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SALEM SOUND PHYTOPLANKTON SUMMARY

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I. INTRODUCTION

The Massachusetts Bay phytoplankton data presented in this section were collected by Dr. Hugh F. Mulligan and associates. These data were presented in part in Chapter Eight of "A Socio-Economic and Environment Inventory of the North Atlantic Region" TRIGOM-PARC (Mulligan and DeLara, 1974). The phytoplankton data available for Salem Harbor were examined as a scientific basis suitable for and highly relevant to a review of outfall location options for the South Essex Sewage District. Therefore, the data collected off Baker's Island in Salem Harbor will be particularly emphasized. Phytoplankton data collected at other stations which might pertain to this region, and hydrographic data collected currently with the phytoplankton sampling program are also included in this summary.

II. PREVIOUS STUDIES

Bigelow (1926, 1927) must be credited more than any other individual for a comprehensive analysis of the plankton characteristics and physical oceanography of the Gulf of Maine. He studied the regional phytoplankton distributions and abundance from 1912 to 1940, primarily at stations located more than 8km offshore. In addition to Bigelow's fundamental studies, other plankton studies were conducted by Bigelow, Sears & Lillick (1940), Fish (1925), Riley (1941-1947), Lillick (1937; 1938; 1940), and Sears (1941). Gran and Braarud (1935) conducted studies in the

Bay of Fundy and offshore waters (Gran, 1933; Braarud 1934). These studies represent nearly all the historic phytoplankton data of the Gulf of Maine.

Because these studies represent the only historic data available, they must be utilized even though the following limitations are evident: seasonal cycles are generalized from sampling in various years; most studies are limited to surface populations; much extrapolation of data was necessary; and, plankton nets allowed the escape of smaller planktonic forms and provided only an order-of-magnitude estimate of abundance. Of this historic data, the observations of Gran and Braarud should be used preferentially, since they used quantitative techniques, including plankton collections made by water bottles rather than qualitative net-tows. The modern and more accurate methods of phytoplankton collection and enumeration introduced by Gran and Braarud have generally been used in studies after 1931. More recent investigations including those by Mulligan et al. (1974); Parker (1974); McAlice (1972); and Donovan (1973) supply quantitative data on phytoplankton dynamics along the western coastal regions and in specific bays and inshore areas. Smayda (1980) has summarized the principal features of the phytoplankton of the Gulf of Maine and its contiguous waters. This provides a most useful comparison to assess the phytoplankton

community dynamics in Salem Harbor and potential variations in this indigenous flora.

III. FACTORS AFFECTING COMPOSITION

Phytoplankton species composition and abundance and dynamics are influenced by many factors, including water circulation, temperature, salinity, dissolved nutrients, dissolved organic matter, suspended materials, light penetration, and water quality. The regional variability of some of these factors will be discussed briefly in this section.

3.1 Circulation and Vertical Stability

Circulation in the Gulf of Maine is predominated by a counterclockwise gyre which is present throughout the year. The water mass movement is strongest in spring and at the surface. Major rivers in the Northern region of the Gulf of Maine contribute 90% of the freshwater runoff entering the Gulf (Bigelow & Shraeder, 1953). The only major input of freshwater in the southern portion of the Gulf is the Merrimack River. Runoff input for the entire region is at its maximum in spring. The large counterclockwise eddy links these environmentally different units into a regionally coherent system. Thus, Salem Harbor cannot be considered as a closed off body of water, but one in continuous exchange with off-shore waters. The magnitude of

any augmented phytoplankton abundance and alterations in this indigenous flora potentially accompanying anthropogenic enrichment will partly reflect water circulation and flushing characteristics. These will vary seasonally and interannually.

Massachusetts Bay is one of the eight major subdivisions of the Gulf of Maine; Salem Harbor is located at the inner edge of Massachusetts Bay. Massachusetts Bay is generally considered to include the region from Cape Ann south to Cape Cod, with an area of 1,200 km². The coastline is rather irregular with many natural harbors. Generally, inshore waters are less than 15m deep with irregular bottoms. The aforementioned counterclockwise movement of water is not constant within Massachusetts Bay, but there is a general southerly flow of water to Cape Cod. Water within Lynn Harbor circles and moves north around Nahant. There are about 20 offshore islands in Massachusetts Bay; the tide ranges from 2-3 meters. Surface water moves around Cape Ann into Massachusetts Bay, especially in the spring; water flows out of Massachusetts Bay through Cape Cod Bay.

3.2 Temperature and Salinity

Temperature ranges from 0-20°C in the Gulf of Maine; July and August are the warmest months. At depths greater than 100 meters, the temperature is maintained at 2-6°C. The waters of Massachusetts Bay are warmer than other

regions of the Gulf due to its shallow depths and relative lack of circulation. Vertical stratification develops, but is transient in waters shallower than 20m due to tidal mixing.

