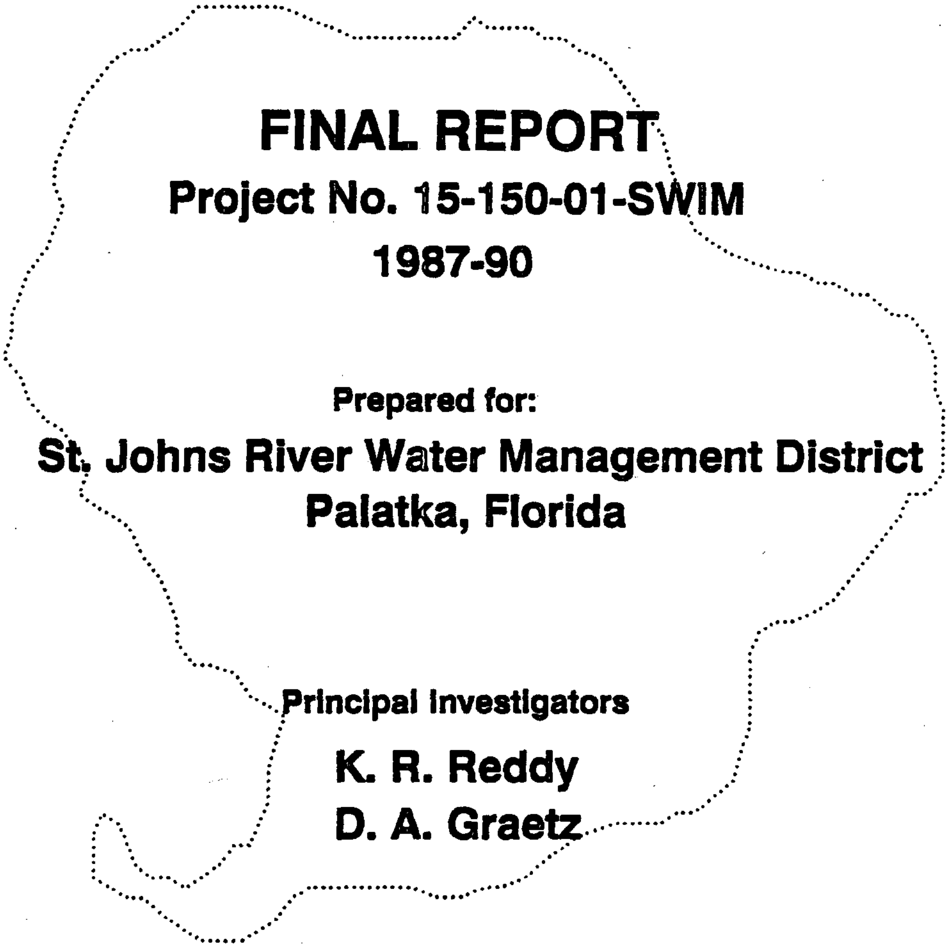
Special Publication SJ 91-SP6

INTERNAL NUTRIENT BUDGET
FOR
LAKE APOPKA



FINAL REPORT
Project No. 15-150-01-SWIM
1987-90

Prepared for:

St. Johns River Water Management District
Palatka, Florida

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Special Publication SJ91-SP6
Internal nutrient budget for Lake Apopka
Errata Sheet

The attached addendum clarifies some issues relating to the referenced report. In addition, pages need to be added or substituted as follows:

- Add Table A2
- Delete Appendix B1
- Add new Appendix B1

Addendum to "Internal Nutrient Budget for Lake Apopka"
K.R. Reddy and D.A. Graetz.
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This addendum is offered in order to clarify some issues regarding the sediment sampling performed by the Wetland Biogeochemistry Laboratory at the University of Florida, for the Lake Apopka Internal Nutrient Budget Project (INB) (Project No. 15-150—01-SWIM). The lake sediments were sampled on two occasions during the course of the INB project, June, 1987 and again in October, 1987. We considered the stratigraphic information from the October sampling to be more accurate than the June sampling; thus this data was presented in the INB Appendix Table B-1, with some exceptions as noted in the accompanying revised Table B-1. We made some small improvements in our sediment sampler between these two sampling efforts which allowed greater recovery of the sampled sediment. For accurate, quantitative analysis of sediment thickness, the October, 1987 sampling data should be used. The mean depth alluded to in **SJ 91-SP6**, Appendix Table B1 and in Figure 3.10 therefore represents the average depth of retrieved material; not the total thickness of the listed sediment type, and thus it should not be used as a quantitative measure of the thickness of any of the listed sediment types. In the case of the consolidated flocculent (CF) sediment, the total thickness of this sediment type was determined in many cases; in others it was either absent or was too deep to measure using our sampling techniques (see Table A2 for details).

Table A2. Lake Apopka INB sampling stations classified according to whether the bottom of the consolidated flocculent (CF) sediment was encountered in the October 1987 sediment sampling, except for station C11 which was classified according to the June 1987 sampling.

CF depth > limits of sampling equipment	CF depth < limits of sampling equipment	CF fraction not encountered	Unclassified
B2, A3, B3, C3, A4, B4, C4, F4, A5, B5, C5, D5, E5, F5,G5, H5, I5, A6, B6, C6, G6,I6, K6, B7, C7, D7, E7, G7, J7, C8, D8, E8, F8, G8, H8, J8, D9, E9, F9, H9, I9, D10, F10, G10, G9. H10, D11, E11, F11, G11, a11, I10, C11, c11, B12, C12, b12,c12, C13, b13.	A2, C2, D2, G2, D3, E3, G3, D4, E4, G4, H4, J5, K5,D6, E6, F6, H6, J6, I8, E10, H7.	C1, E2, F2, H2, F3, H3, I4, F7.	I7.

Any further calculations regarding sediment thickness should be restricted to those sites at which the total thickness of the layer was retrieved by the sampling equipment or those cases were the CF layer was absent (thickness = 0). Thus, the sites listed in column 1 of Table A2 cannot be used to assess the thickness of the CF layer. Also, for quantitative analysis concerning sediment accretion, nutrient storage, etc., analysis should be restricted to appendix table B-1. A copy of this table, which includes some minor revisions, accompanies this addendum.

Table B-1: Water and sediment depth recorded during October, 1987 at selected locations in Lake Apopka. All depths followed by '*' were determined during the June, 1987 sediment sampling. Underlined values were changed or added for October 1997 addendum. Values which are shown as '~~value~~' were found to be erroneous and should be removed from Appendix Table B-1. "Core length" is a summation of all sediment layers encountered during both June and October samplings.

Station		Water	Sediment Depth	1968 UCF	1987 UCF	CF	P	S	C	M	Core Length
1	C	30	305	8	40	0	117			3	160
2	A	45	225	13	42	32	10				84
	B	131	254	13	38	132					254
	C	157	153	13	9	74	20	42			71
	D	176	106	3	35	44		27			62
	E	172	76	3	16	0	2	3	16		37
	F	177	128	15	5*	0	15*				20
	G	139	121	3	8	30	11				49
	H	130	155	0	0	0	23				23
3	A	100	160	64	46	110					156
	B	144	298	8	47	128					175
	C	144	263	5	36	134				2*	172
	D	164	148	13	32	48		37			117
	E	171	124	5	46	44		21			111
	F	163	10	3	0	0					
	G	151	91	5	15	28	11				54
	H	115	73	3	0	0	16				16
4	A	130	442	20	29	120					149
	B	142	359	25	38	116					154
	C	170	324	20	26	135					161
	D	172	130	15	41	47				27	115
	E	167	135	15	43	35				42	120
	F	157	198	23	23	111	23*		3*		160
	G	160	195	25	27	63	10				100
	H	200	80	13	16	10	6				32
	I	170	26	5	14	0			3		17
5	A	117	600	15	50	117					167
	B	124	238	13	45	104				7*	156
	C	160	222	8	43	115				20*	178
	D	165	167	10	33	87				28*	148
	E	167	135	8	26	61				33*	120
	F	165	127	8	33	84				3*	120
	G	170	470	13	31	110				10*	151
	H	156	234	15	18	63			13*		94
	I	154	96	8	30	45			15*		90
	J	138	149	13	36	53	12		5*		106
	K	66	283	8	40	25	24				89

Table B-1(cont'd): Water and sediment depth recorded during October, 1987 at selected locations in Lake Apopka. All depths followed by '*' were determined during the June, 1987 sediment sampling. Underlined values were changed or added for October 1997 addendum. Values which are shown as '~~value~~' were found to be erroneous and should be removed from Appendix Table B-1. "Core length" is a summation of all sediment layers encountered during both June and October samplings.

Station	Water	Sediment Depth	1968 UCF	1987 UCF	CF	P	S	C	M	Core Length
6 A	104	600	3	51*	148	~~23~~				202
B	193	317	5	18*	112					130
C	148	427	3	70	90				15*	175
D	320	190	5	28	36				25	89
E	160	305	8	32	111				11*	154
F	ND	49	5	28	13				8*	49
G	145	205	3	37	60				8*	105
H	152	213	3	23	61		11	13*		112
I	142	145	3	32	72			18*		122
J	220	60	8	20	21		5		10*	56
K	120	252	5	42	84	23*				149
7 B	398	600	5	21	88					101
C	140	600	15	28	114					142
D	170	600	13	27	123	15*	5*		13*	183
E	181	384	8	28	116					144
F	254	13	13	0	0				4*	13
G	157	130	25	25	91			8*		124
H	235	35	1	22	12			8*		30
I	245	40	5	20	0			10*		30
J	144	293	8	46	82	23*				151
8 C	162	600	3	50	85					135
D	174	236	5	76	48				10*	134
E	281	106	5	4	62				8*	74
F	172	180	3	7	112				8*	127
G	230	36	3	12	17				5*	17
H	175	88	5	32	48			8*		88
I	213	114	3	31	37	19	3	~~3~~		90
J	86	222		57	97	10*				164
9 D	263	267	3	20	107					127
E	175	305	8	25	125					150
F	150	300	5	26	108					134
G	143	207	5	25	111				3*	139
H	132	158	10	39	97				8*	154
I	110	336	5	31	88	13*				132

Table B-1(cont'd): Water and sediment depth recorded during October, 1987 at selected locations in Lake Apopka. All depths followed by '*' were determined during the June, 1987 sediment sampling. Underlined values were changed or added for October 1997 addendum. Values which are shown as '~~value~~' were found to be erroneous and should be removed from Appendix Table B-1. "Core length" is a summation of all sediment layers encountered during both June and October samplings.

Station	Water	Sediment Depth	1968 UCF	1987 UCF	CF	P	S	C	M	Core Length
10 D	150	410	5	37	67					104
E	175	600	5	27	50	34				111
F	146	188	8	23	116	20*				159
G	146	600	13	29	130					159
H	106	600	10	37	126					173
I	70	392		48	125		15*			188
11 C	ND	107	5	36*	71*					107
D	125	225	20	21	104	18*				143
E	136	600	15	33	116					149
F	335	104	5	30*	74					104
G	402	600		44	41					85
a	171	600	15	107	36					143
c	159	600	20	23	127					150
12 B	152	600	30	108	47					155
C	180	600	18	24	114					138
b	96	600	15	65	80					160
c	131	600	18	31	124					155
13 C	155	600	15	41	51*					92
b	127	299	30	79	71	5*				155
Mean	164	276	10	33	72	20	17	10	13	117
Std. Dev.	61	191	9	19	43	22	14	5	11	49
n	88	90	87	90	90	24	10	12	24	89
C.V.(%)	37	69	87	59	59	110	85	50	82	42
Max.	402	600	64	108	148	117	42	18	42	254
Min.	30	10	0	0	0	2	3	3	2	13

PROJECT PARTICIPANTS

The principal investigators want to express their appreciation to the following individuals who worked on various tasks presented in this report. Their inspiration, enthusiasm and hard work made this project successful. Financial support for this project was in part provided by the St. Johns River Water Management District, Palatka, Florida, under Project. No. 15-150-01-43-213-SWIM.

Task 1.1.	Physico-Chemical Properties of Lake Apopka Sediments (includes Task 1.2)	M. M. Fisher D. Ivanoff
Task 1.3	Sedimentation Rates as Determined by ^{210}Pb	M. Brenner T. Crissman H. Gottgens
Task 2.	Dissolved Nutrient Fluxes from Sediment to the Overlying Water Column of Lake Apopka	P. A. Moore
Task 3.1.	Organic Matter Decomposition and Nutrient Release as Influenced by Oxygen Supply	P. A. Moore
Task 3.2.	Kinetics of Sediment Organic Matter Decomposition Under Anoxic Conditions	P. M. Gale
Task 3.3.	Diffusion of Organic Acids in the Sediment-Water Column	P. M. Gale K. Van Rees
Task 3.4.	Adsorption/Desorption of Organic Acids in Sediments	P. M. Gale
Task 3.5.	Mineralization of Organic Nitrogen as Influenced by Oxygen Concentration	P. A. Moore
Task 3.6.	Kinetics of Organic Nitrogen Mineralization Under Anoxic Conditions	P. M. Gale
Task 3.7.	Diffusion of Ammonium N in the Sediment-Water Column	D. Ivanoff K. Van Rees
Task 3.8.	Ammonium Adsorption by Sediments	D. Ivanoff
Task 3.9.	Kinetics of Nitrification and Denitrification in the Sediment-Water Column	E. D'Angelo
Task 3.10.	Phosphorus Sorption by Lake Sediment	O. Olila D. Ivanoff
Task 3.11.	Diffusion of Soluble Phosphorus in Sediment-Water Column	D. Ivanoff K. Van Rees
Task 4.1.	Photosynthetic Fixation Rates of Carbon in Lake Apopka	P. M. Gale

Task 4.2.	Nitrogen Fixation in Lake Apopka Water	P. M. Gale
Task 5.1.	Laboratory Microcosm Study to Determine the Sediment Resuspension Effects on Water Quality	M. M. Fisher
Task 5.2.	Sediment Resuspension Effects on Water Quality: In-Situ Studies	D. Ivanoff M. M. Fisher P. A. Moore SJWMD Staff
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EXECUTIVE SUMMARY

Lake Apopka, with a surface area of 12,500 ha (31,000 acres), is located in Central Florida, approximately 25 km (15 miles) northwest of Orlando. The average depth of the lake is about 2 m. Currently, it is highly eutrophic with high concentrations of algal biomass (chlorophyll-a concentrations often exceeds 100 mg m^{-3}). Water quality in the lake is impacted by both external and internal sources. Historical and current external sources of pollution include: discharge of excess drainage water from adjacent vegetable farms, surface and subsurface runoff from adjacent citrus groves, sewage effluent discharge from Winter Garden (this discharge has been stopped for some time), and biological nitrogen and carbon fixation.

The water quality in Lake Apopka can have a significant impact on downstream lakes in the Oklawaha River Basin, since lake water eventually flows into some of these lakes. In recognition of the problems and potential values of Lake Apopka, the Florida Legislature, in 1985, approved funds to study feasible means of restoring the lake. Part of this approval was to design a study for better understanding of the external and internal nutrient inputs to the lake, which would result in the development of a nutrient budget for the lake.

The bottom sediments in Lake Apopka are highly organic and rich in nutrients. Because of shallow water depth and the flocculent nature of these sediments, resuspension of the sediment occurs during periods of heavy winds. The release of nutrients from these sediments can cause nutrient concentrations in the water column to remain high despite reduction of external nutrient loading. The nutrients can be readily utilized by algae and other aquatic biota, thus maintaining hypereutrophic conditions in the lake.

For Lake Apopka, the pollutants of most immediate concern are phosphorus (P), nitrogen (N), and carbon (C). Phosphorus and N are essential nutrients which often limit the rate of algal primary production, the source of flocculent lake sediments. Although C, which is continually supplied through photosynthesis and removed through microbial respiration, is a major component of the flocculent organic sediment, it is not as important in eutrophication as N and P. Nevertheless, the rate of accumulation of flocculent sediments is determined by the balance between C fixation via algal photosynthesis and C mineralization through microbial respiration. Information on the C budget, then, could indicate the level of reduction of algal productivity required to cause the lake to become a net exporter of C. Quantification of these internal sources and sinks is essential for accurate prediction of the response of Lake Apopka to pollution abatement and for informed appraisal of restoration alternatives.

In recent years, it has become clear that nutrient processing by the aquatic biota and sediments of lakes can be a major factor in the determination of trophic status of the lake. To evaluate the role of C, N, and P transformations in the sediment-water column and its impact on water quality, it is critical to develop a basic understanding of these processes.

The major objectives of the research presented in this report were to:

- characterize Lake Apopka sediments for labile and non-labile forms of nutrients,
- determine the flux of dissolved C, N, and P between sediments and the overlying water column,
- establish the relative importance of biogeochemical transformations of sedimentary forms of C, N, and P,
- determine C and N fixation in the water column,
- determine the effects of sediment mixing and resuspension on C, N, and P release into the water column.

The first objective of this study was to characterize labile and non-labile forms of nutrients in Lake Apopka sediments:

- The sediment profile is characterized by five different layers, based on their physical consistency. These are: unconsolidated floc (UCF), consolidated floc (CF), peat (P), sand (S), clay (C), and marl (M). The UCF layer is the surface layer, with an underlying CF layer. About 95% of the sediment surface is covered with a UCF layer. During the past 20 years, the thickness of this layer has increased at a rate of 1.15 cm yr^{-1}.
- Labile (dissolved) forms of nutrients in the sediment porewater account for 0.7% of C, 3.9% of N, and 6.9% of P in the sediments.
- Historical sedimentation rates based on ^{210}Pb-dating techniques were estimated to be 0.03 g cm^{-2} yr^{-1}. This yields accumulation rates for C, N, and P of 91, 7.1, and 2.9 g m^{-2} yr^{-1}, respectively. These values are on the same order of magnitude as those estimated by increases in the thickness of surface sediments over the past 20 years.

The second objective of this study was to determine the flux of dissolved C, N, and P between sediments and the overlying water column:

- Nitrogen flux from the sediment to the overlying water column was in the range 28-40 mg N m^{-2} d^{-1}. Phosphorus flux was in the range 1.7-2.7 mg P m^{-2} d^{-1}. Concentration profiles of ammonium N and soluble P varied spatially, but not temporally, suggesting that the lake is at steady state. Flux of C, N, and P is governed in the UCF sediments by resuspension and in the CF sediments by diffusion and mass flow.

The third objective of this study was to establish the relative importance of biogeochemical transformations of sedimentary forms of C, N, and P.

- One of the transformations of C is decomposition of organic matter. Organic matter decomposition was rapid in sediments exposed to oxygen, with about 25% of the initial C lost in one year. Under anaerobic conditions, about 6% of the initial C was lost from UCF sediments; less than 1% was lost from CF and peat sediments. The decomposition in CF and peat sediments was inhibited by an inadequate supply of electron acceptors.

- A second transformation of C is adsorption and diffusion of organic acids. Soluble organic C concentrations in the water column and in the sediment porewater were approximately the same. Therefore there is no net transport of C from the sediment to the water. The diffusion coefficients for acetic and butyric acids, intermediate products of anaerobic decomposition, were 0.46 and 0.71 cm^{-2} d^{-1}. Acetic acid is more strongly adsorbed in sediment than is butyric acid.

- One of the transformations of N is mineralization of organic N to ammonium. Organic N mineralization in sediments exposed to oxygen was rapid (0.6 mg N L^{-1} d^{-1}). Under anaerobic conditions, N mineralization rates were in the range 0.26-0.37 mg N L^{-1} d^{-1}.

- A second transformation of N is adsorption and diffusion of ammonium N. Ammonium adsorption on sediment was stronger under aerobic conditions than anaerobic conditions. Ammonium adsorption capacity was higher in the surface sediments and decreased with depth. The diffusion coefficients for ammonium moving in the sediment profile were in the range 0.6-1.47 cm^{-2} d^{-1}.

- A third transformation of N is nitrification (oxidation of ammonium N to nitrate N) in sediment resuspended into the oxygenated water column. Soluble ammonium in anaerobic sediments exposed to oxygen was rapidly nitrified at a rate of 1.95 mg N L^{-1} d^{-1}.

- A fourth transformation of N is nitrate reduction. This process can be either assimilatory producing biomass, or dissimilatory with NH_4 or N_2 being formed. Nitrate reduction rates were rapid, with denitrification (nitrate reduction to nitrous oxide and N gas) as the dominant process. Denitrification rates were in the range 1.2-2.6 mg N L^{-1} d^{-1}.

- The combined processes of nitrification and denitrification in the sediment-water column are very important in this system. Nitrification-denitrification processes were rapid in the sediment-water column, with removal rates measured up to 50 mg N m^{-2} d^{-1}.

- One of the transformations of P is adsorption/desorption of phosphate and diffusion of P in sediments. Soluble P decreased when anaerobic sediments were exposed to oxygen but remained constant when sediments were kept under anaerobic conditions. High equilibrium P concentrations in the sediment porewater suggest that P transport is from the sediment to the water column. In the short term, P retention in the sediment is due to adsorption, while over the long term, precipitation of calcium phosphates from the water column controls the porewater concentration of P.

The fourth objective of this study was to determine C and N fixation in the water column.

- Carbon and N fixation in the water column is a function of light penetration and is independent of N and P concentrations in the water. This implies that N and P are not limiting the productivity of Lake Apopka. The C fixation rate was 1.9 mg C L^{-1} d^{-1} assuming a 12-h photoperiod. On an areal basis, the C fixation rate is 1400 g C m^{-2} yr^{-1}. The N fixation rate was 0.16 g m^{-2} yr^{-1}, suggesting that biological N fixation may not be a significant contributor to the total N budget for Lake Apopka.

The fifth objective of this study was to determine the effects of sediment mixing and resuspension on C, N, and P release into the water column.

- Ammonium N release during simulated sediment resuspension of the surface 10 cm was in the range 0.4-0.5 mg cm^{-2} h^{-1}. No significant release in P occurred during this sediment resuspension. Profiles of soluble P concentration in sediments suggest that sediment resuspension involves the surface 8 cm.

The results in this report provide information on the relative rates of several biogeochemical processes related to C, N, and P cycling in Lake Apopka. It is apparent from these results that Lake Apopka is very productive and dynamic in cycling nutrients. The nutrient enrichment in the water column is enhanced by sediments functioning as a steady source of soluble ammonium and P. The sediments are functioning as sinks for nitrate N and for the particulate matter deposited on the sediment surface. To quantitatively evaluate the role of sediments in the overall internal nutrient budget of the lake, it is critical that two physical processes, i.e. sediment resuspension during hydrodynamic events, and steady diffusive flux, be further evaluated.

It should be noted that the rate coefficients reported for various processes were measured under laboratory conditions. The relative rates may be different under field conditions where several environmental factors influence these processes. Future research should be focused on the biogeochemical processes functioning (1) at the sediment-water interface, especially on a micro-scale level in the surface 10 cm depth, and (2) in the water column during sedimentation of particulate dead algal cells. Since the processes functioning are dynamic in nature, they should be evaluated *in situ* on short-term intervals. The information provided in this report should be used in context with the external nutrient inputs when developing management strategies to restore Lake Apopka.

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Chapter 1

TECHNICAL SUMMARY

1.0 TECHNICAL SUMMARY

1.1 Report Format

This report is divided into seven chapters. Two are introductory and the following five deal with each of the five research objectives listed above. Chapter 1 provides the summary and conclusions of the 3-yr research effort to develop an internal nutrient budget for Lake Apopka. Chapter 2 describes the problem, background information on Lake Apopka, and the significance of C, N, and P cycles in evaluating the internal nutrient budget for the lake. Chapter 3 characterizes Lake Apopka sediments for labile and non-labile sources of nutrients, and provides data on C, N, and P storage in sediments. Chapter 4 provides data on the flux of dissolved C, N, and P between sediments and the overlying water column and the relationship between the sediment porewater chemistry and the overlying water quality.

Chapter 5 establishes the relative importance of biogeochemical transformations of sedimentary forms of C, N, and P. Transformations of C evaluated include: decomposition of sediment organic matter as influenced by O_2 supply, temperature, and sediment type; adsorption and diffusion of organic acids. Transformations of N evaluated include: mineralization of organic N as influenced by O_2 supply, temperature and sediment type; adsorption and diffusion of ammonium N; nitrification (oxidation of ammonium N to nitrate N) in the sediment resuspended into the oxygenated water column; nitrate reduction to ammonia and denitrification of nitrate to gaseous end products such as nitrous oxide and N_2 gas; and nitrification-denitrification in the sediment-water column. Transformations of P evaluated include: phosphate adsorption/desorption and diffusion of P in sediments.

Chapter 6 provides data determining C and N fixation in the water column of Lake Apopka. Data on historical sedimentation rates using ^{210}Pb-dating technique are also provided. Chapter 7 evaluates the effects of sediment mixing and resuspension on C, N, and P release in the water column.

1.2 Physico-chemical Properties of Sediments

To understand the role of sediment as a source or sink for nutrients in the overlying water column, it is important to first characterize the sediment for the total nutrient storage in different layers of the sediments and identify the labile and non-labile fractions of nutrients. The objectives of this study were to determine: (1) the total storage of C, N, and P in the sediments, (2) spatial variability of labile and non-labile fractions of selected nutrients in porewater and solid phase, and (3) distribution of nutrients in various horizons (layers) of the sediments.

Sediment samples were obtained from 90 stations established in a grid pattern to provide complete coverage of the lake. The sampling stations were similar to those utilized in 1968 by Schneider and Little (1969) to allow comparison of the sediment characterization conducted 18 years ago. Sediment cores were taken to approximately a meter depth at each station and separated into five horizons. These include: unconsolidated floc (UCF), consolidated floc (CF), peat (P), sand (S), clay (C), and marl (M). Average depth of the surficial UCF layer was 32 cm. The UCF horizon is active in releasing nutrients into the overlying water. The UCF fraction of the sediment is equivalent to the floc-like material measured by Schneider and Little in 1968. Between 1968 and 1987, the UCF fraction increased in thickness by 22 cm or 1.15 cm yr^{-1}. Based on average dry bulk density of 0.035 g cm^{-3} for UCF sediments, the mass of sediment accumulation was 0.04 g cm^{-2} yr^{-1}.

Porewater nutrient concentrations were generally lower in the UCF sediments than in the underlying CF sediments. The total P concentration in the porewater was in the range of 0.17-8.62 mg L^{-1} in the UCF and 0.03-19.1 mg L^{-1} in the CF fractions, respectively. Ammonium N levels were in the range of 3-110 mg L^{-1} in UCF and 5-178 mg L^{-1} in CF porewater. Ammonium N represented about 70% of total porewater N. Total organic C concentration of the UCF and CF porewater was in the range of 13-123 and 16-190 mg L^{-1}, respectively. Total inorganic C concentrations were 1.5-129 and 0.1-231 mg L^{-1}, for UCF and CF porewater, respectively.

The UCF fraction contained 1.413 million metric tons of dry sediment, while the CF fraction contained 8.794 million metric tons. Total C, N, and P contents of UCF sediment were 426,690, 33,674 and 1,371 metric tons, which corresponded to 34.1 metric tons C ha^{-1}, 2.7 metric tons N ha^{-1}, and 0.11 metric tons P ha^{-1}, respectively. The porewater contained 0.67% of the total C, 3.93% of the total N, and 6.14% of the total P. Mass C:N:P ratio in the UCF fraction was 310:24:1, while in the CF fraction these ratios were 542:37:1. These results suggest that biological C dioxide and dinitrogen fixation by algae in the water column and subsequent deposition in the sediment have caused these wide C/P and N/P ratios. The average C, N, and P content of the UCF sediments was 302, 23.7, and 9.7 mg g^{-1}, respectively. Using these values the calculated nutrient accumulation rates in the sediments were 121, 9.5, and 3.9 g m^{-2} yr^{-1}, respectively, for C, N, and P.

1.3 Nutrient Flux From Sediment to the Overlying Water Column

Lake sediments can act as either a sink or a source for C, N, and P. A series of N transformations functioning in the sediment and in the overlying water regulate the water quality of the lake. Decomposition of organic matter results in the release of ammonium (ammonification) which moves into the overlying water. Under favorable conditions, such as that found in oxic, hardwater lakes, the ammonium is oxidized to nitrate via nitrification. The nitrate can then diffuse back into the sediment and be denitrified to dinitrogen or nitrous oxide. Most studies have shown that little or no denitrification occurs in oxidized floodwaters and the rate of nitrate disappearance via denitrification will be dependent on the diffusive flux into anaerobic sediments. Phosphorus transformations include adsorption/desorption of inorganic P, and microbial breakdown of organic P. The transport of dissolved C, N, and P is primarily due to: (1) diffusion and mass flow as a result of concentration gradients across the sediment-water interface, and (2) release of dissolved nutrients during sediment resuspension in the water column during short-term wind events. The objectives of this study were: (1) to determine the mechanisms governing the mobility of dissolved C, N, and P, (2) to assess the impact of algae on lake water chemistry, (3) to determine the interchange of nutrients from the sediment to the overlying water column, and (4) to elucidate the biogeochemistry of P in the sediment-water column for Lake Apopka.

Laboratory studies were conducted using intact sediment-water columns obtained from Lake Apopka and incubated for a period of one year at constant temperature. Results showed that ammonium concentrations in the water column peaked after the first few months at around 5 mg N L^{-1} as a result of diffusion from the underlying sediments. Decreases in ammonium N were coupled with nitrate production, indicating nitrification was the removal mechanism. Nitrate levels were lower due to algal assimilation when the water column surface was exposed to light conditions as compared to dark conditions. These results suggest diel variations in photoperiod can have a significant effect on N concentration in the water column. Sediment porewater ammonium N increased with increasing depth and appeared to be at steady state. Ammonium flux from the sediment to the overlying water column was 30 mg N m^{-2} d^{-1}. A flux of this magnitude could enrich lake water by 5.5 mg N L^{-1} annually.

Soluble organic C concentrations in the water column were approximately the same as those in the sediment porewater, indicating that diffusive flux of soluble organic C from the sediments may not be important in Lake Apopka.

Levels of soluble reactive P in Lake Apopka water were apparently governed by algal uptake under light conditions, while soluble reactive P levels in the water exposed to dark conditions increased several-fold. The P flux from the underlying sediments as inferred from the increase in concentration of the overlying water were in the range of 1.69 to 2.71 mg P m^{-2} d^{-1}. Flux values of this magnitude could increase the lake water soluble reactive P level by 0.5 mg P L^{-1} annually.

Concentrations of porewater P, exchangeable P, and non-apatite P each decreased with depth in the sediments. While the amount of apatite P concurrently increased. Apatite P was the dominant fraction, comprising over 50% of the total P content. Ion activity products calculated using GEOCHEM suggested that the sediments were supersaturated with respect to apatite, beta tricalcium phosphate and whitlockite, with the latter expected to be the phase controlling porewater phosphate activities.

1.4 Carbon Transformations in Sediments

Decomposition of organic matter in aquatic sediments is governed by the nature of the organic matter (energy source for microorganisms) and the supply of electron acceptors. These two components are essential for microbial respiration, thus for decomposition of organic matter. The electron acceptors microbes utilize in the order of preference are oxygen, nitrate, manganic manganese, ferric iron, sulfate and C dioxide. In Lake Apopka, iron and manganese are present in limited quantities and are not as important as other electron acceptors. Under most conditions, sediment organic matter decomposition is limited by the electron acceptor supply. In shallow lakes, aerobic decomposition occurs in the water column and at the sediment-water interface, while anaerobic decomposition occurs within sediments. As a result of wave action from wind events, the flocculent surface sediments can be easily resuspended, thus depleting oxygen in the water column. Under these conditions decomposition of organic matter is affected by the dissolved oxygen concentrations in the water column and biological oxygen demand of the suspended sediment.

A series of experiments were conducted to determine: (1) the influence of oxygen supply on organic matter decomposition, (2) the effect of temperature and sediment type on anaerobic decomposition of organic matter, (3) the adsorption of organic acids (indicator of soluble organic C) in sediments, and (4) the diffusion coefficients of selected organic acids in sediments.

Sediments incubated under varying oxygen levels strongly affected the redox status, with 2.0 and 20.0% oxygen treatments resulting in oxidizing (aerobic) conditions, and 0 and 0.2% oxygen treatments causing reducing (anaerobic) conditions. Oxygen levels also affected pH and alkalinity, with lower values for both noted in the oxidized treatments. Carbon dioxide evolution was very dependent on oxygen treatment, with first order rate constants of 0.000010, 0.00027, 0.00062, and 0.00068 d^{-1}, for the 0, 0.2, 2.0, and 20.0% oxygen treatments, respectively. These rate constants indicate that organic matter decomposition is about 6-fold greater under aerobic conditions than anaerobic conditions. Even at low levels of oxygen (0.2%), the decomposition rate increased 3-fold over strictly anaerobic conditions. However, production of soluble organic C was greater under anaerobic conditions. These results suggest that when sediment is resuspended into the water column, aerobic decomposition can be rapid even under conditions of low oxygen levels, thus impacting water quality.

The decomposition rates for Lake Apopka sediments under anoxic conditions are very slow. Of the sediment types studied, anaerobic decomposition of the UCF (unconsolidated floc) sediment resulted in approximately 10% of the C being evolved as gaseous end products during the 534 day incubation. The percent decomposition for the CF and peat sediments was 10-fold lower, having values of 1.5 and <1%, respectively. The slow decomposition rate in CF sediments is probably due to the nature of organic substrate and limited supply of electron acceptors, and inhibitory effects of sulfate reducers. Temperature (15-35°C) had little effect on the rate of organic matter decomposition. Volatile fatty acids (acetic, butyric and propionic), intermediates of anaerobic decomposition, were highest in the UCF sediments and decreased during the decomposition period.

It is recognized that the decomposition rate constants determined in this study are most likely lower than those occurring naturally within the lake. This is especially true in regards to the UCF sediment which is most likely in contact with enough oxygen to undergo limited aerobic decomposition. Under field conditions, a steady supply of electron acceptors (such as nitrate and sulfate from external and internal sources) can also enhance the decomposition rate in the sediments.

The mobility of soluble organic C is governed by the capacity of sediments to adsorb soluble organic compounds, and rate of diffusion of these compounds in the sediment profile. The adsorption of organic acids by Lake Apopka sediments is a function of the acidic properties of these compounds. Adsorption of acetic acid by these sediments was responsible for removal of approximately 35% of the acid from the sediment porewater. A wide range (10-80%) of adsorption percentages was found for butyric acid. For this acid, the percent of the added acid adsorbed was highest at the lowest solution concentrations. The adsorption coefficients (K) (the ratio between porewater organic acid concentrations and the amount of acid adsorbed on solid phase), were 16.4 and 14.1 L kg^{-1} for acetic and butyric acids, respectively.

Diffusion of acetic acid was slower than butyric acid as indicated by their respective diffusion coefficients. The estimated diffusion coefficients for acetic and butyric acids were 0.46 and 0.71 cm^2 d^{-1}, respectively. The slow rate of diffusion of acetic acid is due its stronger affinity for adsorption on solid phases of the sediment.

1.5 Nitrogen Transformations in Sediments

In lake sediments, N occurs in inorganic and organic forms with the latter predominating. More than 90% of the total N in sediments is in the organic form. Thus, the N transformations regulating the breakdown of organic N forms are critical in supplying the N to phytoplankton and other aquatic biota.

Anaerobic sediments are characterized by the accumulation of ammonium N, an end product of organic N mineralization. Mineralization of organic N under anaerobic environments is governed by the type and chemical composition of organic matter and the availability of electron acceptors. Ammonium N formed is present in (1) water soluble form, primarily in porewater, and (2) exchangeable fraction, ammonium adsorbed on cation exchange complex.

The ability of anaerobic sediments to retain ammonium depends on physico-chemical characteristics of the sediments and associated N transformations. It has been shown that ammonium N added at concentrations considerably greater than those present in the sediment porewater can be retained on the cation exchange complex of the sediment. Ammonium present in the adsorbed phase is in reversible equilibrium with the ammonium present in the porewater. The cation exchange complex of calcareous sediments such as in Lake Apopka is generally dominated by calcium and magnesium. Under these conditions, ammonium may not be the major cation occupying the exchange complex. Since the movement of ammonium is controlled by the adsorption and desorption processes, it is critical to describe the adsorption coefficients in order to determine the transport of ammonium in the sediment-water column.

Nitrification is defined as the biological conversion of reduced N forms (ammonium N) to more oxidized states (nitrate N). The nitrifying bacteria are confined largely to aerobic chemoautotrophs of the genera *Nitrosomonas* (ammonium → nitrite) and *Nitrobacter* (nitrite → nitrate). Nitrification provides the substrate (nitrate) for denitrification, a major N removal mechanism in lake systems. In Lake Apopka, nitrification can occur in the water column, and in the surface oxidized sediments.

Denitrification (a nitrate reduction mechanism) is a respiratory process in which facultative anaerobic bacteria use nitrate (or nitrite), in the absence of oxygen, as the terminal electron acceptor during the oxidation of organic C, resulting in the production of gaseous end products such as nitrous oxide and N gas. A competing mechanism called dissimilatory nitrate reduction to ammonia (DNRA) is also a respiratory process used by facultative and obligate anaerobic bacteria which also use nitrate as the terminal electron acceptor. Both processes are beneficial to organisms living in anaerobic, electron-rich environments such as lake sediment, since N oxide compounds act as electron sinks, which coupled to electron transport phosphorylation, produces energy for the organisms. A third mechanism, called assimilatory nitrate reduction, conserves N within the lake ecosystem, since the organisms responsible utilize N in protein synthesis and other catabolic processes.

A series of experiments was conducted to determine: (1) mineralization rate of organic N under aerobic and anaerobic conditions, (2) adsorption-desorption of ammonium in bulk sediments, (3) diffusion coefficients of ammonium, (4) nitrification rates of ammonium in oxidized (aerobic) sediments, and (5) nitrate reduction in anaerobic sediments.

Ammonium concentrations decreased rapidly when anaerobic sediments were exposed to varying levels of oxygen, with concurrent increases in nitrate, indicating rapid nitrification. The ratio of organic N mineralized to C dioxide evolved was higher at low oxygen levels, while the amount of N mineralized versus the sum of C metabolites (carbon dioxide + methane + soluble organic carbon) was relatively constant under all oxygen levels. Organic N mineralization rate in UCF sediments under anaerobic conditions was in the range of 0.26-0.37 mg N L^{-1} d^{-1}, in the temperature range of 15-35°C. Mineralization in the CF fraction involves more potential loss pathways and as such will contribute less to the nutrient load to the water. The peat sediments were resistent to decomposition, thus their contributions to nutrient loads will be minimal.

The ability of sediments to adsorb ammonium as determined by their adsorption coefficient (ammonium in exchangeable fraction/porewater ammonium) was stronger under aerobic than anaerobic (reduced) conditions. The average adsorption coefficient (K) for Lake Apopka sediments was 7 L kg^{-1}. The higher the adsorption coefficient value, the stronger the ammonium adsorption. More than 90% of soluble ammonium was easily desorbable. The ability of sediments to adsorb ammonium was stronger in surface sediments and decreased with depth. Between 20 and 60 cm, adsorption coefficient values were found to be constant.

Estimated diffusion coefficients (D_s) for ammonium N were in the range 0.6-1.47 cm^2 d^{-1}, showing considerable variability. The D_s values were adjusted for the effects of adsorption of ammonium by using K_d (adsorption coefficients) determined in independent experiments for the same sediments. The diffusion coefficients (D_w) of ammonium in the overlying water column of sediments were 1.22-1.25 cm^2 d^{-1}. The D_s is an important parameter needed in diagenetic models to predict the ammonium concentration profiles and to quantitatively describe the internal cycling of ammonium in the sediment-water column.

Soluble ammonium in anaerobic sediments when exposed to oxygen was rapidly nitrified at a rate of 1.95 mg N L^{-1} d^{-1}. The nitrification rates in the Lake Apopka system are limited by ammonium concentrations in the water column and at the sediment-water interface. Future studies should focus on nitrification rates in the water column when sediment is resuspended into the water column during hydrodynamic events. High rates of nitrification associated with high ammonium concentrations can result in increased oxygen demand in the water column.

Ammonium and nitrate removal from floodwater was found to be rapid and the removal rate was equal to the loading rate (50 mg N m^{-2} d^{-1}). About 86 and 90% of floodwater ammonium and nitrate, respectively, were lost from the systems as a result of associated N transformations, while the remaining 10-14%, respectively, were incorporated into the sediment. Ammonium added to anaerobic sediments was found to be stable and up to 20% of added ammonium (labelled N-15) was incorporated into microbial biomass in peat sediments, compared with only 5% in UCF sediments. In Lake Apopka, ammonium N in the anaerobic sediments can only be lost through diffusion to the sediment-water interface and through desorption into the water column from the resuspended sediment. Ammonium released is rapidly transformed into nitrate in this oxidized environment. The nitrate subsequently diffuses back into the sediments and is used as an electron acceptor during anaerobic respiration.

Changes in chemical, physical, and biological characteristics occurring with sediment depth significantly affected the partitioning of nitrate between the three reductive processes. Increased nitrate assimilation into the organic fraction was associated with low C/N ratios (less than 10) at the sediment surface (0-2 cm), accounting for over 21% of the added nitrate ^{15}N. Assimilation played a minor role in nitrate reduction when C/N ratios increased at sediment depths greater than 2 cm. Denitrification was the major nitrate reductive process when sediment C/N ratios were between 10-13 at depths of 0-27 cm, accounting for up to 57% of the added nitrate N. The high rates of denitrification suggest that *in situ* denitrification is restricted to the upper 27 cm of the sediment surface. Dissimilatory nitrate reduction to ammonium at the sediment surface (0-2 cm), accounted for about 13% of the added nitrate. At depths greater than 27 cm when the C/N ratio was between 13-16, dissimilatory reduction of nitrate to ammonium surpassed denitrification as the major reductive process. The denitrification rate was found to be directly affected by the amount of nitrate added to the sediment. The denitrification capacity of the bulk sediment amended with nitrate was 4-5 times the denitrification capacity measured at *in situ* nitrate concentrations. Therefore, it was concluded that the denitrification rate was limited by the amount of nitrate in the lake sediment.

1.6 Phosphorus Transformations in Sediments

The capacity of lake sediments to retain or release P is an important factor in determining the sediment's effect on the overlying water quality. Phosphorus may be released to, or removed from the overlying water. The extent to which P release or removal occurs not only depends on the physical and chemical characteristics of the sediment but also on the environmental characteristics of the lake ecosystems.

In this study, the ability of Lake Apopka sediment to regulate dissolved inorganic P in the overlying water was evaluated by a series of experiments to determine P adsorption coefficients and equilibrium P concentrations (EPC) under a range of conditions likely to be found in Lake Apopka.

Soluble reactive P in the porewater decreased initially when anaerobic sediments were exposed to oxygen, and as the organic matter was decomposed soluble reactive P levels increased. The porewater soluble reactive P levels remained the same when sediments were maintained under anaerobic conditions.

Phosphate adsorption for Lake Apopka sediments was best described by simple linear isotherms. The adsorption coefficient values decreased as a function of incubation time. High P retention at longer incubation periods was probably due to precipitation of calcium phosphates, rather than adsorption. The equilibrium P concentration values under anaerobic conditions were in the range 0.2-9.6 mg P L^{-1}, while the adsorption coefficient values were in the range 21-35 L kg^{-1}. At ambient sediment-solution ratios, the equilibrium P concentration value was 13.8 mg L^{-1} and the adsorption coefficient was 7.03 L kg^{-1}. The phosphate adsorption isotherms obtained at different levels of oxygen did not follow either Freundlich or Langmuir equations, but could be best described by linear relationships. A linear correlation existed between the phosphate removed from solution and the solution P concentration with adsorption coefficient values in the range 5.1-6.7 L kg^{-1}, while equilibrium P concentration values were in the range 2.5-5.3 mg P L^{-1}, for various oxygen levels. High equilibrium P concentration values suggest that the direction of P transport is from the sediment to the water column, since lake water soluble reactive P is usually less than the equilibrium P concentration of the sediments.

1.7 Carbon and N Fixation in the Water Column

The highly productive algal community in Lake Apopka has resulted in the buildup of a sediment consisting of partially decomposed algal cells. Since the sediment consists almost exclusively of algal biomass the growth rate of this community deserves investigation. The phytoplankton community of Lake Apopka is comprised mainly of blue-green algae. The blue-green algae are prokaryotic microorganisms, some of which have the ability to fix atmospheric N. These microorganisms can be an important source of N in ecosystems where they proliferate. Fixation of N involves the uptake of atmospheric dinitrogen and its reduction to ammonia, a form of N which can be used metabolically by microorganisms. In N-limited systems, dinitrogen fixation plays a key role in the cycling of this nutrient.

Since the potential for C and dinitrogen fixation in Lake Apopka is great, a nutrient budget for this lake must include a measure of these important potential C and N input into the system. Field experiments were conducted to measure *in situ* C and dinitrogen fixation rates in Lake Apopka, as influenced by seasonality.

The phytoplankton community of Lake Apopka is very active. Measurement of lake water ammonium N and soluble reactive P concentrations indicate that limitations of primary production by the lack of either of these nutrients is unlikely. In the Lake Apopka system, light penetration of the water column seems to have the greatest effect upon primary production. Average net C fixation was approximately 477 mg C m^{-3} h^{-1} for all sites and sampling times. Extrapolation of this value over a year results in 68.6 x 10^6 kg C being produced annually within the lake. Results of sediment depth measurements have indicated that sediments were accumulating at a rate of approximately 1.1 cm yr^{-1}. This is equivalent to an accumulation rate of 7.5 x 10^6 kg C yr^{-1}. These results imply that 90% of the C fixed by primary producers within this system is decomposed, and does not contribute to sediment accumulation.

The annual average dinitrogen fixation rate found in this study was 18.5 μg N m^{-3} h^{-1}. Extrapolation of this rate over a year results in an annual input of 1.6 kg N ha^{-1} yr^{-1}. This value is on the lower end of the range (0.6 to 54 kg N ha^{-1} yr^{-1}), for other eutrophic lakes. The ability of the phytoplankton community to fix atmospheric dinitrogen suggests that N limitations to growth would be unlikely. The lack of a correlation between nutrient concentrations and dinitrogen fixation rates indicates that these elements are not limiting algal growth and metabolism in this system.

1.8 Sedimentation Rates in Lake Apopka

To obtain an overall nutrient budget, it is critical to determine the rate of C, N, and P deposition on the sediment surface. The increase in unconsolidated sediment depth over the past 20 years was used as an indicator of sedimentation rate. This value was estimated to be 1.15 cm yr^{-1}. It should be noted this is a crude estimate, and further verification of this value is needed. Historical sedimentation rates were determined by dating techniques using ^{210}Pb, a naturally-occurring radioactive isotope. Sedimentation rates using ^{210}PB data were measured at one station in Lake Apopka.

Data from site D-7 suggest that ^{210}Pb dating of sediments from Lake Apopka is feasible despite their flocculent nature. Results demonstrate that during the past 140 years, net sediment accumulation rates in Lake Apopka have increased, whether expressed on a depth or mass basis. Starting 136 years ago with a net sediment accumulation rate of 0.003 g cm^{-2} yr^{-1}, the rate rose continuously to 0.36 g cm^{-2} yr^{-1} in 1942. For the past half century, net sediment accumulation rate has been variable (range = 0.017 - 0.052 g cm^{-2} yr^{-1}), but generally faster than rates recorded in older deposits. The mean bulk sedimentation rate for the past 30 years (1959-1989) was 0.030 g cm^{-2} yr^{-1}, about twice as high as the average recorded for the previous 106 years (1853-1959 = 0.014 g cm^{-2} yr^{-1}). This would result in the accumulation of 90.6, 7.1, and 2.91 g m^{-2} yr^{-1} of C, N, and P, respectively. These estimates are in the same range as those estimated using net sediment depth increase over the last 20 years. When expressed on a depth basis (cm yr^{-1}), sedimentation rates have increased by more than an order of magnitude. This is attributed to the effects of compaction and increasing mass deposition. When mass accumulation alone is considered, it is also clear that there has been an increase in net sedimentation. During the past three decades, the mean sediment accumulation rate was about twice that recorded for the previous century.

