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Resource Limitation of Phytoplankton In the Virginia Chesapeake Bay and Tributaries Using Nutrient-Addition Bioassays

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SUMMARY

Nutrient-addition bioassays were conducted periodically in the James, York and Rappahannock Rivers and the mainstem, lower Chesapeake Bay from 1985 through early 1993 for the purpose of describing temporal and spatial patterns of nutrient limitation of phytoplankton growth and abundance in these tidally-influenced aquatic systems. All studies involved the addition of nitrogen (N), phosphorus (P) and silica (Si), either singly or in combination, to contained, natural water samples and, after some period of growth (days), a comparison of the response of the phytoplankton in the nutrient-enriched treatments to those without added nutrients (i.e. controls). The magnitude of the response of the phytoplankton community (as measured by chlorophyll) to an added nutrient is proportional to the degree of limitation imposed by that nutrient in the natural environment. Nutrient response indices were determined for each treatment for the day of maximum response of the phytoplankton community. There were instances when phytoplankton in the control increased over time, but there was no additional response of the phytoplankton community to any of the added nutrients. We interpret this as the response of a nutrient-replete, light-starved phytoplankton community to an increased irradiance encountered in the bioassays compared to the natural environment, and quantified a light limitation index. The tidal freshwater Rappahannock is strongly light limited throughout most of the year and if light were not limiting, phosphorus would be limiting for most of the year. N and Si are consistently in excess relative to the needs of the phytoplankton. In the lower River, there is a seasonal cycle of P limitation in the spring and N limitation in the summer. The tidal freshwater James is strongly light limited and N, P and Si are in excess of the needs of the phytoplankton. The lower James River is N limited throughout the year and P is in excess of phytoplankton needs throughout the James River. The tidal freshwater Pamunkey is primarily light limited and this limitation is strongest in winter-spring months. During the summer there are periods of moderate N limitation. The transition zone (i.e. the region of the turbidity and chlorophyll maxima) is light limited primarily in the spring months with a summer period of N limitation more prolonged than in the tidal freshwater region. A similar seasonal cycle of N limitation in the summer is evident in the lower York River. Light limitation is not a factor in the lower river. The lower Chesapeake Bay is primarily N limited. This limitation is most strongly expressed at the more southern station with periods of N limitation in the late winter-early spring and in the summer. The spring season was characterized by P limitation in May. At the more northern station the summer period of N limitation was not as strongly expressed and the spring period of P limitation was more pronounced.

INTRODUCTION

Nutrient-addition bioassays were conducted periodically in the James, York and Rappahannock Rivers and the mainstem, lower Chesapeake Bay from 1985 through early 1993 for the purpose of describing temporal and spatial patterns of nutrient limitation of phytoplankton growth and abundance in these tidally-influenced aquatic systems. Although the methodologies employed during this study varied, they all involved the addition of nutrients (nitrogen, phosphorus and silica) either singly or in combination to contained, natural water samples and, after some period of growth (days), a comparison of the response of the phytoplankton in the nutrient-enriched treatments to those without added nutrients (i.e. controls). The theoretical basis of this type of experiment is that the greater the phytoplankton response to an added nutrient the more dominant is its limitation of growth or biomass of phytoplankton in the natural environment. We further propose that such experiments can provide information about light limitation of phytoplankton growth and biomass in the natural environment and thus expand our consideration of resource limitation beyond nutrients to include light.

METHODS AND MATERIALS

VIMS Pier

From August 1985 through July, 1988, seventeen nutrient enrichment bioassays were conducted using York River water (YRW) collected at the VIMS pier at Gloucester Point, VA. In August and December 1985 the bioassays were conducted as batch cultures using 4 l polypropylene containers filled with 3 l of water. Nutrient enrichment treatments included: +N (320 uM NH_4Cl); +P (32 uM NaH_2PO_4), +N+P and a control containing no enrichment. All treatments were conducted in duplicate in August and in triplicate in December. The containers were maintained under natural sunlight in a shallow (ca. 20 cm depth), flow-through water table (ambient YRW) and sampled daily for chlorophyll content.

The remaining fifteen bioassays (October, 1985, February, April, June, July, September, November, 1986 and February, March, May, July, October, 1987, January, March, July 1988) were conducted in flow-through microcosms constructed of transparent fiberglass (37 cm diameter, 50 cm high) with two overflow holes located so as to maintain a 50 l volume. Experiments were started by filling the microcosms with filtered YRW (<40 um pore size Polyversol Gelman filter). After the initial filling, a constant flow of filtered YRW (sequential filtration through spun cartridges of 5 and 1 mm porosity followed by membrane cartridges of 1.0 and 0.22 um porosity) was supplied to each tank at a rate sufficient to maintain a dilution of 0.5 culture volumes day^{-1}. A constant flow of nutrient solutions (prepared in filtered YRW) provided the following ambient nutrient treatments: +N (25 uM as NH_4Cl); +P (5 uM as NaH_2PO_4), +N+P; control (no N and P addition). In July, September and November, 1986, the

dilution rate was decreased to 0.3 culture volume day^{-1} without decreasing the rate of nutrient input, resulting in an increase in the predicted ambient nutrient concentration of ca. 50%. All nutrient concentrations assume no utilization within the microcosms. Each treatment, including the control, was conducted in triplicate. Aeration and mixing was provided to each microcosm by air through 15 cm airstones at a rate of approximately 1.8 l min^{-1}. All microcosms were sampled daily for chlorophyll content.

York, Pamunkey Rivers

From March 1990 through August 1991 batch culture, nutrient-addition bioassays were conducted at a series of stations in the York/Pamunkey river system. On each of ten dates, water was collected from the near surface at the VIMS Pier (lower York River, Gloucester Point,VA) and from a fixed station in the tidal freshwater Pamunkey River located 85 km from the mouth of the York River (TF 4.2). In addition, stations at both the chlorophyll and turbidity maxima of the upper York, lower Pamunkey rivers were sampled. Since the location of both maxima varied with time, these two stations were not fixed. The location of each maxima was determined on each sampling date by traversing the rivers with a flow-through nephelometer and in vivo fluorometer. The turbidity maximum occurred within the Pamunkey, 53 to 80 km from the mouth of the York while the chlorophyll maximum was located near the confluence of the Pamunkey and the York, 40 to 50 km from the mouth of the York.

