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SPRING PHYTOPLANKTON ABUNDANCE AND PRODUCTIVITY IN
GRAND TRAVERSE BAY, LAKE MICHIGAN, 1970¹

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Abstract. In May 1970, phytoplankton abundance in Grand Traverse Bay ranged from 1455 cells/ml to 3355 cells/ml. Highest standing crop estimates were obtained from stations in the lower portion of the west arm. Lowest standing crop estimates were obtained from stations in the upper east arm. The same populations dominated the assemblages at all stations and estimated diversity of assemblages was relatively high and uniform, ranging from 2.3 to 2.6.

Estimates of primary productivity from the same stations ranged from 3.8 mg C m⁻³ hr⁻¹ to 9.1 mg C m⁻³ hr⁻¹ and followed the same general pattern of areal distribution as the standing crop estimates.

In June, standing crop estimates increased significantly, with values ranging from 2500 cells/ml to 6469 cells/ml. Highest standing crops again were found at stations in the lower west arm, in the vicinity of Traverse City. Similar dominant populations were present again at all stations, but estimated diversity of the assemblages at all stations decreased, with values ranging from 1.8 to 2.2.

Estimates of primary productivity were more variable during the June sampling period, with values ranging from 2.7 mg C m⁻³ hr⁻¹ to 13.4 mg C m⁻³ hr⁻¹, with greatest differences again being between most productive stations in the lower west arm and least productive stations in the upper east arm. (Key words: Phytoplankton; standing crop; productivity; Grand Traverse Bay).

INTRODUCTION

Grand Traverse Bay is a narrow inlet of Lake Michigan. Because of the bay's sheltered waters and relatively high fisheries potential, it has attracted considerable research interest. Ward (1896) made a general biological survey of the region. Lauff (1957) has given an account of the morphometry and general physical characteristics of the bay. Also included in Lauff's investigation were measurements of currents and certain chemical parameters of interest to the present investigation. In 1959, Saunders et al. (1962) conducted an extensive series of experiments on the methodology of measuring primary productivity, using Grand Traverse Bay as one of their test areas.

The total area of the bay is 681.6 km². The lower, or southerly, portion of the bay is longitudinally divided by Old Mission Point (Fig. 1) into two approximately equal segments, generally referred to as the east arm (160.6 km²) and west arm (167.8 km²). These two areas compose approximately one-half of the surface area of the entire bay. Although, as Lauff (1957) pointed out, this subdivision is not entirely logical from the standpoint of morphometry, since the deep basins of the two arms extend well into the open bay, this natural cartographic subdivision is still attractive in attempting to determine gross patterns of phytoplankton response to nutrient input.

The major stream input to the bay and the major population center of the area are found at the southern end of the west arm. The Boardman River,

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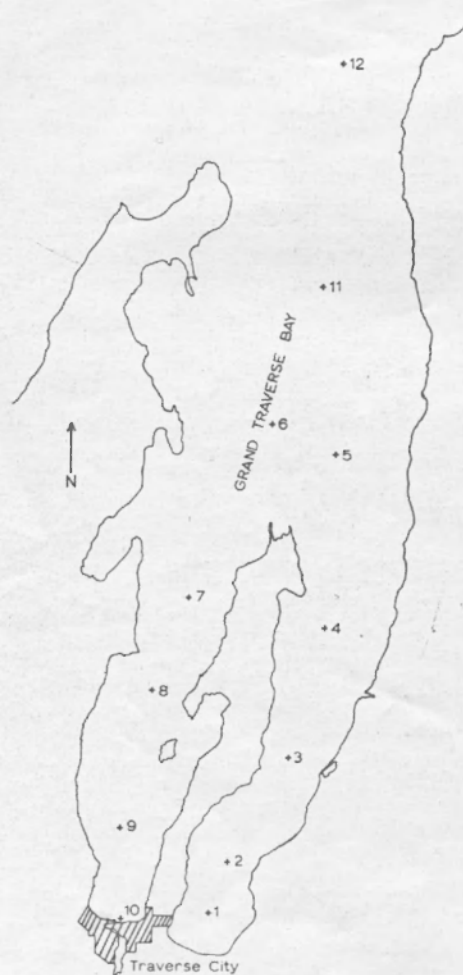


FIG. 1. Outline of Grand Traverse Bay showing station locations.

which enters the southern end of the west arm, drains areas of moderately intense agriculture and also receives treated sewage from Traverse City. This city contributes to the drainage a certain amount of waste derived from light industry and at least one active food processing plant. In the past, several fruit-packing operations were active in the area during the cherry harvests.