1.9 Sediment Resuspension Effects on Nutrient Release

Resuspension of unconsolidated surface sediments in shallow lakes during periods of heavy winds can have a major influence on the quality of the overlying water. Some of the parameters which can have a major influence include turbidity and nutrient release. The conditions can significantly affect light penetration, thus influencing algal productivity. In Lake Apopka, the surface unconsolidated (UCF) sediments are characterized by 97% water and about 3% solids, thus offering a greater potential for rapid resuspension during hydrodynamic events.

Laboratory and field studies were conducted to determine: (1) the rate of ammonium and soluble reactive P release during sediment resuspension under simulated conditions, (2) the potential ammonium and soluble reactive P desorption from solid phase to liquid phase in recently settled suspended sediments, (3) *in situ* measurements of the sediment resuspension effect on water quality, and (4) the spatial and temporal variations in sediment porewater ammonium and soluble P.

The results of laboratory studies clearly document the potential effects of sediment resuspension on ammonium and soluble reactive P release into the water column. Ammonium N release during sediment resuspension was rapid with release rates of 403-508 $\mu g\ cm^{-2}\ h^{-1}$. Ammonium concentrations remained high even after a 24-h settling period of suspended sediment, while soluble reactive P levels dropped to near background levels in the same time period. It should be noted that the release rates were measured under laboratory conditions, and caution should be exercised when extrapolating using these values to field conditions. The hydrodynamic processes functioning in Lake Apopka are complex and the biogeochemical processes associated with N and P release are dynamic and need further investigation to quantitatively evaluate the effects of sediment resuspension on water quality.

Field measurements of water quality showed a significant relationship between total suspended solids and total Kjeldahl N and total P, but no relationship between TSS and soluble reactive P and ammonium. The water quality data presented need further evaluation to determine the relationship with rainfall, wind speed and other related parameters associated with sediment resuspension.

Soluble ammonium and soluble reactive P concentration profiles in the water column showed spatial variability, but showed very little or no temporal variability, indicating steady-state conditions in the lake. The ammonium flux from sediment to the overlying water column was estimated to be 28-40 mg N $m^{-2}\ d^{-1}$, while soluble reactive P flux were 0.8-2.7 mg P $m^{-2}\ d^{-1}$. Soluble P concentrations in the surface 8 cm sediment layer was approximately in the same range as the concentrations of the overlying water column. These results suggest that the surface 8 cm of sediment is frequently resuspended during wind-driven resuspension. It can be concluded from these observations that ammonium and soluble reactive P transport from the surface 8 cm is due to release during sediment resuspension, while below 8 cm sediment depth, upward mobility of ammonium and soluble reactive P is governed by diffusion related processes. The biogeochemical processes functioning at the sediment-water interface need further investigations to quantitatively evaluate the impact of sediments on water quality.

Chapter 2

INTRODUCTION

2.0 INTRODUCTION

2.1 State of the Problem

Eutrophication of lakes and streams in Florida has been a subject of concern to various state agencies, local agencies, and private citizens for the past two decades. Many water bodies in Florida are impacted by the nutrient loads from urban and agricultural activities adjacent to the lakes. In central Florida, Lake Apopka, the headwater and largest lake in the Oklawaha River Basin (Fig. 2.1), is currently hypereutrophic. The remaining lakes in the same drainage basin are also eutrophic. Since the water from Lake Apopka flows through a chain of lakes in the Oklawaha River Basin, the poor water quality of this lake can significantly influence the quality of water downstream.

The surface area of this lake is 12,500 ha (31,000 acres). The lake is located approximately 25 km northwest of Orlando. The average water depth in the lake is less than 2 m. Historically, the lake was noted for its bass fishing. Currently, the lake is dominated by rough fish such as shad, gar, and catfish. One of the primary reasons for loss of bass population was thought to be hypereutrophic conditions in the lake. Loss of aquatic vegetation and increased algal productivity has created turbidity problems and build-up of organic-rich flocculent sediments.

Nutrient budgets presented for Lake Apopka (EPA, 1979) suggest that about 30% of total N and 58% of total P inputs are due to drainage water pumpage from adjacent vegetable farms. About 17% of the total N and 7% total P inputs were estimated to be from precipitation. Currently, the St. Johns River Water Management District (SJRWMD) is developing improved estimates of external sources of N and P inputs to the lake, through extensive water quality monitoring.

Bottom sediments in Lake Apopka are flocculent and rich in organic matter. Because of the shallow water depth, these sediments can be readily suspended into the overlying water, thereby affecting water quality. Currently, the extent of sediment resuspension in the water column and its ultimate impact on algal productivity is not clear.

In recognition of the problems and potential values of Lake Apopka, the Florida Legislature, in 1985, passed Chapter 85-148, Laws of Florida, which funds studies aimed at determining feasible means for restoring the lake. This research plan describes a project designed to address a portion of the requirements of subsection 5(3) of Chapter 85-148 which directs the SJRWMD to "Develop a nutrient budget for the lake to ensure that appropriate regulatory efforts are instituted with respect to nutrient loading."

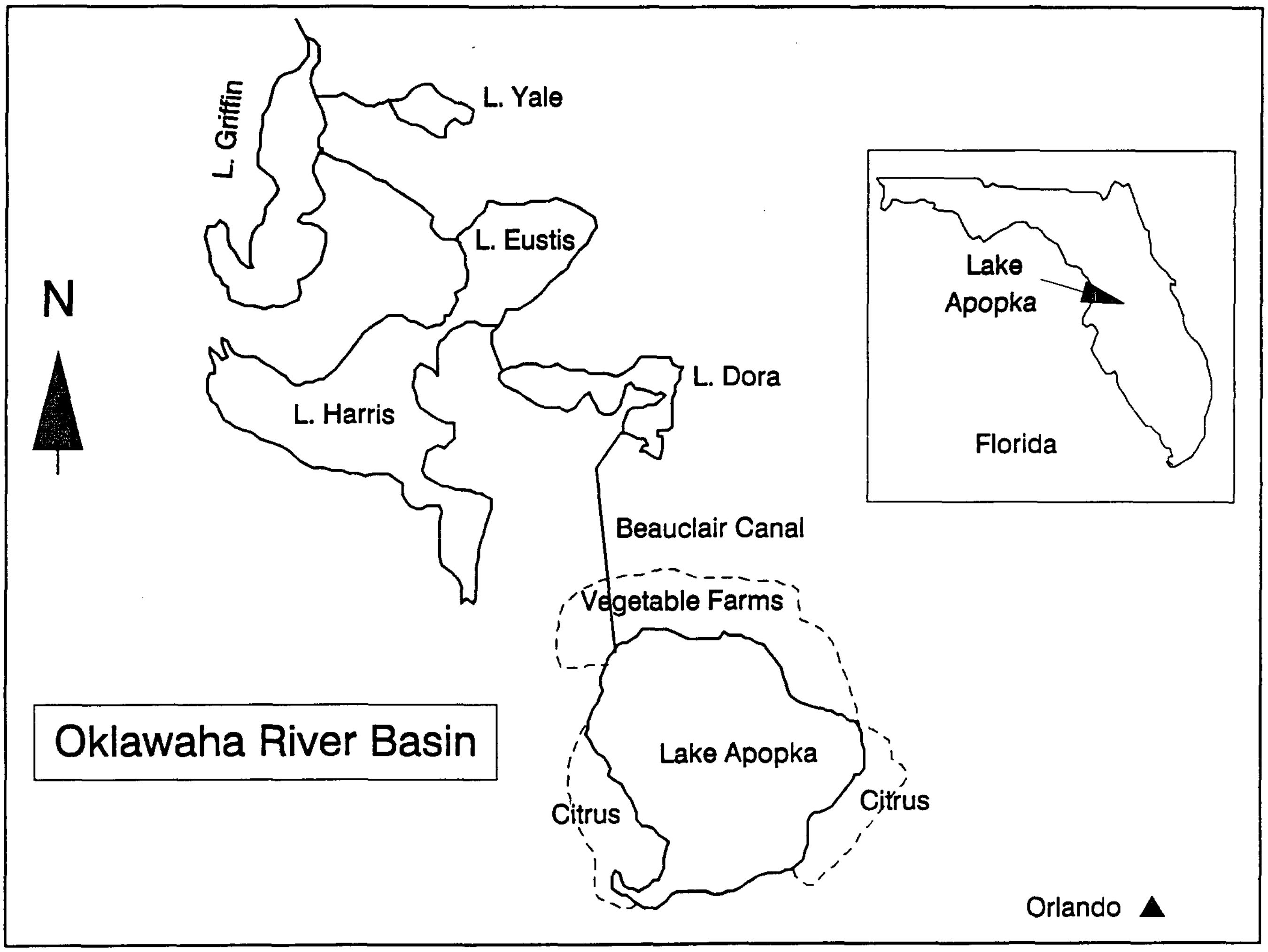


Fig. 2.1. Lake Apopka and associated chain of lakes in the Oklawaha River Basin.

2.2 Need for Research

In order to predict the effects of different strategies of pollution abatement for Lake Apopka, it is essential to have an accurate understanding of the budgets of the affected pollutants. For Lake Apopka, the pollutants of most immediate concern are P, N, and C. Phosphorus and N are essential nutrients that often limit the rate of algal primary production, the source of flocculent lake sediments. Although C, which is continually supplied through photosynthesis and removed through microbial respiration, is a major component of the flocculent organic sediment, it is not as important in eutrophication as N and P. Nevertheless, the rate of accumulation of flocculent sediments is determined by the balance between C fixation via algal photosynthesis and C mineralization through microbial respiration. Information on the C budget, then, could indicate the level of reduction of algal productivity required to cause the lake to become a net exporter of C.

In recent years, it has become clear that nutrient processing by the aquatic biota and the biogeochemical processes in sediments of lakes can be a major factor in the determination of a lake's trophic state (Fig. 2.2). The bottom sediments in Lake Apopka can function as a source or sink for the nutrients in the water column. The direction of flux between the sediment and overlying water column is dictated by the external inputs of the nutrients and biogeochemical processes in the sediments and water column. Nutrient dynamics in Lake Apopka are complex because many hydrodynamic, sedimentary, biological and chemical processes are involved. These processes include: photosynthetic C fixation, microbial decomposition of organic C, N transformations (ammonification, adsorption/desorption of ammonium, nitrification-denitrification, ammonia volatilization, dinitrogen fixation), and P transformations (mineralization of organic P, adsorption/desorption of P). The balance between these sources and sinks of nutrients can either augment or reduce the trophic state of the water.

2.2.1 Carbon

The processes regulating the C exchange between the sediment and the overlying water column are depicted schematically in Figure 2.3. The sources of organic C in Lake Apopka sediments are external inputs such as particulate matter from agricultural drainage water and other non-point sources and internal sources such as algae and other aquatic biota. For the Lake Apopka system, it is hypothesized that deposition of dead algal cells is the major source of organic C in the sediment. The rate of algae deposition depends on the rate of C fixation and associated factors (such as nutrients and light) limiting the algae's productivity. Dead algal cells undergo decomposition both in the water column and in the sediment. The decomposition rate in the sediments and the overlying water column depends on the microbial communities, O_2 supply, and amounts of other electron acceptors. In a shallow lake such as Lake Apopka, wind mixing sufficiently maintains O_2 levels to support aerobic respiration in the water column. Algal organic matter is the major source of flocculent sediments. The decomposition of this organic matter is influenced by the types of structural compounds present

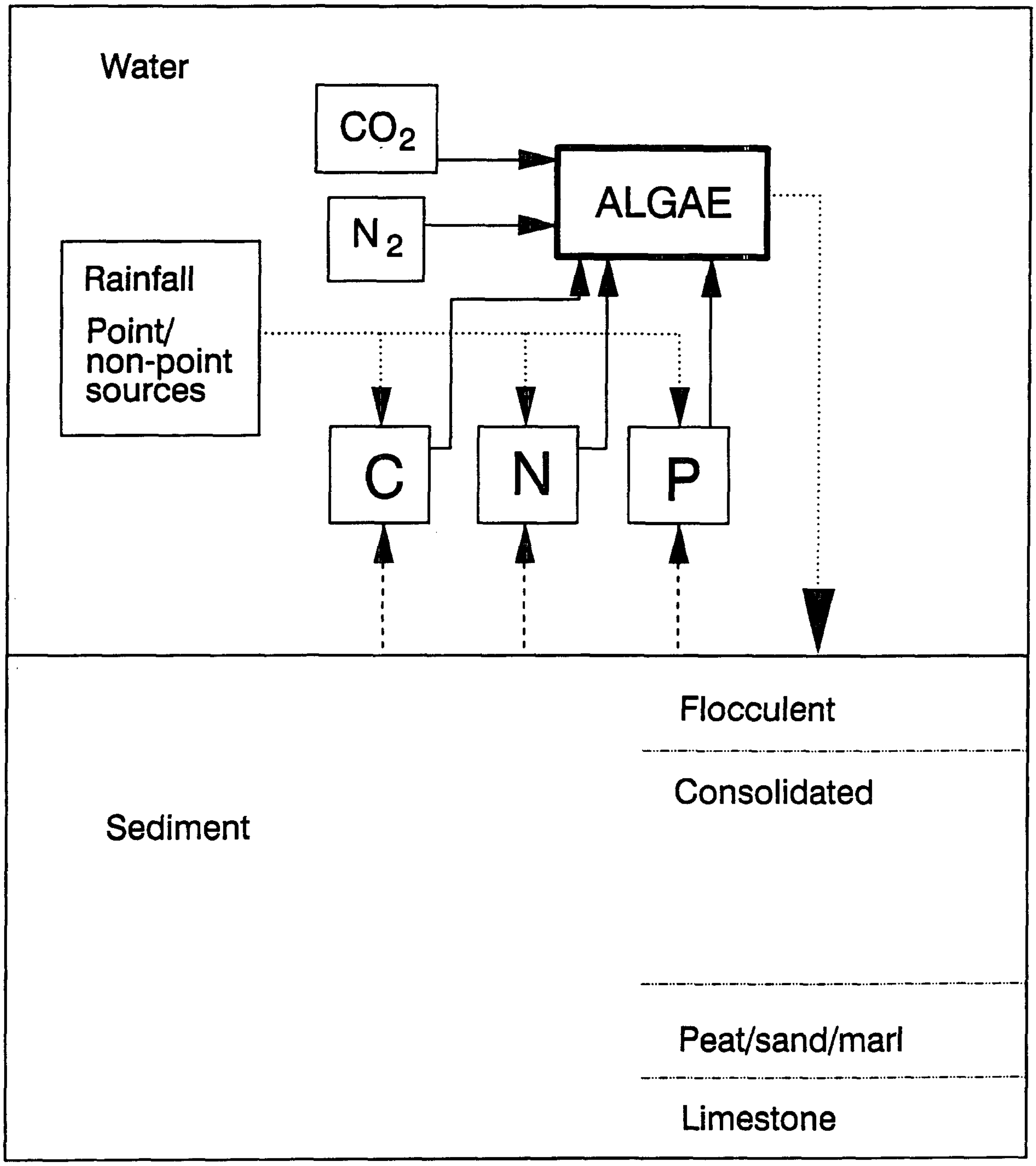
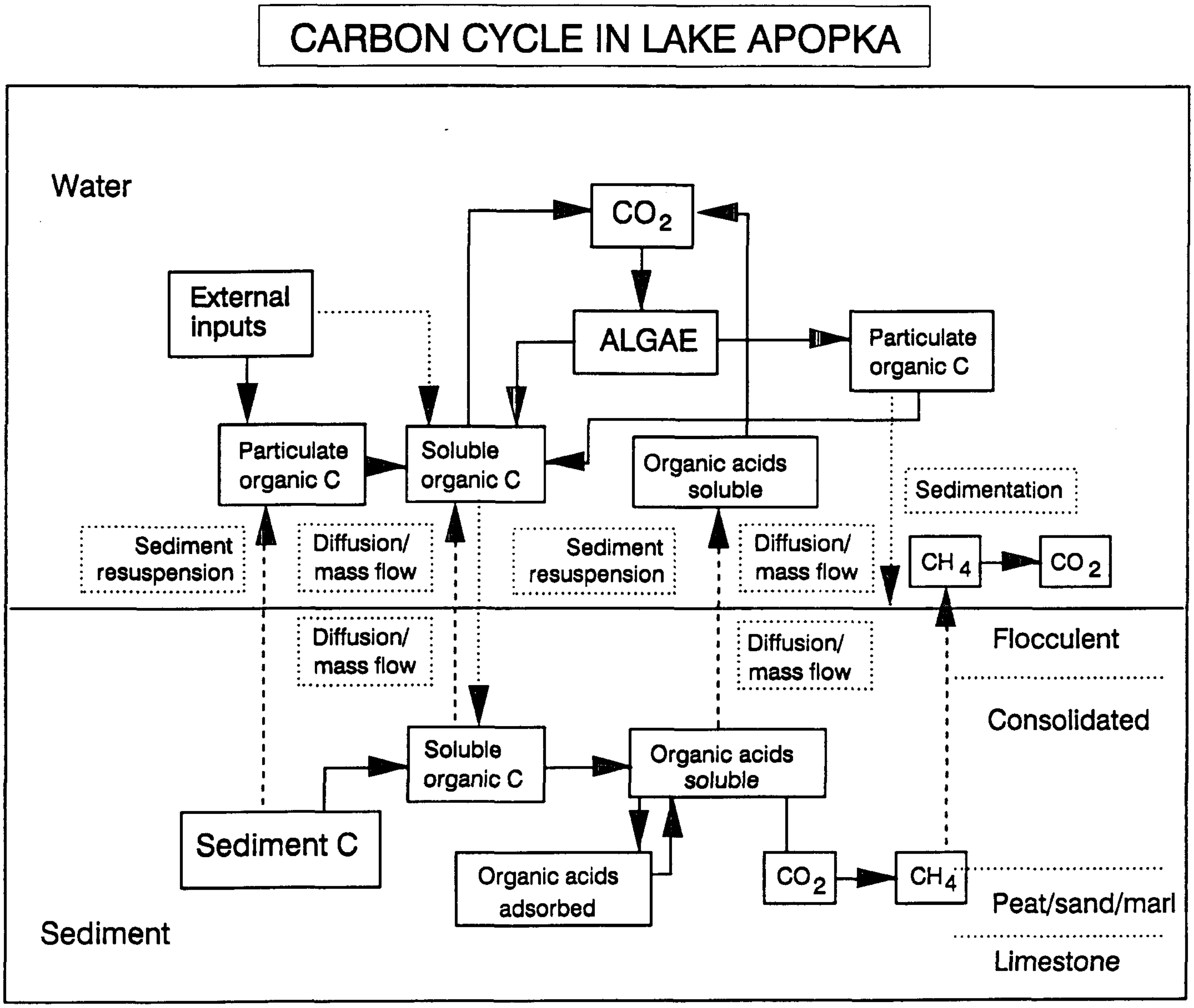


Fig. 2.2. Schematic of C, N and P inputs/outputs in the sediment-water column of Lake Apopka. Arrows with solid lines represent transformations and with dotted lines represent transport process.



CARBON CYCLE IN LAKE APOPKA

Fig. 2.3. Schematic of the transport and transformations of C in the sediment-water column of Lake Apopka. Arrows with solid lines represent transformations and with dotted lines represent transport processes.

(polysaccharides and phenolic polymers) and the availability of electron acceptors to support aerobic, facultative anaerobic, and anaerobic respiration. Microorganisms utilize electron acceptors in the order of O_2 > NO_3^- > MnO_2 > FeOOH > SO_4^{2-} > CO_2. Several recent review articles have discussed the significance of different types of respiratory processes in lake sediments and wetlands (Jorgensen, 1983; Reeburgh, 1983; Reddy et al., 1986; Capone and Kiene, 1988; Oremland, 1988).

The rate of decomposition of sediment has an important environmental impact on the overlying water quality as a result of nutrient release. Relative rates of decomposition under the conditions needed to be established in order to determine the impacts on the overlying water column. Biogeochemical processes such as decomposition associated with physical processes (e.g., wind-induced sediment resuspension) determine the rate of sediment build-up in the lake.

2.2.2 Nitrogen

Nitrogen in the sediments and the overlying water column is present in organic and inorganic forms with the organic form predominating. Organic N consists of compounds from amino acids, amines, proteins, and humic compounds with low N content. Inorganic N forms consist of NH_4^+, NO_3^- and NO_2^-. In the water column, NH_4^+ and NO_3^- are present in sufficient concentrations to support the productivity of aquatic biota, while in sediments NO_3^- and NO_2^- occur in trace quantities. Ammonium N is the dominant inorganic form of N in the sediments. In Lake Apopka, N is derived from: (1) external sources (rainfall, drainage water from vegetable farms and runoff from non-point source), and (2) internal sources such as biological N_2 fixation and N transformations in the sediments (Fig. 2.4).

Nitrogen transformations and transport processes in the sediment profile regulate the role of sediments as a sink or source of N. Organic N in sediments is converted to NH_4^+ during the microbial breakdown of organic matter. The rate of NH_4^+ accumulation is governed by the composition of organic matter and the availability of electron acceptors. Usually NH_4^+ concentrations in the sediment porewater are several-fold higher than the NH_4^+ concentrations in the overlying water column. Thus, NH_4^+ tends to diffuse from the sediment to the overlying water column in response to the concentration gradient. Ammonium N is also released into the water column during wind-driven sediment resuspension. Depending on the O_2 concentration of the water column and at the sediment-water interface, NH_4^+ is rapidly converted to NO_3^-. Because of the high demand for electron acceptors in the sediments, NO_3^- diffuses back into the sediment where it is readily converted to gaseous end products such as N_2O and N_2. These processes continuously deplete sediment N by converting organic forms of N to gaseous forms. Biological N_2 fixation in the water column and deposition of dead algal cells provide continuous inputs of N to the sediments. The balance between the internal inputs and outputs dictates the rate of sediment N accumulation. The kinetics of many of these processes and the interacting biogeochemical processes have not been evaluated for Lake Apopka sediments. Several reviews have discussed the significance of these processes in sediments and wetlands (Keeney, 1973; Reddy and Patrick, 1984; Seitzinger, 1988).

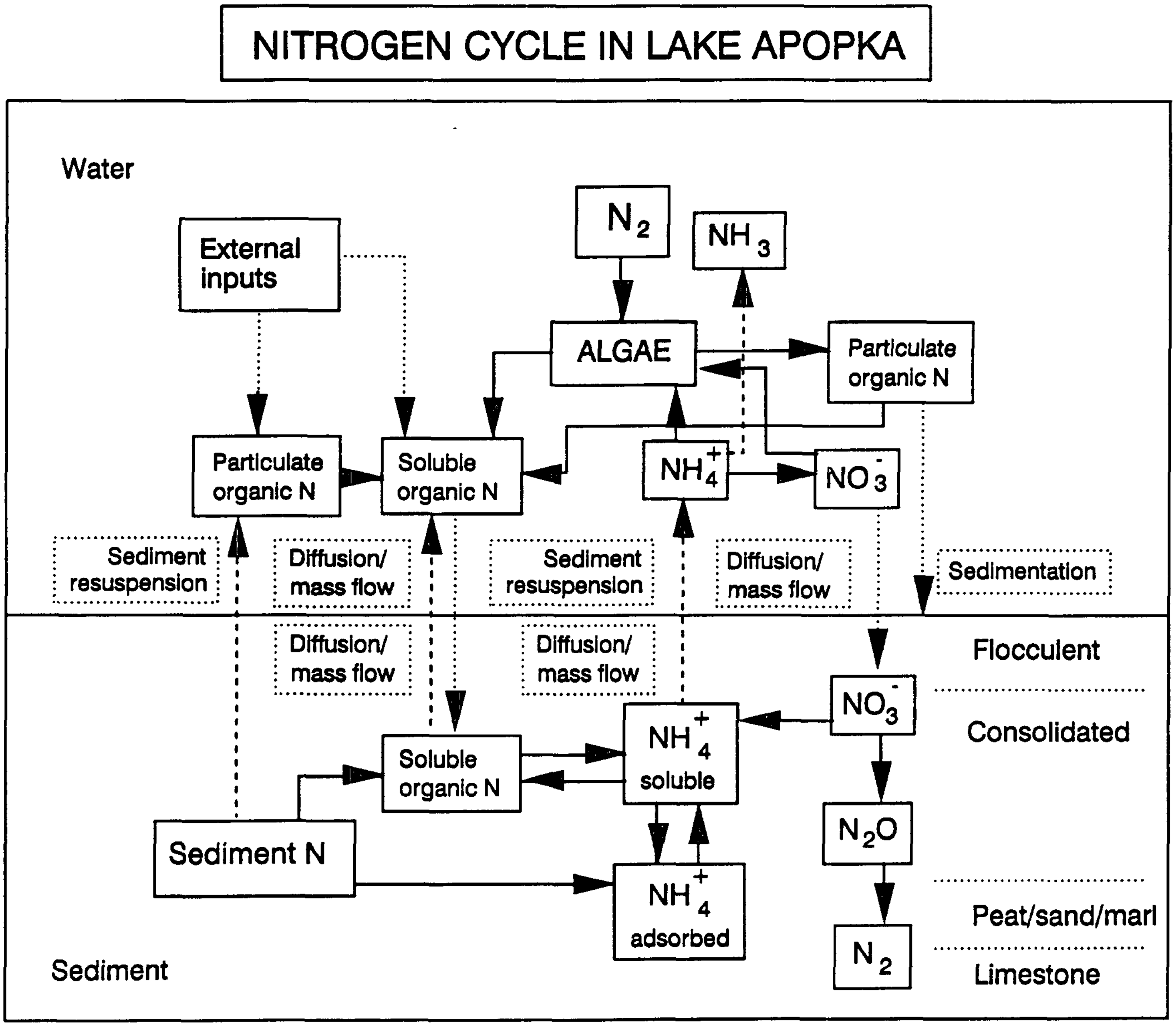


Fig. 2.4. Schematic of the transport and transformations of N in the sediment-water column of Lake Apopka. Arrows with solid lines represent transformations and with dotted lines represent transport processes.

2.2.3 Phosphorus

Phosphorus dynamics in Lake Apopka are very complicated because of complex biogeochemical reactions functioning in the water column and the bottom sediment (Fig. 2.5). Lake sediments typically accrete P and can develop sediment porewater concentrations several-fold higher than the P concentrations of the overlying water column. Phosphorus cycling in lakes has been extensively studied and sediments have been identified as a major component of the P cycle (Syers et al., 1973; Froelich, 1988; Sonzogni et al., 1982).

Phosphorus in sediments is present in inorganic and organic forms. Inorganic P can be divided into: (1) porewater P, (2) exchangeable P, (3) non-apatite P (NAIP), and (4) apatite P (AIP). Non-apatite P primarily is comprised of inorganic P associated with Fe and Al, while apatite P is associated with calcium P. The porewater and exchangeable P forms are readily available, while Fe/Al-bound P and Ca-bound P are slowly available. The stability of most of the P compounds in sediments is governed by the intensity of sediment anaerobiosis (measured as oxidation-reduction potential) and pH and by associated cations. It is important to determine the different forms of P in Lake Apopka sediments in order to establish the impact of sediments on P concentrations of the overlying water column.

Although organic P frequently comprises a major fraction of the P in lake sediments, very little is known of the nature and behavior of organic P. Deposition of dead algal cells is probably one of the major sources of organic P in surface sediments. Organic P is mineralized during microbial breakdown of organic matter, thus the kinetics of organic P mineralization need to be better understood. Limited information is currently available on the characteristics of dissolved organic P compounds and their bioavailability in the lake. In Lake Apopka, organic P forms play a key role in algal nutrition. Total P concentrations in the water column are greater than 0.25 mg L^{-1} while soluble reactive P (SRP) levels are less than 0.007 mg L^{-1}, suggesting a large portion of the P is in organic form. Recent studies on Lake Apopka (Newman et al., 1989) have shown that phosphatases play a dominant role in regulating organic P dynamics in the water column.

Dissolved P concentration in the porewater is regulated by the P retention characteristics of the solid phases in the sediment. It is important to determine the phosphate adsorption (removal of P from solution and retention by solid phase) – desorption (release of P from solid phase into solution) as they relate to sediment physico-chemical properties. The phosphate buffer mechanisms in sediments have been recently reviewed by Froelich (1988). These processes play a significant role in transport of soluble P either by diffusion or release during sediment resuspension in the water column.

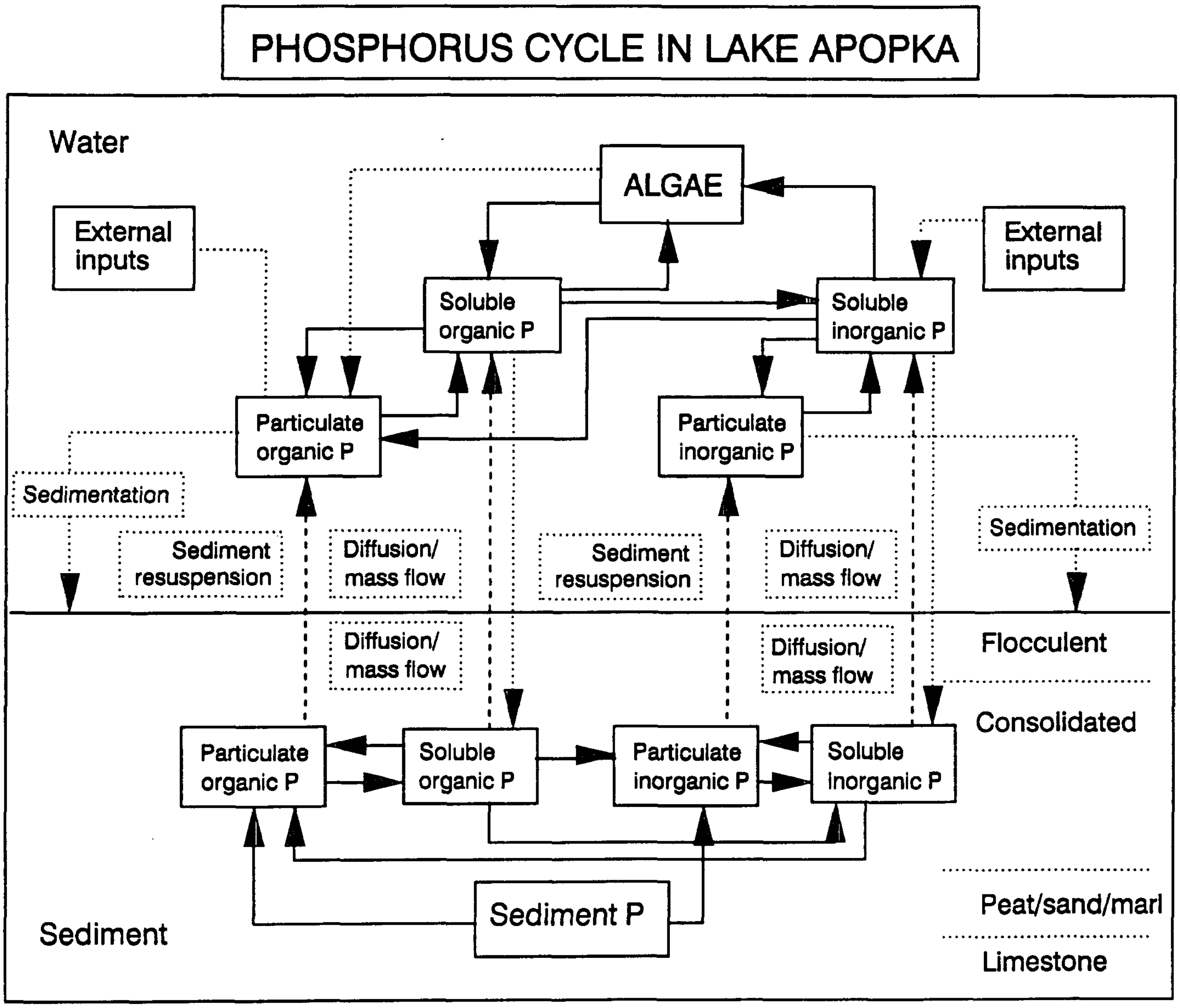


Fig. 2.5. Schematic of the transport and transformations of P in the sediment-water column of Lake Apopka. Arrows with solid lines represent transformations and with dotted lines represent transport processes.

2.3 Objectives

A 3-yr research project was initiated to accomplish the following objectives:

1. Characterize Lake Apopka sediments by determining the rate of accumulation of organic C, the spatial variation of organic sediment depth, the intensities of aerobic and anaerobic decomposition, and the concentrations of labile and non-labile forms of C, N, and P.

2. Determine the net flux of dissolved C, N, and P between the sediments and the overlying water column.

3. Determine the relative importance of biological and physico-chemical processes in the transformation of sedimentary forms of C, N, and P. Determine the effects of these processes on the rate of release of dissolved forms of C, N, and P from the sediments.

4. Determine the rates and nature of C, N, and P transformations in the water column.

5. Determine the effects of sediment resuspension on C, N, and P flux across the sediment-water interface and water quality.

2.4 References

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Chapter 3

PHYSICO-CHEMICAL PROPERTIES OF LAKE APOPKA SEDIMENTS

3.0 PHYSICO-CHEMICAL PROPERTIES OF LAKE APOPKA SEDIMENTS

[Tasks 1.1 and 1.2]

3.1 Introduction

Bottom sediments appear to play a crucial role in internal nutrient cycling of lakes. The biogeochemical processes associated with cycling of nutrients can significantly impact the water quality of the lakes. Nutrient flux from sediment to the water column of a lake or stream are dependent on physical, chemical and biological properties of the sediment. The study by Schneider and Little (1969) reported the basic characteristics of the bottom sediments of Lake Apopka, thus providing base-line data on the characteristics of the sediments that can be used to evaluate the impacts of nutrient loading on Lake Apopka for the past 20 years. This study however did not identify the labile pools of nutrients readily available for release to the overlying water column. In order to understand the functional role of sediments as a source or sink for nutrients to the overlying water column, it is important to first characterize the sediments, for total nutrient storage in different layers and identify the labile and non-labile fractions of nutrients.

The purpose of this study was to determine: (1) the total storage of C, N and P in the sediments, (2) the spatial variability of labile and non-labile fractions of selected nutrients in porewater and solid phases, and (3) the distribution of nutrients in various horizons of the sediments.

3.2 Site Description

Lake Apopka, with a surface area of 12,500 ha (31,000 acres), is located in Central Florida, approximately 25 km (15 miles) northwest of Orlando (Fig. 2.1). The average depth of the lake is about 2 m. Currently, it is highly eutrophic with high concentrations of algal biomass (chlorophyll-a concentrations often exceeding 150 mg m^{-3}). Water quality in the lake is impacted by both external and internal sources. Historical and current external sources of pollution include: (1) discharge of excess drainage water from adjacent vegetable farms, (2) surface and subsurface runoff from adjacent citrus groves, (3) sewage effluent discharge from Winter Garden (this discharge has been stopped for some time), and (4) rainfall. Internal nutrient loading includes: (1) nutrient release from underlying sediment, and (2) biological N_2 and C fixation.

3.3 Materials and Methods

3.3.1 Sampling

Sediment samples were obtained from 90 stations established in the lake on a grid pattern using a LORAN (Fig. 3.1). LORAN coordinates (latitude and longitude) for each station are given in Appendix A-1. U.S. Geological Survey

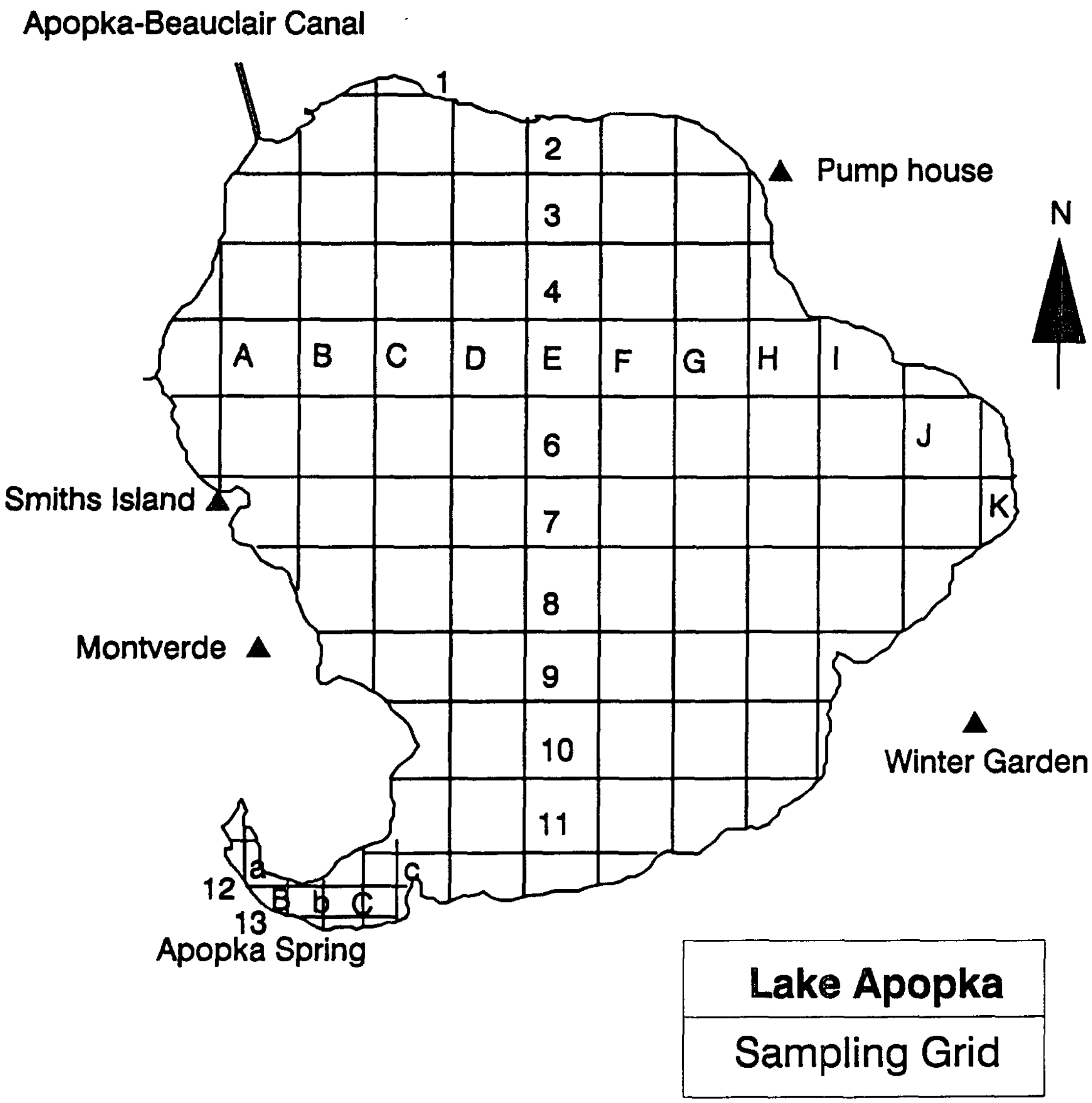


Fig. 3.1. A schematic presentation of the sampling grid used to obtain intact cores from Lake Apopka.

quadrangle (scale 1 cm = 240 m or 1" = 2000 ft) maps were used to establish a pattern with an approximate distance of 1220 m (4000 ft) between stations, with the 5 cm (2 inches) grid. The distance between stations was decreased to 610 m (2000 ft) in the Apopka Spring area, which allowed for a greater number of stations. The sampling stations were similar to those utilized in 1968 by Schneider and Little (1969). This allowed comparison of the data obtained 18 years ago.

Sediment cores were obtained during June 1987, using a piston corer specifically designed for use in soft sediments (Fig. 3.2). This sampler allowed us to obtain an intact sediment core in a Plexiglas tube (6.3 cm I.D. x 2 m). The water above the sediment core was siphoned off under a N_2 atmosphere. The sediment was then slowly extruded by applying slight positive pressure on the top of the core and sectioning the sediment at the bottom at defined horizons. Sectioned sediment samples were homogenized and immediately transferred into Nalgene Mason Jars equipped with rubber septums. The jars were immediately purged with N_2 gas to eliminate O_2, placed in an ice chest and transported to the Wetland Soils Research Laboratory, in the Soil Science Department of the University of Florida. Sediment samples were stored in a refrigerator (T = 4°C) until analyzed for chemical parameters.

The thickness of each horizon was recorded. Additional cores were obtained from the same locations to determine bulk density, water content, pH, alkalinity and conductivity. All sub-sample transfers from the bulk samples were made under N_2 gas using a glove bag.

3.3.2 Sediment and water depth

Total sediment depth to 600 cm was determined by pushing a 1.25-cm OD galvanized tube through the sediment until hard bottom was encountered. Water depth was measured using a light sensitive depth finder (Fig. 3.3). This meter essentially consisted of an electrical circuit with a cadmium sulfide photocell wired in series with a voltage-ohm meter, which was used to determine absence or presence of light. In the presence of light, the circuit is normally closed, registering approximately zero ohms resistance. As the photocell touches the sediment-water interface, light transmittance is reduced, the circuit resistance approaches infinity and the depth is recorded.

3.3.3 Bulk density

The volume and weight of sediment from each horizon were determined and a sub-sample was obtained to determine water content. The bulk density of each horizon was calculated on wet and dry sediment basis, as follows:

$$\text{Bulk density (g cm}^{-3}\text{)} = \frac{\text{Oven dry weight or wet weight of sediment in the horizon, g}}{\text{Volume of wet sediment in the horizon, cm}^3}$$

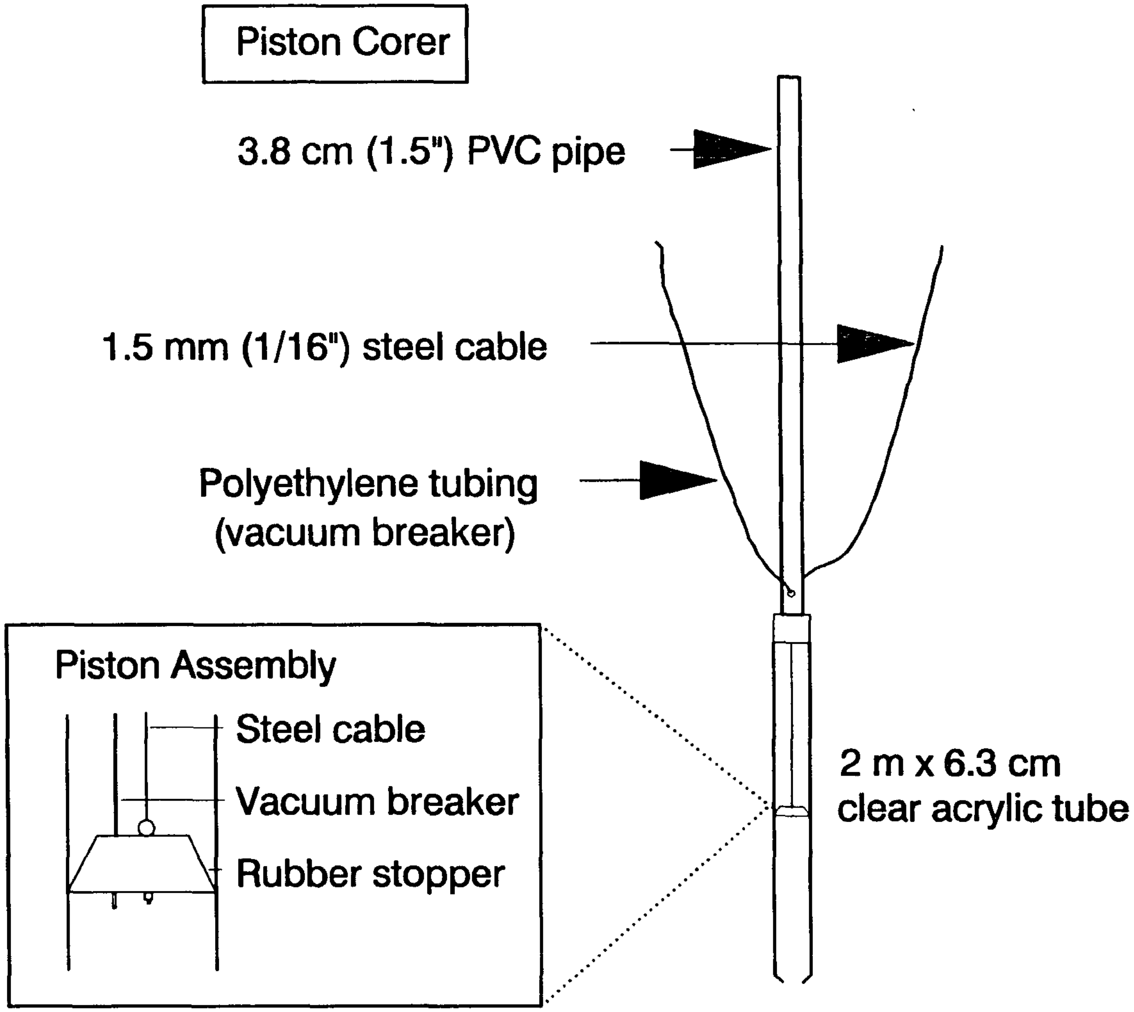
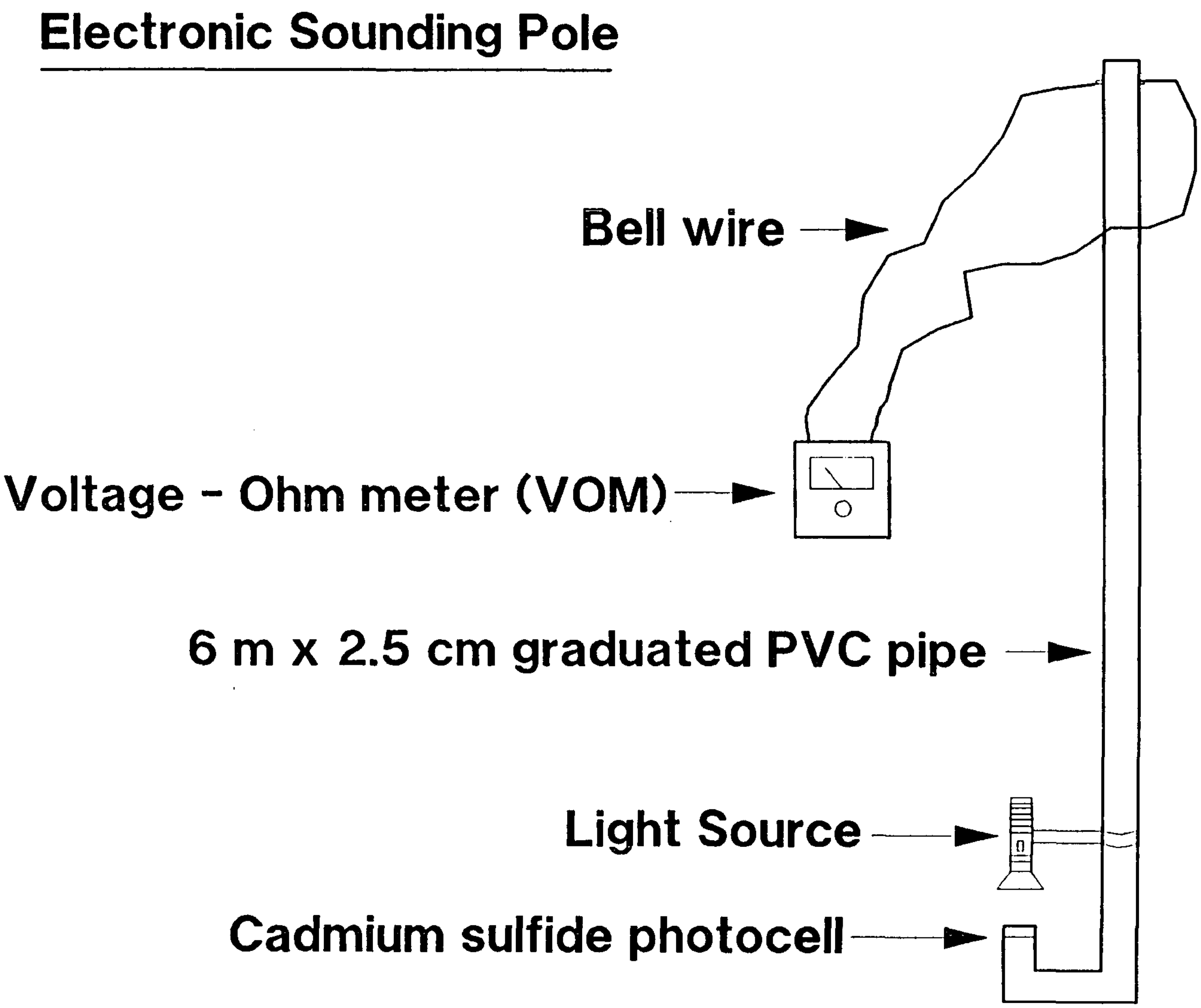


Fig. 3.2. A schematic presentation of piston corer used to obtain intact sediment cores from Lake Apopka.



