 107, f. 168; Skuja, 1939, p. 94-95, pl. 5, f. 10-11; Prescott, 1962, p. 442, pl. 95, f. 40.

Cells large, body elliptical to ovoid, widest portion in middle of cell or slightly posterior to this, over twice as long as wide, slightly compressed laterally, obliquely truncate anteriorly, rounded posteriorly, dorsal contour more convex than ventral contour, the latter sometimes straight. Length 18-27 μ, breadth 8.5-12 μ. Trichocyst area broad, extending to the middle of the cell or somewhat past it, only slightly nearer the ventral side of the body. Flagella 2, 1/2 to 2/3 the body length, inserted in an anterior-ventral depression before the gullet.

Chromatophores 2, parietal, covering the lateral faces of the cell, olive-yellow to olive-brown. Pyrenoid absent. A refractive elliptical body may be present dorsal to the trichocyst area in the anterior portion of the cell, other smaller granules may be found scattered in the cytoplasm.

Cosmopolitan, usually fresh water.

Gales Creek: Rare, in spring and summer; euryhaline, from 0 to 30°/oo salinity; observed in 8 samples.

The few Gales Creek cells observed were near the smaller end of the great size range, 14-68μ x 8-26μ, reported by Skuja (1939) for this variable species.

Studies: Flagella and periplast fine structure -- Hibbard (1971). Phototaxis -- Bendix (1960). Pigments -- Gantt, *et al.* (1971). Chromosome number -- Godward (1966). Fatty acids -- Beach, *et al.* (1970).

Cryptomonas erosa Ehrenberg
(pl. 1, f. 7 a-b)

Cryptomonas erosa Ehrenberg, 1838, p. 41; Pascher & Lemmermann, 1913, p. 103, f. 163-164; Skuja, 1948, p. 354, pl. 38, f. 15, 16; Prescott, 1962, p. 442, pl. 95, f. 39.

Cells moderate in size, body obovoid to somewhat elliptical, widest portion in the anterior half of the cell, compressed laterally, ventral margin straight or convex, dorsal side more strongly convex, anterior end obliquely truncate, dorsal and ventral contours tapering posteriorly to an acutely rounded end. Length 12-16 μ, breadth 6-8.5 μ. Trichocyst area moderately broad, extending to the middle of the cell or slightly beyond. Flagella 2, sub-equal, about 3/4 the body length, inserted anterior-ventrally.

Chromatophores 2, olive-yellow to olive-green, parietal, covering all but an anterior portion of the cell. Pyrenoid absent. 1 or 2 large elliptical refractive bodies present dorsally in the middle portion of the cell, smaller granules scattered around the periphery.

Cosmopolitan, from fresh and salt water.

Gales Creek: Rare, late spring, summer and early winter; from 0 to 27°/oo salinity; observed in 26 samples.

The Gales Creek forms had cell dimensions at the lower end of the size range given by Skuja for this species (length 13-45μ, breadth 6-26 μ, thickness 6-17μ). The more tapered posterior outline and more oblique anterior profile served to distinguish these forms from the previous species, *Cryptomonas ovata* Ehrenberg.

Cryptomonas borealis Skuja
(pl. 2, f. 10 a-c, pl. 22, f. 19)

Cryptomonas borealis Skuja, 1956, p. 347, pl. 60, f. 17-26.

Cells large, body strongly compressed laterally, elliptical in side view, dorsal surface more convex than the ventral surface, which may be almost straight; a blunt rostrum, broad in dorsal view, projects forward anteriorly, and ventral to it lies the mouth of the gullet; body broadly rounded posteriorly. Lenght 25-41 μ, breadth 12-22 μ, thickness 7-10 μ. Gullet 2/3 the length of the body, clavate in shape, broadening as it extends posteriorly and somewhat dorsally, all but the anterior portion lined with a multitude of trichocysts. Flagella 2, subequal, 2/3-3/4 the length of the cell.

Chromatophore appears to be single, parietal, covering the entire body surface, olive-yellow in color, granular. Pyrenoid absent. 1-3 large elliptical assimilate bodies present dorsally.

Described from fresh water in Sweden.

Gales Creek: Rare, July; fresh water only; observed in 6 samples.

Skuja (1956) describes the cells as having either one or two chromatophores. *Cryptomonas rostratiformis* Skuja in Huber-Pestalozzi (1950), the substitution for the illegitimate name *C. rostrata* Skuja (1948), is a species very similar in form but is larger (48-60μ in length) and lacks the 1-3 characteristic elliptical bodies.

Cryptomonas croatanica sp. nov.
(pl. 2, f. 12 a-c, pl. 22, f. 20)

Cells moderate in size, body obovoid in dorsal view, unsymmetrically obovoid in lateral view, circular in cross-section, broadly obliquely truncate anteriorly both in lateral and dorsal view, tapering and rounded posteriorly; dorsal surface convex, ventral surface straight or somewhat concave, the anterior-ventral corner of the cell extended into a buldge which contains the mouth of the gullet. Length 15-20 μ, width 11-12 μ. Gullet less than half the body length but extending beyond the middle of the cell in an oblique direction from the

mouth, lined with several rows of 4-6 trichocysts. Flagells 2, equal, body length, inserted in the mouth of the gullet.

Chromatophores 2, olive-green to olive-brown, extensive, one covering the dorsal and half the anterior surface, the other the ventral surface. Pyrenoid absent, but one or two large elliptical bodies often present dorsally. Other assimilate granules small and scattered.

Gales Creek: Rare, in february and March; oligohaline, from 0-5°/oo salinity; observed in 5 samples.

The distinctive form of this obovoid organism is created by the projection of the gullet mouth into a bulge at the ventral end of the broadly obliquely truncate anterior surface. The only similar species described, *Cryptomonas pusilla* Bachmann (1923) (see Skuja, 1954), differs in its smaller size (7-12μ x 5-7μ), single chromatopore, and the more dorsal position of the gullet mouth anteriorly.

(Class Dinophyceae)

Prorocentrum micans Ehrenberg
(pl. 3, f. 13 a-d; pl. 23, f. 1)

Prorocentrum micans Ehrenberg, 1833, p. 307; Schiller, 1933, p. 35, f. 37; Martin, 1929, p. 11, pl. 3, f. 10-13, pl. 7, f. 4; also Bursa, 1959, and Dodge, 1965.

Cells very large, obovoid, compressed, theca composed of two valves with punctate surfaces, the dorsal valve more convex than the ventral valve, body anteriorly truncate or slightly emarginate and bearing a pointed tooth which may vary in length from 1 to 10μ, body acutely rounded or pointed posteriorly. Length 40-50μ, width 25-33μ, thickness 18μ. Flagella 2, inserted in a small anterior depression, one normally undulating around the tooth, the other extending ventrally and posteriorly, approximately equal to the cell in length.

Chromatophores two, large, one underlying each valve, yellow-brown. Nucleus elliptical, basal, with short chromasomal bodies

visible. Large pusule reservoir present anteriorly.

Widely distributed in esturine, neritic and oceanic waters in both North and South Atlantic.

Gales Creek: Present in early spring and late autumn; euryhaline, from 1 to 32°/oo salinity; observed in 21 samples.

Studies: Fine structure--Dodge (1965). Pyrenoid matrix--Kowallik (1969). Pigments--Pinckard, *et al.* (1953); Riley & Wilson (1967). Chromosome numbers-- Dodge (1963c); Godward (1966). Chromosome helix--Dodge (1963). Nuclear division--Dodge (1963b). Trichocysts--Bouck & Sweeney (1966). Phototaxis--Halldal (1958). Growth rates--Braarud (1961). Fatty acids--Chuecas & Riley(1969). Toxicity--Pinto & Silva (1956).

Prorocentrum minimum (Pavillard) Schiller
(pl. 3, f. 14 a-c; pl. 23, f. 2)

Prorocentrum minimum (Pavillard) Schiller, 1933, p. 32, f. 33. *Exuviaella minima* Pavillard, 1916, p. 11, pl. 1, f. 1a-b. *Prorocentrum triangulatum* Martin, 1929, p. 12, pl. 3, f. 14-18.

Cells large, broadly obovoid to sub-triangular, strongly compressed, theca of two valves with punctate surfaces and striated margins; anterior contour very broad, bearing a short tooth, body rounded posteriorly. Length 13-25μ, width 12-22μ, thickness 8-10μ. Flagella two, one undulating about the tooth, the other extending posteriorly and equal to the cell length.

Chromatophores yellow-brown, irregularly lobed. Nucleus elliptical, basal, small chromosomal bodies visible. Pusule reservoir anteriorly positioned with exit canal throught the flagellar pore.

Atlantic coasts and Mediterranean Sea.

Gales Creek: Present all year, with high densities in April, up to 206 cells/ml; euryhaline, from 1 to 33°/oo salinity; observed in 60 samples.

Mainly on the basis of shape, Hulburt (1965) creates two varieties from previously described species: *P. minimum* var. *triangulatum* (Martin) Hulburt, a triangular form, and *P. minimum* var. *mariae-lebouriae* (Parke & Ballantine) Hulburt, a toothless oval form. The shape of the Gales Creek specimens was found to lie between the illustrations of Schiller and the more triangular figures of Martin.

Prorocentrum redfieldi Bursa
(pl. 3, f. 15 a-b; pl. 23, f. 3-4)

Prorocentrum redfieldi Bursa, 1959, p. 19, f. 121-124.

Cells large, elongately obovoid ("comma-shaped"), theca of two valves with the dorsal valve convex and the ventral valve flat to concave; anterior contour rounded and bearing an apical tooth composed of a narrow spine with a hyaline wing, body narrowly tapering to a point posteriorly. Length 25-27μ, width 8.5-10μ, thickness 5μ, length of tooth 4-5μ. Flagella 2, inserted anteriorly adjacent to the tooth, around which one undulates, the other extending posteriorly, shorter than the body length.

Chromatophores two, one in each valve, moderate in size, lobed. Nucleus elliptical, posterior, short chromosomal bodies visible. One or two orange stigmatic granules and pusule reservoir present anteriorly.

Described from Woods Hole.

Gales Creek: One appearance in June; from 24 to 27°/oo salinity; observed in 2 samples.

Exuviaella compressa (Stein) Ostenfeld
(pl. 3, f. 16 a-c; pl. 23, f. 5-6)

Exuviaella compressa (Stein) Ostenfeld, 1899, p. 59; Schiller, 1933, p. 17, f. 11; Martin, 1929, p. 10, pl. 3, f. 5-6; Wood, 1968, p. 55, f. 137. *Dinopyxis compressa* Stein, 1883, pl. 1, f. 34-38. *Prorocentrum compressum* (Stein) Abe, 1967, p. 372.

Cells large, elliptical, slightly compressed, theca of two valves both slightly indented anteriorly and rounded posteriorly, with no conspicuous poroids; apical tooth absent. Length 21-31μ, width 15-19μ, thickness 13-15μ. Flagella 2, arising from the flagellar pore in the anterior depression, one ribbon-shaped and normally undulating in a circle, the other terete, slightly shorter than the cell length and extended posteriorly when the cell is freely moving.

Chromatophores two, yellow to brown, one against each valve, large and irregularly lobed. Two spherical pyrenoid-like bodies present centrally, one in each valve. Nucleus large, spherical, basal, large oval chromosomal bodies visible. Pusule reservoir very large, anterior, with exit canal through the flagellar pore. Various large red stigmatic granules often present.

Cosmopolitan species: Mediterranean Sea, Atlantic coasts, Caribbean and Gulf of Mexico.

Gales Creek: Present in low numbers all year except June and July; euryhaline, from 4 to 32°/oo salinity; observed in 45 samples.

The Gales Creek specimens, like those observed by Wood (1968) from the Caribbean and adjacent areas, differed from the type in the absence of an apical tooth, the lacking of conspicuous poroids, and the lesser degree of compression, but also differed from Woods' material in being smaller than the 30-50μ size range he gives.

Exuviaella marina var. *adnatodens* var. nov.
(pl. 3, f. 17 a-d; pl. 23, f. 7-8)

Exuviaella marina Cienkowski, 1881, p. 159, f. 36-37; Schiller, 1933, p. 20, f. 15; Carter, 1937, p. 57, pl. 6, f. 32-34. *Exuviaella lima* (Ehrenberg) Butschli, 1885, p. 5, pl. 41, f. 2; Martin, 1929, p. 11, pl. 1, f. 1-2, pl. 3, f. 7-9.

Cells very large, body elliptical, broadest below the middle, strongly compressed and elongate-elliptical in side view, theca of two valves, one slightly indented at the apex, the other deeply indented in a "V" shape, in the middle of which arises a longitudinal

ridge which extends anteriorly to form a short blunt apical tooth; body broadly rounded posteriorly. Length 40-50μ, width 32-39μ, thickness 14-20μ. Flagella two, inserted anteriorly next to the longitudinal ridge, one undulating around the rim of the anterior depression about the tooth, the other extending posteriorly and equal to the length of the cell.

Chromatophores two, one covering each valve surface, deep yellow-brown. Nucleus elliptical, large, basal, short chromosomal bodies visible. Orange stigmatic granules often present. Pusule reservoir large, anterior, with exit canal through the flagellar pore.

The species is common on both coasts of the temperate Atlantic.

Gales Creek variety: Present from autumn through winter to early spring; from 14 to 33°/oo salinity; observed in 20 samples.

This variety is distinguished from the species by the presence anteriorly, in the more indented valve, of the longitudinal ridge which extends apically into a blunt tooth.

Abe (1967) concludes from his studies that *Prorocentrum, Exuviaella, Cenchridium* and *Porella* have no significant basic characteristics available to separate them, and therefore unites them all under the name *Prorocentrum.* If his conclusions are accepted, then the Gales Creek form would become *Prorocentrum marinum* var. *adnatodens* var. nov.

Sinophysis aff. *ebriolum* (Herdman) Balech
(pl. 3, f. 18 a-b; pl. 23, f. 9)

Sinophysis ebriolum (Herdman) Balech, 1956, p. 32-33, f. 9-12; *Phalacroma ebriola* Herdman, 1924, p. 79, f. 24; *Thecadinium ebriolum* (Herdman) Kofoid & Skogsberg, 1928, p. 32.

Cells large, body laterally compressed, elliptical in lateral view, elongate-elliptical in dorsal view. Length 40-41μ, width 20μ, thickness 26μ. Epitheca very reduced, short-cylindrical, 1/9 the body length, as broad as long, apex flattened, mounted somewhat sunken

and at an angle on the more dorsal side of the cell's anteriority. The anterior margin of the hypotheca surrounds a torus shaped cavity with the epitheca in the middle. Dorsal contour of the hypoteca straight, ventral contour convex, antapex broadly rounded. A weak list-like structure extends down the curved ventral surface from the apex to the middle of the body. The transverse flagellum undulates completely within the torus-shaped anterior cavity; the longitudinal flagellum appears to become free of the body at the base of the list, and from this point exhibits a length about that of the body.

Chromatophores and stigma absent. Nucleus spherical, in the posterior portion of the cell. Ingested bodies, assimilate globules and crystals present.

English Channel; Irish Sea.

Gales Creek: Appearances in October and November; from 30 to 35°/oo salinity; observed in 2 samples.

Compared with Herdman's description, the Gales Creek material was not so irregularly elliptical in shape, and possessed a shorter ventral list and a smaller more deeply sunken epitheca. The material also differed from Balech's illustrations in the greater proportionate length and lesser degree of lateral compression of the body, as well as the more angular tilt of the epicone. Despite these differences the Gales Creek material has been tentatively placed in this taxon until such time as more cells may be observed in greater detail.

Thecadinium aureum sp. nov.
(pl. 4, f. 19 a-b; pl. 23, f. 10-11)

Cells very large, body laterally compressed, obpyriform in lateral view, elongate-elliptical in ventral view with an oblique basal contour. Length 54µ, width 34µ, thickness 43µ. Epitheca small, less than 1/3 the body length, broadly hemispherical. Hypotheca in lateral view with curved sides and a rounded antapex, in ventral view with convex left margin and almost straight right margin. Girdle moderately narrow and deep with sharply defined margins, displaced

more than two girdle widths (1/5 the cell length). Sulcus beginning at an obtusely angled junction with the anterior portion of the girdle, deflected to the right as it proceeds posteriorly and ventrally in the intercingular region, then broadening and flattening as it extends straight towards the left side of the antapex. Transverse flagellum inserted at the angled junction of the sulcus and the anterior limb of the girdle, encircling the epitheca. Longitudinal flagellum not observed. Plate structure of the theca was not observed.

Chromatophore brown, forming a continuous parietal mantle which covers all but the most posterior portion of the cell, tending to obscure internal detail. Nucleus not observed. Large irregularly shaped red stigmatic granule may be present posterior-ventrally.

Gales Creek: Observed in January from one sample, $20^{\circ}/oo$ salinity.

A species very similar in size and general shape to this Gales Creek organism is *Thecadinium inclinatum* Balech (1956), which, however, differs in having a more flattened epitheca with an apical notch, a more elliptical body outline, more lateral compression, and an apparent absence of chromatophores (Balech does not mention their presence in his description). *Thecadinium kofoidi* Kofoid & Skogsberg (1928) is also similar in form, though smaller in size (30-33μ), and though it does possess chromatophores, it may be distinguished from the Gales Creek material by its flatter epitheca, straighter dorsal margin, and less deflection of the girdle.

Dinophysis lachmanni Paulsen
(pl. 4, f. 20 a-b; pl. 23, f. 12)

Dinophysis lachmanni Paulsen, 1949; Solum, 1962, p. 8-24, f. 2, 5, 9. *Dinophysis acuminata* sensu Jorgensen, 1899, p. 30, pl. 1, f. 7-9.

Cells very large, body elliptical, compressed laterally, the dorsal surface slightly more convex than the ventral, the antapex rounded. Length 43-45μ, width 22-38μ exclusive of lists. Epitheca

small, broadly convex, not protruding beyond the broad funnel formed by the anterior cingular list. Both cingular lists smooth or finely ribbed, the more developed anterior list almost as broad as the transverse furrow. Right sulcal list short and small; left sulcal list delicate, extending little more than half way down the body, supported by three well-developed ribs. Transverse flagellum completely encircling the body; longitudinal flagellum almost 1 1/2 times the body length. Surface of theca finely punctate.

Chromatophores peripheral, diffuse, brownish-yellow to greenish in color. Nucleus elliptical, central or slightly posterior of center, short chromosomal bodies visible. Various assimilate bodies present.

Cosmopolitan euryhaline, eurythermal species of the Atlantic from the Straits of Florida to the Norwegian Sea.

Gales Creek: Present only in April; polyhaline, from 23-27^{o}/oo salinity; observed in 7 samples.

Claparede & Lachmann described *Dinophysis acuminata* in 1859. Jorgensen in 1899 observed a form on the west coast of Norway which he referred to *D. acuminata* though it differed considerably from that shown in Claparede & Lachmann's (1859) illustration. Since then many investigators have considered Jorgensen's (1899) figures as representative of *D. acuminata* (e.g. Schiller, 1933, p. 120, f. 113 a-c). However, later collections by Jorgensen from the same area showed specimens practically identical with Claparede & Lachmann's figure. This suggested to Paulsen that *D. acuminata* might have to be divided into two or several species. Thus in his taxonomic revision of the *Dinophysis* populations of Icelandic waters Paulsen (1949) reserved the name *D. acuminata* for the cells which are in accordance with Claparede & Lachmann's original description: cells characterized by being much broader in the posterior than in the anterior portion, and having a small triangular posterior protuberance ventrally to the midline. He distinguished *D. lachmanni* Paulsen as a new species which included the *D. acuminata* specimens of Jorgensen (1899). He also referred several other forms named *D. acuminata* by various authors to another new species, *D. borealis* Paulsen.

Solum (1962), in her studies on *Dinophysis* populations from Norwegian waters, follows Paulsen in assigning her forms to *D. lachmanni*. She found, however, that *D. borealis* Paulsen did not also deserve specific status and therefore has referred it as a form under *D. lachmanni*.

Dinophysis caudata Saville-Kent
(pl. 4, f. 21)

Dinophysis caudata Saville-Kent, 1880, p. 455, 460. *D. caudata* f. *acutiformis* Kofoid & Skogsberg, 1928, p. 330, f. 46; Schiller, 1933, p. 156-158, f. 145 a-f.

Cells very large, laterally compressed, ovoid-elliptical in lateral view with a truncate apex and an antapex extended posterior-ventrally into a large acutely tipped lobe. Length 76μ, width 37μ (exclusive of lists). Epitheca short and broadly flattended, not protruding beyond the broad funnel formed by the anterior cingular list. Both cingular lists smooth except for a few fine ribs. Anterior cingular list flaring, as broad as the transverse furrow, more developed than the somewhat narrower posterior cingular list. Right sulcal list narrowing posteriorly and extending down 1/2 the body length, left sulcal list a broad delicate sail 1/2 the width of the body, extending down almost 2/3 the body length, supported by 3 well-developed ribs. Flagella not seen. Theca thick, bearing numberous distinct pores.

Chromatophores or pigmentation not observable in this preserved material. Nucleus elliptical, positioned dorsal to the middle of the cell.

Widely distributed tropical and subtropical estuarine-neritic species.

Gales Creek: Observed in June and August, from two preserved plankton tows, 18-25°/oo salinity.

Oxyrrhis marina Dujardin

(Pl. 4, f. 22 a-f; pl. 24, f. 1-3)

Oxyrrhis marina Dujardin, 1841, p. 347, pl. 5, f. 4; Schiller, 1933, p. 264, f. 255.

Cells large, elongate-elliptical to fusiform, circular in apical view, hypocone very unsymmetrical. Length 27-35 μ, width 14-25 μ. Epicone longer than broad, with rounded apex. Hypocone smaller than epicone, composed of a dorsal lobe continuous with the dorsal surface of the epicone and acutely rounded posteriorly, a smaller lateral lobe, and a stubby tentacular appendage arising from the posterior surface of the posterior-ventral surface of the epicone. No typical girdle or sulcus present; the left-laterally and posteriorly oriented cavities in which the two flagella are inserted are joined behind the tentacular appendage. Transverse flagellum undulating, shorter than the cell; longitudinal flagellum 1 1/2 times the cell in length.

Chromatophores absent. Cytoplasm granular, sometimes tinted various colors depending on the nature of ingested bodies. Nucleus spherical, in the epicone. A variety of different sized assimilate granules and ingested bodies are usually present.

A cosmopolitan marine and brackish water species in Europe and along the eastern coast of the United States.

Gales Creek: Appeared in February and April; 14-25°/oo salinity; from 2 samples.

Studies: Vitamin requirements - Provasoli (1963). Chromosome number - Dodge (1963c); Godward (1966).

Protodinium simplicius Schiller

(Pl. 4, f. 23)

Protodinium simplicius Schiller, 1928, p. 126, f. 2, pl. 5, f. 1-4; Schiller, 1933, p. 274, f. 261 a-d.

Cells large, body elongate-ovoid, slightly compressed dorsiventrally. Length 28 μ, width 15 μ. Epicone sub-hemispherical; hypotheca the same though slightly longer and sometimes broader than the epicone. Girdle slightly supra-median, with margins very difficult to discern; sulcus flattening the ventral surface of the hypocone but also very difficult to discern. Transverse flagellum partially encircling the body; longitudinal flagellum somewhat longer than cell length.

Chromatophores brown to yellow-brown, diffuse, filling the epitheca and hypotheca while leaving a clearer area in between. Nucleus spherical, central. Red granules sometimes present.

Mediterranean Sea.

Gales Creek: Present in 5 samples from April; 20 to 27°/oo salinity.

These cells often appear to be merely ovoid brown bodies with two laterally inserted flagella. The girdle is so obscure that its presence and position may only be indicated by a slight constriction of the middle of the cell. The density of the chromatophores obscured the nature of their form. A stigma, described as usually visible for the species, was not observed in these specimens, though several red granules were often present in other areas of the cell than adjacent to the sulcus.

Amphidinium crassum Lohmann

(Pl. 4, f. 24 a-c; pl. 24, f. 4-5)

Amphidinium crassum Lohmann, 1908, p. 261, pl. 17, f. 16; Lebour, 1917, p. 188, f. 2; 1925, p. 31, pl. 3, f. 2 a-c; Hulburt, 1957, pl. 1, f. 3.

Body large, elongate-elliptical, slightly compressed, broadly elliptical in cross section. Length 18-27 μ, width 7.5-15 μ. Epicone very small, less than 1/4 the body length, broadly conical with a pointed apex; hypocone with sides parallel in the anterior half, rounding into an obtuse antapex. Girdle not displaced, wide, shallow, its posterior margin wider than the anterior. Sulcus very narrow and shallow, straight, extending the length of the straight portion of the hypocone. Transverse flagellum completely encircling the body; longitudinal flagellum equal to the body length.

Chromatophores absent. Nucleus positioned basally, spherical, containing short chromosomal bodies. Spherical assimilate body slightly smaller than nucleus present in left anterior portion of hypocone; ingested bodies also common.

English channel; Adriatic Sea; Woods Hole area; Straits of Florida.

Gales Creek: Present in spring and late summer, greatest abundance 44 cells/ ml in June; from 5 to 29°/oo salinity; observed in 28 samples.

Amphidinium klebsi Kofoid & Swezy
(Pl. 4, f. 25 a-f; pl. 24, f. 6-8)

Amphidinium klebsi Kofoid & Swezy, 1921, p. 144, f. U-14; Herdman, 1924, p. 76, f. 6-10; Schiller, 1933, p. 298, f. 292; emend. Taylor, 1971, p. 129-131, f. 1; non Carter, 1937, p. 58, pl. 8, f. 12-15.
Amphidinium wislouchi Hulburt, 1957, p. 199, pl. 1, f. 2.

Cells moderate in size to large, variable in size and shape, body elliptical to sub-globose in ventral view, compressed dorsiventrally, elongate-elliptical in lateral view, in apical view the ventral contour flattened and the dorsal contour convex. Length 16-37 µ, width 11-25 µ. Epicone very small, asymmetric, projecting anterior-laterally to the left, tongue-shaped in dorsal view, with a more or less obliquely flattened apex. Hypocone truncate-elliptical in ventral view, asymmetric, with the right contour more convex than the left, antapex broadly rounded. The proximal end of the girdle begins somewhat anterior to the lower end of the epicone near the midline of the cell, proceeds anterior-laterally beneath the projecting left side of the epicone. leads transversely across the dorsal surface, and finally extends diagonally to the posterior-ventral end of the epicone. From this point the sulcus extends posteriorly in a slight arc down the right ventral side of the hypocone and fades out, while a shallow extension of the sulcus continues anteriorly to connect with the proximal end of the girdle. Transverse flagellum encircling the epicone, inserted in a narrow posteriorly-directed pocket; longitudinal flagellum inserted in a shallow pocket at the base of the epicone, 1 1/2 times the length of the body.

Chromatophore yellow to brown, complex in structure, composed of numerous irregular elongate lobes which radiate from a central pyrenoid, and if extending to the periphery of the cell may then spread out to form a parietal mantle which may completely envelop the hypocone and extend into the epicone. Orange to red stigmatic granules occasionally present, either centrally or, rarely, in the epicone. Nucleus large, sub-spherical, posteriorly positioned in the hypocone, containing short chromosomal bodies. A spherical pyrenoid-like body is sometimes visible anterior to the middle of the cell forming the center of the chromatophore. In one specimen the periplast was observed to be finely punctate.

Cosmopolitan species from England to Brazil, from the Mediterranean Sea to Woods Hole, and even Port Hacking, Australia.

Gales Creek: Present all seasons but summer; euryhaline, from 4 to 32°/oo salinity; observed in 35 samples, normally those collected from bottom waters.

According to Taylor (1971) the many radiating lobes of the chromatophore extending from the central pyrenoid characterizes this species as distinct from *Amphidinium carterae* Hulburt (1954) a smaller species with a peripherally arranged chromatophore supporting a central pyrenoid, first described by Carter (1937) as *A. klebsi* with cell lengths of 12-21 μ. The size range of the measured Gales Creek specimens did not overlap that of *A. carterae* as measured from Woods Hole by Hulburt (12-15μ), but it is conceivable that specimens of *A. carterae* may have been present in some of the Gales Creek samples, since the exact nature of the chromatophore in smaller specimens could have been overlooked during counting. The size range of the Gales Creek material (16-37μ in length) encompassed *A. klebsi* as measured by Taylor (25-30μ) and Lebour (30-36μ), and *A. wislouchi* as measured by Hulburt (20-25μ). The latter species is described by Hulburt as having many chromatophores often arranged in a somewhat radiating manner with a central pyrenoid, but Taylor considers it synonymous with *A. klebsi*. This is understandable since dense peripheral portions of the chromatophore lobes can obscure the nature of their common origin in the pyrenoid.

The type species, *A. operculatum* Clap. & Lach. (see Schiller, 1933) differs from *A. klebsi* in having a minute triangular epicone, not one that is tongue-shaped and deflected to the side, and a more centrally placed sulcus.

Studies: Vitamin requirements - Provasoli (1963). Chromosome number - Dodge (1963c); Godward (1966). Fatty acids - Harrington, *et al.* (1970).

Amphidinium machapungarum sp. nov.
(Pl. 5, f. 26 a-b)

Cells large, body strongly compressed dorsiventrally, broadly elliptical in ventral view, elongate-elliptical in lateral view, slightly reniform in apical view. Length 17-30 μ, width 12-25 μ, thickness 8-15 μ. Epicone 1/4 the body length, broadly rounded, almost 3 times as wide as long; hypocone sub-trapezoidal, sides slightly curved and tapering to the obliquely truncate antapex. Girdle narrow and deep, displaced one girdle width. Sulcus absent from the epicone, narrow and proceeding posteriorly in a straight or slightly curved path down the middle of the hypocone, broadening and flattening as it approaches the truncate antapex. Transverse flagellum completely encircling the cell; longitudinal flagellum equal to body length.

Chromatophores absent. Nucleus sub-spherical, in the center of the hypocone. Large dark red granules, few or numerous, often present in two lateral rows to either side of the nucleus. Other ingested bodies sometimes present basally.

Gales Creek: Present in February, July and October; from 14 to 30°/oo salinity; observed in 8 samples.

Though this is a rather distinctive and easily recognized organism, two species may appear somewhat similar to it: *Amphidinium pellucidum* Herdman (1922), which is distinguished through its larger size, narrower girdle, and presence of the sulcus on the epicone; and *Amphidinium ovum* Herdman (1924), which possesses chromatophores.

Amphidinium incoloratum sp. nov.
(Pl. 5, f. 27 a-b)

Cells large, body broadly elliptical in ventral view, compressed dorsiventrally, elongate-elliptical in lateral view. Length 21-24 μ, width 15-18 μ. Epicone very small, asymmetric, projecting anterior-laterally to the left, tongue-shaped in dorsal view. Hypocone broadest below the middle of the cell, with curving sides and broadly rounded antapex which may be obliquely flattened or slightly emarginate. Girdle beginning anteriorly near the midline of the cell, proceeding laterally around 3/4 of the epicone before dropping diagonally to the midline on the ventral surface several girdle-widths below its proximal end. Sulcus narrow, nearer the right margin of the cell, beginning slightly posterior to the distal end of the girdle, proceeding in a straight or slightly curved path posteriorly, broadening as it nears the antapex. Transverse flagellum encircling the epicone. Longitudinal flagellum arising at the anterior end of the sulcus, slightly over 2/3 the body length.

Chromatophores and stigma absent. Nucleus large, spherical, in the posterior portion of the hypocone, containing short chromosomal bodies. Ingested bodies usually present.

Gales Creek: Present in March, April, August and October; from 24 to 28°/oo salinity; observed in 4 samples.

This species is similar in both shape and size to another species in Gales Creek, *Amphidinium klebsi* Kofoid & Swezy, but differs in the absence of chromatophores, the more globular shape, and the shorter longitudinal flagellum.

Gymnodinium stellatum Hulburt
(Pl. 5, f. 28 a-b; pl. 24, f. 9-11)

Gymnodinium stellatum Hulburt, 1957, p. 205, pl. 4, f. 4-6.

Cells very large, laterally compressed, elliptical in lateral view, and obliquely sub-truncate posteriorly; elongate-elliptical in dorsal and ventral views. Length 25-44 μ, thickness 20-33 μ, width 17-23 μ.

Epicone in dorsal or ventral view taller than wide, with sloping slightly concave sides and rounded apex, in lateral view wider than tall with the dorsal side sloping more than the ventral side, apex rounded. Hypocone similar to epicone in shape but with an obliquely sub-truncate antapex in lateral view, wider than tall, and with a deep antapical notch in dorsal or ventral view. Girdle narrow, deep, with slightly flaring edges, displaced 1/7 the body length. Sulcus narrow, extending onto the epicone a short distance, curving slightly in the intercingular area, then descending straight down the hypocone, at the same time forming a deep sinus that extends diagonally between the two lateral antapical lobes from just below the girdle region ventrally to the posterior dorsal corner. Transverse flagellum encircling less than half the cell circumference. Longitudinal flagellum inserted deep within the hypoconal sinus slightly ventral to the midline, scarcely longer than body length.

Chromatophores absent. Nucleus elliptical and laterally depressed, in the epicone, containing small elongate chromosomal bodies. Assimilate granules, some rather large, also present.

Woods Hole area.

Gales Creek: Present in March; euryhaline, from 2 to 32°/oo salinity; observed in 7 samples.

This species is similar in shape and form to *Gyrodinium uncatenum* Hulburt, also present in Gales Creek, but is easily distinguished by the less displaced girdle, the straighter sulcus, and the absence of chromatophores.

Gymnodinium nelsoni Martin
(Pl. 5, f. 29 a-c; pl. 25, f. 1-3)

Gymnodinium nelsoni Martin, 1929, p. 14, pl. 3, f. 25-26; Hulburt, 1957, p. 203, pl. 2, f. 1-4.

Cells very large, broadly fusiform, with truncate antapex, very compressed dorsiventrally. Length 50-75 μ, width 38-59 μ, thickness 25 μ. Epicone in ventral view varying from sub-hemispherical to somewhat angled with sides straight or concave and apex broadly pointed.

Hypocone trapezoidal, its sides convex, straight, or concave; antapex wide, emarginate to broadly indented. In lateral view dorsal contour convex, ventral contour straight or somewhat concave; end-on view similar. Girdle narrow, deeply impressed, subcentral, displaced one to two girdle widths. Sulcus not present on epicone, narrowing and sigmoid in the intercingular region, straight on hypocone, expanding posteriorly and showing a large excavation at the antapex. Anterior and posterior flagellar chambers overlapping. Transverse flagellum not completely encircling cell; longitudinal flagellum equal to the body length.

Chromatophores many, golden brown, irregularly elliptical, randomly oriented peripherally but sometimes appearing to radiate from the center of the cell. Stigma absent. Cytoplasm granular. Nucleus central, wider than long, with numerous elliptical chromosomal bodies. Cells usually free from assimilate and ingested bodies.

New Jersey coast; Woods Hole.

Gales Creek: Present in low numbers from late winter to mid-autumn with largest counts in April; from 19 to 33°/oo salinity; observed in 51 samples.

This species apparently differs from *Gymnodinium splendens* Lebour (1925) only in possessing short elliptical chromatophores rather than elongated slender ones which radiate from the center of the cell. The chromatophores in the Gales Creek material measured 5-7 μ × 2.5-3 μ, though in dying cells the chromatophores tend to coalesce and appear to radiate from the center somewhat like the description for *G. splendens*.

Studies: Trichocysts - Bouck & Sweeney (1966). Nuclei - Mendiola, *et al.* (1966). Excreted carbon - Hellebust (1965). Fatty acids - Harrington, *et al.* (1970).

Gymnodinium danicans sp. nov.
(Pl. 5, f. 30 a-f; pl. 25, f. 4-6)

Cells moderate in size, dorsiventrally compressed, body orbicular to broadly fusiform in ventral view with an obliquely truncate antapex, fusiform in lateral view, epicone and hypocone subequal. Length 12-19 μ, width 11-19 μ, thickness 8-15 μ. Epicone broadly sub-conical; hypocone broadly hemispherical to somewhat trapezoidal, with rounded to

flattened and oblique antapex, sometimes slightly indented. Girdle slightly sub-equatorial, wide and shallow, displaced about 1/2 girdle width. Sulcus not present on the epicone, wide and shallow on the hypocone, flattening or indenting the antapex. Transverse flagellum encircling the circumference of the cell; longitudinal flagellum 1 1/2 times body length.

Chromatophores irregularly elliptical, yellow-brown, numbering from 5 to 15, peripheral. Nucleus spherical, positioned centrally, with chromosomal bodies visible. One to several red stigmatic granules adjacent to the sulcus, with other red granules often present in other parts of the cell.

Gales Creek: Present in low numbers all year, with largest counts in August (76 cells/ml) from oligohaline waters; euryhaline, from 1 to 32^{o}/oo salinity, observed in 120 samples.

This organism is very similar to *Glenodinium danicum* Paulsen, also found in Gales Creek, but is distinguished by its smaller size and absence of a theca. This latter character possibly may not hold true, however, for an E.M. survey on thecal fine structure in the Dinophyceae by Dodge & Crawford (1970) has revealed that, for the several members of the Gymnodiniaceae which they examined, a theca of delicate plates was present. Should this be the case for the Gales Creek form, then a difference in thecal plate arrangements rather than just the degree of thecal plate thickness will be necessary for separating these two species.

This organism also resembles somewhat the fresh-water species *Gymnodinium ordinatum* Skuja (1939) which, however, is smaller, has fewer chromatophores, and lacks the stigmatic granules and displaced girdle.

Gymnodinium verruculosum sp. nov.
(Pl. 5, f. 31 a-d; pl. 25, f. 7-8)

Cells moderate-sized, obovoid-fusiform with a verrucose surface, circular in cross-section, hypocone 1 1/2 times as long as epicone. Length 15-20 μ, width 8-12 μ. Epicone broadly conical to sub-hemispherical and bearing a small apical papilla; hypocone conical with

convex sides. Girdle moderately wide and deep, displaced one girdle-width (almost 1/5 body length), the anterior margin sharply defined but the posterior margin more rounded. Sulcus not extending onto the epicone, sigmoid in the intercingular region, becoming shallower and broader as it descends the hypocone, flattening the left ventral survace of the antapex. Transverse flagellum encircling 2/3 the body circumference; longitudinal flagellum equal to body length.

Chromatophore single, irregularly elongate, usually extending from epicone to hypocone, with chromosomal bodies visible. Cytoplasm granular.

Gales Creek: Present in low numbers from spring to autumn; from 20 to 29°/oo salinity; observed in 43 samples.

The single elongate pale green chromatophore and the rugose surface of the cell made this species distinctive and easy to identify in all samples.

Gymnodinium gracilentum sp. nov.
(Pl. 5, f. 32 a-c; pl. 25, f. 9)

Cells moderate in size, body fusiform, circular in cross-section, with hypocone 1 1/2 times longer than epicone. Length 9-17 μ, width 5-9 μ. Epicone rounded-conical, hypocone the same only longer. Girdle wide, moderately deep, displaced one girdle width (almost 1/5 body length), the anterior margin well defined but the posterior margin more rounded and grading into the hypocone. Sulcus very difficult to observe, but not extending onto the epicone, very shallow and broadening as it descends the hypocone, where it slightly flattens the posterior-ventral surface. Transverse flagellum only partially encircling the body; longitudinal flagellum as long as body.

Chromatophores oval, from olive-green to yellow-brown, 3 to 10 but usually 4 or 5, distributed evenly in the hypocone and epicone. Nucleus spherical, in the anterior portion of the hypocone, with chromosomal bodies visible. Oil droplets and other small granules sometimes present.

Gales Creek: Present from the end of August, which showed the greatest concentration of cells (18 cells/ml), to November; from 9 to 30°/oo salinity; observed in 19 samples.

This distinctive species somewhat resembles *Gymnodinium simplex* (Lohmann) Kofoid & Swezy (1921) (see Schiller, 1933) in the number, location and color of the chromatophores, but differs in its narrow fusiform shape, shorter longitudinal falgellum, and displaced girdle.

Gymnodinium aurantium sp. nov.
(Pl. 6, f. 33 a-d)

Cells moderate in size, body ovoid to fusiform, epicone and hypocone equal. Length 12-13 μ, width 7-8 μ. Epicone conical with straight or slightly convex sides and narrowly rounded apex. Hypocone similar or more hemispherical in shape. Girdle wide and shallow, displaced 1/2 girdle width. Sulcus obscure. Transverse flagellum almost completely encircling the body. Longitudinal flagellum slightly longer than the cell.

Chromatophores 3-5, orange, irregularly lobed and positioned peripherally, in both the epicone and hypocone. Nucleus small, spherical, sub-median. Assimilate granules few.

Gales Creek: Present in June, August and September, from 10 to 26°/oo salinity; observed in 4 samples.

The shape of this organism's body and color of its chromatophores is very similar to the larger thecate species *Heterocapsa triquetra* (Ehrenberg) Stein (1883), also present in Gales Creek. *Gymnodinium pulchrum* Schiller (1928) differs in having small elliptical chromatophores and a more anteriorly placed girdle. *Gymnodinium simplex* (Lohmann) Kofoid & Swezy (1921) is elliptical in shape with four large round greenish-yellow chromatophores and a much longer longitudinal flagellum.

Gymnodinium valdecompressum sp. nov.
(Pl. 6, f. 34 a-d)

Cells moderate in size, circular to sub-rhomboid in ventral view, sometimes broader than long; extremely compressed dorsiventrally, elongate-elliptical in lateral view; reniform in apical view with ventral surface concave. Length 10-20 μ, width 15-20 μ, thickness 5 μ. Epicone in ventral view rounded to broadly sub-conical, hypocone similar in shape and slightly smaller than epicone, sometimes with a truncated or slightly emarginate antapex. Girdle slightly sub-equatorial, moderately shallow and wide, deflected less than 1/2 girdle width. Sulcus absent from epicone, wide and shallow on the hypocone, sometimes flattening or indenting the antapex. Transverse flagellum incompletely encircling the cell circumference; longitudinal flagellum equal to body length.

Chromatophores yellow to brown, peripheral, irregularly elliptical, few in number but often diffuse and difficult to delineate. An elongate red stigma is present sub-centrally near the insertion of the flagella, and other red globules may be scattered in the cytoplasm. Nucleus central, with short chromosomal bodies visible.

Gales Creek: Observed in April and November, 29°/oo salinity, from two samples.

This species is most closely related to *Gymnodinium danicans* sp. nov. from Gales Creek, but may be distinguished by its greater proportionate breadth, shorter longitudinal flagellum, and the extreme degree of dorsiventral compression.

Gymnodinium roseostigma sp. nov.
(Pl. 6, f. 35 a-d)

Cells moderate in size, broadly elliptical, somewhat compressed dorsiventrally, elliptical in cross-section. Length 8-15 μ, width 6-12 μ. Epicone hemispherical, equal to or slightly larger than the hypocone; hypocone hemispherical with antapex rounded to obliquely truncate to emarginate. Girdle sub-equatorial, wide and shallow, not displaced. Sulcus shallow, difficult to discern, extending from the girdle to, and often slightly excavating, the antapex. Transverse flagellum completely

encircling the body; longitudinal flagellum slightly longer than the length of the cell.

Chromatophores absent. Stigma an elongate body in the hypocone adjacent to the sulcus, pale red but sometimes lacking any pigmentation. Nucleus spherical, with short chromosonal bodies, sub-central to entirely within the hypocone. Various assimilate and ingested bodies present, usually within the epicone.

Gales Creek: Scattered presence from spring to autumn with largest cell counts (66 cells/ml) in August; euryhaline, from 1 to 30°/oo salinity; observed in 19 samples.

This species is somewhat similar to *Katodinium stigmaticum* (Lindemann) Fott (1957) (see Schiller, 1933, under *Massartia*) but differs in the smaller size, median position of the girdle, and the larger more elongate stigma.

Gymnodinium subroseum sp. nov.
(Pl. 6, f. 36 a-c; pl. 25, f. 10-11)

Cells moderate-sized, body somewhat sub-pentagonal, slightly compressed dorsiventrally, with hypocone about 1 1/2 times larger than epicone. Length 11-20 μ, width 8-15 μ. Epicone broadly conical; hypocone sub-trapezoidal with an obliquely truncate antapex. Girdle deep, displaced 1-1 1/2 girdle widths (about 1/6 to 1/5 the body length). Sulcus slightly sigmoid, not extending onto the epicone, narrow in the intercingular region, becoming wider and shallower on the hypocone and flattening or indenting the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum inserted deep within the sulcus, equal to body length.

Chromatophores absent. Cytoplasm with a distinct pink tint. Nucleus spherical, in the hypocone, with slightly elongate chromosomal bodies visible. A few ingested bodies and assimilate granules normally present posteriorly.

Gales Creek: Scattered presence in spring and summer, low numbers but high frequency in autumn samples; from 21 to 32°/oo salinity; observed in 43 samples.

This species is quite similar to *Gyrodinium metum* Hulburt (1957), also present in Gales Creek, but differs in the distinct pink color, the lesser degree of girdle displacement, and the larger girdle width.

Gymnodinium galesianum sp. nov.
(Pl. 6, f. 37 a-d)

Cells moderate in size, body sub-globose, almost as broad as long and only slightly compressed. Length 12-21 μ, width 10-17 μ. Epicone hemispherical to broadly sub-conical with rounded apex; hypocone hemispherical but often with a flattened or shallowly emarginate antapex. Girdle equatorial, moderately wide and shallow, displaced 1/2 girdle-width. Sulcus absent from the epicone, moderately wide and shallow on the hypocone and descending straight to the antapex. sometimes flattening or slightly excavating it. Transverse flagellum incompletely encircling the body; longitudinal flagellum approximately equal to the body length.

Chromatophores and stigma absent. Cytoplasm granular and foamy. Nucleus large, elliptical, with elongate chromosomal bodies, more or less within the right side of the hypocone. Small refractile assimilate bodies present. A large unpigmented body is often present in the epicone.

Gales Creek: Present in low numbers all year, with moderate frequency and cell counts up to 20 cells/ml in autumn; euryhaline species from 1 to 33°/oo salinity; observed in 101 samples.

The lesser degree of dorsiventral compression, the more globular shape, and the narrower girdle serve as characters to differentiate this species from *Gymnodinium incoloratum* Conrad & Kufferath (1954). *Gymnodinium lantzschii* Utermöhl (see Schiller, 1933), *G. albulum* Lindemann (see Schiller, 1933), and *G. amplinucleum* sp. nov. are all distinguished by their connate epicones, while *G. minor* Lebour (see Schiller, 1933) is a larger form with a trapezoidal hypocone sharply truncated at the antapex.

Gymnodinium amplinucleum sp. nov.
(Pl. 6, f. 38 a-b)

Cells moderate-sized, broadly ovoid, slightly compressed dorsiventrally, elliptical in cross section. Length 12-18 μ, width 12-15 μ. Epicone broadly conical with rounded apex. Hypocone sub-hemispherical; antapex obliquely emarginate with the left posterior lobe larger than the right. Girdle equatorial, wide and moderately deep, no displacement. Sulcus not extending onto the epicone, wide and deepening as it descends the hypocone to excavate the antapex. Transverse flagellum only extending half way around the circumference of the cell; longitudinal flagellum slightly longer than the body length.

Chromatophores and stigma absent. Cytoplasm granular. Nucleus large, broadly elliptical, occupying the anterior 2/3 of the cell, containing short chromosonal bodies. Assimilate and ingested bodies sometimes present posteriorly.

Gales Creek: Observed from one surface sample collected in April, 1967.

This species is rather easily distinguished from the several somewhat similar species that have been described: *Gymnodinium incoloratum* Conrad & Kufferath (1954) has a hemispherical epicone, broader girdle, and a smaller sub-central nucleus; *Gymnodinium albulum* Lindemann (see Schiller, 1933) greatly varies in general form but its antapex is rounded; *Gymnodinium lantzschii* Utermöhl (see Schiller, 1933) also has a rounded antapex, and its nucleus is small and central; and *Gymnodinium minor* Lebour (see Schiller, 1933) is a larger species with a more tapering trapezoidal hypocone and small central nucleus.

Gymnodinium boguensis sp. nov.
(Pl. 6, f. 39 a-b; pl. 25, f. 12-13)

Cells large, broadly elliptical to sub-globose, sometimes depressed-globose. Length 18-23 μ, width 17-20 μ. Epicone slightly larger and wider than hypocone, normally hemispherical but sometimes more conical, at times with a flattened apex; hypocone broadly

hemispherical, antapex sometimes flattened. Girdle sub-median, shallow and moderately wide, displaced about one girdle width (1/6 the body length). Sulcus shallow and wide, absent from the epicone, deflected to the right as it descends the hypocone and narrowing to an acutely rounded end short of the antapex. Transverse flagellum incompletely encircling the body; longitudinal flagellum 1 1/2 times the length of the cell.

Chromatophores absent. Cytoplasm granular and sometimes stained slightly yellow. Nucleus sub-central. Small granules, oil droplets, and larger ingested bodies normally present.

Observed from two samples early in the study, obtained in June, 1965.

This species is similar in form though smaller in size, to *Gymnodinium flavum* Kofoid & Swezy (1921), but lacks chromatophores, has a smaller hypocone, and a right-deflected rather than straight sulcus.

Gymnodinium lobularis sp. nov.
(Pl. 7, f. 40 a-b)

Cells moderate-sized, body asymmetric, elliptical to oboviod in ventral view, strongly compressed dorsiventrally. Length 10-13 μ, width 8-12 μ, thickness 5-7 μ. Epicone in ventral view broadly conical to sub-hemispherical with rounded apex, wider than long, shorter than the hypocone, elliptical in apical view. Hypocone in ventral view conical to sub-trapezoidal, reneform in antapical view, antapex obliquely truncate with the right posterior lobe longer than the left and more ventrally projecting. Girdle narrow and deep, supra-median, with no significant displacement. Sulcus absent from epicone; straight, wide and deeply excavating the ventral surface of the hypocone, extending to the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum 1 1/2 to 2 times the length of the cell.

Chromatophores and stigma absent. Cytoplasm unpigmented, granular. Nucleus not seen. Assimilate granules sometimes present.

Gales Creek: Rare, presence from March to April and July to September; euryhaline, from 1 to 27°/oo salinity; observed in 8 samples.

This species is distinguished from *Gyrodinium metum* Hulburt (1957) also present in Gales Creek, by its strong dorsiventral flattening and absence of marked girdle displacement. The smaller size, epicone broader than hypocone, and projecting antapical lobe are characters separating this species from *Gymnodinium wulffii* Schiller (1933).

Gymnodinium agaricoides sp. nov.
(Pl. 7, f. 41 a-c)

Cells moderate in size, body with a small broadly rounded epicone set on the end of the larger elliptical hypocone to create a general shape somewhat like that of a young mushroom. Length 10-12 μ, width 5-8 μ. Epicone less than 1/3 the length of the cell, broadly rounded. Hypocone elliptical, the dorsal surface more convex than the ventral. Girdle apparently not displaced, shallow and obscure on the ventral side but deep and wide dorsally with a sharp anterior margin though no definite posterior margin. Sulcus shallow and obscure, not present on the epicone. Transverse flagellum encircling the cell; longitudinal flagellum slightly longer than the body.

Chromatophores and stigma absent. Nucleus not seen. A spherical retractive body and smaller granules are usually present posteriorly.

Gales Creek: Present in May and from August to October; from 19 to 33°/oo salinity; observed in 8 samples.

The distinctive morphology of the Gales Creek specimens, observable in the illustrations, makes this an easy species to recognize in the field. A similar species in size and general shape is *Gymnodinium glandiforme* Conrad & Kufferath (1954), but it is described as having a cylindrical hypocone which is not as wide as the epicone, a longitudinal flagellum twice the body length, and there is no indication of the girdle creating a dorsiventral asymmetry.

Gymnodinium endofasciculum sp. nov.
(Pl. 7, f. 42 a-b)

Cells large, body broadly elliptical, somewhat compressed dorsiventrally, elliptical in cross-section. Length 20-25 μ, width 14-16 μ.

Epicone equal to or slightly smaller than the hypocone, hemispherical. Hypocone similar but with an obliquely truncate to emarginate antapex. Surface striations absent. Girdle slightly supra-median, narrow and moderately deep, displaced almost 2 girdle widths (1/7 the body length), margins sometimes slightly flaring. Sulcus slight on epicone, straight or slightly deflected to the left in the intercingular region, narrow but broadening as it descends the hypocone to indent the left side of the antapex. Flagella not observed.

Chromatophores absent. Cytoplasm granular. Nucleus in the hypocone elliptical with the long axis diagonal to the cell axes, small chromosomal bodies visible. Diagonally positioned in the anterior portion of the cytoplasm are a number of parallel fibrillar bodies about 15 μ in length. Refractive assimilate bodies are scattered through the cell.

Gales Creek: From 4 samples, in May, August and early September, with salinities of 20 to 26°/oo.

The strikingly distinctive feature of this species is the diagonal bundle of parallel fibrillar bodies, function unknown, present in the epicone.

Gymnodinium translucens sp. nov.
(Pl. 7, f. 43)

Cells large, body broadly ovoid to elliptical, epicone slightly shorter than hypocone. Length 38 μ, width 31 μ. Epicone hemispherical to subconical with rounded apex. Hypocone hemispherical to sub-trapezoidal with a flattened antapex. Girdle supra-median, deep and moderately narrow, the anterior margin sharp and well defined but the posterior margin rounded and more obscure; displaced 1 1/2 girdle widths. Sulcus absent from the epicone, shallow and widening as it descends the hypocone to the flattened antapex. Transverse flagellum encircling almost 1/2 the circumference of the body; longitudinal flagellum slightly shorter than the cell length.

Chromatophores and stigma absent. Cytoplasm coarsely granular and foamy. Nucleus elliptical, supra-median, with short chromosomal bodies

visible. Large basal ingested body normally present as well as small, refractive assimilate bodies.

Gales Creek: Observed in only one sample from early spring at 19°/oo salinity.

This organism is most similar to the somewhat smaller species *Gymnodinium minor* Lebour (1917), which, however, has an epicone larger than its hypocone instead of smaller, and which seems to store its ingested bodies in the epicone rather than basally.

Gymnodinium hulburtii sp. nov.
(Pl. 7, f. 44)

Cells large, body broadly fusiform with acutely rounded apex and antapex, epicone and hypocone equal. Length 25 µ, width 15 µ. Epicone conical with slightly convex sides; hypocone similar. Surface with delicate longitudinal striations, 7 visible across the ventral face of epicone and hypocone. Girdle deep and moderately wide, displaced about 2 girdle widths (almost 1/5 the body length), the anterior margins of both limbs curving posteriorly before joining the sulcus. Sulcus narrow and shallow on the epicone and extending almost to the apex, sharply deflected to the left in the short intercingular region, narrow and straight on the hypocone, extending almost to the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum shorter than the length of the cell.

Chromatophores absent. Nucleus sub-spherical, supra-median. Large ingested body normally present posteriorly.

Gales Creek: From one sample in September, at 24°/oo salinity.

The short displacement of the girdle serves to distinguish this species from the otherwise very similar *Gyrodinium dominans* Hulburt (1957), also found in Gales Creek. It differs from *Gymnodinium helviticum* Penard (see Schiller, 1933) in its smaller size, proportionately fewer longitudinal striae, and displaced girdle. *Gymnodinium striatissimum* Hulburt (1957) is more globular in shape and has more longitudinal striations on the hypocone than on the epicone.

Gymnodinium sp. "a"
(pl. 7, f. 45 a-c)

Cells large, body generally fusiform with an obliquely truncate antapex, body somewhat dorsiventrally compressed, elliptical in cross-section. Length 28-39μ, width 15-21μ. Epicone shorter than the hypocone, narrowly conical, apex acutely to obtusely rounded. Hypocone with straight or slightly curved lateral margins tapering posteriorly to the obliquely truncate antapex. Striations absent from the body surface. Girdle deep and moderately narrow, supramedian, displaced between 1 and 2 girdle widths (1/6 to 1/8 the body length), sometimes with slightly flaring margins. Sulcus somewhat sigmoid, narrow on epicone and extending almost to the apex, deflected somewhat to the left in the intercingular region, narrow on the anterior portion of the hypocone but broadening posteriorly to flatten or slightly indent the left side of the antapex. Transverse flagellum not seen. Longitudinal flagellum 1/2 the body length.

Chromatophores absent. Nucleus spherical, central, with elongate chromosomal bodies visible. Other granules and bodies absent from specimens observed.

Gales Creek: Observed from two samples in August and September, 23-24°/oo salinity.

This species has not been given a name for the following reason: The girdle displacement of under 1/5 the body length places this organism in the genus *Gymnodinium*, but in other characters it is similar to *Gyrodinium pellucidum* (Wulff) Martin (1929), also found in Gales Creek. This species is described by Martin (1929) as very variable in shape and size. If this variability should be found to include a degree of girdle displacement from 1/3 and 1/4 the body length to 1/8 the body length, then this species should perhaps be placed under *Gyrodinium pellucidum*. Though the character traditionally separating *Gymnodinium* from *Gyrodinium* has been a girdle displacement under 1/5 the body length, this character has been shown to be artifician in several species where the girdle displacement bridges

this figure (e.g. *Gyrodinium aureolum* Hulburt (1957), also found in Gales Creek).

Gymnodinium sp. "b"
(pl. 7, f. 46 a-b)

Cells moderate in size, body fusiform, circular in cross-section, epicone shorter than hypocone. Length 15μ, width 11μ. Epicone conical with acutely rounded apex and convex sloping sides; hypocone similar in shape but slightly longer. Surface striations absent. Girdle supra-median, wide and deep, with a somewhat flaring anterior margin, displaced one girdle width (1/7 the body length). Sulcus on epicone narrow and extending half the distance to the apex, deflected slightly to the left descending the intercingular region, then broadening as it continues straight to the left side of the antapex. Transverse flagellum not seen. Longitudinal flagellum 1/2 the body length.

Chromatophores and stigma absent. Nucleus spherical, supramedian, with large chromosomal bodies. Various granules and ingested bodies present posteriorly.

Gales Creek: From one sample in August, 22°/oo salinity.

Though observed from only one sample, these cells are distinctive enough, due to their small size, fusiform shape, wide and deep girdly only slightly displaced, straight sulcus, and absence of body striations, to not readily fit into any existing taxa, nor be readily confused with similar species found in Gales Creek: *Gyrodinium pellucidum* (Wulff) Martin (1929) has a narrower girdle with much greater displacement; *Gymnodinium* sp. "a" is twice as large, more elongately fusiform, with a proportionately narrower girdle and more deflected sulcus; *Gymnodinium endofasciculum* sp. nov. is elliptical in shape and contains parallel cytoplasmic fibrillar structures anteriorly; *Gymnodinium hulburtii* sp. nov. is larger and bears longitudinal body striations, as does *Gyrodinium dominans* Hulburt (1957).

Woloszynskia micra Leadbeater & Dodge
(pl. 7, f. 47 a-b)

Woloszynskia micra Leadbeater & Dodge, 1966, p. 1, f. 1.

Cells moderate-sized, broadly elliptical, circular in cross-section. Length 16μ, width 12μ. Hypocone hemispherical; epicone similar but slightly more conical. Girdle equatorial, deep and narrow, displaced almost 2 girdle widths. Sulcus narrow, extending to near the apex on the epicone, markedly deflected to the cell's right as it descends the intercingular region, directed posteriorly on the hypocone and broadening as it nears the antapex. Transverse flagellum not seen. Longitudinal flagellum almost equal to the cell in length. Flexible theca of hexagonal plates not observed.

Chromatophores yellow-brown, irregularly elliptical, few in number, present in both epicone and hypocone. Red bodies slightly smaller than the chromatophores also present. Nucleus very large, elliptical, in the hypocone, with short chromosomal bodies visible.

Described from the English Channel.

Gales Creek: Observed in one sample from February, $14^{o}/oo$ salinity.

Leadbeater & Dodge (1966) were able to observe the thin theca in this species throught the use of electron microscopy. Though Thompson (1950) created the genus Woloszynskia for *Gymnodinium*-like species with a theca, Leadbeater & Dodge conclude from their examination of a range of so-callen non-thecate dinoflagellates that all dinoflagellates will probably eventually be found to have a theca, with only degree of thickness separating "armored" fron "naked" species.

In shape and form this species is most similar to *Gymnodinium vitiligo* and *G. veneficum*, both described by Ballantine (1956), but differs in the very large and easily visible nucleus in the posterior part of the cell and in the greater lateral displacement of the sulcus to the right descending the intercingular region--in most

species of *Gymnodinium* with a girdle displacement this deflection of the sulcus is to the left.

Studies: Nuclear and cell division--Leadbeater & Dodge (1967a). Flagella--Leadbeater & Dodge (1967b, 1967c). Plastids and pyrenoids--Dodge (1968). Pigments--Whittle & Casselton (1968).

Katodinium rotundatum (Lohmann) Fott
(pl. 7, f. 48 a-c; pl. 26, f. 1)

Katodinium rotundatum (Lohmann) Fott, 1957, p. 288. *Amphidinium rotundatum* Lohmann, 1908, p. 261, pl. 17, f. 9. *Massartia rotundata* (Lohmann) Schiller, 1933, p. 438, f. 464; Hulburt, 1957, p. 207, pl. 1, f. 5-8.

Cells small, body resembling an arrowhead in outline, circular in cross-section. Length 7.5-11-(17)μ, width 6-7.5-(12)μ. Epicone between 1/2 and 2/3 the length of the body, conical, with straight to slightly convex sides, and acutely rounded apex. Hypocone length about half its width, narrower than the epicone, broadly rounded. Girdle very wide, no real displacement, anterior margin overhanging and of larger diameter than the posterior margin which is sometimes indistinct. No sulcus discernable. Transverse flagellum completely encircling body; longitudinal flagellum equal to body length.

Chromatophores two, yellow-brown, the anterior one band-shaped and partially encircling the periphery of the epicone, the posterior one filling the bottom of the hypocone and extending up into the epicone on the ventral side--in some cells this lobe fuses with the anterior plastid to create a single chromatophore. Nucleus elliptical, positioned somewhat posterior of center, short chromosomal bodies barely discernable. Rarely an orange stigma-like granule was observed below the insertion of the longitudinal flagellum

Cosmopolitan species from both coasts of the Atlantic Ocean and adjacent seas from the Caribbean to the Baltic and Mediterranean.

Gales Creek: Present every month but May, with frequency above 60% in autumn and early winter with densities up to 775 cells/ml by the end of January, and a second bloom of up to 1,548 cells/ml in

August. Euryhaline, from 0 to 36°/oo salinity, with highest cell concentrations in 3-9°/oo salinity; observed in 103 samples.

Studies: Chromosome number--Dodge (1963c); Godward (1966).

Katodinium asymmetricum (Massart) Fott
(pl. 7, f. 49 a-c; pl. 26, f. 3)

Katodinium asymmetricum (Massart) Fott, 1957, p. 288. *Gymnodinium asymmetricum* Massart, 1920, p. 132, f. 22 a-d. *Massartia asymmetrica* (Massart) Schiller, 1933, p. 434-5, f. 460 a-c; Carter, 1937, p. 59, pl. 8. f. 17-18; Hulburt, 1957, p. 207, pl. 1, f. 10, 14.

Cells moderate-sized, broadly elliptical in outline, slightly compressed dorsiventrally, epicone over two times as long as the hypocone. Length 13µ, width 10µ. Epicone hemispherical with a small apical notch; hypocone small, twice as wide as long, broadly rounded with an obliquely flattened antapex. Girdle wide, displaced less than one girdle width, the anterior margin wider and more defined than the posterior margin. Sulcus moderately deep, widening as it extends to the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum equal to body length.

Chromatophores absent. Nucleus elliptical, in the hypocone, chromosomal bodies discernable. Large spherical body, sometimes orange colored, and smaller assimilate granules often present in the epicone.

England; Belgium; Germany; Woods Hole area.