Since salinity is influenced by the volume of input of freshwater and no major rivers empty into Massachusetts Bay, the salinity here ranges only from 27 to 33 ‰. Vertical differences in salinity are generally less than 1 ‰. Ten year averages measured at the Boston Light Ship had a high of 32.38 ‰ (January) and a low of 30.71 ‰ (May).

3.3 Dissolved and Suspended Materials

The influence of dissolved organic compounds on phytoplankton populations in the Gulf of Maine has not been documented but various hypotheses have been proposed in other locations. Prakash and Rashid (1968) and Margold (1968) suggest that organic materials including those in runoff may favor the growth of dinoflagellates, or inhibit other forms of phytoplankton. Curl (1962) proposed that vitamin B₁₂ in land drainage may have been responsible for coastal blooms of Skeletonema costatum.

Most of the research done had focused on relating dissolved inorganic nutrients to phytoplankton populations, specifically phosphorus, nitrogen and silicon. Silicon does not appear to limit diatom growth in this region according to Riley & Chester (1971). Phosphorus levels, (Bigelow,

Lillick & Sears, 1940), are not considered to be a significant limiting factor either. Ketchum (1947) has demonstrated that the rate of phosphorus uptake was dependent on the concentration of nitrate, but not the reverse. Nitrogen appears to be the limiting element in the Gulf of Maine since levels are sometimes non-detectable (Bigelow et al., 1940); (Vaccaro, 1963). Vaccaro noted that N-NH_4 is abundant in the Gulf of Maine and may be an important source of nitrogen for phytoplankton growth, maximum concentrations occurring in August. Because both phosphorus and nitrogen levels are high for several months before spring blooms, these elements alone are not considered responsible for the initiation of spring blooms. It is suggested that a combination of many factors must be responsible for initiating phytoplankton blooms (Lane, 1973). However, thereafter nitrogen availability limits phytoplankton growth, with its supply as NH_4 strongly influenced by animal excretion and water column remineralization, and augmented by periodic infusions of NO_3 introduced by injections of deep water (Carpenter and Capone, 1983). This singular role of nitrogen limitation in the coastal waters of New England is significant to the influence of potential inputs of this nutrient into Salem Harbor.

Thermal stratification, which occurs for most of the summer in waters deeper than 20m, prevents nutrient

regeneration from the bottom. Some minor regeneration of nutrients occur in the surface lighted zone (Bigelow, 1940) because of bacteria, whose maxima closely correspond to phytoplankton maxima (Reuszer, 1933). Barlow and Bishop (1965) have shown that the migration and feeding of zooplankton in the euphotic zone is a means of returning phosphorus and particulate matter to surface layers. The combined mechanisms of water column and benthic animal excretion of nutrients in addition to exogenous nutrient inputs apply to Salem Harbor.

3.4 Light Penetration

The euphotic zone is defined as that portion of the water column in which there is sufficient light for photosynthesis. The depth of the euphotic zone is usually defined as the depth to which 1% of the incident surface irradiance penetrates. The euphotic zone along the coast from Rye, NH to Boston Harbor ranges from 0.5 - 28 meters. The open Gulf of Maine has the highest values of transparency due to the lack of suspended materials and runoff.

Although phytoplankton are only minor constituents of the total mass of particulate matter during most of the year in the coastal waters of the Gulf of Maine, during spring blooms they become a major component by volume. Suspended material in the water column of Gulf of Maine (coastal

waters) reaches a minimum at a depth of 50m and then increases exponentially to the bottom (Spencer & Sacks, 1970).

IV. SEASONAL CYCLES

4.1 Gulf of Maine Overview

Seasonal phytoplankton cycles exhibit similarities throughout the Gulf of Maine (Smayda, 1980). The main differences between regions are differences in species composition, date of initial blooms, ultimate size of populations and length of dominance. Gulf of Maine phytoplankton populations are at their lowest levels of abundance from November to February. From February to June, various diatom species appear in the water column in great abundance. Spring blooms of Chaetoceros occur after Thalassiosira blooms. Chaetoceros socialis is common in Massachusetts Bay and in inshore areas to the north. Skeletonema costatum and Rhizosolenia spp. bloom from June to early fall in many of the more coastal areas of the Gulf. Secondary late summer and fall blooms of some neritic diatoms occur, such as Skeletonema, Guinardia, Leptocylindrus and Rhizosolenia spp.

4.2 Massachusetts Bay Overview

During winter months, Ceratium tripos and C. longipes are usually dominant within Massachusetts Bay. By the

beginning of April, diatoms become abundant; Ceratium longipes is the most abundant dinoflagellate in this period. After the spring diatom bloom, diatoms become scarce from the end of April until mid-May. In the first week in May, Ceratium spp. dominate the phytoplankton south of Cape Ann. Massachusetts Bay blooms appear to last a short time (a few days or weeks). This led Bigelow (Bigelow, et al., 1940) to suggest that productivity may be low in relation to other regions of the Gulf. More recent productivity studies of Mulligan and Parker (1974) have shown this is not the case.