Four liter polypropylene containers were filled with 3 liters of river water which was prescreened through Nitex (50 um mesh) to remove large zooplankton. Nutrient enrichment treatments included +N (310 uM as NH4), +P (3.16 uM as PO4) and a control (no enrichment). All treatments, including the control, were run in duplicate. The bottles were wrapped in plastic screen which reduced incident irradiance by 50% and placed in a shallow, flow-through water table constantly supplied with YRW to maintain ambient temperature. All incubations were conducted on the VIMS pier at Gloucester Point, VA. Phytoplankton biomass in each container was measured as chlorophyll (in duplicate) each day.

James, Rappahannock and Chesapeake Bay

From February 1992 through February 1993 six stations were sampled monthly (except December). All six stations are Chesapeake Bay Program water quality and phytoplankton monitoring stations (except TF 3.2 for the latter) and include stations in the tidal freshwater James and Rappahannock (TF), stations at the mouths of each of these rivers (LE) and two stations in the mainstem of the Virginia portion of the Chesapeake Bay (CB). All samples (20 l) were collected from a 0.5 m depth by the personnel and using the same protocol as for the established monitoring programs and returned to VIMS where the bioassays were conducted. The water was filtered through 90 um Nitex to remove larger grazers, a subsample was collected (triplicate) for determining initial chlorophyll content and the water was then subdivided into paired, 1 l, clear polycarbonate bottles. Each pair of bottles received one of the following enrichment treatments: +N (25 uM NH_4 as NH_4Cl), +P (5 uM PO_4 as NaH_2PO_4); +Si (30

uM SiO_4 as $NaSi0_3$); +N+P, +N+P+Si. One pair with no nutrient enrichment served as a control. The two mainstem stations (CB) and the two river mouth stations (LE) did not receive the +Si or +N+P+Si treatment from July through November. The bottles were placed in a shallow (ca. 50 cm water depth) flow-through, water table (ambient YRW) which was covered with a plastic screening to provide a 50% reduction in ambient irradiance and sampled daily in duplicate for chlorophyll content.

Enrichment Response Indices

Batch culture nutrient bioassays were typically conducted for a period of 4-8 days and terminated after a maximum response of the phytoplankton community was obtained. A nutrient response index based on chlorophyll *a* (see below) was determined for each treatment for the day of maximum response of the phytoplankton community. The flow-through nutrient bioassays were typically conducted for 8-12 days and a nutrient response index for these experiments was determined at the termination of the incubation. In both systems, the response index for a particular bioassay was determined on the same day for each treatment.

The response of the phytoplankton community to nutrient enrichment was quantified by determining a nutrient response index for nutrient enrichment for each treatment. The index is the ratio of phytoplankton biomass (measured as chlorophyll *a*) of a treatment to the control on the day of maximum phytopankton response. The greater the ratio, the greater the response of the community to that treatment. A ratio of unity indicates no response to nutrient addition compared to the control and a ratio <1 indicates a treatment biomass less than the control. On the basis that the magnitude of the response of the phytoplankton community to an added nutrient is proportional to the degree of limitation imposed by that nutrient in the natural environment, a response index greater than unity indicates limitation by that nutrient in the natural environment while an index close to or less than unity for a particular nutrient indicates that nutrient was at a sufficiently high concentration that it was not limiting growth or abundance of the phytoplankton in the natural environment. Chlorophyll measurements were performed by filtering 5-10 ml of sample onto GF/F filters which were extracted in the dark in acetone/DMSO (Webb and Hayward, unpublished manuscript) and read by fluorometer (Loftus and Carpenter, 1971) calibrated by spectrophotometry (Jeffrey and Humphrey, 1975

In a number of cases, the chlorophyll content of the controls increased substantially over the course of the incubation. This does not affect the determination of the nutrient enrichment indices since their magnitude for a given treatment is relative to the control on the day of maximum response. However in many instances when the control increased over time, there was no additional response of the phytoplankton community to any of the added nutrients; treatments and controls responded essentially identically. We interpret this as a response of a nutrient replete, light-starved phytoplankton community to an increased irradiance encountered in the bioassays compared to the natural environment. The absence of any added response in the nutrient treatments relative to the controls indicates sufficient nutrients for growth in the light-

deficient, natural environment. We quantify the magnitude of the light limitation as the ratio of the phytoplankton biomass in the control on the day of peak response to the biomass at the beginning of the incubation. Although both the nutrient limitation and light limitation indices are determined as biomass ratios, the former compares a treatment to the control at a given time while the latter quantifies the magnitude of the change of biomass in the control over a time interval. Thus the two indices are relative measures of resource limitation in their own right but are not directly, quantitatively comparable.

RESULTS

Limitation indices were determined for nitrogen, phophorus and silica enrichments for each bioassay to which they were provided. Indices are not provided for the multiple nutrient additions (i.e. +N+P, +N+P+Si). However, such results have value in further discriminating, both quantititively and qualitatively, the nature of nutrient limitation of natural phytoplankton populations (Fisher and Butt, 1994). A light limitation index was determined for each bioassay. To facilitate the analyses of temporal variability in the limitation indices, the results for each series of bioassays are grouped by month within a one year time frame for each station. Stations are then grouped according to their salinity regime. The results for tidal freshwater stations are provided in Fig. 2a-c, transition zone in Fig. 3a and b, lower estuary in Fig. 4a-d, and mainstem, lower Chesapeake Bay in Fig. 5a and b.

Tidal Freshwater

In general the tidal freshwater regions of all three river systems show a very limited response to nutrient additions. On only one occasion (June, Pamunkey, +N) is a limitation index greater than two observed. By contrast, nutrient indices in the lower rivers and mainstem typically are in the range of 2-6. The lack of nutrient limitation is particularly marked in the James River where both the N and P indices are very near unity throughout the year. By contrast, the Rappahannock station reveals a limited but consistent response to P additions in ten of the eleven months tested even though light is the dominant limiting resource for phytoplankton (see below). Analyses of the tidal, freshwater Pamunkey results are complicated because bioassay results over 18 months are consolidated into a single 12 month period. The June response to N enrichment occurred in 1991, while the September response to both N and P enrichment occurred in 1990. In general, over the 18 months at this station there was little if any singular response to P additions with indications of slight N limitation during some summer months.