The major stream input to the east arm is the Elk River. Unlike the Boardman River, this stream drains largely nonagricultural areas through a chain of large lakes. Although there are areas of quite intensive cottage development, especially at the southern end of the east arm, there are no large population centers on this body of water.

In general, Grand Traverse Bay is thought of as having waters of very high quality. The region attracts considerable recreational activity and is one of the most favored areas for sport fishing on Lake Michigan. In the past, Traverse City has experienced some difficulty with bacterial contamination, which led to the closing of beaches and to the problem of maintaining a satisfactory potable water supply from the west arm. Most of this problem is thought to have been associated with wastes derived from the local fruit-packing industry. However, today, aside from very local areas, the waters of the bay still give the appearance of

oligotrophic conditions and compare favorably with any found in modern Lake Michigan.

The study reported here was undertaken with two general objectives in mind. The first of these was a continuing assessment of limnologic conditions in different regions of Lake Michigan, especially those receiving different loadings of nutrients and consequently having differing levels of productivity, phytoplankton standing crop and alterations of species composition in the phytoplankton assemblage. The second objective was a first order assessment of the difference in such conditions in the various portions of the bay. Because Grand Traverse Bay is an area which has not yet undergone gross ecological perturbation, but may be stressed in the future because of the high projected rate of population growth of the surrounding area, it was considered to be a prime study site for a management-oriented program undertaken by the University of Michigan Sea Grant Program. The project reported here was intended as an aid in designing a rational sampling program for the subsequent, more extensive and protracted project.

MATERIALS AND METHODS

Stations shown in Fig. 1 were sampled on 20 May and 18 June 1970. Samples were collected in all instances by Nansen bottle cast. Values reported from the 20 May sampling are all from a depth of 5 m. In June, values for particulate phosphorus, nitrate and silica are reported for depths of 5 m from the surface and 1 m above the bottom at each station.

Secchi disc transparencies were estimated using a 24 cm diameter, solid, white disc. Chemical parameters were measured colorimetrically, using a Technicon Autoanalyzer with samples that were filtered and frozen in the field. Methods used are described in detail by Schelske and Callender (1970) and Schelske and Stoermer (1972). Carbon fixation rates were estimated from triplicate samples incubated aboard ship according to the method described by Schelske and Callender (1970).

Estimates of phytoplankton cell numbers and species composition were made from counts of six radii on semipermanent slides prepared by aldehyde fixation, filtration onto 25-mm AA-Millipore filters and subsequent clearing and embedding in beechwood creosote. Species present were identified and counted using research microscopes with oil-immersion objectives, giving 1250x magnification and 1.30 N.A.

RESULTS

During the May sampling period, stations in the east arm (Stations 1, 2, 3 and 4) had considerably greater Secchi disc transparencies (Table 1) than either stations in the west arm (Stations 7, 8, 9 and 10) or those in the open bay (Stations 5, 6, 11 and 12). Particulate phosphorus values followed the same general trend, although there was a greater difference between stations in the west arm and those in the open bay. During this sampling period, only minor differences in the levels of nitrate nitrogen were present between all of the stations sampled, although there was an apparent trend toward greater concentrations in the west arm from south to north. Unlike other chemical parameters measured, silica levels were highest in the east arm, lowest in the west arm and intermediate in the open bay. Stations in both arms of the bay showed a trend from lowest values at the most southerly stations to highest values near the outer bay. As might be expected, phytoplankton standing crop estimates were opposite in trend to the dissolved silica levels. Total cell counts were a factor of two less at the outer station in the east arm than at the most southerly station in the west arm. Again, cell count values for stations in the open bay were intermediate. Estimates of primary production rates followed the same general trend as the standing crop estimates, with lowest values in the east arm, values as much as a factor of two higher in the west arm and intermediate values in the open bay. The values differed in that there was very little north-south trend in values in the east arm, but a very pronounced trend in the west arm.