Gales Creek: Scattered presence in spring and autumn; euryhaline, from 2 to 32°/oo salinity; observed in 21 samples.

Katodinium pluristigmatum sp. nov.
(pl. 8, f. 50 a-c)

Cells moderate in size, ovoid, slightly compressed dorsiventrally, elliptical in cross-section. Length 11µ, width 8µ, thickness 7µ. Epicone sub-conical, from 3/5 to 3/4 the length of the body,

with straight or somewhat convex tapering sides and an acutely rounded apex. Hypocone broadly rounded, as wide as the epicone, half as long as broad, from 1/5 to 1/10 the length of the cell. Girdle moderately deep, 1/5 the cell length in width, not displaced. Sulcus not discernable. Transverse flagellum completely encircling the body; longitudinal flagellum equal to the body length.

Chromatophores absent. Several round or elongate pale red stigmatic granules are present ventrally along the midline of the cell, one or several at the position of flagellar insertion, the rest above these in the epicone. Nucleus spherical, somewhat posterior of center, difficult to discern.

Gales Creek: Present in two samples from July and August; euryhaline, from 1 to 26°/oo salinity.

This species is closely related to *Katodinium stigmaticum* (Lindemann) Fott (1957) (see Schiller, 1933, under *Massartia*), described by Lindemann from a Berlin pond, a species which, however, is elliptical in shape, possesses only one elongate stigmatic granule, and is larger in size, measuring 12-25μ in length.

Gyrodinium aureolum Hulburt
(pl. 8, f. 51 a-b)

Gyrodinium aureolum Hulburt, 1957, p. 209, pl. 2, f. 8, 9.

Cells large, sub-pentagonal to broadly elliptical in ventral view, compressed dorsiventrally, and elliptical in cross-section, with epicone and hypocone sub-equal. Length 27-30μ, width 25-28μ, thickness 22μ. Epicone hemispherical to broadly conical, with rounded apex. Hypocone hemispherical to trapezoidal, sides convex or straight, antapex truncate to slightly emarginate. Girdle moderately wide and deep, displaced less than two girdle widths or about 1/7 the body length. Sulcus extending up less than 1/2 the length of the epicone, narrow, only slightly deflected in the intercingular region, widening on the hypocone and flattening or slightly excavating the

antapex. Transverse flagellum almost completely encircling the body; longitudinal flagellum about 1 1/2 times the length of the cell.

Chromatophores numerous, elliptical, yellow-brown. Nucleus spherical, slightly anterior of center, chromosomal bodies visible. Cells normally appear free of assimilate bodies.

Woods Hole area; Norway.

Gales Creek: Present in four samples from mid-March; polyhaline, from 18 to 24°/oo salinity.

Hulburt's illustrations indicate a girdle displacement between 1/4 and 1/6 the body length, with the consequence that his species straddles the line between *Gymnodinium* and *Gyrodinium*. In the Gales Creek specimens the girdle displacement of 1/7 the body length first caused me to try placing them in the former genus. But I was later able to observe cultures which Hulburt agreed were of this species, located at the Institutt for Marin Biologi in Oslo, where girdle displacements ranged from 1/4 to 1/10 the body length (see Braarud & Heimdal, 1970). This great variation in degree of girdle displacement again emphasizes the great need for a complete reworking of the generic concept in these related groups.

Kimball & Wood (1965) believe that this species may be synonymous with *Gymnodinium nelsoni* Martin and *Gyrodinium resplendens* Hulburt, species also present in Gales Creek.

Gyrodinium resplendens Hulburt
(pl. 8, f. 52 a-b; pl. 26, f. 4)

Gyrodinium resplendens Hulburt, 1957, p. 210, pl. 2, f. 6, 7.

Cells large, elliptical, with obliquely truncate antapex, somewhat flattened dorsiventrally, epicone and hypocone equal. Length 23-26μ, width 20-23μ, thickness 18μ. Epicone sub-hemispherical to trapezoidal in ventral view, the apex rounded to obliquely truncate, sides convex or straight and sloping. Hypocone trapezoidal with sloping convex sides and an obliquely truncate to emarginate antapex. Girdle deep, moderately wide, displaced two girdle widths, about 2/7 the body

length, and overlapping about one girdle width. Sulcus extending onto the epicone deflected as a short and narrow superficial gooove at a 45° angle to the cell's right, narrow and sigmoid in the intercingular zone, broadening as it extends down the hypocone to indent the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum equal to body length.

Chromatophores many, small, oval, brown. Nucleus slightly anterior of center, elliptical, with chromosomal bodies visible. Internal detail normally obscured by the dense chromatophores.

Woods Hole area.

Gales Creek: Present from 5 samples in April and one in December; polyhaline, from 19-27°/oo salinity.

The cells observed from Gales Creek were smaller than those measured by Hulburt (36-62μ by 32-48μ), possessed an obliquely truncate antapex, and did not show the more curving longer sulcal groove on the epicone.

Kimball & Wood (1965) believe that this species may be synonymous with *Gymnodinium nelsoni* Martin and *Gyrodinium aureolum* Hulburt, both of which were also identified from Gales Creek.

Studies: Pigments--Loeblich & Smith (1968). Phototaxis--Bendix (1960).

Gyrodinium uncatenum Hulburt
(pl. 8, f. 53 a-c; pl. 26, f. 5-6)

Gyrodinium uncatenum Hulburt, 1957, p. 210, pl. 4, f. 1-3.

Cells very large, slightly compressed laterally, elliptical to subquadrangular in lateral view, elliptical to oblong in ventral view, epicone and hypocone sub-equal. Length 30-62μ, width 20-43μ, thickness 23-45μ. Epicone subtrapezoidal to subhemispherical, broadly rounded at apex, with slightly concave, straight, or slightly convex sloping sides; hypocone similar but slightly shorter, antapex slightly more truncate in lateral view and emargenate in ventral view. Girdle narrow, deep, displaced 1/3 body length, descending steeply before

rejoining sulcus. Sulcus extending onto epicone a short distance, curving slightly to the left in the intercingular area, then to right on the hypocone, cutting a deep sinus across the antapex to the dorsal side, appearing in lateral view as an oblique line descending from ventral to dorsal side of hypocone. Transverse flagellum completely encircling the body and normally confined to the girdle groove; longitudinal flagellum inserted deep within the hypoconal sinus slightly ventral of midline, about equal to the body length.

Chromatophores many, yellow-brown, varying in size but oblong to elongate, radiating from the center of the cell. Nucleus spherical, in the epicone, with small slightly elongate chromosomal bodies visible. Various assimilate particles present, some rather large.

Woods Hole area.

Gales Creek: Present from July to November; from 5 to 30°/oo salinity; observed in 18 samples.

This is a distinctive species whose basic shape is reminiscent of unpigmented *Gymnodinium stellatum* Hulburt (1957).

Studies: Phototaxis--Bendix (1960).

Gyrodinium mundulum sp. nov.
(pl. 8, f. 54 a-d; pl. 26, f. 7-8)

Cells moderate-sized to large, body elliptical to broadly fusiform, circular in cross-section. Length 12-22μ, width 8.5-16μ. Epicone hemispherical to broadly conical with rounded apex; hypocone similar in size and shape but sometimes with a slightly flattened or indented antapex. Girdle moderate to wide and deep, displaced 2 to 3 girdle widths (around 1/3 body length). Sulcus narrow, extending almost to the apex on the epicone, deflected somewhat to the left in the intercingular region, and extending almost to the antapex. Transverse flagellum encircling body; longitudinal flagellum equal to cell length.

Chromatophores yellow-brown, difficult to delineate but apparently several and elliptical in shape, distributed mostly in the hypocone. One to several red or sometimes orange bodies slightly smaller than

the chromatophores also present in the hypocone. Nucleus large, elliptical, with short chromosomal bodies, filling most of the epicone.

Gales Creek: Present in October and November; from 20 to 33°/$_{oo}$ salinity; observed in 9 samples

Though similar in size and form to this species, *Gyrodinium lebourae* Herdman (1924) has a narrower more displaced girdle and apparently lacks chromatophores, though possessing a red basal body. *G. estuariale* Hulburt (1957) is smaller, with a truncated antapex, fewer larger chromatophores, and deflection of the sulcus to the right. *G. aureolum* Hulburt (1957) is larger, with a truncate antapex, numerous chromatophores and a central nucleus. The fresh-water species *Gymnodinium marylandicum* Thompson (1947) has less girdle displacement, is dorsiventrally compressed, and the 4-6 large chromatophores fill the cell.

Gyrodinium estuariale Hulburt
(Pl. 8, f. 55 a-g)

Gyrodinium estuariale Hulburt, 1957, p. 209, pl. 1, f. 15, 16.

Cells moderate-sized, broadly elliptical, slightly compressed dorsiventrally, elliptical in cross-section. Length (8.5)-10-16-(18)μ, width 6.5-12-(15)μ. Epicone hemispherical to broadly conical with rounded apex; hypocone subhemispherical to subtrapezoidal with an obliquely truncate or sometimes slightly emarginate antapex. Girdle central, deep and moderately wide, displaced slightly over one girdle width (between 1/4 and 1/3 the body length). Sulcus shallow, often difficult to discern, very slight on epicone, straight or deflected slightly to the right in the intercingular region, widening and extending to the flattened or slightly excavated antapex. Transverse flagellum completely encircling the body; longitudinal flagellum equal to body length.

Chromatophores yellow to yellow-brown, 1-3 in the hypocone and 0-2 in the epicone, irregularly elliptical in shape. Nucleus

spherical, central or sub-central, short chromosomal bodies visible. Cytoplasm granular; assimilate granules occasional, small red stigma-like granules sparce if present.

Described from Woods Hole area.

Gales Creek: Present in spring and September with moderate frequencies in May and June; euryhaline, from 5 to 31°/oo salinity; observed in 24 samples.

This organism differs from two very similar species, *Gymnodinium vitiligo* and *Gymnodinium veneficum*, both described by Ballentine (1956), in the greater displacement of the girdle ends, the wider and deeper girdle, and in the oblique, instead of symmetrically rounded, antapex. This last character also distinguishes it from *Gyrodinium carteretensis* sp. nov., described below, which has an acutely pointed antapex.

Gyrodinium carteretensis sp. nov.
(pl. 9, f. 57 a-b, pl. 26, f. 9-11)

Cells moderate-sized, elliptical, circular in cross-section, epicone and hypocone sub-equal. Length 17μ, width 12μ. Epicone hemispherical with a small apical notch; hypocone hemispherical but for an acute antapex. Girdle shallow, the margins often difficult to distinguish, displaced 1/3 the body length. Sulcus deeper and narrower, extending a short distance onto the epicone as a right hook, deflected to the cell's right 1/4 the width of the body in the intercingular region, then broadening and extending to the left side of the antapex. Transverse flagellum encircling the body; longitudinal flagellum equal to the cell in length; both flagella inserted in small pockets.

Chromatophores yellow, few in number, plate-shaped and peripheral in epicone and hypocone. Cytoplasm granular. Nucleus large, elliptical, in the hypocone, with round chromosomal bodies visible.

Gales Creek: Observed in crude cultures made from an April Gales Creek sample with 20°/oo salinity.

This species is similar to Ballantine's (1956) *Gymnodinium vitiligo* and *Gymnodinium veneficum* both in form and in having the right-deflected intercingular sulcal segment, but the great girdle displacement places it closer to *Gyrodinium estuariale* Hulburt (1957) which, however, has a central rather than posterior nucleus, and an obliquely truncate rather than acute antapex.

Gyrodinium complanatum sp. nov.
(pl. 9, f. 56 a-c)

Cells moderate-sized, body broadly elliptical, dorsiventrally compressed, semicircular in cross-section with flat ventral and convex dorsal surfaces, epicone slightly shorter than hypocone. Length 18μ, width 13μ, thickness 10μ. Epicone hemispherical to subtrapezoidal with slightly curved sloping sides and a broadly rounded apex; hypocone subtrapezoidal with convex sides and an obliquely truncated antapex. Girdle moderately wide and deep, displaced almost two girdle widths (1/4 the body length); sulcus absent from the epicone, forming a sharp angle with the anterior limb of the girdle, narrow, straight and deflected to the left in the intercingular region, deflected less to the left on the hypocone and broadening posteriorly to flatten the antapex. Transverse flagellum incompletely encircling the body; longitudinal flagellum not observed.

Chromatophores two, large, brown, filling the hypocone. A large red granule positioned by the ventral face of the epicone. Nucleus large, round, in the epicone, with short chromosomal bodies visible.

Gales Creek: Present in a single November sample at 29°/oo salinity.

This species bears some resemblance to *Gymnodinium punctatum* Pouchet (see Martin, 1929) but differs in the distinct girdle displacement and the flattened ventral surface.

Gyrodinium cf. *metum* Hulburt

(Pl. 9, f. 58 a-q; pl. 26, f. 12)

Gyrodinium metum Hulburt, 1957, p. 211, pl. 1, f. 11, 12.

Cells moderate-sized, elliptical to broadly fusiform but variable in shape, round in cross-section to slightly compressed dorsiventrally, hypocone larger than epicone. Length 7.5-16μ, width 5-14μ. Epicone broadly rounded to broadly conical; hypocone rounded to subtrapezoidal, antapex conical to obliquely truncate or sometimes emarginate, acutely rounded in lateral view. Girdle deep and moderately wide, displaced 1-1 1/2 girdle widths, about 1/4-1/6 the body length; sulcus sigmoid, not extending onto the epicone, narrow in the intercingular region, broadening on the hypocone, flattening or indenting the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum 1 1/2 times body length.

Chromatophores absent. Cytoplasm grayish, somewhat granular. Nucleus spherical, in the left side of the hypocone, small chromosomal bodies visible. A few ingested bodies often present posteriorly.

Woods Hole area.

Gales Creek: Present in all seasons, up to 39 cells/ml in June; polyhaline, from 20 to 31°/oo salinity; observed in 78 samples.

The many variable specimens obtained from Gales Creek shared in common with Hulburt's species the "chinaman-hat" shape of the epicone, and have been tentatively placed together here despite the usually wider girdles and the sometimes more obliquely truncate antapices. The displacement of the girdle in these specimens points up the problem of the artificial separation of *Gymnodinium* and *Gyrodinium* on the basis of girdle displacement being less or greater than 1/5 body length.

Gyrodinium formosum sp. nov.

(Pl. 9, f. 59 a-c)

Cells moderate in size, body elliptical with an obliquely truncate antapex, slightly compressed dorsiventrally, elliptical in cross-section, epicone somewhat shorter than hypocone. Length 17-22μ,

width 12-19μ. Epicone sub-conical to hemispherical; in some cells the dorsal surface was evenly divided by a shallow groove extending to and slightly notching the apex. Hypocone subtrapezoidal with straight or convex tapering sides and an obliquely truncate antapex. Surface striations absent. Girdle deep and wide, supra-median, displaced about 2 1/2 girdle widths (1/3 the body length) and overlapping almost the same amount; sulcus sigmoid, absent from the epicone, narrow and strongly deflected to the left in the intercingular region, curving somewhat to the right on the hypocone, widening abruptly near the antapex. Transverse flagellum inserted in a deep posteriorly directed pocket, completely encircling the body. Longitudinal flagellum arising from a shallow pocket, slightly shorter than the body length.

Chromatophores absent. Cytoplasm granular, unpigmented or sometimes faintly yellow. Nucleus large, sub-spherical, mostly in the epicone, with short chromosomal bodies. Numerous refractive assimilate bodies present.

Gales Creek: Present from each season; from 23 to 32°/oo salinity; observed in 5 samples.

The sharp curve of the anterior limb of the girdle joining the strongly deflected sulcus is a distinctive feature of this species, as is the dorsal groove on the epicone.

Gyrodinium glaebum Hulburt

(pl. 9, f. 60)

Gyrodinium glaebum Hulburt, 1957, p. 211, pl. 1, f. 17, 18.

Cells moderate-sized, body broadly elliptical with equal epicone and hypocone. Length 19μ, width 16μ. Epicone sub-hemispherical. Hypocone also sub-hemispherical, with a slightly oblique emarginate antapex. Girdle moderately wide and deep, displaced between two and three girdle widths (about 1/3 the body length). Sulcus present on the epicone, narrow and deflected to the left in the intercingular region, then broadening on the hypocone and indenting the antapex. Flagella not observed.

Chromatophores absent. Nucleus sub-spherical, supra-median, with elongate chromosomal bodies. Many refractive assimilate bodies of varying sizes scattered through the cytoplasm along with several ingested bodies.

Woods Hole region.

Gales Creek: Present in one sample from August at 21°/oo salinity.

The Gales Creek material differed from Hulburt's (1957) description of the species only in the somewhat more broadly elliptical shape, the slightly longer extension of the sulcus onto the epicone, and the absence of a single large brown ingested body.

Gyrodinium katodiniascens sp. nov.
(pl. 9, f. 61 a-c)

Cells moderate-sized, elongate-ovoid, epicone 1 1/2 to 2 times as long as hypocone. Length 12-20μ, width 5-7μ. Epicone conical with rounded apex and convex sides; hypocone hemispherical with obliquely flattened or emarginate antapex. Girdle narrow and deep, displaced 3 girdle widths (from 1/4 to 1/3 the body length); sulcus narrow, extending onto the epicone, curving slightly to the left in the intercingular region, becoming shallower as it extends to the antapex. Transverse flagellum not seen; longitudinal flagellum 2/3 to 3/4 the body length. Surface striations absent.

Chromatophores absent. Nucleus not seen. A refractive spherical assimilate body is often present in the hypocone.

Gales Creek: Present in three samples from May and October; 21 to over 30°/oo salinity.

The shape and form of this organism is rather like *Katodinium glaucum* (Lebour) Fott (1957) (see Schiller, 1933, under *Massartia*) but is less than half the size, lacks surface striations, and has a proportionally shorter epicone. In some of these specimens the girdle was positioned far enough posteriorly to suggest placement in

Katodinium, demonstrating the artificiality of separating this genus only on the basis of the hypocone length being less than 1/5 the length of the epicone.

Gyrodinium pellucidum (Wulff) Martin
(pl. 9, f. 62 a-d; pl. 27, f. 1-2)

Gymnodinium pellucidum Wulff, 1916, p. 107, pl. 1, f. 2a, b. *Gyrodinium pellucidum* (Wulff) Martin, 1929, p. 17, pl. 1, f. 12-21. *Gyrodinium pellucidum* (Wulff) Schiller, 1933, p. 490, f. 521.

Cells large, broadly fusiform, circular to elliptical in cross-section, up to twice as long as broad, epicone and hypocone sub-equal. Length 20-31-(49)μ, width 12-22-(30)μ. Epicone broadly to narrowly conate with rounded apex and straight or convex sloping sides; hypocone conate to subhemispherical with rounded to obliquely truncate antapex and convex sides. Surface striations absent. Girdle moderately deep and wide, displaced 1/5 to 1/3 the body length; sulcus straight or only slightly deflected in the intercingular area, projecting half way or more up the epicone, extending to the posterior margin of the hypocone on left side of the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum about equal to the cell length.

Chromatophores absent. Cytoplasm often somewhat foamy or granular. Nucleus spherical, central, chromosomal bodies visible. Large ingested bodies usually present basally, other assimilate granules scattered through the cytoplasm.

Barents Sea; Barnegat Bay.

Gales Creek: Absence of longitudinal body striations, the feature which readily separates this organism from the following species, *Gyrodinium dominans*, could not be determined at the low magnifications used for cell counts, so the following data encompasses both species: Present from April to November with abundance in August and September, up to 108 cells/ml; euryhaline, from 4 to 32°/oo salinity; observed in 136 samples.

These cells are generally somewhat more broadly fusiform than those of *Gyrodinium dominans* Hulburt (1957), and may be distorted in shape when large amounts of material have been ingested, when often the posterior portion of the cell will be more rounded than conical. In Martin's (1929) material, also doubtfully referred to this species, girdle displacement was greater, varying from 1/3 to over 1/2 body length.

Gyrodinium dominans Hulburt
(pl. 10, f. 63 a-b; pl. 27, f. 3-4)

Gyrodinium dominans Hulburt, 1957, p. 212, pl. 3, f. 1-3.

Cells moderate-sized to large, fusiform, circular in cross-section, epicone somewhat shorter than hypocone. Length (13)-18-31-(40)μ, width 9-16-(20)μ. Epicone conate with rounded apex and straight or rounded sloping sides; hypocone conate with rounded to very obliquely flattened antapex and straight of curved sloping sides. Surface with longitudinal striations extending from apex to antapex, with 7 to 10 striations across the ventral face. Girdle moderately deep and wide, displaced 2 1/2-4 girdle widths (1/4-1/3 body length), overlapping about one girdle width, sometimes with slightly flaring margins; sulcus sigmoid, extending halfway up the epicone, deflected to the cell's left as it descends the intercingular region, extending to the posterior left margin of the hypocone. Transverse flagellum completely encircling the body; longitudinal flagellum 1/2 to equal the body length.

Chromatophores absent. Nucleus spherical, slightly anterior to slightly posterior of center, with elongate chromosomal bodies. Large ingested bodies usually present in the hypocone.

Woods Hole area.

Gales Creek: The distinguishing feature--presence of longitudinal body striations--which separates this species from cells referred to *Gyrodinium pellucidum* was not observable at the low magnifications used for cell counts of these species, so the following data is for the two species together: Present from April to November with abundance in

August and September, up to 108 cells/ml; euryhaline, from 4 to 32°/oo salinity; observed in 136 samples.

Gyrodinium dominans differs from *G. pingue* Schutt (see Schiller, 1933), *G. obtusum* Schutt (see Schiller, 1933), and *G. fissum* Kofoid & Swezy (1921) chiefly in the flexure of the sulcus, which is 1/4 the body width in *G. dominans* but comparatively straight in the other three. *G. pellucidum*, described above, not only has a straighter sulcus, but also lacks the longitudinal striations on the body.

Gyrodinium grossestriatum sp. nov.
(pl. 10, f. 64 a-c)

Cells large, body fusiform, circular in cross-section, epicone shorter than hypocone. Length 25-26μ, width 14-15μ. Epicone conate with acutely rounded apex and slightly convex sides; hypocone similar but longer. Surface with about 11 strong longitudinal striations, actually narrow ridges, extending from apex to antapex, with five visible across the ventral surface. Girdle moderately wide and deep, displaced 3 girdle widths (about 1/4 the body length) and overlapping approximately 2 girdle widths; sulcus sigmoid and narrow, extending onto the epicone, deflected strongly to the left in the intercingular region, then becoming more shallow and continuing to the flattened left side of the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum 1/2 to 2/3 the body length.

Chromatophores absent. Nucleus spherical, varying in position within the middle third of the body, with elongate chromosomal bodies visible. Ingested bodies and assimilate granules present posteriorly.

Gales Creek: Present in 3 samples from June and October; from 21 to 27°/oo salinity.

This species is very similar to *Gyrodinium dominans* Hulburt (1957) but differs in the stronger flexure of the sulcus and the fewer heavier longitudinal striations which are observable even with lower power magnifications.

Gyrodinium sp. "a"
(pl. 10, f. 65 a-b)

Cells moderate in size, body broadly fusiform with truncate antapex, epicone and hypocone sub-equal. Length 15-18μ, width 11-15μ. Epicone conical with straight or slightly convex sloping sides and rounded or sometimes flattened apex; hypocone trapezoidal with sides similar to the epicone, flattened antapex. Girdle wide and moderately deep, displaced 1 1/2 girdle widths (1/4-1/5 body length); sulcus broad and shallow, absent from the epicone, proceeding straight to the flattened antapex. Transverse flagellum encircling 1/2 the body circumference; longitudinal flagellum slightly longer than the cell length.

Chromatophores absent. Nucleus large, elliptical, filling the left side of the hypocone, short chromosomal bodies visible. Various sizes of assimilate bodies present through the cytoplasm.

Gales Creek: Present in two May samples; 8 and 25°/oo salinity.

This species is similar in form to *Gymnodinium minor* Lebour (1917) but is smaller, has a wider girdle with greater displacement, and a non-central nucleus.

Gyrodinium sp. "b"
(pl. 10, f. 66)

Cells large, body broadly fusiform with acutely rounded ends, epicone and hypocone sub-equal. Length 29μ, width 24μ. Epicone conical with slightly convex sides; hypocone similar. Surface striations absent. Girdle wide and moderately deep, displaced almost three girdle widths (almost 1/2 the body length). Sulcus narrow and straight, extending from near the apex to near the antapex. Flagella not observed.

Chromatophores absent. Nucleus large and elliptical, supramedian, with elongate chromosomal bodies.

Gales Creek: Present in one November sample, 33°/oo salinity.

The girdle in this form is two to three times as wide as those found in the cells identified as *Gyrodinium pellucidum*, described above, but other characteristics are very similar.

Gyrodinium sp. "c"
(pl. 10, f. 67 a-b)

Cells large, body elliptical to elongately sub-pentagonal, dorsiventrally compressed, elliptical in cross-section, with a short antapical tentacular lobe. Length 30μ, width 20μ, thickness 15μ. Epicone sub-hemispherical to broadly sub-conical with rounded apex, shorter than hypocone; hypocone sub-trapezoidal with straight tapering sides and a very broadly rounded antapex interrupted in the middle by an extension of the left posterior margin of the sulcus into a short pointed tentacular lobe, 8μ x 4μ, deflected to the right. Surface striations absent. Girdle supra-median, deep and moderately wide, deflected slightly more than two girdle widths (1/5 the body length); sulcus sigmoid, extending onto the epicone, deflected somewhat to the left in the intercingular area, continuing posteriorly to be overlapped by the left sulcal margin's antapical lobe. Flagella not observed.

Chromatophores absent. Nucleus large, spherical, central, with short chromosomal bodies. Ingested and assimilate bodies present.

Gales Creek: Present in a single September sample with 25°/oo salinity.

The only other *Gyrodinium* with a similar form is *G. wulffii* Schiller (1933), but its antapical lobe is formed from the right posterior margin of the sulcus, and this larger species also differs in having surface striations and a larger girdle displacement.

Gyrodinium sp. "d"
(pl. 10, f. 68)

Cells moderate sized, body elliptical, dorsiventrally compressed, with obliquely emarginate antapex. Length 16-22μ, width 13.5-15μ,

thickness 10μ. Epicone hemispherical to broadly conical with rounded apex; hypocone sub-trapezoidal with convex margins and emarginate antapex. Girdle moderately wide and deep, displaced 2 girdle widths (1/4-1/5 body length); sulcus shallow and faint, extending onto the epicone, deflected only slightly to the left in the intercingular area, descending to the antapex. Transverse falgella not seen; longidudinal flagellum less than 1 1/2 times cell length.

Chromatophores absent. Cytoplasm granular. Nucleus elliptical, sub-central, short chromosomal bodies visible. Various assimilate granules scattered through the cytoplasm.

Gales Creek: Present in 5 samples from May and one from July; 1 to 22°/oo salinity.

Gyrodinium sp. "e"
(pl. 10, f. 69)

Cells moderate sized, body broadly elliptical to sub-pentagonal, dorsiventrally compressed, epicone somewhat smaller than hypocone. Length 15-22μ, width 14-18μ. Epicone broadly subconical with rounded apex; hypocone sub-quadrangular with a broadly emarginate antapex. Girdle moderately wide and shallow, displaced 2 girdle widths (1/5 the body length); sulcus extending onto the epicone as a thin shallow groove, narrow and straight in the intercingular region, becoming more shallow and broad as it descends to the emarginate antapex. Transverse flagellum inserted in a deep flagellar pit, only partially encircling the cell; longitudinal flagellum not observed.

Chromatophores absent. Cytoplasm finely granular. Nucleus large, elliptical, mostly within the epicone, with short chromosomal bodies visible. Various assimilate bodies present posteriorly.

Gales Creek: Observed in 3 samples from October and November; from 23 to 32°/oo salinity.

Gyrodinium sp. "f"
(pl. 10, f. 70 a-b)

Cells of moderate size, body elongate-elliptical, compressed dorsiventrally, outline sometimes asymmetrical, epicone smaller than hypocone. Length 17-22μ, width 10-18μ. Epicone hemispherical to sub-conical with broadly rounded apex; hypocone sub-trapezoidal, with flattened to shallowly emarginate antapex. Girdle moderately wide and deep, displaced two girdle widths (1/5 the body length); sulcus a narrow groove on the epicone, moderately wide and slightly deflected to the left in the intercingular region, descending the middle of the hypocone to a flattened antapex. Transverse flagellum partially encircling the cell; longitudinal flagellum less than cell length.

Chromatophores absent. Cytoplasm granular. Nucleus not observed.

Gales Creek: Present from May to July; from 18 to 27°/oo salinity; observed in 7 samples.

Gyrodinium sp. "g"
(pl. 10, f. 71 a-c)

Cells moderate in size, body strongly compressed laterally, in ventral view fusiform with acutely rounded apex and antapex, epicone and hypocone sub-equal. Length 15-22μ, width 10-15μ, thickness 15-22μ. Epicone in lateral view hemispherical; hypocone in lateral view sub-rectangular with the ventral side drawn down in a rounded antapical lobe. Girdle narrow and moderately deep, displaced 2 to 3 girdle widths (1/3-1/4 the body length), both ends curved posteriorly before joining the sulcus; sulcus slightly sigmoid, narrow and extending partly up the curved ventral surface of the epicone, broader and deflected one girdle-width to the left in the intercingular region, narrowing and extending down the straight ventral surface of the posterior lobe almost to the antapex. Falgella not observed.

Chromatophores absent. Nucleus not seen. Ingested bodies present posteriorly.

Gales Creek: Present in two October samples from 19 to 24°/oo salinity.

The distinctive shape of this *Gymnodinium* species is apparently unique for the genus.

Polykrikos hartmanni Zimmermann
(pl. 11, f. 72; pl. 27, f. 5)

Polykrikos hartmanni Zimmermann, 1930, p. 436, f. 8-9; Schiller, 1933, p. 548, f. 577; Hulburt, 1957, p. 215, pl. 4, f. 7.

Cell a colony, cylindrical, circular in cross-section, with broadly rounded ends, composed of two very large zooids delimited by a slight constriction. Length 75μ, width 43μ. Epicones and hypocones sub-equal. Girdles two, wide, moderately shallow, displaced about two girdle-widths; sulcus narrow, extending onto the anterior epicone, descending in a series of sigmoid curves to the posterior hypocone where it creates a slight antapical depression. Transverse flagella two, incompletely encircling zooids; longitudinal flagella not observed.

Chromatophores numerous, small, elliptical, yellow-brown. Nuclei two, one in each zooid, with very elongate chromosomal bodies visible. Numerous black granules scattered through cytoplasm, concentrated in the posterior portion. Nematocysts not observed.

Adriatic Sea; Woods Hole area.

Gales Creek: Present in 3 samples from October and one from April; from 23 to 27°/oo salinity.

Polykrikos kofoidi Chatton
(pl. 11, f. 73 a-c; pl. 27, f. 6-7)

Polykrikos kofoidi Chatton, 1914, p. 161; Martin, 1929, p. 19, pl. 4, f. 3, 4; Schiller, 1933, p. 549, f. 578.

Cell a colony, cylindrical with broadly rounded anterior and truncate posterior, consisting of two or four very large zooids, each delimited by a slight constriction. Four-zooid colony length 75-116μ, width 40-59μ; two-zooid colony length 49μ, width 20-40μ. Epicones and

hypocones equal except in the anterior zooid where the epicone may be smaller. Hypocone of each zooid bearing longitudinal ribs. Girdles 2 or 4, wide, moderately deep, displaced two girdle widths; sulcus on each zooid straight, narrowing posteriorly, not present on the hypocone, excavating the antapex of the posterior zooid. Transverse flagella incompletely encircling zooids; longitudinal flagella the length of two zooids.

Chromatophores absent. Cytoplasm unpigmented, granular. Nuclei one for every two zooids, large, spherical, chromosonal bodies visible. Many elongate-ovate nematocysts present, distributed more to the dorsal side of the colony. Many small and moderate-sized granules present along with occasional large ingested bodies.

Pacific Ocean off California; Barnegat Bay, N.J.

Gales Creek: Presence in April from three samples; from 20 to 28°/oo salinity.

Previous descriptions have been of colonies colored greenish gray to pale rose to deep pink, but no pigmentation was observed in the Gales Creek specimens. Colonies of this species may possess 2, 4, 8, or even 16 zooids.

Glenodinium cf. *rotundum* (Lebour) Schiller
(Pl. 11, f. 74 a-b, pl. 28, f. 1)

Glenodinium rotundum (Lebour) Schiller, 1937, p. 107, f. 98, 269. *Peridiniopsis rotunda* Lebour, 1922, p. 804, f. 16, 20; Martin, 1929, p. 24, pl. 2, f. 12-16, pl. 3, f. 34, 35.

Cells large thecate, sub-globose, circular in cross section, epicone and hypocone equal. Length 23-28 μ, width 22-24 μ. Epicone hemispherical to subconate, bearing a minute apical horn; hypocone hemispherical. Girdle central, not displaced, with lists; sulcus extending almost to the antapex, the left margin bearing a wing-like list. Transverse flagellum incompletely encircling the body; longitudinal flagellum equal to the cell length. Thecal plate pattern not observed.

Chromatophores absent. Cytoplasm colorless and slightly granular. Nucleus central to somewhat anterior, bearing elongate chromosomal bodies.

Plymouth Sound; Barnegat Bay, N.J., extremely abundant in plankton; Chesapeake Bay; Pamlico Sound.

Gales Creek: Presence from all seasons; from 1 to 24°/oo salinity; observed in 18 samples.

The thecal plates were too delicate for their outlines to be observed, and the form of these specimens is also like *Glenodinium pilula* Ostenfeld (see Schiller, 1937), but they have been tentatively assigned to *Glenodinium rotundum* because this species has been reported from east coast estuaries in the U. S. (Martin, 1929; Hulburt, 1957; Griffith, 1961).

Glenodinium cf. *lenticula* (Bergh) Schiller
(Pl. 11, f. 75 a-b)

Glenodinium lenticula (Bergh) Schiller, 1937, p. 103, f. 95 a-h.
Diplopsalis lenticula Bergh, 1881, p. 244, f. 60-62; Martin, 1929, p. 23, pl. 4, f. 11-13.

Cells large, thecate, body lenticular, broader than long, elliptical in cross section, epitheca and hypotheca equal; epitheca bearing a short apical horn, hypotheca rounded. Length 27 μ, width 43 μ. Girdle central, not displaced, with prominant lists; sulcus extending almost to the antapex, with the left margin bearing a hyaline list which curves somewhat over the posterior portion of the furrow. Transverse flagellum extending around less than 1/3 the circumference of the cell; longitudinal flagellum shorter than the body length, inserted posterior-ventrally in the sulcus. Thecal plate pattern not observed.

Chromatophores absent. Cytoplasm clear. Large vacuole present. Nucleus not observed.

Barnegat Bay.

Gales Creek: Observed in three winter samples; 11 to 20°/oo salinity.

Though the plate structure was not observed, and it was therefore not possible to say whether these specimens were truly *Glenodinium* and not *Diplopsalis* or *Peridiniopsis*, Schiller (1937) considers these latter two genera to be only a part of *Glenodinium*.

Glenodinium danicum Paulsen
(Pl. 11, f. 76 a-b; pl. 28, f. 2)

Glenodinium danicum Paulsen, 1907, p. 6, f. 2; Martin, 1929, p. 21, pl. 2, f. 11, pl. 3, f. 27-30; Schiller, 1937, p. 111, f. 106.

Cells large, thecate, sub-globose to sub-pentagonal, slightly compressed dorsiventrally, elliptical in cross section, epicone and hypocone sub-equal. Length 20-28 μ, width 16-27 μ. Epicone hemispherical to sub-conate; hypocone sub-trapezoidal with truncate or slightly emarginate antapex. Gridle sub-central, wide and shallow, displaced 1/2 girdle width; sulcul shallow, broad, often difficult to discern, not present on the epicone, extending to near the antapex. Transverse flagellum completely encircling the body; longitudinal flagellum about equal to body length. Pattern of thecal plates not observed.

Chromatophores many, elliptical, yellow-brown, peripheral. Stigma red, adjacent to the anterior end of the sulcus, composed of one or two elongate granules. Nucleus central spherical, with short chromosomal bodies visible.

Plymouth Sound; Barnegat Bay, very common; Chesapeake Bay.

Gales Creek: Present from February to April in six samples; from 6 to 29°/oo salinity.

Very similar to this species is a smaller unthecate form newly described from Gales Creek, *Gymnodinium danicans* sp. nov.

Glenodinium obliquum Pouchet
(Pl. 11, f. 77a-c; pl. 28, f. 3-4)

Glenodinium obliquum Pouchet, 1883, p. 444, pl. 20 & 21, f. 37a-e; Schiller, 1937, p. 102, f. 92, (not Pouchet's illustration). Cf.

Coolia monotis Meunier, 1919, pl. 19, f. 13-19; Balech, 1956, p. 47-52, f. 53-66; *Ostreopsis monotis* (Meunier) Lindemann, 1928, p. 97; Schiller, 1937, p. 472, f. 542.

Cells large, thecate, elliptical in ventral view, round in apical view, appearing sub-quadrangular in lateral view with diagonal girdle. Length 28-30 μ, diameter 33-38 μ. Epitheca over twice as broad as tall, rounded, dorsal contour steep but ventral contour gently sloping; hypotheca with same appearance but with antapex closer to the ventral side. Thecal plate pattern not observed. Girdle moderately wide and deep, with ends turned down to join the sulcus; sulcus short, broad, rounded, displaced somewhat to the right. Transverse flagellum completely encircling the cell; longitudinal flagellum length equal to body width.

Chromatophores numerous, brown, elliptical but of varying size. Nucleus not observed. Various particles and small granules in the cytoplasm.

Middle coast of France; Brittany; England; Adriatic Sea.

Gales Creek: Present in five samples from March and April; from 18 to 29°/oo salinity.

The illustrations in Schiller (1937) are not from Pouchet's original description, and are views which do not reveal the true form of the organism. The Gales Creek specimens are easily recognized in Pouchet's original illustrations, which also show a large and reniform nucleus lying against the dorsal surface in the epitheca. Pouchet did not observe the plate structure and therefore placed his species in the catch-all genus *Glenodinium*. The plate structure in an otherwise identical species, *Coolia monotis*, was described by Meunier (1919) and further examined by Balech (1956), who considered the plate arrangement so different from *Ostreopsis siamensis* Schmidt that he did not accept Lindemann's placement of Meunier's species in this monotypic genus. *Coolia monotis* and *Glenodinium obliquum* are identical in shape and form even to the peculiar reniform nucleus in the dorsal portion of the epitheca, and are most likely identical species. Thus, if specimens from Pouchet's locality on the middle coast of France should be found with the *Coolia* plate structure, they should then receive the

name *Coolia obliquum* (Pouchet) comb. nov., as Pouchet's name predates Meunier's.

Heterocapsa triquetra (Ehrenberg) Stein
(Pl. 12, f. 78a-d; pl. 28, f. 5-6)

Heterocapsa triquetra (Ehrenberg) Stein, 1883, pl. 3, f. 30-40; Lindemann, 1928, p. 88, f. 75; Conrad & Kufferath, 1953, p. 118, f. 6, pl. 7, f. 4. *Peridinium triquetrum* (Ehrenberg) Lebour, 1925, p. 109, pl. 18, f. 2; Schiller, 1937, p. 145, f. 147. *Glenodinium triquetrum* Ehrenberg (according to Stein).

Cells large, thecate, spindle-shaped, unsymmetrical, with irregular outline. Length 19-30 μ, width 13-19 μ. Epitheca conical, apex acutely rounded to narrowly truncate; hypotheca about same size and shape as epitheca, or slightly smaller, with acute antapex. Girdle equatorial, displaced 1/2 girdle width; sulcus short, extending half way to antapex. Plate formula 4', 2a, 7", 5"', 2"". Transverse flagellum encircling cell; longitudinal flagellum equal to cell length.

Chromatophore appeared to be single, large, with elongate plate-shaped lobes, yellow-brown. Nucleus spherical, large, occupying the epicone, elongate chromosomal bodies visible. Red granules and various assimilate bodies sometimes present in the cytoplasm.

Cosmopolitan neritic and estuarine species on both coasts of the North Atlantic.

Gales Creek: Abundance from February to April, with densities reaching 230 cells/ml; euryhaline, from 0 to 29°/oo salinity; observed in 61 samples.

In the genus *Peridinium* the 1st apical plate extends to the cingulum, but in this species the 1st apical only reaches half that distance. This distinctive character provides a very strong basis for maintaining *Heterocapsa* as a separate genus and not combining it with *Peridinium*. Two other species add much support to this view. Beicheler (1952) describes *Peridinium chattoni*, an ovoid species with the same plate formula as *Heterocapsa triquetra* and a 1st apical plate which also does not reach the cingulum. It obviously should join

Stein's species in this separate genus as *Heterocapsa chattoni* (Beicheler) comb. nov. K.R. Gaarder at the University of Oslo has an undescribed species which she feels also belongs in *Heterocapsa*. It is from Walvis Bay in Southwest Africa and has more plates than the above species, but it has a 1st apical plate which again does not reach the cingulum. This distinctive plate character thus is not peculiar to Stein's species, so his generic intuition appears well founded.

Heterocapsa triquetra is widely distributed in coastal waters, produces resting spores, and may occur in great abundance in waters of very low salinity. It is euryhaline, and has been grown in cultures from 5 to 38°/oo with maximum growth around 15°/oo salinity (Braarud, 1961). It is tolerant to very low temperatures (Braarud, 1962), but has a temperature optimum around 18°C. It tolerates moderate pollution, but is retarded by higher concentrations (Braarud & Pappas, 1951).

Other studies: Fatty acids - Harrington, *et al.* (1970).

Peridinium trochoideum (Stein) Lemmermann
(Pl. 12, f. 79 a-b)

Peridinium trochoideum (Stein) Lemmermann, 1910, p. 673, f. 14-17; Martin, 1929, p. 27, pl. 5, f. 11-12, pl. 7, f. 5-6; Schiller, 1937, p. 137, f. 134. *Glenodinium trochoideum* Stein, 1883, pl. 3, f. 27-29.

Cells large, thecate, broadly ovoid with an apical horn, round in cross section. Length 18-34 µ, width 17-28 µ. Epitheca conical to hemispherical, with apex elongated into a conspicuous horn; hypotheca hemispherical with a slightly flattened antapex, spines absent. Girdle median, wide and shallow, with inconspicuous lists; sulcus broad and shallow on the hypotheca, extending to the flattened antapex. Flagella not observed. Thecal plate arrangement observed only for the ventral surface, as illustrated.

Chromatophores numerous, small, brown, densely packing the cell. Nucleus spherical, central, chromosonal bodies visible.

Widely distributed neritic and estuarine species on both coasts of the North Atlantic in the middle and low latitudes.

Gales Creek: Presence from mid-winter through spring, with high frequency in early spring; euryhaline, from 9 to 29°/oo salinity; observed in 36 samples and 1 plankton tow.

This species is identical in form, size, and thecal plate arrangement to *Scrippsiella sweeneyi* Balech (1959), but differs in the number of plates in the cingulum and sulcus. These plates were not observed in the Gales Creek material, so identification is tentative.

Peridinium trochoideum is widely distributed in coastal waters, but does not thrive in lowest salinities or coldest waters (Braarud, 1962). Salinity studies showed growth in cultures from 5 to over 40°/oo with a maximum around 20°/oo (Braarud, 1961). The species produces calcareous resting spores, spherical cysts bearing blunt pointed or capitate calcite spines (Wall, *et al.*, 1970).

Other studies: Pigments - Whittle & Casselton (1968); Riley & Segar (1969). Phototaxis - Halldal (1958); Bendix (1960). Excreted carbon - Hellebust (1965). Chromosome number - Dodge (1963c); Godward (1966). Intracellular bacteria - Silva (1962b). Fatty acids - Chuecas & Riley (1969); Harrington, *et al.* (1970).

Peridinium aciculiferum Lemmermann
(Pl. 12, f. 80 a-e; pl. 28, f. 7-9)

Peridinium aciculiferum Lemmermann, 1900, p. 28; 1910, p. 667, f. 25-27; Schiller, 1937, p. 162, f. 160; Whitford & Schumacher, 1969, p. 122, pl. 59, f. 10. *Peridinium urbonatum* var. *aciculiferum* Lemmermann, 1908, p. 181.

Cells large, thecate, broadly ovoid with apical horn, compressed dorsiventrally, elliptical to reniform in cross section. Length 16-38 μ, width 13-30 μ, thickness 12-27 μ. Epitheca conate to hemispherical, elongated into an apical horn; hypotheca angularly hemispherical, bearing three to seven short spines posteriorly, with some spines in pairs. Girdle submedian, wide and shallow, not displaced, with narrow lists supported by delicate spines; sulcus shallow, wide, extending to the antapex. Flagella not seen. Only the hypotheca plate arrangement was observed, as illustrated.

Chromatophores 6 to numerous, elliptical, brownish-yellow, peripheral. One or several large red stigmatic granules present along the ventral midline. Nucleus spherical, central.

A typical winter form from the cooler parts of Europe, also British Columbia, most common at cool seasons, but also occurring in water above 20°C and in summer in North Carolina.

Gales Creek: Presence from June to November; euryhaline, from 4 to 31°/oo salinity; observed in 23 samples.

The Gales Creek specimens were smaller than the published size range for this species (35-50μ by 32-40μ), had more posterior spines than the published number of 3-4, and possessed ventral red stigmatic bodies previously not mentioned. Though the species is described as a typical winter form from cooler waters, Whitford & Schumacher have found specimens in waters above 20°C and in summer, as has also been the case for the Gales Creek material. These differences of the North Carolina material from the species suggests a possible varietal status, so I would like to propose the name *Peridinium aciculiferum* var. *tepidum* var. nov. for this smaller warm water form.

Peridinium cf. *brevipes* Paulsen
(Pl. 12, f. 81)

Peridinium brevipes Paulsen, 1908, p. 108, f. 151; Martin, 1929, p. 29, pl. 7, f. 8-10; Schiller, 1937, p. 200, f. 195.

Cells large, thecate, broadly ovoid, round in cross section. Length (19)-23-34 μ, width (18)-20-33 μ. Epitheca conate to hemispherical with truncate to slightly emarginate antapex, sometimes bearing two small posterior spines. Girdle median, wide and shallow, with inconspicuous lists; sulcus shallow and wide, extending posteriorly to flatten or slightly excavate the antapex. Thecal plates and flagella not observed.

Chromatophores absent. Cytoplasm gray and foamy, sometimes with a faintly brown coloration. Nucleus very large, ellipsoidal, in the hypotheca. No assimilate bodies observed.

Cosmopolitan estuarine, neritic and oceanic species from cold and warm waters of both hemispheres.

Gales Creek: Scattered presence from all seasons, numerous with high frequency in early spring; from 9 to 29°/oo salinity; observed in 39 live and 19 preserved samples.

The Gales Creek material agrees in size and shape with this variable species except for being slightly narrower than the usual case, but the assignment of these forms to this species is tentative as the arrangement of the thecal plates has not been observed.

Peridinium pentagonum Gran
(Pl. 12, f. 82 a-d)

Peridinium pentagonum Gran, 1902, p. 185, 190, f. 15; Schiller, 1937, p. 241, f. 242.

Cells gigantic, thecate, body broader than long, pentagonal in ventral view, dorsiventrally compressed to a thickness 2/3 body width, rhomboid in lateral view, reniform in apical view with a concave ventral surface, apex narrowly rounded, antapex emarginate with two short lateral horns. Length 68-94 μ, width 75-113 μ. Epitheca broadly conical with straight or slightly convex sides; hypotheca trapezoidal with straight tapering sides ending in two stubby lateral lobes each bearing a short strong spine. Girdle central, moderately wide and shallow, displaced 1/2 to 1 1/2 girdle widths, with narrow thin lists supported by numerous spines; sulcus shallow, broadly spatulate on the hypotheca and with a short extension onto the epitheca. Flagella not observed. Only the ventral thecal plate arrangement was seen, as illustrated.

Chromatophores and any pigmentation absent. Nucleus elliptical, in the epitheca. Many refractive assimilate globules present.

A widely distributed estuarine and neritic euryhaline and eurythermal species.

Gales Creek: Present in September and October; from 23 to 29°/oo salinity; observed in 4 live samples and 2 plankton tows.

Studies: Bioluminescence - Tett (1971).

Peridinium excavatum Martin
(Pl. 12, f. 83 a-c)

Peridinium excavatum Martin, 1929, p. 28, pl. 5, f. 8-10.

Cells very large, thecate, body as long as broad, compressed dorsiventrally, reniform in cross section, pentagonal in ventral view with concave sides, antapex deeply cleft with two strong lateral horns. Length 68 µ, width 68 µ, thickness 34 µ. Epitheca conical with concave sides and narrowly rounded apex; hypotheca with strongly concave sides, ending in two conspicuous lateral horns each tipped by a strong spine. Girdle median, wide and deep, not displaced, tilted to the main axis of the cell with the dorsal portion more anterior, with broad thin lists supported by spines; sulcus wide and deep, creating a deep excavation on the ventral surface and between the lateral horns. Plate formula; 4', 3a, 7", 5"', 2"". No internal structure or flagella observed.

Barnegat Bay, N. J.

Gales Creek: Present from August to October; polyhaline, from 20 to 29°/oo salinity; observed in 6 live samples and 2 plankton tows.

This species has the same general shape and form as *Peridinium leonis* Pavillard (1916) (see Schiller, 1937) as well as the same plate arrangement, but according to Martin (1929) it differs in the greater divergence of the posterior horns, the more conspicuously concave sides, and pink color. The Gales Creek specimens lacked any pigmentation, however, and the variation found within *P. leonis*, under which Schiller has placed two varieties, is such that the other characteristics separating *P. excavatum* from it would be of importance only on a subspecific level. Accordingly, a new combination should be erected for this organism: *Peridinium leonis* var. *excavatum* (Martin) comb. nov.

Goniaulax diacantha (Meunier) Schiller
(Pl. 13, f. 84 a-e; pl. 28, f. 10-12)

Goniaulax diacantha (Meunier) Schiller, 1937, p. 300, f. 309; Conrad & Kufferath, 1954, p. 122, pl. 3, f. 1. *Amplax diacantha* Meunier, 1919, p. 74, pl. 19, f. 33-36.

Cells large, thecate, angularly ovoid with truncate antapex, very much compressed dorsiventrally, with dorsal surface convex and ventral surface flattened or concave. Length 25-43 µ, width 17-35 µ, thickness 12-25 µ. Epitheca compressed-conical with sloping sides slightly convex to slightly concave, apex elongated into a blunt horn broken at the tip into short spines; hypotheca subtrapezoidal in ventral view with a somewhat oblique slightly emarginate antapex, and both posterior lobes ending in a winged spine, up to 5 µ long, with the left spine usually the longer. Thecal plates smooth to delicately reticulate; formula 3', 3a, 6", 6"', 1p, 1a. Girdle sub-equatorial, moderately deep and wide, displaced almost one girdle width, with narrow lists supported by numerous delicate spines; sulcus concave and broadening posteriorly to indent the antapex. Transverse flagellum not completely encircling cell; longitudinal flagellum equal to body length.

Chromatophores many, yellow-brown, elongate and appearing to radiate from the center of the cell. Nucleus elliptical, located in the left side of the hypotheca, containing elongated chromosomal bodies. One or more orange granules sometimes present posterior-ventrally.

Brackish water in Belgium, also Straits of Florida and Caribbean Sea.

Gales Creek: Scattered presence from all seasons, strong presence from November to January; euryhaline, from 2 to 35°/oo salinity; observed in 38 samples.

Studies: Cultures - Silva (1962a).

Goniaulax spinifera (Clap. & Lach.) Diesing
(Pl. 13, f. 85 a-b)

Goniaulax spinifera (Clap. & Lach.) Diesing, 1866, p. 96; Schiller, 1937, p. 297, f. 305a-n. *Peridinium spiniferum* Claparède & Lachmann, 1859, p. 405, pl. 20, f. 4-5.

Cells large, thecate, globular to broadly ovoid, round in cross section. Length 33 µ, width 29 µ. Epitheca conate to sub-hemispherical, with a short apical horn; hypotheca hemispherical, antapex slightly truncate. Girdle median, moderately wide and deep, displaced almost 2 girdle widths (1/4 body length), overlapping 1/2 girdle width; sulcus narrow and deflected to the left in the intercingular area, broadening as it descends to flatten the antapex, basal winged sulcal list giving appearance of an antapical spine. Flagella, chromatophores and other internal structures not observed. Thecal plate formula: 3', 0a, 6", 6"', 1p, 1"".

A cosmopolitan inter-oceanic, neritic and estuarine species.

Gales Creek: Present in one preserved plankton tow from June.

Though normally possessing two or more antapical spines, this species is quite variable and the spines may sometimes be reduced or absent. Presence of chromatophores is mentioned in some literature, though detailed studies usually have involved only the empty thecae.

Studies: Cultures - Silva (1962b). Bioluminescence - Tett (1971).

Goniaulax ? scrippsae Kofoid

(Pl. 13, f. 86 a-b)

Goniaulax scrippsae Kofoid, 1911, p. 228, pl. 13, f. 26-27; Schiller, 1937, p. 295, f. 303.

Cells large, thecate, body globular, compressed dorsiventrally, elliptical in cross section. Length 27-28 µ, width 23-26 µ, thickness 20 µ. Epitheca hemispherical, with short apical horn; hypotheca hemispherical with somewhat flattened antapex, no spines present. Girdle median, wide and moderately deep, displaced 2 1/2 girdle-widths (over 1/3 body length) and overlapping 2 girdle-widths; sulcus absent from the epitheca, strongly deflected to the left in descending the intercingular region, then broadening onto the hypotheca. Longitudinal flagellum equal to cell length; transverse flagellum and thecal plates not observed.

Chromatophores 10-15 irregularly elliptical yellow-brown bodies. Nucleus elliptical, basal, chromosomal bodies visible.

From Atlantic, Pacific and Indian Oceans, Mediterranean and Caribbean Seas.

Gales Creek: Observed in 3 samples from April and September; 19 to 23°/oo salinity.

The tentative placement of the Cales Creek specimens in this species, without having observed the plate arrangement, is based on the similarity to Kofoid's (1911) description of the general shape, girdle displacement and overlap, and absence of antapical spines. This and seven similar species are considered by Taylor (1962) to be a single-species complex with *G. polygramma* Stein the earliest described species in the group.

Goniaulax longicornu sp. nov.
(Pl. 13, f. 87 a-b; pl. 29, f. 1-2)

Cells large, thecate, broadly elliptical with a very long apical horn and shorter antapical spines, body slightly compressed dorsi-ventrally, elliptical in cross section. Length including spines 37-49 µ, width 19-27 µ. Epitheca broadly conate, with a long tapering apical horn around 12 µ in length (over 1/2 the main body length); hypotheca sub-hemispherical, with an obliquely truncate antapex bearing a delicate short left and longer right antapical spine, the latter around 6 µ long. Girdle supra-median, wide and moderately deep, displaced 1 1/2 girdle widths, bearing narrow lists; sulcus wide and shallow, straight, extending onto the epitheca, constricted in the intercingular region, flattening the antapex. Thecal plates and flagella not observed.

Chromatophores absent. Cytoplasm foamy. Nucleus large, elliptical, central, with elongate chromosomal bodies.

Gales Creek: Present in early spring; 20 to 27°/oo salinity; observed in 4 samples.

Without being able to observe the plate structure, the placement of this organism in *Goniaulax* is tentative, based on the large girdle displacement. *Goniaulax triacantha* Jörgensen (1899) (see Kofoid, 1911) is similar in shape and long apical horn, but contains many brown chromatophores.

? Goniaulax sp.
(Pl. 13, f. 88 a-b)

Cells large, thecate, body elongate-ovoid, dorsiventrally compressed with the dorsal surface more convex than the ventral. Length 21-38 μ, width 15-22 μ. Epitheca conical with convex or straight margins tapering towards the rounded apex; hypotheca hemispherical. The plate arrangement was not observable but the thecal surface was sometimes rugose. Girdle slightly supra-median, wide and shallow, displaced 2 girdle widths (1/4 the body length), but with margins very difficult to discern. Sulcus wide, shallow, sigmoid, with obscure margins extending onto the epitheca, deflected somewhat to the left in the intercingular area, then proceeding straight to the antapex. Transverse flagellum encircling half the body circumference; longitudinal flagellum slightly longer than the body length.

Chromatophores brown to yellow-borwn, diffuse, filling both epitheca and hypotheca. Nucleus large, spherical, central. Red granules and other bodies sometimes present.

Gales Creek: Present in April; observed in 2 samples.

This organism has been tentatively placed in *Goniaulax* because this genus contains thecate species with large girdle displacements. This form is in many ways similar to *Protodinium simplicius* Schiller (1928), also found in the creek during the spring bloom, but which lacks a theca.

(Class Haptophyceae)

Isochrysis aff. *galbana* Parke
(pl. 14, f. 89)

Isochrysis galbana Parke, 1949, p. 264, text-figs. 24-45, pl. 1, f. 4-10.

Cells small, slightly metabolic, elongate-elliptical to cylindrical, circular to elliptical in cross-section, flattened anteriorly, rounded posteriorly. Length 9-12μ, width 5-7μ. Cell surface smooth. Flagella two, equal, slightly longer than the body, inserted anteriorly and extended forward when cell is moving.

Chromatophores two, yellow-brown, elongate and parietal, laterally placed. Stigma not observed. Various sized assimilate globules present.

Described from sea water, England.

Gales Creek: Present in 5 autumn samples; from 24 to 34°/oo salinity.

This identification is tentative because the Gales Creek specimens were twice the size of Parke's material and apparently lacked an eyespot.

Bourrelly (1957) feels that the type species of the genus *Wyssotykia* created by Lemmermann (1899) from Wissotyky's *Ochromonas biciliata* may be synonymous with *Isochrysis*, but that it is better to abandon this old name because the genus is poorly known and incompletely described.

Studies: Excreted carbon--Guillard & Wangersky (1958). Pigments--Riley & Wilson (1967).

Parachrysidalis estuariale Hulburt
(pl. 14, f. 90 a-b)

Parachrysidalis estuariale Hulburt, 1965a, p. 88, pl. 1, f. 24-26.

Cells small, strongly compressed, squarish to ovoid in broad lateral view, reniform in narrow lateral view. Diameter 4-5.5μ, thickness 2.5-3μ. Cell surface smooth. Flagella two, equal, length over 3 times the width of the cell, inserted laterally in the middle of the concave side of the cell.

Chromatophores two, brownish-yellow, parietal. Small assimilate granules sometimes present.

Described from marine waters from the Woods Hole area.

Gales Creek: Present from September to December; from 19 to 34°/oo salinity; observed in 10 samples.

The Gales Creek specimens were somewhat smaller than those described by Hulburt (1965a). This is the type species for the genus, similar to *Erkenia* but with laterally inserted flagella. The figure for Hulburt's description is mistakenly labelled *P. marina*.

Prymnesium parvum Carter
(pl. 14, f. 91 a-d, pl. 29, f. 3-5)

Prymnesium parvum Carter, 1937, p. 40, pl. 3, f. 5-16, pl. 8, f. 16; Hulburt, 1965a, p. 88, pl. 1, f. 1-7.

Cells small, slightly compressed, longer than wide though varying in shape between ovoid, obovoid, elliptical and cylindrical, rounded posteriorly; rounded, flattened, or even emarginate anteriorly. Length 7-12μ, width 4-8μ. Cell surface sometimes revealing a finely beaded cover of delicate scales. Flagella two, equal, slightly longer than the cell, inserted anteriorly but lying back as they undulate, with a short rigid attachment organ--a haptonema--directed anteriorly between the flagella.

Chromatophores two, brown to olive in color, elongate and parietal, often extending the length of the cell. Several refractive assimilate globules normally present.

Described from brackish water in England.

Gales Creek: Present from March to May and October to December; from 17 to 35°/oo salinity; observed in 14 samples, and several cultures.

Some cells were observed to have an inflated posteriority from which radiated what appeared to be many filiform pseudopodia (pl. 14, f. 91d; pl. 29, f. 5). Their appearance was somewhat similar to the radiating basal spines illustrated for *Chrysocampanula spinifera* Fournier (1971), but they were more numerous and of varying lengths.

Studies: Fine structure--Manton & Leedale (1963). Haptonema--Manton (1964a, 1967); Leadbeater (1971). Scale production--Manton (1964c). Toxin--Saunders (1957); Paster, *et al.* (1966; Padilla (1970). Pigments--Riley & Wilson (1967). Excreted carbon--Guillard & Wangersky (1958). Division cycle--Manton (1964c).

Chrysochromulina ? minor Parke & Manton
(pl. 14, f. 92 a-f; pl. 29, f. 6)

Chrysochromulina minor Parke & Manton, in Parke, Manton & Clarke, 1955, p. 594-601, f. 36-44; Manton & Leedale, 1961, p. 520-523 and figs.

Cells minute, sperical to broadly elliptical or obpyriform, anteriorly flattened. Diameter 3-6.5μ. Cell surface appears smooth. Flagella two, equal, length between 2 and 3 times cell diameter, inserted anteriorly with a long attachment organ, or haptonema, equal to flagella length when fully extended, though sometimes shortened, coiled, or contracted into a short hook, directed anteriorly while the flagella lie back and undulate.

Chromatophores two, occasionally single, brownish-yellow to yellow, parietal, laterally positioned. Leucosin body and other assimilate granules present posteriorly.

Described from British coastal waters.

Gales Creek: At magnifications used for counting cells, this organism was not distinguishable from a slightly larger form tentatively classified as *Chrysochromulina kappa* Parke & Manton (see below), so the following data covers both species: Present in all seasons, with greater abundance in April, October, and November where a concentration of 590 cells/ml was attained; euryhaline, from 9 to 36°/oo salinity; observed in 55 samples.

This species is smaller, has relatively longer flagella and haptonema, and yellower chromatophores than the cells identified as *Chrysochromulina kappa* from the creek. The delicate scales of these forms are observable only with the electron microscope, but without such information proper identification in not possible. The Gales Creek specimens are placed here tentatively on the basis of size and morphology, but require further examination.

Chrysochromulina ? kappa Parke & Manton
(pl. 14, f. 93 a-b)

Chrysochromulina kappa Parke & Manton, in Parke, Manton and Clarke, 1955, p. 583-594, f. 1-12; Manton & Leedale, 1961, p. 523-525 and figs.

Cells small, sub-spherical to broadly ellipsoidal, anteriorly flattened. Diameter 5-7μ. Cell surface appears smooth. Two equal flagella and one attachment organ, or haptonema, inserted anteriorly; the flagella 1 1/2 to 2 1/2 times cell diameter in length, the haptonema about equal to the flagella when extended anteriorly but often shortened, coiled, or contracted into a small hook.

Chromatophores two, yellow-brown, lateral and parietal, saucer-shaped. Leucosin body and other assimilate granules present posteriorly.

Described from British coastal waters.

Gales Creek: At magnifications used for counting cells, this organism was not distinguishable from the slightly smaller form tentatively classified as *Chrysochromulina minor* Parke & Manton (see above) so the following data covers both species: Gales Creek: Present in

all seasons, with greater abundance in April, October, and November where a concentration of 590 cells/ml was attained; euryhaline, from 9 to 36°/oo salinity; observed in 55 samples.

The minute scales of *Chrysochromulina kappa* are observable only with the electron microscope, a necessity for proper identification. The smoothness of the cell surface under light microscopy in the Gales Creek material suggested that larger spined scales, as in the very similar *C. brevifilum* Parke & Manton (Parke, Manton & Clarke, 1955), were not present, so based on size and morphology these organisms have been tentatively placed in *C. kappa*, and await further examination.