All three tidal freshwater stations showed significant responses to light, with indices generally ranging from 2-7 compared to values consistently <1 at the mainstem Bay stations. The singular response to light limitation is most apparent in the James River where there is a consistent response to light but no response to nutrient additions. The smaller light indices in the James from July through October (Fig. 2c) are the result of very high initial chlorophyll a values in the bioassays (> 60 ug/l). As a result, even

though there was a substantial increase in the absolute chlorophyll in all treatments including the control during the incubations (ca. 60 ug/l) the percentage increase was somewhat reduced (ca 100%), resulting in a lower light index.

Transition Zone

Interpretation of the transition zone results is again complicated by the consolidation of 18 months of data into a 12 month period. There is not a bimodal peak of response to N enrichment at these stations. At both stations, the June-July response to N enrichment occurred in 1991 while the September response occurred in 1990. When viewed sequentially over the 18 month period of collection, the results indicate a summer/early fall period of N limitation each year at both stations. There is no response to P enrichment for the entire period, except in August 1991, when it was limiting.

Lower Tributaries

For most of the year there is little evidence of light limitation at the lower estuary stations. In the both the lower James and York (Figs. 4b and 4c respectively) there is evidence of light limitation in the early winter but in each case there is a response to nitrogen as well. In general for all three stations, nitrogen is the dominant limiting nutrient and its dominance is greatest during the summer/early fall months. This is especially evident in the lower James where there is no response to P additions at any time of the year. In the lower Rappahannock (Fig. 4a) there is a period of P limitation in the late spring. Over the 18 months of observations in 1990-91 in the lower York River, N was limiting over the summer months with only one observation of P limitation occurring in August 1991.

Lower Chesapeake Bay

Both of the Bay stations are characterized by a moderate/strong but time-varying response to nutrient enrichment and no response to light. Nitrogen limitation is more strongly and consistently expressed at 6.4 than 6.1, with a strong nitrogen limitation in the summer and minimal nutrient limitation in the winter. CB 6.1 shows a longer period of P limitation in the spring and a reduced summer N limitation compared to CB 6.4.

Silica Limitation

For reasons of clarity, the silica response indices are not included in Figs. 2, 4 and 5. At the tidal freshwater stations (TF 3.2, TF5.5) there was no response to silica additions either singly or in combination for the entire year in which such additions were made (1992-93). At the lower estuarine stations (LE 3.6 and LE 5.5) and the mainstem Chesapeake Bay stations (CB 6.1, CB 6.4) there was no response to silica additions either singly or in combination during the January through June time period in which they were made.

SUMMARY CHARACTERIZATION

Rappahannock River

The tidal freshwater Rappahannock is strongly light limited throughout most of the year. Were light limitation to be ameliorated, phosphorus would be limiting for most of the year. N and Si are in excess relative to the needs of the phytoplankton. In the lower River, there is a seasonal cycle of P limitation in the spring and N limitation in the summer.

James River

The tidal freshwater James is strongly light limited. N, P and Si are in excess of the needs of the phytoplankton. The lower James River is N limited throughout the year P is in excess of phytoplankton needs throughout the James River.

York River

The tidal freshwater Pamunkey is primarily light limited and this limitation is strongest in winter/spring months. During the summer there are periods of moderate N limitation. The transition zone appears light limited primarily in the spring months with a summer period of N limitation more prolonged than in the tidal freshwater region. A similar seasonal cycle of N limitation in the summer is evident in the lower York River. Light limitation is not a factor in the lower river. In August 1991 a substantial portion of the York River experienced P limitation.

Lower Chesapeake Bay

The lower Chesapeake Bay is primarily N limited and this limitation is most strongly expressed at the more southern station with periods of N limitation in the late winter/early spring and in the summer. The spring season was characterized by P limitation in May. At the more northern station the summer period of N limitation was not as strongly expressed and the spring period of P limitation was more pronounced. It is perhaps worth noting the similarity between the lower Rappahannock River station and the adjacent lower Bay station, CB 6.1 (Figs. 4a and 5a respectively) and the lower James station, LE5.5, and the lower Bay station CB6.4 (Figs. 4b and 5b respectively).

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Jeffrey, S. W. and G. F. Humphrey. 1975. New spectrophotometric equations for determining chlorophyll *a*, *b*, *c1*, and *c2* in higher plants, algae, and natural phytoplankton. Biochem. Physiol. Pflanzen 167: 191-194.

Loftus, M. E. and J. H. Carpenter. 1971. A fluorometric method for determining chlorophylls *a*, *b* and *c*. J. Mar. Res. 29:319-338.