In July and August, Rhizosolenia alata may dominate the phytoplankton of Massachusetts Bay. Skeletonema costatum is predominant in the inner portions of the Bay in late August, while Ceratium spp. dominates outer portions of the Bay. The variable inflow of water from areas north of Cape Ann however, makes seasonal descriptions of the Massachusetts Bay phytoplankton difficult. From late August to late October, Skeletonema costatum blooms continuously. Ceratium tripos outnumbers C. longipes by mid-September and becomes abundant in Massachusetts Bay in early November.

V. RYE, NH TO BOSTON HARBOR, MA

A coastal phytoplankton study of this portion of the Gulf of Maine was undertaken by Hugh F. Mulligan, with

support from Raytheon-U.N.H. Sea Grant funds. This study, which was initiated in the summer of 1971, examines the variability of phytoplankton population along an 80km coastal transect from Rye, NH to Boston Harbor.

Hydrographic and phytoplankton data were collected at six stations located 2-5km offshore. Three stations were located north of Cape Ann (Rye, Merrimac, and Annisquam) and three stations were located south of Cape Ann (Baker's Island, Flip Rock and Pope Rock). Figure 1 shows the locations of these sampling stations. Station depths at MLW ranged from 9m at Annisquam to 15m at Baker's Island.

Sampling occurred monthly from August, 1971 to August, 1972, with additional sampling during the spring. Samples were collected at 3 depths. Occasionally, sampling cruises were abbreviated or cancelled (early April, Baker's Island), due to weather conditions.

Phytoplankton and hydrographic data collected at the Baker's Island, Salem Harbor station will be described and compared to similar data collected from Flip Rock, Pope Rock, and stations north of Cape Ann.

5.1 Currents

At all stations, the general movement of surface water is southerly and offshore, but movement is variable in exposed areas. Water in the area of Baker's Island and Flip

Rock flows mainly offshore. Water masses off Flip Rock have a somewhat northerly flow (Bigelow, 1927); at Pope Rock, water flows directly south.

5.2 Salinity

The most constant salinity readings of all the coastal stations occurred at Baker's Island and Flip Rock in February, 1972. Maximum salinity values occurred in January and February; lowest values occurred in late April. There was a decrease in surface salinity in June at the Baker's Island station which may be attributed to a period of increased rainfall. Lower salinities and extreme stratification were noted at both the Baker's Island and Flip Rock stations. Salinity values followed similar trends north and south of Cape Ann and ranged from 9.3 to 33.8 0/00.

5.3 Temperature

Water at Baker's Island appeared to be well mixed most of the year. Lowest temperature values at this station, (2.5°C) were registered in January and February. In May, a thermocline started to develop with a 4°C difference between surface water and that at 13m. In early June however, temperature values remained constant 10°C from the surface

to 10m. Reduced temperature and salinity values suggest that storm generated vertical mixing had occurred or that colder more mixed waters, perhaps from the north, were carried south and inshore in late May. A rapid warming trend elevated surface temperatures in July to 18°C. Vertical stratification was also evident in July, with a difference of 8°C in 13m. This stratification continued until September (Figure 2).

Temperature fluctuations at the Flip Rock and Pope Rock stations were similar to those observed at Baker's Island. A thermocline developed in late May and continued through September. Greatest temperature differences between surface waters and waters below 10m (8-9°C) were observed in July.

Temperature values for the entire sampling area ranged from 1°C (January) to 18.1°C (September). Surface temperatures in waters south of Cape Ann were generally 3-4°C higher in the summer than waters off Rye, NH. Temperatures of bottom waters and winter surface temperatures were consistent throughout the sampling stations.

5.4 Percent Light Transmittance

One meter light penetration values varied from 90% - 45% at the Baker's Island Station during the year of sampling. In August and September (1971) 60% of surface

light was noted at a depth of 1m. Transparency decreased in October to a low of 45% and remained low in November (50%), corresponding to the development of the fall bloom. One meter light penetrations values ranged from 65 to 90% during winter months (December - March).

Light penetration values at 5m appear to follow the same general trend as 1m readings and ranged from 9-40%. Values again decreased in October coincident with the fall bloom and transparency was relatively high during winter months.

The 10m light values correspond somewhat to trends noted at shallower depths. Transparency values were high during winter months with the exception of December when 1% was recorded at this depth. This low reading was most likely due to the resuspension of bottom sediments since there is little biological activity at this time. Light penetration values of 1-2% were also noted at 10 meters in August, October and May (see Figure 3).

No significant correspondence could be found between percent light transmission readings and phytoplankton blooms in the spring. No cruise was conducted in early April due to inclement weather. Maximum spring phytoplankton populations could have occurred at that time.

The Flip Rock station also had low light transmittance values in October, coincident with phytoplankton blooms but minimal transparency occurred in late August and mid

May. Chlorophyll a values in late August and early September were the highest observed in the entire sampling region at that time, suggesting a correlation then between light values and biological activity. Lower light values observed in October and early May do suggest a correspondence between these values and increased phytoplankton populations.