Chrysochromulina sp.
(pl. 14, f. 94 a-c)

Cells of moderate size, orbicular to elliptical and sometimes obpyriform, rounded posteriorly and flattened to emarginate anteriorly. Diameter 8-14μ. Cell surface appears smooth. Two equal flagella, between 1 1/2 and 2 1/2 times the length of the cell, and one haptonema slightly shorter than the flagella when fully extended anteriorly but sometimes contracted into a short hook, inserted in a shallow anterior depression.

Chromatophores two, sometimes three, yellow-brown, parietal, lateral, saucer-shaped. Various assimilate globules present, including a large basal leucosin body.

Described from British coastal waters.

Gales Creek: Present in autumn and winter; from 27 to 36°/oo salinity; observed in 10 samples.

This organism is similar in form to specimens classified as *Chrysochromulina kappa* Parke & Manton (see above), but is twice as large, with an average cell size between 10-11μ in diameter. For proper identification, the body scales must be observed with an electron microscope. The occasionally observed shallow anterior depression in which the flagella are inserted is like that of *Chrysochromulina polylepis* Manton & Parke (1962), a similar-sized

species which, however, is laterally compressed with the two chromatophores entirely covering the broad sides of the cell.

Hymenomonas carterae (Braarud & Fagerland) Braarud
(pl. 14, f. 95; pl. 30, f. 1-2)

Hymenomonas carterae (Braarud & Fagerland) Braarud, 1954, p. 3; emend. Manton & Peterfi, 1969, p. 14. *Syracosphaera carterae* Braarud & Fagerland, 1946, p. 4, f. a-h. *Cricosphaera carterae* (Braarud & Fagerland) Braarud, 1960, p. 211. *Syracosphaera brandti* Schiller in Carter, 1937, p. 37, text-fig. 3.

Cells moderate in size, ovate to orbicular, covered with small scales. Cell diameter 12-17μ. Scales small elliptical monomorphic coccoliths of the cricolith type measuring about 1.3μ x 2μ. Flagella two, equal, approximately two cell diameters in length.

Chromatophores two, brown, parietal. Various granules present in the cytoplasm, including endogenously developing coccoliths and basal refractive assimilate globules.

Described from brackish water in England; widely distributed, described only from inshore waters.

Gales Creek: Present in all seasons but summer, with higher frequencies in November and December; from 13 to 34°/oo salinity; observed in 25 samples.

The nature of this species' cricoliths is revealed through E. M. work by Braarud, Gaarder, Markali & Nordli (1952). *Aspidiophora viridissima* Sjöstedt (1924, p. 9, f. 19-26), described from brackish coastal waters in Sweden, would appear to be a synonymous species except for its slightly smaller coccoliths, 1μ x 1.5μ in size. If this is within the range of variability of *Hymenomonas carterae* scales, then Sjostedt's name would take priority, since his description predates all others.

Hymenomonas carterae also has a non-motile sedentary phase which exhibits a range of forms including *Chrysonema-*, *Gloeochrysis-*, *Apistonema-* and *Chrysotila*-like stages (Parke, 1961). There is an

alternation of chromosomal generations which corresponds to the morphological alternation, the motile phase being diploid and the non-motile phase haploid (Rayns, 1962).

Other studies: Scale formation--Pienaar (1969a, 1969b); Manton & Leedale (1969). Haptonema--Leadbeater (1971). Pigments--Parsons (1961). Growth--Braarud (1961).

Hymenomonas roseola Stein
(pl. 14, f. 96 a-b; pl. 30, f. 3-4)

Hymenomonas roseola Stein, 1878, pl. 14, f. 1-3; Pascher & Lemmermann, 1913, p. 49, f. 77; Shiller, 1930, p. 237-241, f. 2, 25, 92, 116. 119; Huber-Pestalozzi, 1941, p. 152, f. 209.

Cells moderate in size, laterally compressed, variable in shape from narrowly and broadly elliptical to cordiform, rounded posteriorly, rounded, truncate or emarginate anteriorly; body enveloped by a delicate gelatinous envelope imbedded with very small difficult to observe oval coccoliths. Cell length 16-17μ, width 15-16μ, thickness 9μ. Flagella two, equal, somewhat longer than the cell, inserted in a shallow anterior depression.

Chromatophores two, yellow-brown, large and parietal. A few refractive globules and smaller assimilate granules present, usually posteriorly.

Fresh and brackish waters, Europe.

Gales Creek: Present in April and the end of autumn; 27 to 32°/oo salinity; observed in 4 samples.

Studies: Coccoliths--Braarud (1954). Fine structure--Manton & Peterfi (1969).

In November some smaller, more narrowly elliptical cells, measuring 10μ x 7μ, were observed with some form of barely discernable scales in a thin gelatinous envelope. Though smaller than the minimum size reported by Pascher & Lemmermann (1913) for *H. roseola*, the form of

these specimens, as shown in pl. 14, f. 96c-d and pl. 29, f. 7, suggests some affinity to this species, so they tentatively have been included here.

(Class Chrysophyceae)

Ochromonas cf. *nannos* Skuja
(pl. 15, f. 97 a-b)

Ochromonas nannos Skuja, 1939; Huber-Pestalozzi, 1941, p. 168, f. 223A.

Cells small, elliptical to somewhat lemon-shaped, unsymmetrical, obliquely emarginate anteriorly, rounded posteriorly, dorsal surface more convex than the ventral. Length 5-10μ, width 4-9μ. Cell surface smooth. Flagella two, unequal, inserted in the slight anterior depression; the longer flagellum between 1 and 2 times body length, the shorter flagellum less than half the body length.

Chromatophore single, greenish-yellow to brownish-yellow, bowl-shaped, lying mostly against the dorsal side, bearing a pyrenoid-like bulge on its inner surface. Stigma absent. Various sized assimilate bodies present posteriorly.

Described from Latvia.

Gales Creek: Observed in one November sample and three cultures from spring innocula; 24°/oo salinity.

Ochromonas cf. *variabilis* H. Meyer
(pl. 15, f. 98 a-d)

Ochromonas variabilis H. Meyer, 1897; Pascher & Lemmermann, 1913, p. 55, f. 88; Huber-Pestalozzi, 1941, p. 174, f. 239.

Cells small, slightly metabolic, spherical to broadly ellipsoid, slightly emarginate anteriorly, rounded posteriorly. Diameter 5.5-11μ. Cell surface smooth. Flagella two, unequal, inserted in the anterior

depression; the longer flagellum 1 1/2 to 2 times the cell diameter, the shorter about 1/3 cell diameter.

Chromatophores two, irregularly saucer-shaped, often parietal, yellow-brown. Stigma absent. Assimilate globules normally present posteriorly.

Described from a Swiss lake.

Gales Creek: Observed in 3 autumn samples and one culture from a March innoculum; 29 to 32°/oo salinity.

Ochromonas caroliniana sp. nov.
(pl. 15, f. 99 a-c; pl. 30, f. 9-12)

Cells moderate in size, metabolic, elliptical to pyriform, rounded posteriorly and obliquely truncated anteriorly. Length 11-20μ, width 8-11μ. Cell surface smooth. Flagella two, unequal, inserted in a shallow depression in the middle of the truncate cell anteriority; the longer flagellum 1 to 1 1/2 times body length, the shorter 1/4 to 1/5 body length.

Chromatophore single, yellow to yellow-brown, band-shaped with curled lateral margins and irregular anterior and posterior margins, centered in the anterior portion of the cell. Stigma small, orange, associated with the anterior end of the chromatophore near the flagellar bases. A large basal body of leucosin and smaller refractive assimilate bodies present.

Gales Creek: Observed in 11 samples from spring and autumn, and 2 cultures from March innocula; from 13 to 32°/oo salinity.

The smooth periplast, single small chromatophore with associated stigma, and rounded posteriority easily distinguishes this species from similar-sized ochromonads.

Ochrononas sp.
(pl. 15, f. 100 a-b)

Cells small, body sub-globose, truncate anteriorly. Diameter 11μ. Body contained in a thin refractive pellicle embedded with

innumerable small scales appearing as hyaline punctae in surface view. Flagella two, one longer than the body, the other finer and about 1/3 body length, both inserted in a shallow anterior depression.

Chromatophores yellow-brown, covering most of the cell periphery, apparently 2 or 3 in number. Stigma large, red, elliptical, associated with the anterior end of one of the chromatophores. Assimilate bodies not observed.

Gales Creek: Observed in one sample from November.

Whether there were three single chromatophores or one or two lobed chromatophores was difficult to determine. The refractive and punctate nature of the cell surface in this organism was not due to the presence of many small peripheral fat vacuoles as in *Ochromonas perlata* Doflein, or to warty pustulous structures on the surface found in *O. crenata* Klebs, *O. verruccsa* Skuja, and *O. pinguis* Conrad. The only species with a similar periplast, *O. nasuta* Skvortzow, differs in its normally obovoid to cordiform shape and absence of a stigma. (See Huber-Pestalozzi, 1941, for these species).

Monochrysis lutheri Droop
(pl. 15, f. 101 a-c)

Monochrysis lutheri Droop, 1953, p. 34, f. 14-16.

Cells small, sub-triangular to irregularly discoid, strongly compressed dorsiventrally. Length 5μ, width 4μ, thickness 2.5μ. Cell surface smooth. Flagella two, unequal, inserted in the middle of the concave ventral surface; the longer flagellum 1 to 1 1/2 times body length, easy to observe, normally lying in an arc or sigmoid curve, the shorter flagellum very fine and difficult to see, shorter than body length.

Chromatophores two, olive green, lateral. Stigma large, pale orange, granular, associated with one of the chromatophores near the flagellar bases. Two conspicuous refractive assimilate bodies often present posteriorly.

The species is described from salt pools in Finland from 9 to $33^{o}/oo$ salinity.

Gales Creek: Observed in cultures from an autumn innoculum.

Though originally placed in the Chromulinaceae, the systematic position of this species is uncertain because of its possession of a second short flagellum and, according to Parke & Dixon (1968), an attaching organ which may be structurally similar to the haptothrix in *Pavlova gyrans* Butcher (see below).

Studies: Pigments - Parsons (1961); Riley & Wilson (1967). Excreted carbon - Guillard & Wangersky (1958). Vitamin requirements - Provasoli (1963).

Pavlova gyrans var. *simplex* var. nov.
(Pl. 15, f. 102 a-f; pl. 30, f. 5-8)

Pavlova gyrans Butcher, 1952, p. 183, pl. 2, f. 35-38; Green, 1967, p. 302.

Cells small, metabolic, assuming a variety of shapes including spherical, pyriform, obovoid, ellipsoidal and cylindrical, but normally ovoid and compressed, ventral surface flattened, obliquely truncate anteriorly and narrowly elongated and rounded posteriorly. Length 5-10-(13) µ, width 3-6 µ. Cell surface smooth. Flagella two, unequal, inserted anterior-ventrally; the longer flagellum almost twice body lenght, easy to observe, normally lying forward in a series of sharp sigmoid curves, the shorter flagellum finer and difficult to observe, equal to the width of the cell and normally directed out from the body. A long fine attaching organ, or haptothrix, was observed trailing behind a few specimens.

Chromatophore single, yellow-brown, parietal, extending over all surfaces but the ventral, though not reaching the anterior or posterior ends of the cell. Stigma orange-red, associated with the anterior portion of the chromatophore near the flagellar bases. Many small refractive assimilate bodies present posteriorly.

The species is described from England.

Gales Creek: Presence in spring and autumn with high frequency in April and November; euryhaline, from 2 to 33°/oo salinity; observed in 42 samples.

The shape and size of this organism is that of Butcher's species, but the varietal status is based on the presence of only one chromatophore instead of two, and the definite attachment of the stigma to the anterior tip of the chromatophore.

Pavlova hommersandii sp. nov.
(Pl. 15, f. 103 a-c; pl. 31, f. 1-2)

Cells small, slightly metabolic, elongate-ellipsoidal to fusiform, slightly compressed dorsiventrally, truncate anteriorly in ventral view, narrowly rounded posteriorly. Length 8.5-10 μ, width 4-5 μ. Surface of cell smooth. Flagella two, unequal, inserted in a V-shaped anterior-ventral groove about 1/5 the cell length from the apex; the longer flagellum 2 1/2 times the cell length, normally projected forward in a series of sharp sigmoid curves, the shorter flagellum finer and difficult to observe, about 1/2 cell length, straight and projecting out from the body. The ventral groove is broad and shallow at the anterior end and narrows down to a point in the anterior third of the cell.

Chromatophores appear to be two, yellow-brown, lateral, elongate but not extending to the base or apex of the cell. Stigma absent. Several large and many small refractive assimilate granules present posteriorly.

Gales Creek: Observed in three November samples from 32°/oo.

The flagellar form and insertion are as in *Pavlova gyrans* Butcher (1952), the type species for the genus, but distinguishing features are the V-shaped anterior-ventral groove, longer anterior flagellum, and absence of a stigma.

Dinobryon sertularia Ehrenberg
(Pl. 15, f. 104 a-b)

Dinobryon sertularia Ehrenberg, 1835, p. 280; Pascher & Lemmermann, 1913, p. 72, f. 114; Alhstrom, 1937, p. 149, pl. 2, f. 1-16; Prescott, 1962, p. 378, pl. 98, f. 10; Whitford & Schumacher, 1969, p. 98, pl. 44, f. 25.

Cells medium sized, loricate, solitary or forming small colonies. Cells within loricas obovoid to ellipitcal, 10-16 μ long, 6.5-8 μ wide. Lorica elongate-campanulate with smooth lateral margins, a blunt-pointed acute posterior, a swollen central portion, a slightly narrower anterior region, and a wide flaring mouth. Lorica length 30-35 μ, width 7-10 μ. Flagella two, unequal, inserted apically, one very short and the other almost as long as the lorica.

Chromatophores two, yellow-brown, elongate parietal plates. An anterior orange stigma and posterior leucosin globule present.

Common in the plankton of hard water lakes.

Gales Creek: Present in two February samples; oligohaline, from 0 to 3.5°/oo salinity, introduced into the estuary with the fresh-water runoff.

Studies: Fine structure - Wujek (1969).

Chrysodidymus gracilis Prowse
(Pl. 15, f. 105 a-b)

Chrysodidymus gracilis Prowse, 1962, p. 128, pl. 4, f. m.

Cells large, covered with scales, body round in cross section, narrowly truncate anteriorly, rounded posteriorly. Length 32 μ, width 13 μ. Flagella two, unequal but both longer than the body, heterodynamic, the shorter flagellum straight and the longer undulating, inserted in a shallow anterior depression. Body covered with moderately large scales whose anterior margins appear to overlap the scales adjacently above.

Chromatophores two (?), yellow-brown, parietal, extending to both ends of the cell. Few assimilate granules present.

Described from acid swamps in Malaya.

Gales Creek: Present in one July sample at 27°/oo salinity.

The imbricate appearance of the scales may be due to the presence of a short anterior spine on each scale as is found in species of *Synura*. Prowse's (1962) description of this species was of bi-celled colonies, the two cells joined basally with apices 180° apart.

Mallomonopsis elliptica Matwienko
(Pl. 16, f. 106 a-b; pl. 31, f. 3-5)

Mallomonopsis elliptica Matwienko, 1941, p. 42, f. 2; 1954, p. 153, pl. 47, f. 4-7; Ettl, 1960, p. 511, pl. 80, f. h-j; Harris, 1966, p. 176, f. 1-6, pl. 1, f. 1-6.

Cells large, covered with spine-bearing scales, body narrowly obovoid, round in cross section, somewhat obliquely flattened anteriorly, acutely rounded posteriorly. Length 30 μ, width 15 μ. Flagella two, sub-equal, as long as the body, one straight and the other undulating, inserted in a shallow anterior depression. Body covered with large flat sub-circular imbricated scales, each 3 μ in diameter and bearing a long thin 5-10 μ spine projecting away from the body.

Chromatophore appears to be single, yellow-brown, parietal and extensive, absent only from the posterior tip of the cell. Stigma absent.

Ivory Coast; Czechoslovakia; England, fresh water ponds.

Gales Creek: Present in one November sample from 32°/oo salinity.

The general form of this species is similar to *Mallomonas caudata* Iwanoff and *Mallomonas mirabilis* Conrad (see Huber-Pestalozzi, 1941), but is smaller, has two flagella and shorter spines.

Belcher (1969) has observed the presence of a very slender reduced second flagellum in two species of *Mallomonas*. This discovery would confine the genus *Mallomonopsis* to those species with a robust second flagellum approaching the first in thickness. Belcher does not consider this a strong enough generic character, for he proposes that the newer genus *Mallomonopsis* be dropped.

Synura uvella Ehrenberg
(Pl. 16, f. 107 a-b; pl. 31, f. 6)

Synura uvella Ehrenberg, 1838, p. 60, pl. 13, f. 9; Pascher & Lemmermann, 1913, p. 50, f. 78; Conrad, 1926, p. 202-212, f. 17-23; Prescott, 1962, p. 376, pl. 92, f. 6-7; Whitford & Schumacher, 1969, p. 100, pl. 44, f. 37.

Cells in spherical colonies, individual cells moderate in size, covered with spine-bearing scales, oboid to obpyriform, rounded anteriorly and attenuated posteriorly to join at a common center with the other radiating cells of the colony. Individual cell length 20 µ, width 12 µ; colony diameter 40 µ, composed of around 15 cells. Flagella two, unequal, the longer equal to cell length, the shorter about 3/4 this length, inserted anteriorly.

Chromatophores two, yellow-brown, elongate and parietal. Red granules sometimes present in the anterior portion of the cells near the flagellar bases.

Cosmopolitan fresh water species.

Gales Creek: Present in 4 spring samples; oligohaline, from 0 to 1°/oo salinity, introduced into the estuary during heavy freshwater runoff.

Studies: Phototaxis - Bendix (1960).

Chromulina sp.
(Pl. 16, f. 108)

Cells large, somewhat metabolic, elongate-obpyriform with narrowly rounded posterior and emarginate anterior. Length 25µ, width 13µ. Surface of cell smooth. Flagellum single, about equal to cell length, inserted in the shallow anterior depression.

Chromatophore appearing to be single, large, parietal, extending the length of the cell, greenish yellow-brown in color. Stigma large, orange, at the anterior end of the chromatophore. Many small dark granules present in the central cytoplasm.

Gales Creek: Present in one fresh water surface sample in July.

This organism most nearly resembles *Chromulina urophora* Skuja (1948) which is, however, a somewhat larger organism with a smaller stigma and two definite chromatophores that are very thin and broadly V-shaped in cross section. *Crysoglena verrucosa* Wislouch (see Huber-Pestalozzi, 1941) is similar in shape, and slightly larger in size, but also possesses 2 chromatophores, and the body is covered by a periplast embedded with small scales, giving the cell a warty appearance. Proper determination of the Gales Creek organism awaits its further observation.

Pseudopedinella pyriforme Carter
(Pl. 16, f. 109 a-b; pl. 31, f. 7-9)

Pseudopedinella pyriforme Carter, 1937, p. 34, pl. 6, f. 23-31; Conrad & Kufferath, 1954, p. 171; Hulburt, 1965a, p. 87, pl. 1, f. 17-21.

Cells small, short-cylindrical to depressed-globose, with truncate lobed apex and antapex, circular to six-lobed in end view. Length and width usually equal, 6.5-9 μ. Flagellum single, 3 times the length of the cell, inserted in the center of the anterior depression, moving in a series of sigmoid curves. A trailing rhizopod, variable in form, often emerging from the center of the deeper posterior cavity, sometimes attenuated to a length many times that of the cell, often bearing a series of small inflations.

Chromatophores 6, yellow-brown, slightly reniform, peripheral, parallel to the apical axis, producing lateral lobes in the cell outline.

Brackish water organism from England, Belgium, Woods Hole.

Gales Creek: Present from all seasons with greater frequency in winter and spring; euryhaline, from 6 to 33°/oo salinity; observed in 25 samples.

This species is easily recognized by its pistol-revolver-chamber appearance. According to Swale (1969), it differs from members of the very similar genus *Pedinella* by the absence of a ring of anterior tentacles and posterior trailing attachment organ (peduncle).

Studies: Pigments of an unidentified *Pseudopedinella* species have been examined by Riley & Segar (1969).

Apedinella radians (Lohmann) comb. nov.
(Pl. 16, f. 110 a-b)

Apedinella spinifera (Throndsen) Throndsen, 1971, p. 61, f. 1-32.
Pseudopedinella spinifera Throndsen, 1969, p. 175, f. 10, 12a-b.
Meringosphaera radians Lohmann, 1908, p. 256, pl. 16, f. 36; Schiller, 1916, p. 206; Wulff, 1919, p. 103; Pascher, 1939, p. 548, f. 402.

Cells small, broader than long, appearing finely loricate, depressed-cordiform in lateral view, circular to 6-lobed in apical view, emarginate anteriorly, rounded posteriorly. Length 5-7 μ, diameter 6.5-9 μ. Six needle-spined scales, 15 μ long, borne laterally between the lobes, lying straight back when cell is motile, or at times extending radially outward when cell is at rest. Flagellum single, 2 times the cell length, inserted in the anterior depression.

Chromatophores 6, sometimes 5, yellow-brown, ovoid, peripheral, producing lobes in the cell outline.

Has been observed in European waters and from both coasts of the United States.

Gales Creek: Present in winter and spring; euryhaline, from 3.5 to 29°/oo salinity; observed in 15 samples.

Shiller (1916) and Wulff (1919) both expressed doubts as to Lohmann's placement of the non-flagellated cells he observed in *Meringosphaera*, a genus of bristled coccoid xanthophytes. When flagellated cells are observed, the similarity of this six-chromatophored six-lobed organism to *Pseudopedinella pyriforme* Carter (1937) is readily apparent. Throndsen (1969) first placed this organism in *Pseudopedinella*, but then (1971) transferred it to a new genus, *Apedinella*, on the basis of the absence of a posterior trailing pseudopodium of the

Pseudopedinella type. Lohmann's older specific epithet, however, must take precedence over Throndsen's name for this distinctive organism.

Electron photomicrographs by Throndsen show the long spined scales to have triangular bases oriented obliquely to the spine axis, and also reveal the finely loricate appearance of the cells to be due to a multilayered covering of smaller flattened elliptical scales over the entire body.

Calycomonas wulffii Conrad & Kufferath
(Pl. 16, f. 111)

Calycomonas wulffii Conrad & Kufferath, 1954, p. 183, pl. 5, f. 3a-b; Lund, 1959, p. 427, pl. 87, f. 14-17. *C. gracilis* Lohmann in Wulff, 1919, p. 110, pl. 2, f. 19a-b. *C. gracilis* (Lohmann) Wulff in Hulburt, 1965a, p. 94, pl. 2, f. 14-16.

Cells small, loricate; lorica somewhat thimble shaped, with a broadly conical base joining a cylindrical upper portion which tapers somewhat to the wide anterior opening, walls moderately thick, orange-brown, bearing 3 or 4 annular markings. Average length 4.5μ, width 3.5-4 μ. Protoplast within the lorica difficult to observe, possessing a single anterior flagellum equal to lorica length. Chromatophores absent.

Belgium; Woods Hole area.

Gales Creek: Present in October and November, also April 1967; Polyhaline, from 23 to 33°/oo salinity; observed in 18 samples.

Lohmann (1908) illustrates (in Fig. 13a-d of plate 17) three different species under the name *Calycomonas gracilis*. Van Goor (1925), Conrad & Kufferath (1954) and Lund (1959) consider the first illustration, F. 13a, as the type for *C. gracilis*, but Wulff (1919) based his *C. gracilis* on F. 13b and d, so this form has been renamed *C. wulffii* by Conrad & Kufferath (1954). Conrad (1938) considered specimens he observed to be the same as F. 13b, d for which he erected the name *Codonomonas van goori*, but this form has a longer top, thinner walls, and many more annular markings than *C. wulffii*. Lund (1959) feels that the variation within Calycomonas is large enough not to justify

erecting a second genus, and transfers Conrad's form back to the older genus, but keeps *C. wulffii* as a separate species, recognizing that it may possibly be a variety of *Calycomonas van goori* (Conrad) Lund.

Calycomonas ovalis Wulff
(Pl. 16, f. 112 a-b; pl. 31, f. 10-12)

Calycomonas ovalis Wulff, 1919, p. 111, pl. 2, f. 20a-b; Conrad & Kufferath, 1954, p. 183, pl. 5, f. 2; Lund, 1959, p. 427, pl. 87, f. 20-23.

Cells small, loricate; lorica ovoid, with a narrow anterior opening; lorica wall moderately thick, orange-brown, bearing 5-6 annular thickenings at a slightly oblique angle, lorica in end view with 5 broad lobes. Length 4.5-5 µ, width 3.5-4 µ. Flagellum not observed. Protoplast may extend filiform pseudopodia out the lorica orifice. Chromatophores absent.

Barents Sea; North Sea; Belgium.

Gales Creek: Present in summer and autumn, with high frequencies from August to November and densities reaching 63 cells/ml in October; euryhaline, from 0 to 31°/oo salinity; observed in 81 samples.

This species is very similar in form to *Calycomonas gracilis* Lohmann sensu Conrad & Kufferath, (1954) and Lund (1959), but differs in having broad annular thickenings rather than narrow irregularly thickened ridge-like bands around the lorica.

Lund (1959) considers these uniflagellate monads to be chrysophycean algae which are colorless parallels to *Kephyrion* and closely allied to biflagellated *Pseudokephyrion*.

Ebria tripartita (Schumann) Lemmermann
(Pl. 16, f. 113; pl. 31, f. 13-15)

Ebria tripartita (Schumann) Lemmermann, 1903, p. 32, f. 108; Gemeinhardt, 1930, p. 79, f. 66. *Dictyocha tripartita* Schumann, 1867, p. 67, pl. 1, f. 28.

Cells large, circular in broad lateral view, planoconvex in narrow lateral view, containing an elaborate silicified endoskeletin of the same general shape. Average diameter in broad lateral view 30μ. Endoskeletin of two convex mirror-image sides, each in broad lateral view composed of three skeletal arms extending radially from the center which then bifurcate into narrower shorter arms and join a marginal skeletal ring, discontinuous between two of the bifurcations, bearing many short blunt teeth. Flagella absent from observed cells.

Chromatophores absent. Cytoplasm granular, normally containing a large brown spherical assimilate body.

Cosmopolitan organism, living and fossil, in the Atlantic Ocean from the North Sea to Brazil and also the Caribbean and Gulf of Mexico.

Gales Creek: present in April and the latter half of autumn; 18 to 33°/oo salinity; observed in 21 samples.

At division the two convex sides of the endoskeletin apparently separate, with one going to each daughter cell.

[Rhizopoda]

Paulinella chromatophora Lauterborn
(Pl. 16, f. 114 a-b)

Paulinella chromatophora Lauterborn, 1895, p. 543, pl. 30, f. 1-7; Lackey, 1936, p. 493, pl. 1, f. 1; Skuja, 1948, p. 383.

Cells of moderate size, loricate; the lorica ovoid with a narrow anterior opening, lorica wall thick but clear, bearing 5 sets of elongate hexagonal plates arranged in 9 alternating transverse rows, lorica in end view with 5 broad lobes. Length 16-20 μ, width 12-16 μ. Flagella absent.

Chromatophores two, occasionally single, very blue, arcuate with rounded ends, curved about each other. Cytoplasm clear, not filling the lorica. Two contractile vacuoles present, one central, the other more anteriorly placed. Several long filiform pseudopods normally extend out the anterior opening and move slowly.

Fresh water, from Sweden, N.J., Ala., Miss.

Gales Creek: Present in March and from September to December; polyhaline, from 20 to 32°/oo salinity; observed in 8 samples.

This organism appears to be comprised of a symbiotic blue-green alga living within a loricate rhizopod.

(Class Xanthophyceae)

Nephrochloris salina Carter
(Pl. 17, f. 115 a-b; pl. 32, f. 1-2)

Nephrochloris salina Carter, 1937, p. 16, pl. 2, f. 10-22; Pascher, 1939, p. 1058, f. 903; Hulburt, 1965a, p. 88, pl. 1, f. 8-16; Throndsen, 1969, p. 178, f. 15 a-c.

Cells small, elongate-elliptical, dorsiventrally compressed, dorsal surface convex and ventral surface flattened. Length 6-10 μ, width 5-7 μ, thickness 4μ. Cell surface smooth. Flagella two, unequal, inserted anterior-ventrally; the longer flagellum twice body length, easy to observe, normally lying forward in a series of sharp sigmoid curves, the short flagellum finer and difficult to see, equal to the width of the cell and normally directed out from the body.

Chromatophores two, yellow, lateral and parietal, covering all but the ventral side and anterior portion of the cell. Two bluish refractive discoid granules present in tandum in the middle of the cell.

Brackish water in England, Belgium, Norway, Woods Hole area.

Gales Creek: Present in spring and November, with high frequency and abundance in April reaching 69 cells/ml densities; euryhaline, from 6 to 33°/oo salinity; observed in 28 samples.

The systematic position of this species is uncertain and requires reinvestigation, as does *Nephrochloris incerta* Geitler & Gimesi (Geitler, 1925), the type species for the genus which is described as having but one flagellum. Carter (1937) suggests that the second flagellum may have been overlooked, for other similarities to her species

were striking to her: the yellow chromatophore and the 1-2 strongly refractive assimilate bodies.

Throndsen (1969) has observed in this species a very short haptonema inserted with the flagella which is hardly detectable with the light microscope. The configuration of flagella and haptonema suggests a possible kinship with *Pavlova* in the Chrysophyceae.

Olisthodiscus carterae Hulburt
(Pl. 17, f. 116 a-c)

Olisthodiscus carterae Hulburt, 1965a, p. 90, pl. 2, f. 8-13.

Cells moderate in size, generally ovoid though varying from subspherical to pyriform, the dorsal margin more convex than the ventral margin in lateral view, the outline of the cell sometimes irregular. Length 10-19 μ, width 9-14 μ. Flagella two, unequal, heterodynamic, the longer extended forward and undulating, the other trailing, both somewhat longer than body length, inserted anterior-ventrally.

Chromatophores 7 to 15, golden brown, irregularly discoid and peripheral. No assimilate granules observed.

Described from brackish waters near Woods Hole.

Gales Creek: Present in April and from June to August; from 12 to 26°/oo salinity; observed in 10 samples. Also abundant in 6 samples collected in April, 1967, with densities up to 5,770 cells/ml.

The distinguishing features separating this species from similar-sized *Olisthodiscus luteus* Carter (1937) are the lack of any marked dorsiventral flattening of the body, no concavity of the ventral surface in end-on view, and the absence of numerous dark peripheral granules. The Gales Creek material extends upwards by 50% the maximum size of *O. cartarae* given by Hulburt. This organism is very similar to M. Parke's *Olisthodiscus* culture #12a, which also does not possess the marked dorsiventral flattening of *O. luteus*.

Primarily because of the yellow chromatophores in her material, Carter placed *O. luteus*, the type species, in the Xanthophyceae. Leadbeater (1969) considers the evidence he has accumulated in studying

this species sufficient to justify the transfer, at least temporarily, of *Olisthodiscus* to the Chrysophyceae.

Olisthodiscus carterae var. *olivaceus* var. nov.
(Pl. 17, f. 117 a-e; pl. 32, f. 3)

Olisthodiscus carterae Hulburt, 1965a, p. 90, pl. 2, f. 8-13.

Cells small, elliptical to ovoid, fusiform or spherical, the dorsal margin normally more convex than the ventral margin in lateral view, the outline of the cell often irregular. Length 8-16μ, width 6-12μ. Flagella two, sub-equal, heterodynamic, the longer extended forward and assuming a series of sigmoid curves when at rest, the shorter flagellum straight and trailing, both somewhat longer than the cell, inserted ventrally in a small groove 1/4 to 1/3 the cell length from the anterior end.

Chromatophores 4 to 11, olive green, irregularly discoid, peripheral. Assimilate granules rarely observed.

Gales Creek: Present from June to October with dense concentrations in August and September reaching 81,000 cells/ml; euryhaline, from 0 to 26°/oo salinity, with highest concentrations in low salinity waters; observed in 46 samples.

These cells differ from *Olisthodiscus carterae* primarily in the distinct olive green color of the normally fewer chromatophores. Cells assigned to *C. carterae* were also present in some of the same samples. Their golden-brown chromatophores were markedly different from the olive green of these cells, and no color intergrades were observed between these two forms. It is on these observations that the erection of this variety of *O. carterae* is based.

Olisthodiscus magnus Hulburt
(pl. 17, f. 118)

Olisthodiscus magnus Hulburt, 1965a, p. 90, pl. 2, f. 17-28.

Cells large, obovoid, slightly compressed dorsiventrally, cell outline somewhat irregular. Length 27μ, width 22μ. Flagella two, sub-equal, somewhat longer than the cell, heterodynamic; one extended forward in a series of curves, the other straight and trailing, both inserted ventrally in a shallow groove a short distance from the anterior end.

Chromatophores numerous, irregularly discoid, brown, peripheral. Assimilate granules not observed.

Described from brackish water near Woods Hole, Mass.

Gales Creek: Present in two samples from January and October; 19°/oo salinity.

Hulburt (1965a) distinguishes this species from *C. luteus* Carter (1937) and *C. carterae* Hulburt (1965a) on the basis of its much larger size, which he reports as 30 to 48μ in length.

(Class Raphidophyceae)

Merotrichia capitata Skuja
(pl. 17, f. 119; pl. 32, f. 4)

Merotrichia capitata Skuja, 1934, p. 33, f. 12; Huber-Pestalozzi, 1950, p. 89, f. 71; Skuja, 1956, p. 342, pl. 59, f. 16-19; Whitford & Schumacher, 1969, p. 125, pl. 59, f. 36.

Cells large, elliptical to ovoid, anterior end broadly rounded in dorsal view, obliquely truncate in lateral view, posterior end acutely rounded. Length 34μ, width 18μ. Cell surface smooth. Flagella two, unequal and heterodynamic, the anteriorly directed flagellum undulate, shorter than the cell length, the posteriorly trailing flagellum straight, somewhat longer than the cell; inserted anterior-ventrally at the mouth of a large cytopharynx.

Chromatophores many, green, irregularly elliptical, peripheral. Long needle-like trichocysts present peripherally only in the anterior portion of the cell, perpendicular to the periplast. Nucleus very

large, spherical, central, lying posteriorly to the cytopharynx.

A widespread fresh water species.

Gales Creek: Present in two samples from March and July; oligohaline, from 0 to 1°/oo salinity, introduced into the estuary with heavy fresh water runoff.

Vacuolaria virescens Cienkowski
(pl. 17, f. 120)

Vacuolaria virescens Cienkowski, 1870, p. 426, pl. 24, f. 19-20; Pascher & Lemmermann, 1913, p. 177, f. 379; Huber-Pestalozzi, 1950, p. 81, f. 64; Skuja, 1956, p. 339, pl. 59, f. 1-2.

Cells large, elliptical to ovoid, broadly rounded posteriorly, more narrowly rounded anteriorly. Length 29-33μ, width 17-25μ. Cell surface smooth. Flagella two, sub-equal and heterodynamic, inserted anteriorly, the straight flagellum slightly shorter than body length, the longer flagellum undulating in a series of coils.

Chromatophores many, ellipsoidal, green, densely filling the periphery of the cell and obscuring internal detail. Trichocysts absent.

A widespread fresh water species.

Gales Creek: Present in three samples from February and July; oligohaline, from 0 to 1°/oo salinity, introduced with heavy fresh water runoff into the estuary.

A study of the plastid pigments of this species by Chapman & Haxo(1966) has revealed the presence of the same carotenoids found in the Xanthophyceae, and no detectable presence of any green plant xanthophylls, which strongly suggests, as does their flagellar arrangement, that the chloromonads are allied with the Xanthophyceae and not the green algal groups.

Other studies: Fine structure--Schnepf & Koch (1966); Koch & Schnepf (1967).

(Class Euglenophyceae)

Eutreptia cf. *viridis* Perty
(pl. 17, f. a-d; pl. 32, f. 5-6)

Eutreptia viridis Perty, 1852, p. 168, pl. 9, f. 1a, c; Dangeard, 1901, p. 199, f. 24; Pringsheim, 1953, p. 150, 154, f. 1-3; Huber-Pestalozzi, 1955, p. 397, pl. 81, f. 863; Butcher, 1961, p. 3, pl. 1, f. 6, pl. 3, f. 8; Whitford & Schumacher, 1969, p. 86, pl. 44, f. 5.

Cells very large, metabolic, variable in shape but often clavate or fusiform, when fully extended the anterior end is narrowed and truncate, the posterior end narrowly attenuated. Length 40-70μ, width 5-10μ. Periplast elastic, obliquely striated. Flagella two, sub-equal, shorter than the cell length, arising anteriorly from the short and somewhat obliquely positioned canal from the reservoir. Locomotion by euglenoid movement and swimming.

Chloroplasts around 20, elliptical, green, scattered, though sometimes appearing to be grouped around a clustered mass of paramylum bodies anterior to the center of the cell. Paramylum bodies small, elongate-elliptical. Stigma prominent, red, granular, adjacent to the reservoir. Nucleus large, spherical, sub-central.

Common widely distributed species, especially in saline ditches.

Gales Creek: At magnifications used for cell counting it was difficult to distinguish between these specimens and those classified as *Eutreptia lanowii* Steuer, described below, so the following data includes both these forms, and where flagella were absent, possibly *Euglena proxima* Dangeard (see below) as well: Present in all months but May, with concentrations reaching 60 cells/ml in August; euryhaline, from 0 to 35°/oo salinity; observed in 86 samples.

This organism was larger than specimens classified as *E. lanowii* Steuer (see below) and bore a definitely striated pellicle, but in only a few individuals was any clustering of the chromatophores around a central body observed, and in none of the cells was this body clearly a plastidome. Pringsheim (1953) suggests that, though this character

is found in healthy cells of *E. viridis*, the scattering of chromatophores aroung the cell which also occurs may be the result of aging. The chloroplasts from the Gales Creek material were not as elongate as illustrated by Butcher (1961), being more like those shown in Pringsheim's fig. 2.

Eutreptia cf. *lanowii* Steuer
(pl. 17, f. 122 a-g; pl. 32, f. 7-9)

Eutreptia lanowii Steuer, 1904, p. 126-137, f. 1-3; Schiller, 1925, p. 95, pl. 3, f. 19; Huber-Pestalozzi, 1955, p. 398, pl. 81, f. 866; Butcher, 1961, p. 4.

Cells large, very metabolic, varying from clavate to elongate-cylindrical when fully extended, acute posteriorly and rounded to, when extended, narrowed and truncate anteriorly. Free swimming clavate cells 14-20μ long and 5-10μ wide; metabolically moving cells fully extended 40-50μ long and 4-5μ wide. No periplast striations observed. Flagella two, sub-equal, arising anteriorly from a barely perceptible canal; the longer flagellum equal to cell length in shortened cells and normally directed forward, the shorter flagellum 1/2 to 3/4 the length of the longer and normally directed posteriorly. Euglenoid movement extreme and rapid.

Chloroplasts 5 to 15, green, elliptical, in random and varying position and orientation within the cell. Pyrenoids absent. Paramylum bodies few, small, discoid, scattered. Stigma red, composed of one to several granules; other red granules sometimes scattered through the cytoplasm. Nucleus sometimes evident below the middle of the cell.

Trieste and the Adriatic Sea.

Gales Creek: At magnifications used for cell counting it was difficult to distinguish between these specimens and those classified as *Eutreptia viridis* Perty, described above, so the following data includes both these forms, and where flagella were absent, possibly *Euglena proxima* Dangeard (see below) as well: Present in all months but May, with concentrations reaching 60 cells/ml in August; euryhaline, from 0 to 35°/oo salinity; observed in 86 samples.

This is a small species with pellicle striations not apparent and the few chloroplasts and paramylum grains not surrounding a pyrenoid-like plastidome.

Euglena cf. *proxima* Dangeard
(pl. 18, f. 123 a-e; pl. 32, f. 10)

Euglena proxima Dangeard, 1901, p. 154-157, f. 6; Gojdics, 1953, p. 80, pl. 7, f. 7; Huber-Pestalozzi, 1955, p. 86, pl. 14, f. 64; Pringsheim, 1956, p. 60-63, f. 7-8; Prescott, 1962, p. 394, pl. 85, f. 25; Leedale, 1967b, p. 21, f. 10; Whitford & Schumacher, 1969, p. 84, pl. 43, f. 12.

Cells moderate in size to large, metabolic, varying from fusiform to clavate and lanceolate, rounded or truncate anteriorly, tapering to an acute tip posteriorly. Length 10-50μ, width 4-16μ. Pellicle striations delicate. Flagellum arising anteriorly from the canal, slightly longer than the cell. Locomotion by euglenoid movement and swimming.

Chloroplast 5 to 12, green, elliptical, randomly oriented but absent from the posterior tip. Pyrenoids absent. Paramylum bodies small, discoid, rare. Stigma red, composed of one or several granules; other red granules sometimes scattered in the cytoplasm. Nucleus sometimes evident below the middle of the cell.

Fresh and brackish water species in Europe and America.

Gales Creek: Present in summer and autumn; from 9 to 33°/oo salinity; observed in 21 samples. When flagella were absent in the specimens it was not possible to distinguish this *Euglena* from the *Eutreptia* species found in the creek, so some cells no doubt were included in those counts.

According to Pringsheim (1956), *Euglena proxima* has many variants both in fresh and salt water, which differ in size, minor features of shape, habitat adaptation, and probably other physiological properties. The Gales Creek specimens, averaging 20-30μ in length, were smaller than the size range reported by Pringsheim of 45-93μ x 7-30μ. They were

closer in size and form to *E. baltica* Schuler (1910), a species, however, which Pringsheim considers insufficiently described and related or identical with *E. proxima* in the wider sense he has adopted for this species. It is tentatively assumed this wider sense can also include the Gales Creek specimens.

Euglena deses Ehrenberg
(pl. 18, f. 124)

Euglena deses Ehrenberg, 1833, p. 248, pl. 7, f. 8; Gojdics, 1953, p. 133, pl. 23, f. 2; Skuja, 1956, p. 231, pl. 41, f. 1; Pringsheim, 1956, p. 118-121, f. 37; Leedale, 1967b, p. 27, f. 17.

Cells cylindrical and elongated, somewhat metabolic, anteriorly narrowed and truncate, posteriorly rounded. Length 150µ, width 12µ. Pellicle striations not observed. Flagellum absent. Locomotion by creeping.

Chloroplasts less than 10, discoid, parietal, curved against the pellicle. Pyrenoids not observed. Paramylum bodies moderately small, discoid, mostly in the anterior portion of the cell. Stigma composed of several large red granules, adjacent to the reservoir. Nucleus large, below the middle of the cell.

Rather common and very widely distributed on mud in ditches, marshes and estuaries.

Gales Creek: Present in June, July and November; euryhaline, from 3 to 28°/oo salinity; observed in 3 samples.

According to Pringsheim (1956), *E. deses* is an outstanding example of a species composed of a considerable number of closely related taxonomic forms, each liable to morphological modification. He states that the naked pyrenoid in each chloroplast peculiar to this species and *E. mutabilis* Schmitz (see below) cannot always be readily observed. The flagellum is short, and often not visible.

Studies: Phototaxis--Bendix (1960).

Euglena mutabilis Schmitz
(pl. 18, f. 125)

Euglena mutabilis Schmitz, 1884, p. 37 (footnote No. 1), pl. 1, f. 3; Gojdics, 1953, p. 81, pl. 6, f. 7a; Huber-Pestalozzi, 1955, p. 76, pl. 11, f. 53; Skuja, 1956, p. 228, pl. 40, f. 2-3; Pringsheim, 1956, p. 121-123, f. 38; Leedale, 1967b, p. 27, f. 18 a-c.

Cells very large, slenderly fusiform, somewhat metabolic, posteriorly narrowly acute, anteriorly strongly narrowed and truncate. Length 80μ, width 10μ. Pellicle striations and flagellum not observed. Locomotion by slow creeping, coiling, wriggling.

Chloroplasts four, green, large, thin, parietal, curved against the pellicle. Pyrenoids and paramylum bodies not observed. Stigma, small, dense, red, adjacent to the reservoir.

Found on mud, widely distributed in the northern hemisphere, characteristic species of acid habitats.

Gales Creek: Present from all seasons; euryhaline, from 0 to 26°/oo salinity; observed in 7 samples.

Pringsheim (1956) considers this to be a well-defined species closely related to *E. deses* Ehrenberg (see above) but with fewer chloroplasts (3 to 8) and a narrower body. The very short flagellum is often non-emergent from the canal, and the naked pyrenoid in each plastid is not always readily observable.

Euglena ehrenbergii Klebs
(pl. 18, f. 126; pl. 32, f. 11)

Euglena ehrenbergii Klebs, 1883, p. 304; Van Goor, 1925, p. 303, f. 7; Gojdics, 1953, p. 108, pl. 13, f. 3; Huber-Pestalozzi, 1955, p. 69, pl. 9, f. 45; Pringsheim, 1956, p. 65; Prescott, 1962, p. 392, pl. 86, f. 13; Leedale, 1967b, p. 21, f. 8-9; Whitford & Schumacher, 1969, p. 84, pl. 43, f. 5.

Cells huge, matabolic, strap-like and spirally twisted, rounded or tapering to a blunt point posteriorly, narrowing and truncate

anteriorly. Length 78-160μ, width 10-25μ. Pellicle weakly striated. Flagellum not observed. Locomotion by twisted creeping.

Chloroplasts numerous, discoid, about 4μ in diameter, distributed throughout the cell. Pyrenoids absent. Paramylum bodies discoid, slightly smaller than the chloroplasts. Stigma a dark red angular plate of chloroplast size, adjacent to the large reservoir.

Widespread species in Europe and America.

Gales Creek: Rare, autumn and winter, usually from samples near the bottom; from 5 to 36°/oo salinity; observed in 10 samples.

This species is one which seems to occur in various size varieties, though none reported in Pringsheim (1956) were as small as a few of the Gales Creek specimens which have been included here. This species easily loses its very short flagellum

Euglena pumila sp. nov.
(pl. 18, f. 127 a-g)

Cells very small, markedly metabolic but generally elliptical to fusiform, narrowly rounded anteriorly, acutely rounded to pointed posteriorly. Length 7.5-15μ, width 4-5μ. Pellicle smooth. Flagellum equal to body length, inserted anteriorly at an angle to the apical axis. Reservoir and canal indistinct. Locomotion by euglenoid movement and swimming.

Chloroplasts two, sometimes three, light green, elongate-elliptical and flattened, about 4μ long. Pyrenoids absent. Stigma small, composed of a few red granules. Several short paramylum rods sometimes discernable. Nucleus spherical, in the posterior portion of the cell.

Gales Creek: Present in April, August, and November; polyhaline, from 23 to 33°/oo salinity; observed in 9 samples.

This extremely small species is differentiated from *E. minuta* Prescott (see Prescott, 1962)--and *E. pisciformis* Klebs, to which, according to Pringsheim (1956), *E. minuta* probably belongs--by the

smaller size of the chloroplasts and the absence of a pyrenoid within each along with the absence of the ill-defined tail process common among the pisciformes group.

Trachelomonas hispida var. *punctata* Lemmermann
(pl. 18, f. 128 a-b; pl. 33, f. 1)

Trachelomonas hispida var. *punctata* Lemmermann, 1906, p. 165; Pascher & Lemmermann, 1913, p. 150; Carter, 1937, p. 62, pl. 8. f. 25-26; Butcher, 1961, p. 16; Prescott, 1962, p. 414, pl. 84, f. 3-4.

Cells large, loricate, lorica oblong with parallel sides and broadly rounded ends, fairly thick, orange in color, punctate but without sharp-pointed warts or spines, apical pore with a short collar. Average dimensions 29μ x 17μ. Flagellum about twice the cell length, inserted anteriorly through the apical pore.

Chloroplasts around 15 in number, green, discoid. Paramylum bodies few, discoid. Stigma very large and angular, reddish orange, anteriorly placed.

Fresh and brackish water species from Europe and America.

Gales Creek: Present in five samples from spring and summer; euryhaline, from 3 to 23°/oo salinity.

Trachelomonas intermedia Dangeard
(pl. 18, f. 129 a-b; pl. 33, f. 2)

Trachelomonas intermedia Dangeard, 1901, p. 231, f. 42; Pascher & Lemmermann, 1913, p. 307, f. 12; Van Goor, 1925, p. 307, f. 12; Butcher, 1961, p. 16; Prescott, 1962, p. 415, pl. 83, f. 10.

Cells large, loricate, lorica nearly spherical, orange in color, surface finely punctate, apical pore with round thickened collar. Diameter 18-22μ. Flagellum twice the cell diameter, emerging from the apical pore.

Chloroplasts around 15, green, discoid. Pyrenoidal bodies not observed. Paramylum grains small, elongate-elliptical. Stigma very large and angular, reddish orange, supra-median.

From fresh and brackish waters, Europe and America.

Gales Creek: Present in six samples from March and July, all 0 °/oo salinity, introduced into the estuary with heavy fresh-water runoff.

(Class Prasinophyceae)

Heteromastix rotunda (Carter) Manton
(pl. 19, f. 130 a-b; pl. 33, f. 3)

Heteromastix rotunda (Carter) Manton, 1964b, p. 280; Manton, Rayns, Etti & Parke, 1965, p. 247-249, text-fig. 1-6. *Bipedinomonas rotunda* Carter, 1937, p. 13, pl. 1, f. 17-18; Butcher, 1959, p. 38, pl. 2, f. 7, pl. 8, f. 4.

Cells minute, markedly compressed laterally, elliptical in broad lateral view, flattened anteriorly, oblong-elliptical in all other views. Length and width 6-8μ, thickness 2-2.5μ. Flagella two, unequal, the longer about 4 times the cell length and directed laterally, the shorter flagellum coarser, half the length of the longer and curved around the cell.

Chloroplast single, green, parietal, with two anterior lobes. Pyrenoid basal, bounded by a starch shell. Stigma red, at the anterior end of the chloroplast lobe nearer the shorter flagellum. One or two refractive granules usually present in the center of the cell.

From salt marshes in southern England.

Gales Creek: Present in 4 samples from March and October, and cultures from a March innoculum.

This species is distinguished from *H. pyriformis* (Carter) Manton (see below) by its symmetrical broadly elliptical shape, slightly larger size, and longer flagella, though in the Cales Creek material

the longer flagellum did not attain the 30μ length described by Butcher (1959).

Studies: Pigments--Riley & Segar (1969).

Heteromastix pyriformis (Carter) Manton
(pl. 19, f. 131 a-b; pl. 33. f. 4-6)

Heteromastix pyriformis (Carter) Manton in Parke & Dixon, 1964, p. 528. *Bipedinomonas pyriformis* Carter, 1937, p. 12, pl. 1, f. 13-16; Butcher, 1959, p. 38, pl. 8, f. 6.

Cells minute, markedly compressed laterally, ovoid to pyriform in broad lateral view, oblong in dorsal view, with a shallow anterior groove. Length 4-6μ, width 3-4.5μ, thickness 2-2.5μ. Flagella two, unequal, the longer flagellum about 4 times the length of the cell, the shorter flagellum thicker and about 1 1/2 times the cell length, both inserted in the center of the flattened anterior surface; at rest the longer flagellum directed laterally with its proximal portion often lying within the anterior groove, the shorter flagellum curved around the cell.

Chloroplast single, green, parietal, with two unequal anterior lobes, smooth. Pyrenoid basal. Stigma red, at the anterior end of the chloroplast lobe nearer the shorter flagellum. One or two refractive granules sometimes present in the cytoplasm.

Described from a salt marsh in southern England.

Gales Creek: Present from all seasons with higher frequencies in autumn and cell concentrations reaching 20 cells/ml; euryhaline, from 3 to 36°/oo salinity; observed in 70 samples.

Pyraminomas grossii Parke
(pl. 19, f. 132 a-e)

Pyramimonas grossii Parke, 1949, p. 256, f. 1-2, pl. 2, 17, 18; Butcher, 1959, p. 30, pl. 2, f. 1, pl. 8, f. 1-2.

Cells small, of variable shape from ovoid or pyramidal to cordate, lateral margins convex to straight and tapering, posteriorly rounded, truncate and 4-lobed anteriorly, the lobes rather short and wide, apical view sub-quadrate. Length 5.5-10μ, width 3.5-8.5μ. Flagella 4, slightly longer than the cell, inserted in a shallow anterior depression.

Chloroplast green, campanulate, with four long anterior lobes, one passing into each of the periplast lobes; pyrenoid large, basal. Stigma bright red, median in position on one of the chloroplast lobes, though sometimes positioned more anteriorly.

Described from sea water, southern England.

Gales Creek: Present from all seasons; 11 to 34°/oo salinity; observed in 18 samples.

The placement of the stigma in the middle zone of the cell on one of the lobes has been used as the main character to separate these Gales Creek organisms from similar forms with anterior stigmas tentatively identified as *P. micron* and *P. torta* (see below).

Studies: Trichocysts--Manton (1969).

Pyramimonas cf. *torta* Conrad & Kufferath
(pl. 19, f. 133 a-d; pl. 33, f. 7)

Pyramimonas torta Conrad & Kufferath, 1954, p. 232, pl. 8, f. 5; Butcher, 1959, p. 26.

Cells small, pyramidal or cunieform, with straight tapering sides, narrowly rounded posteriorly, strongly 4-lobed anteriorly, lobes long and moderately narrow, diverging anteriorly to give the cell a cruciform shape when viewed apically. Length 9-13μ, width 6.5-8μ. Flagella 4, slightly longer than the cell, inserted in a deep anterior depression.

Chromatophore green, campanulate, with 4 long anterior lobes, one passing into each periplast lobe; pyrenoid large and basal. Stigma bright red, at the apex of one of the chromatophore lobes.

Described from brackish water in Belgium.

Gales Creek: Presence in all seasons, with densities up to 83 cells/ml in November; from 9 to 34°/oo salinity; observed in 42 samples.

Gales Creek specimens were slightly broader than the narrowly cuneate cells illustrated by Conrad & Kufferath (1954). One distorted cell from the estuary of shortened length (see Pl. 19, fig. 133d), when compared to a similar sized cell of *P. micron* (see below) from the creek, illustrates the difference in lobing between these two species. The anterior position of the stigma separates these cells from *P. grossii* Parke (see above) with its lateral stigma.

Pyramimonas cf. *micron* Conrad & Kufferath
(Pl. 19, f. 134 a-d; pl. 33, f. 8)

Pyramimonas micron Conrad & Kufferath, 1954, p. 234, pl. 4, f. 3; Butcher, 1959, p. 29.

Cells small, variable in shape from broadly ovoid to pyramidal with convex to straight tapering sides, rounded posteriorly, truncately 4-lobed anteriorly, lobes moderately broad and long, subquadrate in apical view. Length 4-8μ, width 4-7.5μ. Flagella 4, somewhat longer than the cell, inserted in an anterior depression.

Chloroplast green, campanulate with 4 lobes extending into the 4 periplast lobes; pyrenoid basal. Stigma red, located at the anterior end of one of the chromatophore lobes.

Described from brackish water in Belgium.

Gales Creek: Present from all seasons, with high frequencies in autumn, densities up to 128 cells/ml in August; euryhaline, from 6 to 33°/oo salinity; observed in 83 samples.

Conrad & Kufferath's (1954) species is inadequately described, with no data being given about either pyrenoid or chromatophore. They also describe two similar though slightly larger species, *P. nanella* and *P. pisum* which, however, have straighter untapered lateral sides and finer stigmas. These Gales Creek specimens are separated from those identified as *P. torta* Conrad & Kufferath (see above) on the basis of their shorter relative length and more broadly rounded posterior end, and

from *P. grossii* Parke (above) on the position of the stigma at the anterior end of one of the lobes, rather than laterally.

Pyramimonas plurioculata Butcher
(Pl. 19, f. 135 a-d; pl. 33, f. 9)

Pyramimonas plurioculata Butcher, 1959, p. 31, pl. 7, f. 8.

Cells small, broadly ovoid to pyramidal, narrowly to bluntly rounded posteriorly, lateral margins convex to straight and tapering posteriorly, anterior end truncate and 4-lobed, the lobes short and broad, subquadrate in apical view. Length 5-11μ, width 4-8μ. Flagella 4, a little longer than the cell, inserted in the anterior depression.

Chloroplast green, campanulate, with four lobes extending to the anterior lobes of the periplast; pyrenoid basal. Stigma two paired red granules positioned between two of the anterior lobes; other red granules occasionally present basally.

Described from an English salt marsh.

Gales Creek: Present in autumn and winter, reaching densities of 22 cells/ml in November; euryhaline, from 0 to 32°/oo salinity; observed in 17 samples.

This species lacks the two large wedge-shaped starch grains around the pyrenoid and the prolonged narrow-pointed posterior end of *P. disomata* Butcher (1959), and may be distinguished from *P. micron* Conrad & Kufferath (1954), a similar species from Gales Creek, by the paired stigmas positioned between anterior lobes of the chloroplast.

Pyramimonas amylifera Conrad
(Pl. 19, f. 136 a-b; pl. 33, f. 10-12)

Pyramimonas amylifera Conrad, 1939a, p. 1-10, f. 1-33; Hulburt, 1965a, p. 94, pl. 3, f. 31-32.

Cells moderate in size, laterally compressed, with gradually tapering straight sides, broadly conical posteriorly, truncate anteriorly, quadrangular in apical view. Length 12-16μ, width 8-10μ, thickness

6-9μ. Flagella 8, almost 1 1/2 times the length of the cell, inserted in a deep anterior cavity with the flagellar bases forming a rhomboid pattern when viewed apically.

Chloroplast deeply campanulate, with four long anterior lobes over 1/2 the length of the body; pyrenoid large and basal. Stigma two paired orange granules at the base of adjacent chloroplast lobes on the broad side of the cell.

Brackish water from Belgium and Woods Hole area, Mass.

Gales Creek: Presence with moderate frequency in November, also April, 1967; polyhaline, from 26 to 33°/oo salinity; observed in 21 samples.

Studies: Scales - Manton, *et al.* (1963); scale formation - Manton (1966b). Pigments - Riley & Wilson (1967).

Pyramimonas ? obovata Carter
(Pl. 19, f. 137)

Pyramimonas obovata Carter, 1937, p. 8, pl. 1, f. 9-12; Butcher, 1959, p. 29, pl. 7, f. 9-10; Hulburt, 1965a, p. 92, pl. 3, f. 25-27.

Cells small, elliptical, acutely rounded posteriorly, truncate anteriorly, with convex sides. Length 10μ, width 6μ. Flagella 4, 1 1/2 times the cell length, inserted in a moderately deep anterior depression.

Chloroplast olive-green, deeply campanulate; pyrenoid basal. Stigma moderately large, red, placed in the middle zone of the cell.

From brackish water in southern England and Belgium; Woods Hole area.

Gales Creek: Present in autumn and March, with a density of 61 cells/ml in October; euryhaline, from 5 to 32°/oo salinity; observed in 4 samples.

The anterior portion of the chloroplast was very thin in these specimens and it was difficult to determine whether it was 4-lobed or continuous. The anterior depression was not as deep a cavity as figured in Butcher (1959) and Hulburt (1965a), and the minute puncate described by Carter (1937) were not observed.

Pyramimonas sp.

(Pl. 19, f. 138 a-c)

Cells of moderate size, elongate-elliptical, with convex or straight sides, acutely rounded posteriorly, truncate and 4-lobed anteriorly, the lobes short and broad, subquadrangular in apical view. Length 10-11 μ, width 6.5μ. Flagella 4, 1 1/2 times the cell length, inserted in an anterior depression.

Chloroplast green, deeply campunulate, with anterior lobes extending into the periplast lobes; pyrenoid large, basal. Stigma bright red, in the posterior portion of the cell adjacent to the pyrenoid.

Gales Creek: Observed in two samples from December and March, 22 to 34°/oo salinity.

This species is distinctive because of its definitely posteriorly positioned stigma and elongate-elliptical shape with distinct anterior lobing, but otherwise it is similar to *P. obovata* Carter (1937).

Tetraselmis contracta (Carter) Butcher

(Pl. 20, f. 139 a-b)

Tetraselmis contracta (Carter) Butcher, 1959, p. 63, pl. 12, f. 7. *Platymonas contracta* Carter, 1937, p. 5, pl. 2, f. 32-36. *Platymonas subcordiformis* Skuja, *non* (Wille) Hasen, Skuja, 1927, p. 55, pl. 1, f. 4. ? *Platymonas lilloensis* Conrad & Kufferath, 1954, p. 235, pl. 3, f. 7.

Cells large, with rigid cell wall from which the protoplast is markedly contracted, strongly compressed, elliptical, posteriorly rounded, anteriorly emarginate, in narrow lateral view with dorsal side convex and ventral side flattened, obliquely truncate anteriorly, posteriorly acute. Length 26μ, width 19μ, thickness 8μ. Flagella 4, somewhat longer than the cell, inserted through a shallow apical furrow between the two slight anterior lobes.

Chloroplast bright green, granular, with two large anterior lobes surrounding a sinus the same size as the pyrenoid. Pyrenoid large,

round, submedian. Stigma large, red, positioned in the anterior portion of the cell adjacent to the flattened ventral surface.

Described from brackish waters in southern England.

Gales Creek: Present in April and autumn; polyhaline, from 20 to 35°/oo salinity; observed in 5 samples.

Tetraselmis lilloeisis (Conrad & Kufferath) Butcher (1959), which is inadequately described and figured by Conrad & Kufferath (1954), apparantly differs from this species mainly in its smaller size, 14 x 12 x 7μ. With the protoplast contracted away from the cell wall for a considerable distance, and the large size, *T. contracta* is a distinctive and easily recognized species in Gales Creek.

Tetraselmis gracilis (Kylin) Butcher
(Pl. 20, f. 140 a-b)

Tetraselmis gracilis (Kylin) Butcher, 1959, p. 67, pl. 5, f. 3, pl. 10, f. 15, pl. 11, f. 13, pl. 13, f. 7. *Platymonas gracilis* Kylin, 1935, p. 221, f. 2a-b.

Cells moderate in size, with rigid cell walls, compressed laterally, broadly to narrowly ellipsoid, elongate-elliptical in narrow lateral view, rounded posteriorly, bluntly 2-lobed anteriorly. Length 9-12 μ, width 6-9 μ, thickness 5-6.5 μ. Flagella 4, 1 1/2 times the length of the cell, inserted in an anterior furrow between the two lobes.

Chloroplast green, with two anterior lobes surrounding the wide and deep sinus reaching to the pyrenoid which is large, sub-basal, surrounded by a sphere of starch platelets. Stigma large, orange-red, ellipsoidal, in the middle to anterior region and closer to the lateral margin. Numerous refractive granules often present in the anterior half of the cell.

Brackish waters from Sweden, southern England.

Gales Creek: Present in all months but May to July, with very high frequencies in autumn, reaching densities of 249 cells/ml in November; euryhaline, from 3 to 33°/oo salinity; observed in 69 samples.

This species most nearly resembles *T. verrucosa* Butcher (1959) but does not possess the verrucose posterior end of this other organism. Butcher describes the apex in *T. gracilis* as 4-lobed, but the two smaller lobes were seldom observed in the Gales Creek material. The more anterior position of the stigma was used to separate these organisms from those classified as *T. maculata* Butcher (see below).

Tetraselmis maculata Butcher
(Pl. 20, f. 141 a-b; pl. 33, f. 13)

Tetraselmis maculata Butcher, 1959, p. 67, pl. 5, f. 7, pl. 10, f. 12, pl. 11, f. 12, pl. 13, f. 6.

Cells moderate in size, with rigid cell walls, compressed, broadly to narrowly ellipsoid, elongate-elliptical to oblong in narrow lateral view, rounded posteriorly, bluntly 2-lobed anteriorly. Length 7-13-(16) μ, width 5-9-(11) μ, thickness 3-6.5 μ. Flagella 4, equal to cell length, inserted in the anterior furrow between the 2 lobes.

Chloroplast green, granular, with two anterior lobes, the sinus wide and deep, extending almost to the pyrenoid; pyrenoid basal, medium in size, with starch sheath. Stigma small to large, slightly anterior and lateral to the pyrenoid. Small refractive granules scattered around the periphery of the sinus.