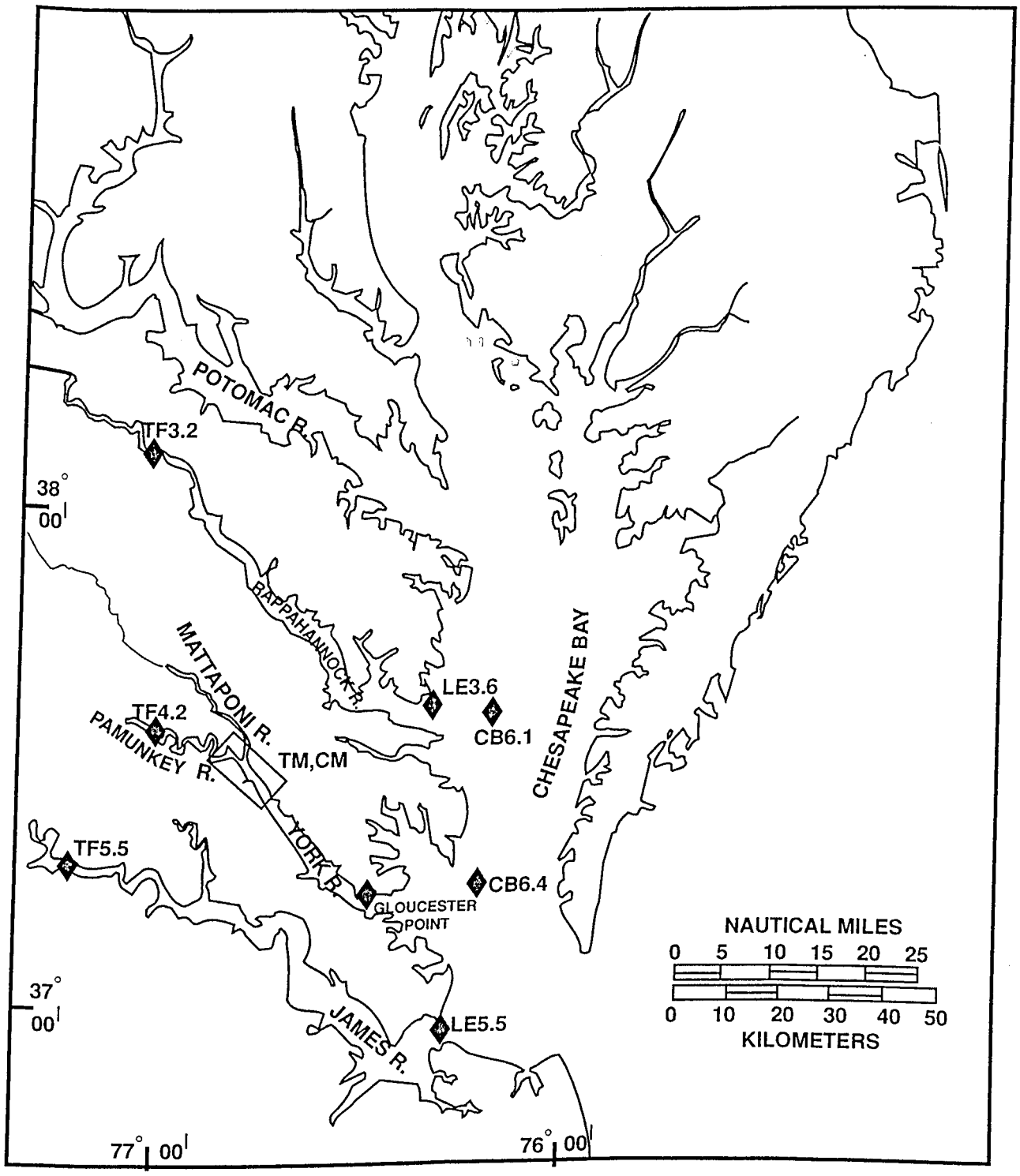

Figure 1. Station locations in the lower Chesapeake Bay and tributaries. The enclosed area in the upper York River indicates the location of the turbidity maximum (TM) and the chlorophyll maximum (CM)

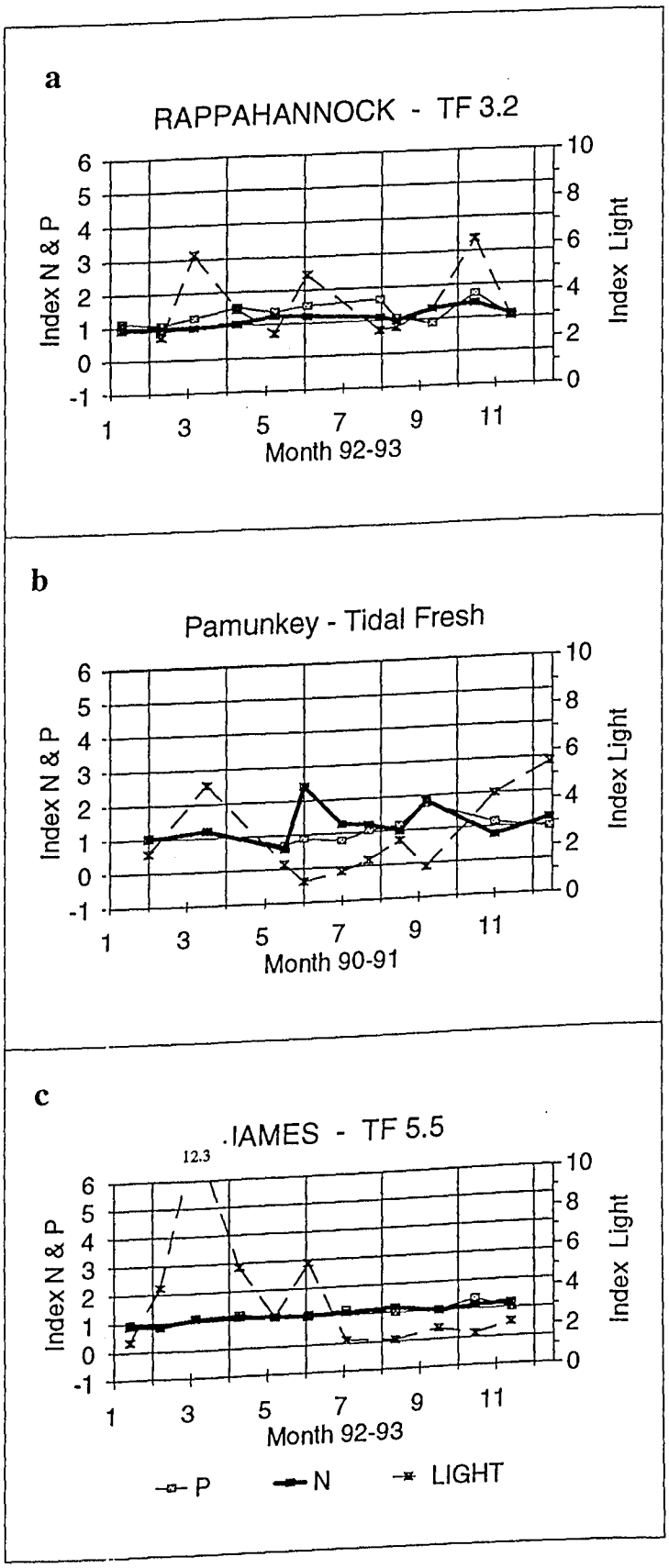

Fig 2. Limitation indices for light, nitrogen (N) and phosphorus (P) for: (a.) tidal freshwater Rappahannock River; (b.) tidal freshwater Pamunkey River; (c.) tidal freshwater James River.