During this sampling period, the dominant populations in the phytoplankton assemblage at all stations sampled were remarkably similar (Table 2). Diversity of the assemblage, as estimated by either the total number of species occurring or by the Shannon-Weiner information index, was also very similar at all stations. The dominant members of the assemblage were generally either characteristic of oligotrophic conditions or eurytopic. Abundance levels of species which tend to become relatively abundant under polluted conditions (Stoermer and Yang 1969, 1970) were very low at all stations (Table 3).

TABLE 1. Productivity related parameters measured at 12 stations in Grand Traverse Bay, Lake Michigan on 18 May and 20 June 1970. Bracketed values derived from samples taken 1 m above bottom; others are derived from samples taken at 5-m depth.

Stations	Secchi disc (m)	Part. P ($\mu\text{g}/\ell$)	NO_3 (mg/ℓ)	Diss. SiO_2 (mg/ℓ)	Standing crop (cells/ m^3)	Productivity $\text{mgC}/\text{m}^3/\text{hr}$
18 May						
1	9.0	7.2	0.234	1.07	1937	4.05
2	9.2	6.7	0.230	1.10	1697	4.13
3	8.5	7.6	0.238	1.18	1527	4.96
4	8.5	7.0	0.229	1.20	1455	4.07
5	8.0	6.9	-	1.13	1978	5.90
6	6.5	8.1	0.243	1.05	1889	4.99
7	7.0	7.4	0.238	1.01	2036	5.90
8	7.0	7.4	0.228	0.93	2730	5.66
9	7.2	8.6	0.222	0.82	2689	8.10
10	5.5	10.1	0.218	0.79	3355	8.63
11	6.5	-	0.231	1.06	2325	4.50
12	6.5	7.0	0.265	1.00	2001	5.27
Mean all stations	7.45	7.6	0.234	1.03	2134	5.51
Mean east arm	8.8	7.2	0.233	1.14	1654	4.30
Mean west arm	6.7	8.4	0.226	0.89	2703	7.07
Mean Open bay	6.9	7.3	0.246	1.06	2048	5.16
20 June						
1	5.5	8.5 (-)	0.124 (0.161)	0.483 (0.512)	3376	4.70
2	5.5	12.9 (9.1)	0.153 (0.209)	0.457 (0.809)	3952	5.54
3	6.0	7.7 (6.7)	0.171 (0.130)	0.414 (1.27)	3188	3.10
4	7.0	8.9 (11.6)	0.153 (0.162)	0.462 (1.24)	3434	3.19
5	6.0	6.4 (7.7)	0.179 (0.199)	0.429 (1.23)	3622	3.72
6	7.5	7.5 (12.2)	0.149 (0.135)	0.498 (0.809)	2500	2.74
7	5.0	11.1 (10.3)	0.169 (0.170)	0.227 (1.15)	5748	7.39
8	4.5	9.8 (8.9)	0.165 (0.138)	0.230 (-)	6388	7.77
9	5.0	12.1 (9.8)	0.152 (0.103)	0.211 (1.19)	6089	8.39
10	4.0	15.9 (15.1)	0.131 (0.118)	0.300 (0.606)	6469	13.44
11	6.5	4.8 (4.4)	0.159 (-)	0.442 (0.811)	3262	2.76
12	4.2	5.3 (6.3)	0.122 (0.194)	0.162 (1.08)	3951	7.86
Mean all stations	5.6	9.3 (9.3)	0.152 (0.156)	0.359 (0.908)	4323	5.88
Mean east arm	6.0	9.5 (9.1)	0.150 (0.166)	0.454 (0.956)	3462	4.13
Mean west arm	4.6	12.2 (11.0)	0.154 (0.132)	0.242 (0.784)	6173	9.25
Mean open bay	6.0	6.0 (7.7)	0.152 (0.176)	0.383 (0.983)	3334	4.27

During the June sampling period, Secchi disc transparencies were reduced from values obtained the previous month (Table 1). Again, the highest values were obtained in the east arm, lowest values in the west arm, with intermedi-