Water at stations north of Cape Ann were more transparent; with higher light transmittance values. Maximum transparency occurred in August. The shallowest depth for the euphotic zone in the overall study was recorded at the Merrimack station during the spring. This was probably due to a combination of large phytoplankton populations and increased runoff from the Merrimack River then detectable.

5.5 Chlorophyll a

Chlorophyll a concentrations/ m^3 were measured at all stations at 5m depth intervals after the methods of Strickland and Parsons (1973).

Chlorophyll a concentrations showed definite seasonal fluctuations at the Baker's Island station. A relatively large quantity of chlorophyll a ($4 \text{ mg}/\text{m}^3$) was noted in surface water during August (1971) and increased in September to between 7 and $11.5 \text{ mg}/\text{m}^3$ at the three depths sampled. These large concentrations of chlorophyll a

coincided with the fall bloom. Levels declined in October and November and the minimum value for this station, (0.5 mg/m³) persisted from December to March. Samples were not collected in early April, but in late April chlorophyll levels increased to 4 mg/m³. The peak of the spring phytoplankton bloom may have occurred in early April. The light transmission levels and appearance of phytoplankton cells collected in late April indicated conditions below the surface layer usually noted after a phytoplankton bloom.

Small summer blooms of phytoplankton and increased detrital material in June and August coincided with a rise in chlorophyll a values (4 and 7 mg/m respectively).

Chlorophyll a values were integrated over depth in Figure 4 for the six sampling stations. Waters off Baker's Island contained lower levels of chlorophyll a than those off Flip Rock and Pope Rock. This suggests lower phytoplankton populations occurred at Baker's Island. However, it is generally not possible to estimate actual population numbers from chlorophyll levels because of species' differences in chlorophyll content and the affect of different species' cell size on chlorophyll content.

High chlorophyll a values noted throughout the water column at the Flip Rock station in September indicated increased phytoplankton activity. The presence of phaeophytin and low light transmission levels in deeper waters suggested the sinking and decomposition of

phytoplankton and/or the resuspension of some bottom sediments. High chlorophyll a levels (10 mg/m^3) in October coincided with a second bloom; the remnants of the September bloom were noted in deeper waters. As at the Baker's Island station, observations were not made in early April. However, chlorophyll a values in late April (3.5 mg/m^3) and the presence of characteristic spring bloom diatoms suggest that the spring phytoplankton populations were probably higher in early April at this station. In June, an increase in chlorophyll a values present in the form of phaeophytin in deeper waters may have been due to a resuspension of bottom detritus since it was not accompanied by a significant phytoplankton population. A rise to 11 mg/m^3 in July however, does correspond to an increase in observed populations.

The highest recorded chlorophyll value for the sampling stations, 15.4 mg/m^3 , was found in August (1971) in the surface waters off Pope Rock. Chlorophyll levels remained high through October, and an increase in detritus and phaeophytin was noted as these populations decomposed. It should also be noted that increased phaeophytin levels are often considered to be symptomatic of increased grazing on phytoplankton by either herbivorous zooplankton or benthic suspension feeders. No data was collected in early April, but the high chlorophyll level in late April (12.5 mg/m^3) suggested that the spring bloom at this location was larger

or occurred later than at the other stations. Chlorophyll a values were generally higher south of Cape Ann.

5.6 Carotenoids and Chlorophyll B

In general, carotenoid pigment levels appeared to parallel chlorophyll a values. Distribution of carotenoids by depth differed somewhat from chlorophyll a- in September and August (1972). Concentrations of carotenoids were found to be about equal to concentrations of chlorophyll a. Chlorophyll B values appeared very high in August (1971) but levels during the remainder of the year appeared very low, as did those at Flip Rock and Pope Rock.

Concentrations of carotenoids at the surface were generally lower than concentrations at the Flip Rock and Pope Rock stations, and were similar to those observed at more northerly stations during the fall peak. Concentrations of carotenoids followed the same seasonal fluctuations as chlorophyll a values at Baker's Island and therefore corresponded with several changes noted at Flip Rock and Pope Rock.

5.7 Phytoplankton Populations - Baker's Island, Flip Rock and Pope Rock

Phytoplankton were identified, counted, and reported on the basis of cell numbers/liter from whole water samples collected near the surface in the Baker's Island Channel

between Baker's and Misery Islands. The taxonomic features, distribution and abundance, and photographs of some of the more numerous phytoplankters are noted in the book, A Photographic Guide to the Phytoplankton of the Coastal Waters, Gulf of Maine (Gowen & Milligan, 1978).

In most cases, whole water plankton samples were collected near the surface from all stations on the same day. All of the stations (including the Baker's Island station) are under the influence of river runoff, tidal and non-tidal currents and weather conditions; these factors are expected to account in large part for the observed station-to-station variability.