Electronic Sounding Pole

Fig. 3.3. A schematic presentation of the electronic sounding pole used to determine the sediment-water interface and to measure water depth.

3.3.4 Water content

A sub-sample of the sediment was obtained and dried at 105°C for a period of 48 h or until constant weight was recorded. Percent water in the sediment was calculated as follows:

$$\text{Water content \%} = \frac{\text{Weight of water loss after drying}}{\text{Wet weight of sediment}} \times 100$$

3.3.5 Porewater extraction

A known amount of wet sediment was placed into a 250-mL polypropylene bottle under N_2 atmosphere and centrifuged at 5,000 rpm for 20 min in a refrigerated centrifuge. Supernatant liquid (porewater) was filtered through a 0.45 μm filter under N_2 atmosphere. One portion of the filtered solution was acidified and stored at 4°C until analyzed for ammonium N, nitrate + nitrite N, total dissolved organic N, soluble reactive P, and total dissolved P (Fig. 3.4). Unfiltered solutions were used to determine total organic N, total P and total organic C.

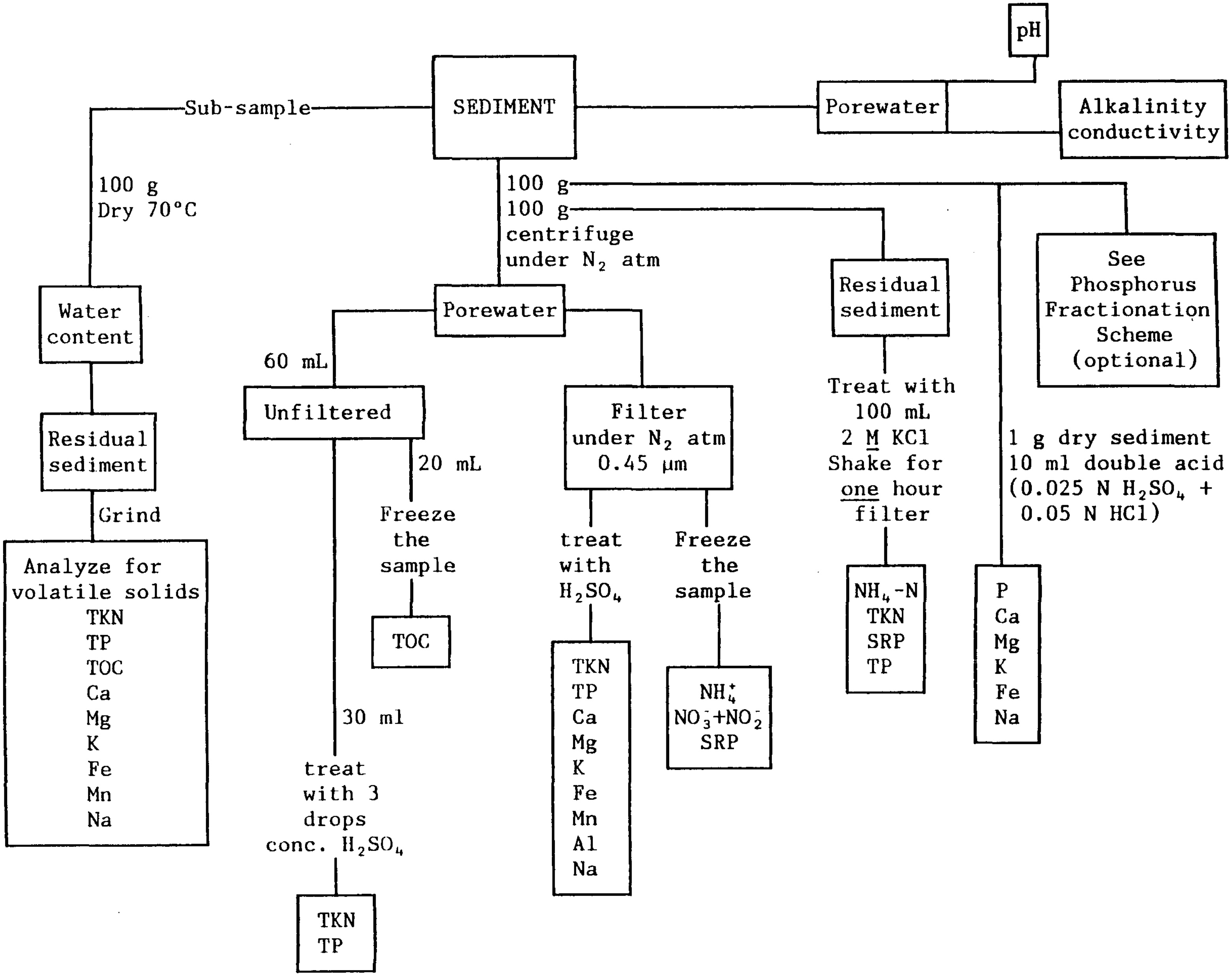
Porewater for pH measurement was obtained by centrifuging a known amount of sediment at 5,000 rpm for 20 min under N_2 atmosphere. The supernatant liquid was transferred into a small beaker, where pH was measured using a combination glass electrode and pH meter. Alkalinity of the porewater was determined using standard methods (APHA, 1985) and expressed as mg $CaCO_3$ per liter.

A portion of porewater extracted using the procedure described above was used to determine ionic strength using a conductivity meter. Conductivity and alkalinity were measured on unfiltered samples to avoid any disruption in carbonate equilibria caused by vacuum filtration.

3.3.6 Extractable fractions

After porewater removal, residual sediment was treated with 2M KCl solution, and the extract was filtered through 0.45 μm filter paper after shaking for an hour. The filtrate was acidified and frozen until analyzed. Dried sediment samples were extracted with double acid (0.025 N H_2SO_4 + 0.05 N HCl) at a sediment to solution ratio of 1 to 10. This extraction procedure is commonly referred to as the Mehlich I method (Olsen and Sommers, 1982). Because of the calcareous nature of the sediment, a second set of samples was extracted with a stronger double acid containing 0.25 N H_2SO_4 + 0.5 N HCl at a sediment to solution ratio of 1 to 10. For both extractions, the equilibrium period used was 5 min under continuous shaking. Extracted solutions were filtered through a 0.45 μm filter and analyzed for soluble reactive P. The solutions extracted with the Mehlich I procedure were also analyzed for selected cations.

Fig. 3.4. Flow-chart showing the scheme used for chemical analysis of sediments.



3.3.7 Fractionation of inorganic phosphate in sediments

Characterization of phosphate compounds in sediments is useful in understanding the P cycle in lakes. The forms and amounts of P in lake systems are regulated by many factors such as external P loading, P output from the lake, and various phosphate reactions. Depending on the forms of phosphate present, the sediments can either release or adsorb P. For example, the sediments dominated by non-apatite inorganic phosphate (NAIP) are more responsive to redox (Eh) and pH changes than those dominated by the apatite inorganic phosphate (AIP) (Manning et al., 1984).

Although several studies have been conducted for Lake Apopka, many of them were on limnology and morphometry (Shannon and Brezonik, 1972a; 1972b). So far, no data are available on the forms and distribution of inorganic P in sediments. An appropriate chemical fractionation of sediment P is needed to determine the labile and non-labile forms, and potential algal available P.

The P fractionation scheme was first developed for soils by Chang and Jackson (1957). This scheme was based upon the ability of extracting reagents to solubilize the phosphate present in minerals such as variscite, strengite, apatite, and others (Peterson and Corey, 1966; Williams et al., 1971). Although the sequential extraction method was initiated by Dean (1938) and modified later by Ghani (1943) and Williams (1950), the Chang and Jackson procedure and its modifications (Peterson and Corey, 1966; Williams et al., 1967) have been extensively used in soils and sediments.

Due to its wide acceptance among soil scientists, the Chang and Jackson method (1957) was extended to lake sediments (Harter 1968; Frink, 1969). Frink (1969) found that both aluminum-bound P (Al-P) and iron-bound P (Fe-P) in lake sediments could be determined readily and precisely by this method but the reductant-soluble P fraction had some analytical difficulty and poor reproducibility. The author observed similar problems when he used the modifications in the scheme made by Peterson and Corey (1966). The modification differed from that of the Chang and Jackson method (1957) only in the order of extraction and in the pH of the NH_4F solution used.

Additional problems were reported when this scheme was used in calcareous lake sediments. Williams et al. (1971) found that the use of NH_4F as Al-P extractant in calcareous lake sediment could result in the formation of CaF_2 which is capable of sorbing the inorganic P released during the NH_4F and the succeeding NaOH extractions. The sorbed inorganic P is released during the subsequent citrate-dithionite (CDB) and acid extractions; hence, it underestimates one fraction and overestimates the others (Syers et al., 1972). In addition, there is considerable evidence that NH_4F is not selective for Al-P (Fife, 1962; Bromfield, 1969; Williams et al., 1971). Hence, Williams et al. (1971) proposed a modified scheme for calcareous sediments using citrate-dithionite-bicarbonate (CDB) to solubilize occluded Fe/Al-P.

In their studies on lake sediments, Hieltjes and Lijklema (1980) reported that the scheme by Williams et al. (1971) was not very effective in separating Ca-bound P from Fe/Al-P. The CDB reagent was found to solubilize substantial amounts of Ca-P due to its citrate ion which is a strong complexing agent for calcium. Hieltjes and Lijklema (1980) also found that phosphate adsorption by carbonates in calcareous lake sediments can be prevented by complete removal of the carbonates prior to the alkaline treatment. Neutralized ammonium chloride solutions of 1.0 M or 0.5 M as originally proposed by Chang and Jackson (1957) were shown to be very effective in removing carbonates and loosely-bound calcium ions. Based on these findings, Hieltjes and Lijklema (1980) proposed a NH_4Cl-NaOH-HCl method which later was evaluated in detail by van Eck (1982) for P fractionation in suspended particulate matter.

After comparing seven P extraction schemes including, among others, those of Hieltjes and Lijklema (1980) and Williams et al. (1971), van Eck (1982) was able to establish a satisfactory procedure for characterizing P into various forms such as exchangeable P, carbonate-bound P, Fe/Al-bound P, calcium-bound P, and labile and resistant organic P. The scheme was developed to avoid the problems encountered with NH_4F and CDB extractants and to minimize possible hydrolysis of labile organic P compounds during colorimetric determination of orthophosphate by the ascorbic acid method (Murphy and Riley, 1962). Based on these developments, it was determined that the van Eck (1982) P fractionation scheme was appropriate for Lake Apopka sediments.

Bulk sediment samples were obtained from the different stations in Lake Apopka and were grouped into five horizons: unconsolidated flocculent (UCF), consolidated flocculent (CF), peat (P), clay (C), and marl (M). Wet samples were placed into de-aerated, well-sealed polycarbonate tubes and centrifuged prior to the removal of pore water. The sediment samples were fractionated for inorganic P according to the scheme shown in Figure 3.5. All extractions were performed using glove bags and special apparatus to maintain anaerobic conditions. Addition and removal of extracting solutions were accomplished using a syringe. Extracts in the syringe were injected immediately into the anaerobic filtration apparatus purged with N_2 gas. The filtrate (0.45 μm filter paper) was stored at 4°C prior to P determination. The Murphy and Riley (1962) method (ascorbic acid method) was done using an autoanalyzer while the Watanabe and Olsen method (1962) was accomplished using a spectrophotometer.

3.3.8 Organic C fractionation

Organic C was fractionated into lignin and cellulose fractions using the procedures described by Goering and van Soest (1970).

3.3.9 Total elemental analysis

A sub-sample of the sediment was dried at 105°C for a period of 72 h and analyzed for total N, P, C, Ca, Mg, K, Fe and Mn using the methods described in

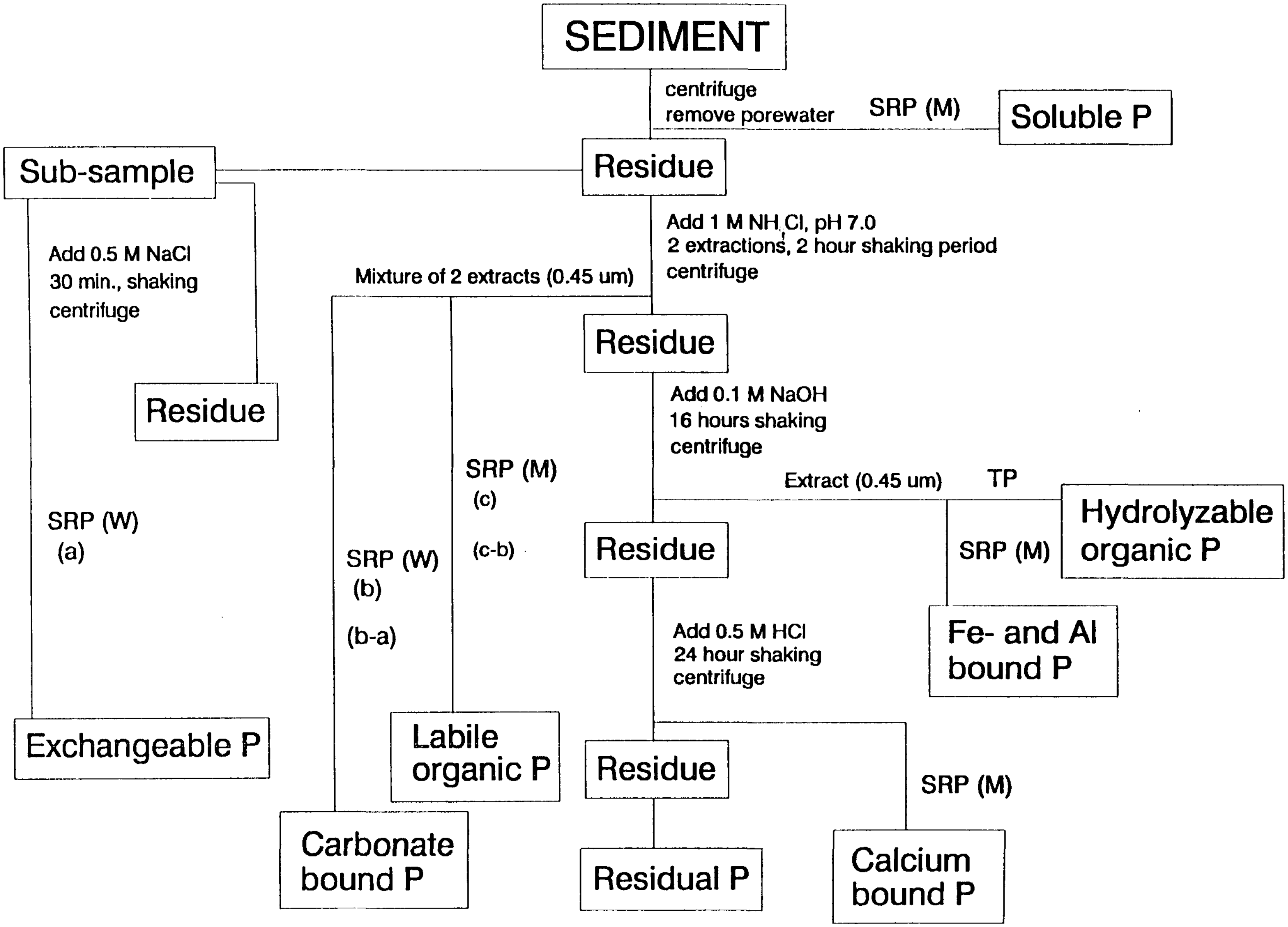


Fig. 3.5. Fractionation scheme used to determine the labile and non-labile pools of P in sediments. W = Watanabe and Olsen method; M = Murphy and Riley method. (VanEck, 1982; Hieltjes and Lijklema, 1980).

Table 3.1. A portion of the dried sediment was also used to determine volatile solids.

3.3.10 Analytical methods

Standard methods were used to analyze the porewater, and extractable and total elements (Table 3.1). All samples were analyzed according to the Quality Assurance Plan.

3.4 Results and Discussion

3.4.1 Water and sediment depth

Average water depth at the time of sampling (June 1987) was 164 cm (Table 3.2). Detailed data for all stations are given in Appendix B-1. Water depth was found to be maximum at stations located on the southern shoreline near Winter Garden (Fig. 3.6). The second deepest stations were found on the western shoreline near Monteverde.

Total sediment depth varied significantly with location (Table 3.2, Fig. 3.7, Appendix B-1). Certain stations had a sediment depth >600 cm especially on transects 10, 11 and 12. All these stations are located in the Apopka Spring area. Our sediment probing technique did not measure depths >600 cm. Results presented by Schneider and Little (1969) indicate a maximum sediment depth of 1200 cm for some stations in the Apopka Spring area. Typical sediment profiles of Transects 2, 6 and 10 are given in Figure 3.8.

Depending on the consistency and physical structure, sediment cores were divided into several horizons. These include: unconsolidated floc (UCF), consolidated floc (CF), peat (P), sand (S), clay (C), and marl (M). The description of each fraction is given as follows:

UCF = Unconsolidated floc. This layer of the sediment primarily consists of recent deposits of algal cells and allochthonous particulate organic matter and is actively involved in resuspension and nutrient release during wave events. This horizon was observed at 86 stations and had an average thickness of 32 cm (min = 0 cm and max = 108 cm) (Fig. 3.9a; Tables 3.2 and Appendix B-1).

CF = Consolidated floc. This fraction of the sediment consists of settled algal cells, detritus from aquatic macrophytes and allochthonous particulate organic matter. This fraction was noted at 81 stations and had an average thickness of 82 cm (min = 0 cm and max = >148). In our study, the maximum core depth retrieved from the lake for horizon differentiation was 200 cm. At certain locations we have measured a total sediment depth of >600 cm using metal tubing (Fig. 3.9b; Tables 3.2 and Appendix B-1).

Table 3.1. Analytical Procedures

For the following parameters, only the reference is presented for EPA, APHA, or other standard analytical procedures. Where a modification of a standard procedure was used, a description of the procedure is provided.

---

1. Carbon

   a. Organic and inorganic carbon - water and sediment pore water
      -Method 415.1 (EPA, 1979)

   b. Organic and inorganic carbon - sediment
      -Sample pretreatment (homogenization)
      -Coulometry (Huffman, 1977)

2. Conductance - water
   -Method 120.1 (EPA, 1979)

3. Nitrogen

   a. Ammonia - water and sediment pore water
      -Method 351.2 (EPA, 1979). This method is also used for ammonia analysis without Kjeldahl digestion.

   b. Exchangeable ammonium - sediment
      -Extraction with 2M KCl - Method 33-3.2 (Keeney and Nelson, 1982)
      -Autoanalysis of filtrate - Method 351.2 (EPA, 1979)

   c. Nitrate + nitrite - water and sediment pore water
      -Method 353.2 (EPA, 1979)

   d. Total Kjeldahl nitrogen - water
      -Method 351.2 (EPA, 1979)

   e. Total Kjeldahl nitrogen - sediment and plant tissue
      -Kjeldahl digestion, aluminum block digester - Method 31-2.3 (Bremner and Mulvaney, 1982)
      Autoanalysis of digestate - Method 351.2 (EPA, 1979)

4. Dissolved Oxygen
   -Method 360.1 (EPA, 1979)

5. pH
   -Method 150.1 (EPA, 1979)

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6. Phosphorus

   a. Soluble reactive phosphorus - water and sediment pore water
      -Method 365.2 (EPA, 1979)

   b. Extractable phosphorus - sediment
      -Double acid extraction - Method 24-5.2 (Olsen and Sommers, 1982)
      -Autoanalysis of filtrate - Method 365.2 (EPA, 1979)

   c. Total phosphorus - water
      -Method 365.4 (EPA, 1979)

   d. Total phosphorus - sediment and plant
      -Kjeldahl digestion, aluminum block digester - Method 31-2.3 (Bremner and Mulvaney, 1982)
      -Autoanalysis of digestate - Method 365.4 (EPA, 1979)

7. Bulk density and volumetric water content
   -ASA - Methods of Soil Analysis (1986)

8. Cellulose, hemicellulose and lignin
   -Goering and Van Soest (1970)

9. Alkalinity
   -APHA (1985)

10. Porewater cations
    Extractable cations

11. Total elemental analysis

Table 3.2. Average water and sediment depth in Lake Apopka.

	Water Depth	Sediment Depth	Sediment Component Thickness						Depth of retrieved core
			UCF	CF	P	S	C	M	
	cm								
Mean	163.8	276.0	32.3	81.8	20.1	18.4	9.5	12.6	117.4
St.Dev.	60.8	189.6	18.8	35.3	21.0	14.3	5.2	10.6	48.9
n	88	90	90	90	25	9	13	25	89
C.V.(%)	37	69	58	43	105	78	55	84	42
Max.	402	600	108	148	117	42	18	42	254
Min.	30	10	0	0	2	3	3	2	13

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Fig. 3.6. Water depth (cm) in Lake Apopka (June 1987).

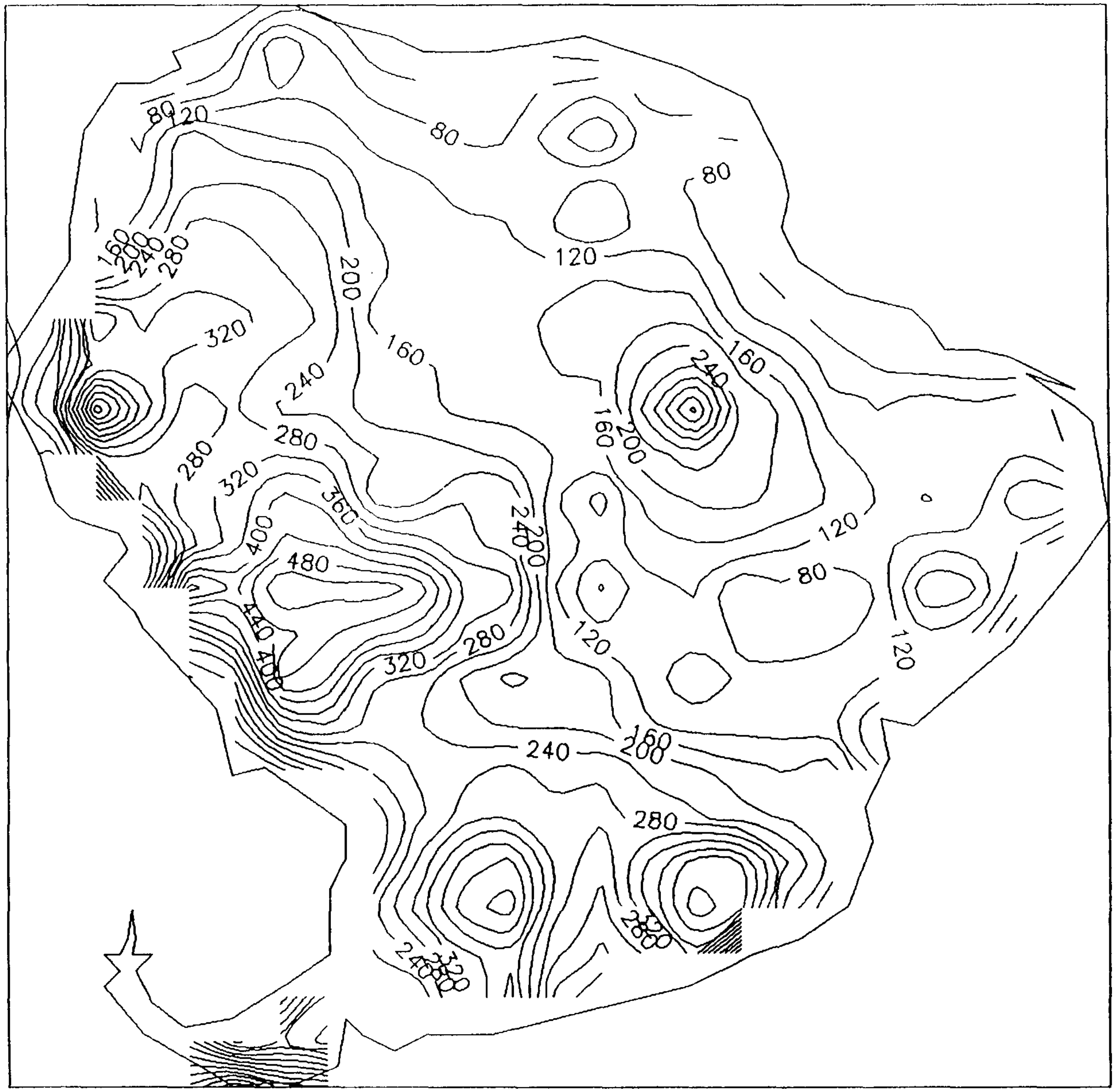


Fig. 3.7. Sediment depth (maximum depth of measuring pole was 600 cm) in Lake Apopka. At some stations sediment depth was >600 cm.

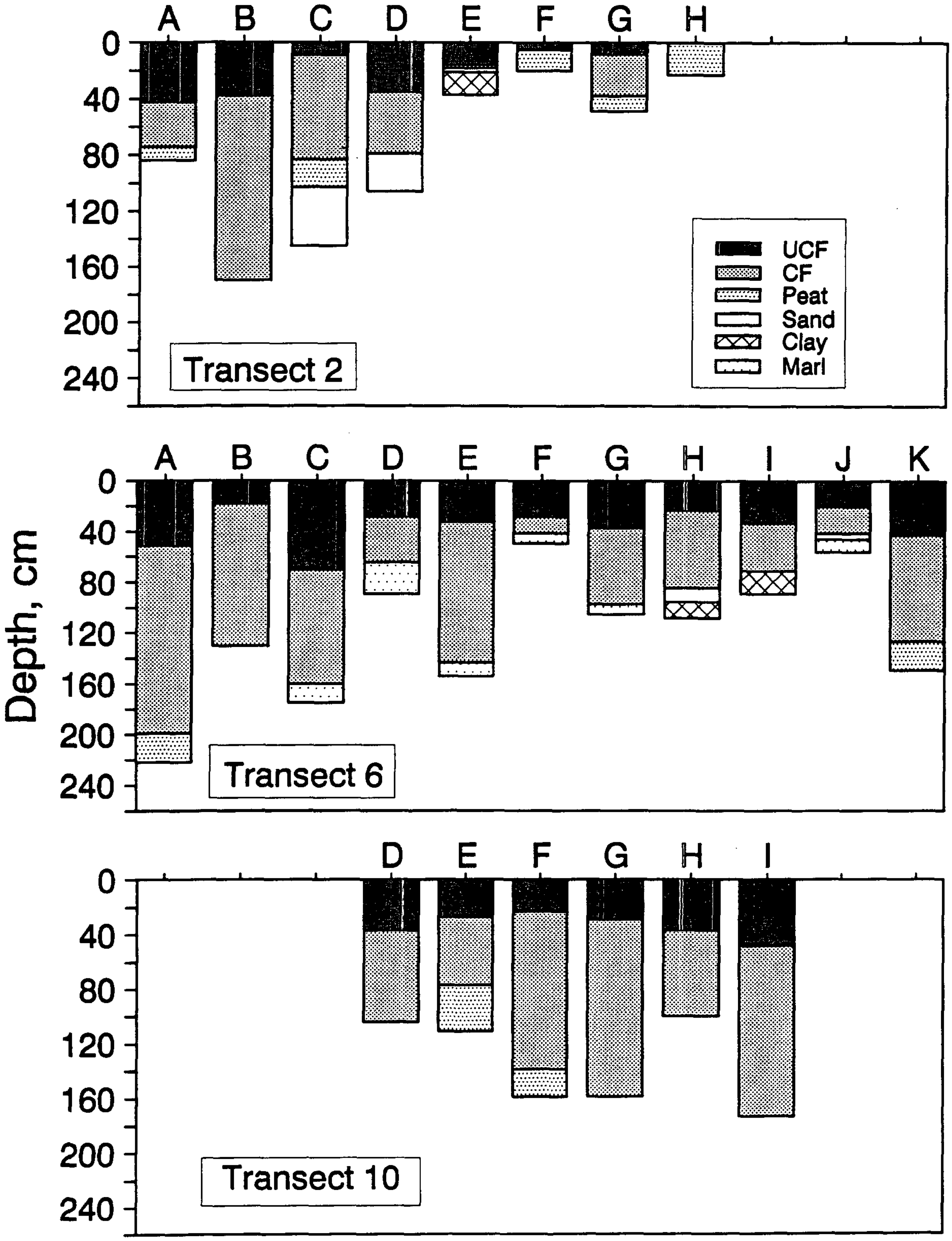


Fig. 3.8. Sediment depths along typical transects (east-west) 2, 6 and 10.

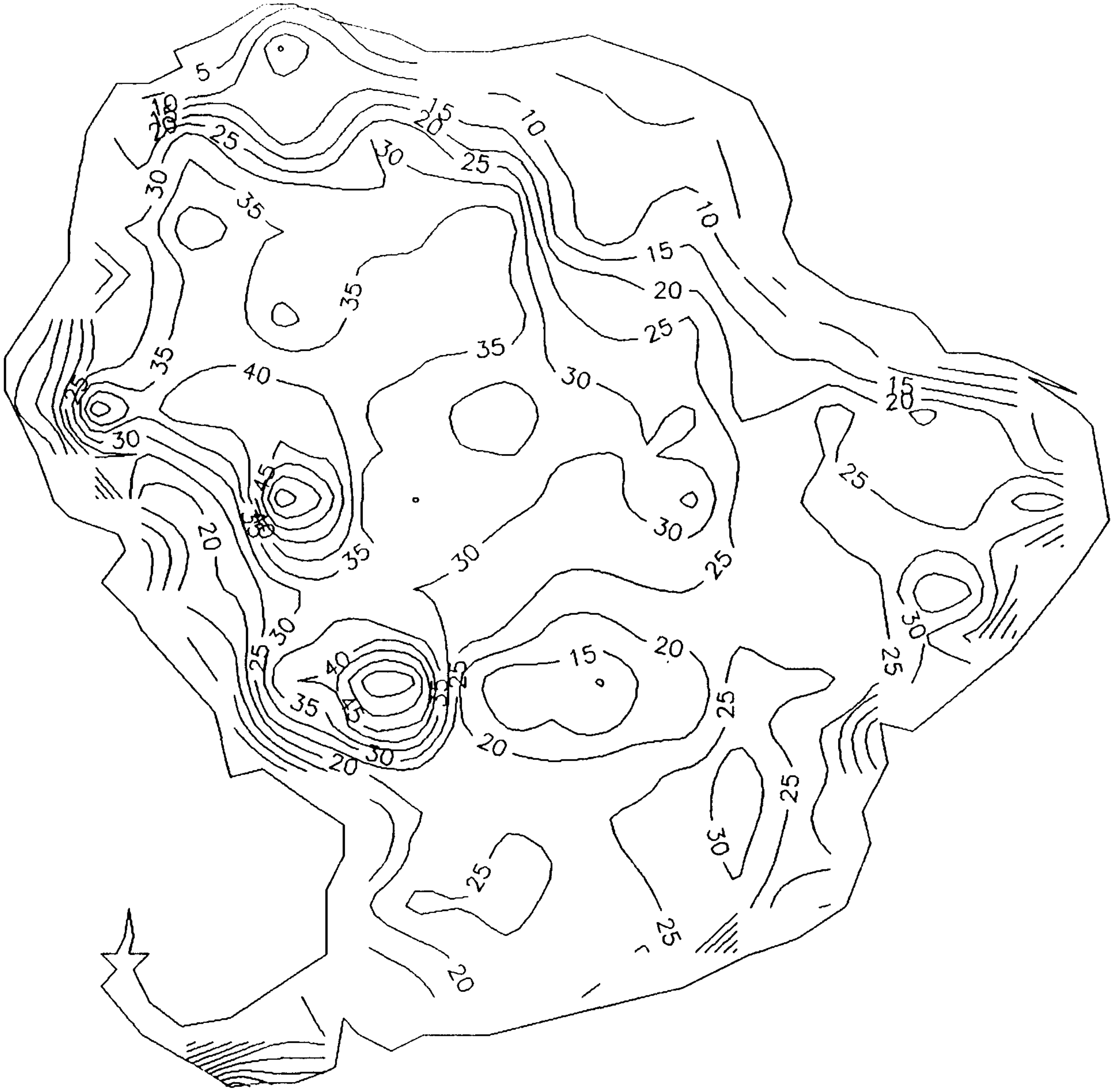


Fig. 3.9a. Unconsolidated floc (UCF) sediment depth (cm) measured at selected stations in Lake Apopka.

Fig. 3.9b. Consolidated floc (CF) sediment depth (cm) measured at selected stations in Lake Apopka.

P = Peat. This fraction consists of partially decomposed tissue of aquatic macrophytes. Peat deposits were noted at 25 stations closer to the shore line. Average thickness of peat was 20 cm (min = 2 cm and max = 117 cm) (Fig. 3.9c; Tables 3.2 and Appendix B-1).

S = Sand. Sand fraction was noted only at 9 stations. Average thickness was 18 cm (min = 3 cm and max = 42 cm) (Fig. 3.9d; Tables 3.2 and Appendix B-1).

C = Clay. Clay was noted at 12 stations and had an average thickness of 10 cm (min = 3 cm and max = 18 cm). This clay is enriched with fine fractions of organic matter probably leached from upper layers of the sediment (Fig 3.9e; Tables 3.2 and Appendix B-1).

M = Marl and limestone. Average thickness of this layer was 13 cm (min = 2 cm and max = 42 cm) (Fig. 3.9f; Tables 3.2 and Appendix B-1). Marl was noted at 25 stations, while limestone was measured at 2 stations. This sediment consists of clay, sand and calcium carbonate. Sediments at these stations were underlain with limestone, with an overlying organic-rich sediment composed of dead aquatic vegetation.

The UCF fraction of the sediment measured in our study is equivalent to the floc-like material measured by Schneider and Little (1969) for sampling conducted in 1968. This provided direct comparison between the data obtained in 1968 and 1987. Average depth of UCF in 1968 was 10.4 ± 9.0 cm, while in 1987, the UCF increased to 32.3 ± 18.8 cm. The mean net deposition thickness during the past 19 years was at 22 cm or 1.2 cm per year (Figs. 3.9g, 3.9h and 3.10). These data assume that the techniques used to measure the UCF fraction in 1968 and 1987 are the same.

The UCF fraction was not observed at stations 2H, 3F, 3H and 7F. Stations 2H, 3F and 3H are underlain with peat indicating that they were once part of the littoral zone, while 7F is underlain with clay. Station 2H is located near Pump House No. 2 and drainage water discharge at this station probably prevented the formation of this flocculent fraction. Both UCF and CF fractions of the sediment are potential sources of nutrients to the overlying water column.

3.4.2 Bulk density and water content

The UCF fraction of the sediment had a mean water content of 96% and a mean total solids content of 4%. The CF fraction was more consolidated with a mean water content of 92% and a mean solids content of 8% (Table 3.3a; Appendix B-2). The average bulk density (dry wt per volume wet) of UCF and CF fraction of the sediment was 0.035 and 0.086 g (dry) cm^{-3}, respectively (Table 3.3a). The corresponding values for wet bulk density are 1.024 and 1.048 g (wet) cm^{-3} (Table 3.3b). The total wet mass of UCF and CF fractions were 45.6 and 110.7 million metric tons, while dry mass was 2 and 9 million metric tons, respectively. Detailed data for all stations are presented in Appendix B-2a - B-2c.

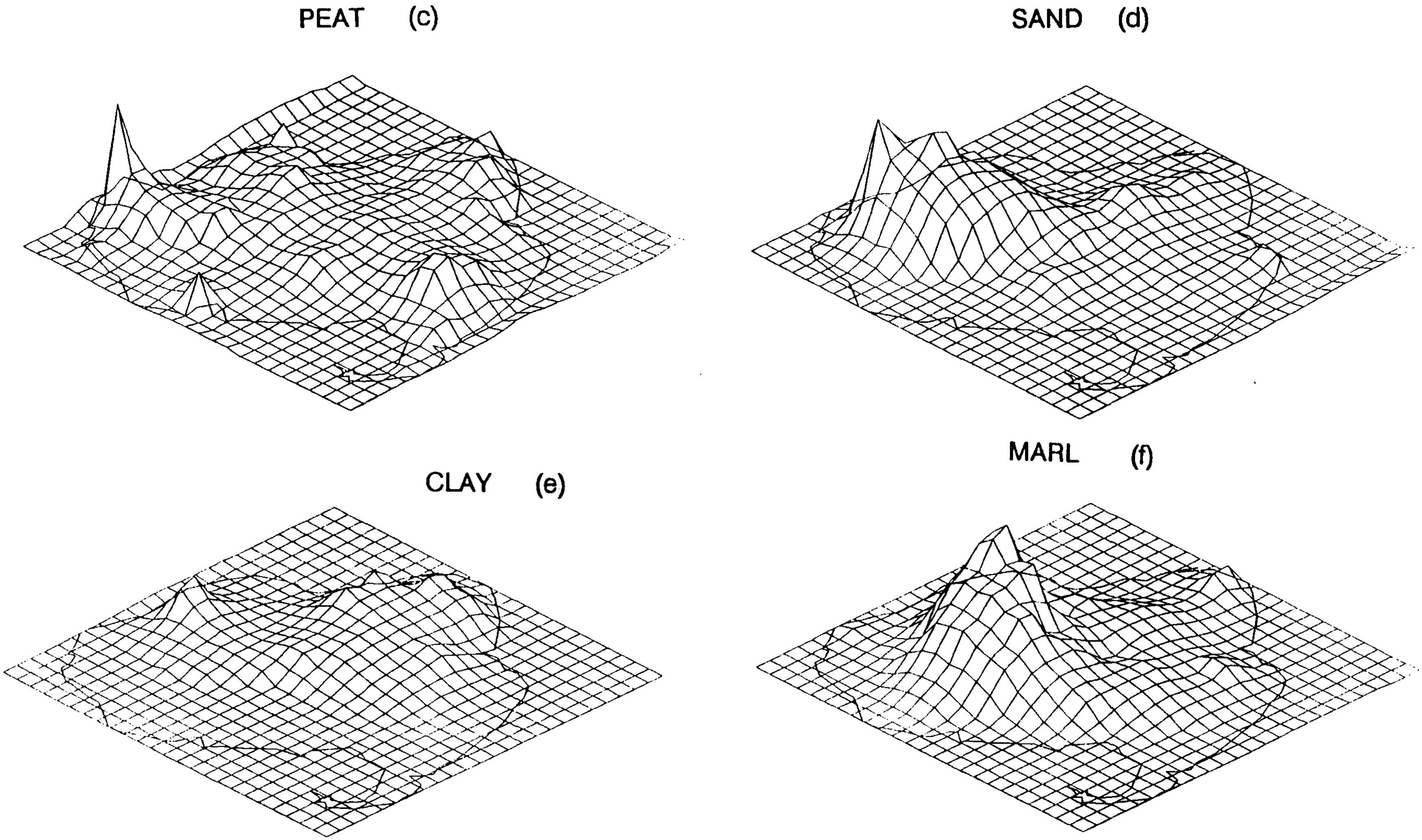
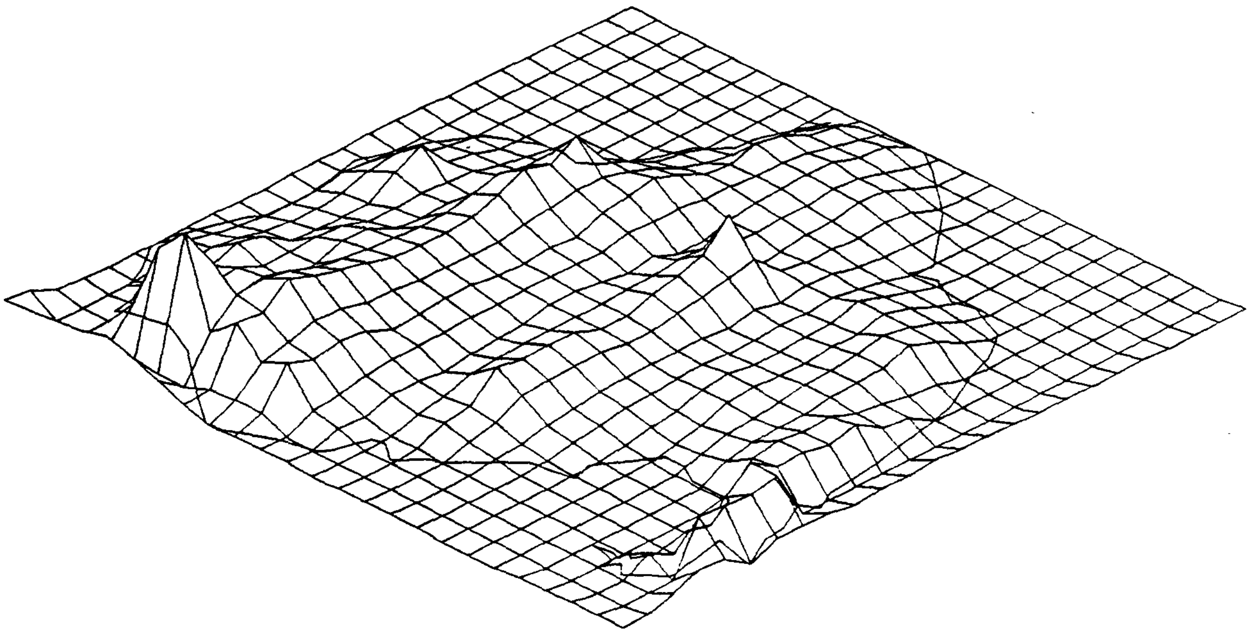


Fig. 3.9c-f. Peat, sand, clay and marl fractions of Lake Apopka sediments.

LAKE APOPKA **UCF** SEDIMENT 1968



LAKE APOPKA **UCF** SEDIMENT 1987

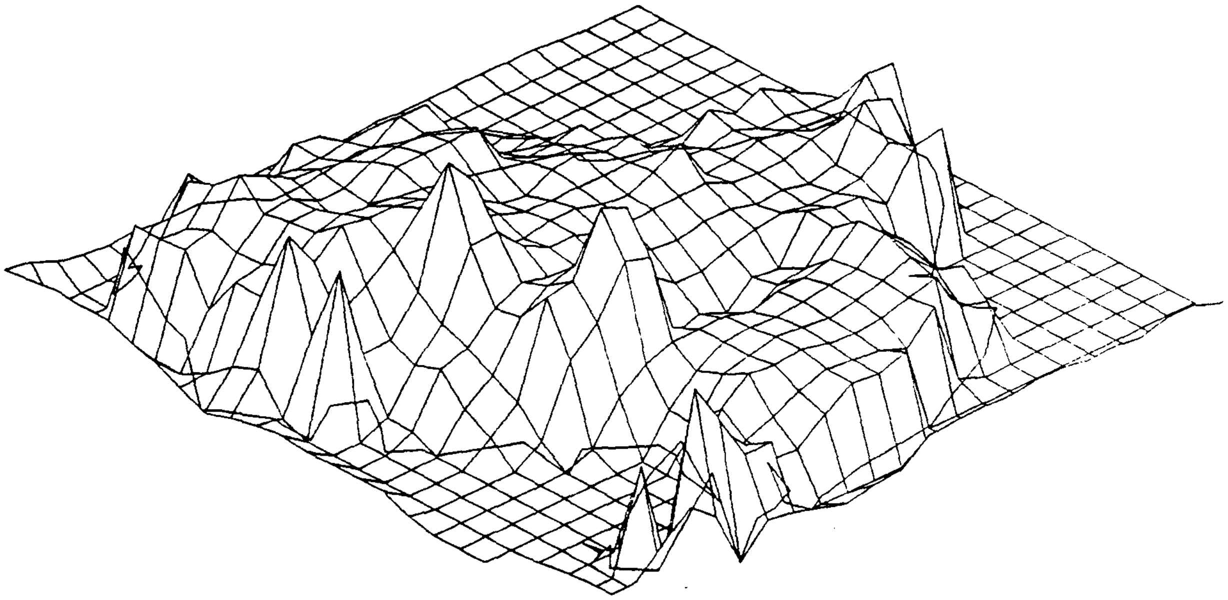
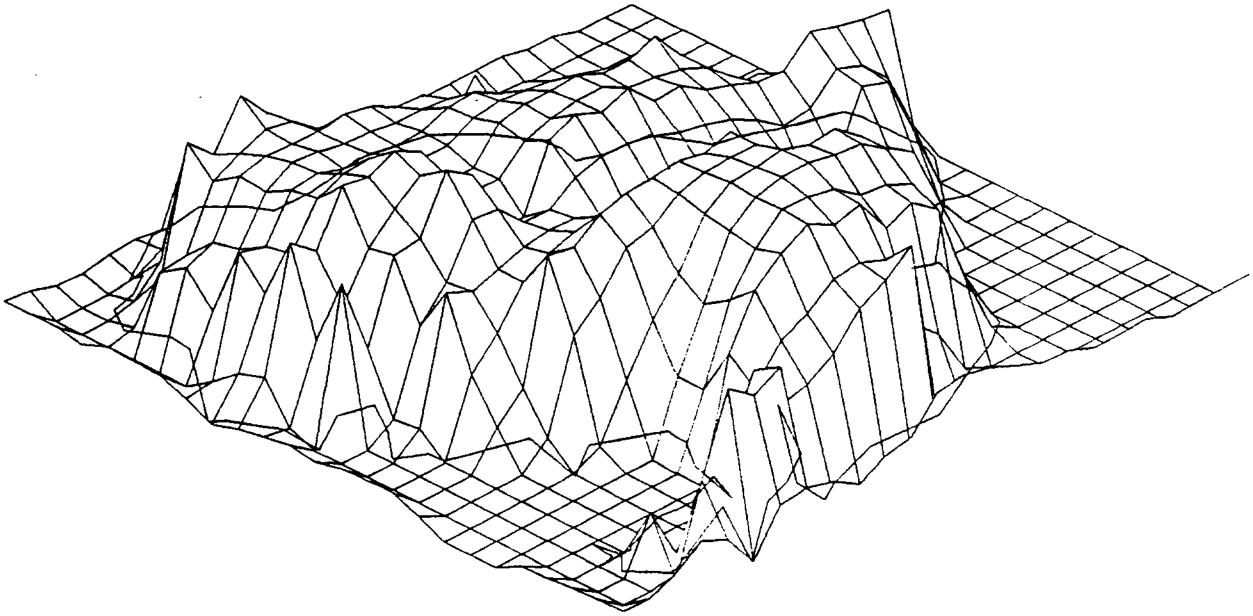


Fig. 3.9g. Unconsolidated floc (UCF) sediment depth (cm) in 1968 (measured by Schneider and Little, 1969) and in 1987 (measured in our study) at selected locations in Lake Apopka.