Salt marsh pools, southern England.

Gales Creek: Presence in all seasons, though more frequent in autumn and winter, up to 52 cells/ml in November; euryhaline, from 1 to 32°/oo salinity; observed in 31 samples, and cultures from a March innoculum.

Butcher distinguishes *T. maculata* from *T. gracilis* (Kylin) Butcher (1959) by the posteriorly positioned stigma and shorter flagella, from *T. inconspicua* Butcher (1959) by the larger pyrenoid, stigma and overall size, from *T. striata* Butcher (1959) by the absence of longitudinal rows of granules or obliquely acute base, from *T. levis* Butcher (1959) by the less posteriorly positioned stigma, and from *T. suecica* (Kylin) Butcher (1959) by its more basal pyrenoid and less granular chromatophore. Whether these distinctions, which are often

difficult to determine in live field samples, constitute species characters and not just culture varieties needs to be determined through further investigations.

Studies: Pigments - Parsons (1961).

Tetraselmis striata Butcher
(Pl. 20, f. 142 a-c)

Tetraselmis striata Butcher, 1959, p. 66, pl. 10, f. 16, pl. 11, f. 8, pl. 13, f. 2.

Cells small, with rigid cell wall, compressed laterally, elliptical in broad lateral view, broadly rounded posteriorly bluntly 2-lobed anteriorly, in narrow lateral view oblong with an obliquely acute posterior end. Length 9μ, width 6.5μ, thickness 4.5μ. Flagella 4, 1 1/2 times the cell length, inserted in the apical furrow between the two lobes.

Chloroplast green, granular, with two anterior lobes, the sinus between rather deep and wide, reaching almost to the large sub-basal pyrenoid surrounded by a spherical starch sheath. Stigma large, bright red, sub-median near the lateral margin by the pyrenoid. Numerous small refractive granules present in the anterior portion of the cell and arranged in several longitudinal rows.

Described from sea water in Wales.

Gales Creek: Observed in a single November sample at 24°/oo salinity.

Distinctive features of this species, according to Butcher, are the small size, the longitudinal rows of granules, and the oblique posterior end in lateral view. Otherwise it is rather similar to *T. maculata* Butcher (1959), also found in Gales Creek.

Tetraselmis sp.
(Pl. 20, f. 143)

Cells large, with rigid cell walls, compressed, elliptical, rounded posteriorly, 2-lobed anteriorly with a shallow apical furrow between

the lobes. Length 20-25 μ, width 14-19 μ. Flagella not observed.

Chloroplast green, granular throughout, with two large anterior lobes surrounding a small sinus which extends to the pyrenoid; pyrenoid large, ellipsoidal, sub-median and central. Numerous small granules present around the periphery of the sinus.

Gales Creek: Present from January to March; polyhaline, from 20 to 35°/oo salinity; observed in 8 samples.

These cells were easily recognized when they appeared in the samples because of their large size, submedian pyrenoid and supramedian stigma. The one species of somewhat similar size and form in the literature, *Tetraselmis helgolandica* (Kylin) Butcher (1959) differs in possessing numerous (2-9) scattered stigmata.

(Class Chlorophyceae)

Chlamydomonas ? bourrellyi Ettl

(Pl. 20, f. 144 a-b)

Chlamydomonas bourrellyi Ettl, 1965a, p. 327, f. 36.

Cells small, body elliptical with rounded ends, bearing a moderately sized sub-hemispherical papilla apically. Length 7.5-9 μ, width 5-7.5 μ. Cell wall not observed. Flagella 2, 1-1 1/2 times the body length.

Chloroplast green, campanulate, somewhat granular, not extending all the way to the apex; sinus cylindrical, as broad as deep. Pyrenoid large, sub-spherical, basal. Stigma large, elliptical, red, in the midzone of the cell. Contractile vacuoles not observed.

A stagnant fresh water European species.

Gales Creek: Present from December to March; euryhaline, from 0 to 35°/oo salinity; observed in 7 samples.

The specimens observed differ from Ettl's species in the rounded rather than truncate apical papilla, in the less cylindrical shape, and

in their somewhat smaller size (Ettl: 9-14 x 4-8 μ) so this classification is extremely tentative. The general form of the cells is similar to *C. debaryana* Goroschankin (see Huber-Pestalozzi, 1961) which, however, is a larger species, above 14μ long.

Chlamydomonas ? uva-maris Butcher
(Pl. 20, f. 145 a-b)

Chlamydomonas uva-maris Butcher, 1959, p. 53, pl. 9, f. 2.

Cells moderate in size, body broadly ovoid-elliptical, rounded posteriorly and anteriorly. Length 8.5-12.5 μ, width 6.5-9.5 μ. Cell wall thick, smooth, in contact with the periplast, bearing a broad flat papilla apically. Flagella 2, 1-1 1/2 times the body length.

Chloroplast green, campanulate, extending almost to the apex to enclose a broad and deep elliptical sinus surrounded by assimilate granules. Pyrenoid large, elliptical, basal. Stigma large, red, elliptical, in the anterior portion of the cell. Contractile vacuoles not observed.

Described from salt marshes and pools from southern England.

Gales Creek: Present in 5 samples from March and autumn, from 5 to 30°/oo salinity.

Chlamydomonas komma Skuja (see Butcher, 1959), *C. microsphaera* Pascher & Jahoda (see Huber-Pestalozzi, 1961) with a spherical body, *C. subglobosa* Pringsheim (see Huber-Pestalozzi, 1961) with a smaller sinus, and *C. kuwadae* Gerloff (see Butcher, 1959), a somewhat larger species, are all similar to *C. uva-maris*, which is distinguished by Butcher on the basis of its much smaller papilla and absence of contractile vacuoles. However, even for species with them, the contractile vacuoles would probably be absent in those cells found in brackish waters, so this latter character is difficult to apply under these conditions. *C. bullosa* Butcher (1959) is also a similar species but possesses a rugose chloroplast with a narrow anterior sinus.

Chlamydomonas ? vernalis Skuja
(Pl. 20, f. 146 a-b)

Chlamydomonas vernalis Skuja, 1956, p. 138, pl. 19, f. 34-36, pl. 20, f. 1-4.

Cells moderate in size, body broadly to somewhat elongately elliptical, both ends rounded. Length 18-20 μ, width 11-18 μ. Cell wall thick, smooth, in contact with the periplast, bearing a large rounded papilla apically. Flagella 2, about equal to the cell length.

Chloroplast green, coarsely granular to rugose, peripheral, very dense, obscuring internal detail. Pyrenoid absent. Stigma moderately sized, dense red, elliptical, in the anterior portion of the cell.

Described from Swedish lakes.

Gales Creek: Present in four samples from February and March, from 1 to 18°/oo salinity.

Chlamydomonas ulla Skuja (see Huber-Pestalozzi, 1961) apparently differs from this species primarily in its smoother chloroplast, and *C. mediocris* Skuja (see Huber-Pestalozzi, 1961) in its slightly smaller size, thinner wall, and less dense chloroplast. A few of the Gales specimens were somewhat more elongately-elliptical than Skuja described for *C. vernalis*, but general similarity was rather close.

Chlamydomonas ? gregaria Butcher
(Pl. 20, f. 147 a-b)

Chlamydomonas gregaria Butcher, 1959, p. 57, pl. 9, f. 13.

Cells small, body narrowly elliptical with rounded ends and a moderately large hemispherical apical papilla. Length 7-9 μ, width 4-5 μ. Cell wall not distinguishable. Flagella 2, 1-1 1/2 times the body length.

Chloroplast green, campanulate, parietal, filling all but the anterior tip of the cell, soemwhat granular. Pyrenoid and contractile vacuoles not observed. Stigma round, red, sub-centrally positioned.

Described from a salt-marsh in Wales.

Gales Creek: Observed in 4 December and January samples, from 2 to 35°/oo salinity.

These few specimens did not exhibit the frequently asymmetric shape, more anteriorly positioned stigma, and distinct pyrenoid described by Butcher (1959) for *C. gregaria*, so this classification is extremely tentative.

Chlamydomonas cf. *vectensis* Butcher
(Pl. 21, f. 148 a-e; pl. 33, f. 14-16)

Chlamydomonas vectensis Butcher, 1959, p. 55, pl. 9, f. 3, pl. 14, f. 10.

Cells minute, body ovoid, anteriorly acute, posteriorly rounded, with a small but definite apical papilla. Length 4-7.5μ, width 3-5μ. Cell wall thin, in contact with the protoplast. Flagella 2, 1-1 1/2 times the cell length, normally directed posteriorly when the cell is at rest.

Chloroplast green, somewhat granular, more or less obliquely campanulate, occupying the posterior 1/2-2/3 of the cell. Pyrenoid not observed. Stigma moderate in size, elliptical, red, at the level of the anterior end of the chromatophore. Contractile vacuoles not observed. Assimilate granules few.

Described from brackish marshes in southern England.

Gales Creek: Presence in all seasons, with very high frequencies in early winter, mid-summer and mid-autumn, reaching concentrations of 9,700 and 11,880 cells/ml in August, 154 cells/ml in November; euryhaline, from 0 to 35°/oo salinity with maximum cell densities in water under 10°/oo; observed in 99 samples.

The Gales Creek material differed from Butcher's description in possessing a more well developed apical papilla, not having an obvious cell wall of medium thickness, and in lacking any sign of a pyrenoid, though Butcher does state that pyrenoids in his specimens were faint. Other species similar to the Gales Creek cells include *Chlamydomonas*

botryopara Rodhe & Skuja (see Huber-Pestalozzi, 1961) which, however, has a very steeply oblique chloroplast with a definite pyrenoid, *C. schilleriana* Gerloff (see Butcher, 1959) which is spherical in shape and lacks a definite apical papilla, *C. viridimaculata* Pascher (see Huber-Pestalozzi, 1961) which lacks a stigma, and *C. coniformis* Pascher (see Huber-Pestalozzi, 1961), a larger species.

Chlamydomonas sp. "a"
(Pl. 21, f. 149 a-d)

Cells small, body elliptical to ovoid, bearing a short broad papilla anteriorly, rounded posteriorly. Length 5.5-6 μ, width 3.5-4 μ. Cell wall thin, closely investing the protoplast in most individuals. Flagella 2, equal to body length, directed posteriorly when cell is at rest.

Chloroplast green, campanulate, granular, extending to the anterior end of the cell to enclose a deep and broad sinus. Definite pyrenoid not observed, though the swollen basal portion of the chloroplast suggests its presence. Stigma large, red, elliptical, supra-median. Contractile vacuoles not observed. Assimilate granules few.

Gales Creek: Presence from all seasons, abundant in August with densities up to 10,200 cells/ml; euryhaline, from 1 to 29°/oo salinity, with highest cell concentrations in mesohaline waters; observed in 33 samples.

Similar to these Gales Creek cells in size and chloroplast shape is *Chlamydomonas coccoides* Butcher (1959) which also possesses a basal pyrenoid, but which differs in having an acute apex, small stigma and yellow-green chloroplast. This Gales Creek material was separated from cells assigned to *C. vectensis* Butcher (1959) by the more elliptical shape, the more extensive chloroplast, and the larger stigma, but its seasonal presence and abundance so parallels the other that it suggests the two may be related varieties and not separate species.

Chlamydomonas sp. "b"

(Pl. 21, f. 150a-e)

Cells minute, body elongate-elliptical to elongate-ovoid, acutely rounded anteriorly, more broadly rounded posteriorly, over twice as long as wide, with a short rounded apical papilla distinguishable when the anterior end of the cell is more broadly rounded. Length 5-6 μ, width 2-3 μ. Cell wall not distinguishable. Flagella 2, equal to the body in length, normally directed posteriorly when the cell is at rest.

Chloroplast green with a blue tint, obliquely campanulate, sometimes appearing almost lateral, occupying the posterior 1/2 or 2/3 of the cell. Pyrenoid absent. Stigma moderate in size, elliptical, red, near the anterior end of the chloroplast in the middle of the cell. Contractile vacuoles not observed. Assimilate granules few, sometimes present in a longitudinal row.

Gales Creek: Present from June to September, with densities up to 244 cells/ml in oligohaline waters from August; euryhaline, from 0 to 26°/oo salinity; observed in 24 samples.

A number of species, including *Chlamydomonas tremulans* Rodhe & Skuja, *C. gloeophila* Skuja, *C. altera* Skuja (for these 3, see Huber-Pestalozzi, 1961) and *C. palla* Butcher (1959), are all rather similar in form and chloroplast shape to this material, but they are all somewhat larger and possess pyrenoids. That these Gales Creek specimens are not swarmers from some multicellular green alga is indicated by the accompanying presence of cysts in some of the samples (Pl. 21, f. 150e). While the elongate shape of these cells made them easily distinguishable from cells assigned to *C. vectensis* and *C.* sp. "a" (both described above), its abundance in August so parallels these other two as to suggest they all may be related forms.

Chlamydomonas sp. "c"

(Pl. 21, f. 151 a-c; pl. 33, f. 17-18)

Cells small, body ovoid to elliptical, rounded anteriorly and posteriorly, with a moderately large rounded apical papilla. Length 6-7 μ, width 5-6 μ. Cell wall separated from the protoplast by a

marked hyaline space. Flagella 2, equal to the cell length.

Chloroplast green, obliquely campanulate, occupying a little more then the posterior half of the cell. A small pyrenoid-like body observed only in one specimen, positioned somewhat laterally. Stigma large, red, elliptical, bulging out from the cell membrane, in the midzone of the cell. Contractile vacuoles not observed. Assimilate granules few.

Gales Creek: Present in 5 samples from August and December, 1965, mesohaline, from 2 to 14°/oo salinity.

The features distinguishing these cells from those classified as *C. vectensis* Butcher (1959) are the cell wall separated from the protoplast by a hyaline area, and the large bulging stigma.

Chlamydomonas sp. "d"
(Pl. 21, f. 152 a-b)

Cells moderate in size, body broadly elliptical to ovoid-elliptical, both ends rounded, bearing a broad flattened apical papilla. Length 7-16 μ, width 6-15 μ. Cell wall thin, smooth, in contact with the protoplast. Flagella 2, 1-1 1/2 times the body length, inserted at either side of the flattened papilla.

Chloroplast green, granular, deeply campanulate with narrow sides, enclosing a large broad sinus with a narrow anterior opening. Pyrenoid apparantly absent. Stigma moderately large, red, elliptical, supramedian. Contractile vacuoles not observed. Small assimilate granules scattered along the inner surface of the chloroplast.

Gales Creek: Present from January to April and perhaps July and August; observed in 10 samples from 0 to 8°/oo salinity, and questionably in 33 more samples (including 18 glutaraldehyde preserved samples) up to 27°/oo salinity and densities up to 244 cells/ml.

These cells do not fit *Chlamydomonas mediocris* Skuja (see Huber-Pestalozzi, 1961) because it is a somewhat larger species that does not have as broad an apical papilla, or *C. depauperata* Pascher (see

Huber-Pestalozzi, 1961) because of its thicker chloroplast, spherical shape, and more elongate stigma, though both these species are rather similar in general form to the Gales Creek specimens.

Chlamydomonas sp. "e"
(Pl. 21, f. 153)

Cells large, body broadly elliptical with rounded ends, no obvious apical papilla. Length 20μ, width 17μ. Cell wall very thin, smooth, in complete contact with the protoplast. Flagella 2, somewhat longer than the cell.

Chloroplast green, granular, a thin parietal mantle with a small opening apically and perforated by several large circular holes. Pyrenoid absent. Stigma moderate in size, bright red, elliptical, supra-median. Several dark irregularly elliptical assimilate bodies present. Contractile vacuoles not observed.

Gales Creek: Present in one July sample at 0^{o}/oo salinity.

This distinctive organism is somewhat like *C. perforata* Pascher & Jahoda (see Huber-Pestalozzi, 1961) which also has a thin perforated chloroplast, but is smaller (11-13μ in length), has a thick cell wall, and is ovoid with an acutely pointed apex.

Ecological Conditions Affecting Phytoflagellate Distribution

Each time a water sample was collected for live counts, measurements were made of water temperature, salinity, oxygen concentration and pH. A Secchi disc measurement at each station also gave an indication of the degree of light penetration. From these data it was possible to gain some awareness of the range of tolerance of the more frequently occurring phytoflagellate species with respect to these physical factors. These data do not, however, indicate how well the populations were adapted to these conditions. That would require information on the growth and productivity of the species, not simply on their presence or absence.

Temperature - It is difficult to separate the influence of temperature from that of light and other factors which vary seasonally when only field data are available. Thus the determining of whether temperature response is the prime factor responsible for the temperature ranges exhibited by Gales Creek phytoflagellates must await gradient studies in the laboratory. A number of species, however, did appear to fall into three general groups, and have been classified warm, moderate, and cold temperature species. Those species occurring in more than 10 samples are grouped according to this classification, with temperature range and number of samples involved, in Table 5.

There is an overlap of some ten degrees between the cold and warm temperature groups. The range of the cold temperature species was slightly greater than the range covered by the winter samples (3-18°C). The warm temperature species range was essentially that covered by the spring samples (13-34°C), while the range for the moderate temperature species was like that for the autumn samples (13-26°C).

Seven of the 15 warm temperature species are included in the characteristic seasonal associations of Gales Creek (compare Table 3), as are 2 of the 3 moderate temperature species, and 1 of the 6 cold

temperature species. One warm temperature species was dominant in summer, and one cold temperature species was dominant in early spring.

Table 5

CLASSIFICATION OF SPECIES ACCORDING TO TEMPERATURE TOLERANCE

SPECIES	TEMPERATURE RANGE °C	NUMBER OF SAMPLES	CHARACTERISTIC SPECIES	DOMINANTS
Warm Temperature Species				
Katodinium asymmetricum	11-32	21		
Gymnodinium nelsoni	12-29	51	*	
Gymnodinium danicans	13-32	120	*	
Prymnesium parvum	14-30	14		
Gymnodinium subroseum	14-32	43		
Calycomonas ovalis	14-33	81	*	
Gyrodinium pellucidum *Gyrodinium dominans*	15-32	126	*	
Gyrodinium uncatenum	16-30	18		
Gymnodinium roseostigma	17-33	19		
Peridinium aciculiferum	17-33	23		
Gymnodinium verruculosum	18-32	43		
Olisthodiscus carterae var. *olivaceus*	20-32	46	*	**
Gyrodinium estuariale	20-33	24	*	
Chlamydomonas sp. "b"	27-32	24		
Moderate Temperature Species				
Prorocentrum micans	14-24	21		
Pavlova gyrans var. *simplex*	14-25	42	*	
Nephrochloris salina	14-25	28	*	
Cold Temperature Species				
Heterocapsa triquetra	3-18	61	*	**
Chrysochromulina sp.	3-18	10		
Exuviaella marina var. *adnatodens*	10-19	20		
Peridinium trochoideum	3-20	36		
Euglena ehrenbergii	6-21	10		
Hymenomonas carterae	6-22	25		

Those species which were not limited in their distribution by any temperature measured in the estuary have been classified as eurythermal species, and are presented in Table 6, along with temperature range and number of samples involved. These are the species which are well adapted to the variable thermal environment of Gales Creek. (It must

be kept in mind, however, that some species in Table 5 may have not shown a eurythermal distribution because of factors other than temperature limiting their range.) It is therefore not surprising to find that 12 of the 16 eurythermal species in Table 6 were represented in the characteristic seasonal associations of Gales Creek (compare Table 3), and that 5 of these were also dominant species.

Table 6

SPECIES WITH EURYTHERMAL TEMPERATURE TOLERANCE

SPECIES	TEMPERATURE RANGE °C	NUMBER OF SAMPLES	CHARACTERISTIC SPECIES	DOMINANTS
Hemiselmis virescens *Chroomonas caroliniana*	4-33	140	*	**
Cryptomonas erosa	4-31	26		
Prorocentrum minimum	3-31	60	*	**
Exuviaella compressa	6-33	45		
Gymnodinium galesianum	9-32	101	*	
Katodinium rotundatum	3-32	103	*	**
Gyrodinium metum	4-33	78		
Apedinella radians	3-32	15		
Heteromastix pyriformis	3-33	70	*	
Pyramimonas plurioculata	4-30	17	*	
Pyramimonas micron	3-33	83	*	
Pyramimonas torta	3-33	42	*	
Pyramimonas grossii	3-32	18	*	
Tetraselmis gracilis	3-34	69	*	
Chlamydomonas vectensis	4-32	99	*	**

Salinity - 84 phytoflagellate species were present in enough samples to draw some conclusions about their salinity tolerances. These species appeared to fall into six basic salinity groups, with the important cut-off points for the tolerance ranges coming at 5, 15, and 25‰ salinity. The tolerance range for these groups and the number of species comprising each of them are presented in Table 7.

Table 7

SALINITY TOLERANCE GROUPS

SALINITY TOLERANCE GROUP	NUMBER OF SPECIES	(Oligo) (Meso) (Poly) (Eu) SALINITY IN °/oo 0 <—> 5 <—> 15 <—> 25 <—> 35
Oligohaline	6	********
Oligo-Meso-Polyhaline	5	************************
Meso-Polyhaline	2	******************
Meso-Poly-Euhaline	22	****************************
Poly-Euhaline	20	********************
Euryhaline	29	**********************************
Total # of species in each salinity range:	84	<—> 30 <—> 58 <—> 79 <—> 72
# of samples in each range:		91 30 101 107

The species comprising these six salinity groups are presented in Table 8, along with the number of samples involved for each species. How well each species may have been thriving within its salinity range is suggested in Table 11, where, for each species present in 4 or more samples, maximum cell concentrations are graphed on a log scale against salinity.

Table 8

CLASSIFICATION OF SPECIES ACCORDING TO SALINITY TOLERANCE

SPECIES	NUMBER OF SAMPLES	CHARACTERISTIC SPECIES	DOMINANTS
Oligohaline Species (0-5°/oo)			
Cryptomonas borealis	6		
Cryptomonas croatanica	5		
Synura uvella	4		
Merotrichia capitata	2		
Vacuolaria virescens	3		
Trachelomonas intermedia	6		
Oligo-Meso-Polyhaline Species (0-25°/oo)			
Cryptomonas erosa	26		
Cryptomonas testacea	32	*	

Table 8
(continued)

SPECIES	NUMBER OF SAMPLES	CHARACTERISTIC SPECIES	DOMINANTS
Olisthodiscus carterae var. *olivaceus*	46	*	**
Euglena mutabilis	7		
Trachelomonas hispida var. *punctata*	5		
Meso-Polyhaline Species (5-25°/oo)			
Gyrodinium aureolum	25	*	
Olisthodiscus carterae	17		
Meso-Poly-Euhaline Species (5-35°/oo)			
Exuviaella compressa	45		
Amphidinium crassum	28	*	
Amphidinium klebsi	35		
Gymnodinium gracilentum	19		
Gyrodinium estuariale	24		
Gyrodinium pellucidum / *Gyrodinium dominans*	136	*	
Gyrodinium uncatenum	18		
Peridinium trochoideum	36		
Peridinium aciculiferum	23		
Peridinium brevipes	58	*	
Hymenomonas carterae	25		
Chrysochromulina minor / *Chrysochromulina kappa*	55	*	
Pseudopedinella pyriforme	25		
Apedinella radians	15		
Ochromonas caroliniana	11		
Nephrochloris salina	28	*	
Euglena ehrenbergii	10		
Pyramimonas grossii	18	*	
Pyramimonas torta	42	*	
Pyramimonas micron	83	*	
Poly-Euhaline Species (15-35°/oo)			
Chroomonas baltica	23		
Exuviaella marina var. *adnatodens*	20		
Dinophysis acuminata	7		
Amphidinium machapungarum	8		
Gymnodinium nelsoni	51	*	
Gymnodinium verruculosum	43		
Gymnodinium subroseum	43		
Gyrodinium metum	78		
Gyrodinium resplendens	6		
Gyrodinium mundulum	9		
Polykrikos kofoidi	8		
Coolia obliquum	5		

Table 8
(continued)

SPECIES	NUMBER OF SAMPLES	CHARACTER-ISTIC SPECIES	DOMI-NANTS
Ebria tripartita	21		
Parachrysidalis estuariale	10		
Prymnesium parvum	14		
Chrysochromulina sp.	10		
Calycomonas wulffii	18		
Euglena pumila	9		
Pyramimonas amylifera	21		
Tetraselmis contracta	5		
Euryhaline Species (0-35°/oo)			
Hemiselmis virescens *Chroomonas caroliniana*	140	*	**
Chroomonas amphioxeia	125	*	
Chroomonas minuta var. *apyrencidosa*	71	*	**
Cryptomonas pseudobaltica	85	*	
Cryptomonas rostrella	9		
Cryptomonas ovata	8		
Prorocentrum micans	21		
Prorocentrum minimum	60	*	**
Gymnodinium stellatum	7		
Gymnodinium danicans	120	*	
Gymnodinium roseostigma	19	*	
Gymnodinium galesianum	101	*	
Katodinium rotundatum	103	*	**
Katodinium asymmetricum	21		
Heterocapsa triquetra	61	*	**
Goniaulax diacantha	38		
Pavlova gyrans var. *simplex*	42	*	
Calycomonas ovalis	81	*	
Eutreptia viridis *Eutreptia lanowii*	86	*	
Euglena proxima	21	*	
Heteromastix pyriformis	70	*	
Pyramimonas plurioculata	17	*	
Tetraselmis gracilis	69	*	
Tetraselmis maculata	31	*	
Chlamydomonas bourellyi	7		
Chlamydomonas vectensis	99	*	**
Chlamydomonas sp. "a"	33	*	
Chlamydomonas sp. "b"	24	*	

The salinity extremes are difficult to separate from other seasonal effects, for low salinity samples were relatively few in autumn, while high salinity samples were rare in late winter, spring and summer. With more observations, a number of species from the middle salinity

ranges may be found to have tolerances that extend into oligohaline or euhaline waters. Least likely to be found with any wider a salinity tolerance are the species in the oligohaline group, for these appear to be essentially fresh water species introduced into the estuary from upstream.

Of the species comprising the characteristic phytoflagellate associations of the estuary (compare Table 3), only 3 were not found in euhaline waters, while 11 were not found in oligohaline waters. The remaining 23 were all euryhaline species, apparently adapted to all salinities occuring in the estuary.

The tolerance of some species to rapid changes in salinity was apparent in those cases where cell concentrations above and below sharp haloclines could only indicate that cells of these species were swimming through a 15 to 25°/oo salinity gradient in a decimeter's distance. This situation was observed for *Prorocentrum minimum, Heterocapsa triquetra, Pavlova gyrans* var. *simplex, Olisthodiscus carterae,* var. *olivaceus, Eutreptia lanowii, Pyramimonas micron* and *Chlamydomonas vectensis.*

Few species of phytoflagellates were contributed by the fresh water inflow, but many could have been introduced with the saltwater inflow from the euhaline sound. From only 35 samples of euhaline water in the estuary a total of over 43 species, other than the 29 euryhaline species, were present, while 91 samples of oligohaline water contained a total of only 11 non-euryhaline species.

The estuary, however, is probably more important than the sound as a reservoir and source of phytoflagellates. In the 173 water samples measured between 15 and 30°/oo salinity were found 105 species of phytoflagellates, over 2/3 the total from the creek. In this range are the only salinities always encountered in large volumes of water in the estuary, even in periods of heavy fresh water runoff, if only in the lower reaches. The constancy of these conditions is attested to by the large number of species adapted to them. These phytoflagellates actively growing in the estuary could be an important seed source for populating the adjacent sound whenever conditions there became favorable.

Oxygen - A number of samples, taken from bottom waters during the warmer part of the year from May to September, contained less than 1 ppm oxygen. For phytoflagellate species without photosynthetic capabilities absence of oxygen would impose an important stress. Of interest, then, are non-chromatophored species found in these particular samples. These species are presented in descending order of frequency in Table 9, along with the percentage of samples below 1 ppm O_2 out of the total number of samples examined.

Table 9

NON-PHOTOSYNTHETIC PHYTOFLAGELLATES IN SAMPLES BELOW 1 ppm OXYGEN

SPECIES	PERCENT OF SAMPLES WITH > 1 ppm O_2	out of TOTAL NUMBER OF SAMPLES	CHARACTERISTIC SPECIES
Amphidinium crassum	25%	28	*
Gyrodinium pellucidum / *Gyrodinium diminans*	8%	136	*
*Gymnodinium verruculosum**	7%	43	
Gymnodinium subroseum	5%	43	
Calycomonas ovalis	4%	81	*
Gyrodinium metum	4%	78	
Gymnodinium galesianum	3%	101	*

* Possesses a small pale yellow-green plastid

For most of these species, only a small percentage of the samples were from essentially anoxic waters, and cell concentrations in these samples were low enough to be accounted for by mixing or migration of cells down from more oxygenated water layers. The interesting exception is *Amphidinium crassum*, which was present in 7 anoxic samples with concentrations up to 14 cells/ml. Perhaps this species is adapted to such conditions through some kind of capacity for anaerobic respiration.

All species present in anoxic water samples are indicated in Table 11.

Light Extinction - Samples collected from depths calculated by Secchi disc readings to be receiving less than 1% of surface radiation ($Z_{1\%}$) were considered possibly to have been below the compensation depth, and therefore photosynthetic phytoflagellates found at these

depths may have been especially adapted to low light intensities. The Secchi disc calculations gave only the minimum possible depth for 1% incident light, however. It may actually have been deeper, since proper calculations from a Secchi disc depend on a uniformly mixed column of water, and in Gales Creek there was often tannin-stained fresh water at the surface with clear more saline water lying below.

The potentially interesting photosynthetic phytoflagellates are listed in Table 10 in descending order of frequency with respect to the percentage of samples found occurring below the 1% incident light level.

Table 10

PHOTOSYNTHETIC PHYTOFLAGELLATES IN SAMPLES BELOW 1% OF SURFACE RADIATION

SPECIES	PERCENT OF SAMPLES WITH > 1% Z out of TOTAL NUMBER OF SAMPLES	CHARACTERISTIC SPECIES	DOMINANTS
Cryptomonas ovata	50% 8		
Cryptomonas borealis	50% 6		
Trachelomonas intermedia	33% 6		
Gymnodinium verruculosum	19% 43		
Chlamydomonas sp. "a"	10% 33	*	
Euglena proxima	10% 21	*	
Eutreptia viridis / *Eutreptia lanowii*	6% 86	*	
Hemiselmis virescens / *Chroomonas caroliniana*	5% 140	*	**
Gymnodinium danicans	5% 120	*	
Chlamydomonas vectensis	5% 99	*	**
Pyramimonas micron	5% 83	*	
Heteromastix pyriformis	4% 70	*	
Olisthodiscus carterae var. *olivaceus*	4% 46	*	**
Katodinium rotundatum	3% 130	*	**
Tetraselmis gracilis	3% 69	*	

Cell densities of most of these species in the low-light samples were under 1 cell/ml, and were therefore of marginal significance, accountable by mixing or migration of cells down from the photic zone above. However, the 5 low-light samples of the *Eutreptia* species contained up to 42 cells/ml, the 7 samples of *Hemiselmis-Chroomonas* up to 47 cells/ml, and the 3 samples of *Katodinium rotundatum* up to 130

cells/ml, which suggests the possibility of some adaptations to low light intensity by these species. Probably of most significance, however, is *Gymnodinium verruculosum*, with its faint yellowish-green plastid, which only achieved a maximum concentration of 5 cells/ml but was present in 8 samples, the largest number of low-light samples for any species.

All species present in samples calculated to have received less than 1% incident light are indicated in Table 11.

pH - Most of the plankton samples were obtained from brackish water, and therefore were buffered sufficiently that the pH ranged only from 7.4 to 8.3. This was not a broad enough variation to permit any conclusions to be made concerning pH tolerance of species. All the samples present at pH levels less than 7.0 were also oligohaline (from 0-5^{o}/oo salinity), which made it impossible in these instances to separate pH adaptation from salinity tolerance. Only with laboratory experimentation can the influence of pH on the distribution of these species be ascertained.

Nutrients - Since nutrient samples were not taken with each live plankton sample, no attempt has been made to correlate between nutrient concentrations and specific phytoflagellates. The main conclusion that can be drawn from the nutrient data is that at times of greater Nitrogen to Phosphorus ratios - in early spring and mid summer - there were also larger concentrations of phytoflagellates.

Though phosphate levels also were low, the often exceptionally low nitrogen levels in the estuary (and consequently the generally very low Nitrogen to Phosphorus ratio) and the rapid flushing rate of the creek appear to be the factors most responsible for the low standing crops attained during the year.

Extremes of salinity and temperature appear to have importance in circumscribing the seasonal and spacial distribution of numerous Gales Creek phytoflagellates. Many of the characteristic species of Gales Creek have eurythermal and euryhaline tolerances, but even these species do not continue to be present in the plankton throughout the year.

Other environmental factors or combinations of factors, such as nutrient availability, light intensity, or factors not measured in this study, must be placing limits on their seasonal distribution.

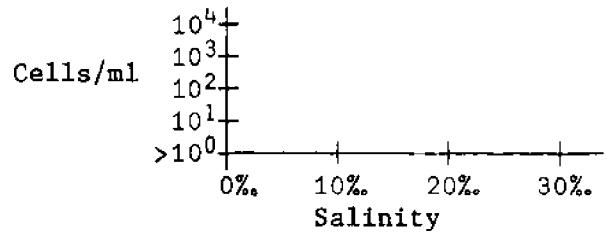
For these species to survive adverse conditions in the estuary they must develop some form of resistant resting stage and await the return of favorable conditions. These resting stages usually take the form of thick walled cysts, produced sexually or asexually, as is common in the dinoflagellates, chrysophytes and xanthophytes among others. Such resting bodies would then sink to the bottom and lie dormant in the surface mud. Other species may form palmelloid colonies on submerged objects, as can occur in the cryptomonads and motile green algae. However, some species may alternate their plankton motile stage with a non-motile benthic epiphytic or endophytic vegetative phase in which blocks or masses, or even filaments of cells are formed. This has been demonstrated by culture work in the case of *Hymenomonas (Cricosphaera) carterae* (Parke, 1961; Rayns, 1962; Boney & Burrows, 1966), where a non-motile sedentary phase exhibits a range of forms including *Chrysonema-*, *Gloeochrysis-*, *Apistonema-* and *Chrysotila*-like multicellular stages. The motile phase of this species was absent from Gales Creek samples in summer, which must therefore be the season when the sedentary phase dominates the life cycle. Such an alternation of life forms may also occur in other species in the creek as well, and certainly deserves investigation by future workers.

If most of the characteristic species of the estuary survive unfavorable seasons by means of various resting stages in the creek, rather than relying on reintroduction from outside sources for repopulation, then even at these times it should be possible to encourage reappearance of the motile forms in the laboratory by exposing cultures from benthic samples to artificial conditions similar to those of more favorable seasons. A few such culturing experiments were attempted during part of this investigation but did not meet with success, so this continues to remain an interesting area open to further study.

Table 11

TOLERANCE OF SPECIES TO SALINITY RANGE,
LOW OXYGEN, AND LOW LIGHT LEVELS

(Species in 4 or more samples)



S = Salinity Range, correlated with greatest cell cencentrations
Vertical scale: Cells/ml in powers of 10
Horizontal scale: Salinity in ‰

N = Total number of samples observed

O = Low Oxygen
Upper number: Number of samples with 1 ppm or less Oxygen
Lower number: Greatest concentration of cells/ml

L = Low Light
Upper number: Number of samples with 1% or less Incident Light
Lower number: Greatest concentration of cells/ml

SPECIES	S	N	O	L
Cryptophyceae				
Hemiselmis virescens *Chroomonas caroliniana*		140	$\frac{7}{775}$	$\frac{7}{47}$
Chroomonas baltica		23	0	0
Chroomonas minuta var. *apyrenoidosa*		71	0	$\frac{1}{4}$
Chroomonas amphioxeia		125	$\frac{1}{.3}$	$\frac{1}{.2}$
Cryptomonas pseudobaltica		85	$\frac{5}{.1}$	$\frac{4}{1}$
Cryptomonas rostrella		9	0	0
Cryptomonas ovata		8	0	$\frac{4}{.1}$

Table 11

(continued)

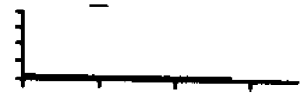
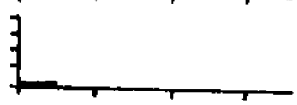
SPECIES	S	N	O	L
Cryptomonas erosa		26	0	$\frac{3}{.2}$
Cryptomonas borealis		6	0	$\frac{3}{.1}$
Cryptomonas testacea		32	$\frac{4}{.3}$	0
Cryptomonas croatanica		5	0	0
Dinophyceae				
Prorocentrum micans		21	0	0
Prorocentrum minimum		60	$\frac{2}{6}$	$\frac{1}{.4}$
Exuviaella compressa		45	$\frac{1}{.1}$	0
Exuviaella marina var. *adnatodens*		20	0	1
Dinophysis lachmanni		7	0	0
Amphidinium crassum		28	$\frac{7}{14}$	$\frac{3}{14}$
Amphidinium klebsi		35	0	$\frac{1}{.1}$
Amphidinium machapungarum		8	$\frac{1}{.2}$	0
Gymnodinium stellatum		7	0	$\frac{1}{.3}$
Gymnodinium nelsoni		51	0	$\frac{2}{.2}$
Gymnodinium danicans		120	$\frac{2}{1}$	$\frac{6}{2}$
Gymnodinium verruculosum		43	$\frac{3}{5}$	$\frac{8}{5}$

Table 11

(continued)

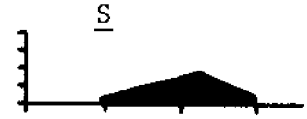
SPECIES	S	N	O	L
Gymnodinium gracilentum		19	0	$\frac{1}{.1}$
Gymnodinium aurantium		4	0	1
Gymnodinium roseostigma		19	0	0
Gymnodinium subroseum		43	$\frac{2}{1}$	0
Gymnodinium galesianum		101	$\frac{3}{.9}$	$\frac{7}{2.5}$
Gymnodinium agaricoides		8	0	0
Katodinium rotundatum		103	1	$\frac{3}{130}$
Katodinium asymmetricum		21	0	$\frac{1}{.3}$
Gyrodinium aureolum		25	0	0
Gyrodinium resplendens		6	0	0
Gyrodinium uncatenum		18	0	0
Gyrodinium estuariale		24	$\frac{3}{.2}$	$\frac{1}{.2}$
Gyrodinium metum		78	$\frac{3}{5}$	$\frac{2}{3}$
Gyrodinium pellucidum *Gyrodinium dominans*		136	$\frac{11}{32}$	$\frac{10}{27}$
Polykrikos kofoidi		8	0	0
Glenodinium rotundum		18	0	$\frac{1}{.5}$
Glenodinium danicum		6	0	0

Table 11

(continued)

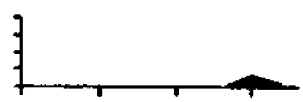
SPECIES	S	N	O	L
Heterocapsa triquetra		61	0	$\frac{4}{.2}$
Peridinium trochoideum		36	0	0
Peridinium aciculiferum		23	0	$\frac{1}{3}$
Peridinium brevipes		58	0	1
Goniaulax diacantha		38	0	$\frac{1}{.6}$
Haptophyceae				
Parachrysidalis estuariale		10	0	0
Prymnesium parvum		14	0	0
Chrysochromulina minor *Chrysochromulina kappa*		55	0	0
Chrysochromulina sp.		10	0	0
Hymenomonas carterae		25	0	0
Chrysophyceae				
Ochromonas caroliniana		11	0	0
Pavlova gyrans var. *simplex*		42	0	0
Pseudopedinella pyriforme		25	0	0
Apedinella radians		15	0	0
Calycomonas wulffii		18	0	0

Table 11

(continued)

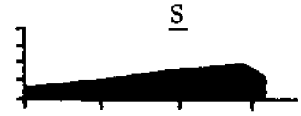
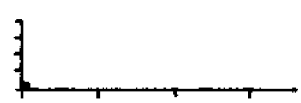
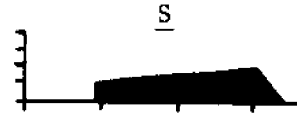
SPECIES	S	N	O	L
Calycomonas ovalis		81	$\frac{3}{3}$	$\frac{3}{12}$
Ebria tripartita		21	0	0
Xanthophyceae				
Nephrochloris salina		28	0	0
Olisthodiscus carterae		17	0	$\frac{1}{1}$
Olisthodiscus carterae var. *olivaceus*		46	$\frac{2}{122}$	$\frac{2}{36}$
Euglenophyceae				
Eutreptia viridis *Eutreptia lanowii*		86	$\frac{2}{15}$	$\frac{5}{42}$
Euglena proxima		21	0	$\frac{2}{.1}$
Euglena mutabilis		7	0	0
Euglena ehrenbergii		10	0	0
Euglena pumila		9	0	0
Trachelomonas hispida var. *punctata*		5	$\frac{2}{.3}$	0
Trachelomonas intermedia		6	0	$\frac{2}{.2}$
Prasinophyceae				
Heteromastix pyriformis		70	0	$\frac{3}{1}$
Pyramimonas grossii		18	0	$\frac{1}{.2}$

Table 11

(continued)

SPECIES	S	N	O	L
Pyramimonas torta		42	0	0
Pyramimonas micron		83	0	$\frac{4}{4}$
Pyramimonas plurioculata		17	0	0
Pyramimonas amylifera		21	0	0
Tetraselmis contracta		5	0	0
Tetraselmis gracilis		69	0	$\frac{2}{3}$
Tetraselmis maculata		31	0	0
Chlorophyceae				
Chlamydomonas bourellyi		7	0	0
Chlamydomonas vectensis		99	0	0
Chlamydomonas sp. "a"		33	0	$\frac{3}{6}$
Chlamydomonas sp. "b"		24	$\frac{1}{5}$	0

SUMMARY AND CONCLUSIONS

The qualitative and quantitative aspects of an annual phytoplankton cycle in Gales Creek, a small shallow natural coastal plain estuary on the North Carolina coast, is described based on data obtained from 29 cruises from August 1965 to November 1966, with samplings at approximately bi-weekly intervals from six stations along the estuary.

General physical and biological characteristics of the estuary are described. Basic environmental parameters of the estuary determined by hydrographic sampling included measurement of temperature, salinity, oxygen, secchi disc depth, pH, chlorophyll, and the nutrients nitrate, nitrite, ammonia, total nitrogen, inorganic phosphate and total phosphorus. 20 formalin preserved net samples were used for determining the qualitative seasonal diatom composition of the plankton, and over 480 water samples were used for live qualitative and quantitative estimation of the phytoflagellates and their seasonal distribution.

Gales Creek was found to have a high flushing rate with a tidal exchange ratio of 0.43, though water is apparently retained longer in the estuary than this figure would imply because in the upper portions of the creek the water masses mainly move back and forth with the tide. Mixing and dilution are still rapid, though, and only fast-growing broad-tolerance species attain any appreciable standing crop, while during periods of heavy fresh water runoff even these species are greatly diluted.

Temperatures in the estuary ranged from 3 to 34^{o}C, while salinities went from 0 to 37^{o}/oo. Stratification of the upper portions of the creek was strong, with a sharp halocline between the fresh surface water which was stained with humic substances, and the underlying clear brackish water. Winter and summer were seasons of heavier fresh water runoff and lower salinities in the creek. Highest salinities occurred during the dry autumn season.

During periods of heavy fresh water runoff the darkly tannin stained water sharply attenuated light transmission. However, the extreme shallowness of the estuary tended to counterbalance this effect, so that few samples were considered to be below the compensation depth for photosynthesis. Anoxic conditions occurred in bottom waters in the upper regions of the creek from late spring to the end of summer, posing a possible stress for species without anaerobic capabilities and/or lacking chloroplasts. In all but the most oligohaline waters pH was well buffered by seawater and was not considered to be a limiting environmental factor.

Both nitrogen and phosphorus showed low concentrations in spring and autumn, which correlated with the periods of low fresh water runoff, while highest concentrations of these nutrients occurred in summer. Nitrate values were low compared to phosphate, as revealed in the yearly NO_3/PO_4 average for the estuary of only 3.75:1. Low nitrogen has been reported from other waters in the region and is considered an important limiting factor.

In terms of number of taxa represented, the Bacillariophyceae was the most important class of phytoplankton present in Gales Creek. Listed with references are a total of 187 diatom taxa identified from the preserved net samples, of which 49 were centric diatoms, and 138 were pennate diatoms. They exhibited a classical bimodal pattern of seasonal abundance, with population maxima in spring and autumn. The most important spring dominant was *Skeletonema costatum*. *Chaetoceros lorenzianus* and *C. teres* were important species in both the spring and autumn seasons. *Coscinodiscus granii* was a typical summer and autumn species. *Chaetoceros curvisetus* dominated the autumn plankton. High autumn concentrations of *Rhizosolenia calcar-avis* and *Cerataulina bergoni* occurred in 1965 but not 1966, indicating that variable conditions must occur in the creek from year to year.

Throughout most of the year diatom concentrations were less than those of the phytoflagellates, which, in terms of total standing crop, were the most important group of plankton in the creek. The yearly average for total phytoflagellate density was 5×10^5 cells/liter, a low standing crop value compared with densities reported from other estuaries on the eastern coast. These low concentrations

are considered to be the consequence of two major limiting factors, low available nitrogen concentrations and high flushing rate of the estuary. The lowness of the figure, however, may partly be due to absence of measured diatom densities. The most stable region in terms of cell densities was the mixing basin, while the most variable was the headwaters, subject to periodic influxes of fresh water. Highest phytoflagellate concentrations occurred in the middle reaches, where the disruptive effect of freshwater inflow is lessened and the tidal influence does not strongly dilute the populations with each exchange.

The phytoflagellates were distributed among nine classes of algae, with the most important of these being the Dinophyceae with 76 species. These nine classes included a total of 152 species of phytoflagellates in 49 genera. These are described and figured from the Gales Creek material, and include 32 species, 4 varieties, and 6 combinations new to science. Characteristic spring species included *Prorocentrum minimum*, *Heterocapsa triquetra*, *Pavlova gyrans* var. *simplex* and *Nephrochloris salina* in early spring, and *Chroomonas minuta* var. *apyrenoidosa* and *Amphidinium crassum* in late spring. The broad late summer-early autumn peak of abundance was characterized by *Chroomonas caroliniana*, *Chroomonas amphioxeia* and *Chroomonas minuta* var. *apyrenoidosa*, *Katodinium rotundatum*, *Gyrodinium pellucidum* and *Gyrodinium dominans*, *Calycomonas ovalis*, *Olisthodiscus carterae* var. *olivacea* and *Pyramimonas micron*. Late autumn saw an abundance of the prasinophytes *Heteromastix pyriformis*, *Pyramimonas micron*, *P. torta*, *P. plurioculata*, and *Tetraselmis gracilis*, along with two species of *Chrysochromulina* and a reappearance of *Pavlova gyrans* var. *simplex*. *Chlamydomonas vectensis* was important in both spring associations, the maximum summer peak and the late autumn community. Winter saw abundant concentrations achieved by *Katodinium rotundatum*, *Heterocapsa triquetra*, and *Pyramimonas grossii*.

The highest cell densities of any species in the estuary were attained by *Olisthodiscus carterae* var. *olivaceus*, which reached 8×10^7 cells/liter in August. This concentration is still under the figure 3×10^8 cell/liter given by Hulburt (1970) as the density below which maximum size nutrient depleted zones about plankton cells cannot

overlap, and therefore where there is no possibility of an abundant species monopolizing the nutrient supply and forcing a less abundant form to extinction, thereby reducing diversity. According to this criterion there is noncompetition for nutrients in Gales Creek, fluctuation in species abundance is benign, and a great array of species exists in harmony limited only by physical factors in the environment. This of course could change should the estuary become enriched by organic wastes.

Eurythermal and euryhaline tolerances appeared to be characteristic for most of the important phytoflagellate species in the creek. For those characteristic species where enough samples were available for correlation, 11 species were considered eurythermal, having been collected from the entire range of temperatures that occurred in the estuary, 5 were from warmer waters, 2 were from intermediate temperatures, and 1 was collected only from colder waters. 21 of the characteristic species were considered euryhaline, having been collected from the entire range of salinities encountered in the estuary, while 10 more were absent only from oligohaline waters. Few species of phytoflagellates are contributed to the estuary by the freshwater inflow, while many more are probably introduced with the tidal exchanges from the adjacent euhaline sound. Over 2/3 of the species in the creek were found in water samples between 15 and 30 $^{o}/_{oo}$ salinity. The only salinities always encountered in large volumes of water in the estuary are in this range. 105 species appeared to be adapted to these brackish conditions, which attests to the relative constancy of these conditions in this fluctuating environment.

The present investigation has concentrated mainly on the phytoflagellates. Now that this study has made available descriptions, references, illustrations, and distribution data for these important estuarine species, together with a list with references and distribution for the diatoms, and description of a simple yet reasonably accurate method for plankton identification and enumeration, it should be much easier for new studies in southern brackish waters to be initated which can encompass the entire phytoplankton community. This study has pointed up a number of other important areas which such future investigations should also include, among them the dynamic questions of the turnover rates of important nutrients,

phytoplankton productivity and growth, and the relative importance of the benthic diatom algal layer in these shallow esturine systems. It is important that many more estuarine studies be done to broaden our understanding of these areas so important to the ecology of our southern coastal waters, before they too should become subject to increasing pollution and destruction rising out of man's ignorance.

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PLATES

PLATE I

(Class Cryptophycene)

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a-b. Lateral views

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i. Apical view of anterior furrow

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PLATE 1

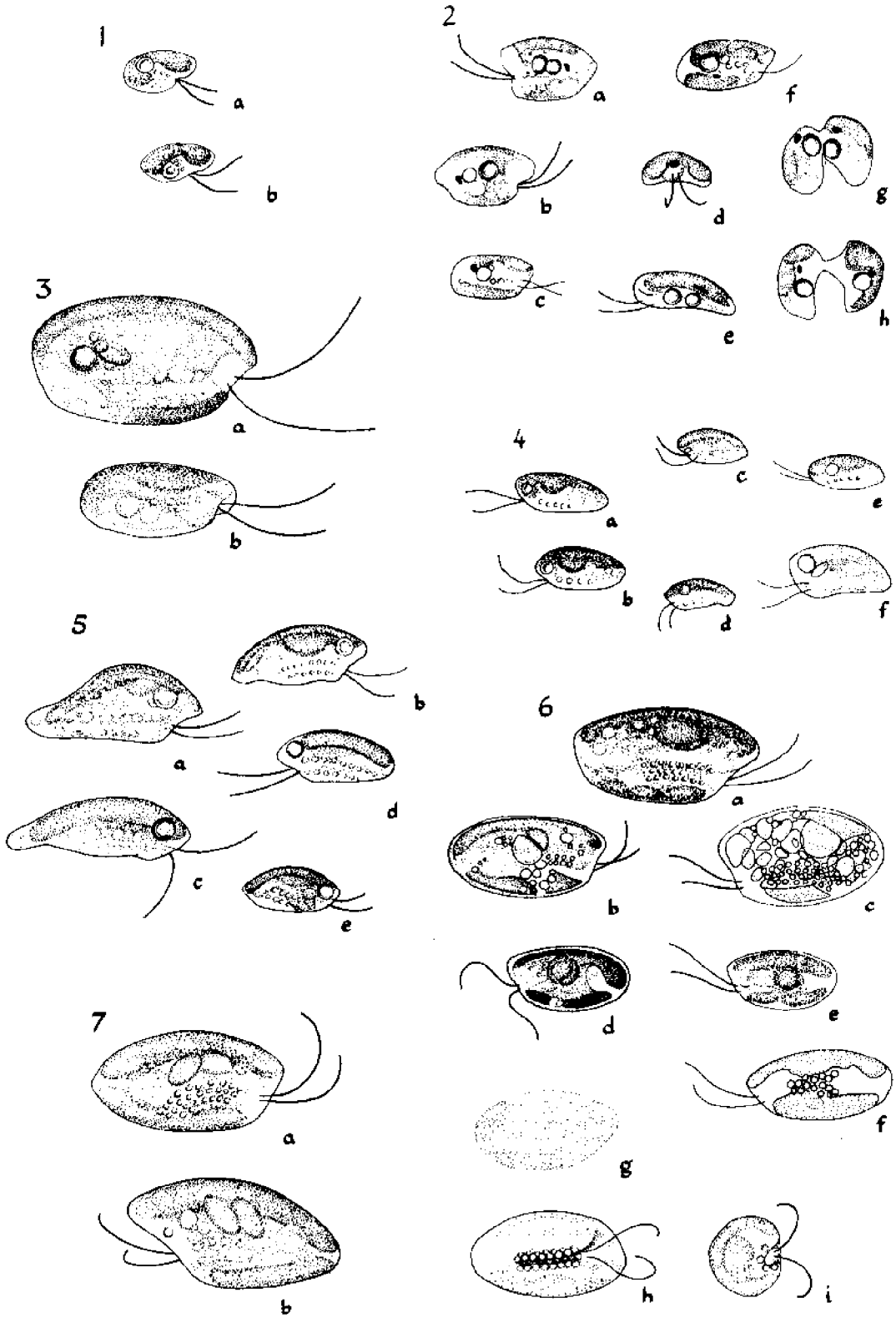

PLATE 2

(Class Cryptophyceae, cont.)

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PLATE 2

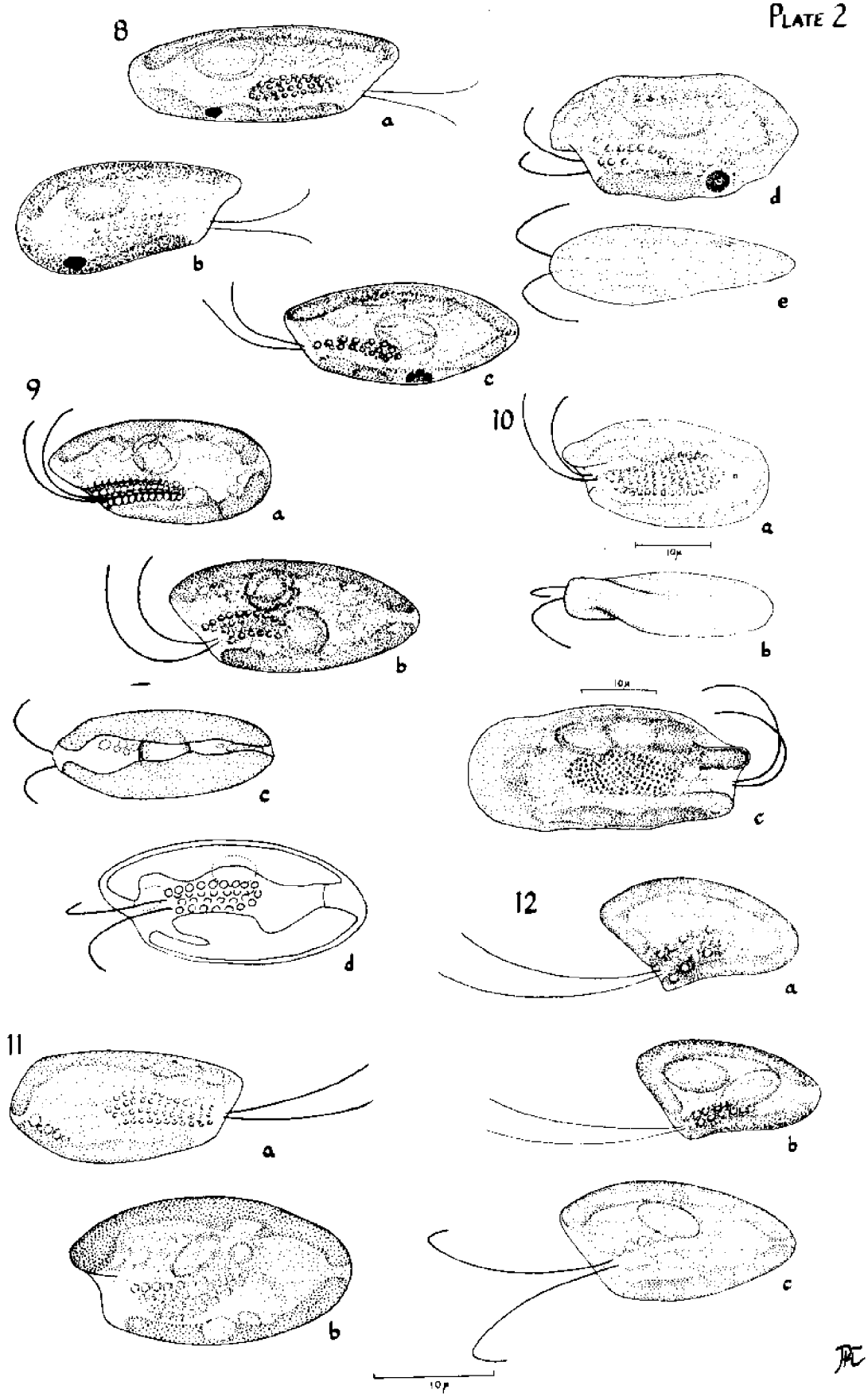

PLATE 3

(Class Dinophyceae)

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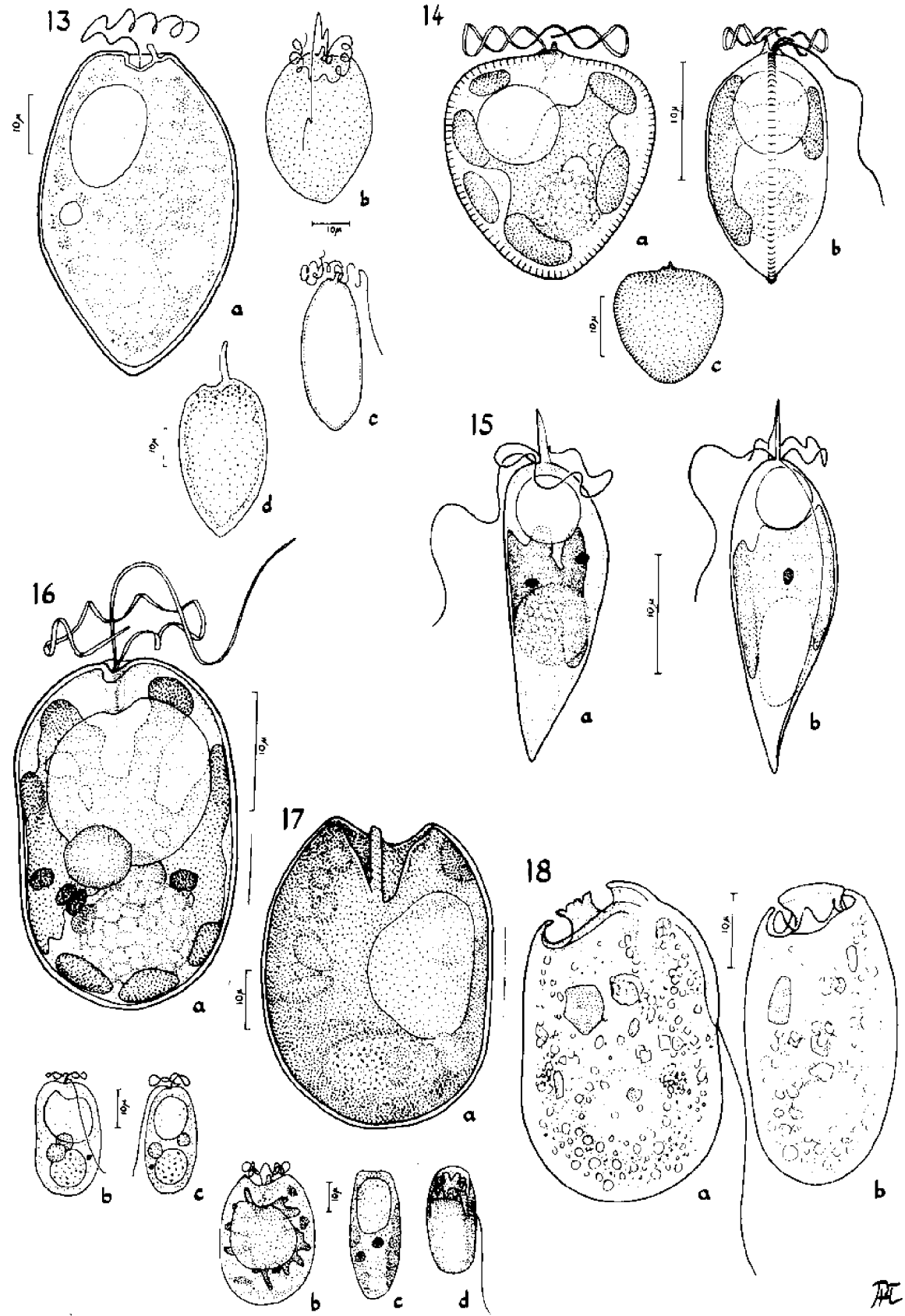
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PLATE 4

(Class Dinophyceae, cont.)

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b. Lateral view

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f. Ventral view of larger cell with flatter epicone and anterior stigma tentatively included in this species (see Plate 24, Fig. 8)

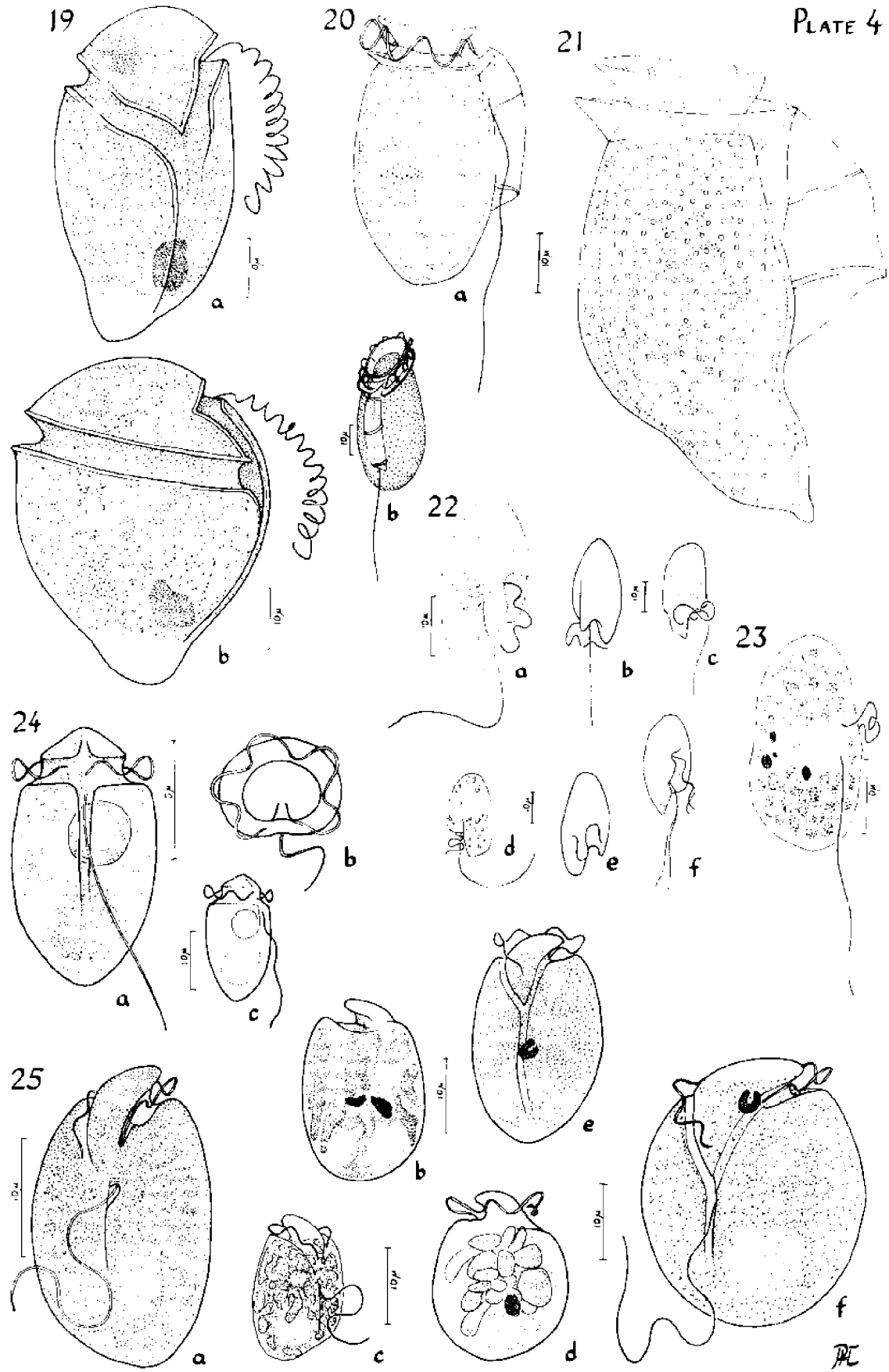
PLATE 4
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PLATE 5

(Class Dinophyceae, cont.)