In comparison with similar phytoplankton data from the other stations, species diversity appeared to be low at the Baker's Island station, exceeding ten species only in April and July. Forty-three diatom species were identified at this station during the sampling period (in addition, six dinoflagellates were also identified to species). A small fall bloom occurred in September and consisted of three diatom species; Nitzschia seriata $158 \text{ cells}/1 \times 10^{-3}$, Skeletonema costatum, $41 \text{ cells}/1 \times 10^{-3}$, and Guinardia flaccida $31 \text{ cells}/1 \times 10^{-3}$, respectively. Smaller quantities of these species occurred in October and November. During this period, Thalassionema, sp. numbers increased. This taxon was noted in eight months of the sampling period and was the dominant form from December through March. However,

the total phytoplankton populations were quite small during that period.

Species diversity remained very low until April. During the spring bloom, Chaetoceros debilis, C. compressus, and Thalassiosira nordenskioeldii were the major components, with 398, 82 and 69 cells/ 1×10^{-3} , respectively. These numbers were recorded on April 20 (the phytoplankton may have been more abundant in early April when the scheduled cruise was cancelled due to weather conditions). These same species were noted in reduced abundance in early May throughout the water column. Many Chaetoceros spp. resting spores were noted in late May. This would indicate the demise of these populations.

A Carteria sp. reached its peak population in early June (135 cells/ 1×10^{-3}). This species was present at the site in reduced numbers from late April to July. The summer bloom took place in July, with Skeletonema costatum (742 cells/ 1×10^{-3}) being the dominant form, comprising 62% of the phytoplankton; Carteria sp. was second in dominance at (83 cells/ 1×10^{-3}) and Chaetoceros compressus and Rhizosolenia delicatula were also present at 34 and 29 cells/ 1×10^{-3} , respectively.

Species diversity appeared to be somewhat higher at the Flip Rock station in Broad Sound; 46 diatom species and 8 dinoflagellates identified. There were only 4 months when

the number of species at this station exceeded ten. Population sizes were greater at this station (as suggested by the increased chlorophyll a values) in September during the fall phytoplankton bloom. The most numerous diatom species were Nitzschia seriata, Thalassiosira decipiens and Guinardia. Nitzschia seriata and Guinardia flaccida were also dominant at the Baker's Island station, but Skeletonema costatum, which appeared in numbers at the Baker's Island station was not among the dominant forms at Flip Rock. As at the Baker's Island station, Thalassionema was the dominant form during the winter months when overall phytoplankton populations were low.

The spring bloom at Flip Rock consisted mainly of Phaeocystis pouchetii (1160 cells/ 1×10^{-3}), various Chactoceros species and Thalassiosira nordenskioeldii. Phaeocystis pouchetii composed 75% of the phytoplankton bloom. Because of weather conditions, no sampling occurred from early March to late April at this station. It is possible that a larger population of the characteristic species for this region occurred at that time.

Species diversity increased after April and the greatest number of species was observed in July. As at the Baker's Island station, remnants of the April bloom were noted in lower numbers and in deeper water in early May. The large summer phytoplankton bloom at Flip Rock consisted

of Skeletonema costatum (728 cells/ 1×10^{-3}), Chaetoceros compressus (168 cells/ 1×10^{-3}) and Eutreptia (169 cells/ 1×10^{-3}). This flora is similar to the summer bloom at Baker's Island in that Skeletonema costatum was the dominant form at both stations and occurred in similar numbers.

Carteria, sp. and Rhizosolenia delicatula, noted at the Baker's Island station, were also present at Flip Rock in varying numbers. The major difference between the summer blooms at these stations is the relatively reduced numbers of Chaetoceros compressus and Eutreptia at Baker's Island. This occurrence of Eutreptia and elsewhere, as noted below, however, is especially intriguing. This and related euglenids are considered to be diagnostic of increased enrichment in marine coastal waters (Smayda, 1980).

Extensive blooms of a similar organism have been found in the nutrient enriched waters of Narragansett Bay especially during the 1985 summer (Smayda, personal communication).

The Pope Rock station appeared rather different from both the Baker's Island and Flip Rock stations. Only 40 species of diatoms and 6 dinoflagellate taxa were identified to species at this station but the phytoplankton populations were relatively high.

Skeletonema costatum (247 cells/ 1×10^{-3}) was the dominant fall bloom phytoplankter, reaching its peak population in September. Nitzschia seriata was also

abundant at 127 cells 1×10^{-3} . Both species dominated at the Baker's Island fall bloom, but in lesser numbers. N. seriata was the most prevalent species at that station. Leptocylindrus danicus (153 cells/ 1×10^{-3}) and Guinardia (18 cells/ 1×10^{-3}) were also noted during the fall bloom at Pope Rock. The species were also noted at Baker's Island, but in reduced abundances (13 and 31 cells/ 1×10^{-3} , respectively). From November through March, Thalassionema spp. was again noted while overall phytoplankton numbers were low.

A large, diverse population occurred during the spring at Pope Rock. The peak occurred in late April - later than at the other stations. Phaeocystis pouchetii numbers were high at that time. Thalassiosira nordenskioeldii and Chaetoceros debilis (251 and 175 cells/ 1×10^{-3} , respectively) were the dominant diatoms, while Skeletonema costatum, Detonula confervacea and C. socialis were also present. Thalassiosira nordenskioeldii and Chaetoceros debilis were dominant at Baker's Island also, however, the other species were not noted.