LAKE APOPKA **CF** SEDIMENT 1968



LAKE APOPKA **CF** SEDIMENT 1987

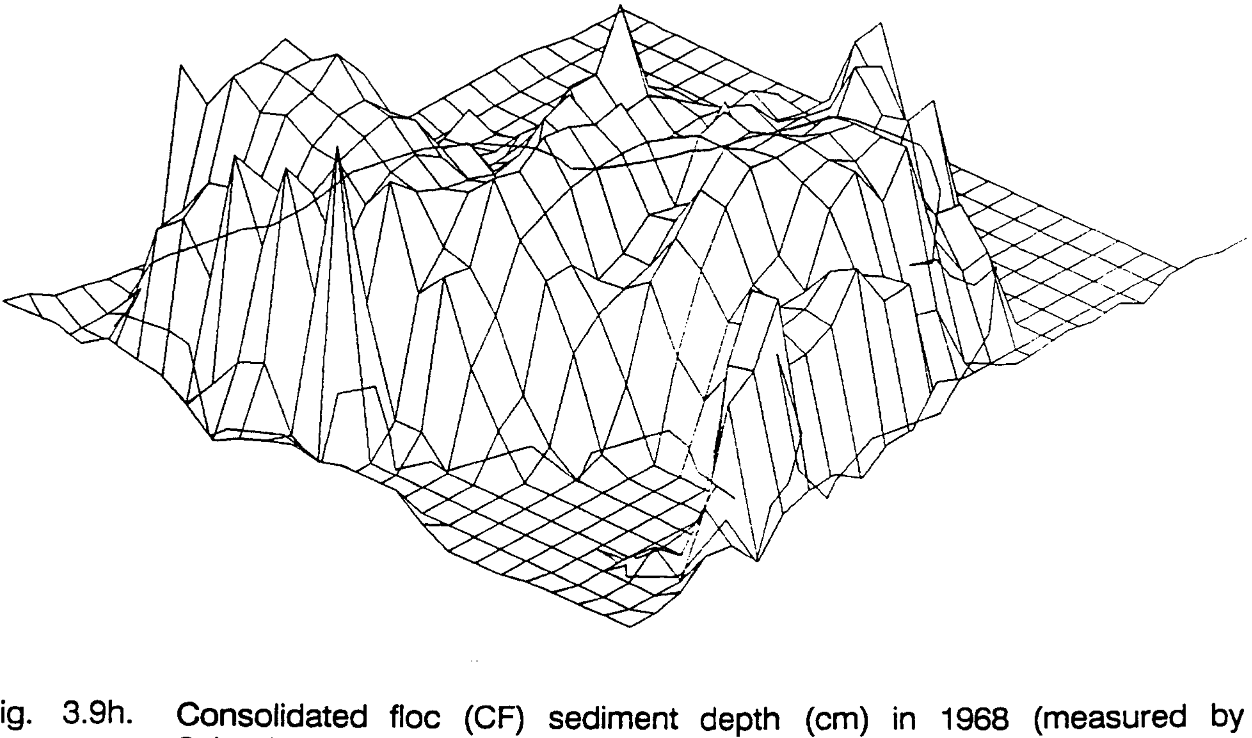


Fig. 3.9h. Consolidated floc (CF) sediment depth (cm) in 1968 (measured by Schneider and Little, 1969) and in 1987 (measured in our study) at selected locations in Lake Apopka.

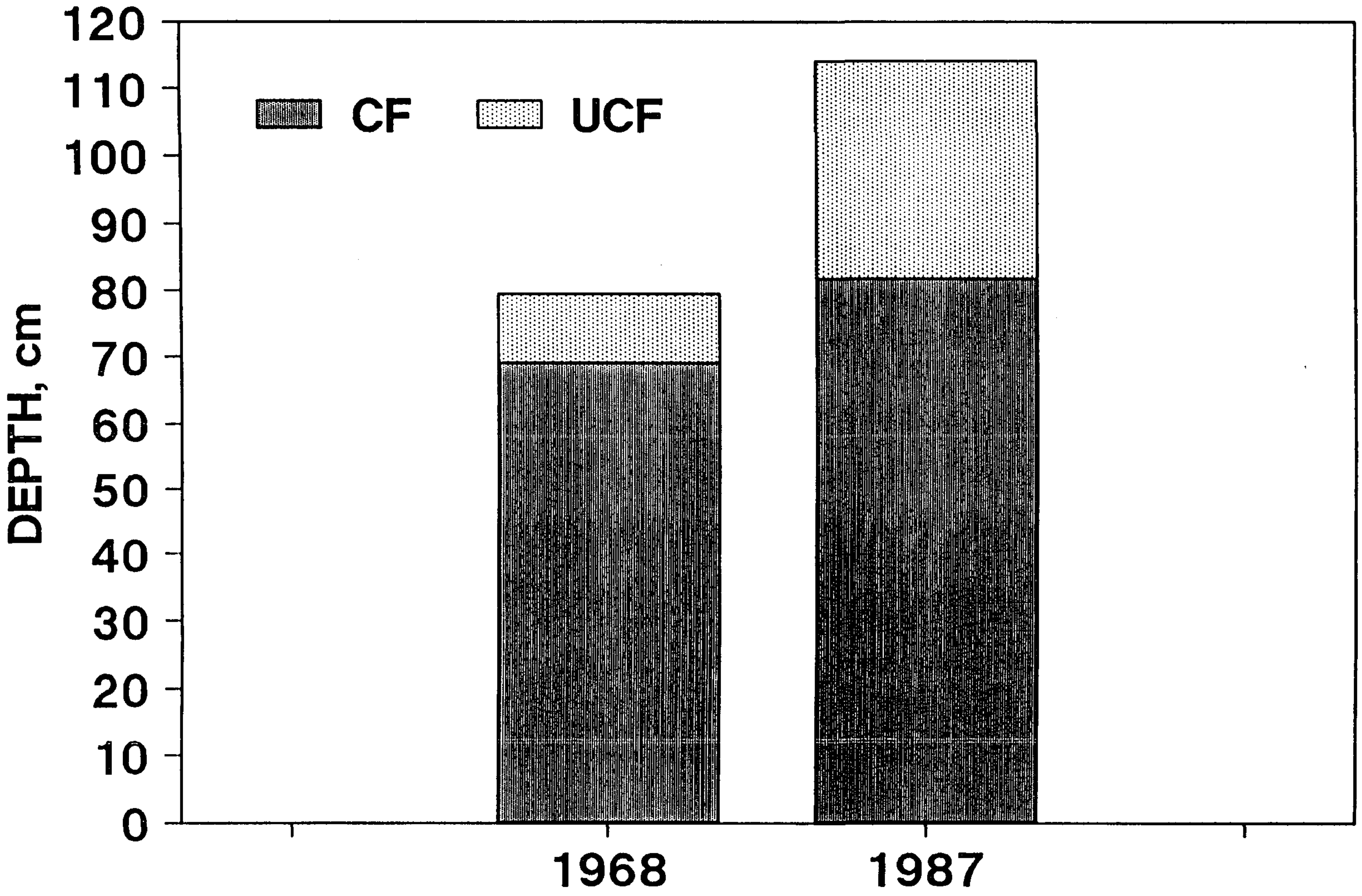


Fig. 3.10. Lake-wide mean sediment depth (cm) of unconsolidated floc (UCF) and consolidated floc (CF) of Lake Apopka as measured in 1968 and 1987.

Table 3.3a. Bulk density and water content of the sediment in Lake Apopka.

	Bulk Density						Water Content					
	UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
	g (dry) cm^{-3}						%					
Mean	0.035	0.086	0.096	0.582	0.54	0.299	96.1	91.9	88.1	67.7	46.4	64.1
St.Dev.	0.014	0.029	0.051	0.461	0.241	0.163	2.9	2.4	9.6	16.9	14.0	19.3
n	84	80	13	6	2	4	87	79	22	9	14	26
C.V.(%)	42	34	53	79	45	55	3	3	11	25	30	30
Max.	0.107	0.205	0.180	1.426	0.781	0.428	99.6	95.5	94.3	84.1	84.8	89.8
Min.	0.004	0.020	0.021	0.230	0.299	0.068	75.5	80.3	52.1	32.1	37.0	32.5

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table 3.3b. Bulk density (g wet/cm^3) of sediment at selected stations in Lake Apopka.

	UCF	CF	P	S	C	M
	--------------------	----------	----------	g (wet)/cm^3	----------	----------
Mean	1.024	1.048	1.172	1.484	1.655	1.388
Std.Dev.	0.112	0.054	0.526	0.416	0.337	0.194
C.V. (%)	10.9	5.1	44.9	28.0	20.4	14.0
n	83	77	14	4	2	6
Min.	1.311	1.287	2.945	2.100	1.992	1.739
Max.	0.571	0.921	0.427	1.075	1.318	1.172

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl; ND = Not Detected.

3.4.3 Sediment porewater chemistry

3.4.3.1 Alkalinity and pH:

Titratable alkalinity was lower in the UCF fraction of the sediment as compared to the CF fraction (Table 3.4, Appendix B-3). High alkalinity in the lower fraction of the sediment was due to the accumulation of CO_2 in the porewater. The pH of the porewater was in the range of 6.6-7.9 for both UCF and CF fractions. Biogeochemical processes functioning within the sediments can alter the alkalinity (Berner et al., 1970; Kuivila and Murray, 1984; Schindler et al., 1986). For example, Schindler et al. (1986) concluded that 79% of the alkalinity in unacidified experimental lakes was the result of sulfate and nitrate reduction. These processes in combination with cation exchange within the sediments can provide significant contribution to the overall alkalinity of the porewater.

3.4.3.2 Conductivity:

Electrical conductivity of the porewater represents ionic strength. The upper portion of the sediment (UCF) generally had lower ionic strength (380 - 1200 $\mu S\ cm^{-1}$) as compared to the CF fraction (345 - 2700 $\mu S\ cm^{-1}$) (Table 3.5, Appendix B-4).

3.4.3.3 Phosphorus:

Average SRP concentration in the surface sediments was 1.26 mg L^{-1} and increased with depth (Table 3.6 and Appendix B-5). The CF fraction of the sediment contained higher P levels in the porewater. No particular relationship was observed between the P concentration of the porewater and the location of sampling. Sampling stations 4B, 4D, 5C, 5I, 7E, 7G and 11G showed significantly higher SRP levels in the porewater than the remaining stations. The SRP levels of the porewater showed significant spatial variability with coefficient of variation >100%. Lower SRP levels in the surface sediments are probably due to P released into the water column either by diffusion and/or release during sediment resuspension. Surface sediments usually have high redox potentials (Eh), and dissolved O_2. In non-calcareous sediments, these conditions can significantly decrease SRP levels of porewater, as a result of ferric phosphate formation. In calcareous sediments (such as in Lake Apopka), redox potential may not have a significant effect, because calcium is not involved in oxidation-reduction reactions. In a recent study, Lake Apopka sediments maintained at high O_2 levels showed an appreciable increase in P retention capacity by the solid phase (see Chapter 5.11).

In the UCF and CF fractions, 50-54% of the total P in the porewater was SRP and the remaining was organic P. Average total P concentration in the porewater was 2.42 ± 1.87 mg L^{-1} in the UCF fraction, while 3.21 ± 4.47 mg L^{-1} was measured in the CF fraction. The soluble organic P is probably derived from decomposition of algal tissue.

Table 3.4. Sediment porewater alkalinity and pH in Lake Apopka.

	Alkalinity						pH					
	UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
	------------mg $CaCO_3$ L^{-1}----------											
Mean	423	540	249	357	385	545	6.98	7.06	7.73	7.62	7.50	7.50
St.Dev.	100	279	202	56	134	127	0.19	0.27	0.27	0.40	0.57	0.34
n	84	80	14	6	2	4	85	80	14	6	2	5
C.V.(%)	24	52	81	16	35	23	3	4	3	5	8	5
Max.	740	1820	820	460	480	720	7.60	7.90	8.10	8.10	7.90	7.90
Min.	140	187	60	310	290	420	6.60	6.65	7.10	7.20	7.10	7.10

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table 3.5. Sediment porewater conductivity (EC) in Lake Apopka.

	UCF	CF	P	S	C	M
	----------------- μS cm^{-1} -----------------					
Mean	801	908	532	663	610	865
St.Dev.	158	348	253	47		52
n	85	80	14	6	1	4
C.V.(%)	20	38	48	7		6
Max.	1200	2700	1180	730	610	910
Min.	380	345	300	610	610	820

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table 3.6. Sediment porewater soluble reactive phosphorus (SRP) and total phosphorus (TP) at selected stations in Lake Apopka.

	SRP						TP					
	UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
	mg L^{-1}											
Mean	1.26	1.47	1.11	0.53	0.33	0.28	2.42	3.00	2.68	0.50	1.05	0.52
St.Dev.	1.24	2.14	1.84	0.076	0.56	0.35	1.89	4.23	4.03	0.32	1.76	0.38
n	86	72	23	7	8	22	87	78	23	7	5	21
C.V.(%)	99	145	166	1	171	124	78	141	151	63	168	73
Max.	5.05	10.42	7.45	2.51	1.67	1.56	8.62	19.08	17.56	0.85	4.17	1.70
Min.	0.02	0.02	0.02	0.07	0.01	0.02	0.17	0.03	0.08	0.10	0.03	0.08

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Porewater P concentrations generally decreased in the sediment fractions below the CF. Average SRP and total P in the porewater of the peat fraction was 1.07 ± 1.85 mg L^{-1} and 2.68 ± 4.03 mg L^{-1}, respectively. Low SRP and high total P in the porewater of the peat fraction indicate high concentrations of organic P. Phosphorus storage in deeper sediments is of less concern with respect to lake water quality. Soluble reactive P content of sand, clay and marl fractions of the sediments was significantly lower than surface sediments (0.13-0.33 mg L^{-1}). Deeper sediment deposits such as peat, sand, clay or marl typically have an overlying layer of CF that functions as a potential sink for P released from below.

The porewater portion of UCF and CF fractions of the sediment contained a total of 97 and 318 metric tons of P, respectively. This represents a total P storage of 415 metric tons (914,097 pounds; 33.2 kg P ha^{-1}) in the porewater which can be potentially released into the overlying water column. It should be noted that the porewater P content represents the equilibrium P concentration in the sediment. Depletion of porewater P as a result of its upward movement into the water column will result in P release from exchange sites on the solid phase of the sediment into the porewater and approach a new equilibrium P concentration. There will be a steady supply of P from the solid phase of the sediment into the porewater through desorption and microbial decomposition processes. Continuous depletion of porewater P will decrease the concentration gradients, thus causing a decrease in the upward flux of P.

3.4.3.4 Nitrogen:

Porewater nitrate N concentrations were <0.01 mg L^{-1} (data not shown) for all stations and for all sediment fractions. Negligible nitrate concentrations in the sediments indicate active denitrification and intense anoxic conditions.

Porewater ammonium N concentrations were lower in the UCF fraction (29.3 ± 19.9 mg L^{-1}) as compared to the CF fraction (37.4 ± 31.9 mg L^{-1}; Table 3.7 and Appendix B-6). Ammonium concentrations were much lower in peat, sand and clay fractions of the sediment. Ammonium N in the porewater showed less spatial variability, with a coefficient of variation of 68 and 88% for UCF and CF fractions, respectively.

In the UCF fraction, ammonium N concentration of the porewater was in the range of 3.0 to 110.2 mg N L^{-1}, while in the CF fraction the range was 5.5 to 178.2 mg N L^{-1}. Station 7E showed high ammonium levels for both UCF and CF fractions. At this station the total P concentration of the porewater was also high (Appendix B-5).

High ammonium N levels in the sediment are an indication of intense microbial activity and anaerobic conditions. Low ammonium levels in the UCF fraction are due to the release of ammonium from the sediment to the water column through: (1) sediment resuspension, and (2) molecular diffusion. During wind-driven wave action, a portion of the surface sediment can be suspended in the water column

Table 3.7. Porewater and exchangeable ammonium N of sediment collected at selected stations in Lake Apopka.

	Porewater Ammonium N						Exchangeable Ammonium N					
	UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
	mg L^{-1}						mg kg^{-1}					
Mean	29.3	37.4	18.0	18.3	22.4	23.8	213.2	234.2	267.9	130.5	205.0	249.5
St.Dev.	19.9	31.9	18.4	5.3	19.4	15.6	161.9	190.0	233.0	129.1	218.5	
n	87	78	23	8	13	9	86	75	22	6	12	1
C.V.(%)	68	85	103	31	86	65	76	81	87	99	107	
Max.	110.2	178.2	83.8	25.1	68.9	47.8	1018.3	827.4	714.9	335.6	845.3	249.5
Min.	3.0	5.3	3.2	8.8	0.8	1.0	10.3	18.2	13.4	25.1	23.5	249.5

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

resulting in the release of ammonium. Ammonium thus released is either assimilated by algae or lost through physico-chemical and biochemical processes.

The pH of the water column in Lake Apopka is regulated by the balance between photosynthesis and respiration, and the buffering capacity of the carbonate system. This results in an elevation of pH levels to 10 during high photosynthetic activity and a decrease to near neutral levels during night time (Reddy, 1981). High pH levels favor the conversion of ammonium N to aqueous ammonia which can be lost from the system through volatilization. Nitrification, a microbially mediated process, can convert ammonium to nitrate in the water column, and the nitrate can diffuse into underlying sediments and undergo denitrification.

Ammonium N in the porewater is regulated by the adsorption capacity of the sediment solid phase and its physico-chemical properties. As the retention capacity of the solid phase increases, the concentration of ammonium in the porewater decreases, thus less ammonium is released into the overlying water column.

Total N in the porewater was analyzed in two fractions. After the sediments were centrifuged at 5,000 RPM, a portion of the supernatant porewater was directly analyzed for total Kjeldahl N (Table 3.8 and Appendix B-7) while a second portion was filtered through 0.45 μm filter paper and also analyzed for dissolved total N (DTKN) (Table 3.9 and Appendix B-8). The total organic N (TON) was calculated from the difference between total Kjeldahl N and ammonium N. Unfiltered solutions represent total N in the porewater, while the filtered solutions represent total dissolved N (DTKN) and dissolved organic N (DTON) in the porewater.

Total N concentration in the porewater was in the range of 8.9 to 115.1 mg N L^{-1} in the UCF fraction and 12.2 to 217.9 mg N L^{-1} in the CF fraction. Average concentrations for UCF and CF fractions were 37.8 ± 18.4 and 54.8 ± 41.2 mg N L^{-1}, respectively. Total Kjeldahl N content of the porewater in peat, sand, clay and marl fractions was also high (38.3 to 61 mg N L^{-1}), indicating significant amounts of soluble organic N move within the sediment profile.

Total N stored in the sediment porewater of Lake Apopka was estimated to be 1,509 metric tons (3.32 million pounds) in the UCF fraction and 5,467 metric tons (12.04 million pounds) in the CF fraction. Total N storage in the porewater of both the UCF and CF fractions was 6,976 metric tons (558 kg N ha^{-1}) which can be potentially transferred into the overlying water column. Ammonium N represents 78% of the total porewater N for the UCF fraction and 69% of the total porewater N for the CF fraction. The remaining N is in organic form which potentially can be mineralized into ammonium N. The TKN/TP ratio in the porewater was found to be 16. Depletion of porewater P via hydroxy apatite formation and increase in dissolved N fractions as a result of biological N_2 fixation and decomposition of sediment organic N can also result in higher N:P ratios.

Table 3.8. Sediment porewater total Kjeldahl nitrogen (TKN) and total organic nitrogen (TON) at selected stations in Lake Apopka.

	TKN						TON					
	UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
	mg L^{-1}											
Mean	37.8	54.8	44.3	60.6	37.1	51.2	9.3	17.2	23.4	26.5	17.0	27.6
St.Dev.	18.4	41.2	24.9		13.7	30.9	8.4	20.6	19.7	22.1	14.1	30.8
n	87	69	23	1	9	20	84	69	23	3	10	20
C.V.(%)	49	75	56		37	60	91	120	84	83	83	112
Max.	115.1	217.9	109.2	60.6	61.7	131.8	43.2	141.3	91.1	51.8	52.7	113.2
Min.	8.9	12.2	13.6	60.6	22.3	18.4	ND	ND	5.3	10.6	2.4	7.4

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl; ND = Not Detected.

Table 3.9. Dissolved total Kjeldhal nitrogen (DTKN) and organic nitrogen (DON) of sediment porewater at selected stations in Lake Apopka. Dissolved fractions were analyzed after porewater was filtered through 0.45 μm filter paper.

	DTKN						DON					
	UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
	---mg L^{-1}---											
Mean	33.7	49.5	32.3	30.0	26.3	37.9	5.5	13.0	14.4	14.0	10.8	19.4
St.Dev.	20.4	34.5	22.3	12.5	15.3	22.0	9.0	13.6	13.0	10.3	5.5	29.1
n	87	78	22	5	9	21	84	76	22	5	6	10
C.V.(%)	61	70	69	42	58	58	162	105	90	74	51	150
Max.	113.0	196.4	100.4	44.0	57.7	105.8	67.1	83.2	63.2	28.0	17.1	87.3
Min.	4.3	9.2	10.7	15.0	4.0	15.9	ND	ND	1.2	1.0	2.6	0.3

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl; ND = Not Detected.

3.4.3.5 Carbon:

Data on the total organic C (TOC) concentrations of the porewater are presented in Table 3.10 and Appendix B-9. Average TOC in the porewater was 32.5 ± 20.0 mg L^{-1} in the UCF fraction and 34.0 ± 22.0 mg L^{-1} in the CF fraction of the sediments. At lower sediment depths, a much higher porewater TOC concentration (50.6 to 109.5 mg L^{-1}) was measured. The maximum TOC concentration was observed at station 4H for UCF and station 11E for CF fractions. The total TOC storage for the whole lake was estimated to be 1,298 metric tons (2.86 million pounds) in the UCF and 3,366 metric tons (7.4 million pounds) in the CF fraction which can be potentially decomposed and release nutrients, including inorganic C, into the overlying water column. Total mass of TOC in both the UCF and CF fractions was 4,664 metric tons (373 kg C ha^{-1}).

Data on the dissolved inorganic C (DIC) content of the porewater are shown in Table 3.11 and Appendix B-10. The dissolved inorganic C content in the UCF fraction of the sediment was in the range of 1.5 to 128.6 mg C L^{-1} (average = 53.3 ± 26.3 mg L^{-1}), while DIC concentration was significantly higher in the CF fraction of the sediment (average = 68.6 ± 46.3 mg L^{-1}). In the peat fraction, DIC decreased significantly to 17.0 ± 24.2 mg C L^{-1}. High DIC levels are representative of calcareous sediments. The mass of porewater DIC in UCF and CF fraction was 2,130 and 6,849 metric tons, respectively, with a total of 8,979 metric tons (718 kg C ha^{-1}). The total mass of both organic and inorganic C was 13,643 metric tons (1091 kg C ha^{-1}), of which 34% is contributed by organic C and 66% by inorganic C.

3.4.3.6 Selected cations:

Data on porewater concentrations of selected cations are presented in Tables 3.12-3.17 and Appendix B-11 - B-16. In all sediment fractions, calcium was the most dominant cation with an average concentration of 107.0 ± 20.5, 102.3 ± 37.5, 35.1 ± 26.2, 49.2 ± 8.5, 65.0 ± 29.8 and 56.7 ± 22.7 mg L^{-1}, in UCF, CF, P, S, C and M fractions of the sediments, respectively. Similar trends were also noted for porewater magnesium concentrations, with an average concentration of 29.7 ± 7.6 mg L^{-1} in the UCF fraction and 24.2 ± 12.2 mg L^{-1} in the CF fraction. The peat fraction contained the lowest levels of magnesium in the porewater.

Potassium concentrations were also higher in UCF fractions and decreased with depth. The average potassium concentration was 12.4 ± 2.5 mg L^{-1} with a maximum of 16.7 mg L^{-1} and a minimum of 2.4 mg L^{-1}. Sodium concentrations were also higher in the surface sediments and decreased with depth.

Iron concentrations showed no definitive trend. High iron concentrations were noted in the porewater of the peat fraction (0.37 ± 0.93 mg L^{-1}). In this fraction, the maximum iron concentration was 4.2 mg L^{-1}. In the UCF fraction, the average iron concentration was 0.16 ± 0.23 mg L^{-1}, while in the CF fraction, the average iron concentration was 0.19 ± 0.23 mg L^{-1}. The low solubility of iron is due to high pH conditions in the porewater.

Table 3.10. Total organic carbon (TOC) of sediment porewater at selected stations in Lake Apopka.

	UCF	CF	P	S	C	M
	------------------------mg L^{-1}----------------------					
Mean	32.50	34.00	109.50	54.23	50.59	107.71
St.Dev.	20.03	21.99	213.68	15.40	20.03	138.01
n	86	69	22	7	10	25
C.V.(%)	62	65	195	28	40	128
Max.	123.04	190.07	1047.00	81.25	82.14	584.43
Min.	12.87	16.39	10.67	37.23	24.88	28.90

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table 3.11. Dissolved inorganic carbon (DIC) content of sediment porewater at selected stations in Lake Apopka.

	UCF	CF	P	S	C	M
	mg L^{-1}					
Mean	53.62	68.65	22.32	28.14	39.57	36.48
St.Dev.	26.38	46.31	32.92	12.90	36.28	19.95
n	87	75	21	3	10	19
C.V.(%)	112	67	147	46	92	55
Max.	128.56	231.30	119.90	42.98	129.34	79.72
Min.	1.50	ND	ND	19.56	7.17	12.74

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl; ND = Not Detected.

Table 3.12. Concentration of major cations in the unconsolidated flocculent (UCF) sediment at selected stations in Lake Apopka.

Station	Ca	Mg	K	Fe	Mn	Al	Cu	Na
	mg L^{-1}							
Mean	107.24	29.89	12.49	0.16	0.10	0.01	0.02	17.4
Std. Dev.	20.48	7.38	2.25	0.23	0.05	0.03	0.14	2.5
n	87	87	87	87	87	87	87	87
C.V. (%)	19.1	24.7	18.0	146.0	52.3	369.6	810.0	14.6
Max.	141.85	63.33	16.67	1.25	0.23	0.10	1.30	21.5
Min.	17.70	5.10	2.40	ND	ND	ND	ND	3.4

ND = Not Detected.

Table 3.13. Concentration of major cations in the porewater of consolidated flocculent (CF) sediment at selected stations in Lake Apopka.

Station	Ca	Mg	K	Fe	Mn	Al	Cu	Na
	----------	----------	----------	mg L^{-1}	----------	----------	----------	----------
Mean	102.3	24.2	9.3	0.2	<0.1	<0.1	<0.1	15.1
Std. Dev.	37.4	12.3	3.7	0.2		0.1		4.9
n	68	68	68	68	68	68	68	68
C.V. (%)	37	51	40	126	82	825	461	32
Max.	180.0	54.5	20.5	1.1	0.2	1.1	0.3	23.3
Min.	25.2	5.0	1.0	0.0	0.0	0.0	0.0	4.4

Table 3.14. Concentration of major cations in the peat (P) at selected stations in Lake Apopka.

Station	Ca	Mg	K	Fe	Mn	Al	Cu	Na
	mg L^{-1}							
Mean	33.59	7.33	7.42	0.39	0.007	0.04	0.02	12.19
Std. Dev.	25.97	4.21	3.89	0.95	0.03	0.13	0.04	3.85
n	20	20	20	20	20	20	20	20
C.V. (%)	130	21	19	5	0	1	0	19
Max.	105.33	17.33	16.54	16.54	0.133	0.56	0.13	18.96
Min.	7.10	2.06	0.91	0.91	ND	ND	ND	5.20

ND = Not Detected.

Table 3.15. Concentration of major cations in the porewater of sand (S) at selected stations in Lake Apopka.

Station	Ca	Mg	K	Fe	Mn	Al	Cu	Na
	----------	----------	----------	----mg L^{-1}	----------	----------	----------	----------
Mean	49.2	12.1	6.0	0.1	ND	ND	ND	13.7
Std. Dev.	8.5	7.6	2.9	0.1	ND	ND	ND	5.6
n	3	3	3	3	3	3	3	3
C.V. (%)	17	62	49	173	173	173	173	41
Max.	56.5	20.6	8.6	0.2	ND	ND	0.1	17.2
Min.	39.8	6.0	2.8	ND	ND	ND	ND	7.2

ND = Not Detected.

Table 3.16. Concentration of major cations in the porewater of clay (C) at selected stations in Lake Apopka.

Station	Ca	Mg	K	Fe	Mn	Al	Cu	Na
	----------	----------	----------	-------mg L^{-1}	----------	----------	----------	----------
Mean	65.0	15.3	9.8	<0.1	<0.1	ND	<0.1	16.5
Std. Dev.	29.8	8.8	4.1					4.9
n	10	10	10	10	10	10	10	10
C.V. (%)	46	57	42	316	229		149	30
Max.	104.4	27.2	18.2	0.3	0.1	ND	0.2	24.6
Min.	14.3	3.4	5.5	0.0	0.0	ND	0.0	11.1

ND = Not Detected.

Table 3.17. Concentration of major cations in the porewater of marl (M) at selected stations in Lake Apopka.

Station	Ca	Mg	K	Fe	Mn	Al	Cu	Na
	mg L^{-1}							
Mean	56.7	18.7	7.6	0.1	ND	ND	ND	14.9
Std. Dev.	22.7	11.0	3.6	0.2	ND	ND	ND	4.5
n	20	20	20	20	20	20	20	20
C.V. (%)	40	59	48	250	179		112	30
Max.	95.0	44.8	15.8	0.6	ND	ND	0.1	20.3
Min.	ND	ND	ND	ND	ND	ND	ND	ND

ND = Not Detected.

Trace concentrations of manganese, aluminum and copper were measured for all sediment fractions. Porewater manganese concentrations were in the range of 0.006 to 0.095 mg L^{-1}, with high values measured in the UCF fraction, while low values were measured in the peat fraction. Aluminum concentrations were <0.02 mg L^{-1}, and copper concentrations were <0.04 mg L^{-1} for all sediment fractions. The solubility of these metallic cations is governed by the pH, with low pH favoring their solubility.

Generally, all cations were higher in the UCF fraction and decreased with depth. Concentration of cations was in the order of Mg > Na > K > Fe > Ca > Mn > Cu > Al. This relationship was found for all sediment fractions.

The data presented on cations and anions can be used to determine solid phases governing the solubility of various compounds, complexation and speciation of various ionic species using computer programs such as GEOCHEM and WATEQF.

3.4.4 Extractable nutrients

The extractable nutrients in the sediment represent labile nutrients which are potentially available to algae or other macrophytes.

3.4.4.1 Ammonium nitrogen:

The ammonium N extracted using 2 M KCl solution represents the exchangeable N adsorbed on the solid phase of the sediment. In the UCF, sediment ammonium N in the exchangeable fraction was 213 mg kg^{-1} of sediment (oven dry), while the CF sediment contained 234 mg kg^{-1} of sediment (oven dry) (Table 3.7 and Appendix B-6). Ammonium N adsorbed on the solid phase is in equilibrium with the ammonium N in the porewater and the concentration in the porewater is controlled by the adsorptive capacity of the sediment, which is described by the partition coefficient (K = ammonium N adsorbed/ammonium N in the porewater). The partition coefficients for ammonium in the UCF and CF sediments were 7.3 and 6.5 L kg^{-1}, respectively, indicating that the surface sediments have slightly higher ammonium adsorptive capacity.

3.4.4.2 Phosphorus:

Labile P present in the sediments was extracted using double acid (0.025 N H_2SO_4 + 0.05 N HCl) (Olsen and Sommers, 1982) (Table 3.18a and Appendix B-17a). This extraction procedure was developed for making P fertilizer recommendations for growing agricultural crops. A second extraction procedure with stronger acid mixture (0.5 N HCl + 0.25 N H_2SO_4) was used to extract non-labile mineral forms of P (Table 3.18b and Appendix B-17b).

Acid extractable P represents the P potentially available to biota. Labile P concentrations were higher in the UCF fraction and decreased with depth. The peat

Table 3.18a. Sediment double acid (0.05 N HCl + 0.025 N H_2SO_4) extractable phosphorus at selected stations in Lake Apopka.

Station	UCF	CF	P	S	C	M
	----------------	----------------	----------------	mg L^{-1}	----------------	----------------
Mean	218.9	119.8	79.5	181.1	50.7	27.9
Std. Dev.	166.0	112.3	70.6	429.2	31.2	54.8
n	86	67	24	10	12	25
C.V. (%)	76	94	89	237	62	196
Max.	1415.1	924.3	277.1	1397.2	106.3	279.5
Min.	36.1	12.9	11.9	4.8	0.0	0.0

UCF = unconsolidated flocculent; CF = consolidated flocculent; P = peat; S = sand; C = clay; M = marl.

Table 3.18b. Sediment double acid (0.05 N HCl + 0.25 N H_2SO_4) extractable phosphorus at selected stations in Lake Apopka.

	UCF	CF	P	S	C	M
	----------------------mg	kg^{-1}----------------------				
Mean	490.3	318.2	149.6	394.3	148.8	146.8
Std.Dev.	229.9	180.7	116.0	612.6	142.8	150.2
n	87	68	24	6	14	22
C.V.(%)	47	57	78	155	96	102
Max.	1291.8	1082.9	406.9	1632.9	532.9	647.5
Min.	97.5	28.8	17.3	40.2	ND	0.7

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl; ND = Not Detected.

fraction contained lower concentrations of double-acid extractable P. Values presented in Tables 3.18a,b and Appendix B-17a,b include porewater P plus P present as calcium phosphate and other mineral forms.

The weak double acid extractable P probably represents the labile fraction of P which may be biologically available. In the UCF and CF fractions, mass of P present in this form was 309 (25 kg ha^{-1}) and 1053 (84 kg ha^{-1}) metric tons of P, respectively. Porewater P represents 28% of the weak acid extractable P.

In the UCF and CF fractions of the sediment, mass of P present in acid extractable (0.5 N HCl + 0.25 N HCl) form was 693 (55 kg ha^{-1}) and 2,798 (224 kg ha^{-1}) metric tons of P, respectively. Total P in the strong acid extractable form was 3,491 metric tons (279 kg P ha^{-1}). Porewater P represents about 11% of the acid extractable P, while the remaining P is present in stable inorganic form. The P extracted with the strong acids represents apatite forms and hydrolysis of some organic P. A significant portion of this fraction may not be readily available.

3.4.4.3 Fractionation of sediment phosphorus:

The total P of the UCF sediment (0-35 cm) ranged from 670 to 1520 mg P kg^{-1} while that of the CF (35-127 cm) ranged from 210-1090 mg P kg^{-1} (Table 3.19). The deeper horizon of the lake sediments which had either peat, clay, or marl had total P content less than 400 mg P kg^{-1}. Generally, the total P content of the sediments decreased with depth. This may indicate that the sediments could have accumulated P by deposition.

Among the phosphate forms, calcium-bound P was the most predominant fraction in all sediment samples (Table 3.19). Calcium-bound phosphate varied from 25-40% of the total P in the UCF layer (Fig. 3.11) while it ranged from 30-80% in the CF fraction (Fig. 3.11). A considerable fraction of the total P in the surface (UCF) horizon was also bound to Fe and Al and carbonates. This indicates that P in the upper most layer exists in various forms and is widely distributed among the different constituents of the sediments. Phosphorus in the subsurface layers (CF, P, C, and M) was generally less distributed and existed mainly in Ca-P form.

The P fractions shown in Table 3.19 are expressed in terms of percent total P in each sample. The sum of P recovered in the extraction procedure was the total of all P fractions namely: soluble reactive P (SRP), NaCl extractable P (extr P), carbonate bound P (CO_3-P), iron and aluminum-bound P (Fe/Al P), and calcium-bound P (Ca-P). The residual P was calculated by subtracting the P recovered in fractionation from total sediment P determined by perchloric acid digestion.

Although the UCF showed a wide distribution of phosphate among the different P fractions, it had a low P recovery. The P recovered from the UCF layer ranged from 29-63% while that of the CF ranged from 45-83% (Table 3.19). The mean residual P for these horizons were 48% and 34%, respectively. The low P recovery in the UCF layer could be attributed to its high organic fraction. Since this layer

Table 3.19. Phosphorus distribution of Lake Apopka sediments as determined by chemical fractionation (Van Eck, 1982).

	Labile P				Non-labile P			
Station	SRP	Extr P	CO_3-P	Lab org P	Fe/Al P	Ca-P	Residl P	Total P
	% of total P (by $HClO_4$)							mg kg^{-1}
Unconsolidated Flocculent (UCF):								
C3	0.4	3.1	4.1	4.3	9.7	40.9	37.4	980
G3	1.4	1.1	1.4	2.9	7.2	39.1	46.9	670
E5	0.4	0.9	0.8	2.1	4.6	37.5	53.7	840
I5	5.9	3.1	5.2	4.5	11.2	30.9	39.1	1100
C7	1.4	0.6	1.8	2.9	11.5	39.4	42.5	1000
G7	5.6	3.1	5.5	4.3	18.9	25.7	37.0	1520
D9	8.5	4.0	7.1	3.1	6.8	27.0	43.6	1360
H9	1.5	0.6	1.4	1.7	4.7	19.0	71.1	1170
F11	2.5	0.6	3.3	2.8	14.2	29.5	47.0	1360
C12	0.7	0.2	2.6	0.4	10.6	23.1	62.4	880
Mean	2.8	1.7	3.3	2.9	9.9	31.2	48.1	1089
Consolidated Flocculent (CF):								
E5	0.3	0.3	1.5	0.1	2.2	40.9	54.7	640
I5	0.3	0.4	0.9	0.6	4.2	68.6	24.9	210
C7	0.2	0.3	0.5	0.7	2.8	75.7	19.8	460
G7	4.8	7.6	9.0	3.8	6.4	31.0	37.5	1090
D9	4.3	2.9	7.2	3.0	9.0	56.1	17.4	620
H9	0.6	0.5	1.0	0.8	2.8	55.3	38.9	430
E10	0.2	0.0	0.1	0.2	1.4	78.4	19.8	700
F11	0.1	0.0	0.2	0.0	3.8	52.0	43.9	420
C12	0.0	0.0	0.0	0.0	2.0	45.5	52.5	390
Mean	1.2	1.3	2.3	1.0	3.8	56.0	34.4	551
Peat (P):								
G3	0.2	0.1	0.4	0.1	1.4	32.7	65.1	380
E10	0.0	0.2	0.2	0.4	1.0	9.4	88.8	290
Mean	0.1	0.1	0.3	0.2	1.2	21.1	76.9	335
Clay (C):								
I5	0.0	0.0	0.0	0.0	0.2	24.4	75.4	170
G7	0.6	1.2	0.3	0.7	2.9	38.6	55.8	240
Mean	0.3	0.6	0.2	0.3	1.5	31.5	65.6	205
Marl (M):								
C3	0.1	0.2	0.6	0.2	0.6	20.8	77.6	235
H9	0.0	0.0	0.0	0.0	0.1	85.3	14.6	250
Mean	0.0	0.1	0.3	0.1	0.4	53.0	46.1	243

SRP = soluble reactive phosphate; Extr P = 0.5 M NaCl extractable P; CO_3-P = carbonate-bound P; Lab org P = labile organic P.

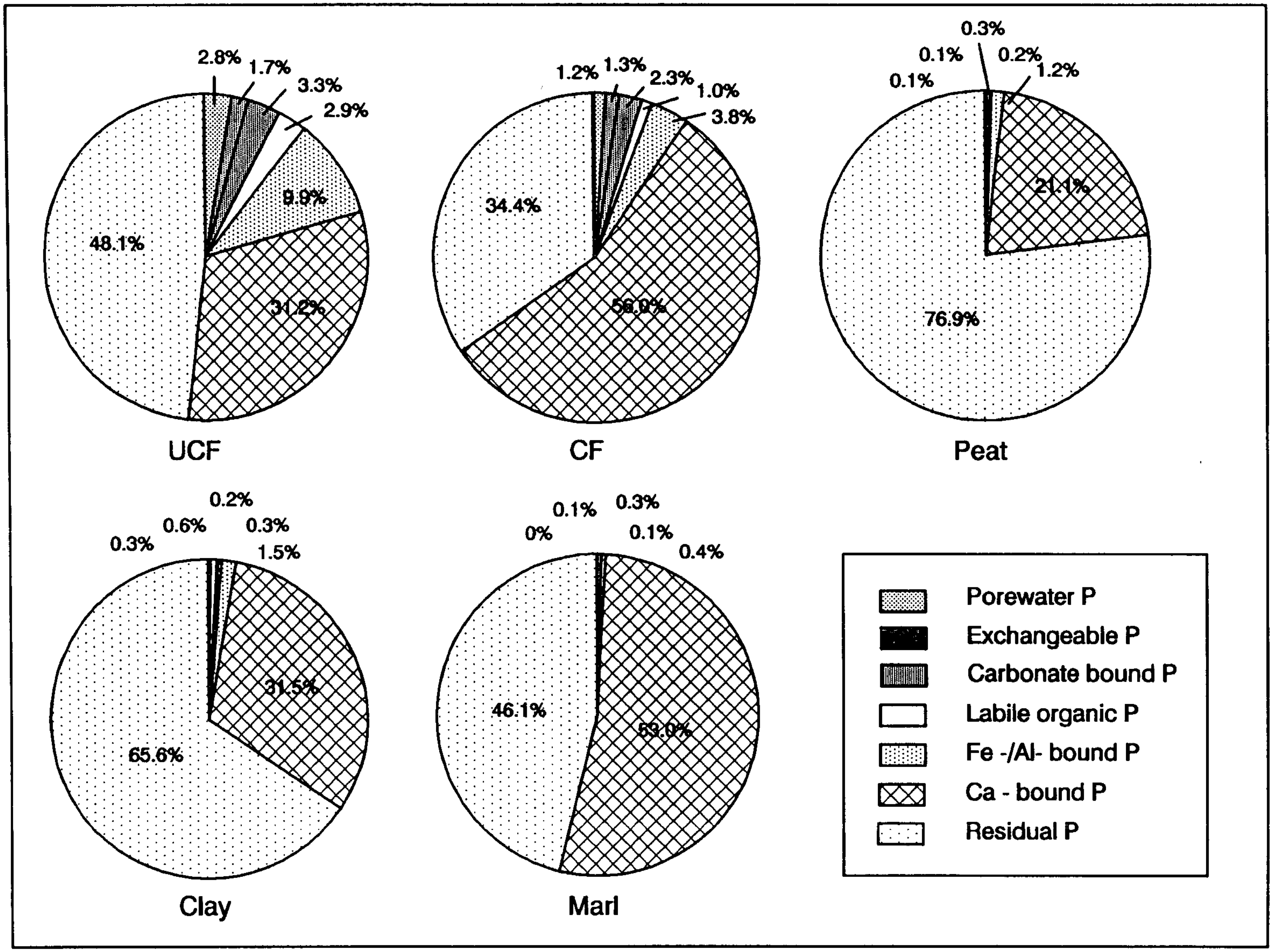


Fig. 3.11. Phosphorus distribution in Lake Apopka sediments as determined by chemical fractionation.

generally contained higher total organic C than the CF layer, it is possible that a large portion of the total P was in organic form. This is supported by the results obtained from the peat layer in which only about 11-35% of the total P was recovered as inorganic phosphate (Table 3.19). This horizon which had a total organic C content greater than 40% had an average residual P of 76.9%. Such a large fraction of residual P is believed to be bound to the organic fraction, and only available upon decomposition by microorganisms.

This observation, however, seems contradictory to the result obtained in the clay and marl horizons. The clay zone which had less than 3% total C, gave a P recovery of about 34% and an average residual P of 66% (Fig. 3.11). The marl horizon which was viewed to be predominantly inorganic gave an average residual P of only 46% (Fig. 3.11). The considerably low inorganic P recovery in these horizons is quite difficult to account for at this point. A possible explanation could be the particle-size heterogeneity of the samples from these horizons. Unlike the UCF, CF, and peat samples which were uniformly fine-textured and flocculent, the clay and marl samples were somewhat coarse and contained some shell fragments and P present in these fractions was not adequately extracted with reagents used in the scheme. The subsequent decrease in total reactive surface area per unit weight could reduce the efficiency of the entire fractionation scheme. Further investigation on this particular problem and a fractionation study on organic phosphate in lake sediments would provide additional support to these findings.

It can be concluded from this study that among the phosphate forms fractionated from Lake Apopka sediments, calcium-bound P was more predominant than the other forms. Calcium-bound P in the UCF layer ranged from 35-40% of the total P while that in the CF layer ranged from 30-80% of total P. A considerable fraction of the total P in the surface horizon (UCF) was bound to Fe and carbonates which allowed P "speciation." Inorganic P in the subsurface horizons (CF, P, C, and M) were less "speciated" and existed mainly as Ca-P. The extraction procedures used for P fractionation were found to be reliable for soils and sediments with high mineral matter (Van Eck, 1982). Lake Apopka sediments are primarily organic and it is likely that some portion of organic P is extracted with each chemical used in extraction procedures. Future research should develop a reliable fractionation scheme to determine labile pools of P in lake sediments.

3.4.4.4 Extractable cations:

Calcium and magnesium are the dominating cations extracted from the sediments with Mehlich I (double acid 0.025 N H_2SO_4 + 0.05 N HCl) (Table 3.20 and Appendix B-17c-g). Extractable Ca concentrations (expressed as average of all stations) were 28.3, 24.9, 18.8, 30.8, 18.0 and 31.3 mg g^{-1} for UCF, CF, peat, sand, clay and marl sediments, respectively. Extractable Mg concentrations were 2.4, 1.8, 2.4, 0.9, 1.8 and 1.4 mg g^{-1} for UCF, CF, peat, sand, clay and marl sediments, respectively. Extractable Al, Fe and Mn concentrations in UCF sediments were 40, 6 and 25 mg kg^{-1} of dry sediment, while CF sediments contained 147, 43 and 27 mg kg^{-1}, respectively. More than 50% of total Ca, Mg and K were extracted with

Table 3.20. Concentration of selected cations in Lake Apopka sediment extracted with Mehlich I extraction method (0.025N H_2SO_4+0.05N HCl).

Station	Ca	K	Mg	Fe	Al	Zn	Cu	Mn
	mg kg^{-1}							
Unconsolidated Flocculent:								
Mean	28290	736	2365	6.1	40.0	2.6	0.8	25.1
Std.Dev.	3741	269	760	11.1	78.0	6.7	2.4	13.8
n	71	83	83	83	83	83	83	83
C.V.(%)	13	36	32	183	195	263	321	55
Max.	38100	1572	5186	90.0	594.0	58.0	19.8	96.0
Min.	18428	46	126	0.0	0.0	0.0	0.0	2.2
Consolidated Flocculent:								
Mean	24884	361	1819	43.3	146.5	5.4	1.0	26.8
Std.Dev.	8683	88	592	76.1	178.0	22.9	2.6	15.0
n	60	68	68	68	68	68	68	68
C.V.(%)	35	24	33	176	121	424	254	56
Max.	43760	602	3888	396.0	854.0	192.0	19.2	84.0
Min.	4030	184	242	0.0	4.0	0.0	0.0	5.2
Peat:								
Mean	18835	368	2375	121.5	262.6	2.7	0.7	42.1
Std.Dev.	7148	107	1013	115.3	343.8	1.7	0.8	25.7
n	14	22	22	22	22	22	22	22
C.V.(%)	38	29	43	95	131	62	122	61
Max.	33060	576	4206	378.0	1660.0	6.0	3.0	96.0
Min.	7610	186	396	0.0	4.0	0.0	0.0	4.0
Sand:								
Mean	30792	210	924	1	4	0	0	22
Std.Dev.	1900	23	524	1	1	0	0	13
n	5	5	5	5	5	5	5	5
C.V.(%)	6	11	57	122	18	NA	133	60
Max.	33280	232	1612	2	6	0	0	42
Min.	28520	182	366	0	4	0	0	5
Clay:								
Mean	17962	378	1848	32.9	175.8	2.5	1.3	24.2
Std.Dev.	9499	104	657	36.4	129.9	3.9	1.8	11.8
n	9	13	13	13	13	13	13	13
C.V.(%)	53	27	36	111	74	157	147	49
Max.	29970	586	2832	146.0	368.0	15.0	7.2	50.0
Min.	3382	206	372	0.0	4.0	0.0	0.0	7.4
Marl:								
Mean	31284	257	1404	4.4	16.5	1.4	1.8	22.2
Std.Dev.	4494	131	510	9.3	50.6	3.3	6.1	19.1
n	22	22	22	22	22	22	22	22
C.V.(%)	14	51	36	213	306	243	342	86
Max.	39440	832	2294	46.0	248.0	15.0	29.4	66.0
Min.	16558	180	276	0.0	4.0	0.0	0.0	2.0

Mehlich I methods, while only a small fraction (<1% of total) of Fe, Al, and Mn were extracted, suggesting relative stability of these nutrients in Lake Apopka sediments.

This extraction method was originally designed to estimate the plant available nutrients in soils planted with food crops such as corn and wheat. At this time we do not know the applicability of this extraction method for lake sediments to determine available nutrients. However, the extractable nutrients presented will provide an estimate of available nutrients to aquatic macrophytes.