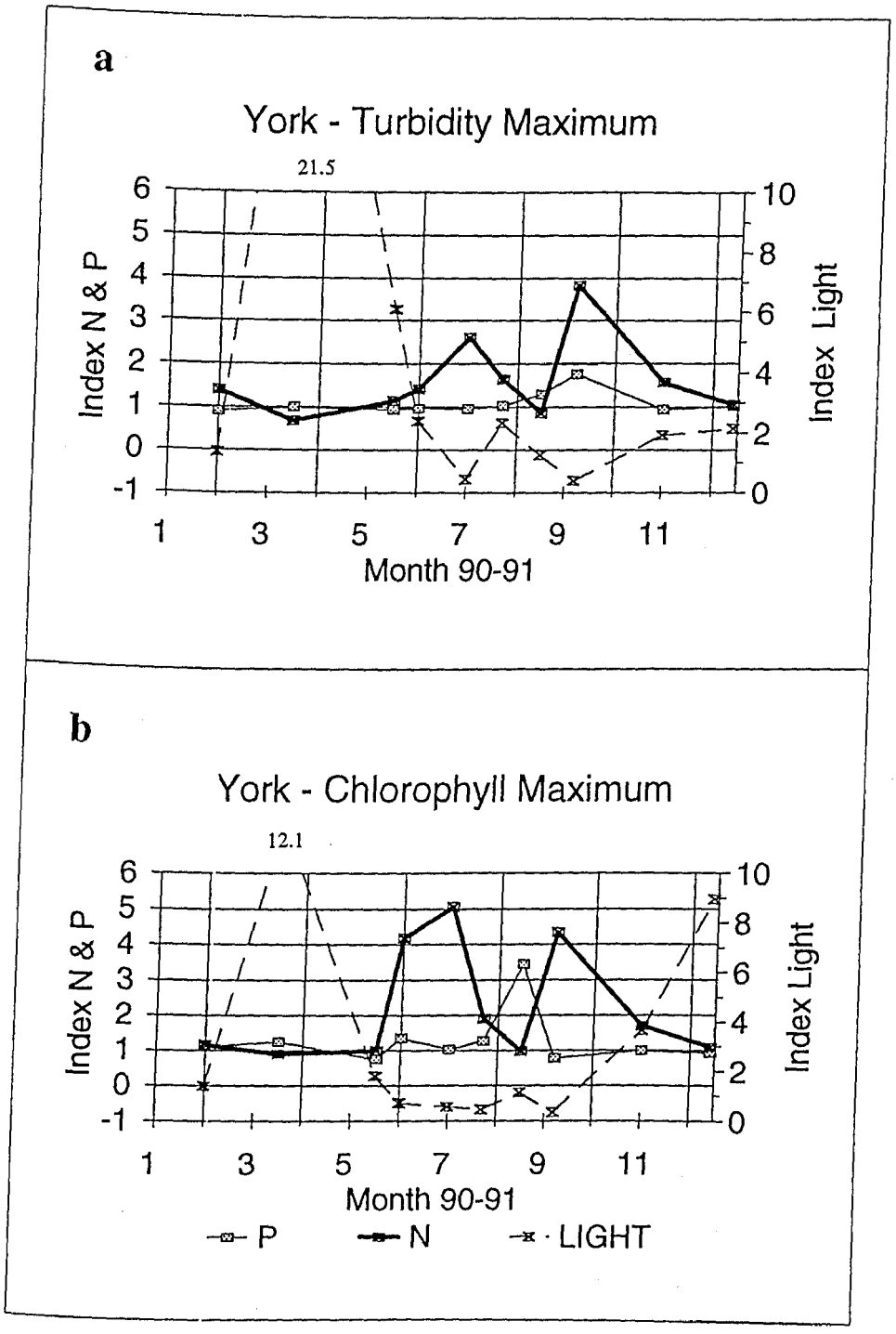

Fig. 3. Limitation indices for light, nitrogen (N) and phosphorus (P) for: (a.) York-Pamunkey turbidity maximum; (b.) York-Pamunkey chlorophyll maximum.