Skeletonema costatum was again the dominant form during the summer bloom at Pope Rock. At 2164 cells/ 1×10^{-3} in June, and high populations through July, it comprised 82% of the observed population. Eutreptia (129) and Carteria sp. (84 cells/ 1×10^{-3}) were present at Baker's Island. Carteria spp. abundance at Pope Rock was similar (83 cells/ 1×10^{-3}) but Eutreptia numbers were very low (6.4 cells/ 1×10^{-3}).

5.8 Phytoplankton Populations - Massachusetts Bay; Comparison with other Studies.

Although earlier studies by Bigelow (1926) and Lillick (1937, 1940) concentrated on regions more offshore (greater than 8km) some qualitative similarities can be seen. Yearly variations were noted in species present, times of initial appearances and duration of population blooms.

Massachusetts Bay appeared to be less influenced by river drainage and had smaller standing crops of phytoplankton as compared to stations north of Cape Ann. The initiation of the spring bloom appeared three weeks later in Massachusetts Bay (Bigelow, 1926) and (Mulligan, et al., 1974). Mulligan noted that species common to both inshore and offshore areas appeared to be present for similar lengths of time. Studies by Bigelow (1926) and Lillick (1940) showed that Thalassiosira gravida and T. nordenskioldii were followed by Chaetoceros debilis in Massachusetts Bay. Mulligan found Detonula confervacea to be dominant in the spring in addition to Thalassiosira and Chaetoceros debilis, followed in abundance by C. socialis.

All studies noted a decline in diatom abundance after the spring bloom; and the concurrent appearance of Phacocystis pouchetii was noted in some years. In earlier studies, Rhizosolenia alata and peridinian dinoflagellates were dominant during summer blooms. During the 1971-72

summer season, however, Rhizosolenia delicatula, R. fragilissima and Skeletonema costatum were the dominant species. In all studies Skeletonema costatum bloomed from late August through October. Lillick (1940) noted large numbers of phytoplankton of the genus Ceratium but in 1972, Guinardia flaccida and Leptocylindrus sp. appeared to be more dominant.

5.9 Gonyaulax tamarensis - Red Tide

No single set of hydrographic conditions appear to coincide with red tide blooms in Massachusetts Bay. Reduced salinities, high temperatures and high concentrations of dissolved organic matter appear to precede or occur simultaneously with red tide blooms. Salinity and temperature seem less important than the following: upwelling for enrichment; a period of warm, dry weather which increases stratification and results in an increased concentration of sewage derived nutrients in river water; and an increase in rainfall which moves the dinoflagellates into estuaries (Mulligan, 1974).

Gonyaulax tamarensis blooms resulting in Paralytic Shellfish Poisoning have occurred in September of 1972 and in May and August of 1974 and sporadically since that time. During the summer of 1972, low levels of Gonyaulax tamarensis were noted in Massachusetts Bay in Boston Harbor, Salem Harbor and north of Cape Ann. Even though both areas

were subjected to the same meteorological conditions, populations increased to bloom proportions only north of Cape Ann and remained at low levels to the south.

The difference in hydrologic conditions between the two areas appears to be that the area north of Cape Ann is the site of more upwelling. In addition to this upwelling, detritus from previous phytoplankton blooms could have added nutrients. The Merrimack River may have been the distinguishing feature, however. The periods of reduced rainfall preceding each bloom concentrated sewage waste water in the river. This runoff, combined with the rise in temperature, added nutrient rich, warm river runoff to the "seed" population of Gonyanlax tamarensis which was then swept up into the coastal rivers by periods of heavy rainfall.

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STATION

4

BAKER'S ISLAND.