3.4.5 Total elemental analysis

3.4.5.1 Volatile solids:

Volatile solids represent the ash-free organic matter content of sediments as determined by combusting the dry sediment at 550°C for four hours (Table 3.21 and Appendix B-18). The average volatile solids content of the UCF sediments was 54.7 ± 14.6%, while CF sediments contained 59.0 ± 14.2%. The remaining fraction of the UCF and CF sediments consists of mineral matter. The average volatile solids content of peat sediments was 72.9 ± 24.1%, while the sand fraction of the sediment contained 11.4 ± 8.6% volatile solids.

3.4.5.2 Carbon:

Sediments contain C in both organic and inorganic fractions (Table 3.22 and Appendix B-19). Organic C was determined by the difference between total C and inorganic C.

The total C content of the surface sediments (UCF) was in the range of 2.5 - 48.4% (dry wt basis) with an average value of 30.2 ± 8.3%, while in the CF fraction, the average value was 32.5 ± 8.0%. The total C content of the sediment had a low spatial variability, with a coefficient of variation of 27%. The peat fraction contained the highest C content, with an average value of 40.9 ± 11.2%.

Total inorganic C in the UCF fraction was 1.2 ± 0.72% and 0.88 ± 1.15% in the CF fraction. Peat and clay fractions contained low (0.31 - 0.53%) inorganic C content while sand and marl contained high (3.2 - 6.1%) inorganic C content.

In the UCF and CF fractions, total mass of C present was 423,262 (33,861 kg C ha^{-1}) and 2,847,674 (227,814 kg C ha^{-1}) metric tons, respectively. Inorganic C represents 14,537 and 70,534 metric tons, for UCF and CF fractions, respectively. Total C content stored in the sediment was 3,284,579 metric tons and 2.9% of total C is present as carbonates and bicarbonates. Porewater TOC and DIC represent 0.14 and 0.26% of total sediment C, indicating a large reservoir of C in the sediment.

Table 3.21. Volatile solids of sediment samples collected from selected stations in Lake Apopka.

	UCF	CF	P	S	C	M
			%			
Mean	54.68	58.98	72.90	11.40	16.29	28.83
St.Dev.	14.58	14.19	24.13	8.57	10.87	
n	85	65	19	6	21	1
C.V.(%)	26.66	24.07	33.10	75.11	66.71	
Max.	71.68	86.15	93.98	28.5	41.18	28.83
Min.	3.79	12.92	17.25	5.42	4.74	28.83

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table 3.22. Total and inorganic carbon concentration (dry wt. basis) of the sediment at selected stations in Lake Apopka.

	Total Carbon						Total Inorganic Carbon					
	UCF	CF	P	C	S	M	UCF	CF	P	C	S	M
						%						
Mean	30.16	32.50	40.88	3.94	7.21	13.86	1.16	0.88	0.31	0.53	3.24	6.11
Std.Dev.	8.26	7.97	11.22	2.98	6.16	7.12	0.72	1.15	0.73	0.91	3.74	3.02
n	86	69	21	12	7	18	86	69	21	12	7	18
C.V.(%)	27	25	27	76	85	51	62	130	234	172	115	49
Max.	48.41	42.87	54.09	12.47	18.27	30.54	3.58	5.95	2.68	3.06	10.54	10.50
Min.	2.50	3.58	10.44	1.30	2.30	2.45	0.17	ND	ND	ND	0.06	0.15

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl; ND = Not Detected.

3.4.5.3 Nitrogen:

The total N content of the UCF sediment was 23.7 ± 7.5 mg g^{-1} (dry wt), while the CF sediment had a N content of 22.4 ± 4.3 mg g^{-1} (Table 3.23, Appendix B-20). Surface sediments (UCF) contained a minimum total N content of 1.35 mg g^{-1} at station 7F and a maximum total N content of 34.7 mg g^{-1} at station 8J. The coefficient of variation among the sampling stations was 32 and 21% for UCF and CF sediments, respectively. Sediment containing more mineral matter such as sand, clay or marl had a total N content of 5.5 to 8.8 mg g^{-1}. For the whole lake, the mass of total N stored in the UCF sediment was 33,674 metric tons (74.2 million pounds) and 196,856 metric tons (434 million pounds) in the CF sediments. The total N storage in the UCF and CF fractions amounted to 230,530 metric tons (508 million pounds). The total N stored in the porewater represented only 3% of the total N stored in the sediments, while only 1.1% of the total N is present as ammonium in exchangeable form on the solid phase. A large reservoir of N is present in organic form and can be potentially mineralized and released into the overlying water column.

3.4.5.4 Phosphorus:

The total P content was highest in the surface sediment and decreased with depth (Table 3.23 and Appendix B-20). The average P content was 0.97 ± 0.43 mg kg^{-1} in the UCF fraction and 0.60 ± 0.37 mg kg^{-1} in the CF fraction. In relation to C and N, P content was low, indicating the significance of C and N fixation in the system.

For the whole lake, the mass of total P stored in the UCF and CF fractions was 1,371 and 5,276 metric tons, respectively. Porewater P represents 5.9% of total P, while double acid extractable P represents 52.2% of total P. Phosphorus not extracted with double acid likely represents resistant organic P.

3.4.5.5 Selected cations:

Total elemental analysis of selected cations in various sediment horizons is shown in Tables 3.24 and 3.25, B-21 to B-26. Calcium concentrations exceeded those of other cations in all horizons, with an average value of 49.7 and 54.3 mg g^{-1} in the UCF and CF fractions, respectively. For all horizons elemental concentrations were in the order of Ca > Al > Fe > Mg > K > Mn > Cu. The availability of these elements to aquatic biota is dependent on the stability of these mineral bound elements in the sediments. The concentrations of the elements found in the UCF and CF fractions are typical of those found in the algal biomass or the aquatic macrophytes grown in Lake Apopka water.

3.4.6 Characterization of sediment organic carbon

Sediment organic C was fractionated into: (1) cellulose + hemicellulose, (2) lignin and (3) acid insoluble ash. The methods used in the fractionation are frequently used to determine the lignocellulose in feedstuffs to evaluate digestibility.

Table 3.23. Total nitrogen and phosphorus content (dry wt. basis) of sediment samples collected from selected stations in Lake Apopka.

	Total Nitrogen						Total Phosphorus					
	UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
	mg g^{-1}											
Mean	23.69	22.39	26.12	6.00	4.20	8.76	0.97	0.60	0.38	0.42	0.29	0.45
Std.Dev.	7.51	4.29	8.28	4.97	3.34	5.93	0.43	0.37	0.24	0.38	0.20	0.35
n	87	69	23	9	15	25	86	69	23	9	15	26
C.V.(%)	32	19	32	83	80	68	45	62	64	90	71	78
Max.	34.71	35.19	37.63	15.31	10.64	19.04	2.26	2.91	1.04	1.36	0.68	1.49
Min.	1.35	3.19	6.25	0.01	0.01	0.012	0.1	0.11	0.16	0.06	0.05	0.1

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table 3.24. Concentration of major cations in Lake Apopka sediments at selected stations. Analyses performed after perchloric acid digestion of dried sediment.

Unconsolidated Flocculent Sediment

	K	Ca	Mg	Fe	Mn	Cu	Al
	$mg\ g^{-1}$						
Mean	0.99	49.67	4.31	5.29	0.09	0.07	9.48
Std.Dev.	0.36	26.99	1.28	1.74	0.03	0.30	4.28
C.V.(%)	36.6	54.3	29.8	33.0	29.9	413.4	45.2
n	86	86	86	86	86	86	86
Max.	3.28	194.66	9.55	14.84	0.19	2.55	32.32
Min.	0.14	0.05	0.05	0.05	0.00	0.00	0.05

Consolidated Flocculent Sediment

	K	Ca	Mg	Fe	Mn	Cu	Al
	$mg\ g^{-1}$						
Mean	1.22	54.28	4.35	5.98	0.08	0.01	6.73
Std.Dev	0.79	38.83	1.09	1.87	0.02	0.01	4.62
C.V.(%)	64.1	71.5	25.0	31.2	29.8	83.7	68.5
n	64	64	64	64	64	64	64
Max.	3.94	167.00	7.31	14.74	0.12	0.04	13.20
Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Peat

	K	Ca	Mg	Fe	Mn	Cu	Al
	$mg\ g^{-1}$						
Mean	0.74	30.06	2.77	2.14	0.06	0.01	2.80
Std.Dev.	0.45	40.24	0.99	1.58	0.02	0.01	3.35
C.V.(%)	61.0	133.8	35.9	74.1	39.7	76.3	119.7
n	19	19	19	19	19	19	19
Max.	2.12	190.50	4.80	6.20	0.11	0.05	11.26
Min.	0.29	8.65	1.25	0.48	0.02	0.00	0.00

Table 3.25. Concentration of major cations in Lake Apopka sediments at selected stations. Analyses performed after perchloric acid digestion of dried sediment.

Sand

	K	Ca	Mg	Fe	Mn	Cu	Al
	mg g^{-1}						
Mean	0.79	129.68	4.18	3.61	0.12	0.01	4.77
Std.Dev.	0.43	115.09	3.52	2.37	0.09	0.01	4.94
C.V.(%)	54.3	88.7	84.3	65.7	78.0	59.8	103.4
n	6	6	6	6	6	6	6
Max.	1.29	359.19	10.20	6.57	0.29	0.03	13.04
Min.	0.28	12.57	0.95	1.10	0.03	0.00	0.00

Clay

	K	Ca	Mg	Fe	Mn	Cu	Al
	mg g^{-1}						
Mean	1.02	36.07	8.46	11.47	0.1	0.02	22.29
Std.Dev.	0.43	39.14	4.19	5.5	0.03	0.02	10.77
C.V.(%)	42.1	108.5	49.5	47.9	33.7	68.2	48.3
n	13	13	13	13	13	13	13
Max.	2.14	157.10	18.35	18.06	0.14	0.08	33.98
Min.	0.37	3.47	0.32	0.56	0.01	0.01	0.60

Marl

	K	Ca	Mg	Fe	Mn	Cu	Al
	mg g^{-1}						
Mean	0.54	218.42	8.11	3.72	0.15	0.01	5.19
Std.Dev.	0.43	92.83	8.73	2.35	0.12	0.01	4.64
C.V.(%)	79.0	42.5	107.6	63.2	79.9	74.1	89.4
n	21	21	21	21	21	21	21
Max.	2.10	397.64	40.61	9.43	0.48	0.02	18.73
Min.	0.09	34.45	0.67	0.29	0.02	0.00	0.00

Surface sediment (UCF fraction) contained cellulose + hemicellulose content of 19 to 40% (dry wt basis), while lignin content ranged from 11 to 19% (Table 3.26a). The acid insoluble ash content was in the range of 20 to 46%. Similar ranges were also noted for the CF fraction (Table 3.26b) and peat (Table 3.26c). A higher cellulose + hemicellulose fraction represents the labile fraction of C which can be readily degraded during microbial respiration as compared to the lignin fraction. Using similar methods, Moorhead et al. (1987) have reported that water hyacinth biomass C contained 4.3 to 14.5% lignin and 17 to 27% cellulose. Algal biomass deposited on the surface of lake sediments probably contains a higher proportion of cell wall constituents (such as chitin) which are slowly decomposable. Chapter 5.2 presents the rate of sediment decomposition of organic C under anaerobic conditions.

3.4.7 Water chemistry

A summary of selected chemical parameters of water samples collected at 91 stations in June 1987 is shown in Tables 3.27 and 3.28, and detailed data are given in Appendix B-27 and B-28.

Maximum nitrate levels of 3.5 mg L^{-1} were noted at Apopka Spring, while minimum values of <0.01 mg L^{-1} were noted at a majority of the stations (Table 3.27 and Appendix B-27). Detectable nitrate levels were measured at stations near Apopka Spring, indicating the possibility of nitrate inputs from adjacent citrus groves or Apopka Spring water. Elevated nitrate levels were also noted at stations near Winter Garden (I10). Ammonium N concentrations in the water did not show any particular spatial trend, with maximum values of 0.48 mg L^{-1} at station K-6, near Fisherman's Paradise. Ammonium N concentrations (Tables 3.27 and Appendix B-27) were also high at stations near pump house #2 where agricultural drainage water is discharged into the lake. The average ammonium N concentration for the whole lake was 0.14 ± 0.06 mg L^{-1}. Total Kjeldahl N content showed little variation with the exception of water samples at Apopka Spring. At this station, the TKN value was 0.62 mg L^{-1}. TKN values at the remaining stations were in the range of 4.4 to 7.3 mg L^{-1}.

The average total P (TP) concentration for the whole lake was 0.22 ± 0.07 mg L^{-1}, with a maximum of 0.44 mg P L^{-1} at station 2C and a minimum of 0.07 mg P L^{-1} at Apopka Spring (Tables 3.27 and Appendix B-27). Dissolved TP (after filtration through 0.2 μm filter) concentrations were very low, with average DTP concentration of 70 ± 30 μg L^{-1}, while SRP levels were in the range of 1 to 12 μg L^{-1}, indicating rapid assimilation of SRP by algal biomass.

The TKN/TP ratio of the lake water was 22 indicating the significance of biological N_2 fixation by algae and possible P limitation. Phase II of this program will establish some of these relationships.

Concentrations (of selected cations in water samples collected at 91 stations) were in the order of Ca > Mg > Na > K (Table 3.28 and Appendix B-28).

Table 3.26a. Fractionation of organic carbon in unconsolidated fraction (UCF) of Lake Apopka sediment.

Station	Acid detergent fiber	Cellulose + hemicellulose	Lignin	Acid insoluble ash
		------------% dry wt basis------------		
2B	74.45	39.86	14.21	20.37
2G	72.27	31.80	18.84	21.83
5D	64.43	27.57	13.03	24.02
6J	67.78	20.47	13.92	33.39
10H	62.32	25.05	15.52	21.75
11D	75.76	18.87	10.60	46.30
Mean	69.50	26.94	14.35	27.94
SD ±	5.51	7.78	2.74	10.15

Table 3.26b. Fractionation of organic carbon in the consolidated fraction (CF) of Lake Apopka sediments.

Station	Acid detergent fiber	Cellulose + hemicellulose	Lignin	Acid insoluble ash
		------------% dry wt basis------------		
2B	78.58	44.56	7.73	26.28
5D	67.25	31.67	11.22	24.36
6J	79.76	20.18	11.39	48.19
7G	67.62	13.48	8.82	45.32
10H	76.62	33.28	20.50	22.84
11D	93.71	8.23	7.51	77.97
Mean	77.26	25.23	11.20	40.83
SD ±	9.72	13.66	4.85	20.26

Table 3.26c. Fractionation of organic carbon in selected fractions of Lake Apopka sediment.

Station	Acid detergent fiber	Cellulose + hemicellulose	Lignin	Acid insoluble ash
		------------% dry wt basis------------		
Peat				
2G	82.68	55.04	6.47	21.17
11D	95.27	9.97	8.22	77.07
	88.98	32.51	7.35	49.12
Marl				
5D	61.22	27.55	8.73	24.94
6J	29.63	0.39	1.28	27.96
	45.43	13.97	5.01	26.45
Clay				
7J	86.18	2.91	9.33	73.94
Sand				
6J	91.31	1.25	8.63	86.43

Table 3.27. Water chemistry at selected stations in Lake Apopka.

	Total					Dissolved				
	TKN	ON	TP	TOC	TIC	NH_4-N	NO_3-N	TKN	TP	SRP
	mg L^{-1}								µg L^{-1}	
Mean	4.92	4.77	0.22		16.12	0.14	0.06	2.89	65.5	3.0
Std. Dev.	0.85	0.84	0.07		2.53	0.06	0.39	0.52	27.9	2.0
C.V.(%)	17	18	33	ERR	16	39	612	18	43	68
n	91	91	91		91	91	91	91	91	91
Max.	7.34	7.21	0.44	0.00	25.18	0.48	3.50	4.05	255	12.0
Min.	0.62	0.53	0.07	0.00	8.96	0.03	0.00	1.55	35	0.0

Dissolved = 0.2 µm filtered.

Table 3.28. Water chemistry at selected stations in Lake Apopka.

	GTOC	K	Ca	Mg	Na	Cl
Mean	31.20	10.15	28.38	17.16	14.66	36.09
Std.Dev.	3.27	1.15	1.30	1.41	1.31	4.37
C.V.(%)	10	11	5	8	9	12
n	89	91	91	91	91	91
Max.	38.49	11.80	31.90	19.60	16.90	43.10
Min.	8.86	1.80	22.70	8.10	5.70	9.50

GTOC = Glass-Fiber Filtered.

Negligible concentrations of Fe, Mn and Al were measured in the water samples. Similar trends in cation concentration were also noted for sediment porewater, although concentrations were significantly higher in the sediments.

3.5 Summary

Lake Apopka sediment was characterized into five horizons. These include: unconsolidated floc (UCF), consolidated floc (CF), peat (P), sand (S), clay (C), and marl (M) (Fig. 3.12). Average depth of the surficial UCF layer was 32 cm. The UCF horizon is active in releasing nutrients into overlying water. The UCF fraction of the sediment is equivalent to the floc-like material measured by Schneider and Little in 1968. Between 1968 and 1987, the UCF fraction increased in thickness by 22 or 1.15 cm yr^{-1}.

Porewater nutrient concentrations were generally lower in the UCF sediments than in underlying CF sediments. The total P concentration in the porewater was in the range of 0.17 - 8.62 mg L^{-1} in the UCF and 0.03 - 19.1 mg L^{-1} in the CF fractions, respectively. Ammonium N levels were in the range of 3-110 mg L^{-1} in UCF and 5-178 mg L^{-1} in CF porewater. Ammonium N represented about 70% of total porewater N. Total organic C concentration of the UCF and CF porewater was in the range of 13-123 and 16-190 mg L^{-1}, respectively. Total inorganic C concentrations were 1.5-129 and 0.1-231 mg L^{-1}, for UCF and CF porewater, respectively.

The UCF fraction contained 1.413 million metric tons of dry sediment, while CF fraction contained 8.794 million metric tons (Tables 3.29a,b). Total C, N and P content of UCF sediment was 426,690, 33,674 and 1,371 metric tons, which corresponded to 34.1 metric tons C ha^{-1}, 2.7 metric tons N ha^{-1} and 0.11 metric tons P ha^{-1}, respectively (Figs. 3.13, 3.14, and 3.15). Porewater of the sediment contained 0.67% of the total C, 3.93% of the total N and 6.14% of the total P. Mass C:N:P ratio in the UCF fraction was 310:24:1, while in the CF fraction these ratios were 542:37:1. These results suggest that biological CO_2 and N_2 fixation by algae in the water column and subsequent deposition on the sediment have caused these wide C/P and N/P ratios.

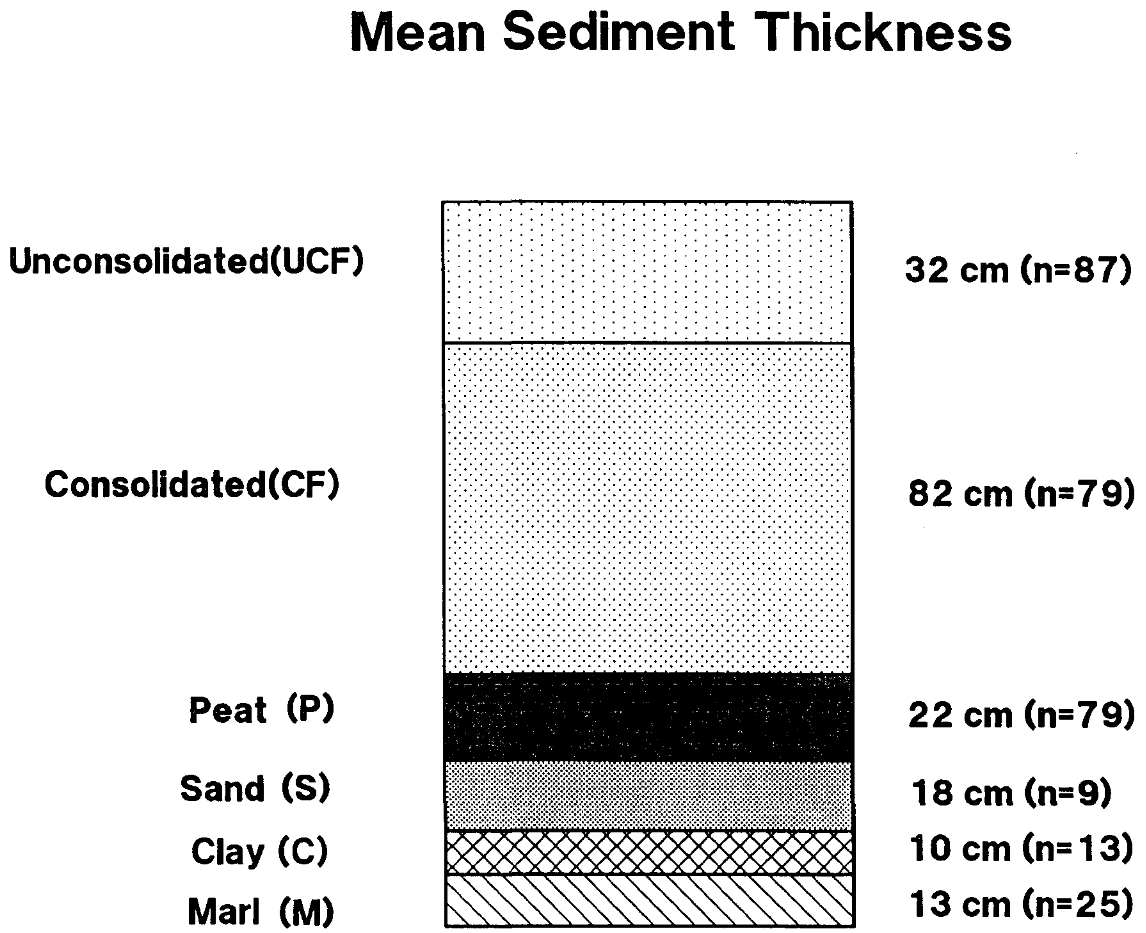


Fig. 3.12. Lake-wide mean sediment thickness (cm) of various fractions of Lake Apopka sediments.

Table 3.29a. Physical properties of Lake Apopka sediments.

Component	UCF	CF
Depth, cm	32.3	81.8
Surface area, m^2	125×10^6	125×10^6
Sediment volume, m^3	40.38×10^6	102.25×10^6
Wet weight (total), metric tons	41.35×10^6	107.16×10^6
Dry weight (total), metric tons	1.413×10^6	8.794×10^6
Porewater, metric tons	39.937×10^6	98.367×10^6

Table 3.29b. Storage of nutrients in Lake Apopka sediments. Values shown in parenthesis represent percent of total element content. Sediment depth: UCF = 32.3 cm and CF = 81.8 cm. Lake surface area = 12,500 ha.

Component	UCF	CF
	metric tons	
Carbon		
Porewater		
Inorganic	2,130 (0.50)	6,849 (0.24)
Organic	1,298 (0.30)	3,366 (0.12)
Sediment		
Inorganic	14,537 (3.41)	70,534 (2.47)
Organic	408,725 (95.8)	2,777,140 (97.17)
Total	426,690	2,857,889
Nitrogen		
Porewater - Total	1,509 (4.48)	5,467 (2.78)
Ammonium N	1,170 (3.47)	3,731 (1.90)
Organic N	339 (1.01)	1,706 (0.87)
Sediment		
Exchangeable Ammonium N	301 (0.89)	2,059 (1.05)
Organic N	31,864 (94.6)	189,360 (96.18)
Total Kjeldahl N	33,674	196,856
Phosphorus		
Porewater		
SRP	50 (3.6)	150 (2.84)
Total P	97 (7.1)	318 (6.03)
Sediment		
Dilute acid extractable P	309 (22.5)*	1,053 (19.96)*
Strong acid extractable P	693 (50.5)*	2,798 (53.03)*
Residual P (organic P)	678 (49.5)	2,478 (46.96)
Total	1,371	5,276

*Includes porewater P.

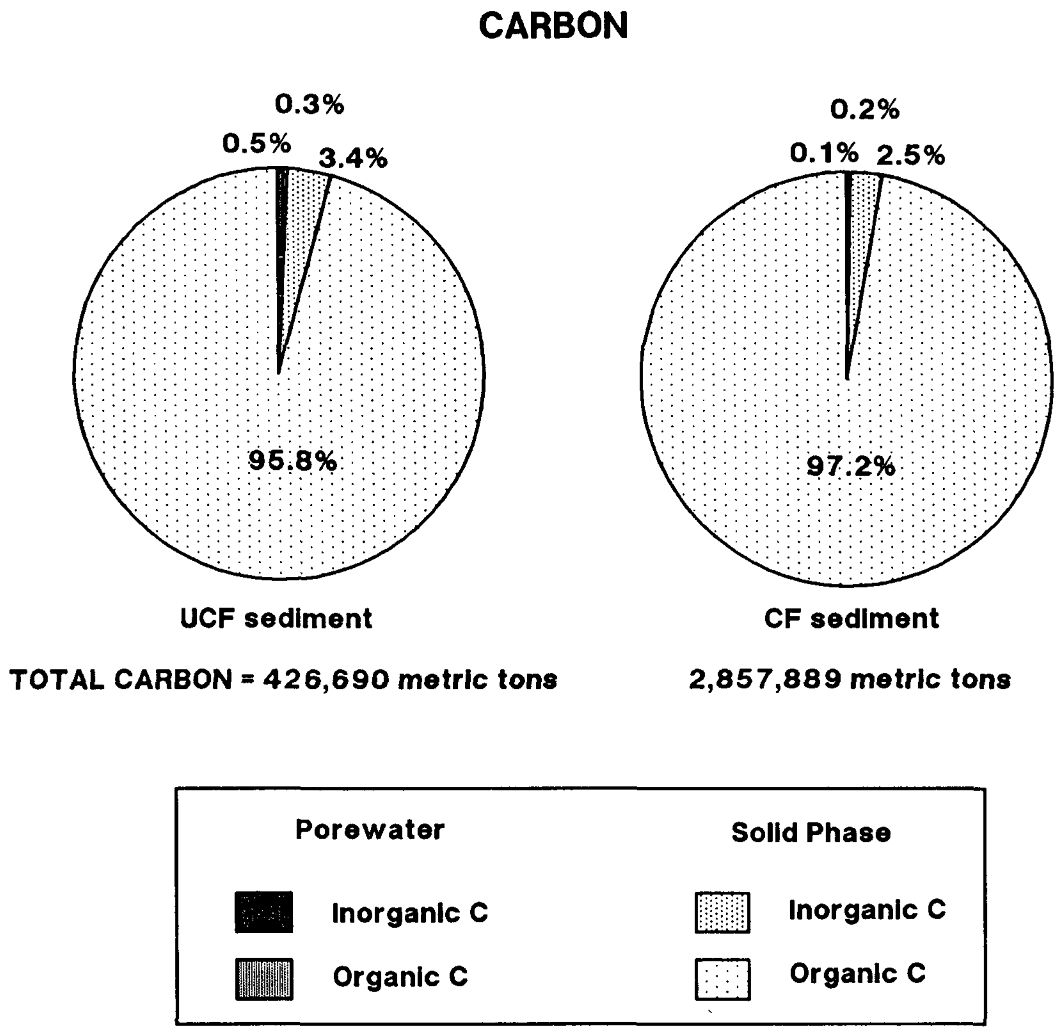


Fig. 3.13. Percent distribution of inorganic and organic C content in the porewater and solid phase of Lake Apopka sediments.

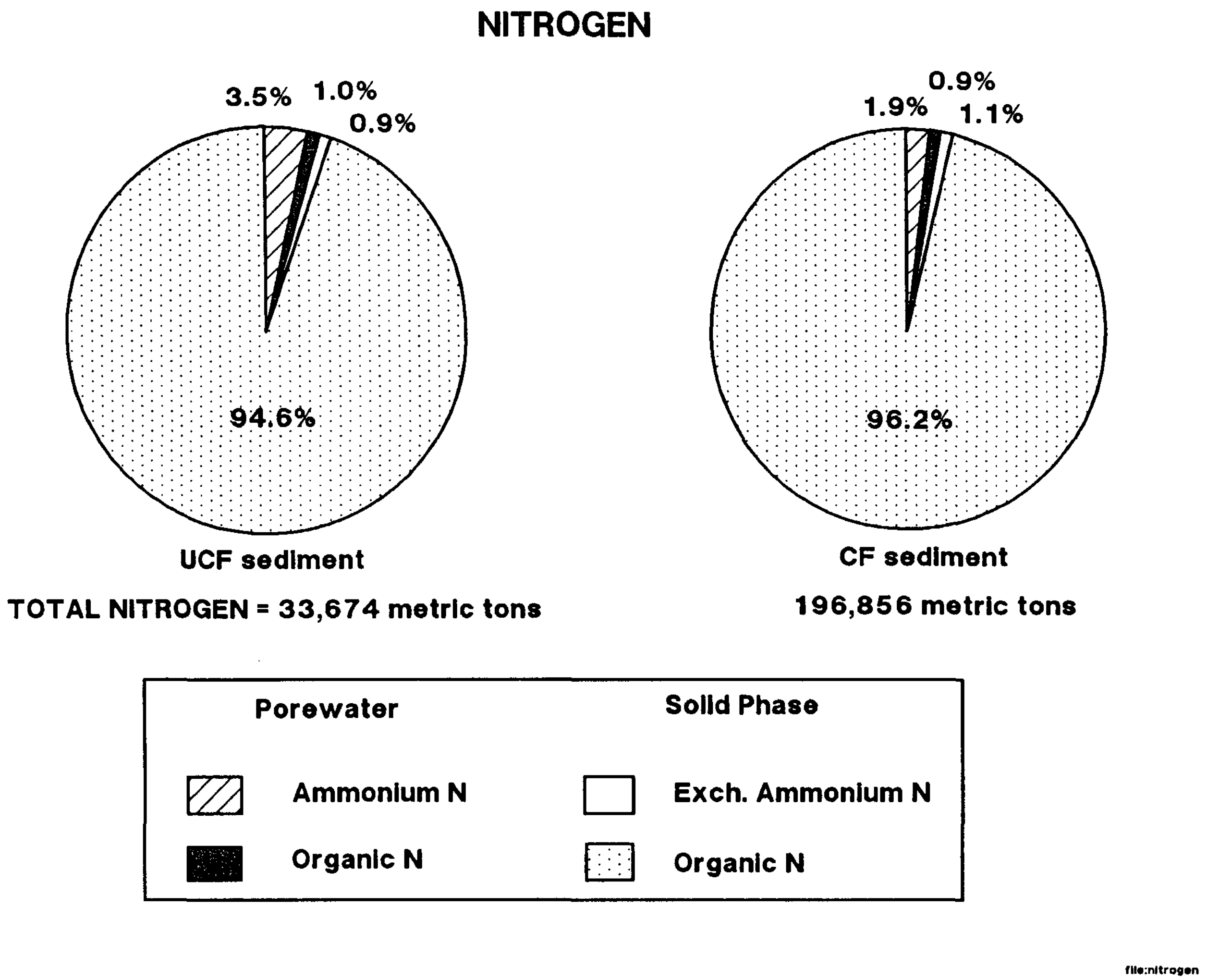


Fig. 3.14. Percent distribution of inorganic and organic N content in the porewater and solid phase of Lake Apopka sediments.

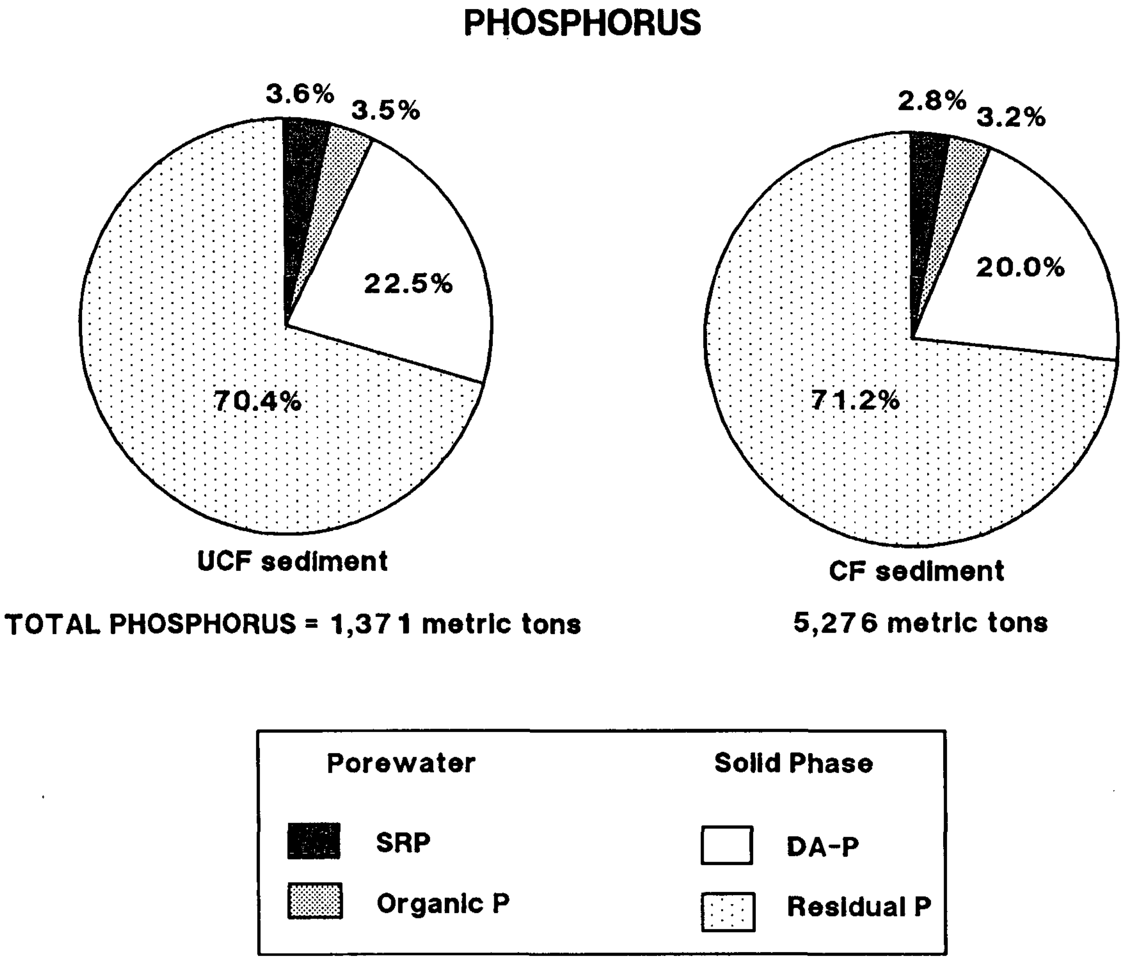


Fig. 3.15. Percent distribution of inorganic and organic P content in the porewater and solid phase of Lake Apopka sediments.

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Chapter 4

DISSOLVED NUTRIENT FLUXES FROM THE SEDIMENT TO THE WATER COLUMN

4.0 DISSOLVED NUTRIENT FLUX FROM SEDIMENT TO THE OVERLYING WATER COLUMN OF LAKE APOPKA

[Tasks 2.1 and 2.2]

4.1 Nitrogen and Carbon

4.1.1 Introduction

Lake sediments can act as a sink or source for N. A series of N transformations functioning in the sediment and in the overlying water regulate the water quality of the lakes (for a detailed review see Kemp et al., 1982; Reddy and Patrick, 1984). Decomposition of organic matter results in the release of NH_4^+ (ammonification) which moves into the overlying water (Byrnes et al., 1972). Under favorable conditions, such as that found in oxic, hardwater lakes, the NH_4^+ is oxidized to NO_3^- via nitrification (Chen et al., 1972). The NO_3^- can then diffuse back into the sediment and be denitrified to N_2 or N_2O. Most studies have shown that little or no denitrification occurs in oxidized floodwater (Engler et al., 1976; Reddy et al., 1980) and the rate of NO_3^- disappearance will be dependent on diffusion into the sediment.

Graetz et al. (1973) reported that the NH_4-N release rate from lake sediments under anoxic water column conditions was relatively constant. They estimated that these processes contributed approximately 30% of the N entering Lake Mendota from external sources. Fillos and Swanson (1975) reported N release rates from 120 mg N m^{-2} d^{-1} for Lake Warner to 360 mg N m^{-2} d^{-1} for Muddy River sediments in Massachusetts. Although they found that anoxic water conditions resulted in increased release rates of Fe and P, release of N was unaffected. Reddy et al. (1988) estimated that the NH_4-N flux from Lake Apopka sediment to the overlying water was 48 mg m^{-2} d^{-1}, while the soluble organic N flux was 58 mg m^{-2} d^{-1}.

Heavy N loading from adjacent vegetable farms and citrus groves over a number of years has resulted in tremendous algal populations in Lake Apopka. Rapid turnover of algae has contributed to sediment buildup and over the years, settling of undecomposed algal biomass has resulted in sediment accumulation at a rate of about 1.15 cm yr^{-1}. This flocculent sediment (about 97% water) is very active in releasing dissolved forms of nutrients into the water column. Mineralization of organic N to inorganic forms and subsequent release to the overlying water may perpetuate the eutrophic condition of this lake even after external inputs have been eliminated. The overlying water quality is to some extent governed by the transport of dissolved forms of C and N from the sediment to the water. This transport is primarily due to: (1) diffusion and mass flow as a result of concentration gradients across the sediment-water interface, and (2) possible release of dissolved nutrients during sediment resuspension in the water column during short-term wind events (Pollman, 1983). Therefore, in order to establish regulatory strategies for the management of this lake and the adjacent watershed, knowledge of the extent of this internal nutrient cycling is necessary.

The objectives of this research were: (1) to determine the mechanisms governing the mobility of dissolved N and C, (2) to assess the impact of algae on lake water chemistry, and (3) to determine the interchange of nutrients from the sediment to the overlying water column. These objectives fulfill the requirements of Task 2 of the Research Program Manual. Based on our experiences in preliminary research, we have slightly modified this task, in order to obtain a better data-base to quantify the dissolved nutrient fluxes from the sediment to the water column.

4.1.2 Materials and methods

Thirty-six intact sediment cores (6.35 cm x 60 cm) were taken in one meter Plexiglas tubes from station K-6 (Fig. 3.1) utilizing a plunger-equipped corer (see Chapter 3 of this report for the description of the corer). Upon returning to the lab, the water depth above the sediment was adjusted to 30 cm and aeration was provided with aquarium pumps via Tygon tubing. The columns were incubated under either light or dark conditions at 25°C for one year. The light treatment (200 μEinst cm^{-2} s^{-1}) consisted of a 12-h light and 12-h dark cycle, which was provided by fluorescent growth lights. Sediment samples were taken at 0, 1, 2, 4, 7, and 12 months; water samples were taken weekly. There were three replications per treatment. The amount of water taken for weekly samples (60 mL) was replaced with filtered lake water of known composition.

Redox potential (Eh) measurements were taken with bright platinum electrodes inserted through rubber septums located at 1, 3, 6, 12, 24, and 40 cm sediment depths. After the electrodes equilibrated for 24 h, Eh was measured by placing a single-junction sleeve-type calomel reference electrode in the overlying water.

At the end of each incubation period, sediment cores were sectioned at 2, 4, 8, 12, 24, 48 and 54 cm depths in a glove bag under a N atmosphere and transferred into 240-mL centrifuge tubes. Sediment wet weights in each section were determined and subsamples were taken for water content. Sediment porewater was obtained by centrifuging the sediment at 5,000 rpm for 20 min and filtering anaerobically through 0.45 μm filter paper.

Water samples and porewater were analyzed for alkalinity, electrical conductivity (EC), dissolved organic carbon (DOC), NH_4-N and NO_3-N. Alkalinity, EC, and pH were determined on unfiltered samples (in order to avoid degassing). Dissolved organic C in water and porewater samples was determined on filtered (A/E glass fiber filters) samples by IR following a persulfate oxidation (USEPA, 1979). Samples taken for NH_4-N and NO_3-N were filtered through 0.45 μm filter paper and acidified with concentrated ultra pure sulfuric acid (1 drop/20 mL sample). After the sediment had been centrifuged to remove porewater, five grams of wet sediment were shaken for two hours with 20 mL of 2 M KCl. Afterwards, the samples were centrifuged and filtered as above. KCl extracts were used to determine exchangeable NH_4-N. Inorganic N analyses were conducted with a Technicon auto-analyzer. Ammonium-N was determined with the salicylate-nitroprusside technique according to method 351.2 (USEPA, 1979). Nitrate (+nitrite) was determined using the cadmium reduction method according to method 418-F (APHA, 1985).

Total organic and inorganic C in the sediment was determined by coulometry (Huffman, 1977), while total N in the sediment was determined according to the method of Bremner and Mulvaney (1982).

4.1.3 Results and discussion

4.1.3.1 Water chemistry:

Ammonium concentrations in the water column peaked after 7 and 14 weeks of incubation, respectively, for light and dark treatments (Fig. 4.1.1). Decreases in NH_4-N concentrations were coupled with increases in NO_3-N concentrations, indicating the mechanism of removal was nitrification (Fig. 4.1.2). Nitrate levels in the dark were much higher than in the light, indicating N uptake by algae may govern inorganic N levels in the water.

Soluble organic C (SOC) in the water column decreased with time under light and dark conditions (Fig. 4.1.3). It should be noted that the bulk of the algae in the water column settled to the sediment surface at the beginning of the experiment. This loss of particulate C to the sediment probably played an important role in the decline in SOC with time. In the light treatment the free-floating algae characteristic of the lake, were replaced with periphyton which were attached to the sides of the Plexiglas columns.

The average concentrations of NH_4^+, NO_3^-, SRP, dissolved P, pH, alkalinity and SOC under light and dark conditions are shown in Table 4.1.1. Since the concentrations of some of these parameters changed with time, the values should be taken as relative indices of the treatment effects. Experimental set-up should also be considered when reviewing these data. For instance, since the measurements were always taken in the afternoon following 6 to 8 h of photosynthesis, the pH of the light treatment was inherently higher. However, if the measurements had been taken in the morning, the values may not have been different. Uptake of NO_3^-, SRP, and Si by algae or diatoms probably caused the concentrations of these nutrients to be lower in the water column exposed to light.

4.1.3.2 Sediment characteristics:

Some of the sediment physical characteristics are shown in Table 4.1.2. Water content of the sediments decreased with depth, from around 98% at the surface, to 95% at the 54-cm depth, which corresponds to 63.7 and 16.9 g H_2O g^{-1} dry sediment, respectively. This significant decrease in water content was reflected in changes in bulk density (dry wt basis), which increased from 0.016 g cm^{-3} at the surface, to 0.051 g cm^{-3} at 54 cm.

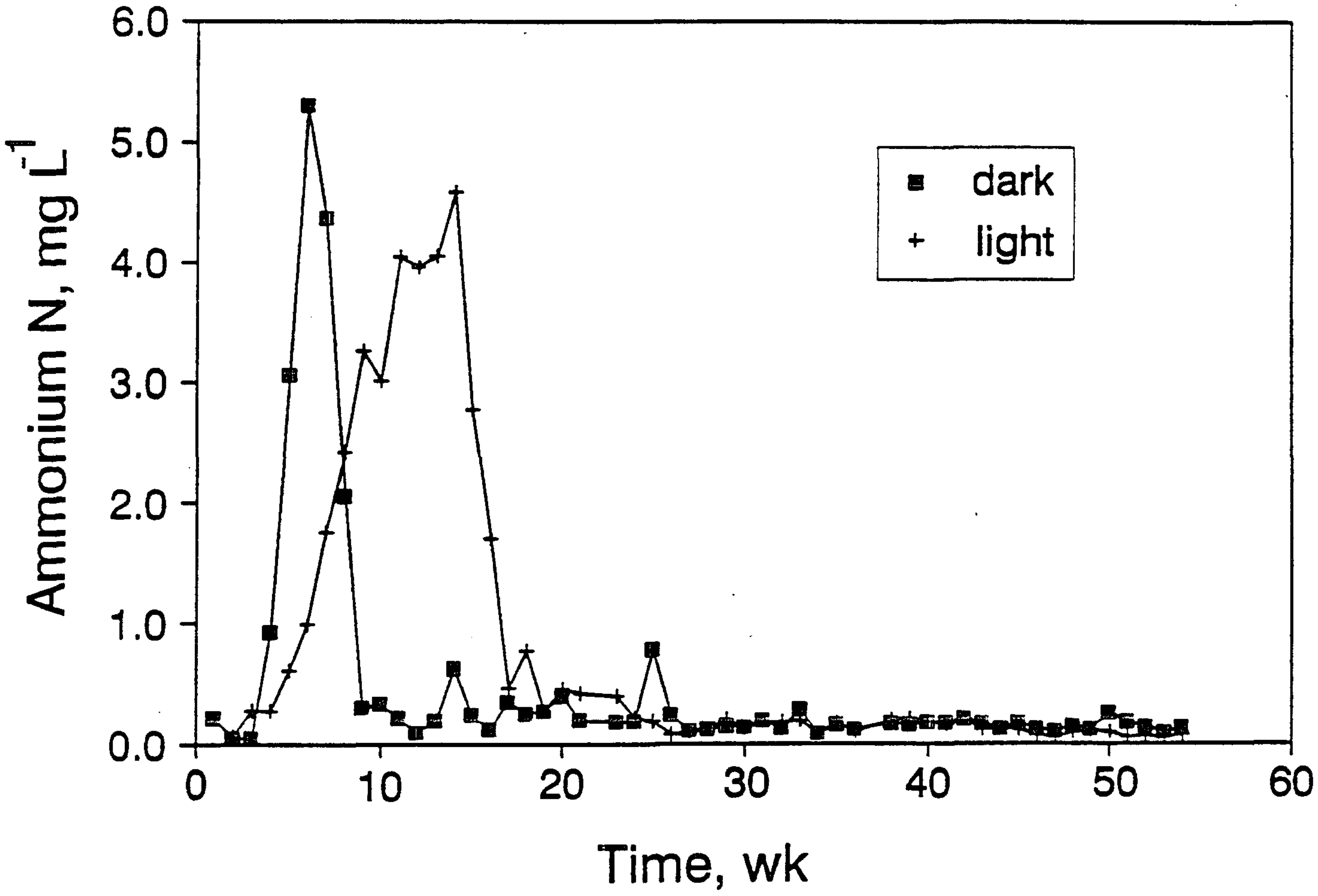

Fig. 4.1.1. Lake water ammonium N concentrations under light and dark conditions.