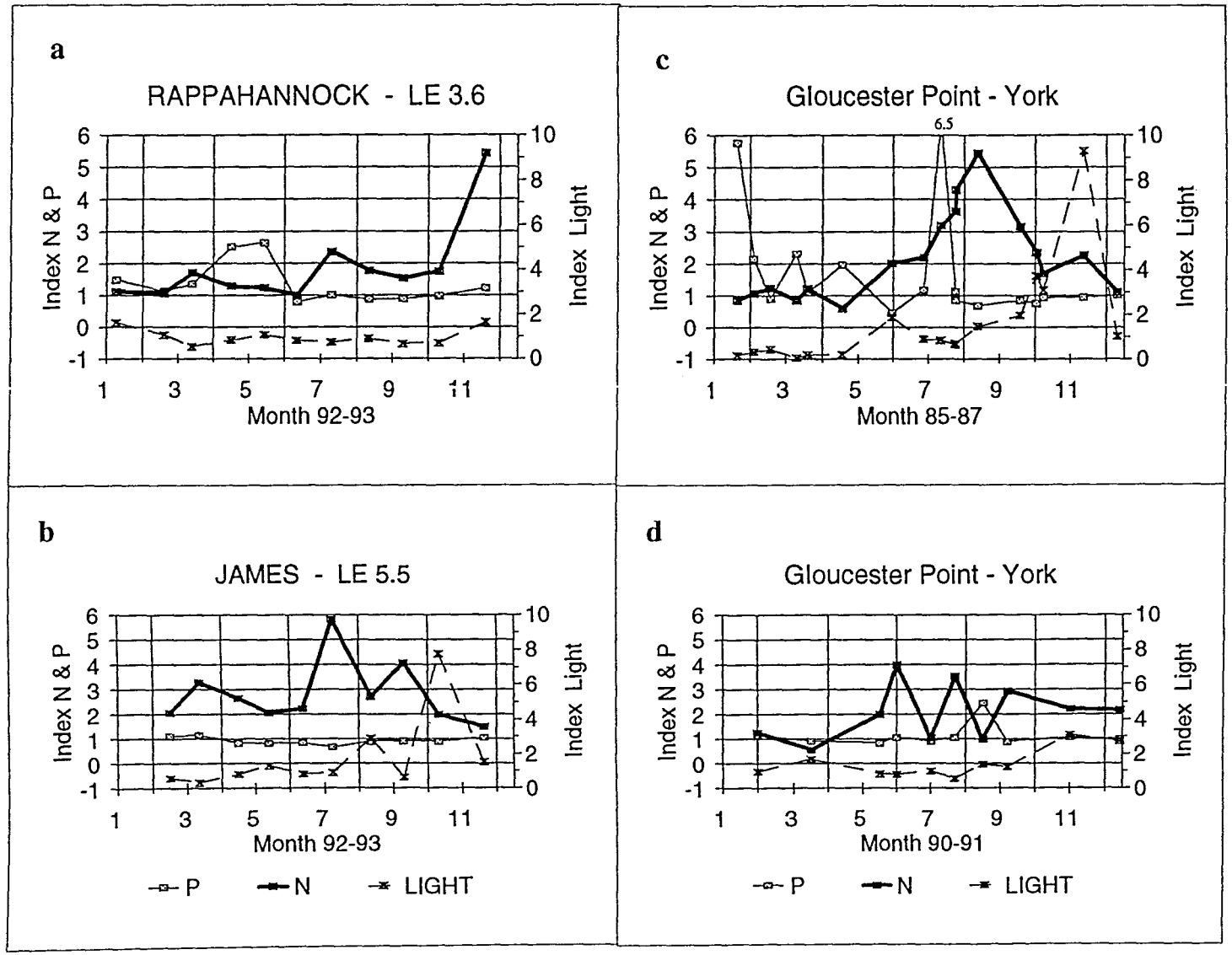

Fig. 4. Limitation indices for light. Nitrogen (N) and phosphorus (P) for: (a.) lower Rappahannock River; (b.) lower James River; (c. and d.) lower York River.

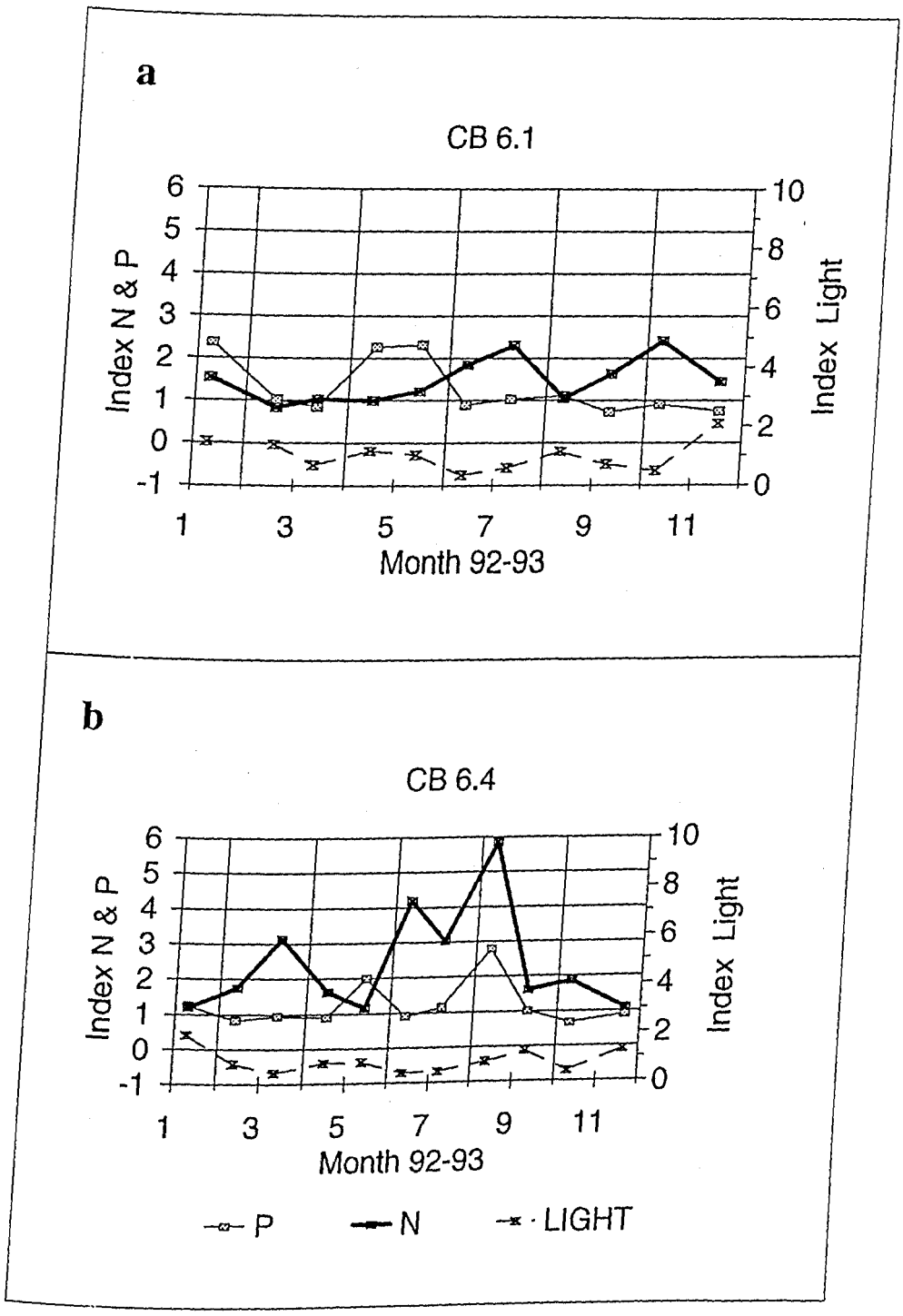

Fig. 5. Limitation indices for light, nitrogen (N) and phosphorus (P) for the lower Chesapeake Bay. (a.) Station CB 6.1; (b.) Station CB 6.4.

Appendix

Table 1. Date at start of incubation and the day enrichment index was determined are shown. Stations are Chesapeake Bay Program stations (TF3.2, TF5.5, LE3.6, LE5.5, CB6.1, CB6.4) or tidal fresh (TF), turbidity maximum (TM), chlorophyll maximum (CM) and VIMS Pier in the Pamunkey-York River system. Indexes are enrichment indexes for nitrogen (N), phosphorus (P), silica (Si) and light. Chlorophyll concentration at the beginning of the incubation (CHL Start) and the concentration of control at the time of the index (CHL at index) are shown.