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b. Lateral view
c. Dorsal view

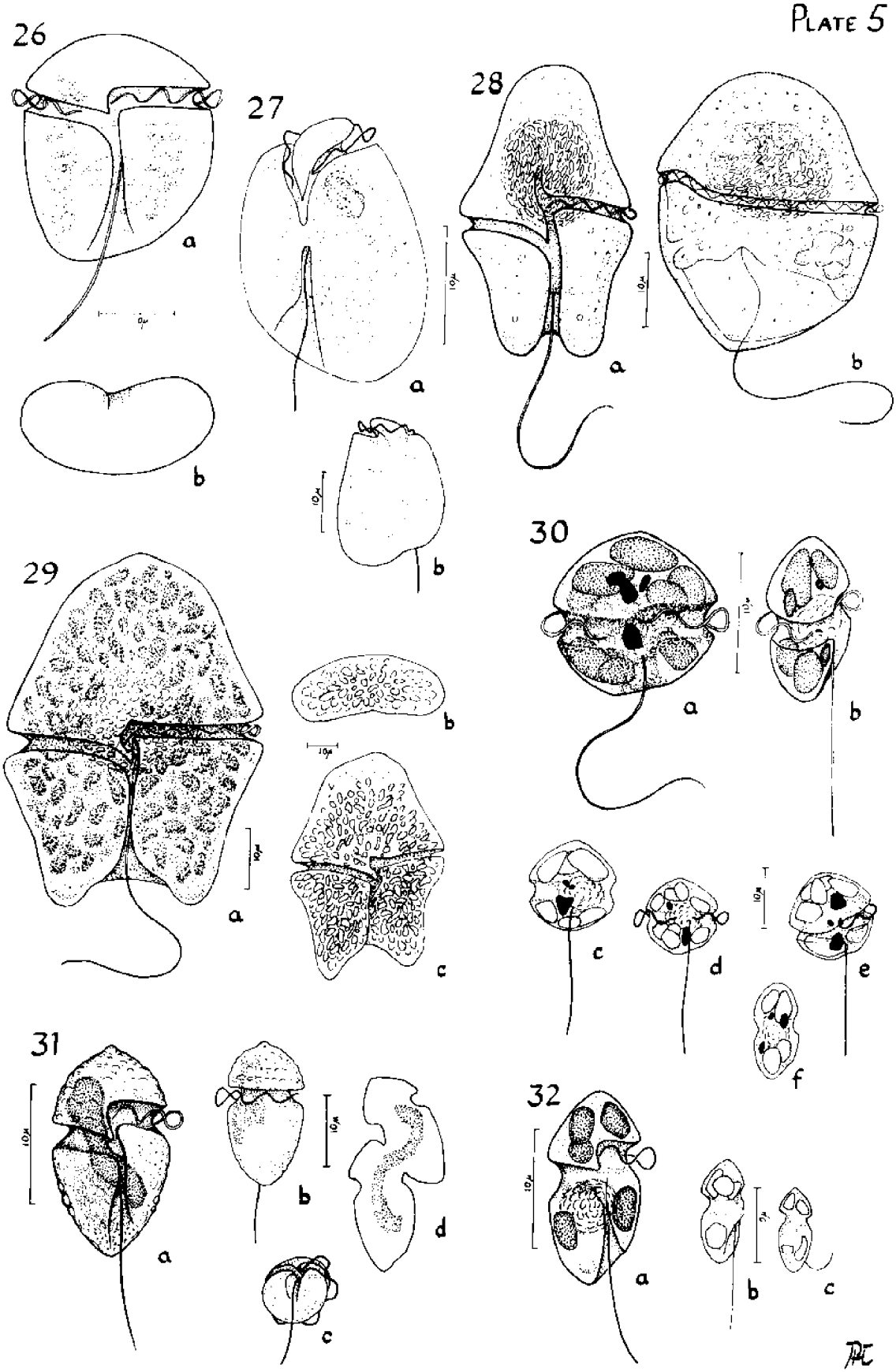
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PLATE 6

(Class Dinophyceae, cont.)

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b. Ventral view

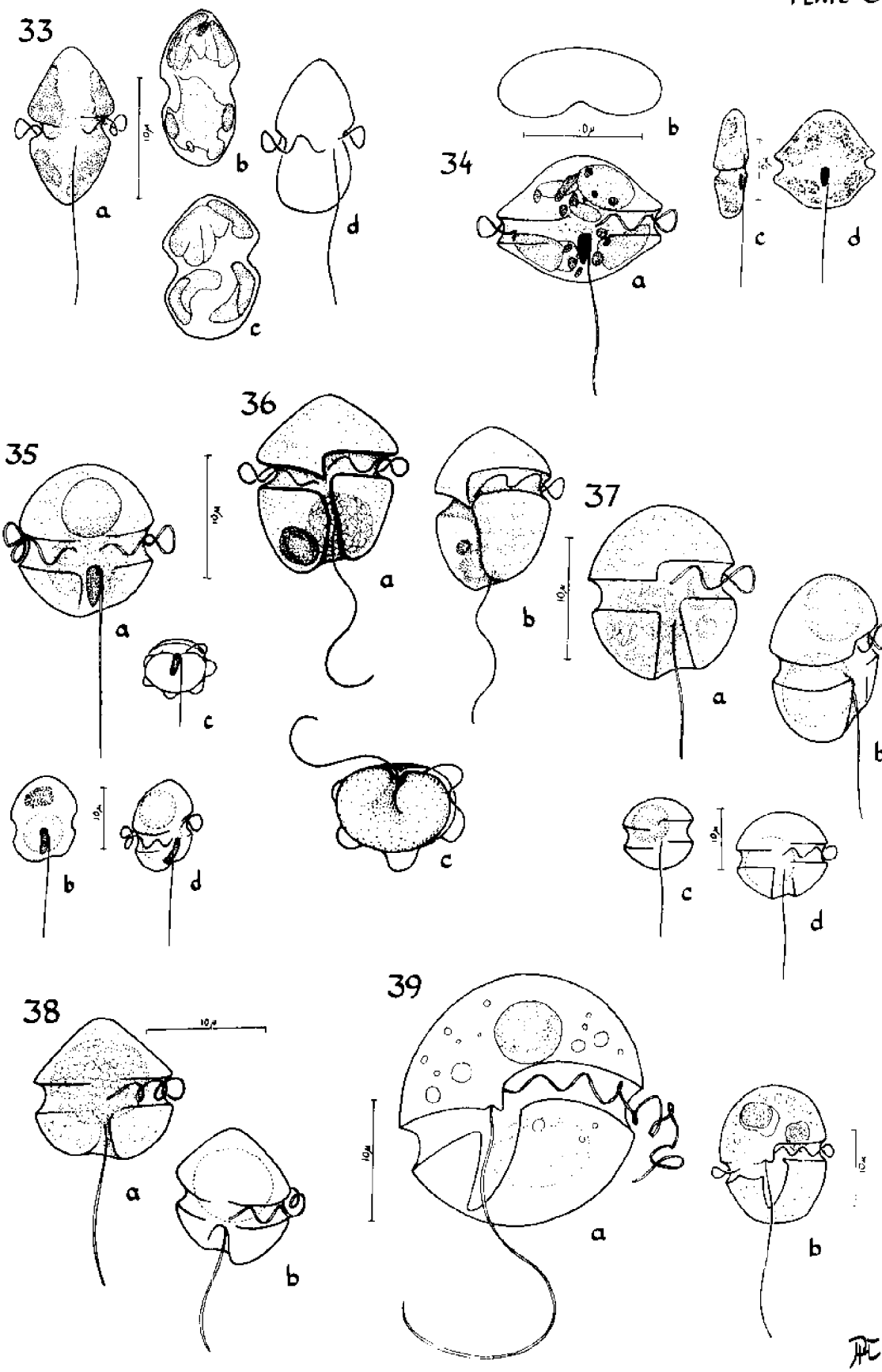
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PLATE 7

(Class Dinophyceae, cont.)

Fig. 40. *Gymnodinium lobularis* sp. nov. . . . . p. 141
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b. Lateral view

Fig. 41. *Gymnodinium agaricoides* sp. nov. . . . . p. 142
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c. Lateral view

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b. Antapical view
c. Ventrilateral view

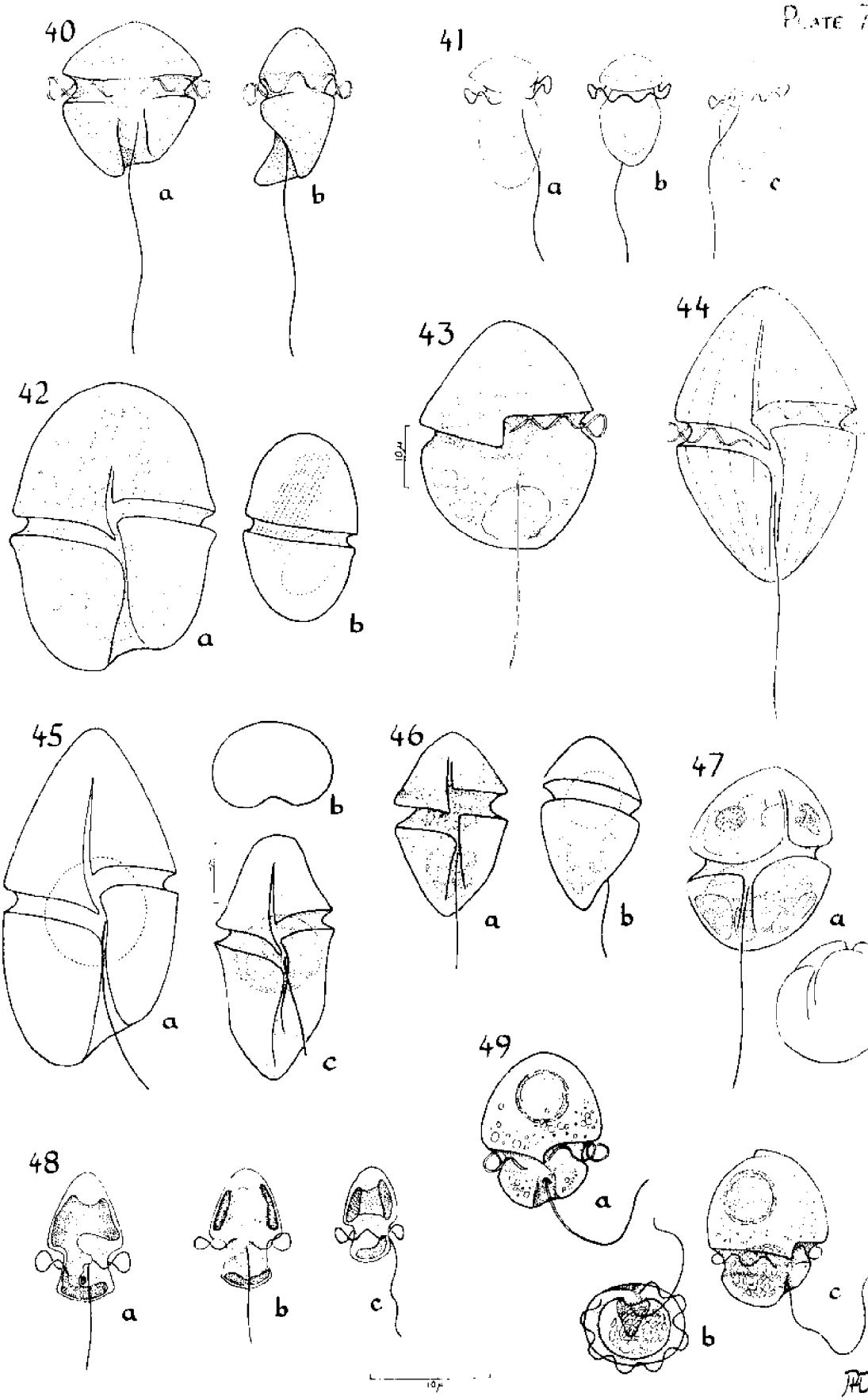
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PLATE 8

(Class Dinophyceae, cont.)

Fig. 50. *Katodinium pluristigmatum* sp. nov. . . . . p. 149
a. Ventral view
b. Ventrilateral view
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Fig. 51. *Gyrodinium aureolum* Hulburt . . . . . p. 150
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b. Ventrilateral view

Fig. 53. *Gyrodinium uncatenum* Hulburt . . . . . p. 152
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a. Ventral view
b. Ventrilateral view
c. Antapical view
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g. Ventral view, very large cell

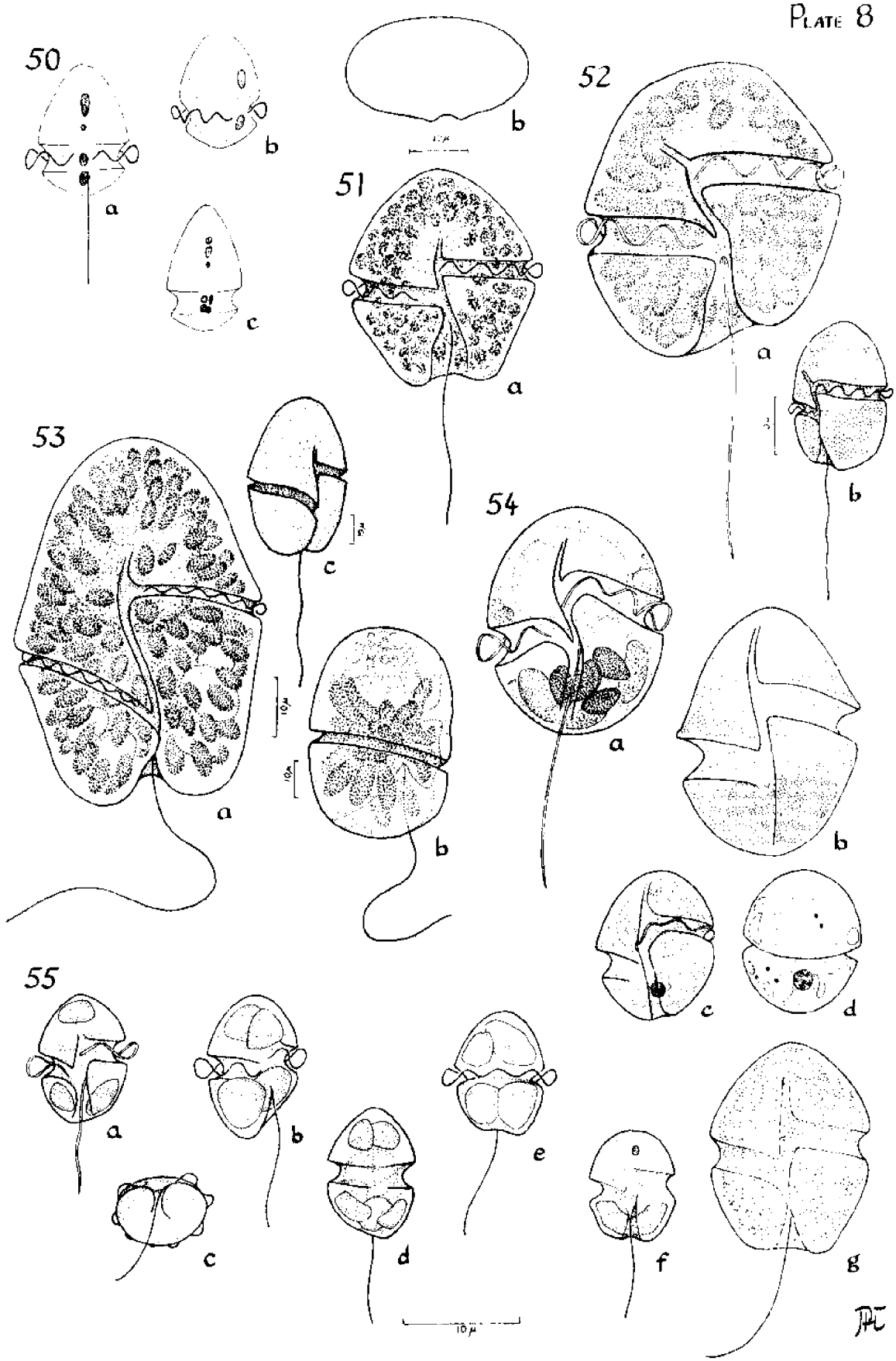
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PLATE 9

(Class Dinophyceae, cont.)

Fig. 56. *Gyrodinium complanatum* sp. nov. . . . . p. 156
a. Ventral view
b. Obliquely apical view
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Fig. 57. *Gyrodinium carteretensis* sp. nov. . . . . p. 155
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b. Ventriantapical view
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g. Lateral view
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j. Dorsiantapical view
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m-q. Ventral views of various cell forms

Fig. 59. *Gyrodinium formosum* sp. nov. . . . . p. 157
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Fig. 60. *Gyrodinium glaebum* Hulburt . . . . . p. 158
Ventral view, flagella absent

Fig. 61. *Gyrodinium katodiniascens* sp. nov. . . . . p. 159
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Fig. 62. *Gyrodinium pellucidum* (Wulff) Martin . . . . . p. 160
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b-d. Ventral views showing variations in form

PLATE 9

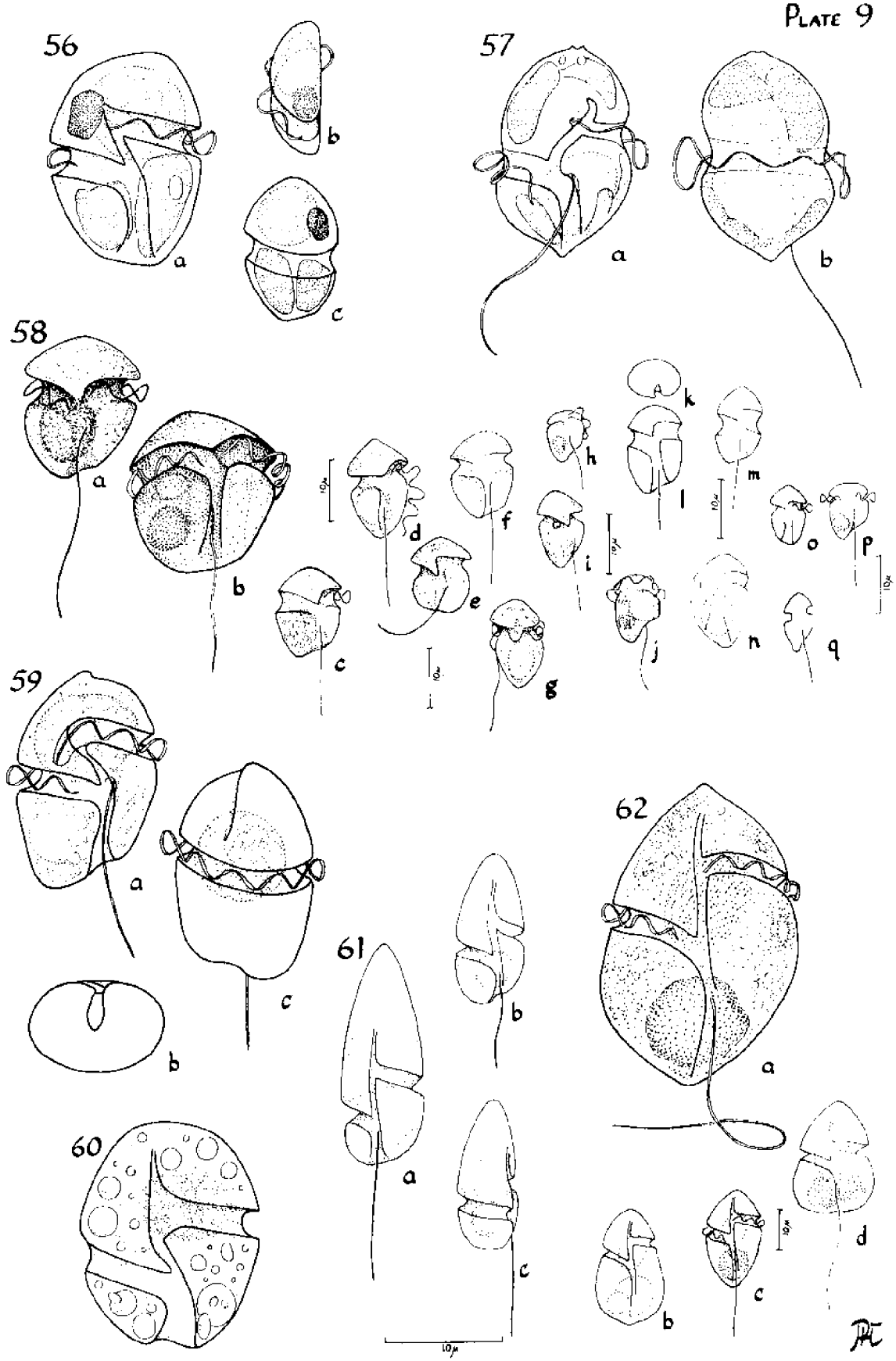

PLATE 10

(Class Dinophyceae, cont.)

Fig. 63. *Gyrodinium dominans* Hulburt . . . . . p. 161
a. Ventral view
b. Ventral view of smaller cell with larger girdle displacement

Fig. 64. *Gyrodinium grossestriatum* sp. nov. . . . . p. 162
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Fig. 66. *Gyrodinium* sp. "b" . . . . . p. 163
Ventral view, flagella absent

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b. Apical view

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Fig. 70. *Gyrodinium* sp. "f" . . . . . p. 166
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b. Ventrilateral view

Fig. 71. *Gyrodinium* sp. "g" . . . . . p. 166
a. Ventrilateral view
b. Ventral view
c. Lateral view

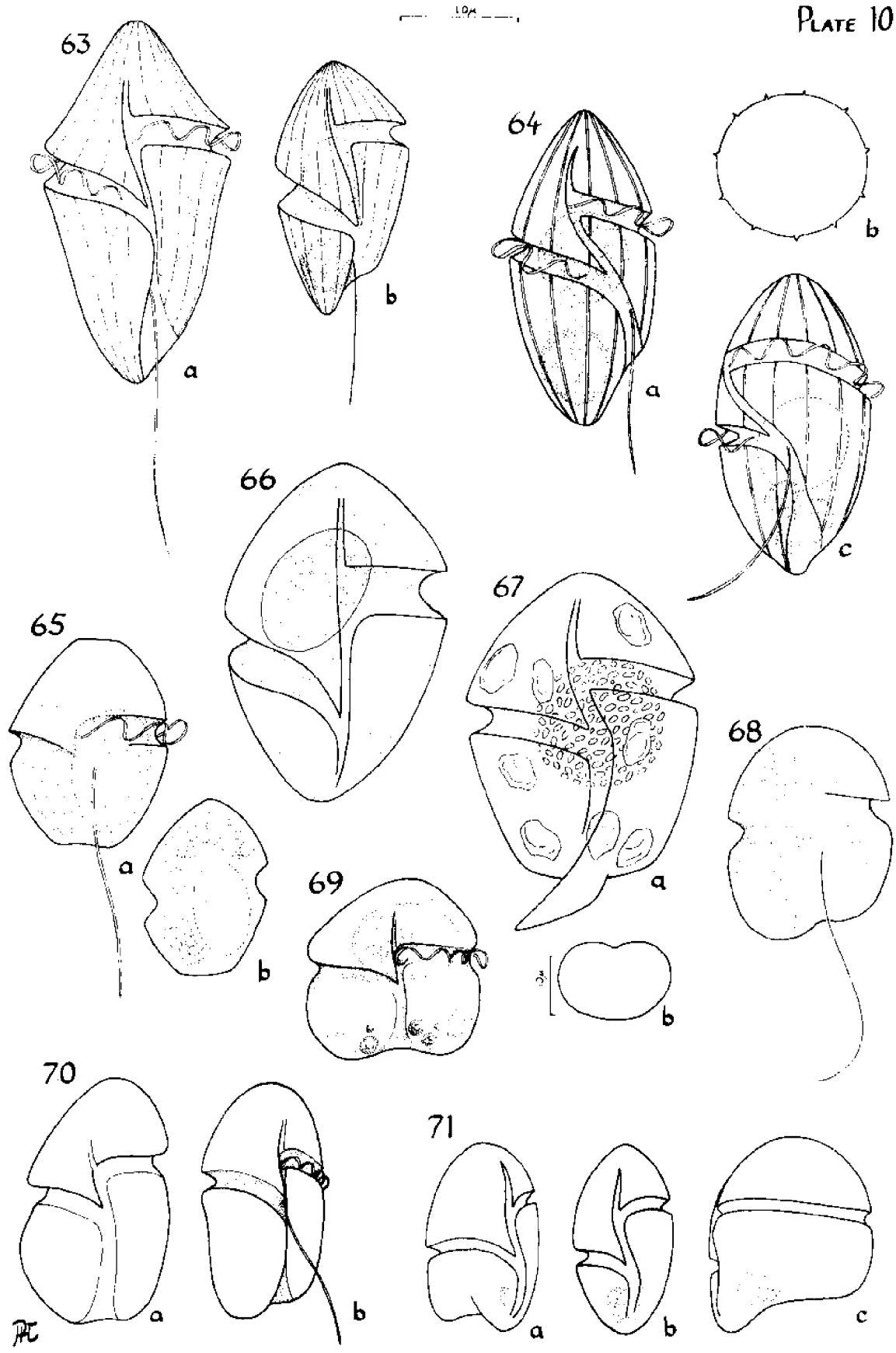
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PLATE 11

(Class Dinophyceae, cont.)

Fig. 72. *Polykrikos hartmanni* Zimmermann . . . . . p. 167
Ventral view, longitudinal flagella absent

Fig. 73. *Polykrikos kofoidi* Chatton . . . . . p. 167
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b-c. Apical and ventral view, two zooid colony

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b. Antapical view

Fig. 76. *Glenodinium danicum* Paulsen . . . . . p. 170
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b. Dorsal view

Fig. 77. *Glenodinium obliquum* Pouchet . . . . . p. 170
a. Lateral view
b. Antapical view
c. Ventral view

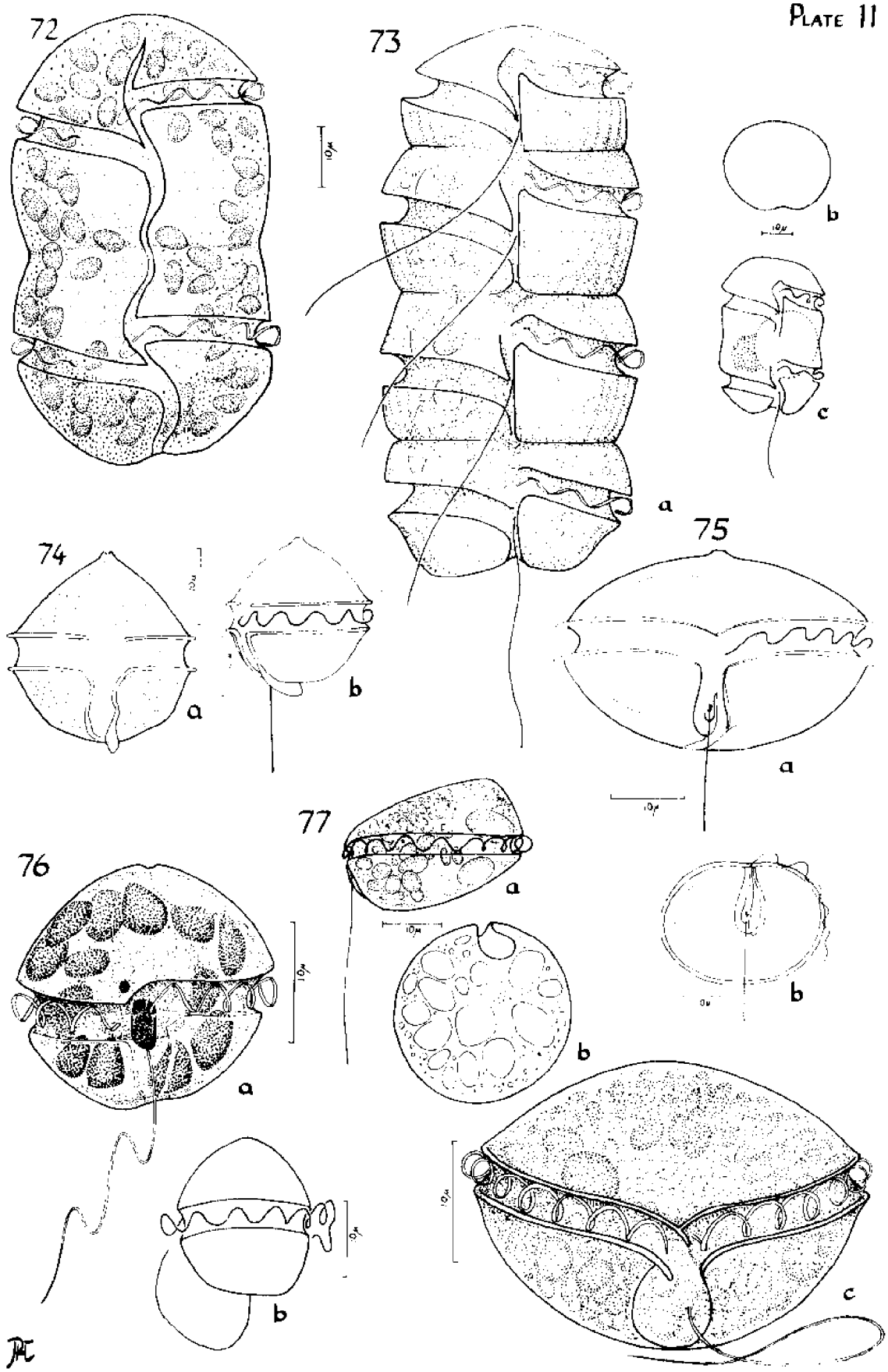
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PLATE 12

(Class Dinophyceae, cont.)

Fig. 78. *Heterocapsa triquetra* (Ehrenberg) Stein . . . . . p. 172
a. Ventral view
b. Ventral view of plate arrangement
c. Cell with flagella absent
d. Obliquely dorsal view of plate arrangement

Fig. 79. *Peridinium trochoideum* (Stein) Lemmermann . . . . p. 173
a. Ventral view, flagella absent
b. Ventral view of plate arrangement

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d. Ventral view

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PLATE 12

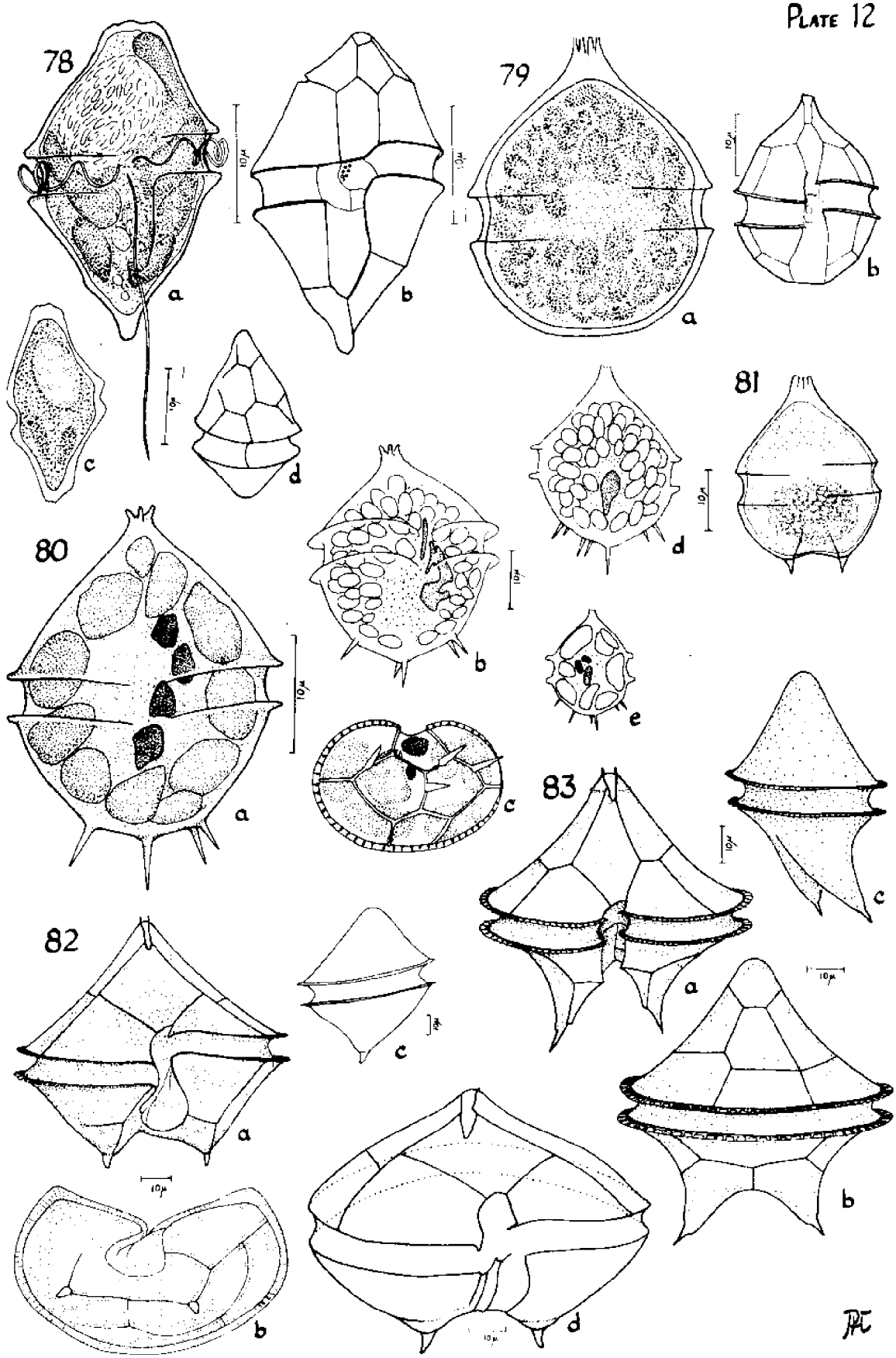

PLATE 13

(Class Dinophyceae, cont.)

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b. Lateral view

Fig. 88. ? *Goniaulax* sp. . . . . p. 181
a. Ventral view
b. Apical view

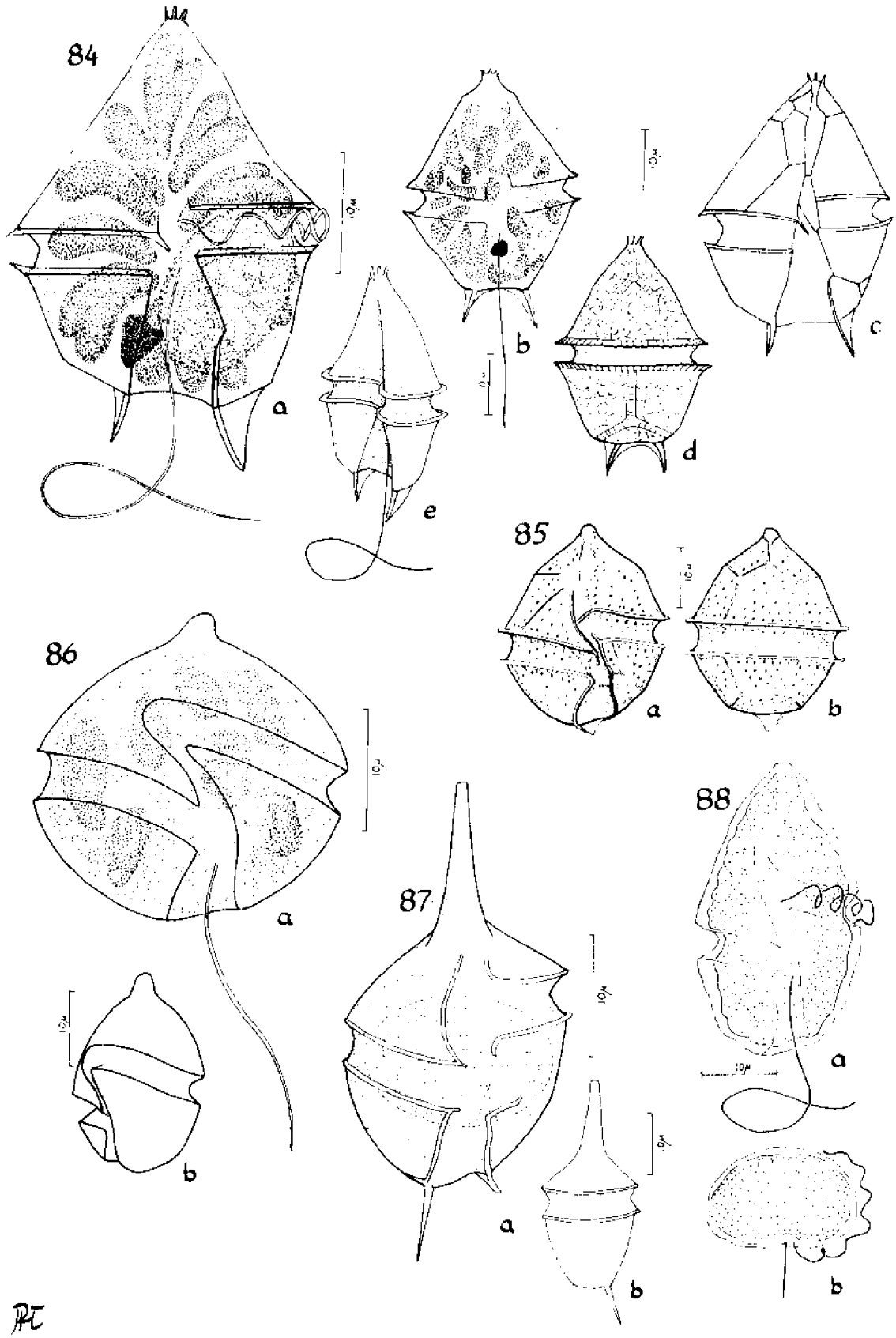
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PLATE 14

(Class Haptophyceae)

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b. Narrow lateral view
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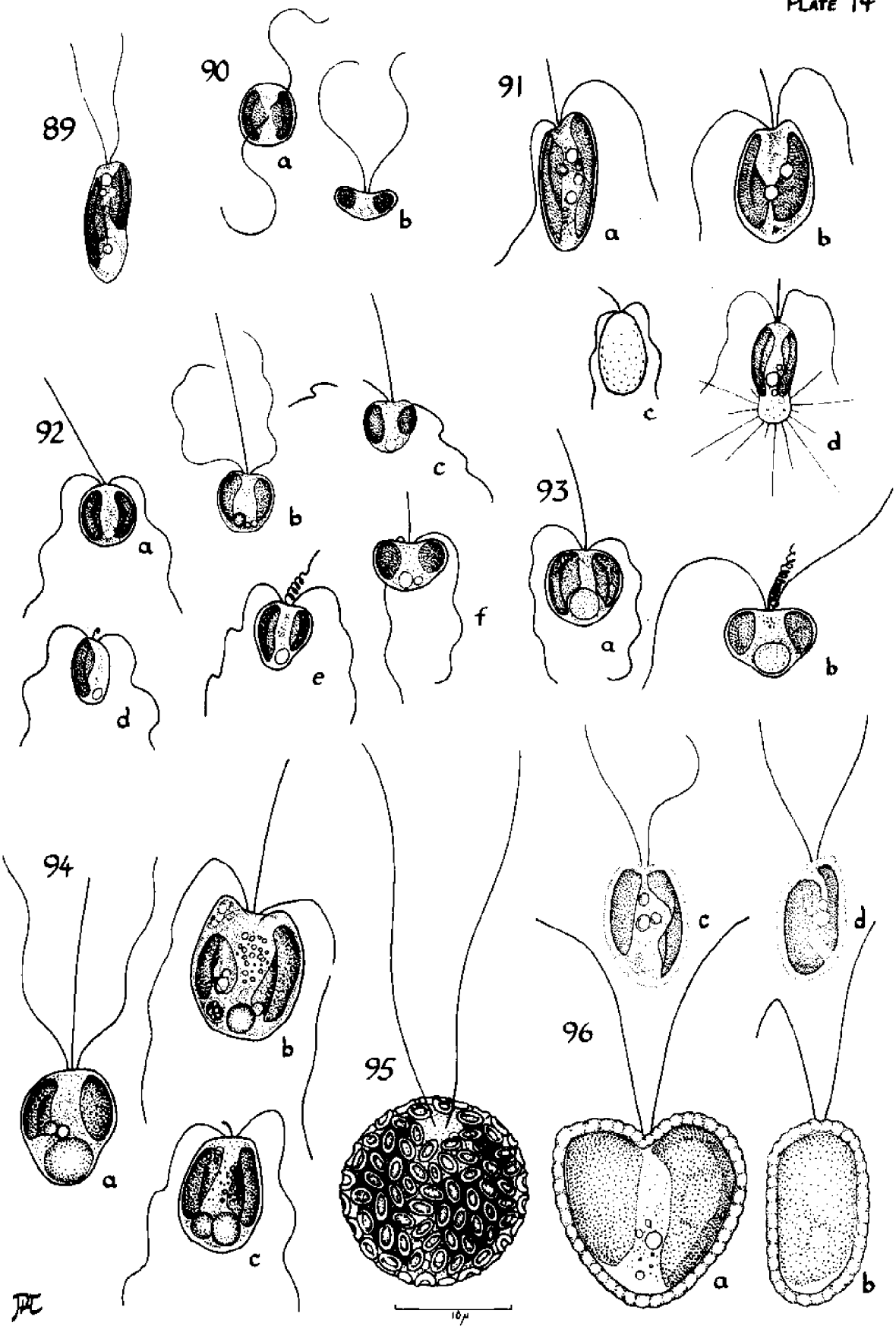
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PLATE 15

(Class Chrysophyceae)

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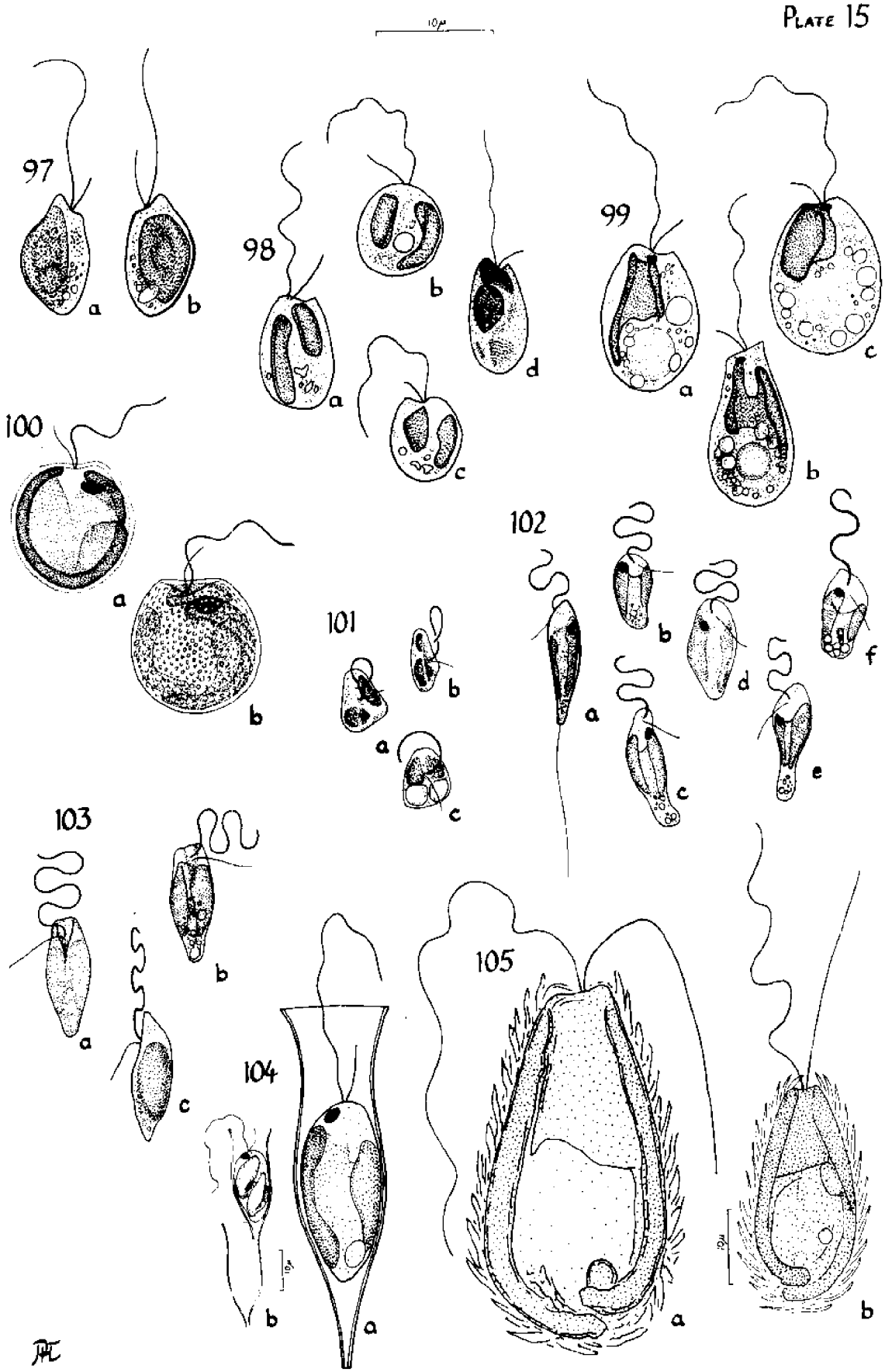
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104
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a
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PLATE 16

(Class Chrysophyceae, cont.)

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[Rhizopoda]

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PLATE 16

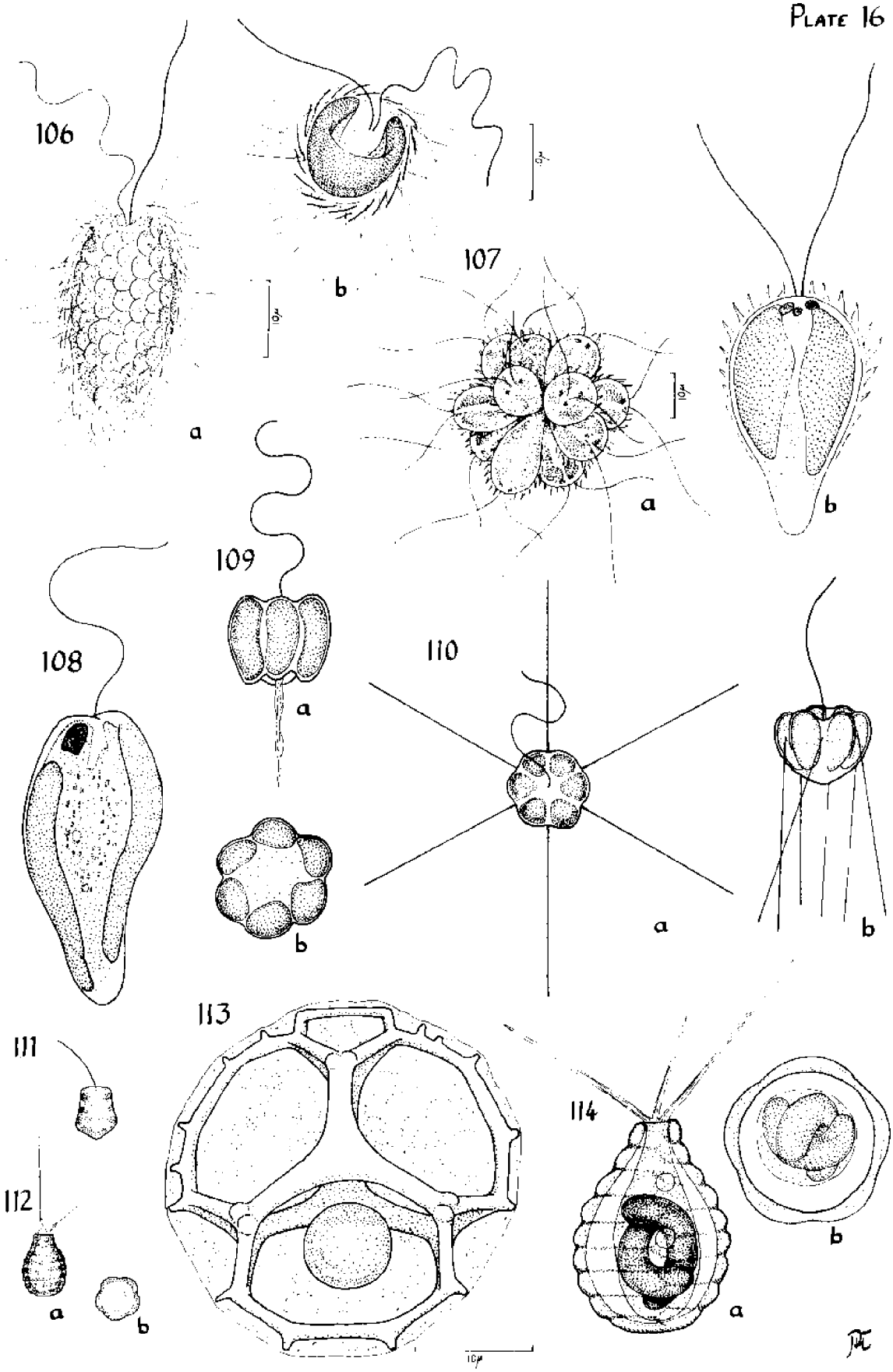

PLATE 17

(Class Xanthophyceae)

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(Class Raphidophyceae)

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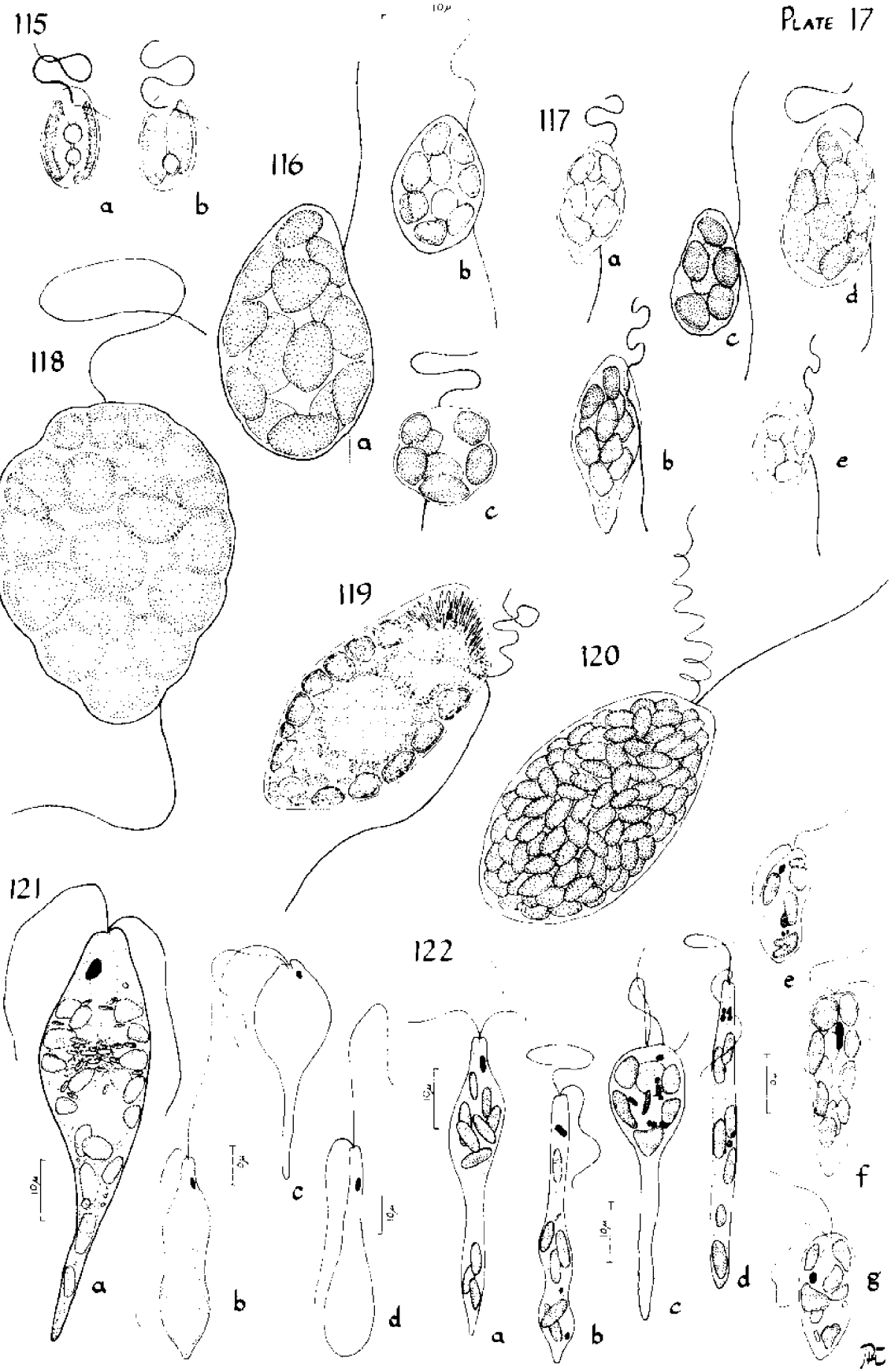
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PLATE 18

(Class Euglenophyceae, cont.)

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b. Punctate surface of lorica

Fig. 129. *Trachelomonas intermedia* Dangeard . . . . . p. 213
a. Lateral view of cell in lorica
b. Punctate surface of lorica

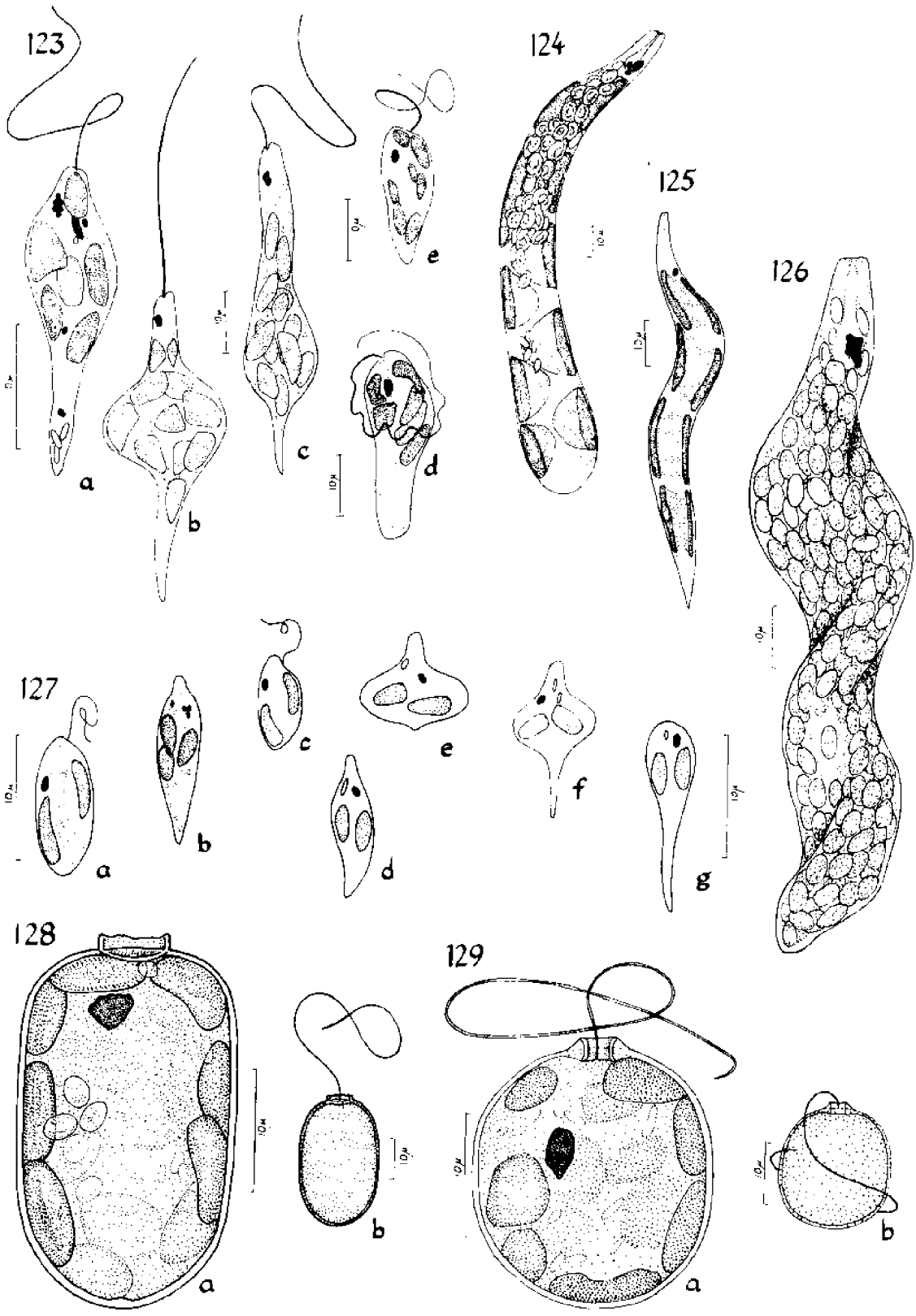
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PLATE 19

(Class Prasinophyceae)

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a. Broad-lateral view
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c-d. Lateral and apical views, more ovoid cell
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Lateral view

Fig. 138. *Pyramimonas* sp. . . . . p. 220
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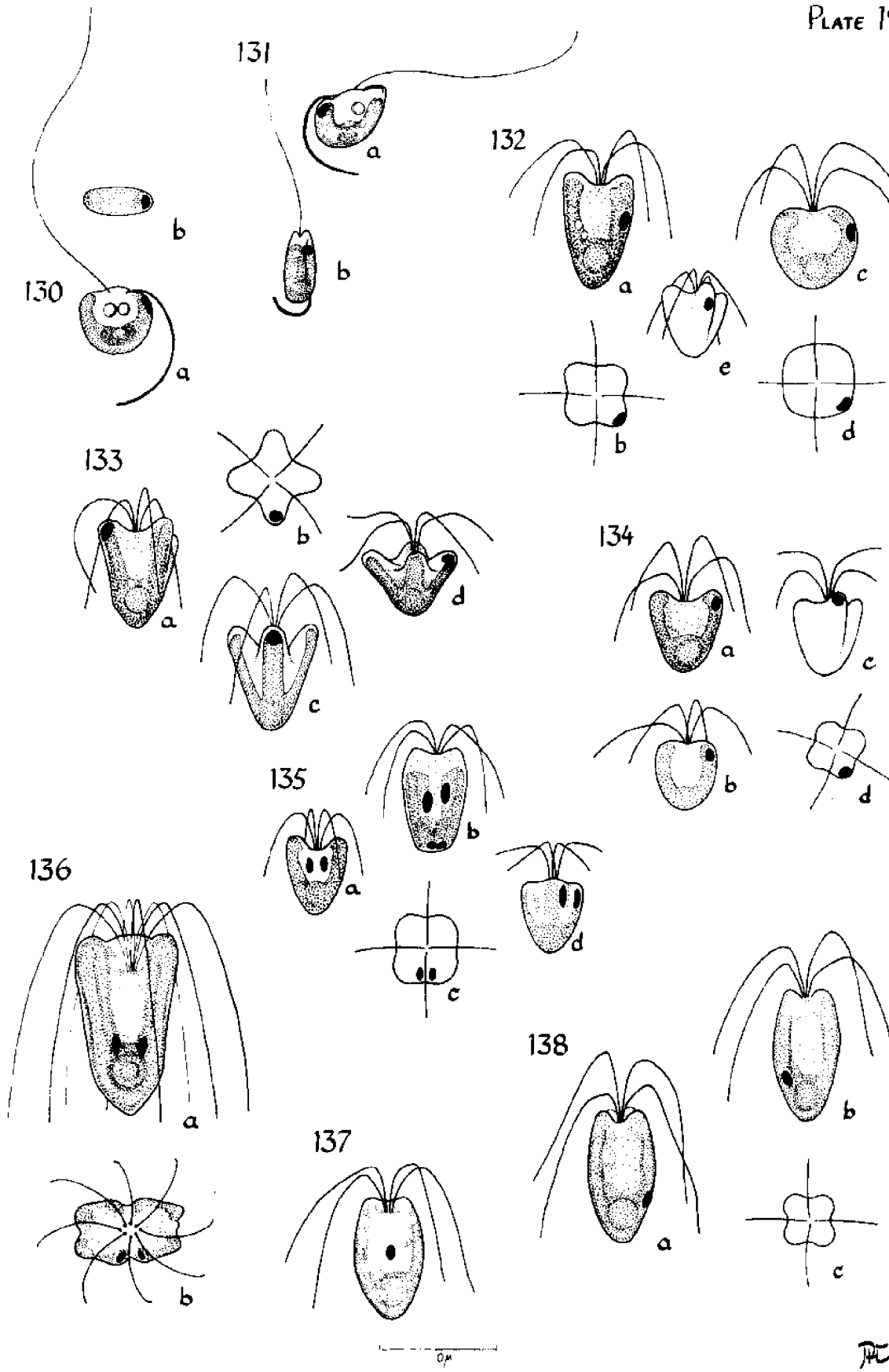
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b
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PLATE 20

(Class Prasinophyceae, cont.)