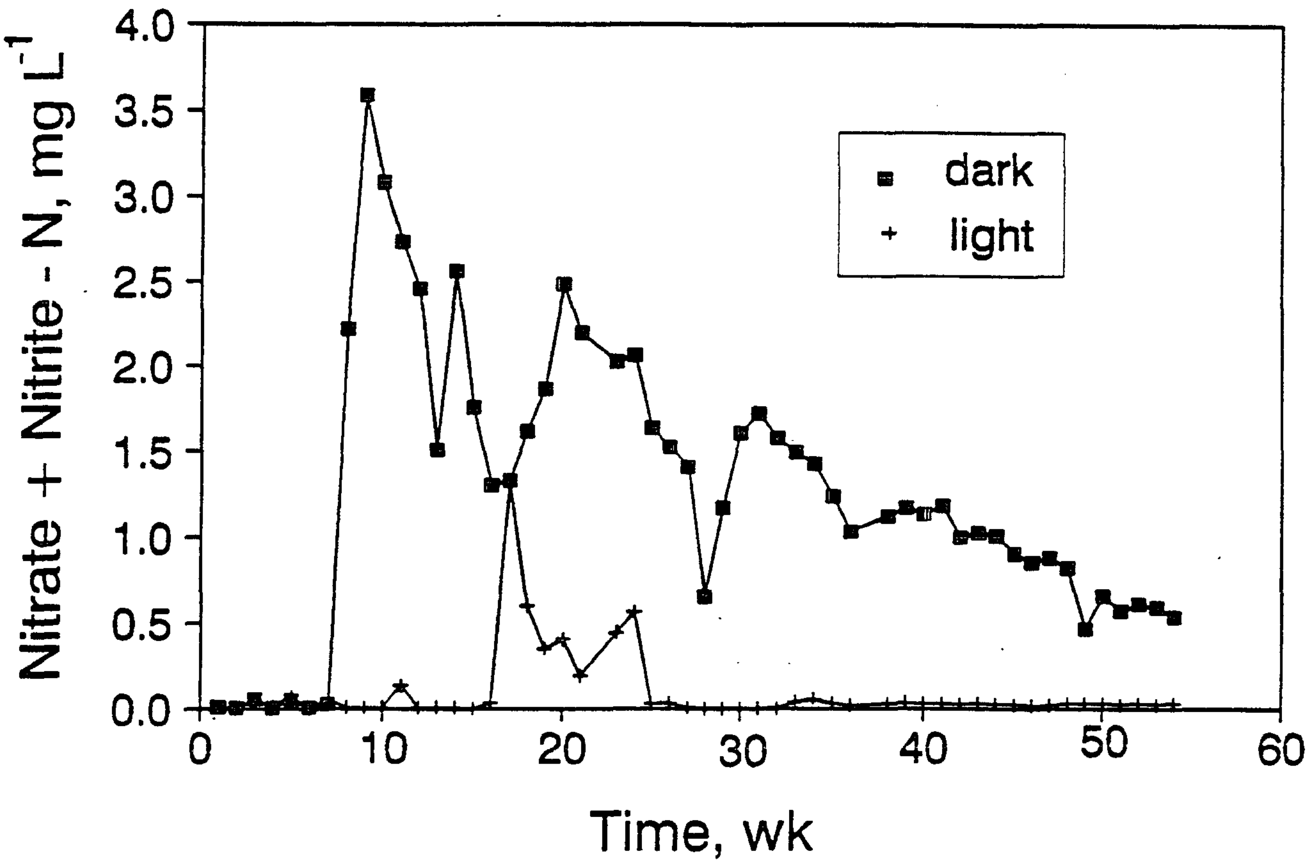

Fig. 4.1.2. Lake water nitrate plus nitrite concentrations under light and dark conditions.

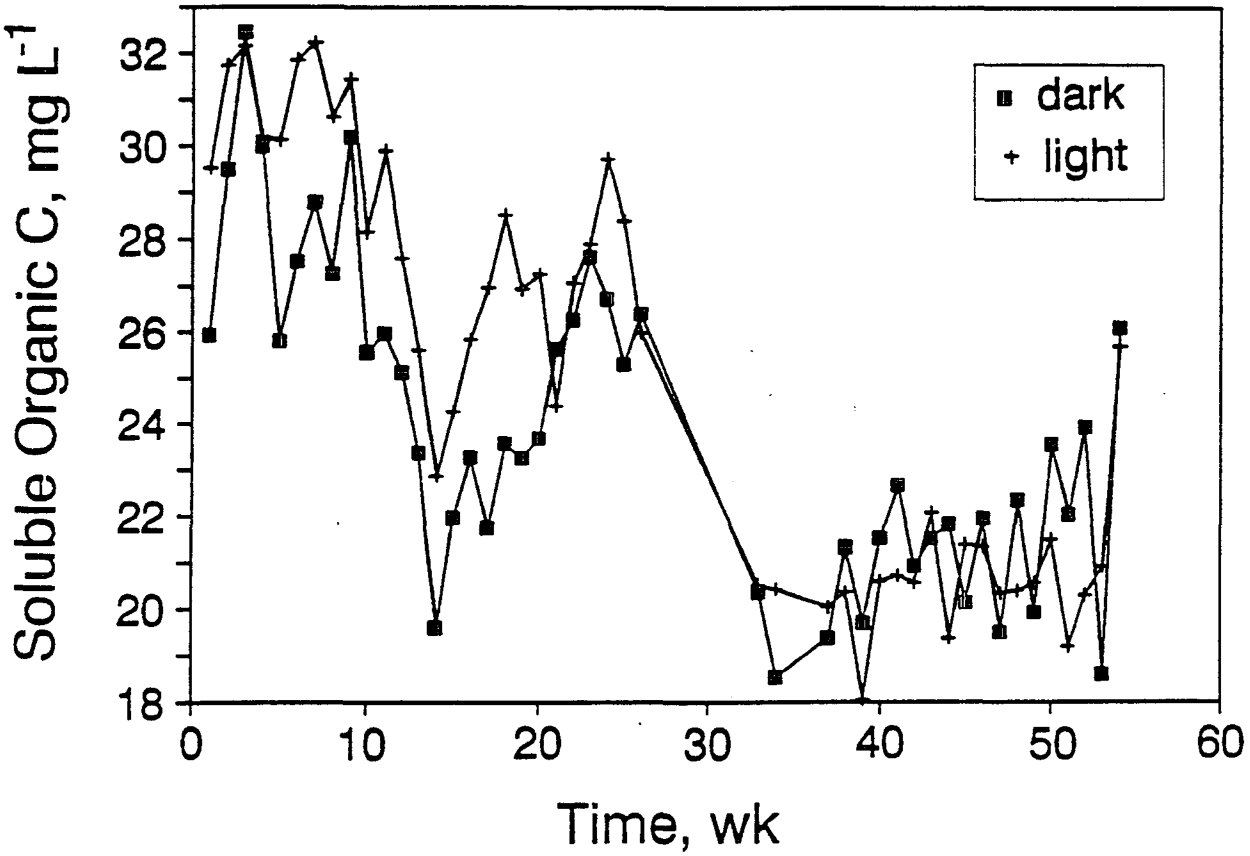

Fig. 4.1.3. Lake water soluble organic C concentrations under light and dark conditions.

Table 4.1.1. Annual average of selected chemical characteristics of water under light and dark conditions (for detailed data see Table A-4.1).

Parameter	Light			Dark		
	Mean	Std. dev.	n	Mean	Std. dev.	n
Ammonium (mg N L^{-1})	0.80	1.39	153	0.49	1.21	156
Nitrate (mg N L^{-1})	0.10	0.38	154	1.29	0.95	159
SRP (mg P L^{-1})	0.02	0.02	154	0.55	0.37	159
Dissolved P	0.06	0.03	125	0.60	0.35	143
pH	8.46	0.15	90	8.20	0.17	91
Alkalinity (mg $CaCO_3$ L^{-1})	136	11	88	154	8	89
SOC (mg C L^{-1})	25	5	129	24	4	136

Table 4.1.2. Bulk densities and water contents of Lake Apopka sediments.

Depth	Bulk density (dry wt. basis)	Water content		
--cm--	----g cm^{-3}----	g g^{-1} wet	g g^{-1} dry	g cm^{-3}
1	0.0157	0.984	63.7	1.000
3	0.0173	0.982	57.8	0.999
6	0.0210	0.979	46.2	0.970
12	0.0264	0.974	35.8	0.945
24	0.0376	0.962	24.3	0.914
40	0.0535	0.947	16.2	0.867
54	0.0508	0.949	16.9	0.859

The sediment C content was fairly constant (334-369 mg C g^{-1}) with depth (Table 4.1.3). Total N was also relatively constant (30.3-35.5 mg N g^{-1}), with somewhat higher concentrations noted near the sediment surface. In contrast, total P decreased from 1.65 mg P g^{-1} near the surface, to 0.6 mg P g^{-1} at 54 cm. While the C/N ratio increased slightly with depth (10.1 to 12.0), the C/P ratio increased nearly threefold (205 to 615), due to decreases in total P content of depth. Enrichment of surficial sediments with respect to total P may be due to anthropogenic sources, such as agricultural runoff from adjacent fields.

4.1.3.3 Porewater chemistry:

Annual averages of all treatments on selected sediment physico-chemical characteristics are shown in Fig. 4.1.4. The pH of the sediment porewater decreased from 7.73 at the surface to near 7 at the 12-cm depth and remained in this range with increasing depth. The redox potential (Eh) of the sediments was lower near the surface than in the bottom sediments. This is probably due to intense microbial activity in the freshly-deposited sediment. Titratable alkalinity increased with sediment depth from 266 mg $CaCO_3$ L^{-1} at the surface, to around 600 mg $CaCO_3$ L^{-1} at the lower depths. This increase in alkalinity is probably due to increasing partial pressures of CO_2 with depth (Emerson, 1976). Increases in electrical conductivity were also observed with depth, and were probably related to the alkalinity. Sediment porewater NH_4^+ concentrations increased with sediment depth (Fig. 4.1.5). There was no significant effect of light and dark treatments on sediment porewater NH_4-N. Porewater NH_4^+ remained relatively constant throughout 12 months of the experiment, indicating steady state conditions. Negligible levels of nitrate N were detected in the surface sediments.

Production of SOC was higher near the surface and decreased with depth (fIG. 4.16). Light and dark treatments showed no significant difference in porewater SOC. Decomposition rates were generally higher in the surface sediments and decreased with depth. This may be due to a limited supply of suitable electron acceptors at lower depths. Soluble organic C fluxes were probably not occurring since there was not a concentration gradient between the sediment and the overlying water.

Diffusional flux of NH_4^+ was calculated from the porewater profiles using Fick's 1st Law,

$$J_i = -\phi D_s (dC/dx)$$

where J_i = diffusion flux of component i in mass per unit area per unit time, ϕ = porosity = volume water/volume sediment, D_s = whole sediment diffusion coefficient in terms of area of sediment per unit time (Berner, 1980). The diffusion coefficients for NH_4^+ and PO_3^{-3} were calculated according to the method of Krom and Berner (1980) as follows;

$$D_s = D_o/\theta^2$$

Table 4.1.3. Total element analysis of Lake Apopka sediments.

Depth	Total C	Std. Dev.	Inorganic C	Std. Dev.	Total N	Std. Dev.	Total P	Std. Dev.	C/N	N/P	C/P
-cm-	------------------	------------------	------------------	------------------mg g^{-1}	------------------	------------------	------------------	------------------			
1	366	8.5	6.8	2.9	34.2	5.9	1.65	0.58	10.7	20.7	222
3	359	11.8	9.0	2.1	35.5	2.7	1.75	0.30	10.1	20.3	205
6	352	13.0	9.6	2.4	33.7	2.1	1.50	0.30	10.4	22.5	235
12	340	8.4	11.7	2.3	31.9	1.6	1.29	0.14	10.7	24.7	264
24	334	5.2	9.8	2.2	30.7	2.7	1.30	0.78	10.9	23.6	257
40	349	5.1	8.2	3.0	30.3	1.0	0.76	0.12	11.5	39.9	459
54	369	24.6	6.2	6.7	30.7	0.9	0.60	0.09	12.0	51.2	615

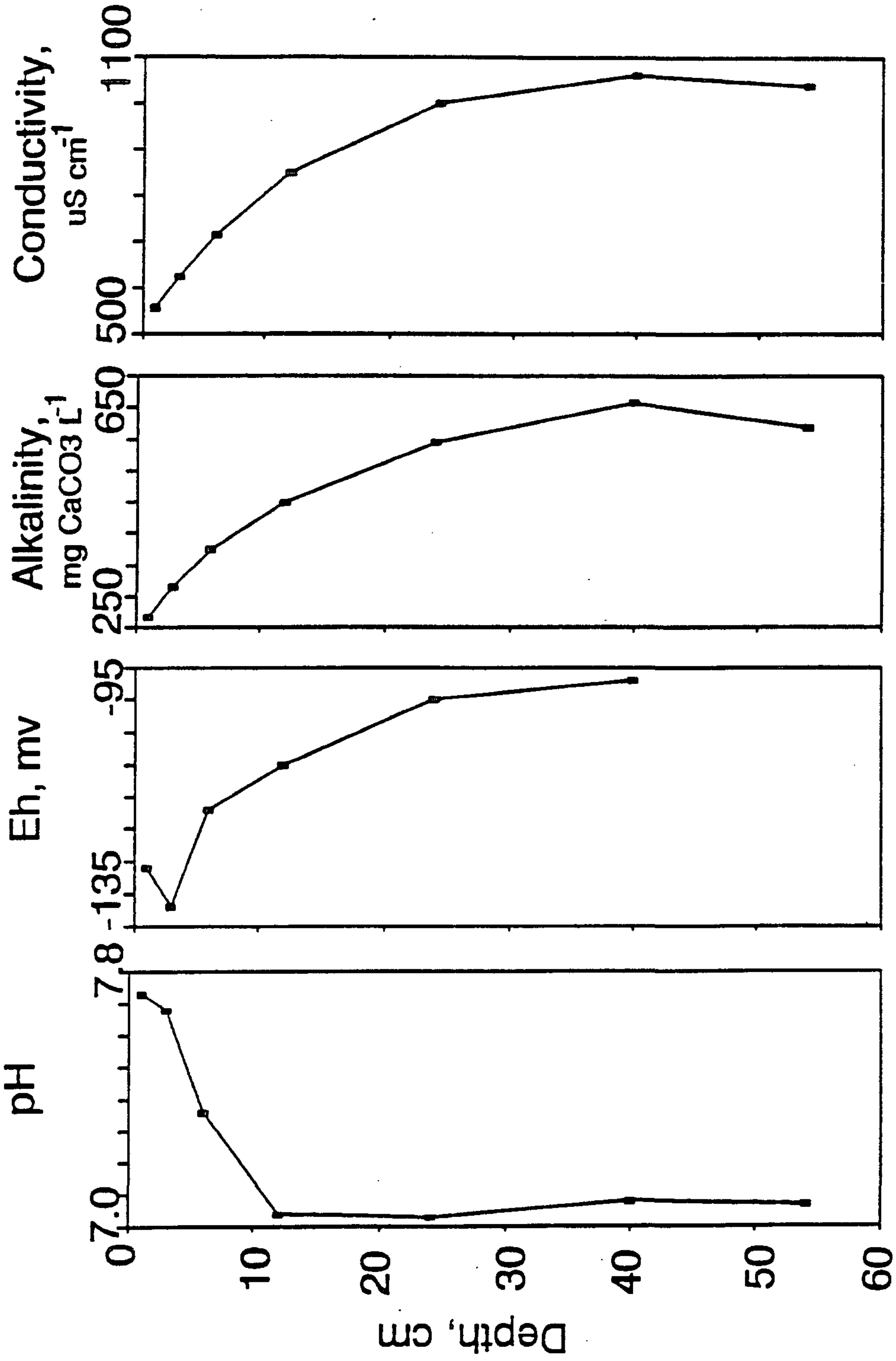

Fig. 4.1.4. Selected physico-chemical characteristics of the sediments as a function of depth.

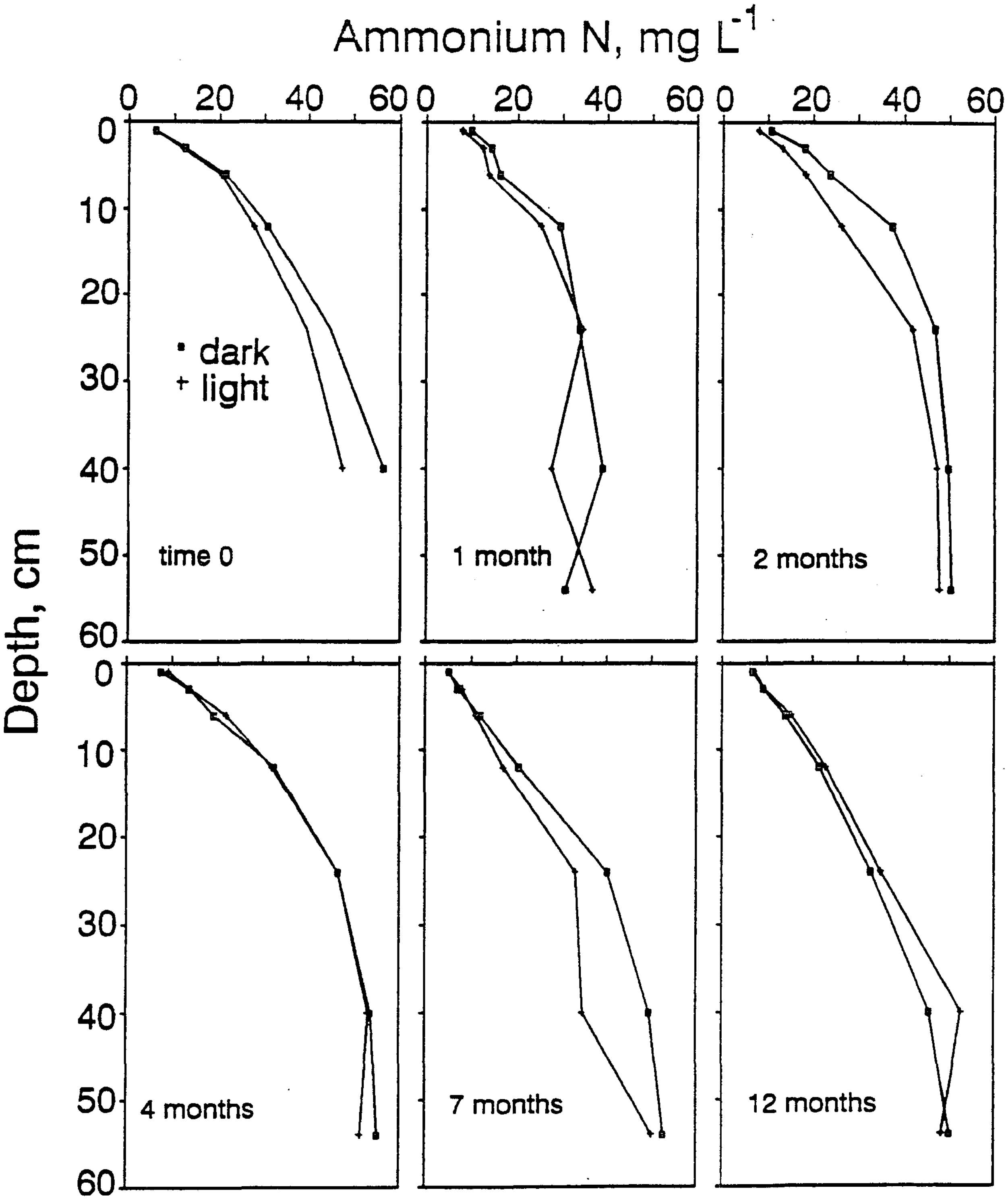

Fig. 4.1.5. Sediment porewater ammonium nitrogen concentrations as a function of depth and time.

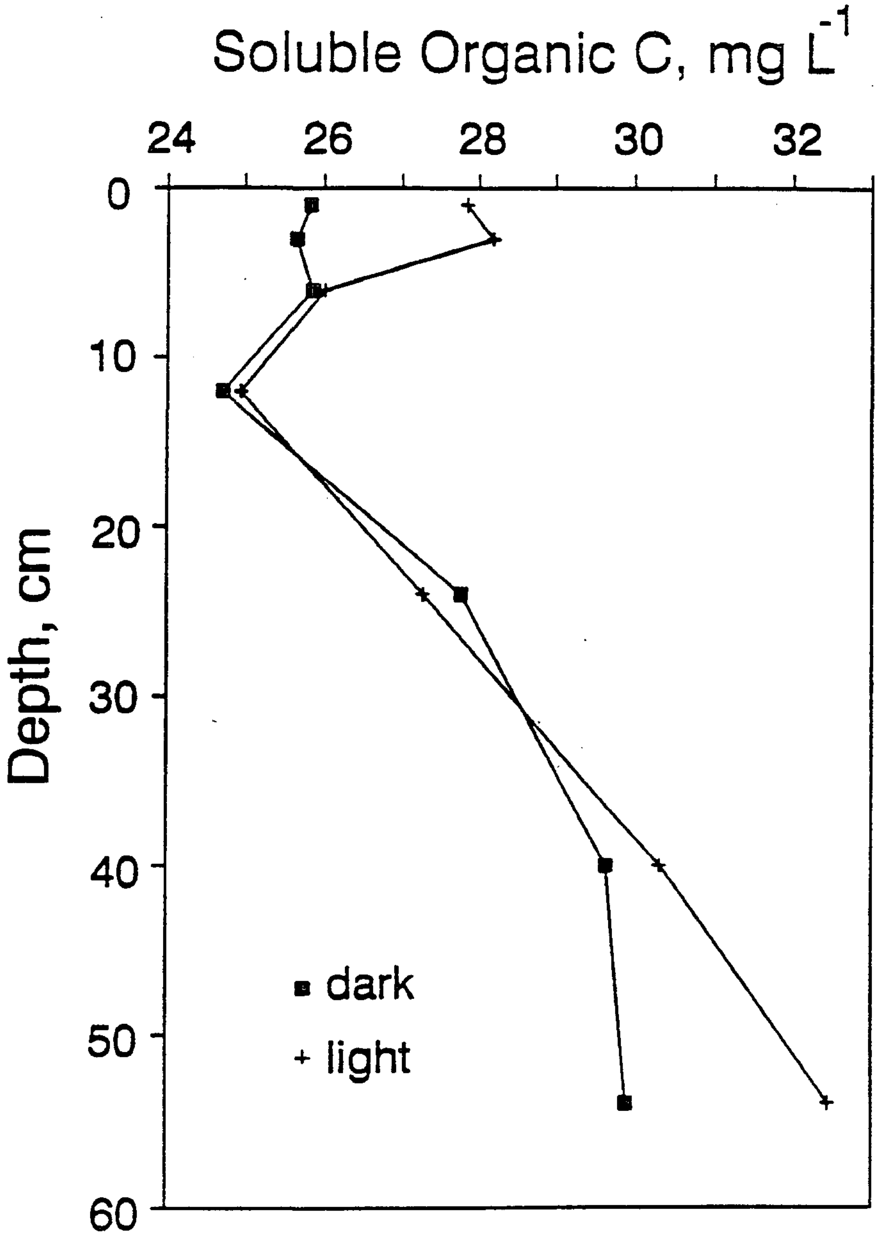

Fig. 4.1.6. Sediment porewater soluble organic carbon (SOC) as a function of depth (yearly average).

where D_o = the diffusion coefficient at infinite dilution ($D_o = 5.0 \times 10^{-6}$ cm^2 d^{-1}, and θ = tortuosity. The relation used to calculate the tortuosity was

$$\theta^2 = \phi R/R_o$$

where R = electrical resistivity of the sediment, and R_o = electrical resistivity of the porewater. In Lake Apopka sediments, the ratio of resistivities of the UCF sediment and the porewater approaches unity, as does the porosity (data not shown). Therefore, the diffusion coefficient is approximately equal to that in water.

The calculated NH_4^+ flux estimated from the porewater gradient (dC/dx = 1.75 µg N cm^{-4}) was 30 mg N m^{-2} d^{-1}. These results compare well to those reported by Reddy et al. (1988), who estimated the NH_4^+ flux with ^{15}N to be 48 mg N m^{-2} d^{-1}.

Exchangeable NH_4-N is plotted as a function of depth in Fig. 4.1.7. Exchangeable NH_4-N increased from around 5 µg N cm^{-3} at the surface, to over 20 µg N cm^{-3} at the lower depths.

4.1.4 Conclusions

Ammonium concentrations in the water column peaked after the first few months at around 5 mg N L^{-1}. Decreases in NH_4-N were coupled with NO_3^- production, indicating nitrification was the removal mechanism. Nitrate levels were lower under light conditions due to algal assimilation.

Porewater NH_4-N increased with increasing depth and appeared to be at steady state. Ammonium flux calculated from the concentration gradient was 30 mg N m^{-2} d^{-1}. Flux of this magnitude could enrich lake water by 5.5 mg N L^{-1} annually.

Soluble organic C concentrations in the water column were approximately the same as that in the sediment porewater, indicating that SOC flux from the sediments is not occurring.

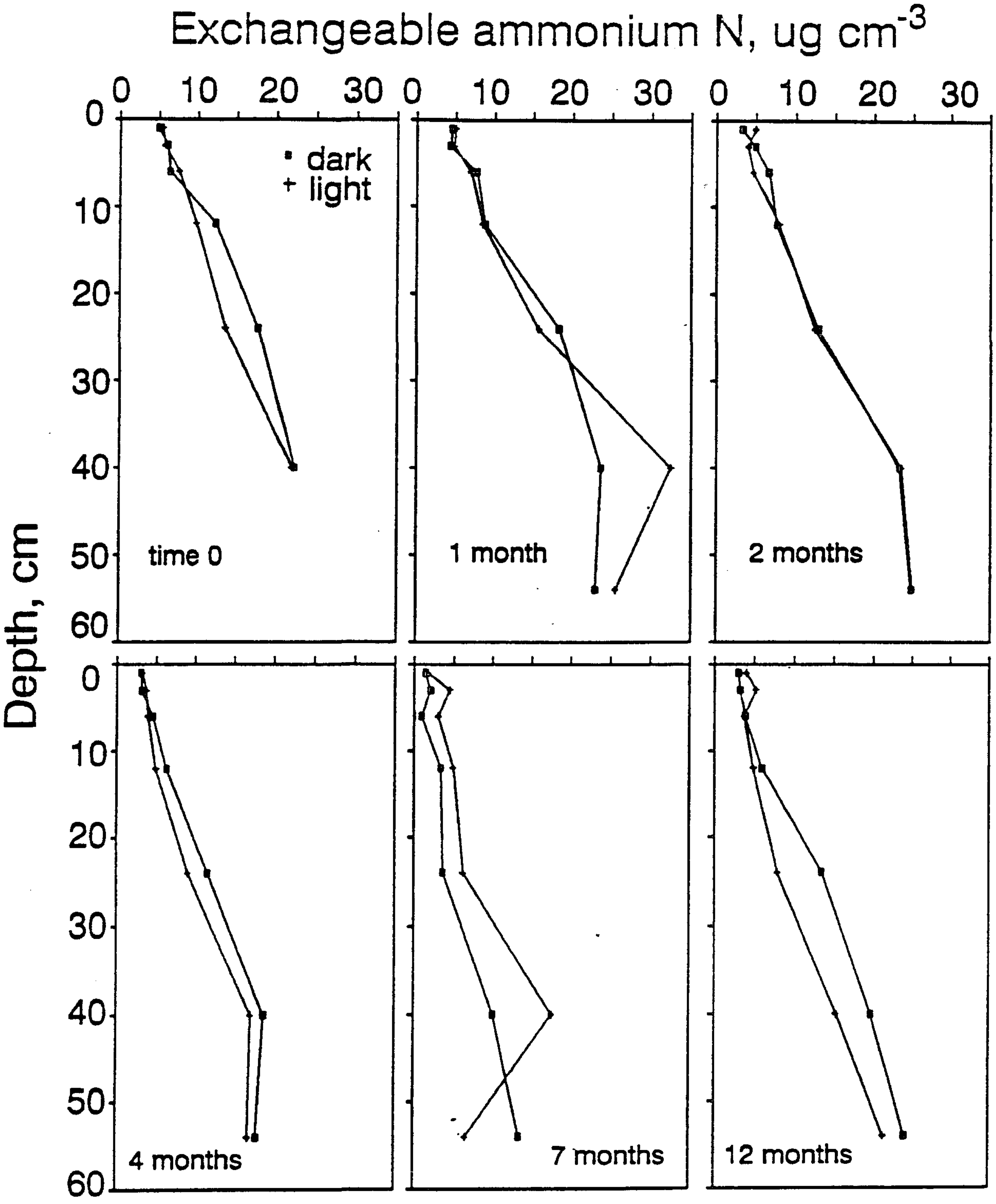

Fig. 4.1.7. Exchangeable ammonium N in the sediment as a function of depth and time.

4.1.5 References

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4.2 Phosphorus

4.2.1 Introduction

Lake sediments can act as either a source or a sink for P. Under normal conditions, sedimentation of P via particulates exceeds the amount released by sediments, causing a net accumulation over time. However, under certain conditions, release of inorganic P by sediments may be large enough to cause, or at least perpetuate, the eutrophication process (Lennox, 1984). For example, Bengtsson (1975) demonstrated that, although 98% of the external P load had been diverted from Lake Södra Bergundasjön in Sweden, it remains eutrophic due to the high rate of P regeneration from the sediments. Bostrom et al. (1982) suggested that the most important processes involving P release from lake sediments include desorption, dissolution, ligand exchange and enzymatic hydrolysis. Once the P is in dissolved inorganic form it can be transported from the sediment to the water via diffusion, wind-induced turbulence, bioturbation and gas ebullition.

A number of approaches have been used to quantify P availability in lake sediments. Many studies have been conducted on P release from intact sediment columns to the overlying water (Anderson, 1975; Banoub, 1975; Lee et al., 1976; Rippey, 1976; Wildung et al., 1977; Theis and McCabe, 1978; Holdren and Armstrong, 1980; Fowler et al., 1987). These studies have usually shown that Eh, pH, temperature, microbial activity and porewater soluble reactive phosphorus (SRP) levels strongly affect P release or retention by sediments. Early work by Mortimer (1941, 1942) demonstrated that sediment P release was greater when the overlying water was anoxic, due to the reduction of relatively insoluble ferric phosphates. Later, work by Holdren and Armstrong (1980) showed that this was true only for non-calcareous lakes. Several researchers have shown that the rate of P release from intact cores increases with pH (Rippey, 1976; Drake and Heaney, 1987). Anderson (1975) showed that P release from sediments increased as pH increased until about pH 9.5, when it started to decrease once more. This was attributed to two processes: (1) P desorption from Fe oxides and hydroxides due to exchange with OH^-, and (2) precipitation of P as hydroxyapatite. Phosphorus release from sediments has also been shown to be highly correlated to the concentration gradient for P in the interstitial waters (Kamp-Nielsen, 1974) and to temperature (Holdren and Armstrong, 1980).

Sequential chemical extraction procedures have been widely used to characterize sediment P. Chang and Jackson (1957) first developed a P-fractionation scheme for soils. Williams et al. (1971) modified the procedure so that it discriminated Fe- and Al-bound P from that associated with Ca; however, their fractionation scheme included the use of citrate dithionite bicarbonate (CDB), which extracts about one-third of the P from calcium phosphate minerals such as apatite (Hieltjes and Lijklema, 1980). Modifications of this procedure by Hieltjes and Lijklema (1980) and by van Eck (1982) suggested using NH_4Cl for loosely bound P, NaOH for Fe- and Al-bound P, and HCl for Ca-bound P. Bostrom et al. (1982) reported that few reports are available which combine studies on fractional distribution of P with studies on associated P release from sediments.

Solubility measurements provide an alternative method of characterizing the stability of P minerals in lake sediments. In Fe-dominated systems that are oxidized, ferrosoferric hydroxyphosphates have been reported to be the most stable minerals (Nriagu and Dell, 1974), whereas vivianite is the dominant phase under reduced conditions (Nriagu and Dell, 1974; Emerson and Widmer, 1978). Golterman (1982) indicated that apatite equilibrium may influence P concentrations in calcareous lakes. However, apatite formation may be hindered by the presence of Mg (Martens and Harriss, 1970), carbonate (Stumm and Leckie, 1970) and organic acids (Inskeep and Silvertooth, 1988) or by the absence of calcite surfaces or seed crystals (Griffin and Jurinak, 1973, 1974).

Lake Apopka, located in central Florida, is a shallow lake (mean water depth 2 m) which is currently hypereutrophic as a result of nutrient loadings from external (agricultural drainage from adjacent vegetable farms and runoff from nearby citrus groves) and internal (sediment) sources (USEPA, 1979). Heavy N and P loadings from the above external sources over a number of years have resulted in tremendous algal populations, with chlorophyll a concentrations at times exceeding 150 μg L^{-1} (Fisher and Reddy, 1987). Rapid turnover of the algae in Lake Apopka also has contributed to sediment buildup and, over the years, settling of undecomposed algal biomass has resulted in sediment accumulation at a rate of about 1.15 cm yr^{-1} (see Chapter 3). This sediment contains up to 97% water, is highly flocculent, and is believed to be releasing dissolved nutrients into the overlying water column via mineralization of organic N, and P to inorganic forms. Such processes may perpetuate the eutrophic condition of the lake even after external inputs have been eliminated, since the quality of overlying waters is to some extent governed by the transport of dissolved forms of C, N and P from the underlying sediments. This transport is primarily due to: (1) diffusion and mass flow as a result of concentration gradients across the sediment-water interface, and (2) release of dissolved nutrients during sediment resuspension in the water column during short-term wind events (Pollman, 1983). Therefore, in order to establish regulatory strategies for the management of Lake Apopka and its adjacent watershed, knowledge of the extent of such internal nutrient cycling is necessary.

The objectives of this research were: (1) to elucidate the biogeochemistry of P in the sediment-water column for Lake Apopka, (2) to assess the impact of algae on associated lake water chemistry, and (3) to determine the degree of interchange for P between bottom sediments and the overlying water column. In the previous section (4.1), we reported N and C interchange between the sediment-water column. In this section, we report P interchange between the sediment-water column.

4.2.2 Materials and methods

Thirty-six intact sediment cores (6.35 cm x 60 cm) were taken in 1-m Plexiglas tubes near Fisherman's Paradise (lake sampling station K-6), utilizing a plunger-equipped corer. Upon returning to the lab, the water depth above the sediment was adjusted to 30 cm and continuous aeration was provided with aquarium pumps via Tygon tubing. The columns were incubated under either partially light or totally dark conditions at 25°C for one year. There were three replications per treatment. The light treatment (200 μEinst cm^{-2} s^{-1}) consisted of a 12-h light and 12-h dark daily cycle, provided by fluorescent growth lights. Water samples were taken weekly. The amount of water taken for weekly samples (60 mL) was replaced with filtered (0.3 μm) lake water of known composition.

At the end of 0, 1, 2, 4, 7, and 12 months, triplicate sediment cores were sectioned horizontally at 2, 4, 8, 12, 24, 48 and 54 cm in a glove bag under a N atmosphere. Sectioned sediment fractions were transferred into 240-mL centrifuge tubes, also under a N atmosphere. Sediment wet weights in each interval were determined and subsamples were taken for water content determinations. Sediment porewater was obtained by centrifuging the sediment at 5,000 rpm for 20 min and filtering anaerobically through 0.45 μm filter paper.

Water samples and porewater were analyzed for SRP, total P and metals (APHA, 1985). Samples taken for metals and SRP were filtered through 0.45 μm millipore filter paper and acidified with concentrated H_2SO_4 (1 drop/20 mL sample). Analysis for inorganic P was conducted using a Technicon AutoAnalyzer. Soluble reactive P was determined using an ascorbic acid technique, according to APHA method 424-G (APHA, 1985). Metals (Al, As, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, P, Pb, Si and Zn) were determined with an inductively coupled argon plasma emission spectrometer (ICAP). Total P in the sediment was determined using modified Kjeldhal N digestion method adapted for total P (Bremner and Mulvaney, 1982).

The computer program GEOCHEM was used to calculate ion activities in lake water and sediment porewater samples (Sposito and Mattigod, 1979). Input consisted of the measured concentrations of Al, B, Ca, Fe, K, Mg, Mn, Na, P, Si, total water-soluble carbonate, an estimate of pCO_2 (based on alkalinity and pH), pH, pe, and an estimate of Cl (35 mg L^{-1}). When calculating ion activities, precipitation was not assumed to occur.

A sediment P-fractionation scheme similar to that of Hieltjes and Lijklema (1980) was employed. After the sediment porewater was removed by centrifugation, five grams of residual sediment were shaken for two hours with 20 mL of 2 M KCl (exchangeable P). Subsequently, the extracts were centrifuged and filtered as above. The residual sediment was then shaken for 17 h with 0.1 M NaOH for assessment of non-apatite P, centrifuged and the supernatant filtered. The residual sediment was then extracted for 24 h with 0.5 M HCl to obtain an estimate of apatite P.

4.2.3 Results and discussion

4.2.3.1 Water chemistry:

Soluble reactive P levels in the water column increased to over 1 mg P L^{-1} during the year under dark conditions, but remained less than 0.01 mg P L^{-1} under light conditions, suggesting that algae may control inorganic-P levels in the lake (Fig.

4.2.1a). Close agreement between lake water SRP and dissolved total P levels (Fig. 4.2.1b) suggests that most of the dissolved P is in reactive form, and thus is readily available to algae. Banoub (1975) also reported that most of the dissolved P in an overlying water column was SRP, with only small amounts of organic P. Such results also suggest that diffusion of dissolved organic P from underlying sediment to the overlying water column is not significant. The increases in SRP levels under dark conditions (corrected for water removal and replenishment) correspond to a flux of 0.99 g P m^{-2} yr^{-1}, which is equivalent to a whole-lake loading of 123.5 metric tons P yr^{-1}. A flux of this magnitude could increase lake water SRP levels by as much as 0.5 mg P L^{-1} yr^{-1}. Actual flux in the lake is probably much higher, due to a greater diffusion gradient and to regular sediment-water mixing caused by wave action.

Pollman and Brezonik (1979) calculated the potential diffusion rate from Lake Apopka sediments to overlying water at 5.25 mg P m^{-2} d^{-1}. This value is of the same order of magnitude as our findings (2.71 mg P m^{-2} d^{-1}). Reddy and Rao (1983) measured a P flux of 9.8 mg P m^{-2} d^{-1} from Lake Apopka sediments that had been drained for agricultural use and then reflooded.

The average metal concentrations in the water column are shown in Table 4.2.1. Most of the metals had similar concentrations under light and dark conditions. However, Si concentrations were depleted under light conditions, suggesting that uptake by diatoms may have occurred. Calcium concentrations, conversely, were slightly higher under dark conditions, possibly due to the difference in pH between the two treatments. Concentrations of most of the transition and heavy metals were low, probably due to their relative insolubilities at high pH.

4.2.3.2 Porewater chemistry:

Sediment porewater SRP concentrations increased with sediment depth (Fig. 4.2.2). There was no significant effect of light and dark treatments on sediment porewater SRP concentrations. Sediment porewater SRP concentrations near the surface increased with time under both light and dark conditions. These increases are probably due to diffusion from underlying sediments. Under natural conditions in the lake, periodic wind events resulting in sediment resuspension would probably deplete SRP in the surficial sediments to extremely low levels, such as observed at time zero. The SRP concentrations in porewaters at the deeper depths were relatively high (averaging 6 mg P L^{-1}), compared to values for other lakes as given by Bostrom et al. (1982). This supports the paradigm that porewater P concentrations reflect the eutrophic state of a lake. In fact, porewater SRP concentrations of up to 15 mg P L^{-1} were observed in a separate study on the temporal and spatial variability of N and P levels in Lake Apopka sediments (see Chapter 7.2).

Diffusional flux of phosphate was calculated as described in Chapter 4.1. For simplicity, the ratio of $HPO_4^{2-}/H_2PO_4^-$ was considered to be unity. This would assume a porewater pH of 7.2, which is in the range observed for the upper sediment layers.

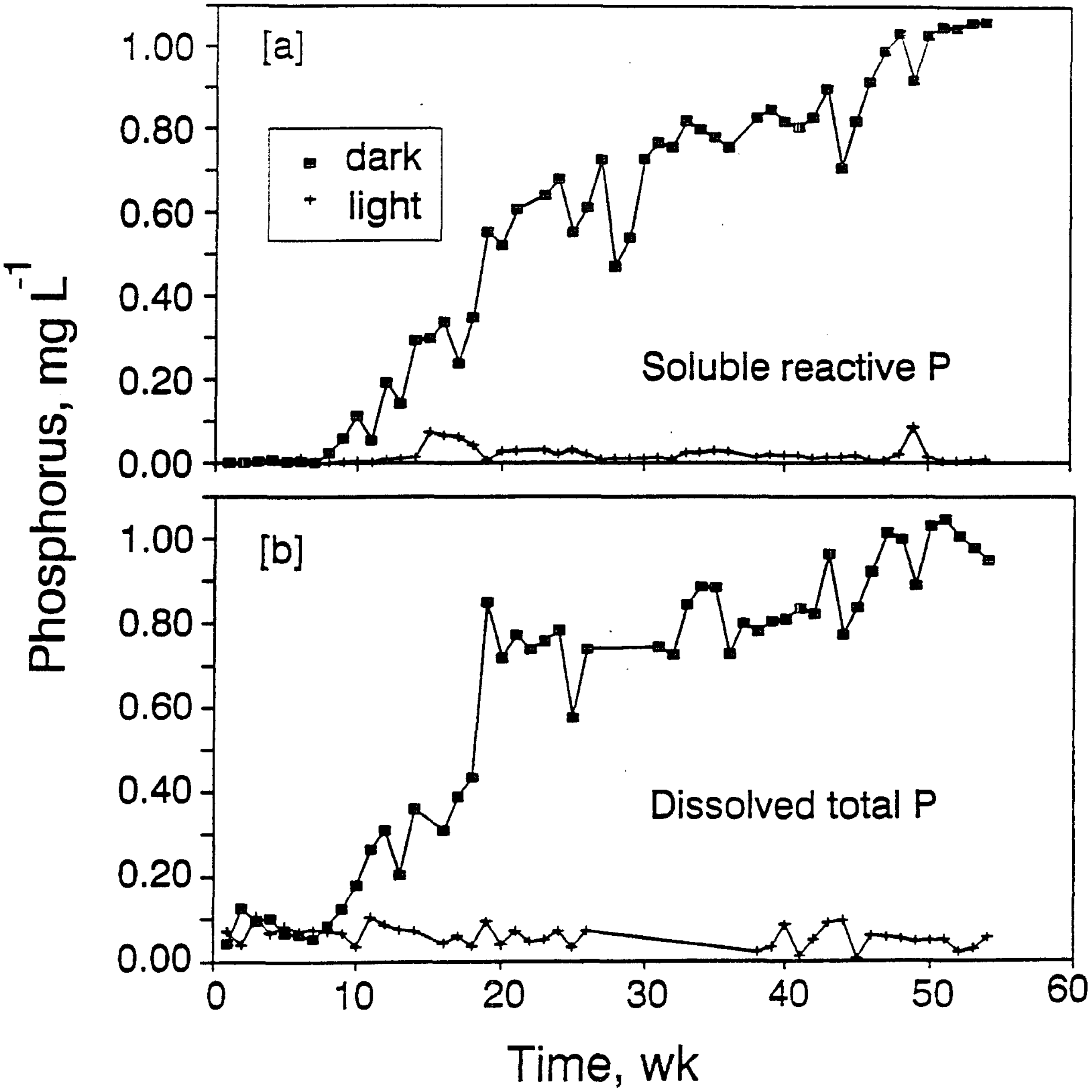

Fig. 4.2.1. Soluble reactive P and total dissolved P in lake water under light and dark conditions.

Table 4.2.1. Annual average metal concentrations in the water column under partially light and totally dark conditions. (For detailed data see Tables A–4.3 through A–4.5).

Metal	Light			Dark		
	Mean	Std. dev.	n	Mean	Std. dev.	n
	mg L^{-1}					
Ca	41.8	7.4	125	47.5	4.1	143
Mg	19.1	2.3	125	19.5	2.1	143
Na	17.3	2.3	125	17.3	2.07	143
K	14.2	6.2	125	15.2	5.1	143
Si	0.99	1.5	125	4.45	3.1	143
Zn	0.08	0.17	111	0.08	0.16	125
As	0.06	0.04	125	0.02	0.02	143
B	0.06	0.05	125	0.11	0.06	143
Fe	0.05	0.09	112	0.06	0.13	125
Al	0.02	0.03	125	0.02	0.04	143
Mo	0.01	0.04	125	0.009	0.04	143
Cu	0.009	0.009	118	0.012	0.014	137
Pb	0.008	0.016	125	0.009	0.024	143
Ni	0.005	0.009	125	0.006	0.013	143
Mn	0.004	0.013	125	0.004	0.008	143
Cd	0.003	0.013	125	0.001	0.002	143
Cr	0.002	0.003	125	0.002	0.002	143

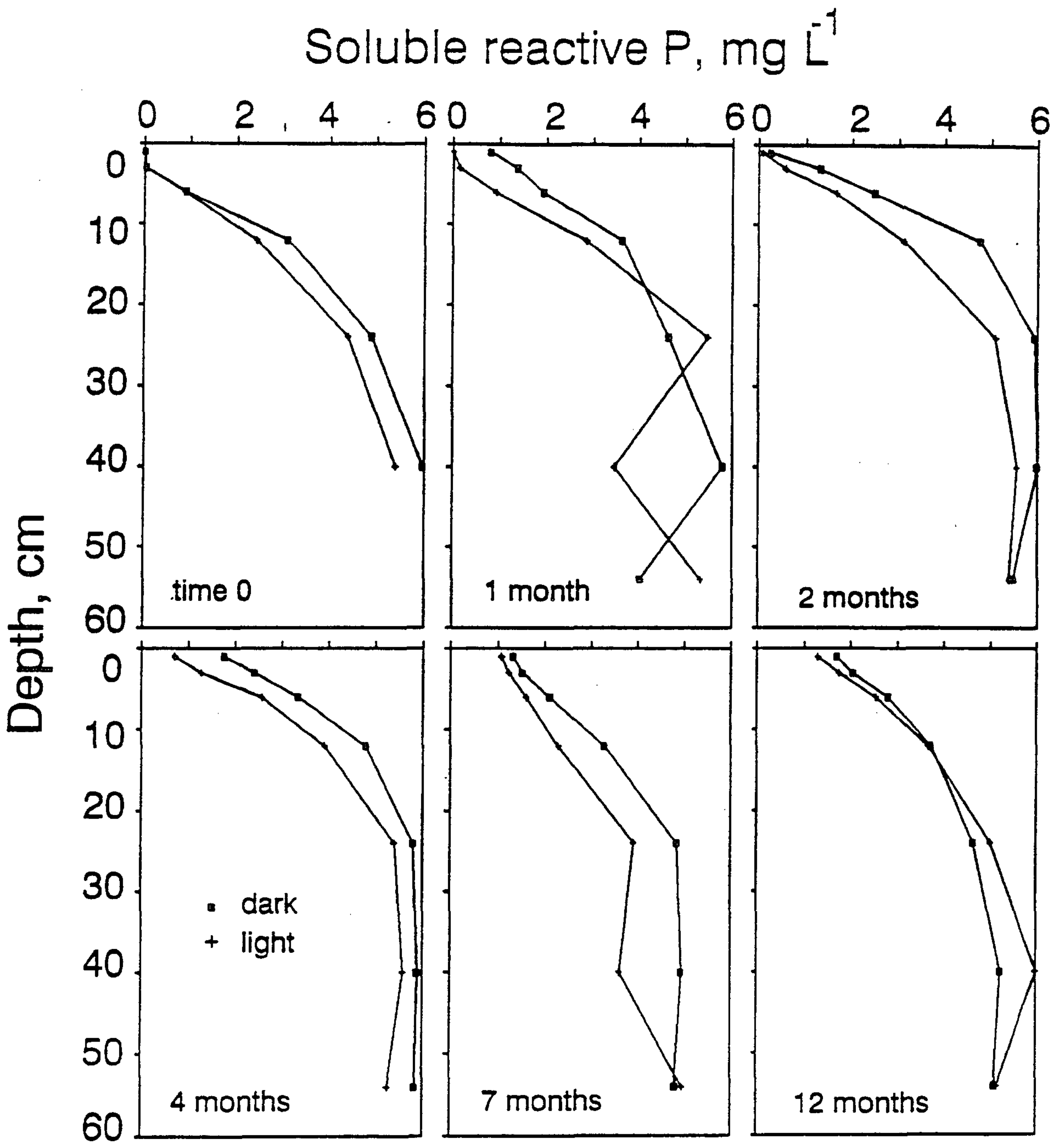

Fig. 4.2.2. Sediment porewater SRP as a function of time and depth.

Values for $D_o(HPO_4^{2-})$, and $D_o(H_2PO_4^-)$ then were taken from Li and Gregory (1974) as 7.34, and 8.46, respectively, in units of 10^{-6} cm^{-2} s^{-1}. Since the ratio of $HPO_4^{2-}/H_2PO_4^-$ was taken as unity, the weighted average $D_o(PO_4)$ was 7.9. Utilizing the assumptions stated above and a concentration gradient of 0.25 μg P cm^{-4}, the calculated P flux was 1.69 mg P m^{-2} d^{-1}. This value is lower than the flux calculated based on overlying water P for the dark treatment.