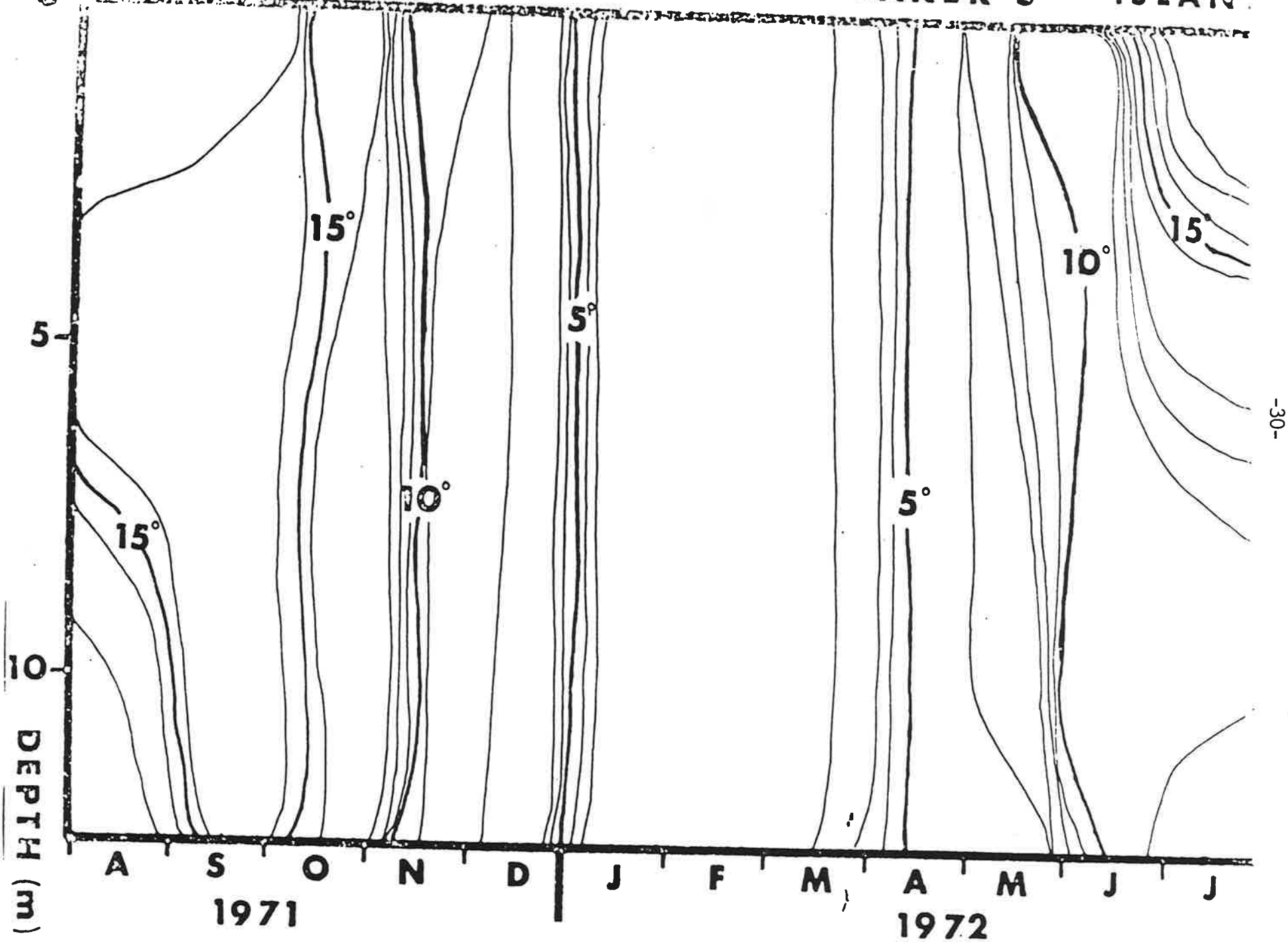


Figure 2 - Temperature Values Bakers Island
Taken from Mulligan and delara, 1974.