TABLE 2. Relative frequency of dominant taxa in samples from 5 m depth, Grand Traverse Bay, Lake Michigan on 18 May and 20 June 1970. A = *Synedra filiformis* Grun.; B = Unident. flagellates; C = *Melosira islandica* O. Müll.; D = *Fragilaria crotonensis* Kitton; E = *Rhizosolenia gracilis* H. L. Smith; F = *Stephanodiscus minutus* Grun.; G = *Cyclotella stelligera* (Grun. & Cl.) V. H.; H = *Tabellaria fenestrata* (Lyngb.) Kütz.; I = *Rhizosolenia eriensis* H. L. Smith; J = *Cyclotella michiganiana* Skv.; K = *Melosira italica* subsp. *subarctica* O. Müll.; L = *Asterionella formosa* Hass.; Species = Total number of species in sample; Div. = Diversity; Tot. % = Percent of assemblage accounted for by dominants.

Station	A	B	C	D	E	F	G	H	I	J	K	L	Species	Div.	Tot. %
18 May															
1	21	26	8	12	5	5	7	3	1	0.8	1	0.6	57	2.3	90.4
2	23	20	10	5	4	7	9	6	2	0.6	1	1	58	2.4	88.6
3	23	20	7	11	6	8	7	3	1	0.09	1	1	45	2.5	87.8
4	23	12	12	5	6	6	11	4	1	0.5	5	0.5	52	2.6	86.0
5	20	21	11	9	6	5	4	3	0.9	0.3	1	0.5	45	2.5	81.7
6	21	21	6	14	6	5	4	2	1	0.3	0.7	1	46	2.5	82.0
7	22	20	11	8	6	7	5	2	0.9	0.4	2	1	53	2.6	83.3
8	24	17	12	10	4	8	4	3	0.8	0.1	1	0.5	54	2.4	84.4
9	26	18	8	12	4	9	5	2	0.7	0.3	1	0.3	51	2.4	86.3
10	23	24	8	13	4	8	4	2	1	0.5	1	0.5	62	2.3	89.0
11	21	21	3	16	6	3	3	5	1	0.3	3	1	51	2.5	83.3
12	15	21	8	13	8	4	5	1	1	0.2	3	1	48	2.6	81.2
20 June															
1	36	14	0.0	20	12	1	0.7	2	4	1	0.06	0.3	56	2.0	91.1
2	35	15	1	18	13	1	1	3	3	0.7	0.5	0.07	51	2.0	91.3
3	40	12	1	17	13	1	1	2	3	1	0.1	0.3	45	1.9	91.4
4	37	21	0.9	14	14	0.7	1	0.4	4	1	0.2	0.3	55	1.8	94.5
5	35	12	0.2	12	22	0.5	0.6	1	4	0.6	0.2	2	60	2.0	90.1
6	41	7	0	9	24	0.2	0.6	0.08	7	0.7	0	1	50	1.8	90.6
7	47	7	0.4	17	12	2	0.8	2	2	0.9	0.2	0.4	59	1.8	91.7
8	46	9	0.5	20	9	2	0.4	2	2	0.8	0.2	0.2	54	1.8	92.1
9	46	12	0.4	17	9	2	0.6	2	2	0.9	0.1	0.2	55	1.8	92.2
10	39	18	1	16	9	2	0.4	2	2	0.8	0.3	0.3	59	1.9	90.8
11	44	13	0	14	15	1	0.8	0.5	3	1	0	0.4	47	1.8	92.7
12	16	15	0.8	26	15	1	1	1	3	0.08	0.03	0.5	48	2.2	79.4

ate values in the open bay. One exception to this trend was found in the low value at Station 12, located near the entrance to the bay. At this time, particulate phosphorus levels were highest in the west arm, lowest in the open bay and intermediate in the east arm. Samples taken at a depth of 5 m also averaged slightly higher in particulate phosphorus than samples taken near the bottom in the two arms, but not in the open bay. Overall average values for particulate phosphorus at a depth of 5 m were higher in June than May.

Nitrate nitrogen values were again similar at all stations sampled in June, but the overall average was substantially reduced from levels measured in May. No substantial differences in nitrate nitrogen levels were apparent between samples taken at a depth of 5 m and those taken near the bottom.