Klump and Martens (1981) found that P flux calculated from diffusion based solely on porewater concentration gradients wasr less than measured flux for Cape Lookout Bight sediments during the warmer months. They suggested that the increased flux was due to sediment-water transport associated with bubble tubes created by methane gas ebullition. This is certainly possible for Lake Apopka sediments as well, since bubble ebullition was frequently observed in the cores. It is highly unlikely that tubificids or other burrowing invertebrates live in these sediments, due to their highly anoxic, fluid, nature.

4.2.3.3 Fractionation of sediment phosphorus:

Up to 20% of the total P in these sediments was in the water-soluble fraction (Fig. 4.2.3). This is partly due to the extremely low bulk densities of these materials, which result in water/dry sediment ratios of 16 to 64, depending upon depth. Bostrom et al. (1982), on the other hand, stated that porewater P generally constitutes less than 1% of the total P in lake bottom sediments. The amount of P extracted by KCl decreased with depth, and often became even slightly negative when corrected for that P associated with the entrained porewater (Fig. 4.2.4). This apparent anomaly may have been caused by the precipitation of calcium phosphate during extraction, because of increases in Ca^{2+} concentration due to exchange with K^+. Curtin et al. (1987) found that P release during sequential water extractions was much greater if originally Ca-saturated soils were first Na-saturated by extracting with NaCl. Later work by Sharpley et al. (1988) indicated that P release following Na-saturation was matched by decreases in Ca-P compounds (HCl-extractable) in Ca-dominated soils.

The amount of P extracted by NaOH decreased with depth. This fraction represents Fe/Al-bound P, plus some hydrolyzable organic P (Fig. 4.2.4). It is highly unlikely that any of the NaOH-extractable P below the top cm of sediment represents ferric phosphates, since the sediments were all highly reduced below this depth.

Over 50% of the total sediment P was extracted with 0.5 M HCl. Although the relative proportion of total P extracted by HCl remained the same, the absolute amount (on a volume basis) increased with sediment depth (Fig. 4.2.4). Traditionally, this extraction has been associated with calcium phosphate minerals.

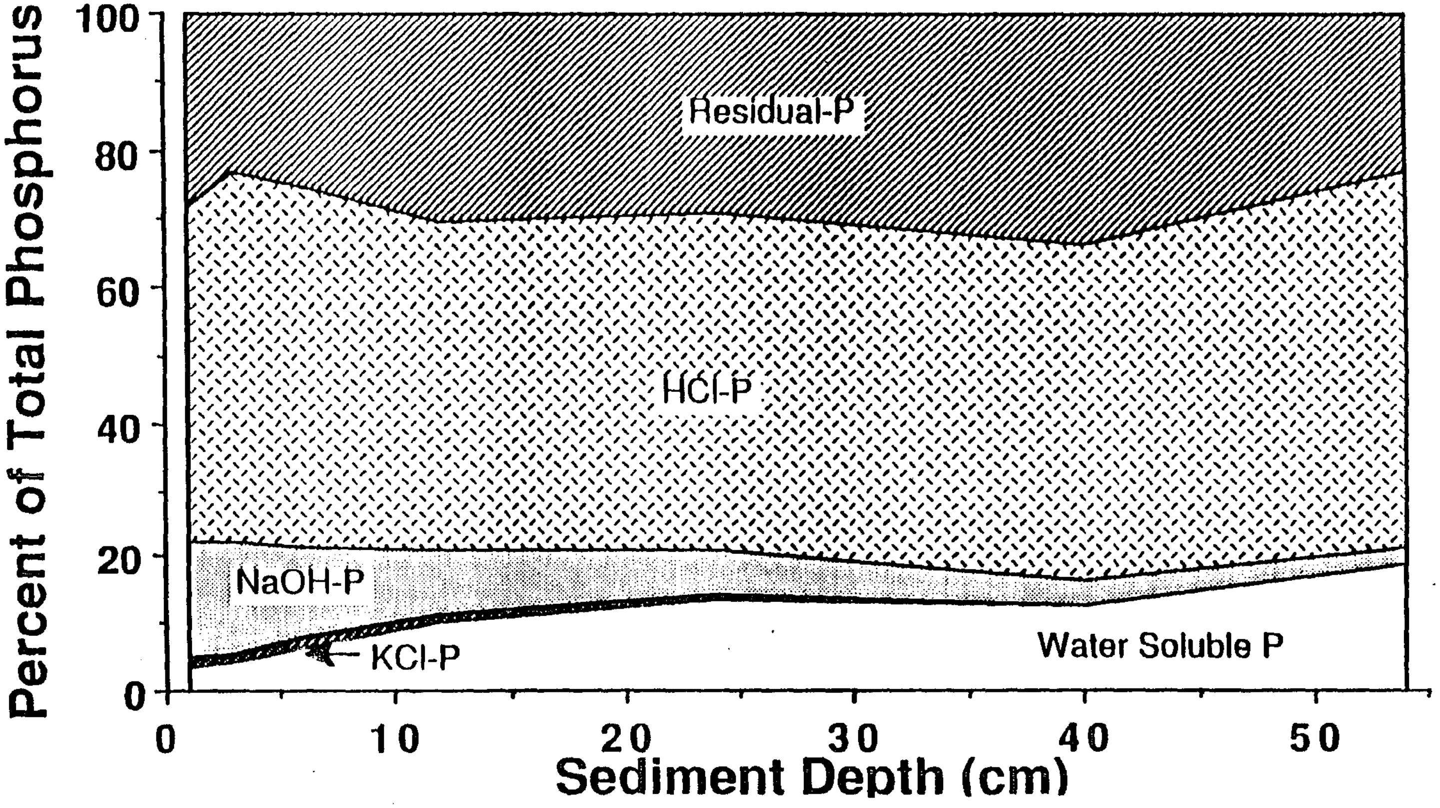

Fig. 4.2.3. Percent of total sediment phosphorus (yearly average) extracted by various reagents as a function of sediment depth.

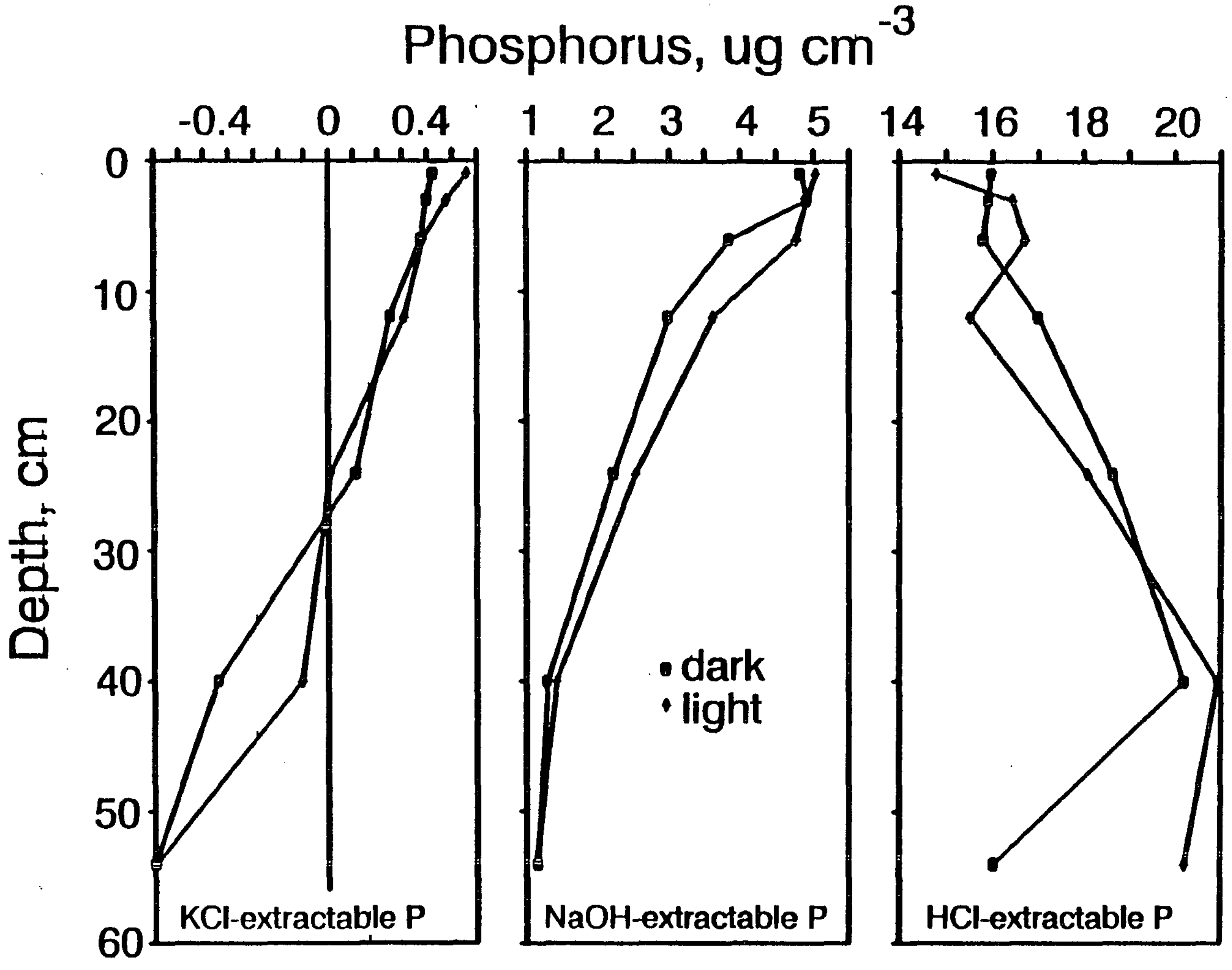

Fig. 4.2.4. The amount of phosphorus extracted by KCl, NaOH and HCl as a function of sediment depth (yearly average).

4.2.3.4 Mineral equilibria:

Ion activity products calculated using the soil-solution model GEOCHEM indicated that the porewaters were undersaturated with respect to Al, Fe and Mn phosphates; and were supersaturated with respect to apatite, beta tricalcium phosphate and whitlockite (Table 4.2.2). When GEOCHEM was run again with solid phases allowed to form, it predicted that apatite would precipitate from these solutions. However, organic acids and Mg^{2+}, each of which were found in relatively high concentrations in these sediments, have been shown to inhibit apatite formation. Therefore, a more soluble mineral phase, such as β-$Ca_3(PO_4)_2$ (beta tricalcium phosphate) or a similar mineral, may be forming instead.

Solubility measurements from sediment-water columns indicate that the porewater and the overlying water in the dark treatment were at or near equilibrium with respect to β-$Ca_3(PO_4)_2$ (Fig. 4.2.5). Phosphorus solubility is probably controlled by algae in the water column under light conditions. Other phases shown in this figure include: dicalcium phosphate dihydrate, also known as brushite (DCPD, $CaHPO_4 \cdot 2H_2O$); octacalcium phosphate (OCP, $Ca_4H(PO_4)_3 \cdot 2.5H_2O$); and dicalcium phosphate, also known as monetite (DCP, $CaHPO_4$).

Norvell (1974) found that inorganic P was precipitated when added to lake sediments. The disappearance of added P was accompanied by decreases in levels of Ca^{2+}, Fe^{2+}, and Mn^{2+}. Solubility equilibria indicated that the interstitial solutions were close to equilibrium with respect to β-$Ca_3(PO_4)_2$ both before and after the P additions. Norvell (1974) referred to this mineral as whitlockite, and stated that substitution of Fe and Mn for Ca, as well as other impurities, are reported to stabilize this phase with respect to transformations into less-soluble apatites. However, pure β-$Ca_3(PO_4)_2$ was shown to be formed only in high-temperature (1000°C) systems free of Mg^{2+} and Fe^{2+} (Gregory et al., 1974). Fixen et al. (1983) also found near-equilibrium with respect to β-$Ca_3(PO_4)_2$, and stated that whitlockite, a similar mineral with average composition $Ca_{18}(Mg,Fe)H_2(PO_4)_{14}$, may be forming instead of β-$Ca_3(PO_4)_2$ in soils. The pK for whitlockite as shown in Table 4.2.2 was calculated assuming a Gibbs-free energy of formation of 6251.0 Kcal mol^{-1}, which was determined using the method of Nriagu (1976).

Porewater Ca and Mg concentrations increased with increasing sediment depth (Figs. 4.2.6a and b). Emerson (1976) also showed increasing Ca and Mg concentrations with depth, and attributed it to associated increases in CO_2. Table 4.2.2 lists the IAP's of both calcite and dolomite. These data suggest supersaturation with respect to calcite ($K = 10^{-8.34}$), aragonite ($K = 10^{-8.16}$) and dolomite ($K = 10^{-17}$). Drever (1982) noted that dolomite is usually formed by alteration of aragonite or calcite as follows;

$$CaMg(CO_3)_2 + Ca^{2+} = 2\ CaCO_3 + Mg^{2+}$$

In solutions where the Mg^{2+}/Ca^{2+} activity ratio is 0.6 or higher, dolomite is generally the thermodynamically stable phase. However, there is a large amount of

Table 4.2.2. Average ion activity products of selected phosphate mineral in Lake Apopka sediments.

Mineral	Formula	pK	Mean pIAP[†]	Range	Std. Dev.
Apatite	$Ca_{10}(PO_4)_6(OH)_2$	119	104	100.5–117.8	3.34
Beta tri-calcium phosphate	β-$Ca_3(PO_4)_2$	28.9	29.2	27.1– 33.2	1.03
Crandalite	$CaAl_3(PO_4)_2(OH)_5 \cdot 5H_2O$	85.9	97.0	93.6–104.7	2.53
Reddingite	$Mn_3(PO_4)_2$	31.8	39.0	37.5– 45.1	1.10
Wavellite	$Al_3(PO_4)_2(OH)_3 \cdot 5H_2O$	31.5	38.5	34.3– 47.8	2.99
Whitlockite	$Ca_{18}(Fe,Mg)H_2(PO_4)_{14}$	222	222	209.2–249.3	7.23
Variscite	$AlPO_4 \cdot 2H_2O$	22.1	23.5	21.7– 27.9	1.33
Vivanite	$Fe_3(PO_4)_2 \cdot 8H_2O$	36.0	42.2	38.2– 46.6	1.15
Aragonite	$CaCO_3$	8.16	8.06	7.2– 8.6	0.26
Calcite	$CaCO_3$	8.34	8.06	7.2– 8.6	0.26
Dolomite	$CaMg(CO_3)_2$	17.0	16.6	15.0– 17.5	0.52
Siderite	$FeCO_3$	10.2	12.2	10.7– 12.9	0.35
Rhodocrosite	$MnCO_3$	10.4	11.3	10.7– 12.0	0.25

[†] n = 131.

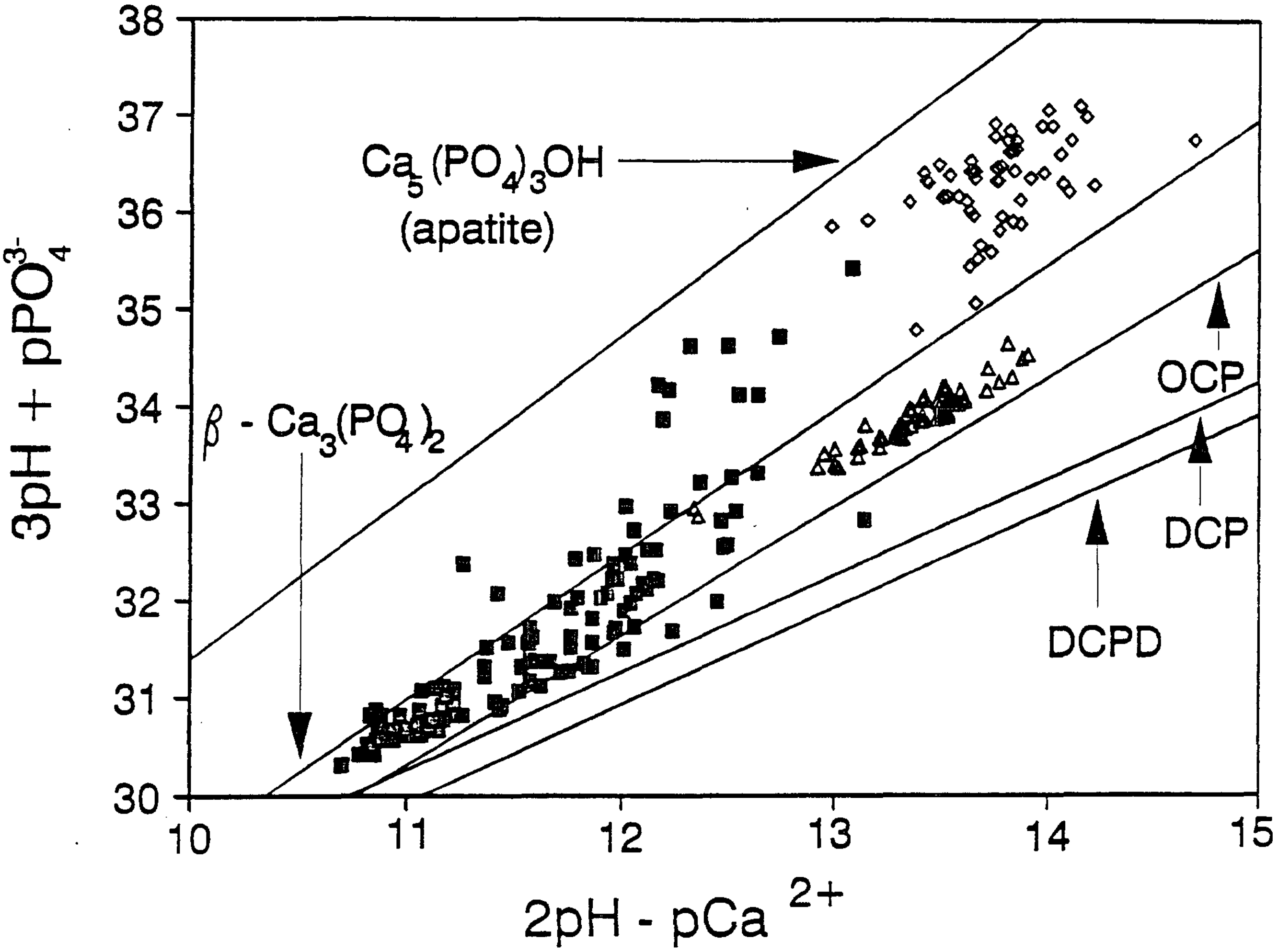

Fig. 4.2.5. Theoretical solubility isotherms of selected calcium phosphate minerals and measured solubilities under light (◆) and dark (▲) conditions in the water and in the porewater (■).

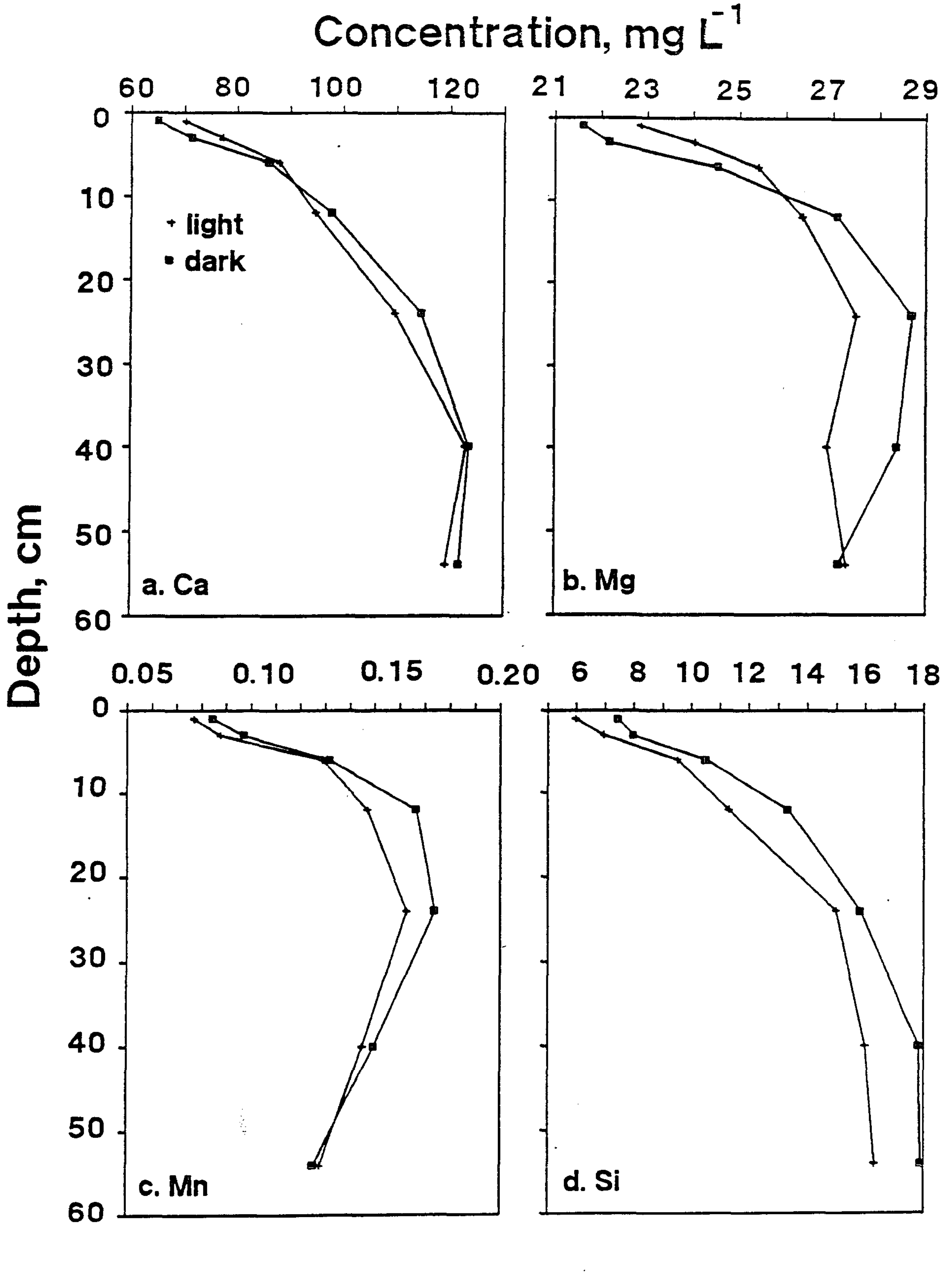

Fig. 4.2.6. Porewater metal concentrations as a function of depth (yearly average).

uncertainty associated with this number, with calcite seldom converting to dolomite unless the Mg^{2+}/Ca^{2+} activity ratio is higher than 10. The average Mg^{2+}/Ca^{2+} activity ratio in the Lake Apopka porewaters was around 0.6.

The solubility of Mn also tended to increase with depth (Fig. 4.2.6c). Since the porewaters were in general saturated with respect to $MnCO_3$ (rhodocrosite), this phase was believed to be controlling Mn solubility. Porewater Si concentrations also increased with increasing depth (Fig. 4.2.6d). Such distribution is likely due to the dissolution of diatoms.

4.2.4 Conclusions

Levels of soluble reactive P in Lake Apopka water were apparently governed by algal uptake under light conditions, while SRP levels in continually dark water increased several-fold. Phosphorus flux from the underlying sediments as inferred from the increase in concentration of the overlying water averaged 2.71 mg P m^{-2} d^{-1}. Flux of this magnitude could increase the lake water SRP level by 0.5 mg P L^{-1} annually. Phosphorus flux calculated from porewater SRP gradients were on the order of 1.69 mg P m^{-2} d^{-1}.

Sediment P-fractionation indicated that porewater P, exchangeable P and non-apatite P each decreased with depth, while the amount of apatite P concurrently increased. Apatite P was the dominant fraction, comprising over 50% of the total P counted. Ion activity products calculated using GEOCHEM suggested that the sediments were supersaturated with respect to apatite, beta tricalcium phosphate and whitlockite, with the latter expected to be the phase controlling porewater PO_4^{3-} activities.

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Chapter 5

TRANSFORMATIONS OF CARBON, NITROGEN AND PHOSPHORUS IN THE SEDIMENT-WATER COLUMN

5.0 TRANSFORMATIONS OF CARBON, NITROGEN, AND PHOSPHORUS IN THE SEDIMENT-WATER COLUMN

5.1. Organic Matter Decomposition and Nutrient Release as Influenced by Oxygen Supply [Tasks 3.1 and 3.5]

5.1.1. Introduction

Decomposition of organic matter in aquatic sediments is governed by the nature of the organic matter and the supply of electron acceptors (Fenchel and Jorgensen, 1977; Reddy et al., 1986). Under most conditions, sediment organic matter decomposition is limited by the electron acceptor supply. In shallow lakes, aerobic decomposition occurs in the water column and at the sediment-water interface, while anaerobic decomposition occurs in the sediments. As a result of wave action from wind events, the flocculent surface sediments can be easily resuspended, thus depleting O_2 in the water column. Under these conditions decomposition of organic matter is affected by the dissolved O_2 concentration in the water column and biological O_2 demand of the suspended sediment.

Tenny and Waksman (1930) observed that the decomposition of cellulose, hemicellulose and lignin was slower under anaerobic conditions than aerobic. Although the decomposition of organic matter is slower under anaerobic conditions than aerobic, the release of inorganic N as NH_4^+ is generally greater, due to the low N requirement of anaerobic organisms (Acharya, 1935a,b,c).

Similarly, decomposition is influenced by alternate aerobic/anaerobic cycles. Reddy and Patrick (1975) found that alternating the aeration status of sediments from aerobic to anaerobic conditions in 2/2- or 4/4-d cycles was equivalent to continuously aerated conditions with respect to decomposition, however, as the length of the anaerobic period increased, decomposition decreased.

Oxygen respirometric techniques, which use *in situ* respiratory quotients ($RQ = CO_2/O_2$), cannot be used in most eutrophic lake sediments due to their anoxic nature (Wetzel, 1975), since organic matter decomposition in these systems is also regulated by other electron acceptors such as nitrate and sulfate.

Although the release of N from sediments has been shown to be proportional to CO_2 release and hence a product of decomposition, solubilization of P has not, and is believed to be dictated by dissolution/precipitation reactions (Elderfield et al., 1981). Mortimer (1942) showed that sediment P release was greater when the overlying water was anoxic, due to reduction of ferric phosphates. However, Holdren and Armstrong (1980) showed that this was true only for non-calcareous lakes. Predictions based on mineral equilibria calculations indicate that ferrosoferric hydroxyphosphates are the most stable P minerals in Fe-dominated systems that are oxidized (Nriagu and Dell, 1974), whereas vivianite is the dominant phase under reduced conditions (Nriagu, 1972; Nriagu and Dell, 1974; Emerson, 1976; Emerson and Widmer, 1978; Elderfield et al., 1981). In calcareous lakes, apatite has been implicated as the mineral phase controlling P solubility (Golterman, 1982).

Although decomposition of organic matter and nutrient release by lake sediments has been evaluated by several researchers, very little is known on the effects of O_2 supply on nutrient biogeochemistry. The objectives of this study were: (1) to investigate the influence of various levels of O_2 on sediment decomposition; (2) to determine the effects of varying O_2 levels on N and P transformations, and (3) to determine the effects of alternate aerobic-anaerobic conditions on sediment chemistry. The results presented in this chapter are the products of the experiments conducted for Tasks 3.1 and 3.5 of the Research Program Manual.

5.1.2. Materials and methods

Sediment samples for this experiment were taken with an Ekman dredge on Feb. 11, 1988 from the flocculent layer (0-30 cm) of the K-6 site near Fisherman's Paradise in Lake Apopka (see Chapter 3 for map showing sampling location). One thousand grams of wet sediment and 1500 mL of filtered Lake Apopka water were placed in eight 2800-mL flasks and incubated under constant stirring at 25°C. Two platinum electrodes and a salt bridge were permanently inserted through a rubber stopper to measure the redox potential (Eh) of the suspension. The flasks were supplied with CO_2-free O_2/N_2 mixtures. The gas treatments were 0, 0.2, 2.0, and 20.0% O_2 with the balance N_2. The flow rates were set at 60 mL min^{-1} using inline flow meters. In order to insure CO_2-free air, NaOH (3M) traps in conjunction with water traps were connected at the inflow end of the gas line. The zero O_2 treatment was also equipped with a trap containing pyrogallic acid and NaOH to facilitate complete O_2 removal. The CO_2 evolved was trapped in 0.5 N NaOH and analyzed every 2-3 d. There were two replications per treatment. Sediment samples were taken at 0, 1, 2, 4, 8, 15, 30, 60, and 100 d. Sixty mL of the sediment slurry were removed with a hypodermic syringe via a rubber septum and placed in centrifuge tubes prepurged with N_2. The tubes were centrifuged at 6,000 RPM for 15 min and aliquots were taken for NH_4-N, NO_3-N, soluble organic carbon (SOC), electrical conductivity (EC), pH and titratable alkalinity. Alkalinity, EC, and pH were determined on unfiltered samples. Samples taken for NH_4-N, and NO_3-N were filtered through 0.45 μm filter paper and acidified with concentrated sulfuric acid. Ammonium-N was determined with the salicylate-nitroprusside technique according to method 351.2 (USEPA, 1979). Nitrate (+nitrite) was determined using the cadmium reduction method according to method 418-F (APHA, 1985). Metals (Al, B, Ca, Cd, Cu, Fe, K, Mg, Mn, Na, P, Pb and Zn) were determined with an inductively coupled argon plasma emission spectrometer (ICAP). In order to determine exchangeable NH_4-N, 5 g of the residual sediment from the water soluble fraction was then shaken with 25 mL of 2 M KCl for 2 h, centrifuged and filtered. Redox measurements were taken on a daily basis. At selected time intervals, a 500 μL portion of the gas samples from 0 and 0.2% O_2 treatments were analyzed for CO_2 and CH_4 using 5840 Hewlett-Packard gas chromatograph equipped with thermal conductivity detector.

A second experiment was conducted to determine the effect of alternate aerobic-anaerobic conditions on C, N and P transformations. Two 2800-mL flasks containing 1000-g wet sediment and 1500 mL of filtered lake water were incubated under constant stirring as described above. At the onset of the experiment, CO_2/O_2-free N_2 gas was bubbled through the suspensions at a rate of 60 mL min^{-1}. After 39 d of incubation, CO_2-free air was bubbled through the suspensions. At day 73, the air treatment was discontinued and N_2 gas was resumed. At day 107, the air treatment was resumed. Scrubbing of CO_2 and O_2 was accomplished with NaOH and pyrogallic acid traps, respectively, as described above. The CO_2 evolved was trapped in 0.5 N NaOH, which was analyzed every 2-3 d. Sediment-water slurry samples were taken after 0, 1, 2, 4, and 7 d of incubation from each aerobic-anaerobic cycle. The samples were taken with a syringe and placed in pre-purged 240-mL centrifuge tubes. The tubes were centrifuged and aliquots were taken for NH_4-N, NO_3-N, SRP, SOC, EC, pH and alkalinity as described above. Redox measurements were made on a daily basis with permanently installed platinum electrodes.

5.1.3. Results and discussion

5.1.3.1. Redox potential:

Redox potentials in the sediment suspensions at time zero were fairly high (400 mV), indicating oxidized conditions (Fig. 5.1.1). This was probably due to mixing with O_2 when the bulk sample was being homogenized. The Eh decreased in sediments incubated under 0 and 0.2% O_2 levels to around -340 mV during the first few weeks, whereas it increased in the 2.0 and 20.0% O_2 treatments to around +450 mV. After this time the Eh remained somewhat constant in all the treatments except the 0.20% O_2 treatment, where the Eh rose during the latter part of the study to around +50 mV for several weeks before declining to the previous reading. The cause of this fluctuation is unknown. Khalid et al. (1978) found that stirred sediment suspensions subjected to 21% and 2.1% O_2 treatments had high (>600mV) redox potentials, whereas 0.11% O_2 resulted in reduced conditions (-150mV).

In the second experiment, redox potentials decreased to around -350 mV within a few days after flushing with N_2 gas was initiated (Fig. 5.1.2). When the gas was switched to CO_2-free air at day 39, the redox potentials rose to 200 mV within hours and slowly increased to over 300 mV. At day 73, when the N_2 gas treatment was resumed, the Eh plummeted to -300 mV within a few days. These data indicate that the redox status of the sediments was poorly buffered. If the system had contained a large quantity of electron acceptors such as Fe^{3+}, Mn^{4+}, or NO_3-N, then the Eh would have been poised at a relatively high redox potential (100-300 mV).

5.1.3.2. Porewater pH:

The porewater pH of all the treatments increased from 7.6 at time zero, to above 8.0 at day one (Table 5.1.1). This initial increase in pH was probably due to a decrease in pCO_2 as the CO_2-free gas mixtures were introduced into the sediment. After this time, the pH of the two oxidized sediments (2.0 and 20.0% O_2) decreased,

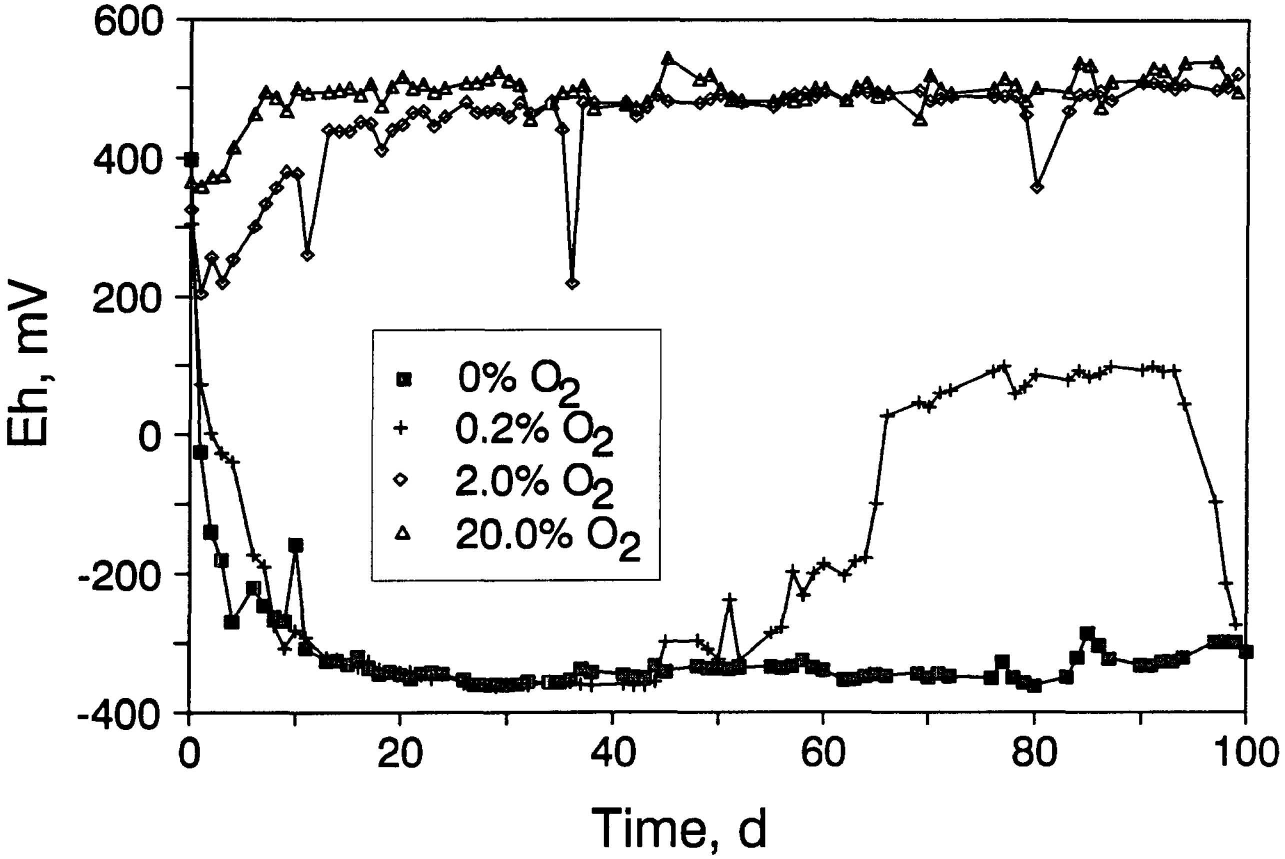


Fig. 5.1.1. Sediment redox potential as a function of O_2 supply and time.

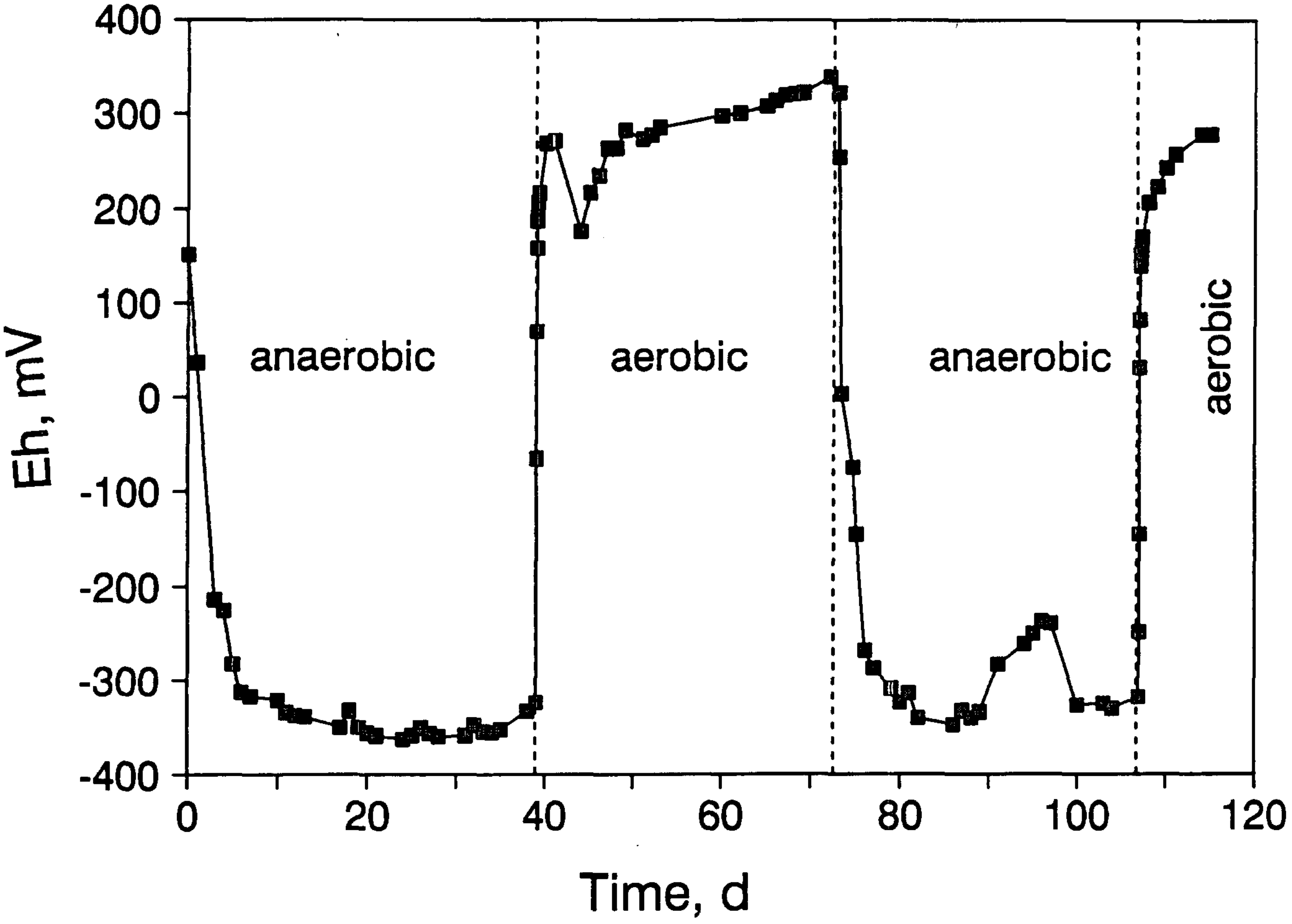


Fig. 5.1.2. Sediment redox potential as influenced by alternate anaerobic and aerobic conditions.

Table 5.1.1. Electrical conductivity, pH and alkalinity as a function of time.

	Time, d								
	0	1	2	4	8	15	30	60	100
0% O_2									
Alkalinity[†]	260	210	195	190	185	195	163	235	277
Conductivity[‡]	533	455	430	412	421	447	594	835	970
pH	7.60	7.95	8.29	8.31	8.55	8.69	8.51	7.88	8.73
0.2% O_2									
Alkalinity	260	210	200	180	200	190	160	250	236
Conductivity	535	435	435	446	446	513	540	625	723
pH	7.58	8.20	8.20	8.22	8.37	8.40	8.55	8.55	8.73
2.0% O_2									
Alkalinity	253	208	185	185	170	63	65	38	50
Conductivity	530	473	458	489	510	593	655	910	1153
pH	7.58	8.06	8.16	8.11	8.24	7.55	7.54	6.75	7.47
20.0% O_2									
Alkalinity	243	198	195	185	70	80	55	95	71
Conductivity	535	438	443	465	495	560	626	830	1005
pH	7.63	8.08	8.05	8.01	7.64	7.65	7.41	7.10	8.00

[†] Units in mg $CaCO_3$ L^{-1}.

[‡] Units in μS cm^{-1}.

probably due to proton production during nitrification. The pH of the reduced sediments (0 and 0.2% O_2) increased to around 8.5, and remained at this level during the 100-d incubation period. The EC of all the treatments decreased from around 520 μS cm^{-1} at time zero to around 450 μS cm^{-1} at day one (Table 5.1.1). The initial decreases in EC were also induced by changes in pH, which affected the alkalinity. The alkalinity of the oxidized treatments decreased to around 70 mg $CaCO_3$ L^{-1} after day 15, whereas that of the reduced treatments remained above 150 mg $CaCO_3$ L^{-1}.

Alternate aerobic/anaerobic cycles in the sediment also influenced pH. The porewater pH increased from around 7.1 at day zero to over 9.0 at day 107 (Fig. 5.1.3). The use of CO_2-free gases probably caused a disruption of the carbonate system as in the first experiment where O_2 supply was controlled. The alkalinity decreased from over 300 mg $CaCO_3$ L^{-1} to 165 mg $CaCO_3$ L^{-1} during the first week (Fig. 5.1.3). The alkalinity then increased steadily for the remainder of the study. Changes in the alkalinity strongly affected the EC, which decreased from 600 μS cm^{-1} at day zero to around 400 μS cm^{-1} at day 7 (Fig. 5.1.4). Afterwards the EC increased to around 1100 μS cm^{-1}.

5.1.3.3. Organic matter decomposition:

Organic matter decomposition was found to be directly related to O_2 supply, with the highest amount of CO_2 evolution in the 20% O_2 treatment (Fig. 5.1.5). These trends appeared to mirror the redox status of the systems. First order rate constants (k) calculated based on CO_2 evolution were 0.00010, 0.00027, 0.00062, and 0.00068 d^{-1} for the 0, 0.2, 2.0, and 20.0% O_2 treatments, respectively. Parr and Reuszer (1962) demonstrated that the percent decomposition of added C (wheat straw) increased exponentially with increasing O_2 concentrations.

Gilmour et al. (1977) and Reddy et al. (1980) used first order kinetics to describe C decomposition in two to three phases. Using this approach it was assumed that the easily decomposable material degrades during the initial phase, while the more complex substrates decompose at slower rates. Gilmour et al. (1977) indicated that the rapid phase involves simple sugars and amino acids; the intermediate involves cellulose and hemicellulose; while the slow phase involves the lipid and lignin fractions. Reddy et al. (1980) found that the first order rate constant for rice straw decomposition under aerobic conditions decreased from 0.0054 d^{-1} during phase I to 0.0013 in phase II, while under anaerobic conditions rates were 0.0024 and 0.0003 d^{-1} for phase I and phase II, respectively. They indicated that the easily decomposable fraction was correlated with the C/N ratio of the substrate. Apparently the organic matter in the sediments used for this study had undergone extensive decomposition prior to sample collection and was in the slow phase of decomposition, as indicated by the linear relationship between cumulative CO_2 and time (Fig. 5.1.5).

The rate at which organic matter is decomposed is very dependent of the chemical composition, with the relative order of the different fractions as follows:

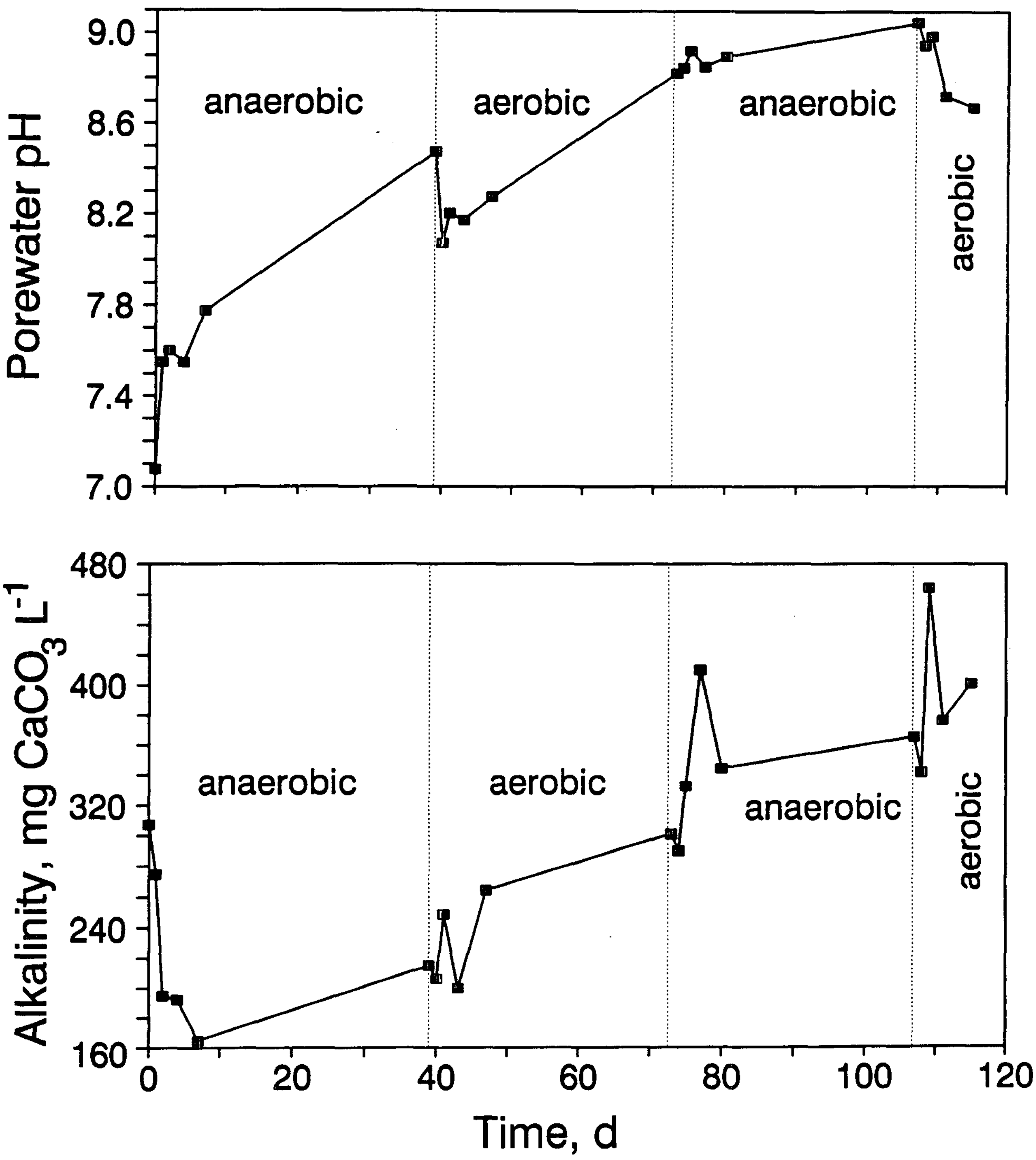


Fig. 5.1.3. Sediment porewater pH and alkalinity as influenced by alternate anaerobic and aerobic conditions.