Date Start	Date Index	Station	INDEX				CHL Start ug/l	CHL at Index, ug/l
			N	P	Si	LIGHT		
08/12/85	08/18/85	VIMS-Pier	5.44	0.68		1.46	8.79	10.9
10/07/85	10/12/85	VIMS-Pier	1.69	0.93		3.09	5.4	16.7
12/09/85	12/18/85	VIMS-Pier	1	1.1		1	5.5	5.5
02/16/86	02/20/86	VIMS-Pier	1.23	0.9		0.44	3.21	1.43
04/17/86	04/29/86	VIMS-Pier	0.59	1.96		0.19	7.75	1.47
06/27/86	07/09/86	VIMS-Pier	2.18	1.16		0.89	13.3	6.05
07/23/86	08/04/86	VIMS-Pier	3.63	1.13		0.64	10.3	1.23
09/18/86	09/20/86	VIMS-Pier	3.15	0.84		1.96	6.01	11.8
11/11/86	11/19/86	VIMS-Pier	2.24	0.94		9.29	4.16	38.7
02/03/87	02/08/87	VIMS-Pier	1.06	2.15		0.31	10.3	3.2
03/09/87	03/19/87	VIMS-Pier	0.84	2.31		0.057	21.1	1.12
05/29/87	06/04/87	VIMS-Pier	2.00	0.45		1.85	7.02	13
07/23/87	7/30/87	VIMS-Pier	4.30	0.84		0.68	9.9	6.8
10/1/87	10/08/87	VIMS-Pier	2.34	0.74		3.72	5.86	21.8
1/20/88	01/29/88	VIMS-Pier	0.86	5.77		0.16	4.45	0.71
03/18/88	03/25/88	VIMS-Pier	1.21	1.08		0.18	21.8	3.97
07/11/88	07/12/88	VIMS-Pier	3.19	6.48		0.84	9.64	10.7
03/05/92	03/13/92	TF3.2	0.94	1.24	1.03	5.91	8.53	50.4
04/08/92	04/14/92	TF3.2	1.02	1.52	1.05	3.52	11.47	40.4
05/07/92	05/12/92	TF3.2	1.24	1.37	0.95	2.44	23.47	57.2
06/02/92	06/06/92	TF3.2	1.2	1.52	1.04	4.94	10.93	54
06/30/92	07/03/92	TF3.2	1.1	1.64	1.06	2.44	23.2	56.6
08/12/92	08/16/92	TF3.2	0.97	1.06	0.92	2.54	40	101.6
09/10/92	09/15/92	TF3.2	1.31	0.86	0.91	3.28	19.87	65.2
10/14/92	10/20/92	TF3.2	1.45	1.73	1.2	6.22	10.61	66
11/12/92	11/16/92	TF3.2	1.09	1.03	0.92	2.89	5.15	14.88
01/20/93	01/26/93	TF3.2	0.92	1.13	0.49	2.95	2.51	7.4
02/09/93	02/13/93	TF3.2	0.93	1.04	0.6	2.41	5.01	12.08
03/04/92	03/12/92	TF5.5	1.09	1.14	0.89	12.27	5.87	72
04/08/92	04/14/92	TF5.5	1.09	1.19	0.97	5.53	15.2	84
05/06/92	05/10/92	TF5.5	1.06	1.04	0.93	2.93	37.6	110
06/02/92	06/06/92	TF5.5	1.01	1.08	1.04	5.58	17.2	96
06/30/92	07/02/92	TF5.5	1.08	1.17	1.11	1.59	84.27	134.4

Appendix, Table 1, Continued

Date Start	Date Index	Station	INDEX				CHL Start ug/l	CHL at Index, ug/l
			N	P	Si	LIGHT		
08/07/92	08/09/92	TF5.5	1.19	1	1.04	1.49	100.53	150
09/15/92	09/18/92	TF5.5	1	1.02	0.98	1.98	78.93	156
10/10/92	10/14/92	LE5.5	1.99	0.89		7.74	7.52	58.2
11/12/92	11/16/92	TF5.5	1.18	1.01	0.97	2.15	49.87	107.2
02/17/92	02/23/92	LE3.6	1.06	1.13	1.11	1.07	4.83	5.16
03/12/92	03/18/92	LE3.6	1.7	1.35	1.01	0.54	5.97	3.2
04/15/92	04/19/92	LE3.6	1.28	2.51	1.2	0.83	8.8	7.32
05/13/92	05/15/92	LE3.6	1.23	2.64	1.13	1.07	9.87	10.6
06/11/92	06/13/92	LE3.6	1	0.79	1.04	0.83	10.27	8.5
07/09/92	07/10/92	LE3.6	2.35	1		0.73	11.01	8
08/11/92	08/14/92	LE3.6	1.76	0.86		0.91	14.08	12.8
09/09/92	09/12/92	LE3.6	1.52	0.88		0.67	16.35	10.88
10/09/92	10/11/92	LE3.6	1.74	0.97		0.69	21.12	14.6
11/17/92	11/23/92	LE3.6	5.43	1.21		1.63	6.77	11.04
01/08/93	01/14/93	LE3.6	1.11	1.48	0.92	1.62	20	32.4
02/14/92	02/19/92	LE5.5	2.05	1.11	1.06	0.60	24.53	14.8
03/11/92	03/17/92	LE5.5	3.27	1.16	1.29	0.35	9.87	3.48
04/15/92	04/18/92	LE5.5	2.65	0.83	1.06	0.81	5.65	4.6
05/12/92	05/16/92	LE5.5	2.07	0.82	1.02	1.27	8.8	11.2
06/11/92	06/13/92	LE5.5	2.22	0.84	1.08	0.84	21.33	18
07/07/92	07/09/92	LE5.5	5.81	0.68		0.90	12.85	11.6
08/11/92	08/13/92	LE5.5	2.71	0.89		2.91	12.53	36.4
09/09/92	09/11/92	LE5.5	4.06	0.92		0.62	19.23	12
10/10/92	10/14/92	LE5.5	1.99	0.89		7.74	7.52	58.2
11/19/92	11/24/92	LE5.5	1.5	1.05		1.54	6.51	10
02/17/92	02/23/92	CB6.1	0.84	1.03	1.21	1.38	3.5	4.84
03/12/92	03/18/92	CB6.1	1.04	0.85	0.98	0.70	6.32	4.4
04/15/92	04/20/92	CB6.1	1.01	2.27	0.91	1.17	5.15	6
05/13/92	05/15/92	CB6.1	1.22	2.33	1.04	1.04	8.67	9
06/11/92	06/14/92	CB6.1	1.85	0.89	0.97	0.35	8.4	2.96
07/09/92	07/11/92	CB6.1	2.31	1.03		0.59	8.83	5.24
08/11/92	08/13/92	CB6.1	1.06	1.12		1.14	12.53	14.28
09/09/92	09/11/92	CB6.1	1.63	0.73		0.72	13.2	9.44
10/09/92	10/11/92	CB6.1	2.43	0.92		0.50	24.45	12.2
11/16/92	11/22/92	CB6.1	1.46	0.75		2.07	7.04	14.6
01/09/93	01/14/93	CB6.1	1.55	2.38	1.3	1.46	14.67	21.48
02/11/92	02/19/92	CB6.4	1.75	0.83	0.97	0.83	6.24	5.18
03/11/92	03/17/92	CB6.4	3.14	0.95	1.03	0.48	7.38	3.56
04/15/92	04/18/92	CB6.4	1.62	0.9	1.02	0.84	8.64	7.28