Fig. 139. *Tetraselmis contracta* (Carter) Butcher . . . . . p. 220
a. Broad-lateral view
b. Narrow-lateral view

Fig. 140. *Tetraselmis gracilis* (Kylin) Butcher . . . . . p. 221
a. Broad-lateral view, more delicate cell
b. Broad-lateral view, typical large stigma

Fig. 141. *Tetraselmis maculata* Butcher . . . . . p. 222
a. Broad-lateral view
b. Broad-lateral view of cyst

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b. Narrow-lateral view
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Broad-lateral view, flagella absent

(Class Chlorophyceae)

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a. Broad-lateral view
b. Narrow-lateral view

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b. Lateral view

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a. Elongately elliptical cell
b. Broadly elliptical cell

Fig. 147. *Chlamydomonas ? gregaria* Butcher . . . . . p. 226
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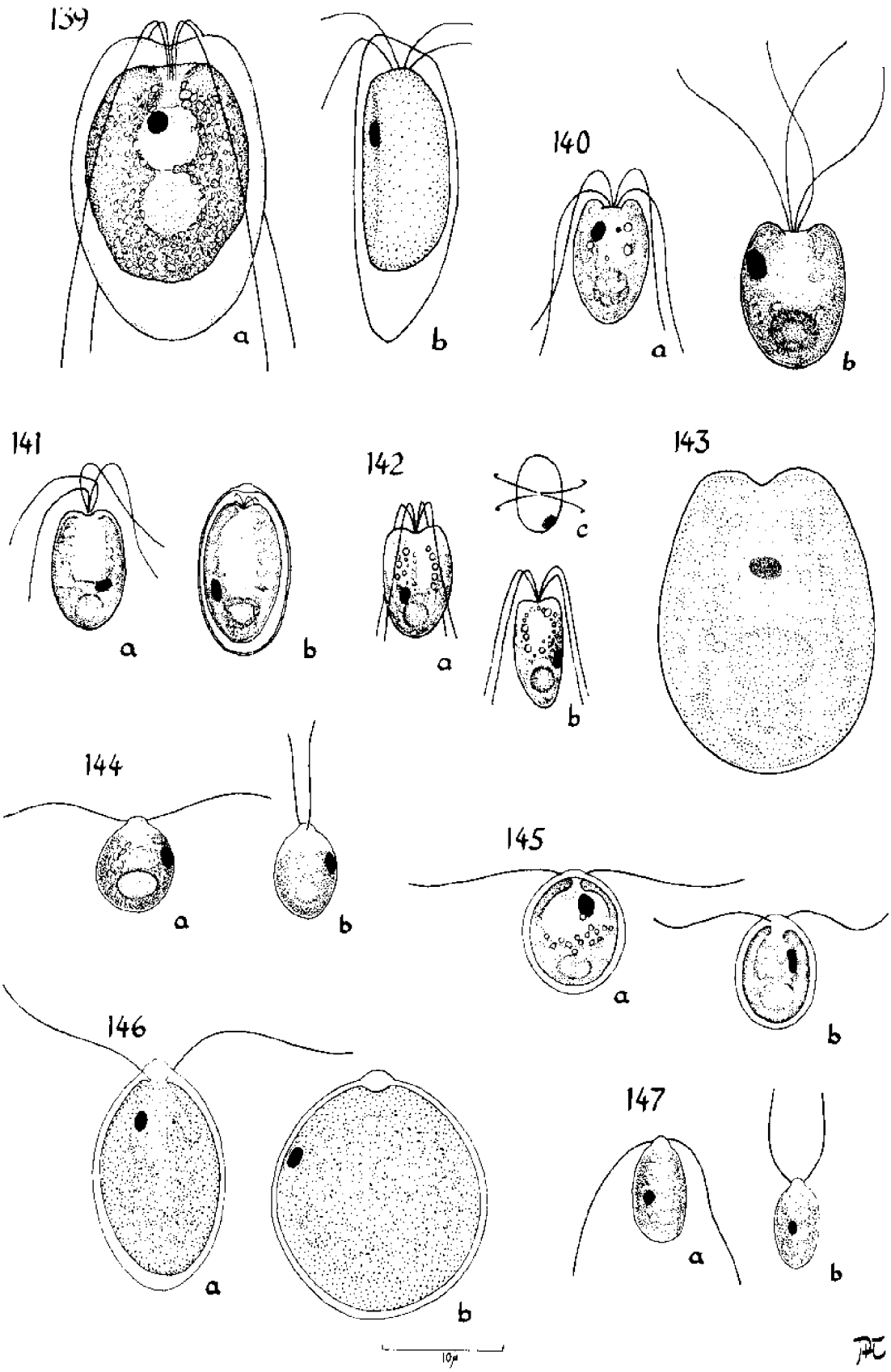
b. Lateral view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10μ

PLATE 21

(Class Chlorophyceae, cont.)

Fig. 148. *Chlamydomonas* cf. *vectensis* Butcher . . . . . p. 227
a-e. Lateral views

Fig. 149. *Chlamydomonas* sp. "a" . . . . . p. 228
a-d. Lateral views

Fig. 150. *Chlamydomonas* sp. "b" . . . . . p. 229
a-d. Lateral views
e. Cyst with two daughter cells

Fig. 151. *Chlamydomonas* sp. "c" . . . . . p. 229
a-c. Lateral views

Fig. 152. *Chlamydomonas* sp. "d" . . . . . p. 230
a-b. Lateral views

Fig. 153. *Chlamydomonas* sp. "e" . . . . . p. 231
Lateral view, with fenestrated plastid

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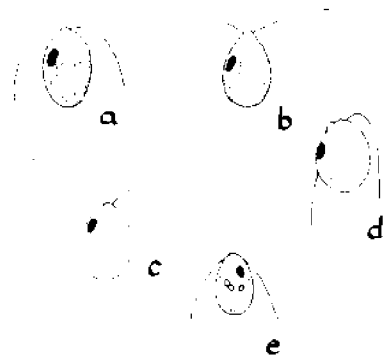

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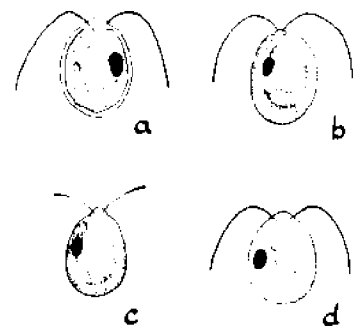

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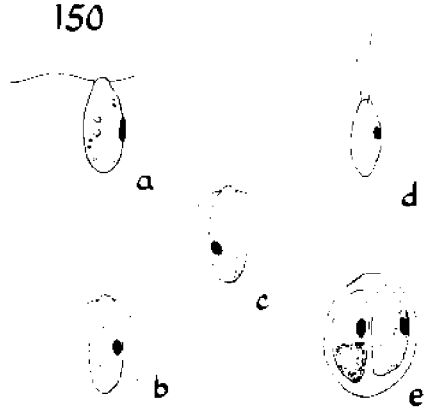

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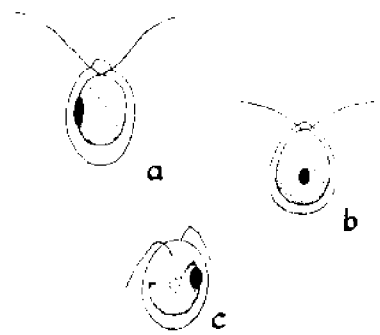

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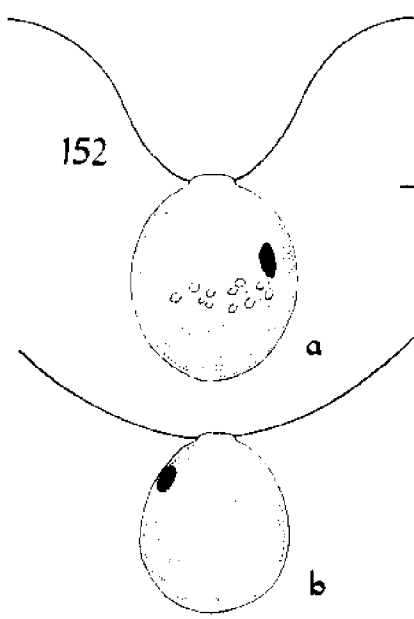

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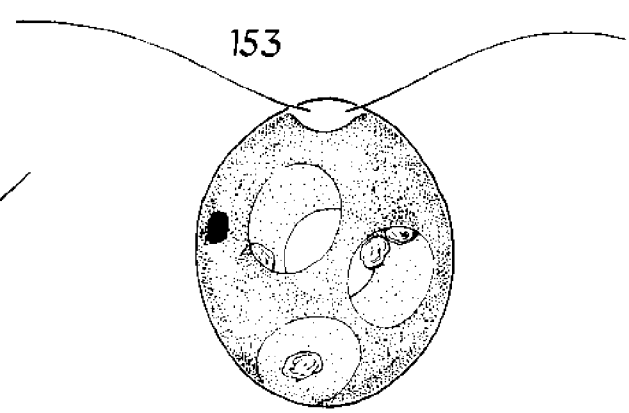


PLATE 22

(Class Cryptophyceae)

Hemiselmis virescens Droop . . . . . p. 103
Lateral views: Fig. 1, X 6400; Fig. 2, X 3600
Fig. 3, X 3000

Chroomonas baltica (Buttner) Carter . . . . . p. 106
Ventral view: Fig. 4, X 1220

Chroomonas minuta (Skuja), comb. nov., var. *apyrenoidosa* Hulburt . . . . . p. 107
Lateral views: Fig. 5, X 5000; Fig. 6, X 4000

Chroomonas amphioxeia (Conrad) Butcher . . . . . p. 108
Lateral views: Fig. 7, typical cell, X 3400;
Fig. 8, smaller individual,
X 3000; Fig. 9, longer cell,
X 1200

Cryptomonas pseudobaltica Butcher . . . . . p. 109
Lateral views: Fig. 10, phase contrast, X 2700;
Fig. 11 & Fig. 12, X 2800

Cryptomonas cf. *rostrella* Lucas . . . . . p. 111
Lateral view: Fig. 13, X 1750, larger cell
tentatively placed in this species
(see Pl. 2, Fig. 8 d-e)

Cryptomonas testacea sp. nov. . . . . p. 113
Fig. 14, lateral view, cell with two pyrenoids,
X 1600; Fig. 15, dorsal and lateral views,
X 1450; Fig. 16, lateral view, smaller individual,
X 1450

Cryptomonas ovata Ehrenberg . . . . . p. 114
Lateral views: Fig. 17, X 1850; Fig. 18, X 2200

Cryptomonas borealis Skuja . . . . . p. 116
Lateral view: Fig. 19, X 1300

Cryptomonas croatanica sp. nov. . . . . p. 116
Lateral view: Fig. 20, X 1700

PLATE 22

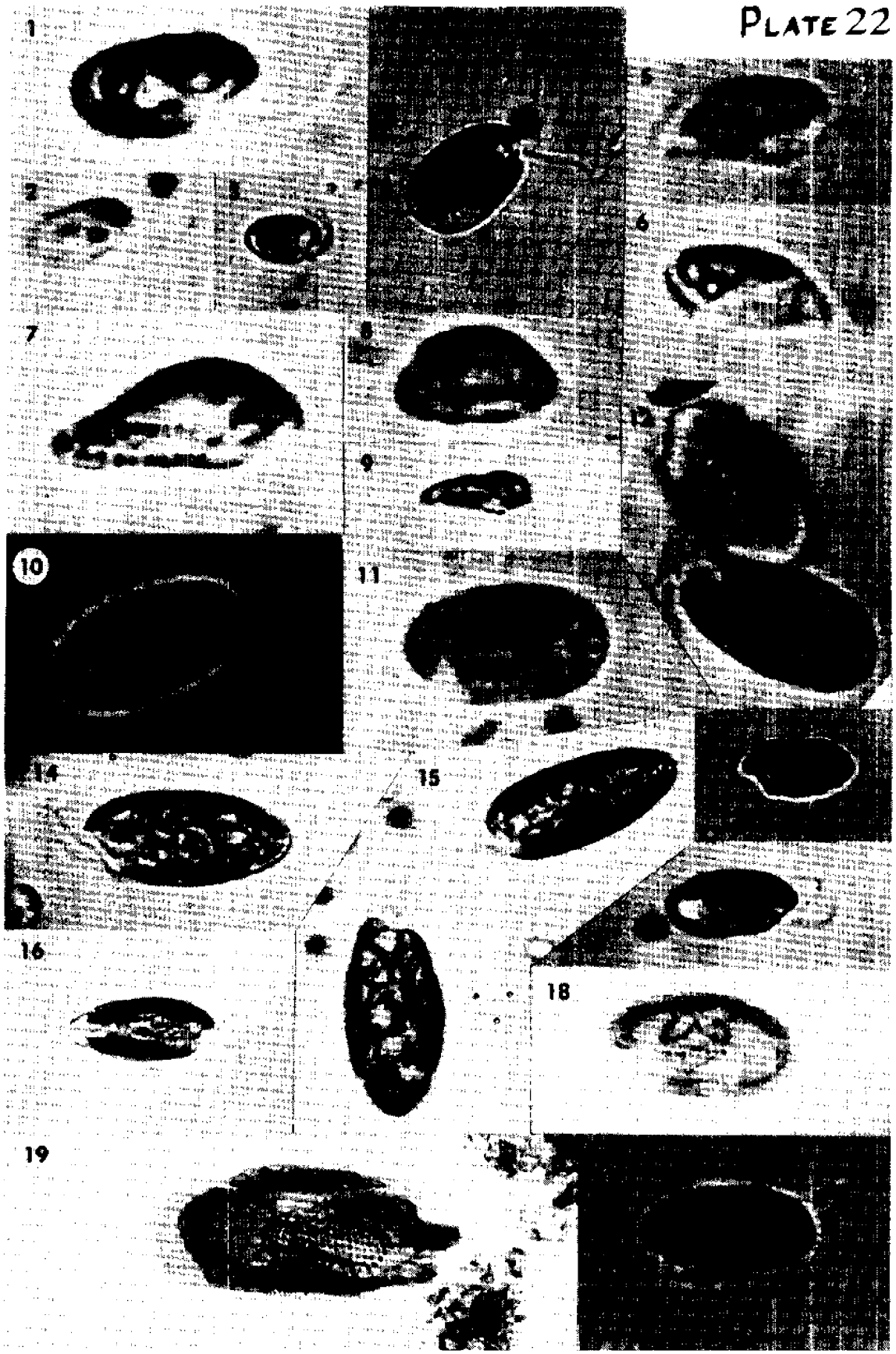


PLATE 23

(Class Dinophyceae)

Prorocentrum micans Ehrenberg . . . . . p. 117
Dorsal view; Fig. 1, X 1000

Prorocentrum minimum (Pavillard) Schiller . . . . . p. 118
Dorsal view: Fig. 2, X 1750

Prorocentrum redfieldi Bursa . . . . . p. 119
Fig. 3, lateral view, X 1700; Fig. 4, dorsal view, X 1700

Exuviaella compressa (Stein) Ostenfeld . . . . . p. 119
Fig. 5, ventral view at level of pusule reservoir, a stigmatic granule and nucleus, X 1300; Fig. 6, view of same cell a level of plastid and pyrenoid, X 1300

Exuviaella marina var. *adnatodens* var. nov. . . . . p. 120
Fig. 7, dorsal view, X 1400; Fig. 8, dorsal view showing large pusule reservoir, X 1400

Sinophysis aff. *ebriolum* (Herdman) Balech . . . . . p. 121
Lateral view: Fig. 9, X 750

Thecadinium aureum sp. nov. . . . . p. 122
Fig. 7, lateral view, Fig. 8, ventral view, both views X 650

Dinophysis lachmanni Paulsen . . . . . p. 123
Lateral view: Fig. 12, X 1300

PLATE 23

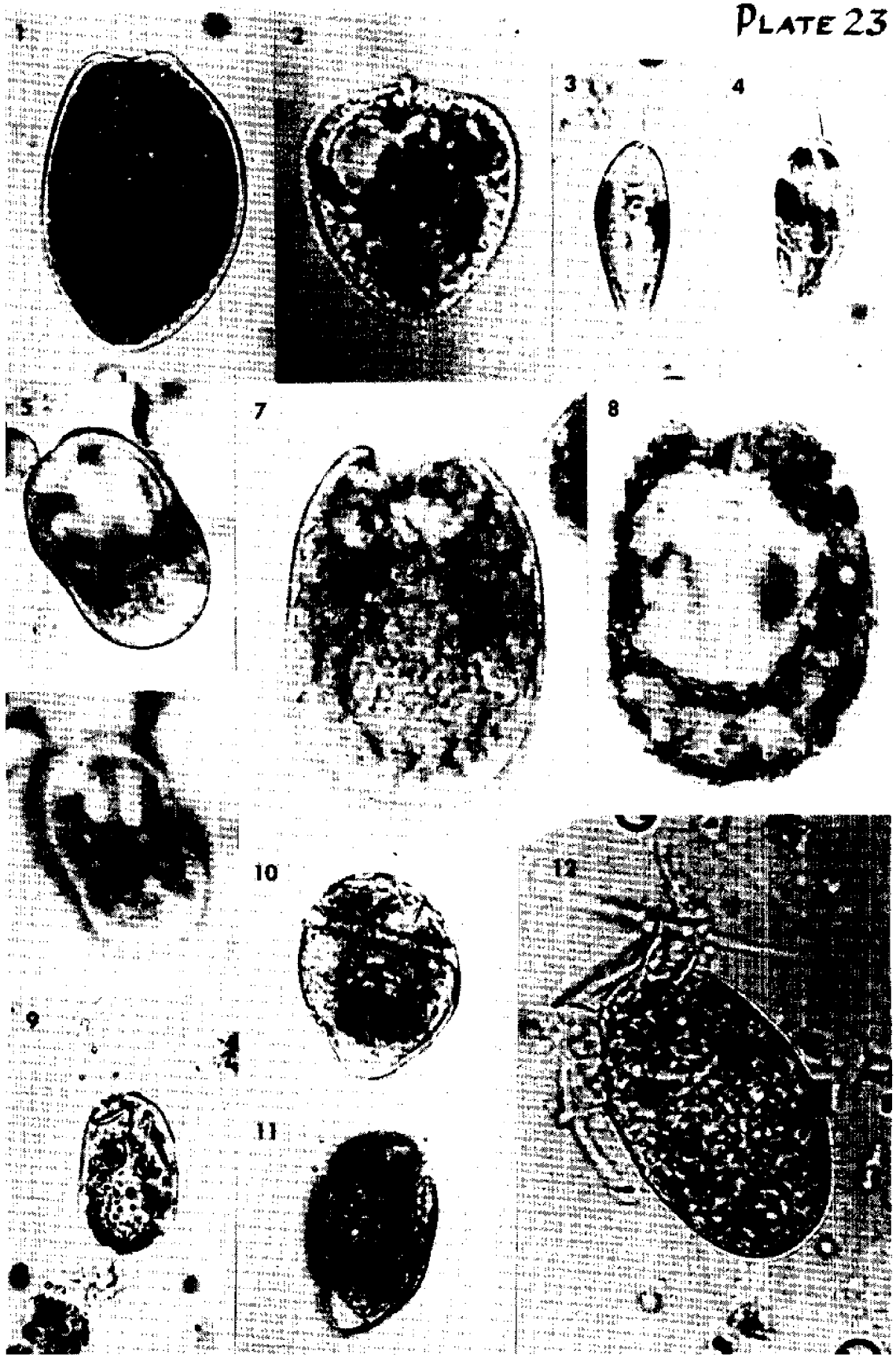


PLATE 24

(Class Dinophyceae, cont.)

Oxyrrhis marina Dujardin . . . . . p. 126
Fig. 1, dorsal view, phase contrast, X 950;
Fig. 2, phase, lateral view, X 800;
Fig. 3, ventral view, phase, X 1600

Amphidinium crassum Lohmann . . . . . p. 127
Lateral views: Fig. 4, X 1650; Fig. 5, X 1350

Amphidinium klebsi Kofoid & Swezy . . . . . p. 128
Fig. 6, two cells in ventral view, phase, X 1550;
Fig. 7, three cells in dorsal view, X 1400;
Fig. 8, ventral view of larger cell with flattened epicone, X 650 (Pl. 4, Fig. 25 f)

Gymnodinium stellatum Hulburt . . . . . p. 131
Fig. 9, obliquely lateral view, phase, X 1250;
Fig. 10, posterior-ventral view, and Fig. 11, lateral view of same cell, X 1500

PLATE 24

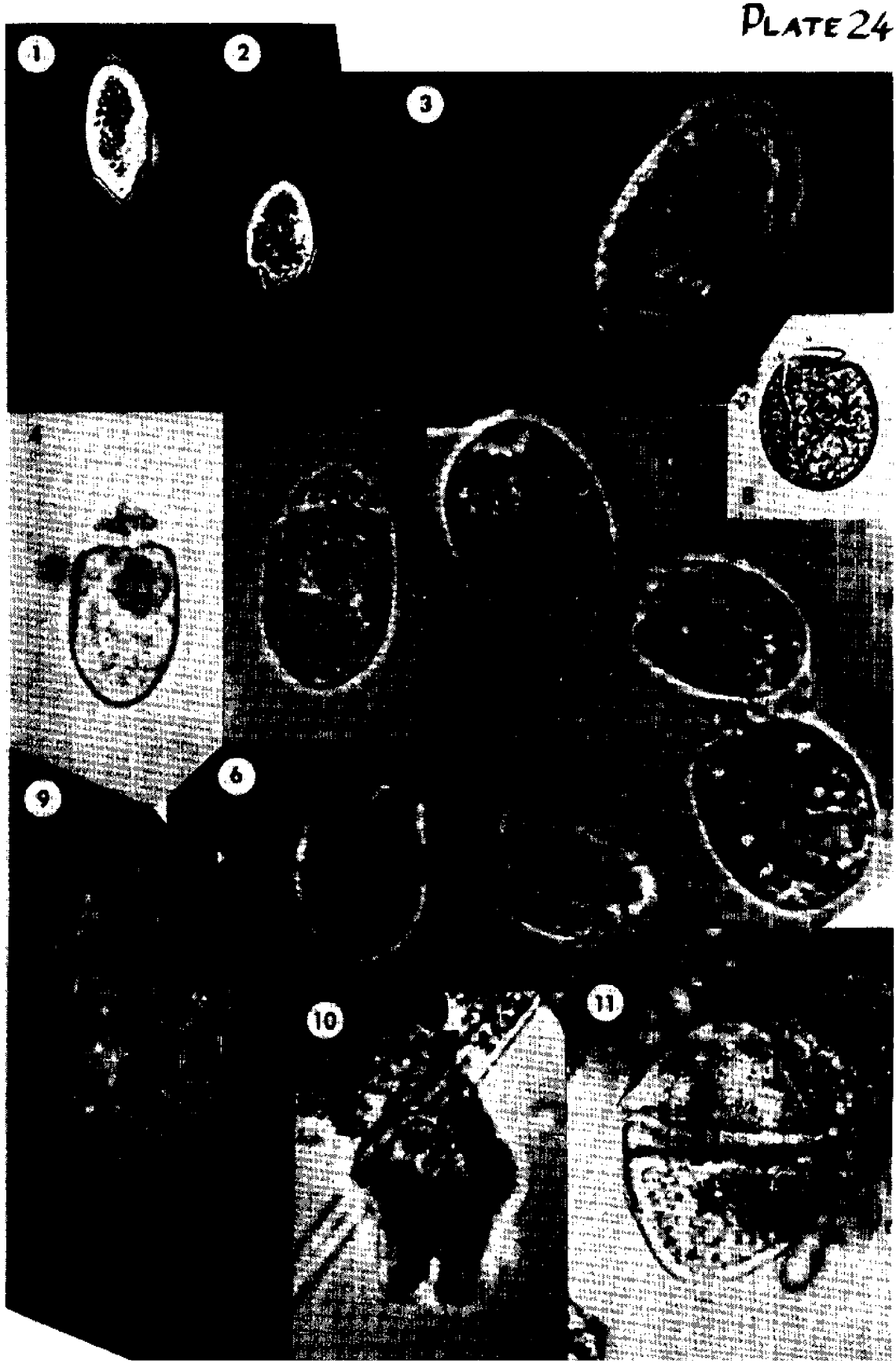


PLATE 25

(Class Dinophyceae, cont.)

Gymnodinium nelsoni Martin . . . . . p. 132
Ventral views: Fig. 1, X 1350; Fig. 2, X 1500; Fig. 3, with chromatophores radiating from center of cell, X 700

Gymnodinium danicans sp. nov. . . . . p. 133
Dorsal views: Fig. 4, X 1250; Fig. 5, X 1200; Fig. 6, X 1100

Gymnodinium verruculosum sp. nov. . . . . p. 134
Fig. 7, ventral view, X 1750; Fig. 8, posterior-ventral view, X 1500

Gymnodinium gracilentum sp. nov. . . . . p. 135
Ventral view: Fig. 9, X 1750

Gymnodinium subroseum sp. nov. . . . . p. 138
Fig. 10, posterior-dorsal view, X 1450; Fig. 11, dorsal view, X 1450

Gymnodinium boguensis sp. nov. . . . . p. 140
Fig. 12, dorsal view through to ventral surface, phase contrast, X 2000; Fig. 13, ventral view, phase, X 2100

PLATE 25

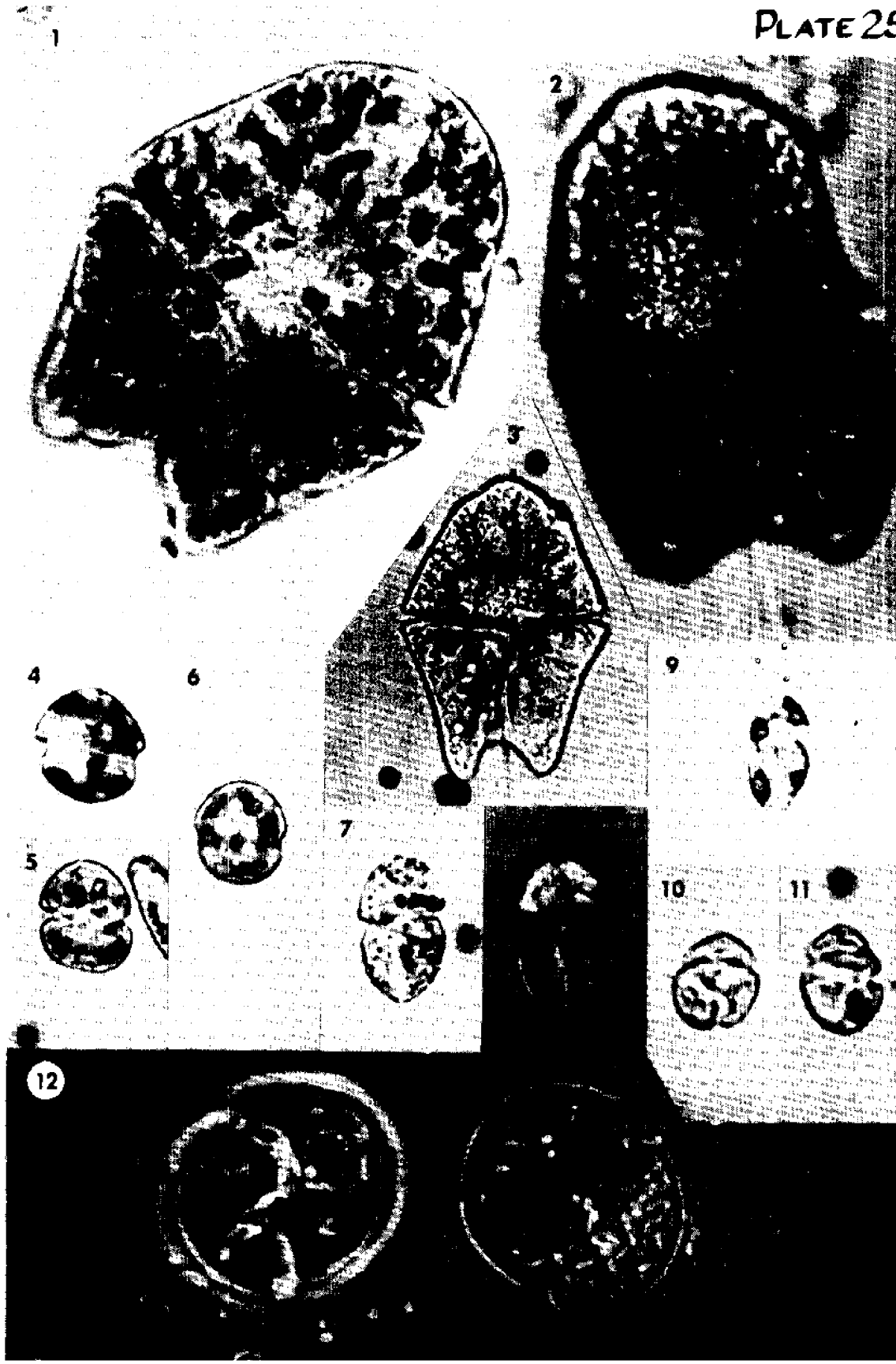


PLATE 26

(Class Dinophyceae, cont.)

Katodinium rotundatum (Lohmann) Fott . . . . . p. 148
Dorsal view: Fig. 1, X 2100

Katodinium asymmetricum (Massart) Fott . . . . . p. 149
Fig. 2, obliquely ventral view, X 1400;
Fig. 3, ventral view, X 2000

Gyrodinium resplendens Hulburt . . . . . p. 151
Ventral view: Fig. 4, X 950

Gyrodinium uncatenum Hulburt . . . . . p. 152
Fig. 5, obliquely ventral view, and Fig. 6,
lateral view of same cell, both X 1350

Gyrodinium mundulum sp. nov. . . . . p. 153
Ventral views: Fig. 7, X 1600; Fig. 8, X 3400

Gyrodinium carteretensis sp. nov. . . . . p. 155
Fig. 9, dorsal view through to ventral surface,
phase, and Fig. 10, dorsal view of same cell,
phase, both views X 1600; Fig. 11, ventral
view, phase, X 1750

Gyrodinium cf. *metum* Hulburt . . . . . p. 157
Ventral view: Fig. 12, X 1650

PLATE 26

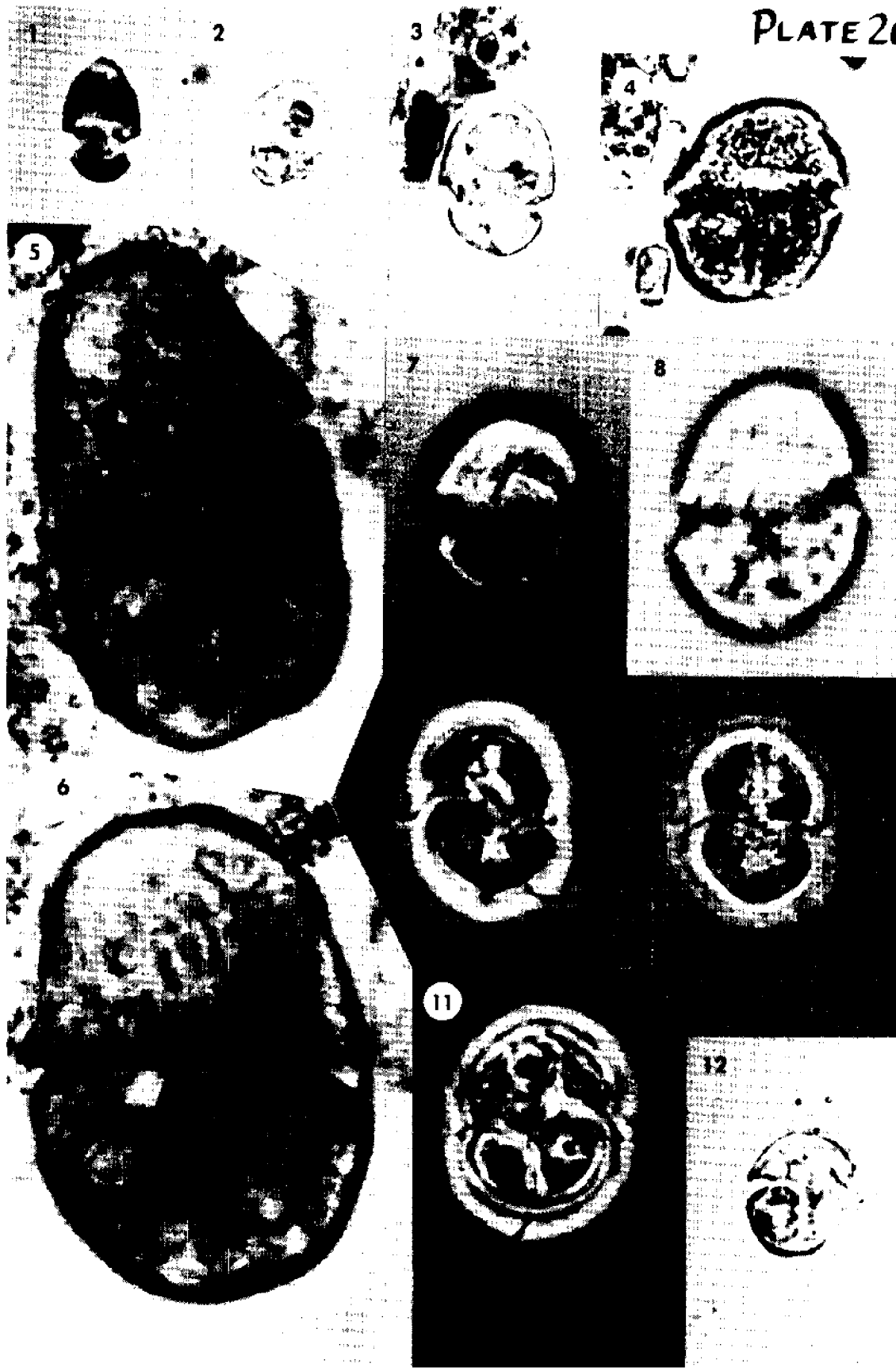


PLATE 27

(Class Dinophyceae, cont.)

Gyrodinium pellucidum (Wulff) Martin . . . . . p. 160
Fig. 1, ventral view, phase contrast, X 1800;
Fig. 2, lateral view at level of nucleus,
phase, X 2000

Gyrodinium dominans Hulburt . . . . . p. 161
Ventral views: Fig. 3, phase, X 2200;
Fig. 4, X 1000

Polykrikos hartmanni Zimmermann . . . . . p. 167
Lateral view: Fig. 5, X 1300

Polykrikos kofoidi Chatton . . . . . p. 167
Fig. 6, ventral view, X 1250; Fig. 7,
ventrilateral view, showing nematocysts, X 1000

PLATE 27

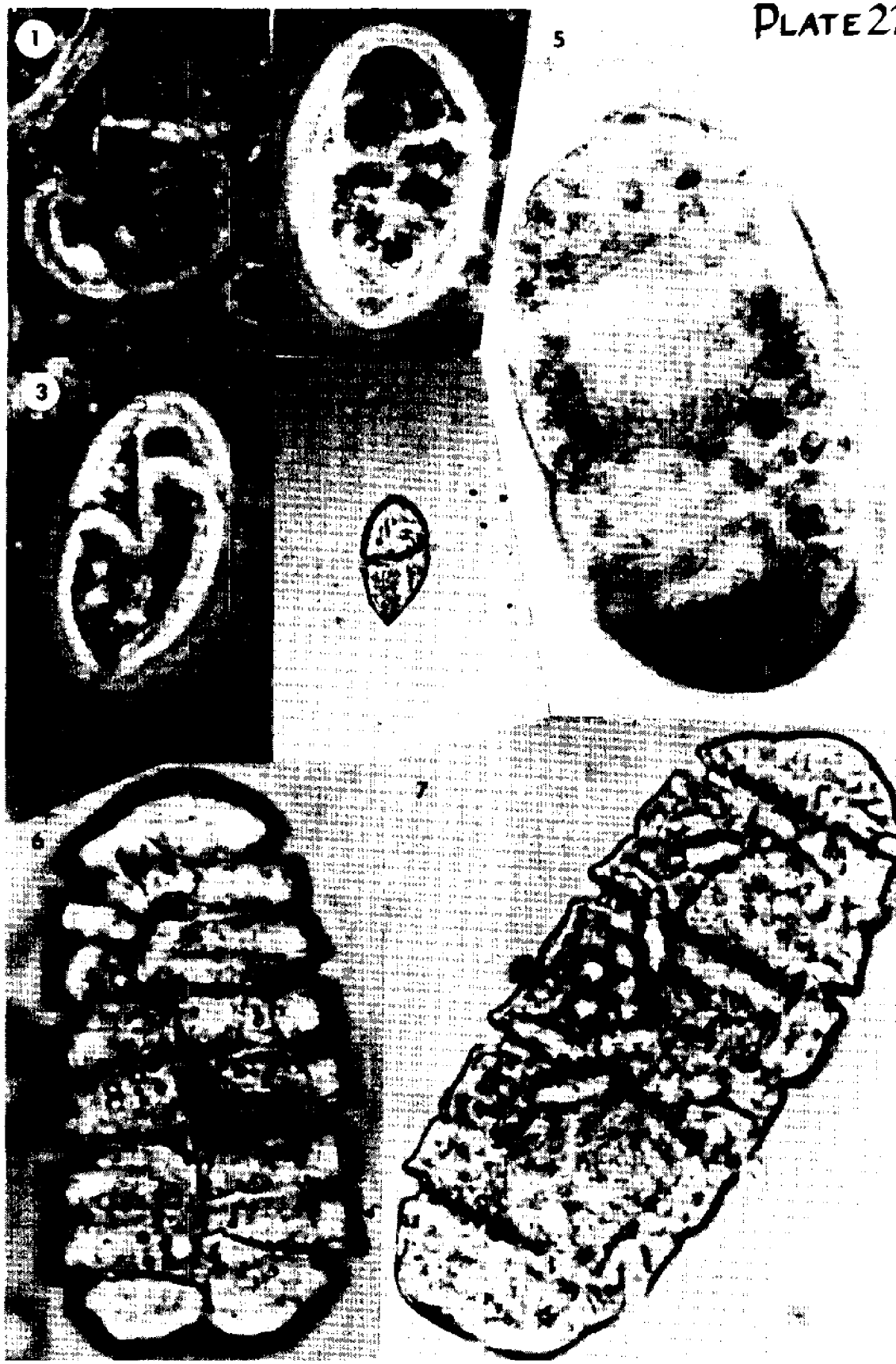


PLATE 28

(Class Dinophyceae, cont.)

Glenodinium cf. *rotundum* (Lebour) Schiller . . . . . p. 167
Ventral view: Fig. 1, X 1250

Glenodinium danicum Paulsen . . . . . p. 170
Two non-motile cells, X 1000

Glenodinium obliquum Pouchet . . . . . p. 170
Fig. 3, lateral view, X 1250; Fig. 4, obliquely ventral view, X 1250

Heterocapsa triquetra (Ehrenberg) Stein . . . . . p. 172
Fig. 5, ventrilateral view, X 1200; Fig. 6, ventral view, X 1200

Peridinium aciculiferum Lemmermann . . . . . p. 174
Fig. 7, ventral view, X 1500; Fig. 8, ventral view, and Fig. 9, antapical view of the same cell, both X 1350

Goniaulax diacantha (Meunier) Schiller . . . . . p. 177
Ventral views: Fig. 10, showing elongated plastids, X 1700; Fig. 11, X 1350; Fig. 12, X 1500

PLATE 28

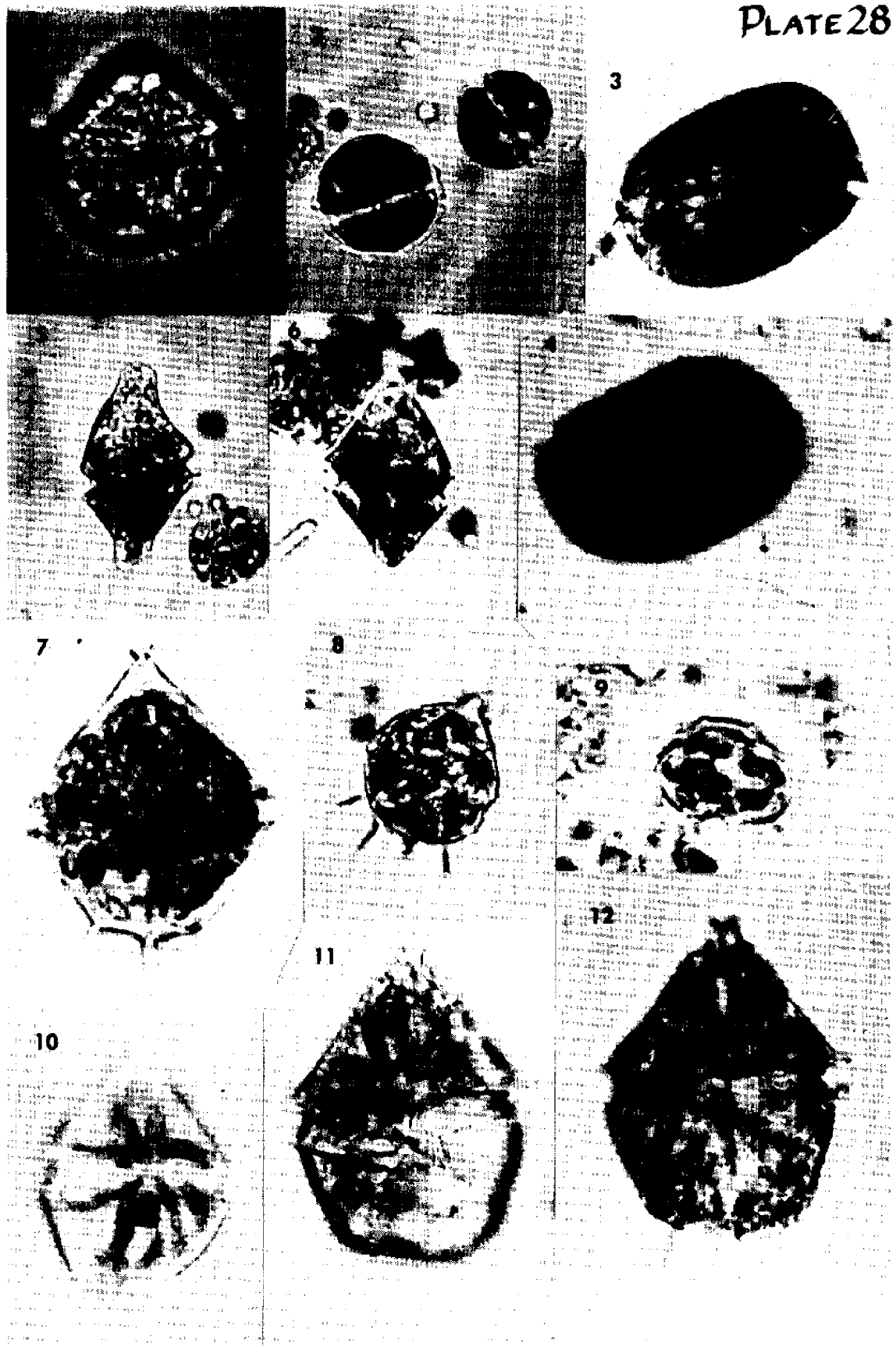


PLATE 29

(Class Dinophyceae, cont.)

Goniaulax longicornu sp. nov. . . . . p. 180
Ventral views of same cell: Fig. 1, anterior protion, Fig. 2, posterior portion, both X 1850

(Class Haptophyceae)

Prymnesium parvum Carter . . . . . p. 183
Fig. 3, several cells in lateral view, X 1650; Fig. 4, two older cells with numerous assimilate globules, X 2500; Fig. 5, cell with filiform pseudopodia radiating from posteriority, X 3000

Chrysochromulina ? *minor* Parke & Manton . . . . . p. 184
Fig. 6, lateral view with extended haptonema, X 3500

? *Hymenomonas roseola* Stein . . . . . p. 188
Fig. 7, smaller cell which suggested a possible affinity to this species, X 4100

PLATE 29

PLATE 30

(Class Haptophyceae, cont.)

Hymenomonas carterae (Braarud & Fagerland) Braarud . . . . p. 187
Fig. 1, lateral view of flagellated cell with coccoliths, X 2500; Fig. 2, phase contrast, showing two plastids, X 2000

Hymenomonas roseola Stein . . . . . p. 188
Lateral views, showing envelope of coccoliths: Fig. 3, X 1100; Fig. 4, X 1300

(Class Chrysophyceae)

Pavlova gyrans var. *simplex* var. nov. . . . . p. 192
Lateral views: Fig. 5, two cells, each with a single parietal plastid with an anteriorly attached stigma, X 4300; Fig. 6, X 2300; Fig. 7, phase, X 1900; Fig. 8, number of cells from culture with a few cells showing the presence of a trailing haptothrix, phase, X 900

Ochromonas caroliniana sp. nov. . . . . p. 190
Lateral views: Fig. 9, two cells of typical form, phase, X 2100; Fig. 10, Fig. 11, and Fig. 12, form variations, each with a single plastid with an anteriorly attached stigma, phase, X 2700

Plate 30

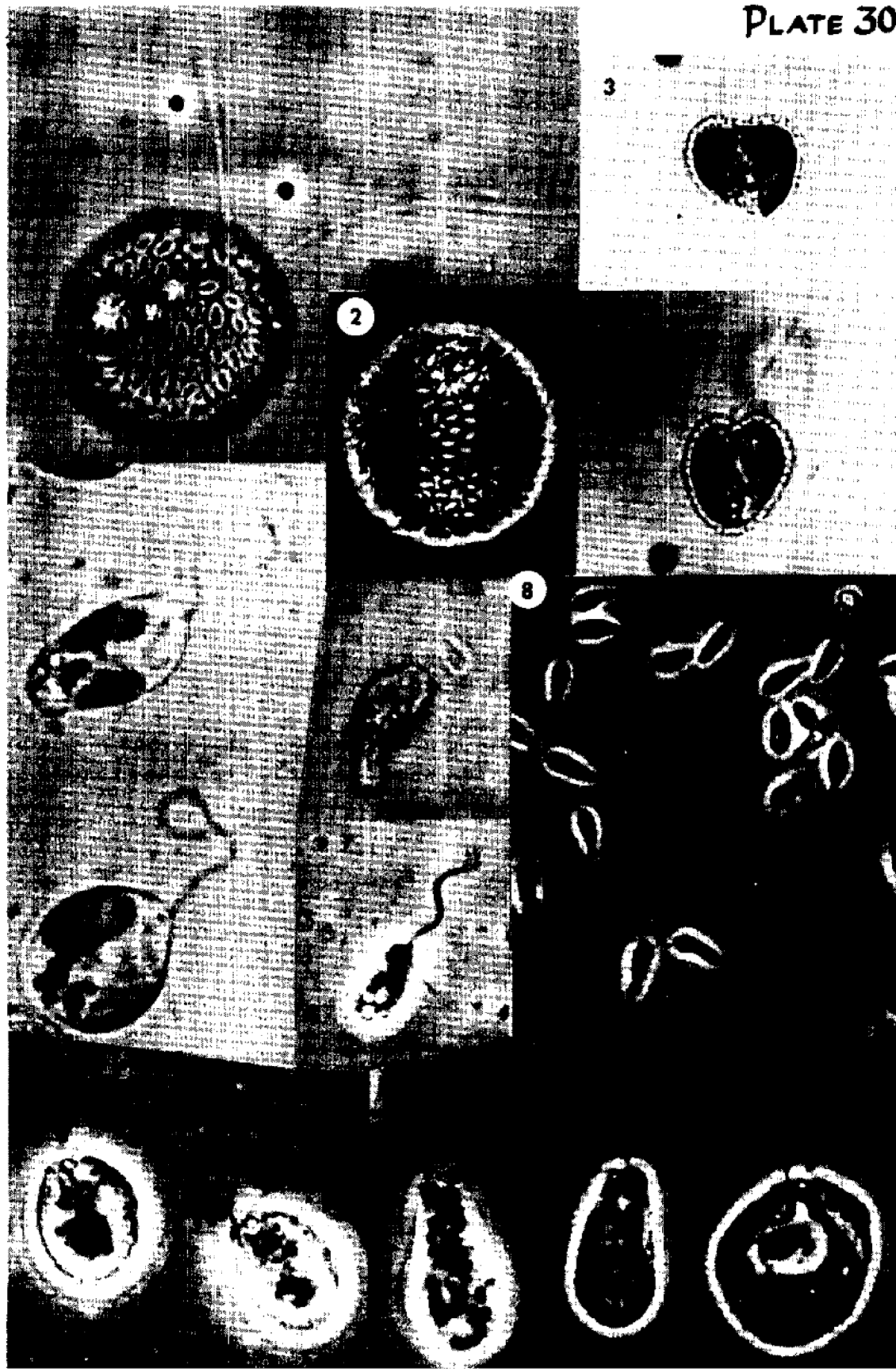


PLATE 31

(Class Chrysophyceae, cont.)

Pavlova hommersandii sp. nov. . . . . p. 193
Fig. 1, ventral view; Fig. 2, ventrilateral view, both views X 3800

Mallomonopsis elliptica Matwienko . . . . . p. 195
Lateral views: Fig. 3, X 2000; Fig. 4, showing spines on scales, X 1770; Fig. 5, surface view of imbricated scales, X 3300

Synura uvella Ehrenberg . . . . . p. 196
View of small colony: Fig. 6, X 950

Pseudopedinella pyriforme Carter . . . . . p. 197
Lateral views: Fig. 7, X 2400; Fig. 8, X 1380; Fig. 9, showing trailing rhizopod, X 625

Calycomonas ovalis Wulff . . . . . p. 200
Lateral views of lorica: Fig. 10 and Fig. 11, showing annular thickenings, Fig. 12, optical cross section, all X 3200

Ebria tripartita (Schumann) Lemmermann . . . . . p. 200
Lateral views: Fig. 13, X 650; Fig. 14, X 1380; Fig. 15, oblique view showing doubled endoskeletin, X650

PLATE 31

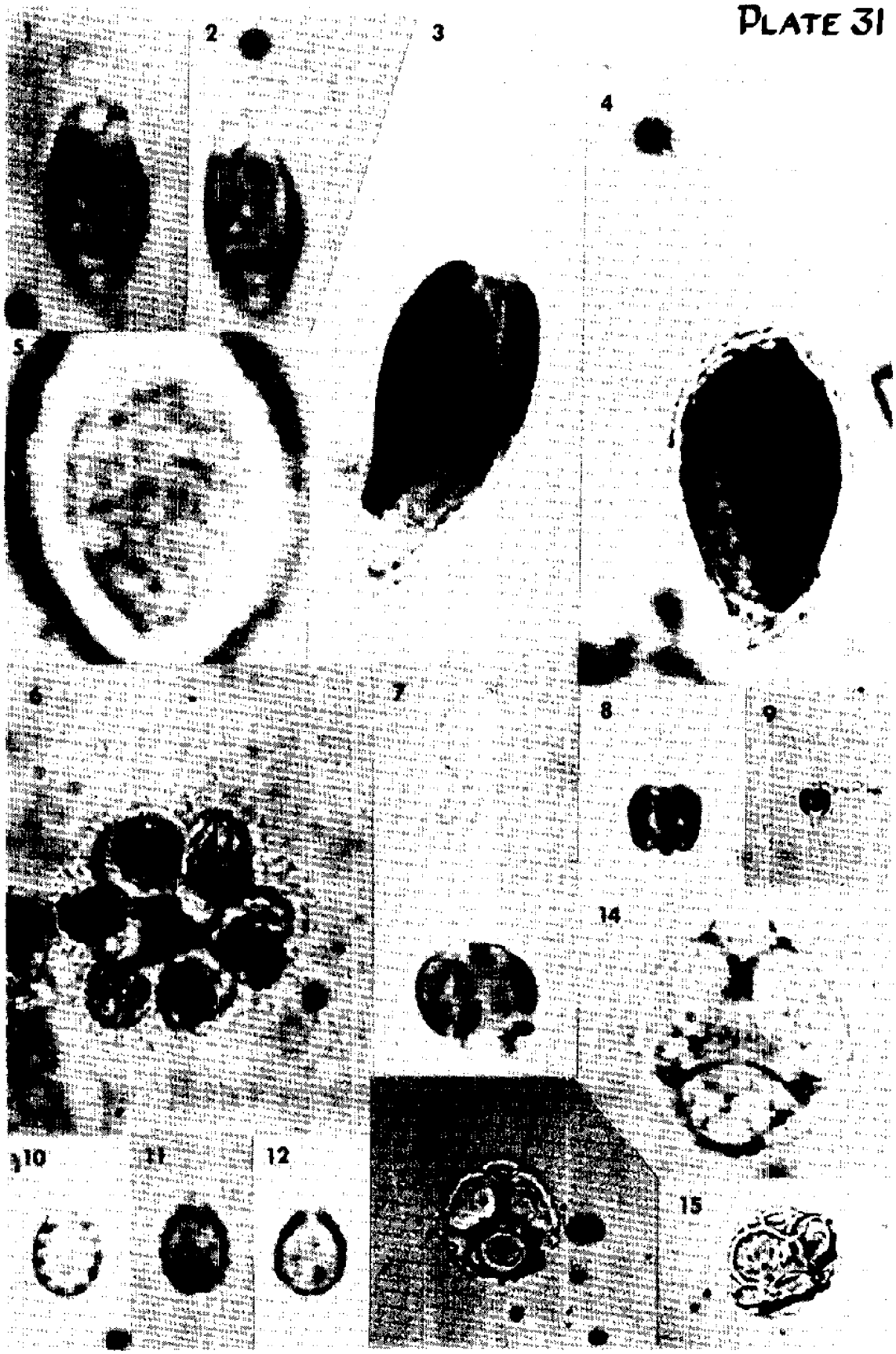


PLATE 32

(Class Xanthophyceae)

Nephrochloris salina Carter . . . . . p. 202
Ventral views: Fig. 1, X 3400; Fig. 2, X 3000

Olisthodiscus carterae var. *olivaceus* var. nov. . . . . p. 204
Lateral view: Fig. 3, phase contrast, X 2900

(Class Raphidophyceae)

Merotrichia capitata Skuja . . . . . p. 205
Lateral view: Fig. 4, X 1250

(Class Euglenophyceae)

Eutreptia cf. *viridis* Perty . . . . . p. 207
Lateral views: Fig. 5 and Fig. 6, both phase contrast X 1000

Eutreptia cf. *lanowii* Steuer . . . . . p. 208
Lateral views: Fig. 7, small cell X 1500; Fig. 8, X 750; Fig. 9, two metabolic cells, X 700

Euglena cf. *proxima* Dangeard . . . . . p. 209
Lateral view: Fig. 10, flagellum absent, X 2500

Euglena ehrenbergii Klebs . . . . . p. 211
Lateral view: Fig. 11, flagellum absent, X 850

PLATE 32

PLATE 33

(Class Euglenophyceae, cont.)

Trachelomonas hispida var. *punctata* Lemmermann . . . . . p. 213
Lateral view: Fig. 1, X 1300

Trachelomonas intermedia Dangeard . . . . . p. 213
Lateral view: Fig. 2, X 1250

(Class Prasinophyceae)

Heteromastix rotunda (Carter) Manton . . . . . p. 214
Broad-lateral view: Fig. 3, phase contrast, X 1550

Heteromastix pyriformis (Carter) Manton . . . . . p. 215
Broad lateral views: Fig. 4, X 2000; Fig. 5, X 1600; Fig. 6, X 1800

Pyramimonas cf. *torta* Conrad & Kufferath . . . . . p. 216
Lateral view: Fig. 7, X 900

Pyramimonas cf. *micron* Conrad & Kufferath . . . . . p. 217
Lateral view: Fig. 8, X 4000

Pyramimonas pluricoculata Butcher . . . . . p. 218
Lateral view: Fig. 9, cell showing double stigma, X 2000

Pyramimonas amylifera Conrad . . . . . p. 218
Fig. 10, broad lateral view; Fig. 11, apical view showing the eight flagella; Fig. 12, narrow-lateral view; all views X 2800

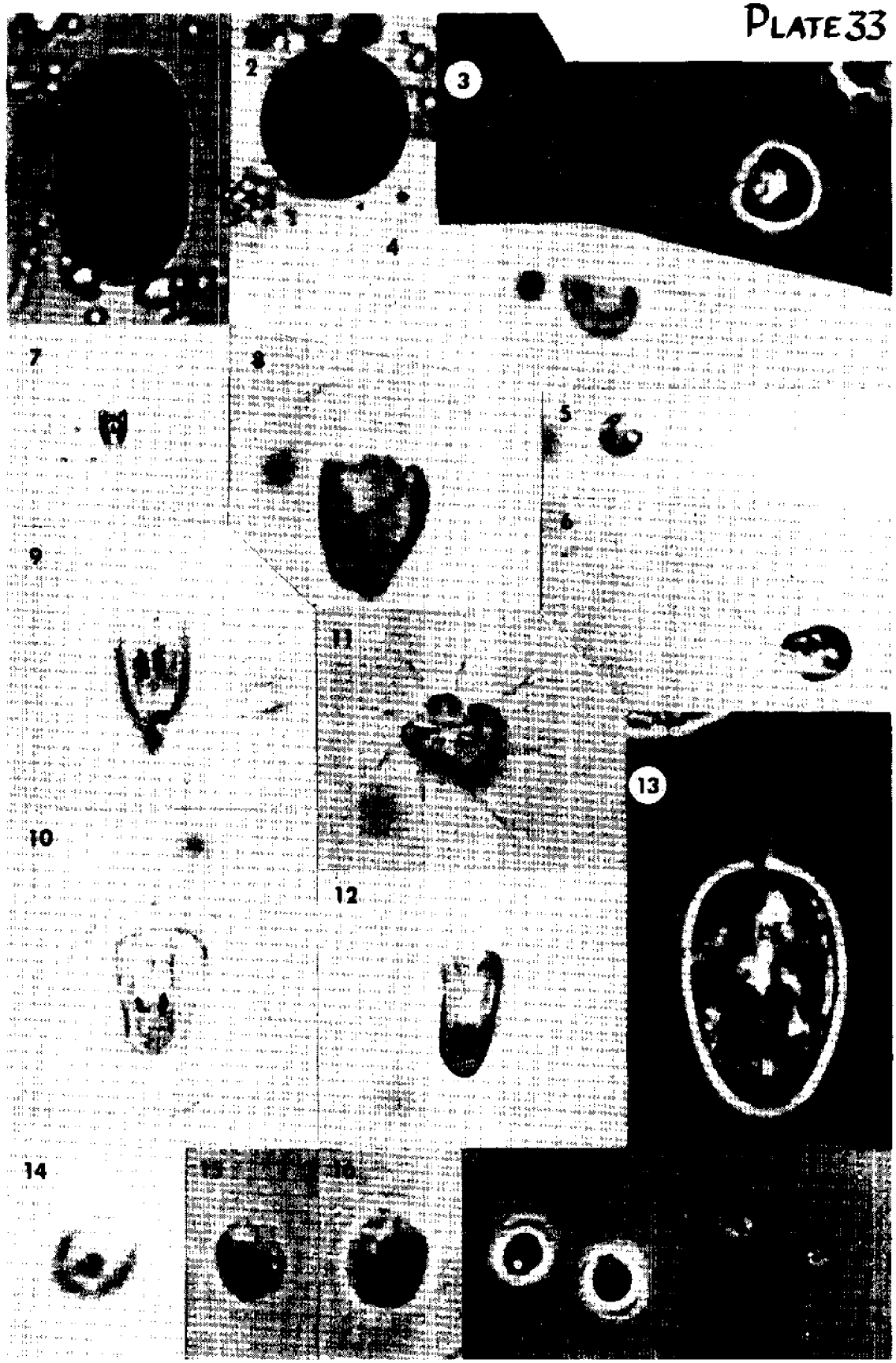
Tetraselmis maculata Butcher . . . . . p. 222
Broad-lateral view: Fig. 13, phase contrast, X 4100

(Class Chlorophyceae)

Chlamydomonas cf. *vectensis* Butcher . . . . . p. 227
Lateral views: Fig. 14, Fig. 15, Fig. 16, all X 3600

Chlamydomonas sp. "c" . . . . . p. 229
Lateral views: Fig. 17, two cells under phase; Fig. 18, same cells under light field, both showing separation of cell wall from protoplast; both X 1750

PLATE 33



APPENDICES

APPENDIX A

METHODS OF SEA WATER ANALYSIS USED IN THE GALES CREEK STUDY

The analysis of the Gales Creek nutrient samples was conducted under the supervision of William Woods in his laboratory at the U.N.C. Institute of Marine Sciences in Morehead City, N.C. The methods presented here, with his permission, are those used and in some cases modified by Dr. Woods.

Nitrate-Nitrogen Analysis (Mullin & Riley, 1955)

1. Place 50 ml of millipore-filtered sample in 125 ml flask.
2. Add 2 ml phenol-sodium phenate buffer while swirling.
   [Buffer is made by mixing 25 ml phenol solution (9.40 gm phenol to 200 ml water, sintered-glass filtered, and then diluted to 250 ml) with 8 ml IN Na OH (40 gm NaOH in 1 liter water) and diluting to 50 ml]
3. Add 1 ml Hydrazine-copper reagent.
   [Reagent is made by mixing 25 ml Hydrazine sulfate solution (1.2 gm Hydrazine Sulfate to 250 ml water, filtered) with 5 ml $CuSO_4$ solution (.0393 g $CuSO_4.5H_2O$ to 100 ml water) and diluting to 50 ml]
4. Leave in dark 20 hours minimum--24 hours maximum for conversion of nitrate to nitrite to occur.
5. Add 2 ml 90% acetone and wait 2 minutes.
6. Add 2 ml sulfanilic acid while shaking, then wait at least 5 minutes but no more than 10 minutes.
7. Add 1 ml alpha-naphthylamine reagent and shake.
   [0.6 gm alpha-naphthylamine added to 100 ml of 1% HCl]
8. Add 1 ml sodium acetate reagent, mix thoroughly, wait 20 minutes.
   [272 gm NaAcetate in 1 liter water]

(Methods of Sea Water Analysis, continued)

9. Read at 524 mμ in 5 cc cell with spectrophotometer.
   Note: For reagent blanks, treat two 50 ml samples of distilled water as above, eliminating step 7 for one sample.

Nitrite-Nitrogen Analysis

(Rider with Mellon, 1946)

1. Place 50 ml millipore-filtered sample in 125 ml flask.
2. Start with step 6 above and continue through step 9.

Soluble Phosphate-Phosphorus Analysis

(Greenfield & Kalber, 1954, modified)

1. Place 50 ml of millipore-filtered sample in 250 ml flask.
   Note: Reagent blank should be distilled water.
2. Add 5 ml Acid-Molybdate solution and swirl.
   [Reagent is made by combining 33.5 gm Ammonium Molybdate in 150 ml distilled water, with 349.5 ml conc. H_2SO_4 added to 400 ml distilled water, and diluting the combination to 1 liter]
3. Add 2 ml Ascorbic Acid solution and swirl.
   [13.4 gm Ascorbic Acid is added to around 30 ml water in a beaker which is heated and stirred until all is dissolved, then diluted to 50 ml]
4. Wait at least 20 hours and read at 820 mμ in appropriate cell.

Ammonia-Nitrogen Analysis

(Riley, 1953, modified by Crowther & Large, 1956)

1. Ensure absence of ammonia traces in apparatus by passing steam through still for 1-2 hours before analysis.
2. Add 50 ml (filtered) sample to digestion type flask.
3. Add 1 ml of indicator (Thymol Blue in NaOH).
4. Add Na-metaborate buffer until indicator turns blue (pH 9.3).
5. Place flask on still, and place receiving vessel, containing 4 ml 0.01N hydrochloric acid, under condenser tip with tip submerged in acid.

(Methods of Sea Water Analysis, continued)

6. Pass steam through sample, distilling for 5 minutes after first drop appears in condenser. After 4 minutes, lower receiving vessel so condenser tip is clear of acid, and distill for 1 minute longer.
7. Dilute distillate to 45 ml.
8. Add 4 ml phenol-sodium hydroxide solution.
   [22 ml phenol solution and 22 ml NaOH solution, diluted to 100 ml]
   (Phenol solution: 62.5 g phenol dissolved in just enough methyl alcohol, plus 18.5 ml acetone, then diluted to 100 ml with methyl alcohol)
   (NaOH solution: 27 g NaOH in 100 ml of deaminated water--distilled water run through column of Folin's Permutit)
9. Add 1 ml Chlorox (5.25% Sodium Hypochlorite).
10. Wait 20 minutes. Read at 625 mμ in appropriate cell.

Total Nitrogen Analysis:

Micro-Kjeldahl digestion with selenium catalyst

(Woods, 1965, modified)

1. Prepare digestion flask by addition of 4 ml of catalyst mixture [2.5 g Selenium Dioxide in water, and 500 ml H_2SO_4, then diluted with water to 1 liter] and 2 or 3 boiling beads.
2. Add 50 ml (unfiltered) sample to flask.
3. Place on digestion rack and evaporate all water.
4. Permit digestion to proceed for 4 hours after acid can be seen refluxing in digestion flask.
5. Cool and add about 20-25 ml ammonia-free water.
6. Add 1 ml Thymol Blue indicator.
7. Add 40% sodium hydroxide - 5% sodium thiosulfate solution until indicator turns blue (pH 9.3, about 7 ml).
8. Place digestion flask on still (which should have been steamed for 1-2 hours previously).
9. Place receiving vessel, containing 2.5 ml 0.01N hydrocloric acid, under condenser tip with tip submerged in acid.
10. Allow to distill for 5 minutes after first drop appears. After 4 minutes, lower receiving vessel so tip of tube is clear of acid. Allow to drip for 1 minute more.
11. Dilute distillate to 45 ml with ammonia-free water.
12. Add 4 ml phenol-sodium hydroxide solution (see Ammonia-Nitrogen Analysis).