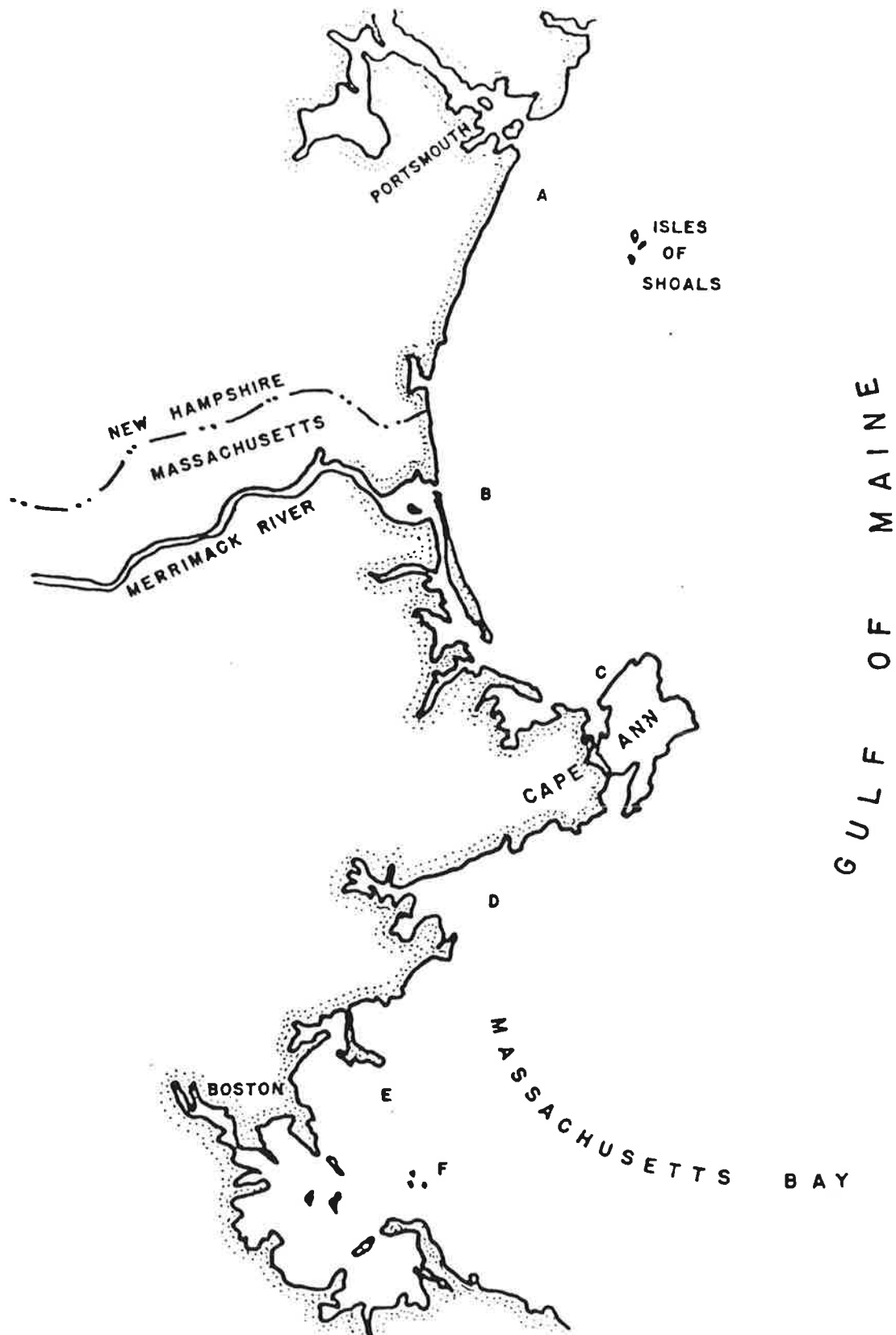


Figure 1 - Sampling Stations - Rye, N.H. to Boston, MA.
Taken from Mulligan and deLara, 1974.

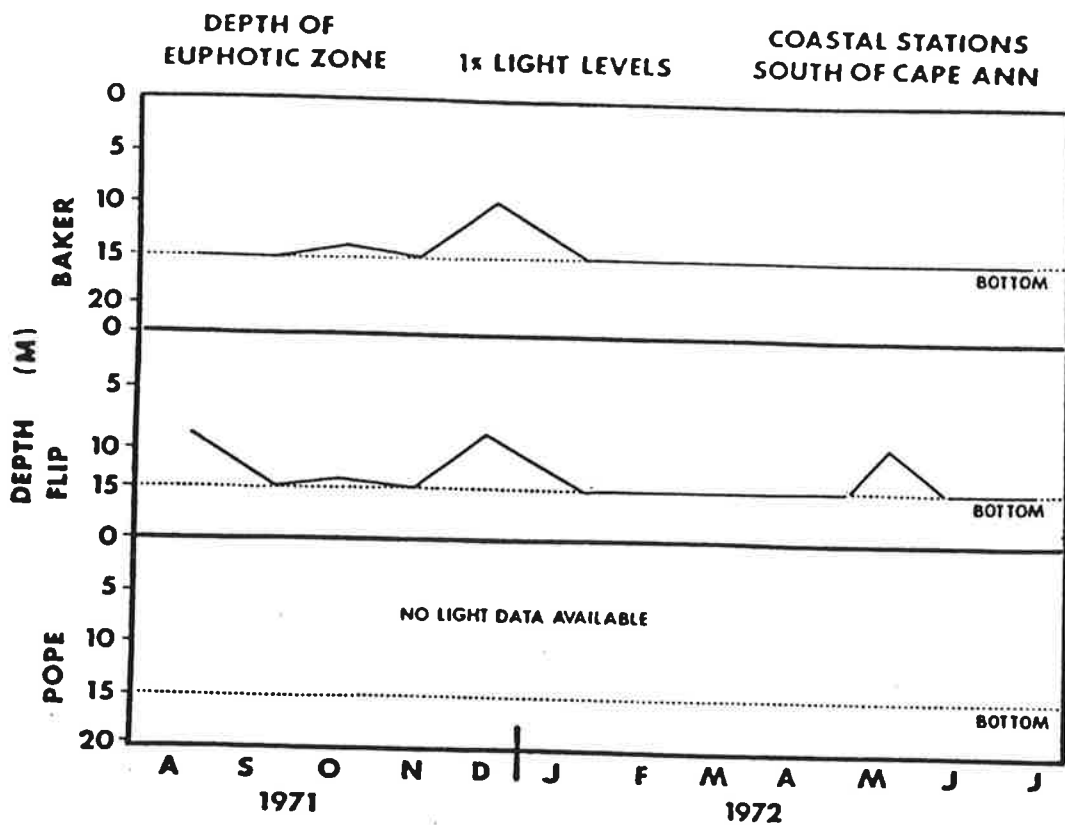


Figure 3 - Euphotic Zone -South of Cape Ann
Taken from Mulligan and deLara, 1974.

Figure 4 - Chlorophyll a Values
Taken from Mulligan and delara, 1974.