Appendix, Table 1, Continued

Date Start	Date Index	Station	INDEX				CHL Start ug/l	CHL at Index, ug/l
			N	P	Si	LIGHT		
05/12/92	05/14/92	CB6.4	1.17	2	1	0.88	10	8.8
06/11/92	06/13/92	CB6.4	4.2	0.91	1.12	0.42	9.6	4
07/07/92	07/09/92	CB6.4	3.04	1.15		0.46	12.96	6
08/11/92	08/13/92	CB6.4	5.85	2.79		0.80	13.2	10.6
09/09/92	09/11/92	CB6.4	1.61	1.01		1.25	8.93	11.2
10/10/92	10/12/92	CB6.4	1.87	0.67		0.44	26.61	11.65
11/18/92	11/20/92	CB6.4	1.09	0.89		1.30	10.93	14.16
01/09/93	01/14/93	CB6.4	1.2	1.25	1.05	2.00	16.27	32.6
03/08/90	03/15/90	TF	1.2	1.21		5.07	3.63	18.4
05/07/90	05/11/90	TF	0.6	0.7		1.63	22.24	36.3
07/23/90	07/25/90	TF	1.22	1.03		1.66	16.9	28
09/05/90	09/10/90	TF	1.84	1.75		1.29	9.77	12.6
10/25/90	10/29/90	TF	0.76	1.14		4.25	6.41	27.3
12/05/90	12/13/90	TF	1.22	0.95		5.51	5.46	30.1
01/29/91	02/04/91	TF	1.01	1.05		2.23	3.33	7.41
05/28/91	06/04/91	TF	2.42	0.88		0.88	13.7	12
07/02/91	07/06/91	TF	1.27	0.78		1.23	13.9	19.2
08/13/91	08/15/91	TF	0.99	1.17		2.42	12.7	22.7
03/08/90	03/15/90	TM	0.68	1.01		21.54	3.52	75.8
05/07/90	05/11/90	TM	1.14	0.95		6.1	8.75	50.7
07/23/90	07/25/90	TM	1.64	1.03		2.33	14.4	33.6
09/05/90	09/11/90	TM	3.83	1.77		0.41	25.3	10.3
10/25/90	10/29/90	TM	1.58	0.95		1.93	14.3	27.7
12/05/90	12/13/90	TM	1.07	1.04		2.15	10.7	22.9
01/29/91	02/02/91	TM	1.39	0.91		1.37	6.8	9.33
05/28/91	05/31/91	TM	1.42	0.97		2.4	13.2	31.6
07/02/91	07/04/91	TM	2.61	0.96		0.46	28.8	13.3
08/13/91	08/15/91	TM	0.87	1.3		1.28	21.6	27.7
03/08/90	03/14/90	CM	0.9	1.25		12.05	4.1	49.4
05/07/90	05/11/90	CM	0.99	0.75		1.82	16.2	29.6
07/23/90	07/25/90	CM	1.9	1.27		0.47	62.6	29.1
09/05/90	09/09/90	CM	4.34	0.78		0.35	68.7	23.7
10/25/90	10/31/90	CM	1.69	1		3.67	12.2	44.6
12/05/90	12/13/90	CM	1.09	0.93		8.95	7	62.7
01/29/91	02/01/91	CM	1.17	1.11		1.42	8.04	11.4
05/28/91	06/02/91	CM	4.2	1.35		0.73	16.9	12.3
07/02/91	07/05/91	CM	5.07	1.03		0.58	26.6	15.4
08/13/91	08/15/91	CM	0.98	3.45		1.15	29.2	33

Appendix, Table 1, Continued

Date Start	Date Index	Station	INDEX				CHL Start ug/l	CHL at Index, ug/l
			N	P	Si	LIGHT		
03/08/90	03/12/90	VIMS-Pier	0.57	0.93		1.69	8.16	13.76
05/07/90	05/11/90	VIMS-Pier	2	0.83		0.83	7.72	6.4
07/23/90	07/25/90	VIMS-Pier	3.54	1.07		0.57	32.8	18.6
09/05/90	09/07/90	VIMS-Pier	2.93	0.9		1.24	11.7	14.4
10/25/90	10/31/90	VIMS-Pier	2.22	1.08		3.1	8.3	25.8
12/05/90	12/13/90	VIMS-Pier	2.18	1		2.74		
01/29/91	02/01/91	VIMS-Pier	1.27	1.16		0.96	16.6	15.9
05/28/91	05/31/91	VIMS-Pier	4	1.07		0.81	16.8	13.6
07/02/91	07/05/91	VIMS-Pier	1.04	0.92		1.00	20.6	20.6
08/13/91	08/15/91	VIMS-Pier	0.99	2.46		1.39	12.0	16.7