(Methods of Sea Water Analysis, continued)

13. Add 1 ml Chlorox (5.25% Sodium Hypochlorite).
14. Wait 20 minutes, read at 625 mμ in appropriate cell.

Total Phosphorus Analysis

(Hansen & Robinson, 1953, modified)

1. Place 50 ml (unfiltered) sample in specially treated flask with 2 or 3 boiling beads.
2. Add perchloric acid solution (300 ml or 70-72% perchloric acid diluted to 1 liter with water) according to salinity:

Salinity °/oo	Volume Perchloric
38	10.5 ml
36	10.0
33	9.5
30	8.5
25	7.5
20	6.5
15	5.5
less	5.0

3. Place on hot plate in hood and evaporate 2/3 to 3/4 of volume.
4. Add 2-3 drops of potassium iodide solution (5 g KI to 100 ml H_2O) and cover with watch glass.
5. Continue evaporation until solid starts to separate. Reduce heat until perchloric acid refluxing begins. If material starts to splatter remove flask from heat until hot plate cools. When refluxing starts increase heat and reflux for 11 minutes, then remove from heat.
6. When flask is cool enough to touch, add 5 ml dilute ammonia solution (100 ml NH_4OH diluted to 500 ml with H_2O).
7. Place flask on hotplate and boil rapidly to remove ammonia. Remove cover glass and reduce heat when solids start to form. Do not permit solids to splatter. Remove from hot plate when still slightly moist. Container heat should evaporate balance of water.
8. When cool, add 50 ml of 0.2% HCl (4 ml conc. HCl to 2 liters H_2O) and dissolve all solids. It may be necessary to heat sample slightly (no more than 50° C).
9. When solids are dissolved add 2-3 drops of sodium sulfite solution (3 g sodium sulfite in 100 ml H_2O - make fresh daily).
10. Add 5 ml acid-molybdate solution.*
11. Add 2 ml ascorbic acid solution.*

*See Phosphate Phosphorus Analysis for these solutions.

(Methods of Sea Water Analysis, continued)

12. Wait 24 hours. Read at 820 mμ in appropriate cell.

Standard Solutions

Nitrate: 1.53 g KNO_3 in 1 liter H_2O.
[1 ml standard/100 ml H_2O = 15 μg A-N]

Nitrite: 0.345 g KNO_2 to 1 liter H_2O.
[1 ml standard = 5 μg A-N]

Ammonia: 0.4716 g $(NH_4)_2SO_4$ to 1 liter H_2O.
[1 ml standard - 7.14 μg A-N]

Phosphorus: 0.816 g KH_2PO_4 to 1 liter H_2O.
[1 ml standard - 6 μg A-P]

APPENDIX B

PREPARATION OF PERMANENT DIATOM MOUNTS

The Gales Creek diatom samples were prepared as permanent slides in Norway following the method used by the staff at the Institutt for Marin Biologi of the University of Oslo.

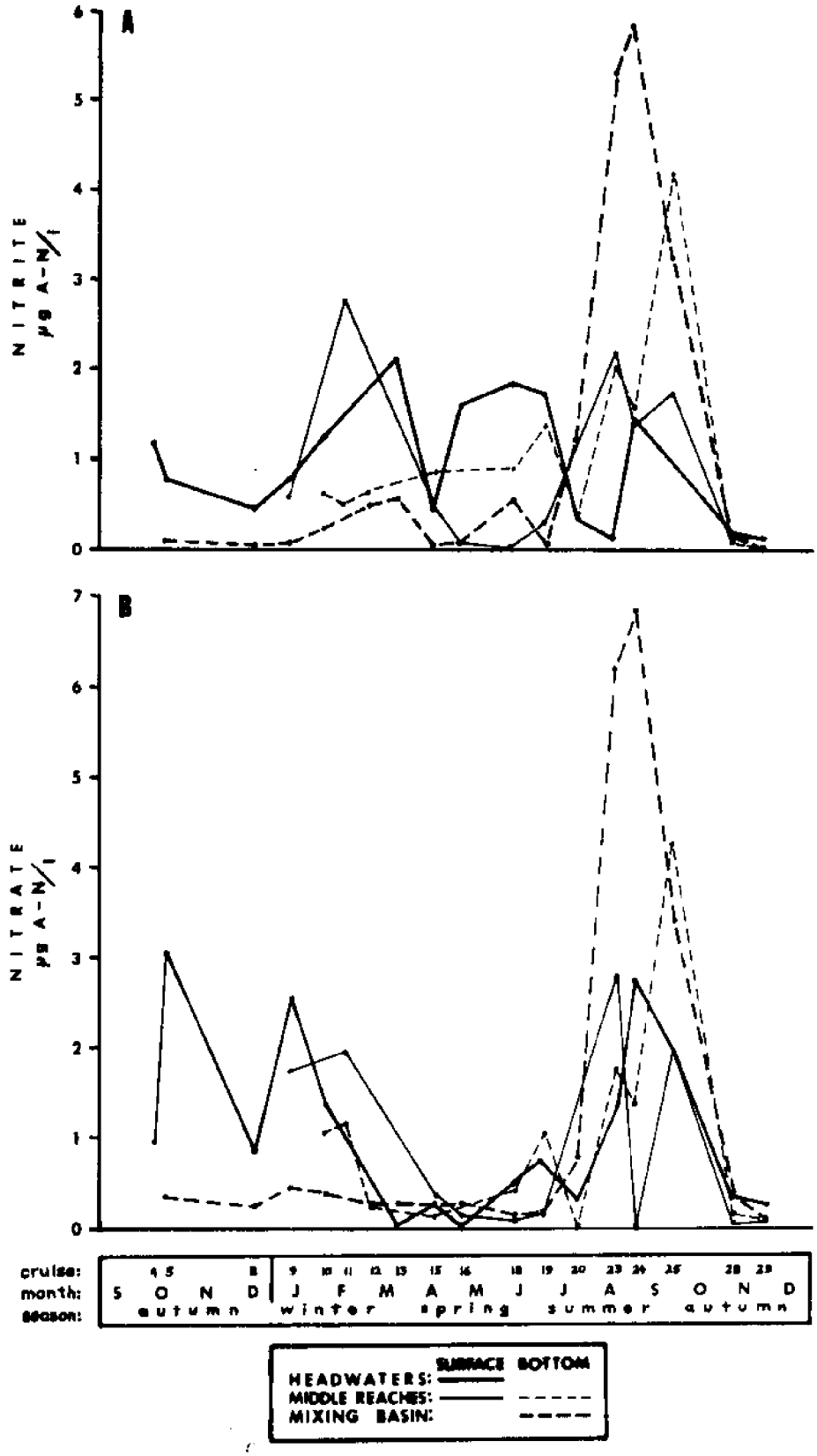
1. Pour diatom sample, fresh or formalin preserved, into the bottom of a beaker.
2. In a hood, add twice as much concentrated sulfuric acid as sample volume.
3. In the hood, add a saturated solution of potassium permanganate until the bluish-red color just becomes brownish.
4. Still in the hood, add saturated oxalic acid until the solution becomes clear.
5. Centrifuge the sample (10 minutes), draw off the supernatant, add distilled water and centrifuge again. Continue this washing process until no more acid is detected with blue litmus paper (takes about 6-7 washings).
6. Place a drop of the concentrated washed sample on a clean dry coverslip which has been washed with alcohol, and let dry in a dust-free place.
7. Add one drop of Hyrax or Coumaron to the center of the coverslip and let dry one day in a dust-free place.
8. Place a clean slide (washed in alcohol) on top of the coverslip which will then stick to the slide, turn the slide over and place on a warming plate. The mounting medium will spread and bubble for a while. When the bubbling has stopped or slowed, remove the slide, let it cool, then label and store.
9. Cleared washed diatoms may be kept in small vials if formalin is added to prevent bacterial contamination, but before solid mounts are made the samples should be washed again with distilled water to remove the formalin.

APPENDIX C

FIGURE 1

A. Seasonal distribution of dissolved nitrite-nitrogen concentrations, in microgram-atoms of nitrogen per liter. Nitrite concentrations plotted are for surface water samples from the headwaters and middle reaches (Stations 15 and 9) and bottom water samples from the middle reaches and mixing basin (Stations 9 and 2).

B. Seasonal distribution of dissolved nitrate-nitrogen concentrations, plotted in the manner of the above graph.

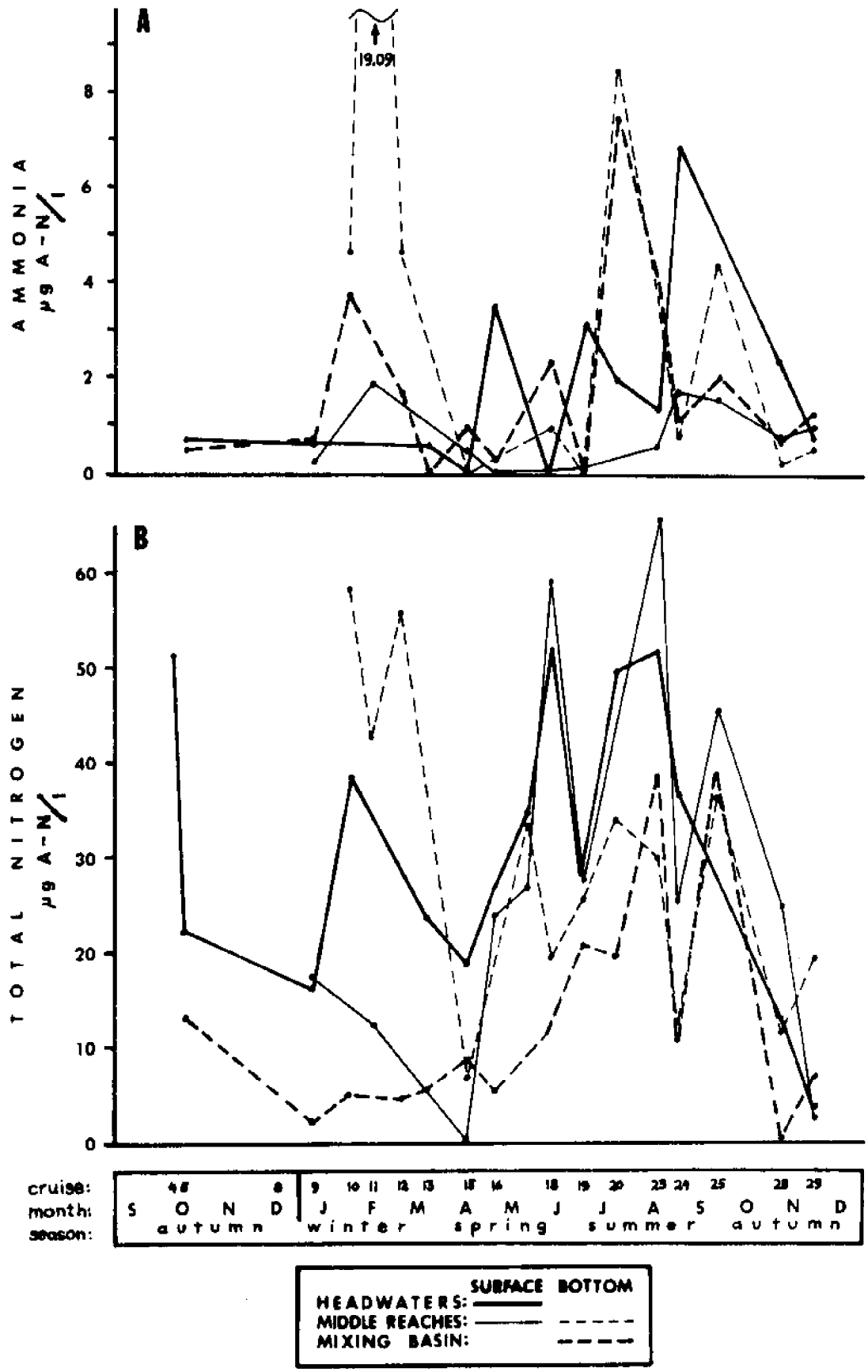

A
NITRITE
µg A-N/l
0
1
2
3
4
5
6
B
NITRATE
µg A-N/l
0
1
2
3
4
5
6
7
cruise:
month:
season:
S O N D J F M A M J J A S O N D
autumn winter spring summer autumn
HEADWATERS:
MIDDLE REACHES:
MIXING BASIN:
SURFACE
BOTTOM

APPENDIX C

FIGURE 2

A. Seasonal distribution of dissolved ammonia-nitrogen concentrations, in microgram-atoms of nitrogen per liter. Ammonia concentrations are plotted for surface water samples from the headwaters (Station 15) and middle reaches (Station 9), and bottom water samples from the middle reaches (Station 9) and mixing basin (Station 2).

B. Seasonal distribution of total nitrogen concentrations, plotted in the manner of the above graph.


A
19.09
AMMONIA
µg A-N/l
0
2
4
6
8
B
TOTAL NITROGEN
µg A-N/l
0
10
20
30
40
50
60
cruise:
month:
season:
S O N D J F M A M J J A S O N D
autumn winter spring summer autumn
SURFACE BOTTOM
HEADWATERS:
MIDDLE REACHES:
MIXING BASIN:

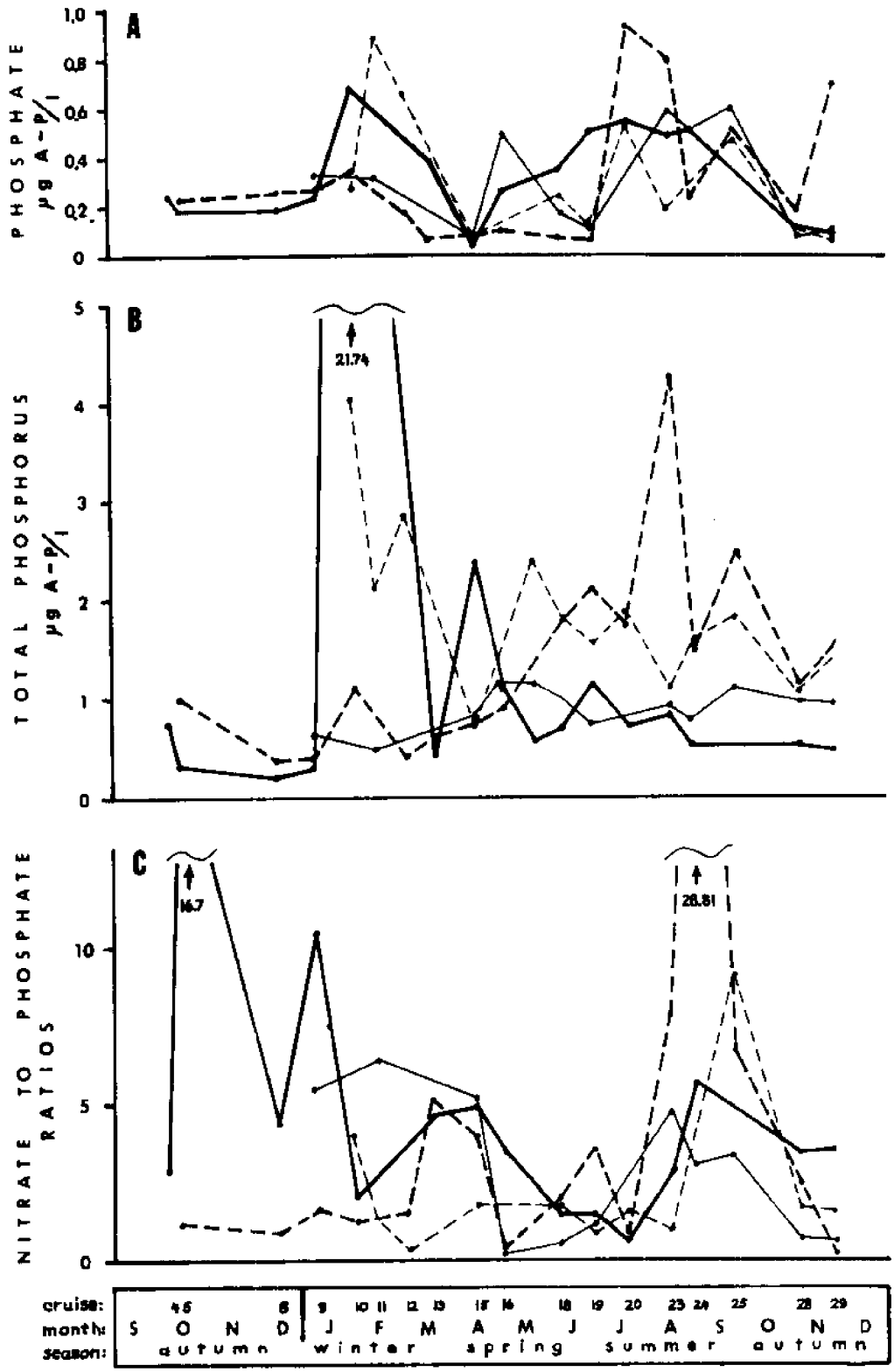
APPENDIX C

FIGURE 3

A. Seasonal distribution of dissolved phosphate-phosphorus concentrations, in microgram-atoms of phosphorus per liter. Phosphate concentrations are plotted for surface water samples for the headwaters (Station 15) and middle reaches (Station 9), and bottom water samples from the middle reaches (Station 9) and mixing basin (Station 2).

B. Seasonal distribution of total phosphorus concentrations, plotted in the manner of the above graph.

C. Seasonal distribution of nitrate-nitrogen to phosphate-phosphorus ratios for the surface samples from Stations 15 and 9, and bottom samples from Stations 9 and 2.


A
PHOSPHATE
µg A-P/l
1.0
0.8
0.6
0.4
0.2
0
B
TOTAL PHOSPHORUS
µg A-P/l
21.74
5
4
3
2
1
0
C
NITRATE TO PHOSPHATE RATIOS
16.7
28.81
10
5
0
cruise: 4 5 6 9 10 11 12 13 15 16 18 19 20 23 24 25 28 29
month: S O N D J F M A M J J A S O N D
season: autumn winter spring summer autumn
SURFACE BOTTOM
HEADWATERS:
MIDDLE REACHES:
MIXING BASIN:

STUDIES ON BRACKISH WATER PHYTOPLANKTON

II. PHYTOPLANKTON POPULATIONS IN BRACKISH WATER PONDS

A REVISED REPORT

by

Peter H. Campbell

Under supervision of

Dr. E. J. Kuenzler
Professor of Environmental Biology
University of North Carolina at Chapel Hill

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INTRODUCTION

This report represents a continuation, through the year 1970 (Campbell, 1971) and the first four months of 1971, of the 18-month study begun by Dr. Edward J. Kuenzler (1970) on effects of sewage plant effluent on phytoplankton populations in self-designing brackish water ecosystems. The ecosystems involved are six man-made ponds, each containing roughly 200 m^3 of water and with a mean depth around 0.4 m, located in Morehead City, N. C. Three of these ponds receive treated sewage from the Morehead City sewage treatment plant and estuarine water from adjacent Calico Creek and are designated polluted (P) ponds, while three other ponds at the Institute of Marine Sciences receive fresh water and estuarine water from adjacent Bogue Sound and are designated control (C) ponds.

Fresh and saline water inflow to the ponds is regulated to maintain brackish conditions throughout the year and to avoid salinity stresses. Seed populations from the local phytoplankton become introduced into the ponds with the pumped-in water, where because they are then no longer subject to the continual flow and mixing of different waters characteristic of the adjacent estuaries, the adaptable phytoplankton species are better able to develop toward climax communities during each season. The response of these phytoplankton populations to presence or absence of sewage plant effluent in the ponds, measured in this study by species composition, distribution and cell concentrations through the year, is not only an important problem in itself, but such detailed information on the phytoplankton community is also of interest to those working on the productivity and nutrient cycling phases of this project.

METHODS

At the end of each month, samples were collected from all ponds for study, a total of 48 C-pond and 48 P-pond samples for the 16-month study. Each of these was an integrated sample obtained by combining pond water collected at depths of 0.7 m, 0.4 m, and 0.1 m. All samples were examined within 5-6 hours of collection in the following manner: A measured portion from each well-shaken integrated sample, normally 10 ml, was placed

in a 15 ml conical centrifuge tube and run at full speed in a clinical centrifuge for 10 minutes, after which all but a few drops of the centrifugate was carefully drawn off by pipette. The phytoplankton cells were then resuspended and thoroughly mixed in the remaining water, about .05 ml. These last drops, when transferred by pipette to a clean slide, just filled the area under a 22 x 22 mm coverslip. This preparation was then examined live under an A. O. Spencer compound microscope with phase-contrast, surveying the slide at 200 X for large species, counting medium-sized species in selected transects across the slide at 450 X, and using oil-immersion at 1000 X for counting small species in selected transects and for careful identification and measurement of all species, using phase contrast for examination of diatom frustules. From knowing the number of fields-of-view across the coverslip for each objective, the number of transects counted, and the original volume of the sample concentrated under the coverslip, the number of cells/ml in the original sample was calculated. When heavy bloom concentrations provided too many cells in a field of view for comfortable counting, smaller volumes of the sample were then centrifuged, or counts were made directly from a buretted .02 ml volume of sample. An 8-gang mechanical counter was an invaluable aid in counting dominants in the samples. All phytoplankton measurements, free-hand drawings, and other taxonomic data were made on 3 x 5 cards for quick reference.

The traditional method of plankton counting centers around preserving the samples, settling them out in special chambers, and observing them with an inverted microscope. But because most phytoflagellates do not preserve well enough to be identifiable with any degree of certainty, live plankton examination becomes an absolute necessity when species other than diatoms and armored dinoflagellates are to be seriously studied. The problem, in the absence of successful preservatives, has been to develop methods which enable both live observation and enumeration at the same time. Methods utilizing special known-volume counting chambers such as haemocytometers, Sedgewick-Rafter cells or Palmer cells allow for accurate counts, but have the disadvantage of too great a chamber depth for critical use of oil-immersion lenses in identification of small species.

The method employed in this study, involving taking a known aliquot volume and concentrating it into a drop spread out by a coverslip to its

edges, enables both a reasonably accurate enumeration of cells per unit volume plus identification of these same cells with oil-immersion lenses, and takes advantage of the inevitable drying out of the slide to bring details of cells more sharply into focus and to gradually slow and immobilize motile flagellates for fine observation after their free-swimming normal character has been noted, thus enabling more confident identifications. By centrifuging two equal volumes of the same sample at a time, a second is readily available should the first dry out too much before counting is completed. This method requires no special inverted microscope, and there is no problem with cleaning and preparing special counting chambers since simple microscope slides and coverslips are all one needs.

RESULTS AND DISCUSSION

Salinities of C-pond samples varied from 16.0 to 21.2 °/oo with an average of 18.2 °/oo, while salinities of P-pond samples ranged from 13.5 to 20.0 °/oo with an average of 17.0 °/oo. Temperatures in C-pond samples ranged from a January low of 5°C. to an August high of 31°C., and in P-pond samples from a January low of 6°C. to an August high of 33°C.

The 1970 yearly average for total phytoplankton abundance in the C-ponds was 3.0×10^4 cells/ml, whereas in the P-ponds it was 1.8×10^6 cells/ml, with maxima in both sets of ponds being at least 100 times their minima. The temporal pattern of total phytoplankton abundance is presented in Figure 1, where it may be seen that in all seasons but spring the P-ponds contained 10 to 100 times the cell concentrations of the C-ponds. The development of these plankton concentrations, as high as 10^7 cells/ml in the P-ponds, was made possible by the combination of organic nutrient inflow from the sewage plant and the low flushing rates of the ponds, between 1/2 and 2 times a month, quite a difference from the adjacent estuaries subject to two tidal exchanges per day.

The ponds contained over 155 taxa of phytoplankton representing ten classes of algae, with a diversity from 15 to 38 (average of 25) species per sample occurring in C-ponds and from 12 to 35 (average of 21) species per sample in P-ponds. The systematic account of the species, with 101 figures, is presented at the end of this report.

Control Ponds

Those species which in any C-pond sample attained concentrations of 10^3 cells/ml or more are presented in Table 1. The seasonal distribution of these dominants is shown in Figure 2.

Many differences appear between the dominant phytoplankton of the C-ponds in 1970 compared to 1969, suggesting that the ponds are continuing to mature. *Monallantus stichococcoides* (Kuenzler's "small forms") continued its bloom concentrations from the fall of 1969 in ponds C-2 and C-3, dying off at the end of spring, but failed to return in the autumn of 1970 with any of the previous year's strength, and by winter had disappeared from all ponds but C-2. In the summer bloom of 1969, tiny *Nannochloris atomus* achieved 10^5 cells/ml concentrations in all C-ponds, but in 1970 it bloomed occasionally in the spring and autumn, with only one spring sample reaching the previous year's peak densities. In 1970 the small pillbox cells of *Cyclotella caspia* showed scattered presence in the C-ponds, and achieved a 10^4 cells/ml summer density only in C-1, while the previous year it did this only in C-3 and was abundant in each season in C-2. Cosmopolitan *Nitzschia closterium*, an autumn and winter species from 1969, also made a strong appearance in the summer of 1970 but did not reach the previous year's autumn peak of 10^3 cells/ml. The only rather close similarity in seasonal distribution was between *Nitzschia frustulum* (perhaps misidentified?) in 1969 and *Nitzschia proxima* in 1970, both abundant in summer and early autumn from C-1 and C-2.

The small blue-green bean-shaped motile cells of *Hemiselmis virescens*, unreported from 1969, were abundant in spring and summer from all C-ponds, and dominated the winter C-pond plankton in 1971. As with other dominants, however, *Hemiselmis* varied in abundance between the three C-ponds, originally designed to provide for replication. *Ochromonas ? vallesiaca* occurred in the summer in only C-1 and C-2. *Ochromonas ? minuscula* achieved a winter bloom in 1970 only in C-3, the only pond in which the spring bloom of *Monochrysis lutheri* also occurred. *Pedinomonas minor* was dense only in one C-2 summer sample. Fig. 1 also reveals differences between ponds in 1970 by showing C-3 and C-2's greater total phytoplankton cell concentrations in the first half of the year, and C-1's build-up in the latter half while C-3 dropped to the levels C-1 had begun the year with.

Polluted Ponds

The nutrient richness of the P-ponds enabled over twice as many species to achieve concentrations of at least 10^3 cells/ml as in the C-ponds. These dominants are presented in Table 2, and their seasonal distribution is shown in Figure 3.

From December 1969 to early May 1970 all P-ponds were pea-soup green with dense 10^6 cells/ml concentrations of the small xanthophyte *Monodus* aff. *guttula*. On May 11th all the blooms suddenly crashed, the ponds turned gray, and many fish and other organisms succumbed to the depleted oxygen levels. In August and September the *Monodus* began reappearing in the plankton and by December all ponds had returned to pea-soup bloom concentrations. These densities continued through the winter of 1971, but by April the anticipated spring reduction in *Monodus* cell concentrations was already beginning in pond C-3.

Monodus is a euryhaline species which shows optimum growth in lower salinity waters at 20°C (Hommersand & Talbert, 1971). Above this temperature *Monodus* populations easily crash, probably because as respiration exceeds photosynthesis, the oil reserves are used up, floating ability is lost, the cells sink from the light, oxygen consumption increases, and death ensues.

Hulburt (1970) has calculated that at cell densities below 3×10^5 cells/ml the nutrient-depleted zones about algal cells do not overlap. Therefore at these concentrations there is no chance for an abundant form to force less abundant forms to extinction by monopolization of the nutrient supply. The *Monodus* blooms normally exceeded this value, and therefore were at concentrations where nutrient monopolization may have aided in their continued dominance. Diversity definitely dropped during these blooms, but eventual extinction of residual forms was prevented by the population crash with warmer temperatures which then freed other species for growth. At total cell densities below this figure phytoplankton diversity did not appear to be affected.

After the spring *Monodus* crash the ponds rapidly recovered with a number of phytoplankton species vying for dominance through the summer and autumn (Figure 3). There were also some differences among the P-ponds. *Goniochloris pulchra*, a xanthophyte with 10 times the cell volume of *Monodus*, (Table 3), assumed dominance in late spring in all P-ponds but dropped off as summer progressed. *Oocystis parva* also appeared in

abundance at this time and continued through the summer and autumn, although not in the concentrations achieved the previous year. The small prasinophyte *Pyramimonas pluriocula*ta was abundant in all P-ponds in the summer, as were the centric diatoms *Cyclotella striata* var. *ambigua* and *Coscinodiscus sublineatus*, and the small flagellate *Chroomonas amphioxeia*. *Nitzschia closterium*'s fluctuating abundance did not achieve the concentrations of 1969 but did extend through summer and autumn in all P-ponds as it also did in the C-ponds, and it returned with a strong P-pond subdominance the following spring. *Nannochloris atomus* occasionally bloomed from late spring to early autumn as it did in the C-ponds. *Hemiselmis virescens* and the minute diatom *Navicula arvensis* were weak in P-2 compared to the strong summer-early autumn abundance in the other two ponds. The small solitary centric diatom *Chaetoceros muelleri* appeared after the *Monodus* crash and then continued in all ponds through to autumn with stronger concentrations than had been achieved in 1969. In P-2 an autumn bloom of 10^5 cells/ml colored the normally green water brownish. In P-2 and P-3 this *Chaetoceros* bloom was followed in November by 10^4 cells/ml concentrations of the cosmopolitan dinoflagellate *Prorocentrum minimum*. This species has almost 60 times the cell volume of *Monodus* (Table 3) and it therefore is more important than its abundance might at first suggest. *Prorocentrum minimum* is unusually large compared with the other dominants in Table 3, all small cells with proportionately large surface areas that enable more rapid metabolism and growth where advantageous conditions appear in the rapidly fluctuating estuarine environment. *Oxyrrhis marina*, an unpigmented dinoflagellate, made a strong winter appearance in all P-ponds in 1971, and *Nephroselmis gilva* appeared in great concentration only in the last month of the study. The apparent absence of such subdominants from the early 1970 samples, however, may partly have been due to a beginner's inexperience with counting species under bloom conditions.

Incidentally, it was noted from observations on zooplankton grazing during the counts that the smaller species of phytoplankton appeared to become food sources for ciliates and rotifers, while the larger species seemed to be consumed by small crustacea. It would be of interest to know what effect changes in the available food particle size has on the herbivore populations in the ponds.

Indicator Species

Those species of phytoplankton which were present in a number of C-pond samples, but found in only a few or no P-pond samples are indicated in Table 1 as being potential indicator species for unpolluted brackish waters in this area, while those species with high frequency in P-pond but low frequency in C-pond samples are indicated in Table 2 as being potential indicator species of the presence of organic wastes in the estuaries. This is at present a tentative conclusion, being based on little more than one year's data from a special environment. There are of course other factors to be considered as well. The possible difference in seed sources could be affecting the distribution of these species, since the C-ponds are supplied plankton from broad shallow Bogue Sound, while the P-ponds receive plankton input from both the sewage plant and small marsh-bordered Calico Creek. The size of the seed population would also be an important factor for many of these species in determining whether or at what time a bloom develops in one pond compared to another, and could account for some of the variation apparent between ponds. It would be interesting to observe the effect on these potential indicator species of transferring concentrations of P-pond phytoplankton to one of the C-ponds, and vice versa, at regular intervals throughout the year.

Class Distribution

Figure 4 presents the seasonal distribution of the major taxonomic groups of phytoplankton averaged for C-ponds and P-ponds. Though generalizations are difficult to draw from these graphs, they do suggest some basic trends: the centric diatoms, pennate diatoms and dinoflagellates in polluted waters paralleled one another in their appearance in the spring and peaking in autumn; the cryptomonads, prasinophytes and chlorophytes were generally more abundant in the warmer months of the year with greater cell concentrations in polluted waters; haptophytes and chrysophytes were generally limited to unpolluted waters, where pennate diatoms were in steady abundance all year. The xanthophytes, normally a class of minor phytoplanktonic significance, stand out as the most important group in this study, with polluted waters containing pea-soup densities of cells in the colder months of the year and strong concentrations even through the summer, and with an abundance of cells in unpolluted waters all months of the year but June and July. It would be

interesting to know whether as xanthophytes these dominant species exert selective pressure on pond food chains over and above the effect of small food particle size or the stress of being in dense concentrations.

CONCLUSION

The polluted ponds have been found to support a high level of primary productivity with sewage plant effluent, but whether this productivity can be converted to a dependable harvest remains to be seen. So far, the production of blue crabs in the ponds has been too low for commercial interest, the palaemonetes shrimp that grew well are not valued as human food, and edible fish did not grow. The system was strongly taxed by very dense phytoplankton concentrations, primarily of a single species, so perhaps better results could be achieved by holding these densities below the 10^5 cells/ml concentration (Hulburt, 1970) where species diversity can still be maintained, possibly by increasing the flushing rate of the ponds from their normal one to two times per month.

The ponds have been found to support a wide diversity of species representing ten classes of phytoplankton. The 155 taxa of phytoplankton observed in the 16-month study included 97 diatoms, 16 dinoflagellates, 9 cryptomonads, 8 prasinophytes, 6 xanthophytes, 5 chrysophytes, 5 green algae, 4 euglenoids, 3 haptophytes, and 2 blue-green algae. A number of these organisms did not readily fit existing descriptions and are probably new taxa merely awaiting further observation and study.

It is hoped that the methods described in this paper, and the following systematic account of the 155 taxa identified from the ponds, along with the associated plates and references, will form a solid basis for encouraging further examinations of phytoplankton populations from these ponds, and from Calico Creek, Bogue Sound, and other polluted and unpolluted estuaries along the Carolina coast.

SYSTEMATIC ACCOUNT OF THE SPECIES

References given are generally those of value in the identification of the species, rather than older often unobtainable references of historical interest.

(Class Bacillariophyceae)

1. *Melosira moniliformis* (Müll.) Ag.; Hustedt, 1930, Kieselalg. 1, p. 236, f. 98. Single cells 19μ x 10μ.

Present in three C-1 samples, July, November and March.

2. *Melosira sulcata* (Ehr.) Kutz.; Hustedt, 1930, Kieselalg. 1, p. 276, f. 118, 119. Cells 29μ and 13μ, in short filamentous colonies.

Present in three C-pond samples, summer and spring; one P-pond presence.

3. *Skeletonema costatum* (Grev.) Cl.; Hustedt, 1930, Kieselalg. 1, p. 311, f. 149. Cells 12-21μ x 2-5μ, in short filamentous colonies. Pl. 1, fig. 1.

Present in 16 C-pond samples from winter and spring, with 10^2 cells/ml in January and February; four P-pond samples.

4. *Cyclotella striata* var. *ambigua* Grun.; Hustedt, 1930, Kieselalg. 1, p. 345, f.176d-e. Cells 12-19μ in diameter, striae 7-8/10μ. Pl. 1, fig. 2.

From 29 P-pond samples, all months, with peaks in summer up to 10^3 cells/ml; one C-pond presence. See fig. 3 for seasonal distribution.

5. *Cyclotella caspia* Grun.; Hustedt, 1930, Kieselalg. 1, p. 347, f. 177. Cells 4-5.5μ in diameter, with very fine striae. Pl. 1, fig. 3.

Present in 12 C-pond samples from all seasons, 10^4 cells/ml in August; two P-pond presences. See fig. 2 for seasonal distribution.

6. *Coscinodiscus sublineatus* Grun.; Hustedt; 1930, Kieselalg. 1, p. 394, f. 205. Cells 21-33μ in diameter, with 10 areolae/10μ. Pl. 1, fig. 4.

Present in 16 P-pond samples, from April to November, 10^3 concentration in June. See fig. 3 for seasonal distribution.

7. *Coscinodiscus rothii* (Ehr.) Grun.; Hustedt, 1930, Kieselalg. 1, p. 400, f. 211. Cells 46-66μ in diameter, 7-8 areolae/10μ.

Present in two P-pond samples, summer.

8. *Leptocylindrus danicus* Cl.; Hustedt, 1930, Kieselalg. 1, p. 558,

f. 318. Cells 55-105μ x 8-9μ, in short filaments.

Present in four C-pond samples from autumn and winter.

9. *Rhizosolenia fragilissima* Bergon; Hustedt, 1930, Kieselalg. 1, p. 571, f. 324. Cell fragments 4.5-6.5μ in width.

Present in two C-2 pond samples, spring and autumn.

10. *Rhizosolenia hebetata* f. *semispina* (Hensen) Gran; Hustedt, 1930, Kieselalg. 1, p. 592, f. 338. Cell 134μ x 2μ with 43μ spines.

Autumn presence in one C-pond sample.

11. *Rhizosolenia calcar-avis* M. Schultze; Hustedt, 1930, Kieselalg. 1, p. 592, f. 339. Cell fragments 19μ in width with 38μ spine.

Single winter presence in C-pond.

12. *Bacteriastrum delicatulum* Cl.; Hustedt, 1930, Kieselalg. 1, p. 612, f. 353. 21μ diameter valve with terminally bifurcating spines.

Present in one winter C-pond sample.

13. *Chaetoceros lorenzianus* Grun.; Hustedt, 1930, Kieselalg. 1, p. 679, f. 385. Cell 13μ x 5μ.

Spring presence in one C-pond sample.

14. *Chaetoceros* cf. *compressus* Lauder; Hustedt, 1930, Kieselalg. 1, p. 684, f. 388, 389. Cells 9μ x 9μ, with short spines and containing smooth resting spores, in short filamentous colony.

March presence in one C-pond.

15. *Chaetoceros affinis* Lauder; Hustedt, 1930, Kieselalg. 1, p. 695, f. 396. Cells 7-16μ x 9-24μ, in short filamentous colonies.

One February C-pond and one March P-pond presence.

16. *Chaetoceros costatus* Pav.; Hustedt, 1930, Kieselalg. 1, p. 699, f. 399. Cells 21μ x 20μ, in short filamentous colony.

Single C-pond presence in winter.

17. *Chaetoceros subtilis* Cl.; Hustedt, 1930, Kieselalg. 1, p. 723, f. 413. Cells 10μ x 7μ in short filamentous colony with 115μ spines.

Winter presence in one C-pond.

18. *Chaetoceros debilis* Cl.; Hustedt, 1930, Kieselalg. 1, p. 740, f. 428. Cells 5μ x 4μ with 25μ spines, in filamentous colonies of 2-4 cells. Pl. 1, fig. 5.

Present in five C-pond, five P-pond samples from spring, autumn and winter.

19. *Chaetoceros muelleri* Lemm.; Hustedt, 1930, Kieselalg. 1, p. 756, f. 439. Cells solitary, normally 4-10μ x 3-9μ; resting spores in

May 10μ x 8μ. In P-pond October blooms cells were thinly silicified with faint setae and were smaller in size: 3.5-6μ x 2.5-4μ. Pl. 1, fig. 6a-c.

Present in 12 C-pond samples from all seasons, up to 10^2 cells/ml, with a December bloom of 10^4 cells/ml in C-3. Abundant in 23 P-ponds from spring to autumn with densities each season reaching 10^4 cells/ml with dominance in October reaching 10^5 cells/ml helping to color the water a reddish-brown. See fig. 3 for seasonal distribution.

20. *Triceratium reticulum* Ehr.; Hustedt, 1930, Kieselalg. 1, p. 823, f. 485-486. 43μ cell, 5 areolae/10μ.

Present in one summer C-pond sample.

21. *Cerataulina bergoni* Per.; Hustedt, 1930, Kieselalg. 1, p. 869, f. 517. Cells 43-57μ x 7-10μ. Pl. 1, fig. 7.

Present in six C-pond samples, autumn and winter.

22. *Grammatophora marina* (Lyngbye) Kützc.; Hustedt, 1959, p. 43, f. 569. Cell 30μ x 12μ.

One C-pond presence in March.

23. *Fragilaria brevistriata* Grun.; Hustedt, 1959, p. 168, f. 676a-e. Cells 6-13u x 2.5-3u, with 14-18 marginal striae/10u.

Present in two winter C-pond samples.

24. *Synedra* aff. *tabulata* (Ag.) Kutz.; Hustedt, 1959, p. 218, f. 710b. Cells 43-150μ x 4-4.5μ, but differing from the species in having finer marginal striae, 20-24 striae/10μ. Pl. 1, fig. 8.

Present in eight C-pond and two P-pond samples from all seasons.

25. *Asterionella japonica* Cl.; Hustedt, 1959, p. 254, f. 734. Cells 50-68μ x 7-11μ, single or in colonies. Pl. 1, fig. 9a-b.

Present in six C-pond samples from winter and autumn.

26. *Cocconeis scutellum* Ehr.; Hustedt, 1959, p. 337, f. 790. Cells 24-27μ x 18μ, 7 ribs/10μ.

April presence in one C-pond.

27. *Cocconeis* cf. *placentula* var. *euglypta* (Ehr.) Cl.; Hustedt, 1959, p. 349, f. 802e. Only rapheless valves observed: 13-27μ x 7-18μ, 16 striae/10μ.

Present in seven C-pond samples from autumn, winter, and early spring.

28. *Achnanthes orientalis* Hustedt, 1959, p. 390, f. 838. Cells 8-12μ x 4-4.5μ, rapheless valve with 20 striae/10μ, raphe valve with 28 striae/10μ. Pl. 1, fig. 10a-b.

Present in four C-pond and three P-pond samples from summer to winter and early spring.

29. *Acnanthes clevei* Grun.; Hustedt, 1959, p. 391, f. 839a. Only the rapheless valves observed, 11-16μ x 6-8μ, with 12 striations/10μ.

Present in one C-pond and one P-pond sample from spring.

30. *Achnanthes brevipes* Ag.; Hustedt, 1959, p. 424, f. 877. Cells 45-50μ x 11μ, 7 striae/10μ.

Single P-pond presence in March.

31. *Mastogloia pumila* (Grun.) Cl.; Hustedt, 1959, p. 553, f. 983. Cells 25-30μ x 9-10μ, valve marked by a lyrate hyaline area, striae 20-25/10μ, loculiferous rim with two larger central chambers. Pl. 1, fig. 11a-b.

Presence in seven C-pond samples, April to June, November, February.

32. *Gyrosigma fasciola* (Ehr.) Griff, & Henfr.; Patrick, 1966, p. 328, pl. 26, f. 4. Cells 94-106μ x 12-15μ, with transapical striae 25-26/10μ, finer than Patrick's description, and the narrow ends set off less sharply from the body. Pl. 1, fig. 12.

Present in 15 C-pond and 12 P-pond samples from all seasons.

33. *Gyrosigma balticum* (Ehr.) Rabh.; Hustedt, 1930, Bacill., p. 224, f. 331. Cells 196-200μ x 20-23μ, 14 transapical striae/10μ. Pl. 1, fig. 13.

Present in four P-pond samples from May to July, one March C-pond.

34. *Gyrosigma simile* (Grun.) Boyer; Hustedt, 1955, p. 34, pl. 10, f. 3. Cell 120μ x 18μ, with 16 transapical striae per 10μ.

Present in one C-pond sample in December.

35. *Gyrosigma beaufortianum* Hustedt, 1955, p. 34, pl. 10, f. 7-8. Cells sigmoid, 57-82μ x 6-7μ, with stauroid central nodule.

Present in four C-2 pond samples from November to February, two C-ponds and one P-pond in spring.

36. *Pleurosigma ? angulatum* var. *aestuarii* (Breb.) V. H.; Patrick, 1966, p. 332, pl. 27, f. 3a-e. Stubby sigmoid cells with central sigmoid raphe 75-92μ x 19-21μ, with 20 transapical striae/10u and 18 diagonal striae per 10u; diagonal striae absent from ends of valve.

Present in four C-pond samples and one P-pond sample from May and June, one P-pond sample the following April.

37. *Pleurosigma salinarum* Grun.; Patrick, 1966, p. 333, pl. 27, f. 2. Valves 77-105μ x 14-18μ, transapical striae 28-30/10μ. Pl. 1, fig. 14.

Present in 12 C-pond samples and 15 P-pond samples, in all seasons. P-pond maximum of 10^2 cells/ml in August.

38. *Pleurosigma strigosum* W. Sm.; Patrick, 1966, p. 335, pl. 28, f. 2. Valves 185-360μ x 20-29μ, somewhat narrower than Patrick's description, with 16-18 transapical striae/10μ. Pl. 1, fig. 15.

Present in five C-pond samples only from April to June, but in 14 P-pond samples from May straight through to January.

39. *Diploneis smithi* (Breb.) Cl.; Hustedt, 1959, p. 647, f. 1051. Valves 22-38μ x 10-17μ, with 10 ribs/10μ. Pl. 1, fig. 16.

Present in 36 C-pond samples from all seasons, and from May to December was found in all C-ponds each month. Also present in three autumn P-pond samples.

40. *Diploneis smithi* var. *pumila* (Grun.) Hust.; Hustedt, 1959, p. 650, f. 1052d-e. Valve 11μ x 7μ, 14 ribs/10μ.

Presence in four C-pond samples from autumn and winter.

41. *Diploneis* cf. *splendida* (Greg.) Cl.; Hustedt, 1959, p. 712, f. 1089. Valves 40-50μ x 19-23μ, with 6 ribs/10μ.

Single C-pond presence in March.

42. *Diploneis gruendleri* (A.S.) Cl.; Hustedt, 1959, p. 702, f. 1084. Valve 50μ x 39μ, with 7 ribs/10μ.

Single P-pond presence in summer.

43. *Stauroneis salina* W. Sm.; Hustedt, 1930, Bacill., p. 258, f. 414. Valve 45μ x 11μ, 20 striae/10μ.

Presence in one P-pond and one C-pond, March.

44. *Navicula subforcipata* Hustedt, 1964, p. 533, f. 1569. Valves 11-15μ x 7-8μ, with lyrate hyaline area, 18-20 rows of punctae/10μ.

Presence in one C-pond, one P-pond, spring.

45. *Navicula pygmaea* Kutz.; Hustedt, 1964, p. 538, f. 1574. Valves 18-42μ x 8-12μ, lyrate hyaline area and 32 rows of punctae/10μ. Pl. 1, fig. 17.

Presence in 15 C-pond samples from January to June, October to December; presence in seven P-pond samples.

46. *Navicula mutica* var. *tropica* Hust.; Patrick, 1966, p. 455, pl. 42, f. 4. Valve 26μ x 9μ, with stauroid central area, 20 rows of punctae/10μ.

Single C-pond presence from May.

47. *Navicula granulata* Bail.; Hustedt, 1955, p. 25; Hendey, 1951,

p. 49, pl. 12, f. 2. Valves 54-82μ x 26-32μ, with 12 rows of punctae/10μ.

Present in two C-pond samples from summer.

48. *Navicula* cf. *pseudosilicula* f. *olympica* Sovereign; Hustedt, 1966, p. 786, f. 1762. Valve 41μ x 9μ, with 28 rows of punctae/10μ.

Single C-pond presence from spring.

49. *Navicula arvensis* Hust.; Patrick, 1966, p. 483, pl. 46, f. 1-2. Valves 5-8μ x 2-3μ, no striations visible. Pl. 1, fig. 18a-b.

Well presented in 13 P-pond samples in summer and autumn, with densities of 10^4 cells/ml in July and 10^3 in August; one C-pond presence. Large numbers of this species were also found in the estuary adjacent to the P-ponds in the summer. See fig. 3 for seasonal distribution.

50. *Navicula* cf. *muralis* f. *agrestis* (Hust.) Lund, 1946, p. 83, f. 8A-I. Valves 8-10μ x 3-3.5μ, striae 20/10μ in center, 25/10μ at ends. Pl. 1, fig. 19.

Presence only in C-ponds, 16 samples from January to July, with 10^2 cells/ml in February and March.

51. *Navicula* aff. *friska* Carter, 1966, p. 462, pl. 3, f. 7-10. Valves 10-18μ x 3-4μ, with 24-28 striae/10μ. Pl. 1, fig. 20.

Presence only in C-ponds, 16 samples from all seasons, with densities of 10^2 cells/ml in February and March.

52. *Navicula* aff. *obsoleta* Hustedt, 1942, p. 69, f. 12-16. Valves 8-12μ x 2-3.5μ, 23 striae/10μ.

One P-pond sample in January, one C-pond sample in March, four P-pond samples the following spring.

53. *Navicula rogallii* Hustedt, 1961, p. 32, f. 1190. Valves 41-70μ x 4.5-6μ, with 25 striae/10μ. Pl. 1, fig. 21.

Present only in C-ponds, 22 samples from all seasons.

54. *Navicula* sp. Valves 15-36μ x 5.5-9.5μ, with 25-28 striae/10μ. Pl. 1, fig. 22.

Present in 11 C-pond samples, from January to March, then October to December; present in 9 P-pond samples from October to December.

55. *Navicula* sp. Valves 19-30μ x 5-7μ, with 16-20 striae per 10μ. Pl. 1, fig. 23.

Present in 13 C-pond samples from spring, summer and winter; also from six summer P-pond samples.

56. *Navicula salinarum* Grun.; Hustedt, 1955, p. 27, pl. 7, f. 25. Valves 24-36μ x 7-11μ, with 20 striae/10μ. Pl. 1, fig. 24.

Present in seven C-pond and seven P-pond samples from winter and spring.

57. *Navicula lanceolata* (Ag.) Kutz.; Hustedt, 1930, p. 305, f. 540. Valves 30-44μ x 6.5-8μ, with 14-16 striae/10μ, finely delineate. Pl. 1, fig. 25.

Present in 23 C-pond and 17 P-pond samples from all seasons.

58. *Navicula* cf. *abunda* Hust.; Hustedt, 1955, p. 27, pl. 9, f. 10-12. Valves 30-40μ x 7-8μ, narrower than Hustedt's description, with 10-12 delineate striae/10μ.

Present in one C-pond and one P-pond sample from March.

59. *Navicula* cf. *peregrina* (Ehr.) Kutz.; Hendey, 1964, p. 201, pl. 30, f. 12-13. Valves 55-72μ x 12-14μ, half the size range given by Hendey, with 6 delineate striae/10μ in the center, 9/10μ at the ends. Pl. 1, fig. 26.

Present in seven samples only from pond C-3, all seasons.

60. *Navicula yarrensis* Grun.; Hustedt, 1955, p. 32, pl. 9, f. 2. Valves 60-83 μ x 13-24μ, with 7-8 ribs/10μ. Pl. 1, fig. 27.

Present in five P-pond samples from May to August, two C-pond samples from November and December, one P-pond in January.

61. *Amphora* cf. *delicatissima* Krasske; Hustedt, 1930, Bacill., p. 346, f. 635. Single valve 10.5-16μ x 4-6μ, delicate striae 22-25/10μ. Pl. 2, fig. 1a-b.

Presence in nine C-pond samples from spring and summer, also January.

62. *Amphora tenerrima* Ale. & Hust.; Hustedt, 1955, p. 39, pl. 14, f. 15. Single valve 19μ x 5μ, with 24 striae per 10μ.

Obtained in culture by Dr. Wm. Woods from ponds C-2 and P-2.

63. *Amphora* cf. *tumida* Hustedt, 1956, p. 120, f. 51-52. Single valves 14-27μ x 4.5-6μ, with 16-20 striae/10μ. Pl. 2, fig. 2.

Present in 27 C-pond samples and 21 P-pond samples from all seasons.

64. *Amphora granulata* Greg.; Hustedt, 1955, p. 40, pl. 14, f. 8-10. Single valves 30-48μ x 8-11μ, with 12 striae per 10μ. Pl. 2, fig. 3.

Present in three C-pond and two P-pond samples from summer.

65. *Amphora ovalis* var. *affinis* Grun.; Peragallo, 1908, p. 44, f. 18. Single valves 21-55μ x 8-12μ, with 12 rows of elongate pores/10μ. Pl. 2, fig. 4.

Present in 18 C-pond samples and 30 P-pond samples, from all seasons.

66. *Amphora angusta* Greg.; Peragallo, 1908, p. 231, pl. 50, f. 37.

Single valve 25-64μ x 6-15μ, with 16-20 striae per 10μ. Pl. 2, fig. 5.

Present in 13 C-pond samples from all seasons, one P-pond sample from summer.

67. *Amphora angusta* var. *ventricosa* Greg.; Hustedt, 1955, p. 42, pl. 16, f. 26. Single valves 51-81μ x 9-10μ, with 9 striae/10μ. Pl. 2, fig. 6.

Present in six P-pond samples, one C-pond sample, spring to autumn.

68. *Amphiprora alata* Kütz.; Hustedt, 1930, Bacill., p. 340, f. 625. Cell in girdle view 102 x 45μ, with 14 rows of punctae/10μ becoming striae off wing.

Single P-pond presence in February.

69. *Amphiprora paludosa* var. *duplex* Donk.; Peragallo, 1908, p. 185, pl. 38, f. 16-19. Cells in girdle view 29-64μ x 23-30μ, with 36 delicate striae/10μ. Pl. 2, fig. 7.

Present in 27 C-pond samples from all seasons, 6 P-pond samples from May to September.

70. *Amphiprora paludosa* var. *hyalina* Eulenst.; Peragallo, 1908, p. 185, pl. 38, f. 20. Cells 12-17μ x 7-8μ, strongly twisted, no striations visible but 25 punctae/10μ along the keels. Pl. 2, fig. 8.

Present only in C-ponds, 13 samples from winter to summer, with 10^2 cells/ml concentrations from February to April.

71. *Tropidoneis lepidoptera* Greg.; Peragallo, 1908, p. 188, pl. 39, f. 3-7. Cells in girdle view 125-136μ x 35μ, with 16 rows of punctae/10μ. Pl. 2, fig. 9.

Present only in P-ponds, 16 samples from May to October, reaching 10^2 cells/ml concentration in September.

72. *Tropidoneis pusilla* (Greg.) Cl.; Hendey, 1964, p. 256, pl. 27, f. 1-2. Cells in girdle view 55-66μ x 18-27μ, with 18-20 striae/10μ.

Present in one P-pond and two C-pond samples, summer and autumn.

73. *Denticula* cf. *subtilis* Grun.; Hustedt, 1955, p. 43, pl. 9, f. 26. Valve 8μ x 3μ, with 8 costae/10μ.

Single P-pond presence in May.

74. *Rhopalodia musculus* var. *producta* Grun.; Peragallo, 1908, p. 303, pl. 77, f. 23-24. Valves 17-21μ x 7-9μ, with 16 striae/10μ. Pl. 2, fig. 10.

Present in pond C-3 from October to March.

75. *Cylindrotheca gracilis* (Breb.) Grun.; Hustedt, 1930, p. 393,

f. 746. Cells 88-143μ x 3-4.5μ, with 22 fine keel punctae/10μ.

Presence in two C-ponds in February.

76. *Bacillaria paradoxa* Gmel.; Hustedt, 1930, Bacill., p. 396, f. 755. Cells 84-108μ x 4.5μ, with 10 keel punctae/10μ and 30 striae/10μ. Pl. 2, fig. 11.

Presence only in C-ponds, 10 samples from winter to summer.

77. *Nitzschia compressa* (Bail.) Boyer; Wood, 1961, p. 694, pl. 55, f. 174. Valves 17-32μ x 11-14μ, with 7 rows of areolae/10μ. Pl. 2, fig. 12.

Present in four C-ponds from spring and summer, four P-pond samples from summer and autumn.

78. *Nitzschia marginulata* Grun.; Peragallo, 1908, p. 270, pl. 70, f. 14-17. Valve 88μ x 13μ, with 12 keel punctae and 24 striae/10μ.

Single winter C-pond sample.

79. *Nitzschia apiculata* (Greg.) Grun.; Hustedt, 1930, Bacill., p. 401, f. 765. Valves 37-59μ x 6-8μ, with 13 keel punctae and 24 striae/10u. Pl. 2, fig. 13.

Presence in 28 C-pond samples from all seasons, 10 P-pond samples from May and November to March.

80. *Nitzschia hybrida* Grun.; Hustedt, 1930, Bacill., p. 406, f. 778. Valves 57μ x 8μ, with 12 keel punctae and 20 striae/10μ.

Present in two C-pond samples from February and March.

81. *Nitzschia hybridaeformis* Hustedt, 1955, p. 44, pl. 15, f. 9-11. Cells 25-36μ x 6-8μ, half the length given by Hustedt, with 10 keel punctae and 30 delicate striae per 10μ. Pl. 2, fig. 14.

Presence in four C-pond samples, from February to June.

82. *Nitzschia panduriformis* var. *minor* Grun.; Peragallo, 1908, p. 269, pl. 70, f. 6. Valves 16-33μ x 5-13μ, with 10 keel punctae and 24 rows of punctae/10μ. Pl. 2, fig. 15.

Presence in six C-pond samples from spring to autumn, one P-pond sample from May.

83. *Nitzschia spathulata* Breb.; Peragallo, 1908, p. 284, pl. 73, f. 4. Cells 41-61μ x 6-9μ, with 5 keel punctae/10μ. Pl. 2, fig. 16a-b.

Presence in 14 P-pond samples from August to April, two C-pond samples from November and December.

84. *Nitzschia* cf. *angularis* Sm.; Peragallo, 1908, p. 284, pl. 73, f. 6-7. Cells 52-56μ x 8-9μ, with 4-5 keel punctae/10μ. Pl. 2, fig. 17.

Presence in eight C-pond samples from March to June, and three P-pond samples from May to July.

85. *Nitzschia* cf. *communis* var. *hyalina* Lund, 1946, p. 104, f. 136K. Valves 10-14μ x 2-3μ, with 16-18 keel punctae/10μ, no striae visible. Pl. 2, fig. 18a-b.

Presence in 10 P-pond samples from all seasons, with 10^3 cells/ml concentrations from July to September; presence in 9 C-pond samples, January to April and in September. See figs. 2 and 3 for seasonal distribution.

86. *Nitzschia* cf. *laevis* Hustedt, 1955, p. 46, pl. 15, f. 5. Valve 18μ x 5μ, with 16 keel punctae/10μ, no striae visible.

Present in pond C-3 in February and April.

87. *Nitzschia proxima* Hustedt, 1955, p. 46, pl. 16, f. 3. Cells 12-35μ x 1.5-3μ, with 10-13 keel punctae/10μ and 25 striae/10μ. Pl. 2, fig. 19.

January to September C-pond presence in 26 samples with densities reaching 10^2 cells/ml each season and a peak of 10^4 cells/ml in August; presence in six P-pond samples from all seasons with 10^3 cells/ml in May. See fig. 2 for seasonal distribution.

88. *Nitzschia frustulum* (Kutz.) Grun.; Hustedt, 1930, p. 414, f. 795. Valves 25-36μ x 4-5μ, with 11 keel punctae and 22-24 striae/10μ. Pl. 2, fig. 20.

Presence in 30 C-pond samples from all seasons, and seven P-pond samples from July and winter.

89. *Nitzschia grossestriata* Hustedt, 1955, p. 46, pl. 16, f. 8-10. Valves 33-42μ x 5-6μ, with 8 keel punctae and 16 rows of punctae/10μ. Pl. 2, fig. 21.

Four presences in pond C-3, summer and autumn.

90. *Nitzschia* cf. *fonticola* Grun.; Hustedt, 1930, Bacill., p. 415, f. 800. Valves 11μ x 2 μ, with 12-16 keel punctae and 24 striae/10μ.

Presence in three C-pond samples from winter.

91. *Nitzschia* cf. *serpenticula* Cholnoky, 1968, p. 79, f. 148. Valves sigmoid, 20-31μ x 2.5-3μ, with 16-18 keel punctae/10μ. Pl. 2, fig. 22.

Presence in 13 C-pond samples from January to May, also July and October; one P-pond presence in August.

92. *Nitzschia sigma* (Kutz.) Sm.; Hustedt, 1930, Bacill., p. 401, f. 813. Valves 110-335μ x 9-13μ, with 6 keel punctae and 30 striae/10μ. Pl. 2, fig. 23.

Presence in 14 C-pond samples from winter to summer, one P-pond presence in June.

93. *Nitzschia sigma* var. *rigidula* Grun.; Peragallo, 1908, p. 291, pl. 74, f. 10-11. Sigmoid valves 48-120μ x 4.5-6.5μ, with 9 keel punctae and 32 striae/10μ. Pl. 2, fig. 24.

Presence in 19 C-pond samples from all seasons, three P-pond samples in winter.

94. *Nitzschia obtusa* var. *scalpelliformis* Grun.; Hustedt, 1930, Bacill., p. 422, f. 817d. Valves 57-63μ x 4.5-5.5μ, with 8-9 keel punctae/10μ. Pl. 2, fig. 25.

Presence in pond C-3, April to June and September.

95. *Nitzschia longissima* (Breb.) Ralfs.; Cupp, 1943, p. 200, f. 154. Valves 135-225μ x 4.5-7μ, with 12 keel punctae/10μ. Pl. 2, fig. 26.

Presence in 27 C-pond samples from all seasons, three P-pond samples from fall and winter.

96. *Nitzschia closterium* W. Sm.; Hustedt, 1955, p. 48, pl. 16, f. 16-18. Cells 35-92μ x 2-6.5μ, with 12-16 keel punctae/10μ. Pl. 2, fig. 27a-c.

Presence in 35 C-pond samples from every month; presence in 35 P-pond samples from every season with peaks of 10^3 cells/ml in summer, 10^4 cells/ml in October, and 10^5 cells/ml in April. See figs. 2 and 3 for seasonal distribution.

97. Genus? species? Somewhat lunate cells with bluntly rounded ends, containing one or two strap-shaped pale yellow-green plastids, the cell walls surviving treatment for clearing diatom frustules and bearing fine marginal striations, 12/10μ, appearing not to be keel punctae; no raphe present. Cells 34-36μ x 4-5μ. Pl. 2, fig. 28.

Present in three C-pond samples from summer.

(Class Cryptophyceae)

98. *Hemiselmis virescens* Droop; Campbell, 1973, p. 103, pl. 1, f. 1a-b, pl. 22, f. 1-3. Bean-shaped cells 4-6μ x 2-4μ with turquoise chromatophore and spherical refractive body but no stigma. Pl. 2, fig. 29a-b.

Present in 32 C-pond samples from all seasons, numbers building from 10^2 cells/ml in late spring to 10^3 cells/ml levels in July and August; present in 28 P-pond samples from all seasons, with 10^4 cells/ml levels reached in July and September. See figs. 2 and 3 for seasonal distribution.

99. *Chroomonas diplococca* Butcher, 1967, p. 26, pl. 1, f. 14. Ovoid cells 7-8μ x 4-6μ, with single parietal turquoise green chromatophore and 1-2 refractive bodies but no pyrenoid or stigma. Pl. 2, fig. 30.

Present in six P-pond samples from spring to fall, two C-pond samples from summer and two from January.

100. *Chroomonas minuta* var. *apyrenoidosa* Hulbert; Campbell, 1973, p. 107, pl. 1, f. 4a-f, pl. 22, f. 5-6. (Butcher, 1967, places all *Rhodomonas* species with only two rows of trichocysts in the genus *Chroomonas*.) Cells 6-8μ x 3-5μ, with single dorsal golden brown chromatophore sometimes with a reddish tint, and a spherical refractive body near the apex. Pl. 2, fig. 31a-b.

Present in three P-pond samples in August and September, P-3 in August 10^4 cells/ml; presence in nine C-pond samples, in September and January to March, reaching 10^2 cells/ml.

101. *Chroomonas amphioxeia* (Conr. & Kuff.) Butcher; Campbell, 1973, p. 108, pl. 1, f. 5a-e, pl. 22, f. 7-9. Cells irregularly oval but variable in shape, two rows of trichocysts, dorsal yellow-brown chromatophore and anterior refractive body, sometimes a pyrenoid-like bulge present in the chromatophore. Pl. 2, fig. 32a-c showing some of the variability in form. Cells 6-11μ x 4-7μ.