Similarly, concentration of dissolved silica in the near-surface waters in June were substantially lower than in May. The greatest depletion was apparent at stations in the west arm, where values were reduced on the order of one-half those recorded at stations in the east arm and in the open bay. Station 10, near the mouth of the Boardman River, had substantially higher levels than other stations in the west arm, probably reflecting input of this nutrient by the river. However, Station 12, near the mouth of the bay, had the lowest dissolved silica concentrations recorded at any station. Levels of dissolved silica in the bottom waters averaged much higher than in the surface waters and at the deeper stations approached or exceeded levels noted in the near-surface waters in May.

Phytoplankton standing crop increased markedly in June, with stations in the east arm and west arm having cell densities on the order of two times higher than those measured in May. Average cell counts at the four stations in the west arm were nearly two times larger than those from the four stations in the east arm. Relatively less increase in phytoplankton standing crop was noted at stations in the open bay, with the exception of Station 12, which showed somewhat more increase than the other stations.

In contrast to standing crop, estimates of primary production in June were nearly the same as in May in the east arm. Slight increases in primary productivity rate were recorded at the outer three stations in the west arm and a substantial increase occurred at Station 10. In contrast to stations in the arms, the primary productivity rate at stations in the open bay declined from the levels measured in May, except at Station 12, where an increase was recorded.

As had been the case in May, the dominant populations in the phytoplankton assemblage were remarkably similar at all stations except Station 12 (Table 2). This station appeared markedly different from all others in terms of composition of its flora, just as it did on the basis of other parameters noted earlier. The most notable differences in the phytoplankton assemblage between the two sampling dates were an increase in the relative abundance of the most abundant population, *Synedra filiformis*, in June and concomitant reductions in the relative abundance of *Melosira islandica* and *Cyclotella stelligera*. Substantial increases in the relative abundance of the two species of *Rhizosolenia* present in the assemblage, *R. gracilis* and *R. eriensis*, were also noted in June. Although the average number of species noted per sample was approximately the same in June as in May, the average diversity of the assemblage, as measured by the Shannon-Weiner information index, was reduced. As might be expected, the percentage of the assemblage accounted for by the major dominants was consistently greater in June than in May at all stations except Station 12.

In June, as had been the case in May, the relative abundance of pollution tolerant taxa (Table 3) was low at most stations. Slight increases were noted

TABLE 3. Relative frequency of pollution tolerant taxa in samples from 5 m depth, Grand Traverse Bay, Lake Michigan collected on 18 May and 20 June 1970.

Stations	1	2	3	4	5	6	7	8	9	10	11	12
18 May												
<i>Stephanodiscus binderanus</i> (Kütz.) Krieger	0	0	0	0	0	0	0	0	0	0	0	0
<i>S. subtilis</i> (Van Goor) A. Cl.	0	0	0	0	0	0	0	0	0	0	0	0
<i>Diatoma tenue</i> Ag.	0.1	0	0	0.2	0.1	0	0.2	0.5	0.4	0.1	0.2	0.3
<i>D. tenue</i> var. <i>elongatum</i> Lyngb.	0.2	0.3	0.3	0.2	0.07	0.1	0.03	0	0	0	0	0.03
<i>Cyclotella meneghiniana</i> fo. <i>plana</i> Fricke	0.1	0	0	0	0	0	0	0	0	0	0	0
<i>Stephanodiscus tenuis</i> Hust.	0.03	0.08	0	0	0.03	0	0.03	0	0	0	0	0.03
<i>Fragilaria capucina</i> Desm.	0.07	0.2	0.04	0	0	0.07	0	0.02	0.02	0.02	0.03	0
Percentage of assembly	0.5	0.6	0.3	0.4	0.2	0.2	0.3	0.5	0.4	0.2	0.2	0.4
20 June												
<i>Stephanodiscus binderanus</i> (Kütz.) Krieger	0.02	0.03	0	0	0.03	0.03	0.01	0	0	0.01	0	0
<i>S. subtilis</i> (Van Goor) A. Cl.	0	0	0	0	0	0	0	0.08	0	0	0	0
<i>Diatoma tenue</i> Ag.	0.3	0.1	0.4	0.9	0.6	0.9	0.6	0.7	0.5	0.5	0.3	0.2
<i>D. tenue</i> var. <i>elongatum</i> Lyngb.	0.06	0.2	0	0.04	0.5	0.5	0.01	0.03	0.01	0	0.06	3.0
<i>Cyclotella meneghiniana</i> fo. <i>plana</i> Fricke	0	0	0	0	0	0	0	0	0	0	0	0
<i>Stephanodiscus tenuis</i> Hust.	0	0	0	0.02	0.05	0.08	0.01	0.01	0.02	0	0	0.9
<i>Fragilaria capucina</i> Desm.	0.02	0.09	0.02	0.06	0.01	0	0.04	1	0.1	0.01	0.1	0.5
Percentage of assembly	0.4	0.4	0.4	1.0	1.2	1.5	0.7	1.8	0.6	0.5	0.5	4.6