Present in four C-pond samples from spring to autumn; presence in 14 P-pond samples from May to October reaching abundances of 10^4 cells/ml in July and August. See fig. 3 for seasonal distribution.

102. *Cryptomonas stigmaticum* Wislouch; Carter, 1937, p. 53, pl. 6, f. 38-40. Generally ovoid cells 12-16μ x 6-10μ, golden-brown chromatophore parietal, with ventral red stigma, two starch-ensheathed pyrenoids in the middle of the cell.

Present in two P-pond samples, July and October.

103. *Cryptomonas pseudobaltica* Butcher; Campbell, 1973, p. 109, pl. 1, f. 6a-i, pl. 22, f. 10-12. Ovoid cells 13-16μ x 7-9μ, with parietal reddish- to yellowish-brown chromatophore and dorsal pyrenoid with starch sheathe, four rows of trichocysts lining the gullet. Pl. 2, fig. 53.

Present in eight P-pond samples from all seasons, two C-pond samples from September.

104. *Cryptomonas testacea* Campbell, 1973, p. 113, pl. 2, f. 9a-d, pl. 22, f. 14-16. Elongate-elliptical cells 18-25μ x 7-11μ, with central starch-ensheathed pyrenoid.

Presence in three C-ponds, February and March, one February P-pond.

105. *Cryptomonas* cf. *acuta* Butcher, 1967, p. 40, pl. 5, f. 4. Half-ovate cells 15-16μ x 7-8μ, flattened ventrally, posteriorly acute, with central pyrenoid and olive brown chromatophore.

Presence in two C-ponds from July, one P-pond in February.

106. *Cryptomonas ovata* Ehr.; Campbell, 1973, p. 114, pl. 2, f. 11a-b, pl. 22, f. 17-18. Ovate cells 18-21μ x 10-11μ, starch grains obscuring all internal detail but the two parietal olive green golden chromatophores and the large gullet outlined by many trichocyst rows.

One P-pond presence in November, one C-pond presence in December.

(Class Dinophyceae)

107. *Prorocentrum minimum* (Pav.) Schiller; Campbell, 1973, p. 118, pl. 3, f. 14a-c, pl. 23, f. 2. Cells broadly ovoid and compressed, 14-20μ x 11-20μ x 8μ, theca of two valves with striate margins, apical tooth blunt and short, sometimes absent. Yellow-brown chromatophores irregularly lobed, nucleus basal. Pl. 3, fig. 1A.

Present in four C-pond samples from winter, abundant in 11 P-pond samples from fall, winter, and April, reaching 10^4 cells/ml densities in November and December. See fig. 3 for seasonal distribution.

108. *Exuviaella compressa* (Stein) Ostenfeld; Campbell, 1973, p. 119, pl. 3, f. 16a-c, pl. 23, f. 5-6. Elliptical cells slightly compressed, 20μ x 16μ, two yellow-brown parietal chromatophores with two central pyrenoids, basal nucleus.

Single winter C-pond presence.

109. *Oxyrrhis marina* Dujardin; Schiller; Campbell, 1973, p. 126, pl. 4, f. 22a-f, pl. 24, f. 1-3. Cells generally elongate-elliptical with unsymmetrical hypocone, 27μ x 18μ, no chromatophore, granular cytoplasm, nucleus in epicone. Pl. 3, fig. 1B.

Present in 11 P-pond samples from January to April, 10^2 cells/ml each month. See fig. 3 for seasonal distribution.

110. *Gymnodinium danicans* Campbell, 1973, p. 133, pl. 5, f. 30a-f, pl. 25, f. 4-6. Orbicular cells with obliquely truncate antapex, 9-20μ x 8-18μ, dorsiventrally compressed; girdle sub-equatorial, wide and shallow, displaced 1/2 girdle width, sulcus on hypocone only, shallow; transverse flagellum encircling cell, longitudinal flagellum 1 1/2 times body length; chromatophores irregularly elliptical, yellow-brown, peripheral, around five in number; spherical nucleus centrally placed; one to several red stigmatic granules adjacent to the sulcus. Pl. 3, fig. 2.

Present in three C-pond samples from spring and fall, and in three P-pond samples from summer and winter.

111. *Gymnodinium aurantium* Campbell, 1973, p. 136, pl. 6, f. 33a-d. Broadly fusiform cell 14μ x 9μ, with conical epicone and rounded hypocone, median girdle, orange chromatophores.

Single C-pond presence in July.

112. *Gymnodinium* sp.; Orbicular cells 9-13μ x 7-11μ, sub-equatorial girdle displaced 1/2 girdle width, wide and shallow, sulcus shallow on hypocone, longitudinal flagellum 1 1/2 times body length, chromatophores absent, food body often in epicone, nucleus basal. Pl. 3, fig. 3.

Present in four C-pond samples from spring to autumn, and five P-pond samples from spring, autumn and winter.

113. *Gymnodinium roseostigma* Campbell, 1973, p. 137, pl. 6, f. 35a-d. Broadly elliptical cells somewhat dorsiventrally compressed, 8-15μ x 6-12μ; girdle sub-equatorial, wide and shallow, not displaced, sulcus very shallow on hypocone; transverse flagellum encircling the body, longitudinal flagellum somewhat longer than body length; chromatophores absent; large spherical nucleus in hypocone; elongate pale red stigma adjacent to the sulcus. Pl. 3, fig. 4.

Present in six P-pond samples from summer and winter, with 10^2 cells/ml in both seasons; one C-pond sample from autumn.

114. *Katodinium asymmetricum* (Massart) Fott; Campbell, 1973, p. 149, pl. 7, f. 49a-c, pl. 26, f. 3. Arrowhead-shaped cells 17μ x 12μ, chromatophores absent, assimilate body often present in epicone, nucleus in hypocone. Pl. 3, fig. 5.

Present in three P-ponds from summer, with 10^2 cells/ml in July.

115. *Gyrodinium dominans* Hulburt; Campbell, 1973, p. 161, pl. 10, f. 63a-b, pl. 27, f. 3-4. Broadly fusiform cells 16-30μ x 11.5-20μ, longitudinal striations on body, girdle displaced 1/4 the body length,

chromatophores absent, nucleus central, food body often in the hypocone. Pl. 3, fig. 6.

Present in 10 P-pond samples from late spring to early winter with 10^2 cells/ml concentrations from July to September; present in four C-pond samples, May and September.

116. *Gyrodinium estuariale* Hulburt; Campbell, 1973, p. 154, pl. 8, f. 59a-g. Ellipsoid cells 11-15μ x 7.5-9μ, dorsiventrally compressed with somewhat obliquely truncate antapex, wide shallow girdle displaced one girdle width, sulcus shallow on hypocone, chromatophores brownish-yellow, one or two in hypocone and in epicone, central nucleus. Pl. 3, fig. 7.

Presence in two C-pond samples from August, with 10^2 cells/ml in C-1; two P-ponds in August; one P-pond in April with 10^3 cells/ml.

117. *Gyrodinium metum* Hulburt; Campbell, 1973, p. 157, pl. 9, f. 58a-q, pl. 26, f. 12. Broadly fusoid cells 9μ x 7μ, with "chinaman's hat" epicone, chromatophores absent, nucleus sub-central. Pl. 3, fig. 8.

Abundant in three C-pond samples from July to September, reaching 10^3 cells/ml in August; 10^2 cells/ml in three P-ponds from August.

118. *Glenodinium* sp. Orbicular cells 24-32μ x 22-30μ, undisplaced median girdle, chromatophores absent, very granular cytoplasm.

Present in three C-pond samples from spring, summer and winter, three P-pond samples from autumn and spring.

119. *Heterocapsa triquetra* (Ehr.) Stein; Campbell, 1973, p. 172, pl. 12, f. 78a-d, pl. 28, f. 5-6. Thecate spindle-shaped cells 23-25μ x 12-15μ, irregularly lobed yellow-brown chromatophores, large elliptical nucleus in the epitheca. Pl. 3, fig. 6.

Presence in four C-pond samples from winter, five P-pond samples from February and March.

120. *Peridinium aciculiferum* Lemm.; Campbell, 1973, p. 174, pl. 12, f. 80a-e, pl. 28, f. 7-9. Broadly ovoid cells 33-45μ x 27-38μ, theca with apical horn, 2-4 antapical spines, numerous elongate golden-brown chromatophores, large elongate red stigmatic body adjacent to sulcus. Pl. 3, fig. 10.

Present in pond P-3 in September, 10^2 cells/ml, and October; C-pond presence in September.

121. *Peridinium achromaticum* Lev.; Schiller, 1937, p. 229, f. 225. Rhomboid thecate cells 34-41μ x 29-36μ, sulcus excavating the antapex,

chromatophores absent, large elliptical nucleus in center of cell. Pl. 3, fig. 11a-b.

Present only in P-ponds, 15 samples from May to October, with 10^2 cells/ml levels in May and August.

122. *Peridinium* cf. *trochoideum* (Stein) Lemm.; Campbell, 1973, p. 173, pl. 12, f. 79a-b. Pear-shaped cells 21-25μ x 17-18μ, epitheca with apical horn, hypotheca hemispherical, chromatophores deep golden-brown.

Presence in one C-pond and one P-pond in autumn.

(Class Haptophyceae)

123. *Hymenomonas carterae* (Braarud & Fagerl.) Braarud; Campbell, 1973, p. 187, pl. 14, f. 95, pl. 30, f. 1-2. (May be synonymous with *Aspidiophora viridissima* Sjöstedt, 1924, p. 9, f. 19-26.) Globular cells 6.5-13μ in diameter, covered with elliptical ring coccolith scales 1.3 x 2μ in size, two flagella, two golden-brown parietal chromatophores. Pl. 3, fig. 15.

Present in five C-1 pond samples from spring and winter, with 10^3 cells/ml in April.

124. *Chrysochromulina* sp. (species identification requires E. M. detail of body scales); Sub-orbicular cells 4-7μ x 3.5-6μ, two parietal brownish-yellow chromatophores and basal leucosin body, two flagella and a haptonema up to 20μ long when extended. Pl. 3, fig. 16a-b.

Present in nine C-pond samples from spring to winter, with 10^3 cells/ml in August, 10^4 cells/ml in October; present with 10^3 cells/ml concentrations in three P-ponds from May.

125. *Prymnesium parvum* Carter; Campbell, 1973, p. 182, pl. 14, f. 91a-d, pl. 29, f. 3-5. Elongate-elliptical cells 8-11μ x 3.5-4.5μ with obliquely truncate apex, two long parietal brownish- to greenish-yellow chromatophores, two flagella and a short haptonema. Pl. 3, fig. 17.

Present in six C-pond samples, winter to summer.

(Class Chrysophyceae)

126. *Ochromonas* sp. (with affinities to *O. minuscula* Conrad, 1930); Cells 5-9μ x 4-8μ, basically orbicular but variable in shape, two flagella with the shorter 2/3 the length of the longer, a single parietal olive-yellow chromatophore with no stigma. Pl. 3, fig. 18a-d.

Present in three C-pond samples in winter, a density of 10^4 cells/ml in January. See fig. 2 for seasonal distribution.

127. *Ochromonas* sp. (with similarities to *O. vallesiaca* Skuja, 1948); Cells orbicular to elliptical, 4.5-8μ diameter, cell surface rugose probably from presence of small scales, single parietal strap-shaped brownish-yellow chromatophore bearing an orange stigma on an anterior corner; two flagella, the shorter less than 1/3 the length of the longer. Pl. 3, fig. 19.

Presence in eight C-pond samples from spring to autumn with 10^3 cells/ml levels in April and July; single P-pond presence in July with 10^4 cells/ml. See fig. 2 for seasonal distribution.

128. *Pavlova gyrans* Butcher, 1952, p. 183, pl. 2, f. 35-38. Ovoid to obovoid cells 7-9μ x 4-4.5μ; thick sigmoid anteriorly directed flagellum, short fine laterally directed flagellum, and long fine trailing haptothrix all inserted anterioventrally; two parietal brownish- to greenish-yellow chromatophores, one bearing an anterior orange stigma. Pl. 3, fig. 20.

Present in five C-pond samples from February and March.

129. *Monochrysis lutheri* Droop; Campbell, 1973, p. 191, pl. 15, f. 101a-c. Sub-triangular cells strongly compressed, 5μ x 4μ x 2.5μ; a thick sigmoid flagellum anteriorly directed and a fine short flagellum laterally directed both inserted in the concave side of the cell; two olive green chromatophores, the more posterior one associated with a cluster of orange granules. Pl. 3, fig. 21a-b.

Present in three C-pond samples from spring, with 10^4 cells/ml in March and 10^3 cells/ml in April; one P-pond presence in April with 10^2 cells/ml.

130. *Calycomonas ovalis* Wulff; Campbell, 1973, p. 200, pl. 16, f. 112a-b, pl. 31, f. 10-12. Ovoid orange lorica 5μ x 4μ with a small anterior opening and 5-6 annular thickenings. Pl. 3, fig. 39.

Present only in C-ponds, seven samples from August to October.

(Class Xanthophyceae)

131. *Nephrochloris salina* Carter; Campbell, 1973, p. 202, pl. 17, f. 115a-b, pl. 32, f. 1-2. Sub-elliptical cells dorsiventrally compressed, 6-10μ x 5-7μ; thick sigmoid flagellum anteriorly directed, fine short

flagellum laterally directed, both inserted anterioventrally, two parietal greenish-yellow chromatophores, two central disc-shaped refractive bodies. Pl. 3, fig. 22.

Presence only in P-ponds, eight samples from summer to winter, with 10^2 cells/ml in August and September.

132. *Monallantus stichococcoides* Pascher, 1939, Heterokont., p. 425, f. 292. Cylindrical cells 3-7μ x 1.5-2.5μ, with delicate walls, solitary, 1-2 pale green chromatophores with no pyrenoids. Pl. 3, fig. 23a-f.

Abundant in C-ponds only, 18 samples from January to May, October to December, with densities of 10^3 cells/ml in February and March, 10^4 cells/ml in January and May, and 10^5 cells/ml in April. See fig. 2 for seasonal distribution.

133. *Monodus* aff. *guttula* Pascher, 1939, p. 438, f. 301. Comma-shaped cells 3-5μ x 2-4μ, with mucronulately tipped delicate walls, 1-2 pale green chromatophores, several refractive globules in the cell ends. Pl. 3, fig. 24a-i.

Presence in six C-pond samples from winter and spring; from 36 P-pond samples, with abundance in seven samples from August to November and one sample in April with 10^3 to 10^4 cells/ml concentrations, and pea-soup dense dominance in 28 P-pond samples with 10^6 cells/ml densities from January to March building to 10^7 cells/ml in April, followed by a sharp and complete crash of the blooms on May 11, cells returning in August and attaining 10^6 cells/ml concentrations again from October to April. See Fig. 3 for seasonal distribution.

134. *Goniochloris pulchra* Pascher, 1939, p. 623, f. 483. Strongly compressed triangular cells 11μ x 10μ x 2.5-5μ, with a regularly warty patterned cell wall, 3-6 pale green chromatophores, sometimes a cluster of orange granules in the center. Pl. 3, fig. 25a-d.

Presence in two C-pond samples from summer and autumn; presence in 22 P-pond samples from May to December, also February and April, from 10^4 cells/ml in May and June, 10^3 cells/ml in June and July, down through 10^2 cells/ml in August and September. See fig. 3 for seasonal distribution.

135. *Centritractus* aff. *belonophorus* Lemm.; Pascher, 1939, p. 853, f. 707, 709, 711. Cylindrical cells 5-9μ x 2-2.5μ, cell wall halves with acute ends extended into long setae. These cells are less than a third the size given by Pascher. Pl. 3, fig. 26.

Abundant in two C-pond samples from August and September, two P-pond samples from August, 10^3 to 10^2 cells/ml.

136. Genus? species? Elongate-cylindrical cells 4-15μ x 1-1.5μ, with 1-2 elongate pale greenish-yellow plastids, pale bluish globules at the ends of the cell. Pl. 3, fig. 27a-c.

Presence in six C-pond samples from summer to winter and the following spring with 10^3 cells/ml in July and April; presence in two summer P-pond samples.

(Class Euglenophyceae)

137. *Eutreptia* cf. *lanowii* Steuer; Campbell, 1973, p. 208, pl. 17, f. 122a-g, pl. 32, f. 7-9. Fusiform cells long pointed posteriorly, 21-55μ x 7-18μ, with two flagella, one the length of the cell, the other half this length; large red anterior stigma, numerous discoid green plastids, no pyrenoids, numerous elliptical pyramylum grains, central nucleus. Pl. 3, fig. 12.

Presence in four C-pond samples from spring and winter, four P-pond samples from autumn.

138. *Euglena* aff. *proxima* Dangeard; Campbell, 1973, p. 209, pl. 18, f. 123a-e, pl. 32, f. 10. Metabolic cells generally fusiform with tapering posteriority, 23-45μ x 7-15μ, flagella about cell length, anterior red stigma, numerous discoid small green plastids and numerous discoid paramylum grains. Pl. 3, fig. 13.

Present in two C-pond samples in May, up to 10^2 cells/ml; present in four P-pond samples, summer and fall.

139. *Euglena pumila* Campbell, 1973, p. 121, pl. 18, f. 127a-g. Generally fusiform metabolic cell 11μ x 5μ, with anterior red stigma and two green plastids.

Single C-pond presence in July.

140. *Trachelomonas* ? *obovata* Stobes; Pascher & Lemmermann, 1913, p. 151, f. 287. Obovate orange theca 16-18μ x 9-10μ with rugose surface and a ringed apical pore, olive-green plastids inside. Pl. 3, fig. 14.

Presence in pond C-3 from March to July, four other C-pond samples from winter and spring.

(Class Prasinophyceae)

141. *Pedinomonas minor* Korsch.; Ettl, 1967, p. 3, pl. 1, f. 7, pl. 2, f. 6-8. Elliptical cells 3μ x 2μ, laterally placed green plastid with red stigma, a single short flagellum curving around the plastid side of the cell. Pl. 3, fig. 28A.

Present in six C-pond samples from spring to autumn with 10^3 cells/ml in July; four P-pond samples from spring to autumn with 10^3 cells in May.

142. *Nephroselmis gilva* Parke & Rayns, 1964, p. 209, f. 1-25. Ovate cells 3μ x 2μ, laterally compressed, with unequal flagella trailing when motile but the shorter often curved around body when at rest, lobed green plastid with basal pyrenoid, stigma absent. Pl. 3, fig. 28B.

Present in three C-pond samples from spring, summer, and autumn; three P-ponds in April with 10^2-10^4 cells/ml.

143. *Heteromastix pyriformis* (Carter) Manton; Campbell, 1973, p. 215, pl. 19, f. 131a-b, pl. 33, f. 4-6. Pyriform compressed cells 4.5-6μ x 4-5μ x 2-3μ, with a thicker curved 9μ flagellum and thinner 16-27μ flagellum, parietal green plastid with basal pyrenoid and two anterior lobes, one bearing a red stigma. Pl. 3, fig. 29.

Present in 13 C-pond samples from all seasons with 10^2 cells/ml abundances in late spring and summer; present in six P-pond samples with some 10^2 cells/ml concentrations in summer, autumn, and spring.

144. *Pyramimonas grossii* Parke; Campbell, 1973, p. 215, pl. 19, f. 132a-e. Obovoid cells with four-lobed anterior 8μ x 5μ, four-lobed plastid with basal pyrenoid, lateral red stigma, four flagella.

Single summer C-pond presence.

145. *Pyramimonas pluriocula*ta Butcher; Campbell, 1973, p. 218, pl. 19, f. 135a-d, pl. 33, f. 9. Somewhat pyramidal cells 6-8μ x 4-5μ with bluntly rounded posterior and four-lobed anterior, four flagella, a four-lobed green plastid with basal pyrenoid, an anterior double red stigma between two lobes and posterior red granules. Pl. 3, fig. 30.

Presence in nine C-pond samples from spring to early fall; presence in 15 P-pond samples in the same time period with 10^4 cells/ml in June, 10^3 cells/ml in June and July. See figs. 2 and 3 for seasonal distribution.

146. *Pyramimonas* cf. *micron* Conr. & Kuff.; Campbell, 1973, p. 217, pl. 19, f. 134a-d, pl. 33, f. 8. Sub-hemispherical cells 4-5μ x 4-5μ with four-lobed anterior, four flagella, four-lobed plastid with basal pyrenoid and red stigma at the tip of one of the lobes. Pl. 3, fig. 31.

Summer presence in one C-pond; presence in six P-pond samples with 10^4 cells/ml density in June, 10^3 cells/ml densities in July.

147. *Tetraselmis contracta* (Carter) Butcher; Campbell, 1973, p. 220, pl. 20, f. 139a-b. Broadly ovoid cell with two-lobed anterior 19μ x 14μ, compressed, protoplasm contracted away from the cell wall, two-lobed green plastid, large anterior stigma.

Single spring C-pond presence.

148. *Tetraselmis maculata* (Kylin) Butcher; Campbell, 1973, p. 222, pl. 20, f. 141a-b, pl. 33, f. 13. Ovate compressed cells 8-13.5μ x 5-9μ, two rounded anterior lobes, four flagella, two-lobed rugose green plastid with basal pyrenoid, large red stigma near the pyrenoid. Pl. 3, fig. 32.

Presence in six C-pond samples from all seasons, one P-pond sample from summer.

(Class Chlorophyceae)

149. *Chlamydomonas* sp. Ovoid cells 4-5μ x 3-4μ with cup-shaped green plastid filling the posterior half of the cell, large lateral orange-red stigma, two flagella, pyrenoid apparently absent. Pl. 3, fig. 33.

Presence in pond C-3 in February and March, P-1 in July and August with 10^2 cells/ml.

150. *Nannochloris atomus* Butcher, 1952, p. 181, pl. 1, f. 27-29. Small spherical green cells 2.2-3.5μ in diameter, with granular cytoplasm. Pl. 3, fig. 34a-b.

Presence in 16 C-pond samples from all seasons, 10^4 cells/ml in April increasing to 10^5 in May, 10^3 from August to October; abundance in six P-pond samples, 10^3 cells/ml in May, July and September. See figs. 2 and 3 for seasonal distribution.

151. Genus? species? (perhaps related to *Nannochloris bacillaris* Naumann; Whitford & Schumacher, 1969, p. 16, pl. 3, f. 13.) Tiny sub-spherical cells 1.5-2μ in diameter, with a parietal cup-shaped green plastid filling less than half the cell. Pl. 3, fig. 37.

Presence in four C-pond samples from September and December, with 10^3 cells/ml in September; single September P-pond presence.

152. *Oocystis parva* West & West; Whitford & Schumacher, 1969, p. 47, pl. 12, f. 14. Football-shaped cells 6-15μ x 5-12μ, cell wall not thickened to form tips, 1-4 parietal green plastids. Pl. 3, fig. 35a-b.

Single C-pond presence in June; 30 sample P-pond presence from all seasons, with 10^4 cells/ml levels in July and September and 10^3 cells/ml in May, June and August. See fig. 3 for seasonal distribution.

153. Genus? species? Small ovoid cells 4-5μ x 3-4μ, with a parietal green plastid covering the cell surface. Pl. 3, fig. 36a-b.

Presence in seven C-pond samples from July to November, 10^2 cells/ml in summer, 10^3 cells/ml in September.

(Class Cyanophyceae)

154. *Merismopedia glauca* (Ehr.) Nag.; Whitford & Schumacher, 1969, p. 132, pl. 60, f. 46. Monostromatic colonies of groups of tetrads of granular blue-green cells each 4-5μ in diameter.

Single C-pond and single P-pond presence in summer.

155. *Spirulina subsalsa* Oersted; Prescott, 1962, p. 480, pl. 108, f. 14. A 1μ thick bluegreen filament tightly coiled into a 2.5μ spiral, with motility. Pl. 3, fig. 38.

Presence in pond C-3 from September to December, presence in five P-pond samples from autumn and winter.

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TABLE 1

18 C-POND DOMINANT and/or POTENTIAL INDICATOR SPECIES

* = Potential indicator species

	DOMINANT SPECIES attaining concentrations of 10^3 cells/ml or more	SEASON OF DOMINANCE	MAXIMUM DENSITY cells/ml	C-pond/P-pond FREQUENCY RATIO
1.	*Monallantus stichococcoides*	Winter, spring	7×10^5	18/0 *
2.	*Nannochloris atomus*	Spring	9×10^5	16/6
3.	*Ochromonas ? minuscula*	Winter	1×10^4	3/0
4.	*Cyclotella caspia*	Summer	1×10^4	12/2
5.	*Monochrysis lutheri*	Spring	1×10^4	3/1
6.	*Nitzschia proxima*	Summer	1×10^4	26/6
7.	*Hemiselmis virescens*	Summer	3×10^3	32/28
8.	*Ochromonas ? vallesiaca*	Spring	1×10^3	8/1
9.	*Pedinomonas minor*	Summer	1×10^3	6/4
	SPECIES with concentrations less than 10^3 cells/ml showing high C-pond/P-pond frequency ratios			
10.	*Navicula rogallii*			22/0 *
11.	*Navicula* cf. *muralis* f. *agrestis*			16/0 *
12.	*Navicula* cf. *friska*			16/0 *
13.	*Amphiprora paludosa* var. *hyalina*			13/0 *
14.	*Bacillaria paradoxa*			10/0 *
15.	*Nitzschia sigma*			14/1 *
16.	*Amphora angusta*			13/1 *
17.	*Nitzschia* cf. *serpenticula*			13/1 *
18.	*Diploneis smithii*			36/3 *

TABLE 2

23 P-POND DOMINANT and/or POTENTIAL INDICATOR SPECIES

* = Potential indicator species

	DOMINANT SPECIES attaining concentrations of 10^3 cells/ml or more	SEASON OF DOMINANCE	MAXIMUM DENSITY cells/ml	P-pond/C-pond FREQUENCY RATIO
1.	*Monodus guttula*	Autumn, winter and spring	12×10^6	36/6 *
2.	*Chaetoceros muelleri*	Summer, autumn	3×10^5	23/12
3.	*Nitzschia closterium*	Autumn, spring	2×10^5	35/35
4.	*Prorocentrum minimum*	Autumn	9×10^4	11/4
5.	*Nephroselmis gilva*	Spring	9×10^4	3/3
6.	*Hemiselmis virescens*	Summer, autumn	7×10^4	28/32
7.	*Oocystis parva*	Summer, early fall	2×10^4	30/1 *
8.	*Chroomonas amphioxeia*	Summer	2×10^4	14/4
9.	*Goniochloris pulchra*	Late spring	1×10^4	22/2 *
10.	*Pyramimonas plurioculata*	Summer	1×10^4	15/9
11.	*Navicula arvensis*	Summer	1×10^4	13/1 *
12.	*Nannochloris atomus*	Summer	1×10^4	6/16
13.	*Ochromonas ? vallesiaca*	Summer	2×10^4	1/8
14.	*Nitzschia* cf. *communis* var. *hyalina*	Summer	8×10^3	20/9
15.	*Gyrodinium estuariale*	Spring	6×10^3	3/2
16.	*Cyclotella striata* var. *ambigua*	Summer	4×10^3	29/1 *
17.	*Pedinomonas minor*	Spring	2×10^3	4/6
18.	*Coscinodiscus sublineatus*	Summer	1×10^3	16/0 *
19.	*Nitzschia proxima*	Spring	1×10^3	6/26
	SPECIES with concentrations less than 10^3 cells/ml showing high P-pond/C-pond frequency ratios			
20.	*Tropidoneis lepidoptera*			16/0 *
21.	*Peridinium achromaticum*			15/0 *
22.	*Oxyrrhis marina*			10/0 *
23.	*Nephrochloris salina*			8/0 *

TABLE 3

AVERAGE PROTOPLASMIC VOLUMES
FOR DOMINANT PHYTOPLANKTON SPECIES
WITHOUT LARGE CENTRAL VACUOLES
measured in cubic microns

1.	*Nannochloris atomus*	12 μ^3
2.	*Monodus guttula*	20 μ^3
3.	*Monallantus stichococcoides*	25 μ^3
4.	*Monochrysis lutheri*	35 μ^3
5.	*Hemiselmis virescens*	45 μ^3
6.	*Ochromonas* spp.	60 μ^3
7.	*Pyramimonas plurioculata*	90 μ^3
8.	*Chroomonas amphioxeia*	100 μ^3
9.	*Oocystis parva*	130 μ^3
10.	*Goniochloris pulchra*	230 μ^3
11.	*Prorocentrum minimum*	1150 μ^3

Cell volumes determined by measuring the water displacement of clay scale models.

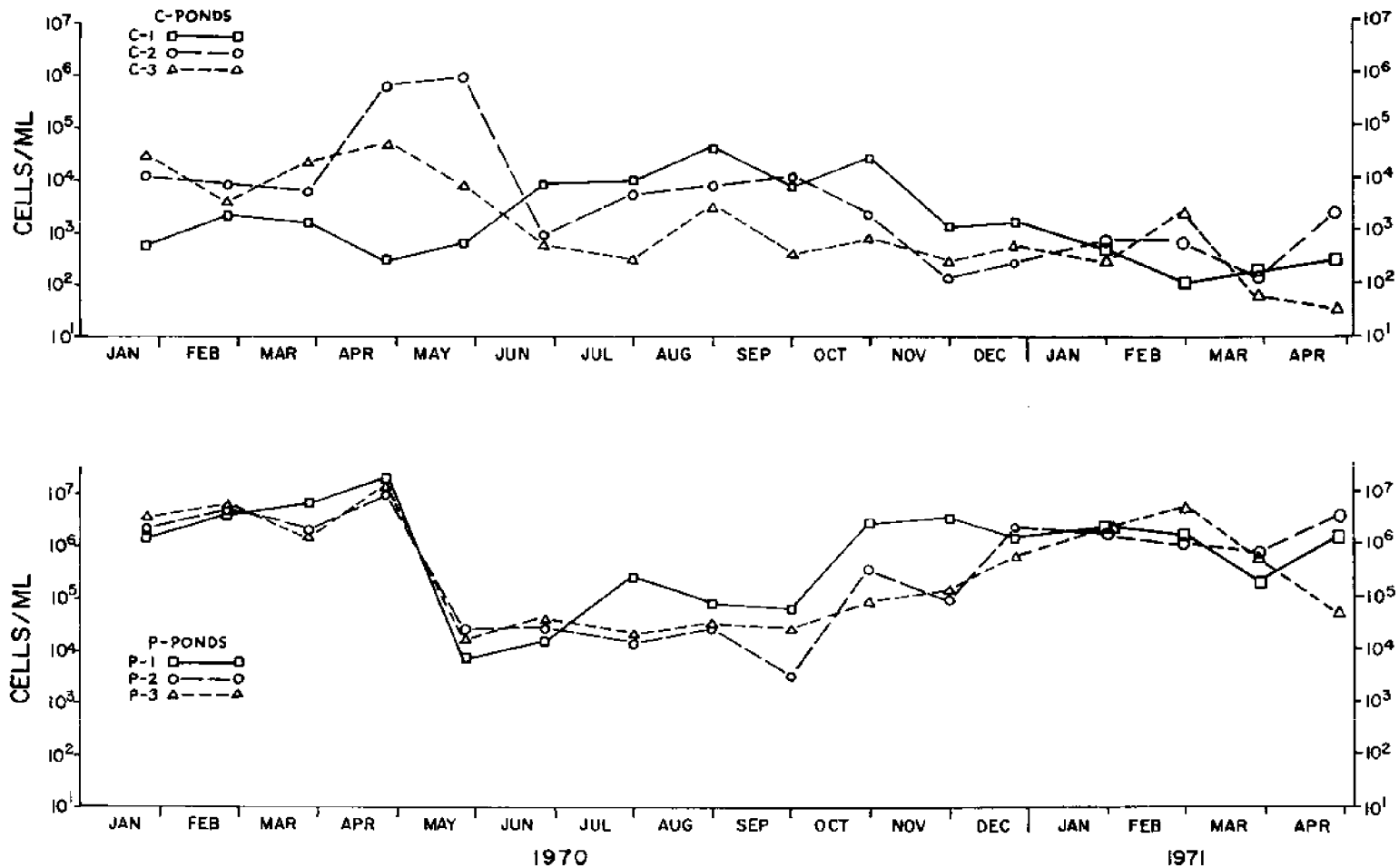


FIGURE 1

SEASONAL DISTRIBUTION OF TOTAL PHYTOPLANKTON ABUNDANCE IN EACH CONTROL AND POLLUTED POND

As in all figures, cell densities are plotted in cells/ml on a logarithmic scale to show greater detail for lower cell concentrations

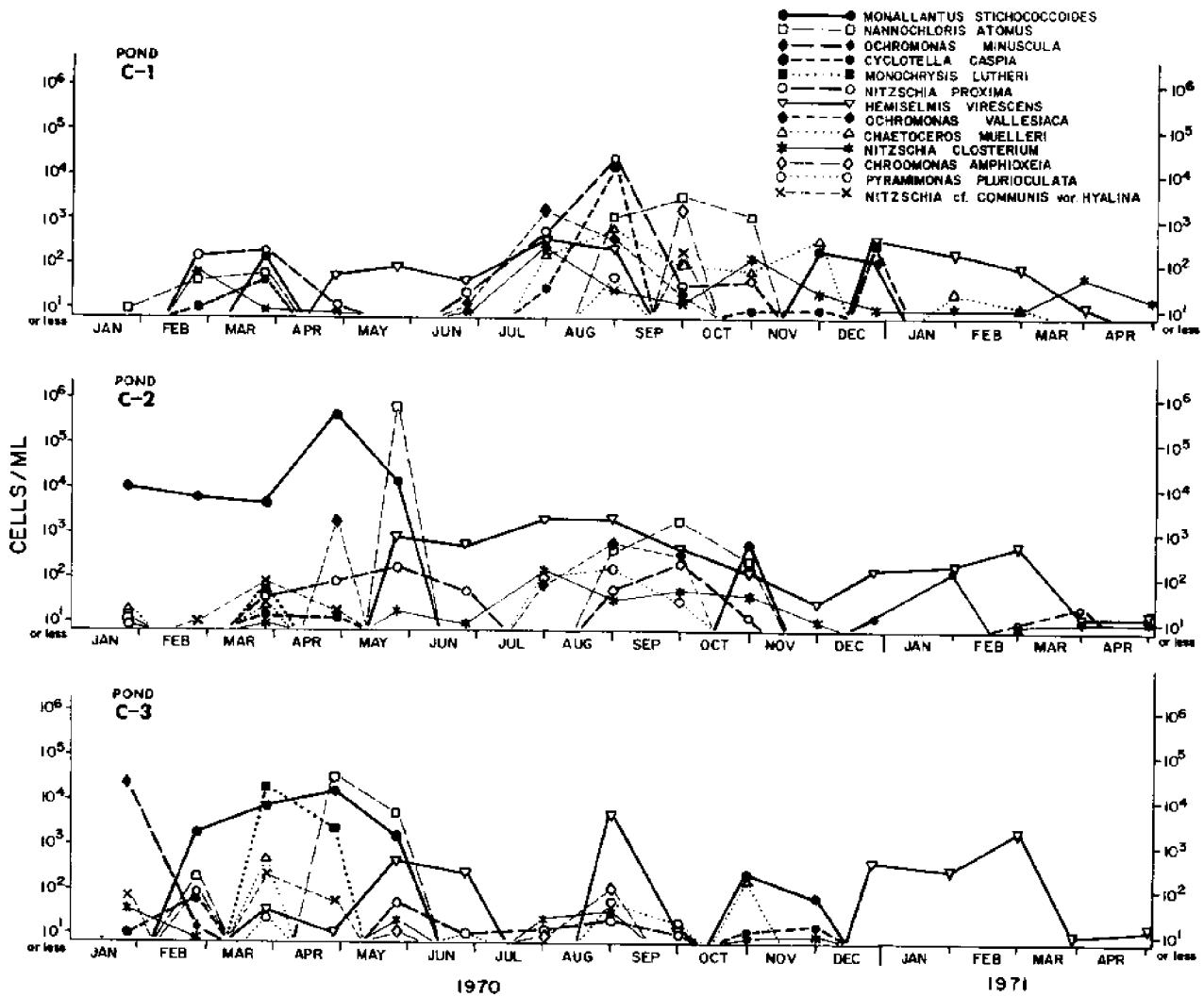


FIGURE 2

SEASONAL DISTRIBUTION OF DOMINANT PHYTOPLANKTON SPECIES IN THE THREE CONTROL PONDS

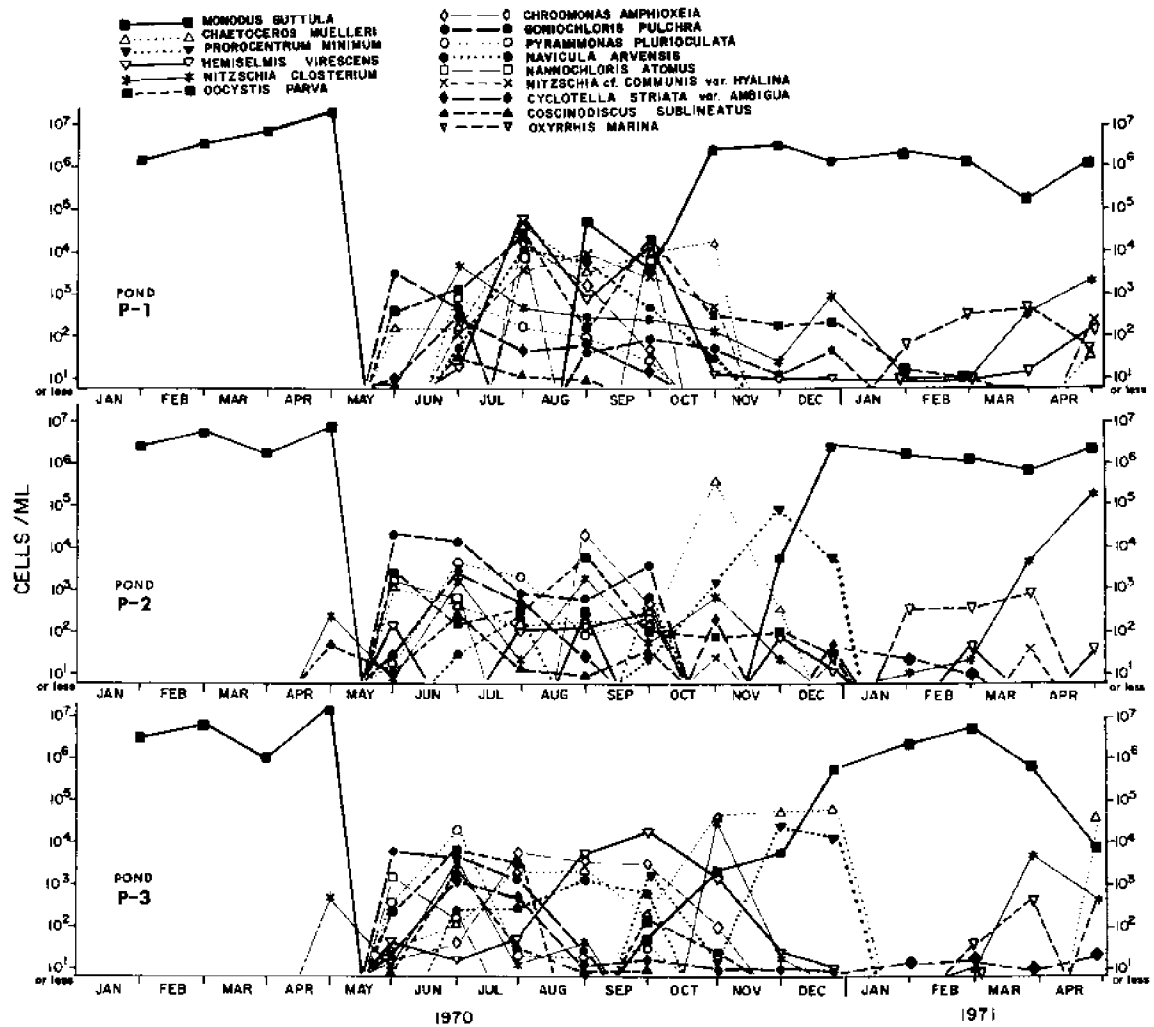


FIGURE 3

SEASONAL DISTRIBUTION OF DOMINANT PHYTOPLANKTON SPECIES IN THE THREE POLLUTED PONDS

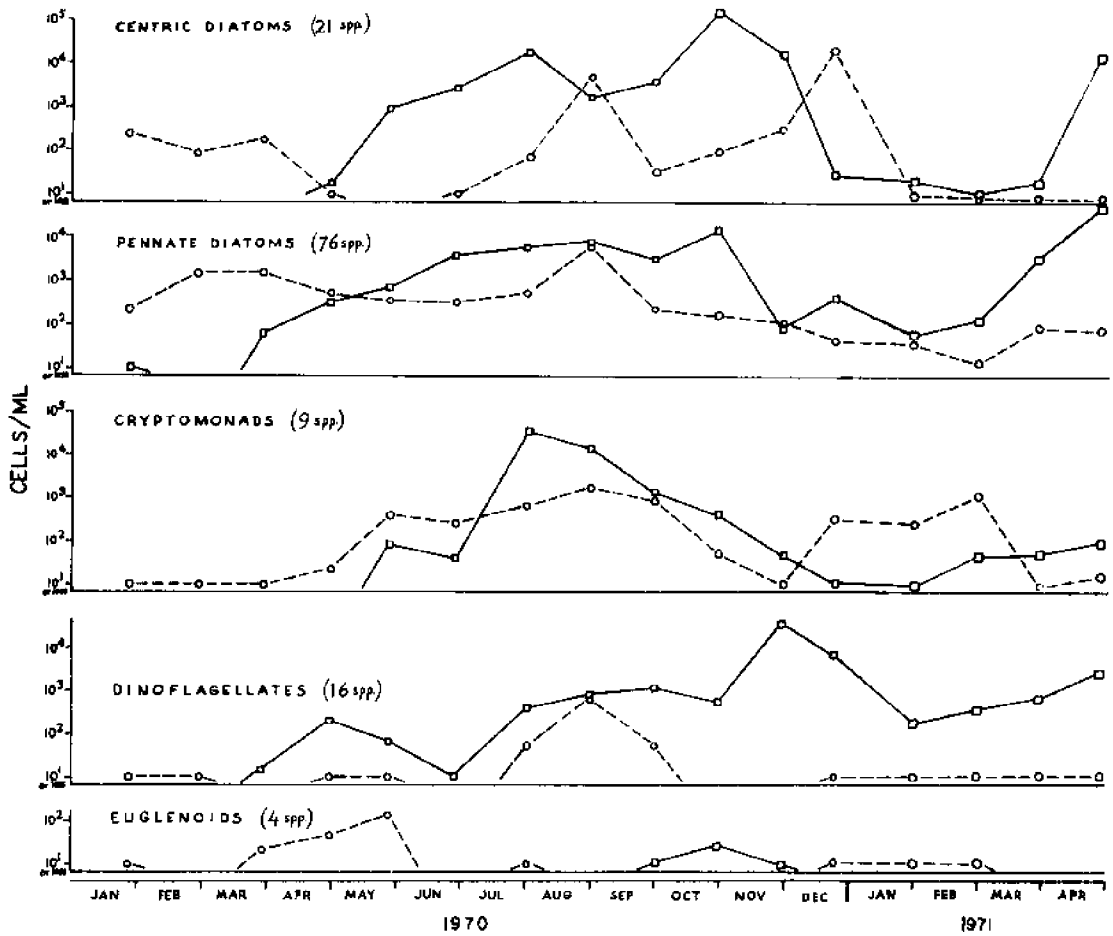
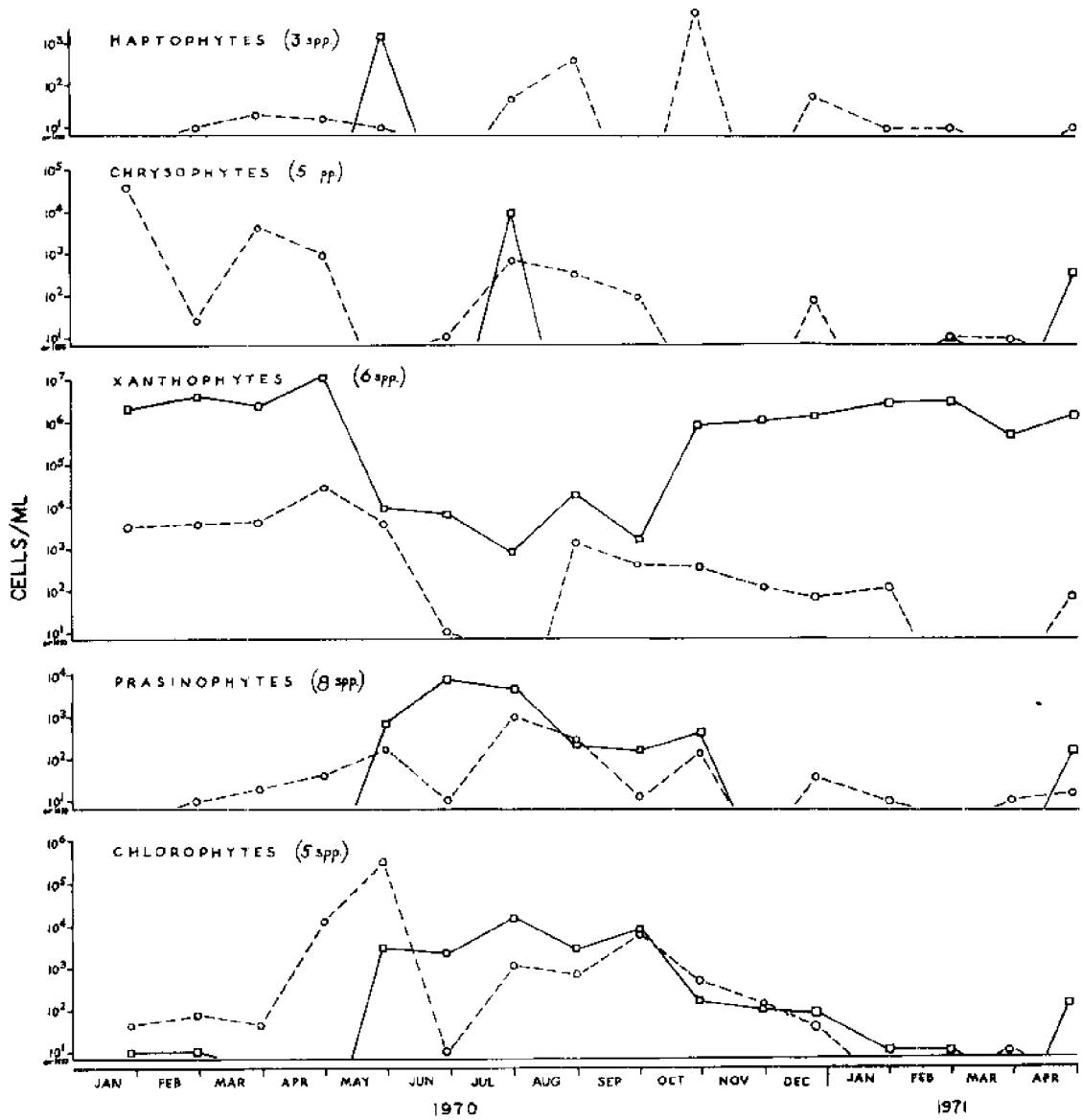


FIGURE 4

SEASONAL DISTRIBUTION OF PHYTOPLANKTON BY MAJOR TAXONOMIC GROUPINGS

Average of three C-ponds O----O
Average of three P-ponds □——□



(FIGURE 4, CONTINUED)

SEASONAL DISTRIBUTION OF PHYTOPLANKTON
BY MAJOR TAXONOMIC GROUPINGS

Average of three C-ponds O- - - -O
Average of three P-ponds □——□

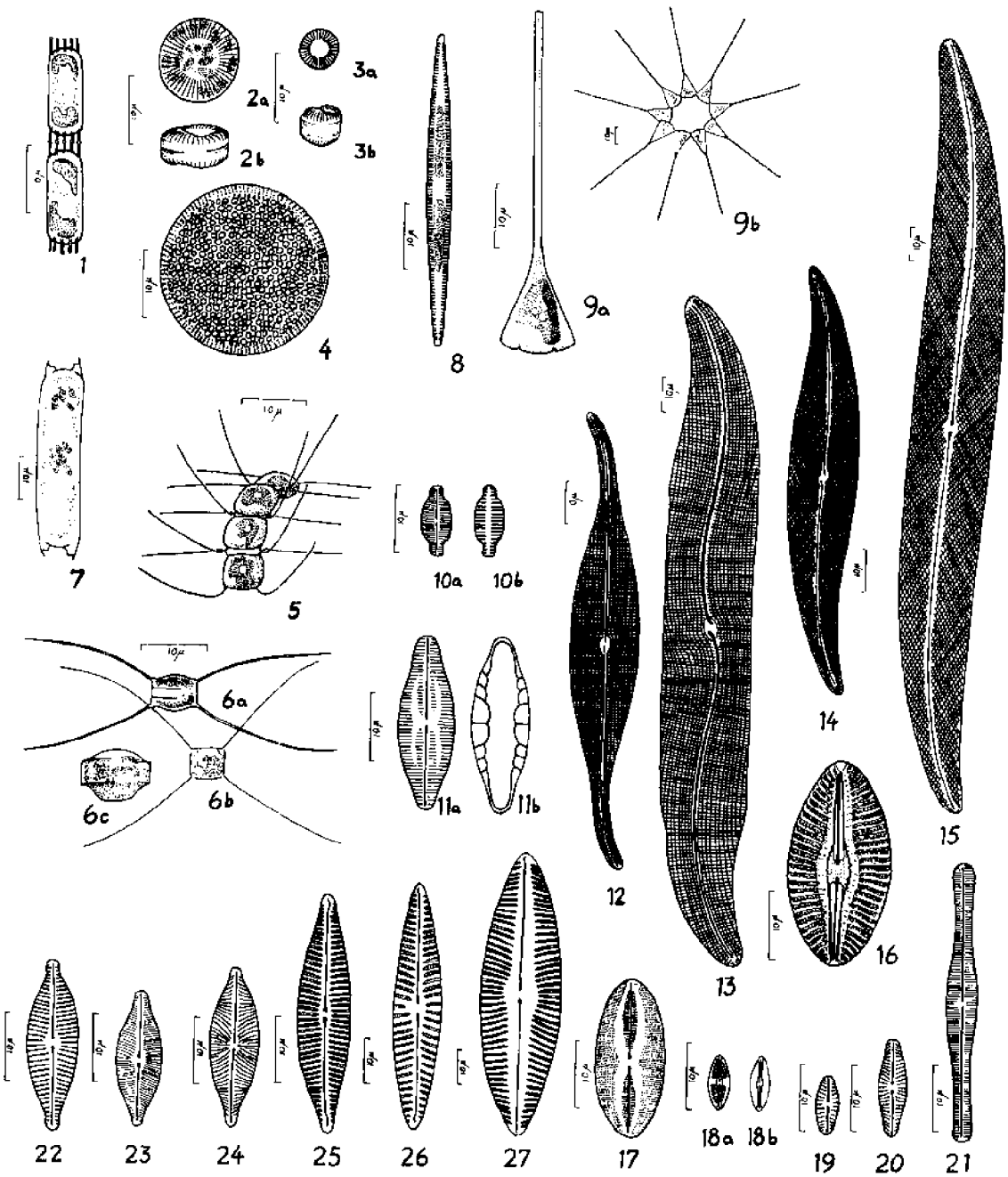


PLATE 1

1. Skeletonema costatum (Grev.) Cl.
2. Cyclotella striata var. ambigua Grun.
3. Cyclotella caspia Grun.
4. Coscinodiscus sublineatus Grun.
5. Chaetoceros debilis Cl.
6. Chaetoceros muelleri Lemm., 6b thinly silicified cell from October, 6c resting spore.
7. Cerataulina bergonii Per.
8. Synedra tabulata (Ag.) Kutz.
9. Asterionella japonica Cl., 9b colony.
10. Achnanthes orientalis Hust.
11. Mastogloia pumila (Grun.) Cl.
12. Pyrosigma fasciola (Ehr.) Griff. & Henfr.
13. Pyrosigma balticum (Ehr.) Tabh.
14. Pleurosigma salinarum Grun.
15. Pleurosigma strigosum W. Sm.
16. Diploneis Smithi (Breb.) Cl.
17. Navicula pygmaea Kutz.
18. Navicula arvensis Hust.
19. Navicula cf. muralis f. agrestis (Hust.) Land
20. Navicula cf. friska Carter
21. Navicula rogalliï Hust.
22. Navicula sp.
23. Navicula sp.
24. Navicula salinarum Grun.
25. Navicula lanceolata (Ag.) Kutz.
26. Navicula cf. peregrina (Ehr.) Kutz.
27. Navicula yarrensis Grun.

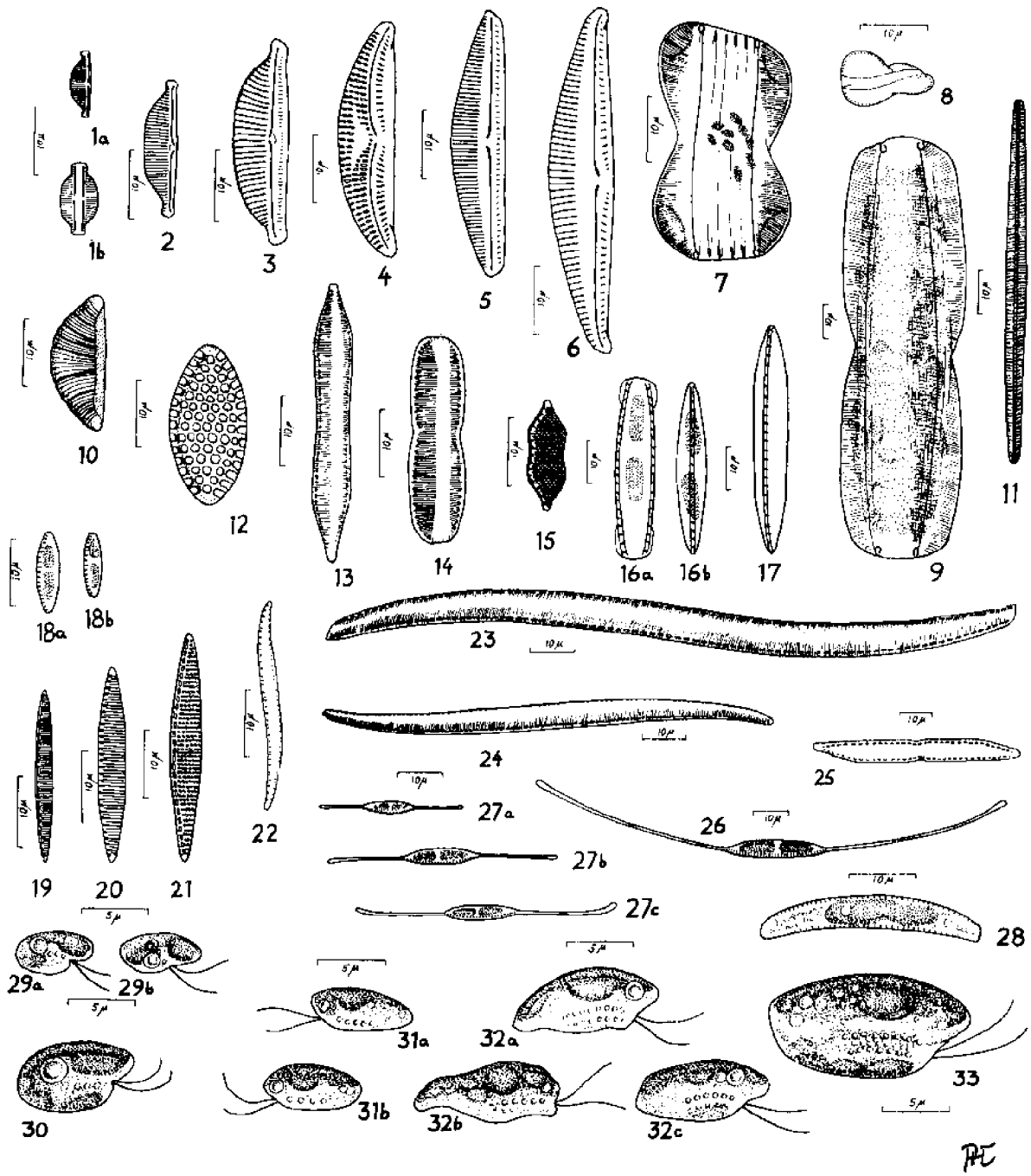


PLATE 2

1. Amphora cf. delicatissima Brasske
2. Amphora cf. tumida Hust.
3. Amphora granulata Greg.
4. Amphora ovalis var. affinis Grun.
5. Amphora angusta Greg.
6. Amphora angusta var. ventricosa Greg.
7. Amphiprora paludosa var. duplex Donk.
8. Amphiprora paludosa var. hyalina Kutzenst.
9. Tropidoneis lepidoptera Greg.
10. Rhopalodia musculus var. producta Grun.
11. Bacillaria paradoxa Gmelin
12. Nitzschia compressa (Bail.) Boyer
13. Nitzschia aniculata (Greg.) Grun.
14. Nitzschia hybridaeformis Hust.
15. Nitzschia panduriformis var. minor Grun.
16. Nitzschia spathulata Greb.
17. Nitzschia cf. angularis Sm.
18. Nitzschia cf. communis var. hyalina Lund
19. Nitzschia proxima Hust.
20. Nitzschia frustulum (Kutz.) Grun.
21. Nitzschia grossestriata Hust.
22. Nitzschia cf. serpenticula Cholnoky
23. Nitzschia sigma (Kutz.) Sm.
24. Nitzschia sigma var. rigidula Grun.
25. Nitzschia obtusa var. scalpelliformis Grun.
26. Nitzschia longissima (Breb.) Ralfs.
27. Nitzschia closterium W. Sm.
28. Gen.? Sp.?
29. Hemiselmis virescens Droop
30. Chroomonas diplococca Butcher
31. Chroomonas minuta var. apyrenoidosa (Hulburt)
32. Chroomonas amphioxeia (Conr. & Kuff.) Butcher
33. Cryptomonas pseudobaltica Butcher

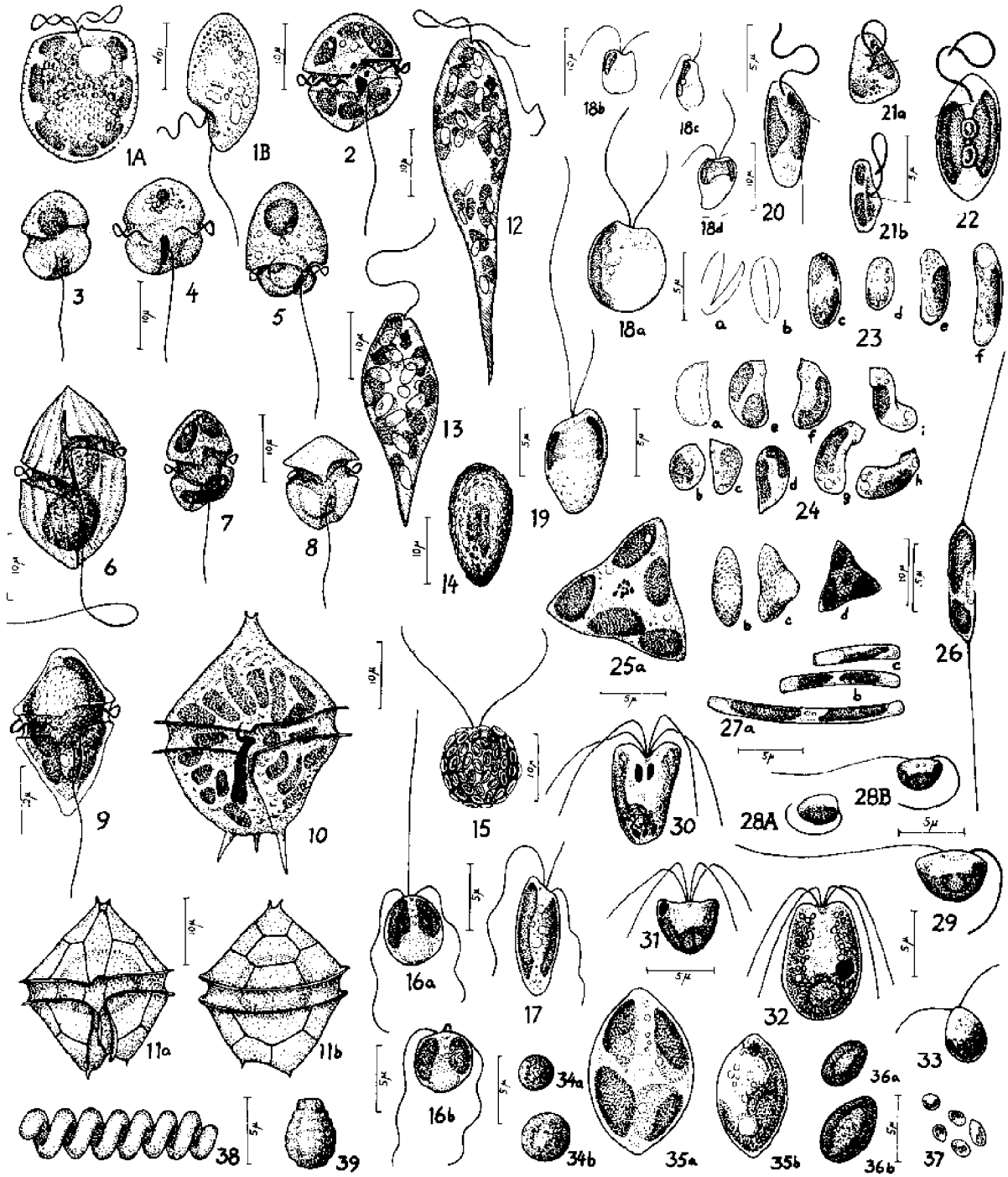


PLATE 3

1A. Prorocentrum minimum (Pav.) Schiller
1B. Oxyrrhis marina Duj.
2. Gymnodinium danicans Campbell
3. Gymnodinium sp.
4. Gymnodinium roseostigma Campbell
5. Katodinium asymmetricum (Massart) Fott
6. Gyrodinium dominans Hulburt
7. Gyrodinium estuariale Hulburt
8. Gyrodinium metum Hulburt
9. Heterocapsa triquetra (Ehr.) Stein
10. Peridinium aciculiferum Lemm.
11. Peridinium achromaticum Lev.
12. Eutreptia cf. lanowii Steuer
13. Euglena aff. proxima Dangeard
14. Trachelomonas ? obovata Stokes
15. Hymenomonas carterae (Braar. & Fag.) Braarud
16. Chrysochromulina sp. 16a: haptonema extended.
17. Prymnesium parvum Carter
18. Ochromonas ? minusoula Conrad
19. Ochromonas ? vallesiaca Skuja
20. Pavlova gyrans Butcher
21. Monochrysis lutheri Droop
22. Nephrochloris salina Carter
23. Monallantus stichococcoides Pascher 23a,b: cast off walls.
24. Monodus aff. guttula Pascher 24a: cast off wall. 24d-f: from autumn, 24g-i: from winter.
25. Goniochloris pulchra Pascher 25b-d: cell wall surfaces.
26. Centritractus aff. belonophorus Lemm.
27. Genus? species?
28A. Pedinomonas minor Korsch.
28B. Nephroselmis olivacea Parke & Rayns
29. Heteromastix pyriformis (Carter) Manton
30. Pyramimonas pluricuiata Butcher
31. Pyramimonas micron Conr. & Kuff.
32. Tetraselmis maculata (Kylin) Butcher
33. Chlamydomonas sp.
34. Nannochloris atomus Butcher
35. Oocystis parva West & West
36. Genus? species?
37. Genus? species?
38. Spirulina subsalsa Oersted
39. Calycomonas ovalis Wulff

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