at stations in the open bay. Some increase in *Diatoma* spp. occurred at Stations 5 and 6 and a very significant increase in the same species occurred at Station 12.

DISCUSSION

It is apparent from the results that the three subregions of Grand Traverse Bay are significantly different in their productivity potential, at least during the spring productivity maximum. Both direct measures of phytoplankton productivity, such as carbon fixation rate and phytoplankton abundance, and

secondary measures, such as major nutrient element uptake and transparency, show a consistent pattern which is only explicable in terms of higher levels of productivity in the west arm than in the other subregions of the bay. Considering possible sources of nutrient input to the bay, this is not an unexpected result. The assumption that the west arm is significantly affected by nutrient input from the Traverse City vicinity is strengthened by consideration of the obvious north-south trend in productivity-related parameters noted in both months.

Some notion of the magnitude of difference between the east arm and the west arm may be gained by inspecting the ratio of average values of the different productivity-related parameters. In May, the average values for standing crop and rate of carbon fixation were both a factor of 1.6 higher in the west arm than they were in the east arm. In June, this factor increased to 1.8 for the standing crop estimate and 2.2 for rate of carbon fixation. If the exceptionally high value for Station 10, near the mouth of the Boardman River, were excluded, the ratios would be the same as they had been in May. The ratio of differences in Secchi disc transparencies was 1.3 in both months and the ratio of differences in particulate phosphorus was on the order of 1.2 in both months. In almost all instances, the values for productivity-related parameters in the open bay were intermediate, between those of the east arm and those of the west arm. Values in this region were, however, considerably more variable. This probably reflects mixing of water masses derived from the two arms of the bay and, to a certain extent, the influence of the main body of Lake Michigan. During May, Station 12, nearest the mouth of the bay, appeared to be essentially similar in characteristics to other stations in the bay. In June, however, this station appeared to be quite different in a number of characteristics from the rest of the stations in Grand Traverse Bay. In the authors' estimation, the characteristics of this station, particularly the flora, were more representative of the general condition of the nearshore waters of northern Lake Michigan than of Grand Traverse Bay. Considering the location of this station, it is not unreasonable to expect that it might be occupied at different times by water masses derived primarily from the bay or from the main lake.

Primarily because of the time of sampling in the study, the level of standing crop and rate of productivity found in Grand Traverse Bay were difficult to compare with reports from other regions in Lake Michigan. The results for carbon fixation were higher, both on average and in absolute maximum, than those reported by Saunders et al. (1962) for Grand Traverse Bay. The results also averaged nearly twice the values reported by Parkos et al. (1969) and Schelske and Callender (1970) for northern Lake Michigan and approach the average values reported by Schelske and Stoermer (1972) for nearshore stations in the vicinity of Grand Haven. Highest optimum rates of carbon uptake reported by Fee (1971) from stations on a transect between Milwaukee and Ludington exceeded any noted in this study. Levels of standing crop (Table 1) were higher than those reported from southern Lake Michigan by Stoermer and Kopczynska (1967) based on samples collected in 1962 and 1963. More recent data would seem to indicate that the highest standing crop densities reported in this study were comparable to current average values for the inshore waters of southern Lake Michigan in May and only on the order of one-fifth as high as the extreme highs encountered in that region of the lake.

The difficulty of comparing the results directly with previous studies serves to point out the necessity of large-scale, systematic sampling of the Lake Michigan system if valid comparisons between regions of the lake are to

be made (Fee 1971). Damann (1960) has shown that large differences in the average yearly standing crop of phytoplankton are present at a single station in Lake Michigan. If the additional uncertainties associated with seasonal succession and transient perturbations are added to this, comparisons based on anything but closely controlled synoptic studies must be treated with extreme caution.

The results indicate that the productivity peak in Grand Traverse Bay occurs somewhat later in the year than it does in the southern part of the lake, as might be expected. Two dates sampled in the study appear to bracket the peak productivity period in Grand Traverse Bay. Although standing crop values in June were appreciably higher than in May, photosynthetic rates did not increase proportionately. The largest difference occurred at stations in the east arm and the least at stations in the lower west arm and at Station 12. It might be inferred from this that populations in the east arm were, by 20 June, being limited by exhaustion of one or more essential nutrient(s), whereas populations in the west arm, particularly in the lower reaches near Traverse City were less affected. Although the data cannot be used directly to answer this question, it appears likely that phosphorus limitation may be involved. Nitrate levels in June, although reduced from values observed the previous month, seemed sufficient to support growth of phytoplankton populations found in the Great Lakes. Concentrations of dissolved silica, the other major nutrient of interest, were significantly more depleted in the west arm than in the east arm. Although these values were lower than those which have been reported previously as limiting to diatoms (Lund 1950), they were probably sufficient to maintain reproduction in Great Lakes populations (Schelske and Stoermer 1972).

In some ways, the most interesting aspect of the data is the qualitative similarity of the phytoplankton assemblage at all stations and dates sampled. Previous investigations in Lake Michigan (Holland 1968, 1969; Stoermer and Yang 1969, 1970) have indicated large differences in the phytoplankton assemblages at stations receiving different levels of enrichment. One might suspect that similar differences would be present between the subregions of Grand Traverse Bay, but this is clearly not the case. The situation in Grand Traverse Bay appears to be analogous to that in Great Central Lake (Parsons et al. 1972), where increased inputs of plant nutrients apparently produced significant increases in primary productivity and standing crop without detectable alteration in the qualitative aspects of the phytoplankton flora.

The cause of this type of response is not entirely clear. It may be that the phytoplankton assemblages involved are able to accommodate nutrient enrichment without significant qualitative change up to some threshold value before qualitative changes begin to occur and that this threshold has not yet been exceeded in Grand Traverse Bay. The other distinct possibility is that the phytoplankton populations in any given assemblage respond to changes in conservative element balance or other factors which are usually associated with nutrient pollution and when such other environmental perturbations are lacking, as is clearly the case in Great Central Lake and possibly the case in Grand Traverse Bay, the response of the flora is primarily in the form of increased productivity rather than in changes in species composition. It is most probable that both types of mechanism of assemblage change operate in the Great Lakes situation. Clearly, sufficient enrichment with phosphorus can cause silica to become limiting and result in gross alteration in the species composition of the phytoplankton assemblage (Schelske and Stoermer 1971). However, although floristic responses to gross alterations in conservative element abundance are well documented (Cholnoky 1968), we know little of the responses caused within the range of concentrations found in the Great Lakes.

SUMMARY AND CONCLUSIONS

During the spring productivity maximum, there appear to be significant differences in the levels of phytoplankton standing crop and primary productivity in three regions of Grand Traverse Bay. All productivity-related parameters measured indicate highest productivity in the west arm of the bay, lowest in the east arm and intermediate but more variable levels in the open bay. Differences noted appear to be directly related to known sources of nutrient loading.

Although the timing of this study relative to more extensive surveys of open Lake Michigan carried out later in the yearly phytoplankton cycle makes direct comparisons difficult, it appears that levels of phytoplankton standing crop and primary productivity are intermediate between high values associated with the inshore waters of Lake Michigan and low values found at offshore stations. In striking contrast to the situation generally reported from the main body of Lake Michigan, composition of the phytoplankton assemblage is very similar in all parts of Grand Traverse Bay which were sampled.

In general, although incipient effects of nutrient enrichment are evident in Grand Traverse Bay, pollution does not appear to have progressed to the point where gross effects are visible. It should be noted, however, that current levels of productivity result in substantial depletion of available dissolved silica in the surface waters of the west arm. Further increases in loadings of other plant nutrients, particularly phosphorus, may result in complete depletion during midsummer and lead to pronounced changes in the phytoplankton assemblage.

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