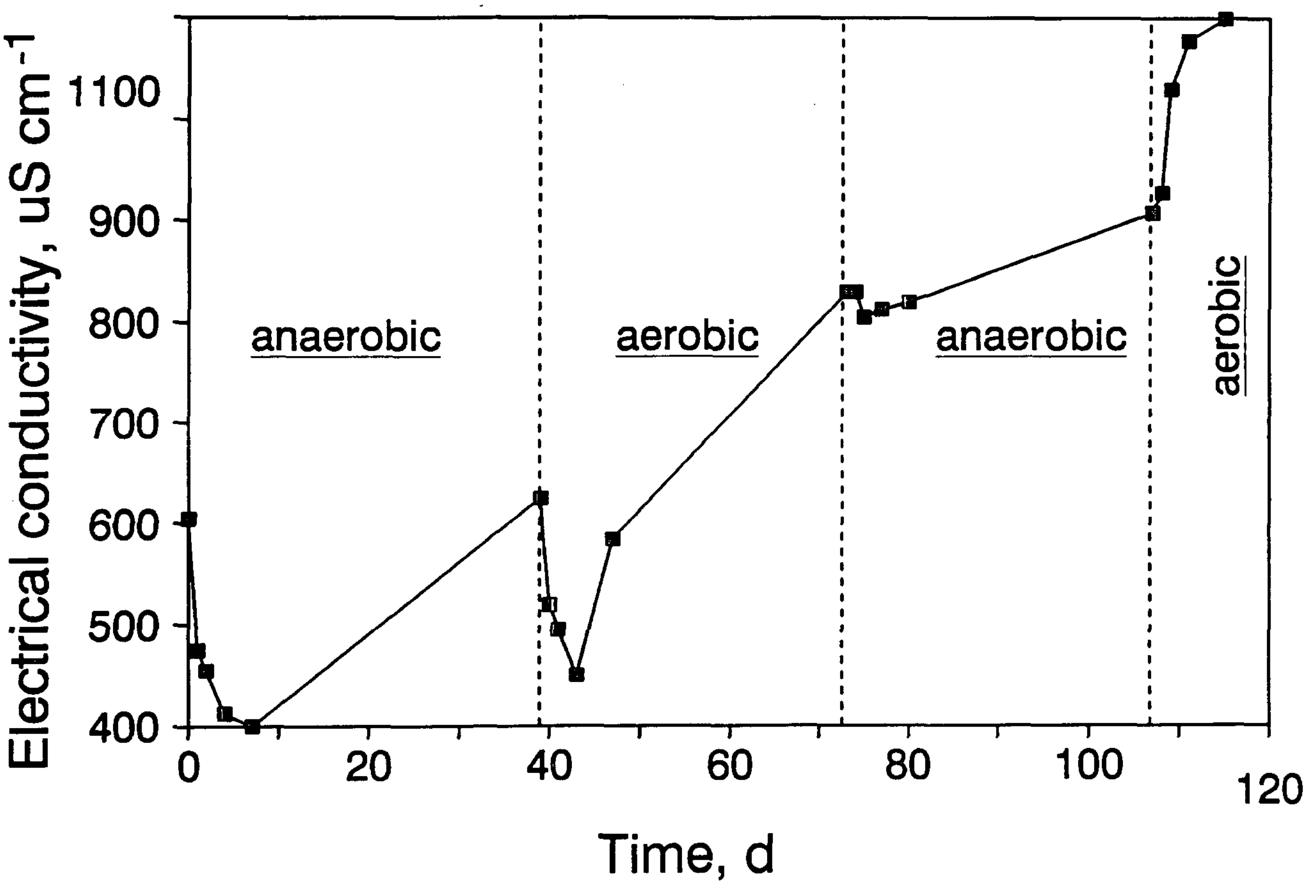


Fig. 5.1.4. Sediment porewater electrical conductivity as influenced by alternate anaerobic and aerobic conditions.

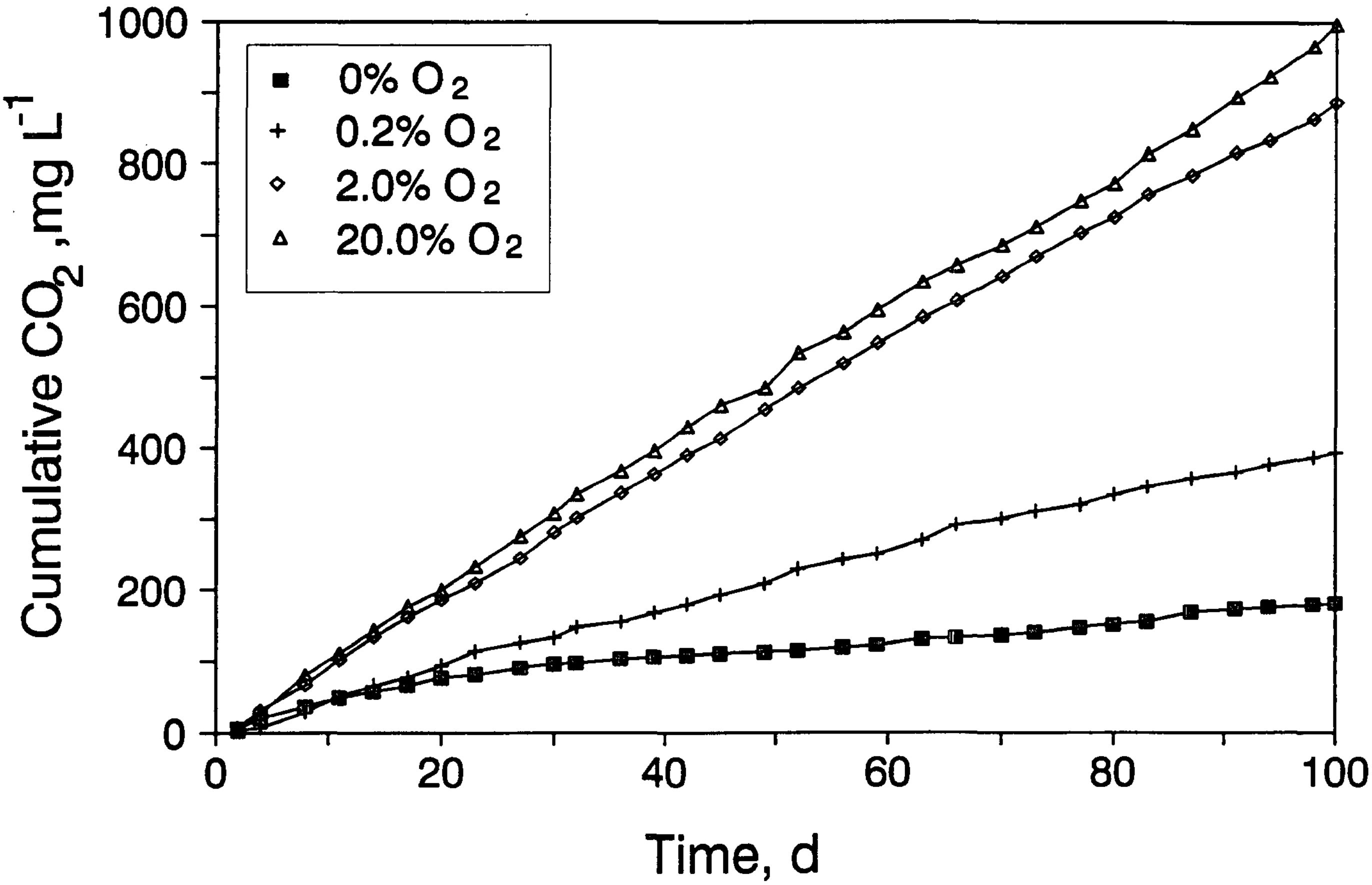


Fig. 5.1.5. Decomposition of sediment organic matter (cumulative CO_2 production) as influenced by O_2 supply.

water soluble organics > hemicelluloses > celluloses > lignin (Tenny and Waksman, 1929). Minderman (1968) reported the rate constants for hemicellulose, lignin, waxes and phenols to be 0.003, 0.001, 0.0002 and 0.0006 d^{-1}, respectively. Paul and van Veen (1978) calculated a rate constant of 0.0002 d^{-1} for physically protected soil organic matter.

In the second experiment, CO_2 evolution was influenced by the redox status of the sediment, with low rates of CO_2 evolved under anaerobic conditions and high rates under aerobic conditions (Fig. 5.1.6). First order rate constants (k) based on CO_2 evolution were 0.000040 and 0.0050 d^{-1}, for the anaerobic and aerobic treatments, respectively.

Methane production was observed in the 0 and 0.2% O_2 treatments, with the average CO_2/CH_4 molar ratio of 3.5 and 192, respectively (Table 5.1.2). Sansone and Martens (1982) found a CO_2/CH_4 ratio of 4 in the methane zone of Cape Lookout Bight sediments. Watanabe (1984) reported CO_2/CH_4 ratios in soils from 7, under anaerobic conditions, to 100, under aerobic conditions. Strict anaerobes obtain their energy by reducing CO_2 to CH_4 (methanogenesis) while oxidizing organic substrates. Zeikus (1977) found that the major *in situ* substrates for methanogenesis are acetate and H_2-CO_2, whereas Cappenberg and Prins (1974) and Strayer and Tiedje (1978) indicated that around 70% of the CH_4 generated in lake sediments originates from the methyl position of acetate. Although the 0.2% O_2 treatment resulted in very reducing conditions (during most of the study), it apparently interrupted CH_4 production. This is not unexpected, since strict anaerobes can not tolerate O_2. Even the addition of other electron acceptors such as SO_4^{2-} to sediments can alter the C and electron flow, due to competition for both acetate and hydrogen by sulfate reducers and methanogenic bacteria (Sansone and Martens, 1982; Winfrey and Zeikus, 1977). The SO_4^{2-} concentration of Lake Apopka water is approximately 30 mg $L^{-1.}$

Soluble organic C increased rapidly in all treatments during the first few days of incubation (Fig. 5.1.7). The initial increase may have been due to desorption from the sediment as it reached equilibrium with the water. After this time, the SOC in the oxidized treatments remained fairly constant or decreased, whereas in the reduced treatments it increased to around 300 mg C L^{-1}. The SOC in these sediments was believed to be very complex in nature, possibly humic acid, since it was not decomposed in the oxidized treatments. Similar results have been reported by Otsuki and Hanya (1972) who found that 30% of the C from algal cell was converted to SOC after 60 d of anaerobic incubation. DeLaune et al. (1981) observed that SOC increased as Eh decreased in a study where the redox potential was controlled by controlling the amount of air entering stirred microcosms. Reddy (1982) showed the SOC in flooded organic soils was more than double that found under drained conditions. Likewise, Gale and Gilmour (1988) found that SOC accumulated under anaerobic, but not aerobic conditions.

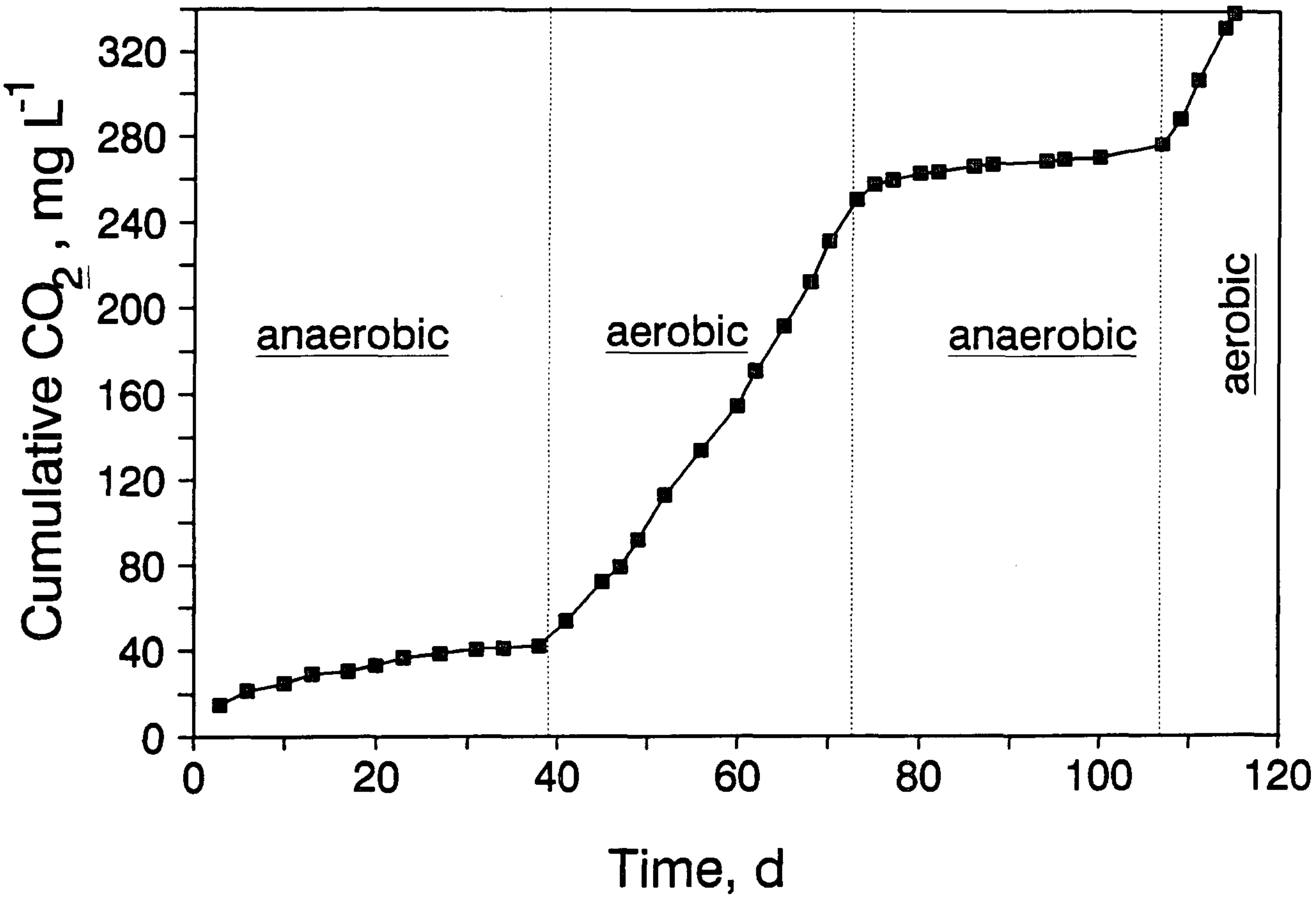


Fig. 5.1.6. Decomposition of sediment organic matter (cumulative CO$_2$ production) as influenced by O$_2$ supply.

Table 5.1.2. CO_2, CH_4 and CO_2/CH_4 ratios as measured by gas chromatography. Values in μmole L^{-1}.

Time	0% O_2			0.2% O_2		
	CH_4	CO_2	CO_2/CH_4	CH_4	CO_2	CO_2/CH_4
—d—						
52	0.18	0.59	3.22	0.010	1.25	125
55	0.18	0.96	5.44	0.016	2.61	163
58	0.31	0.83	2.68	0.041	2.00	48
63	0.54	0.83	1.53	0.040	1.38	34
65	0.14	0.73	5.14	nd	1.58	—
69	0.16	0.87	5.34	0.007	1.56	240
72	0.53	0.54	1.01	0.022	1.26	58
76	0.94	0.94	1.00	0.009	1.21	133
79	2.29	1.21	0.53	0.023	1.16	50
83	0.58	1.18	2.02	0.038	0.96	25
86	1.23	1.15	0.93	0.023	0.95	42
90	0.38	1.01	2.63	0.015	0.62	41
93	0.19	2.08	11.10	0.001	0.96	955
97	0.16	1.07	6.87	0.001	0.58	580
Average	0.56	1.00	3.53	0.017	1.29	192

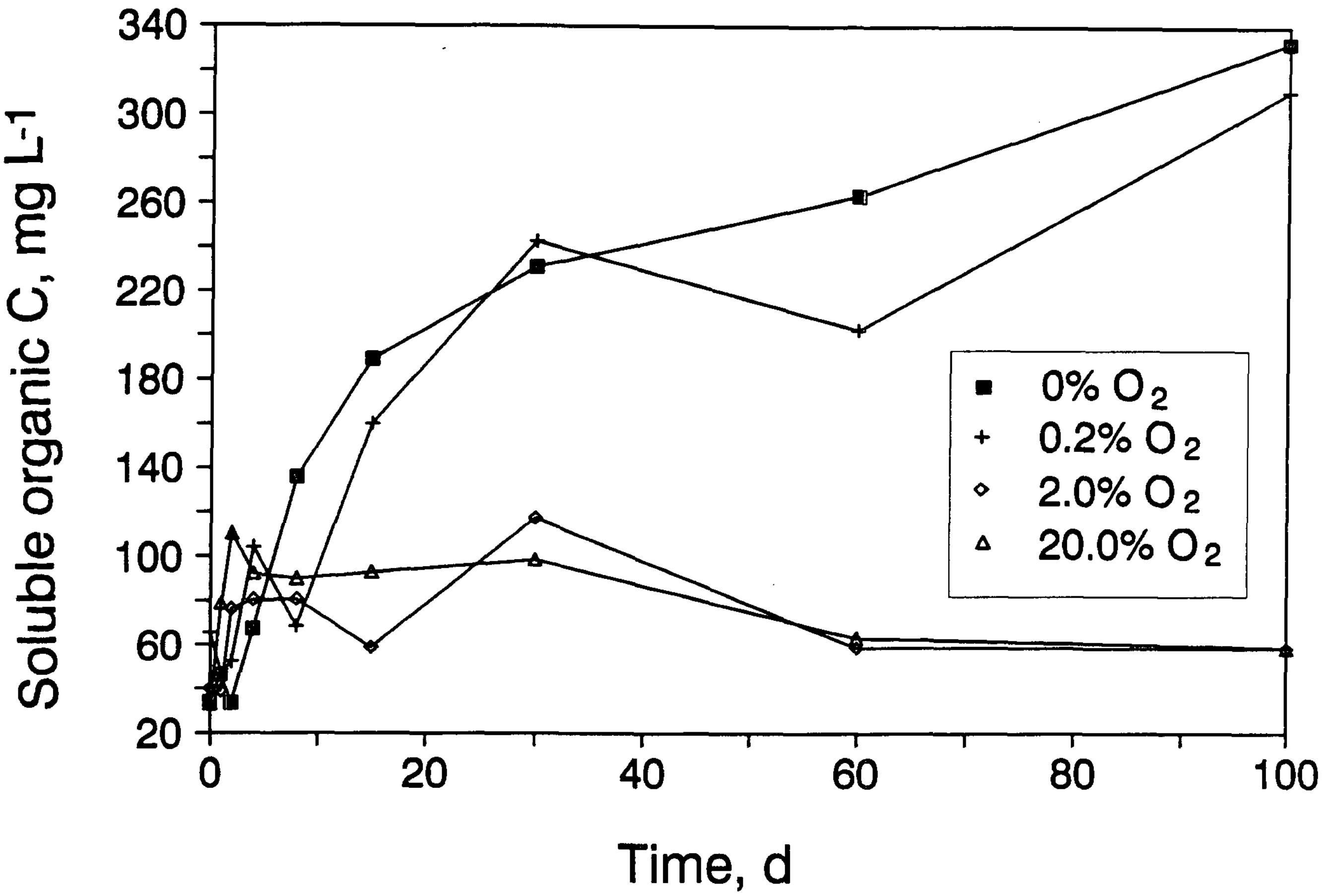


Fig. 5.1.7. Soluble organic C during sediment organic matter decomposition as influenced by O_2 supply.

5.1.3.4. Nitrogen mineralization:

Porewater NH_4-N concentrations in the 0 and 0.2% O_2 treatments remained high throughout the experiment, whereas they declined to near zero in the 2.0 and 20.0% treatments after 15 and 8 d, respectively (Fig. 5.1.8a). Decreases in NH_4-N in the oxidized sediments were accompanied by increases in NO_3-N, indicating nitrification (Fig. 5.1.8b). Nitrate levels at day 100 were near 60 mg N L^{-1} in the two oxidized treatments, whereas NH_4-N levels were only around 30 mg N L^{-1} in the reduced treatments. This was probably due to greater decomposition and mineralization of inorganic N in the oxidized sediments.

Porewater NH_4-N increased during the anaerobic cycle from around 23 mg N L^{-1} at time zero to 27.5 mg N L^{-1} at day 38 (Fig. 5.1.9). During the aerobic cycle, porewater NH_4-N decreased to 11 mg N L^{-1}. Nitrate concentrations were below the detection limits throughout the experiment, indicating that if NH_4-N loss via nitrification did occur, the NO_3-N did not remain in solution. It is possible that the NH_4-N losses were due to NH_3 volatilization, due to basic conditions.

Exchangeable NH_4-N concentrations reflected the changes in water soluble NH_4-N, with concentrations in the oxidized treatments declining after the first two to three weeks to 20 $\mu g\ g^{-1}$, while the concentrations in the 0 and 0.20% O_2 treatments slowly increased (Fig. 5.1.10). These findings are very similar to those reported by Khalid et al. (1978), who showed that water soluble plus exchangeable NH_4^+ concentrations decreased in sediments subjected to 2.11 and 21% O_2 while it remained relatively stable with a 0.11% O_2 treatment.

The amount of N mineralized as a function of cumulative CO_2 evolved was higher under low O_2 conditions (Fig. 5.1.11), with the ratio of N mineralized/CO_2-C evolved decreasing from 0.58 (C/N ratio = 1.7) under the 0% O_2 level to 0.12 (C/N ratio = 8.3) under the 20.0% O_2 level. These data indicate the importance of other decomposition end products under low O_2 conditions. In order to properly evaluate the relationship between N and C mineralization, all of the metabolites (CO_2 + CH_4 + SOC) must be included, as shown in Fig. 5.1.12. The cumulative CH_4 data for the 0% O_2 level were estimated assuming a CO_2/CH_4 ratio of 3.5 as discussed above. These data indicate that the ratio of C/N mineralized was approximately the same under all of the O_2 treatments (7.1). This is slightly lower than the total molar C/N ratios observed in the sediments (11.4), but higher than the C/N molar ratio of Lake Apopka water (algae), which is 5.8. The Redfield ratio is 6.6 (Redfield, 1958).

Elderfield et al. (1981) found $\Delta\Sigma CO_2/\Delta NH_3$ gradients of 7 to 16 in Narragansett Bay sediments. Grundmanis and Murray (1982) found decomposing organic matter in equatorial Pacific sediments with a C/N ratio of 12.6 released CO_2 and NO_3 into the porewater at a C/N ratio of 9.1.

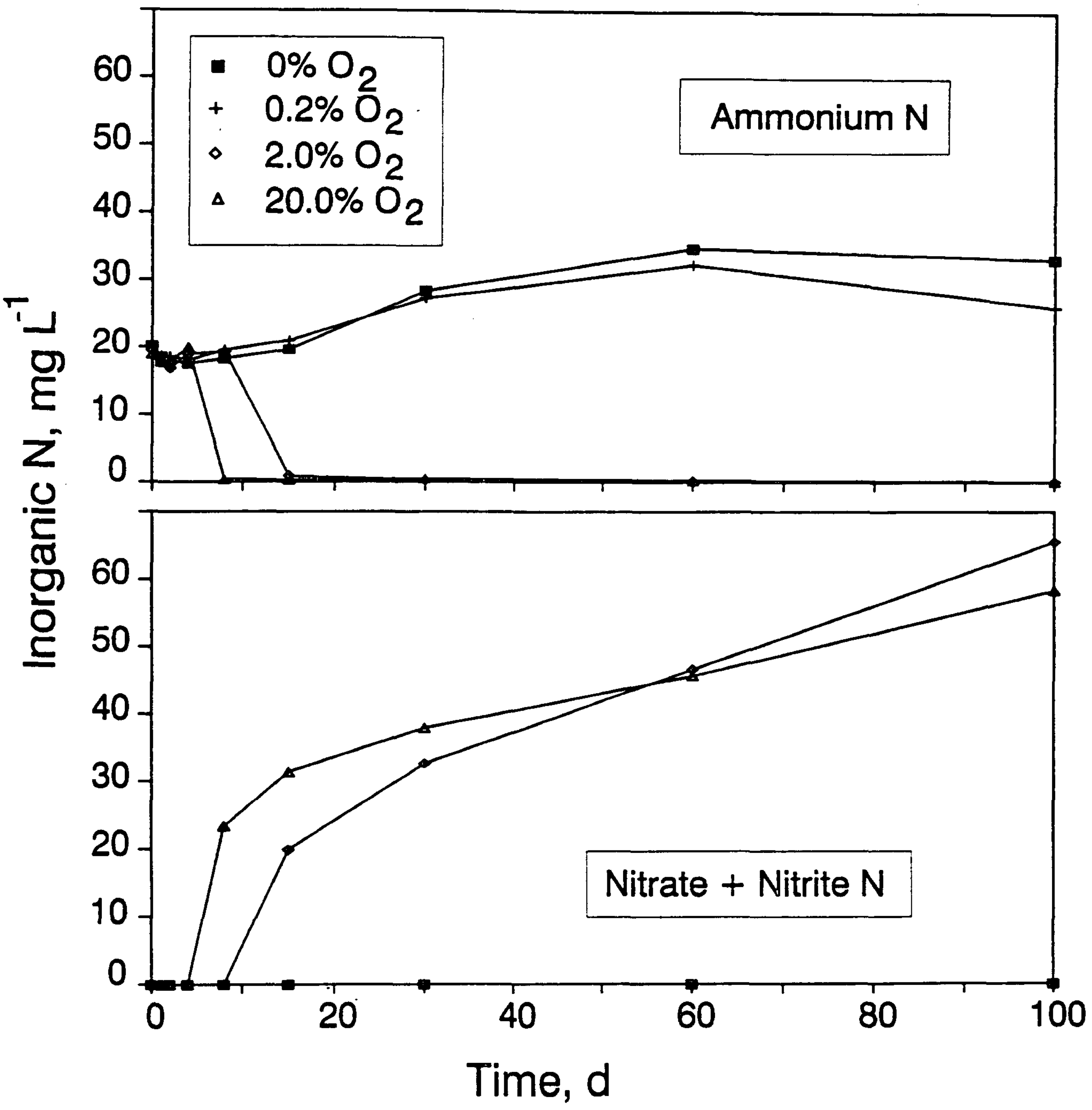


Fig. 5.1.8. Porewater ammonium and nitrate production during mineralization of sediment organic N as influenced by O_2 supply.

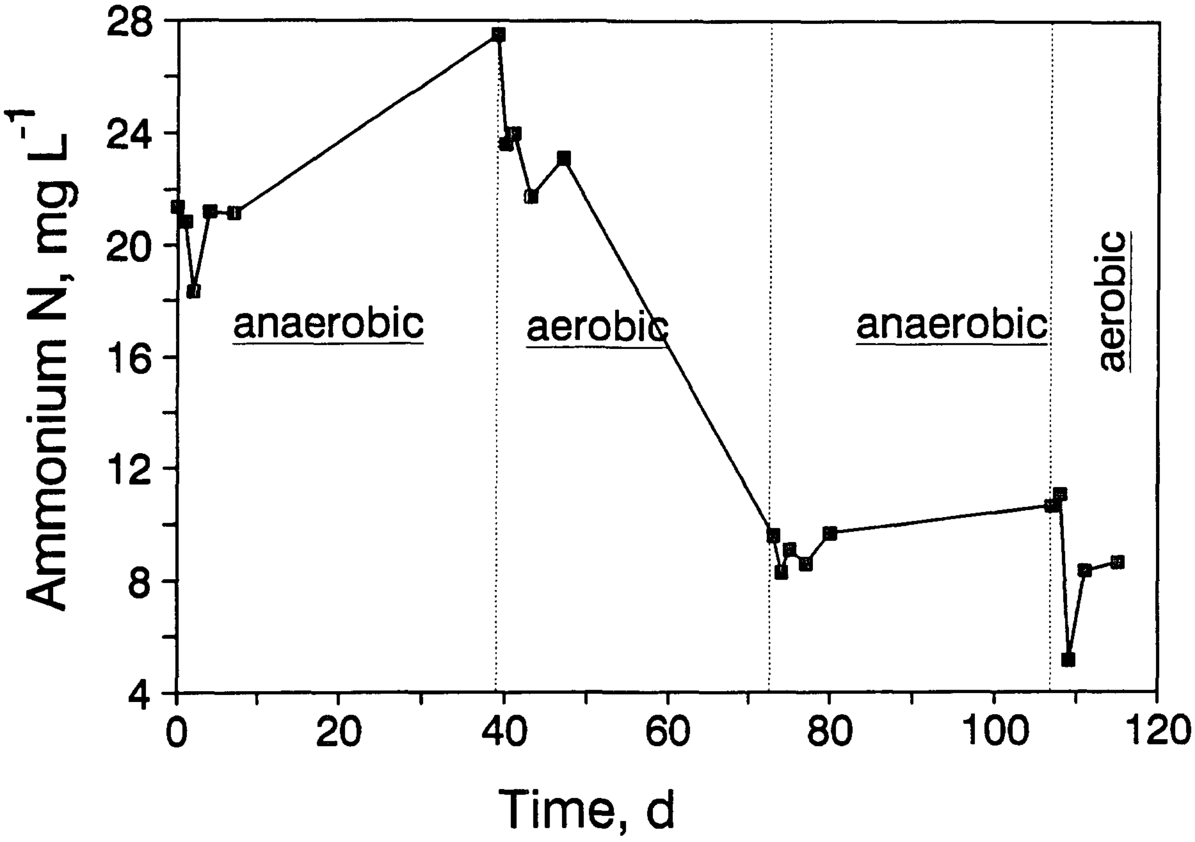


Fig. 5.1.9. Porewater ammonium N production in sediments during mineralization of sediment organic N as influenced by O_2 supply.

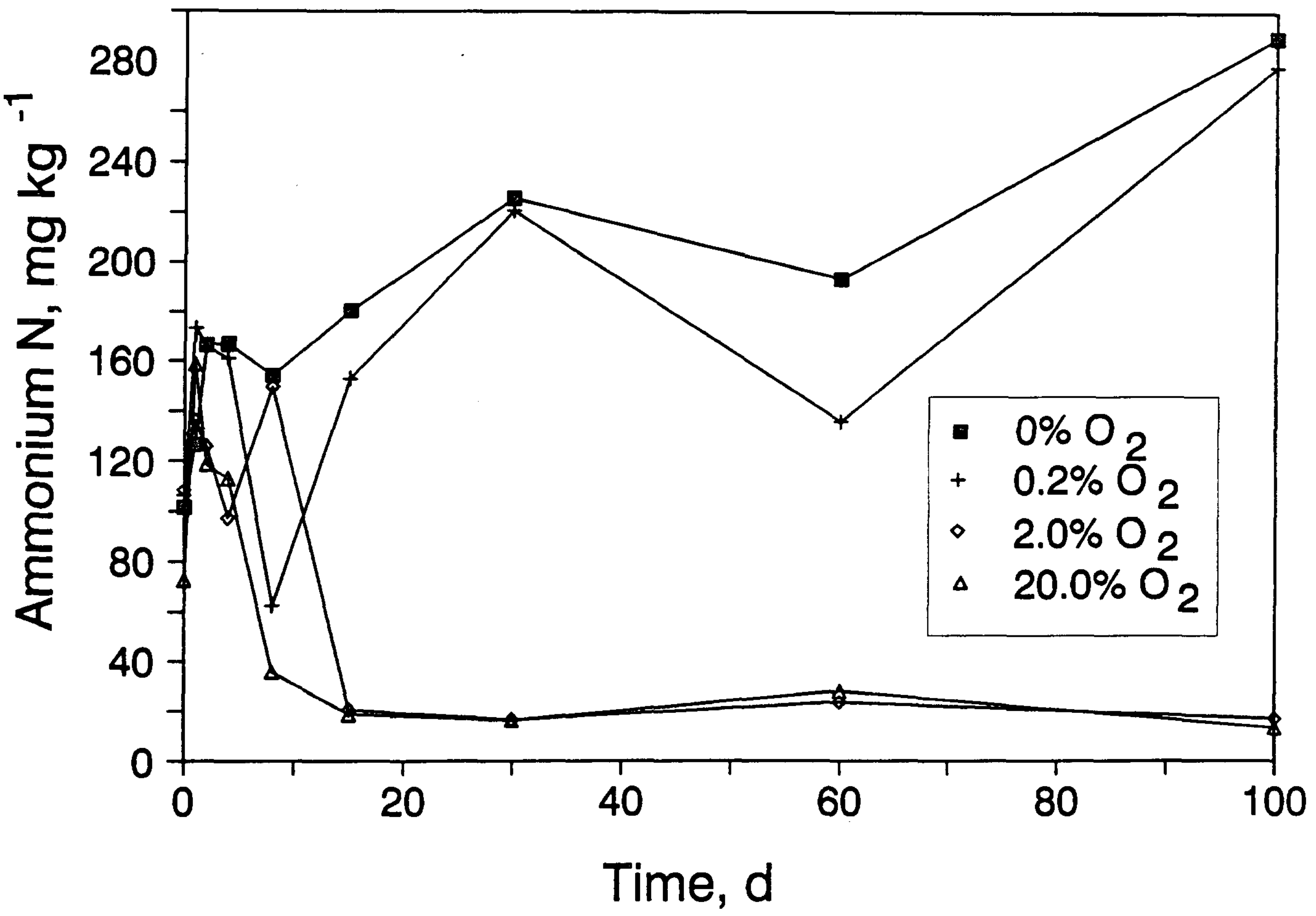


Fig. 5.1.10. Exchangeable ammonium N in sediments as influenced by O_2 supply.

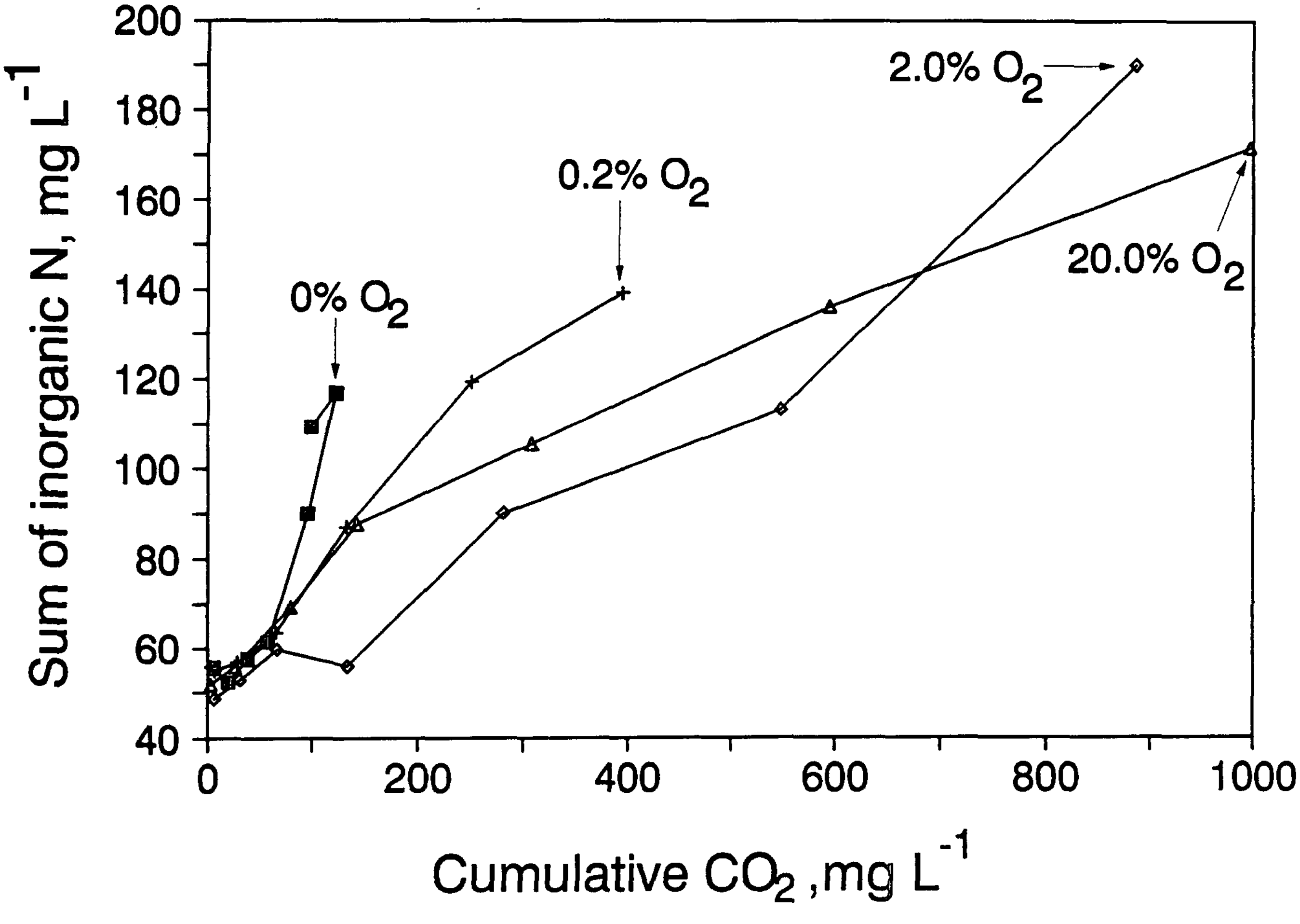


Fig. 5.1.11. Relationship between the sum of N mineralized (NH_4 + NO_3) versus cumulative CO_2 production as influenced by O_2 supply.

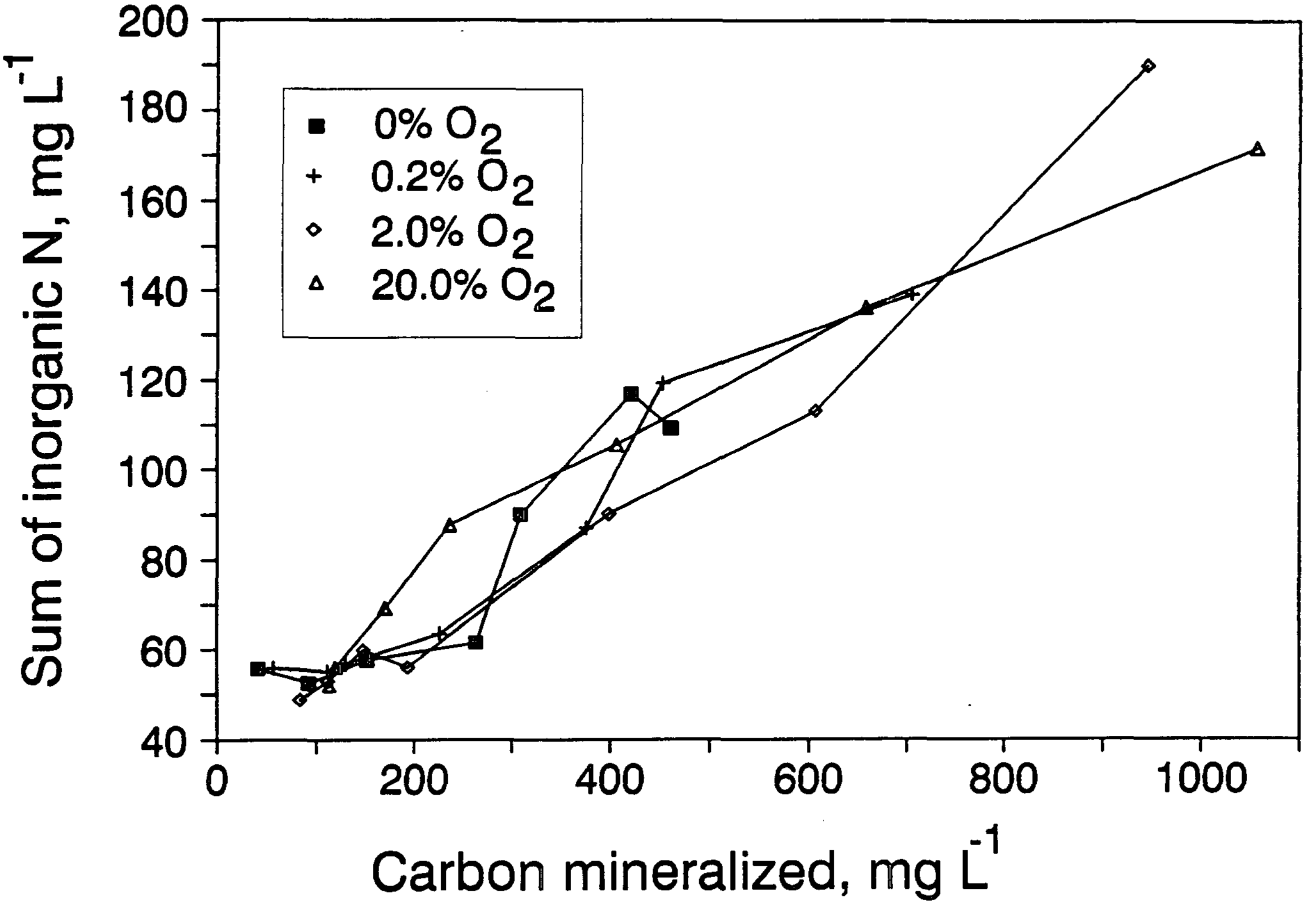


Fig. 5.1.12. The sum of N mineralized (NH_4 + NO_3) versus the sum of C mineralized (CO_2 + CH_4 + SOC) as influenced by O_2 supply.

5.1.3.5. Phosphorus geochemistry:

Soluble reactive P concentrations initially decreased in the 2 and 20% O_2 treatments, and increased thereafter, whereas SRP concentrations in the 0 and 0.2% O_2 did not, even though decomposition was greater in the former (Fig. 5.1.13). Thus, nutrient regeneration via decomposition does not appear to control P in these sediments. Soluble reactive P concentrations increased during the anaerobic cycles and decreased during the aerobic cycles, indicating redox reactions may have played a role in governing P solubility (Fig. 5.1.14). The large fluctuations of SRP at day 40 and day 75 occurred in both reps and paralleled changes in total dissolved P measured by ICAP (data not shown).

One possible explanation for the decrease in SRP under oxidized conditions would be the formation of Fe or Mn phosphates. Ion activity products calculated using SOILCHEM indicated that the sediments were undersaturated with respect to $FePO_4 \cdot 2H_2O$ (strengite), indicating Fe precipitation did not occur (data not shown). However, under oxidized conditions, the sediments appeared to be in equilibrium with $MnPO_4 \cdot 1.5H_2O$ (Fig. 5.1.15). Boyle and Lindsay (1986) indicated that this phase was capable of controlling solution P levels under certain conditions.

Although there have not been any direct reports of P control by Mn in lacustrine or marine sediments, this mechanism could be inferred from the data shown by Froelich et al. (1979). In sediment cores from the eastern equatorial Atlantic, the SRP concentrations remained low in the upper (oxidized) portions of the profiles, but increased greatly at the depth where Mn concentrations increased. This was only apparent in profiles where the nitrate decreased with depth to zero (indicating a reduced substratum which could supply Mn^{2+}). Similarly, the data of Emerson et al. (1980) from MANOP station M from the eastern equatorial Pacific indicate this could be happening.

It should be noted that the sediments in this study were supersaturated with respect to $Ca_{10}(PO_4)_6(OH)_2$ (apatite), $B\text{-}Ca_3(PO_4)_2$ (beta tricalcium phosphate), and $Ca_{18}(Fe,Mg)H_2(PO_4)_{14}$ (whitlockite) both under oxidized and reduced conditions. However, kinetic limitations may hamper the formation of apatite, since organic acids (Inskeep and Silvertooth, 1988), Mg (Martens and Harriss, 1970), carbonate (Stumm and Leckie, 1970), or the absence of calcite surfaces or seed crystals (Griffin and Jurinak, 1973, 1974) interfere with its formation. In an earlier study using intact sediment cores, we concluded that whitlockite was the solid phase controlling P in Lake Apopka sediments (Moore et al., 1990).

When reduced sediments are oxidized, the solid phase controlling Mn levels in solution will change from a reduced form, such as rhodocrosite ($MnCO_3$) or reddingite (MnS_2) to an oxidized one. One possibility would be Mn $PO_4 \cdot 1.5H_2O$. Since the total P is approximately 20 times higher than total Mn, P would be expected to control Mn. However, during the shift from oxidized to reduced conditions, P removal via $MnPO_4 \cdot 1.5H_2O$ could occur. After equilibrium is established, then P levels would once again be governed by Ca. The SRP data shown in Fig. 5.1.14 appear to conform to this scenario.

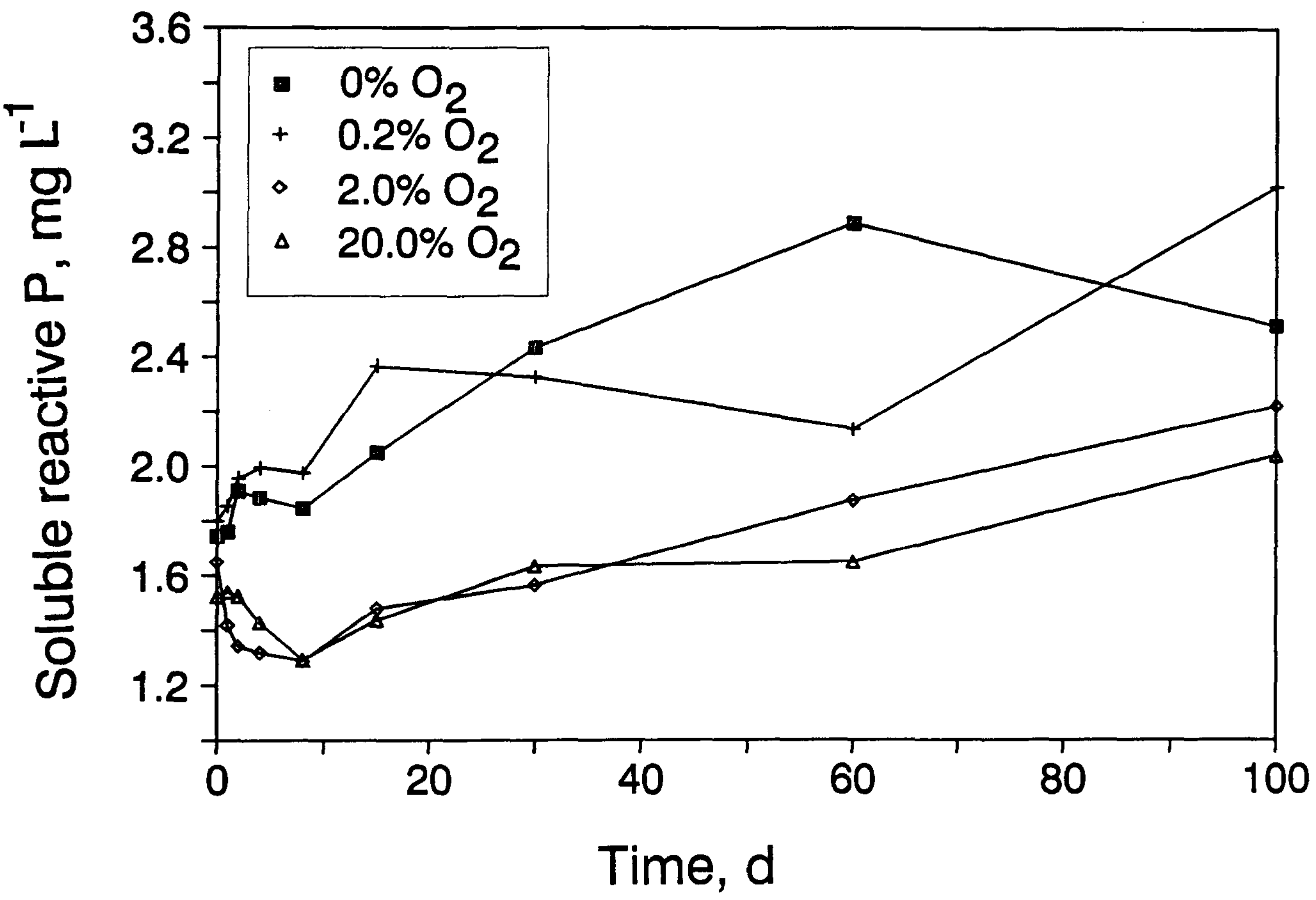


Fig. 5.1.13. Porewater soluble reactive P in sediments during decomposition of organic matter as influenced by O_2 supply.

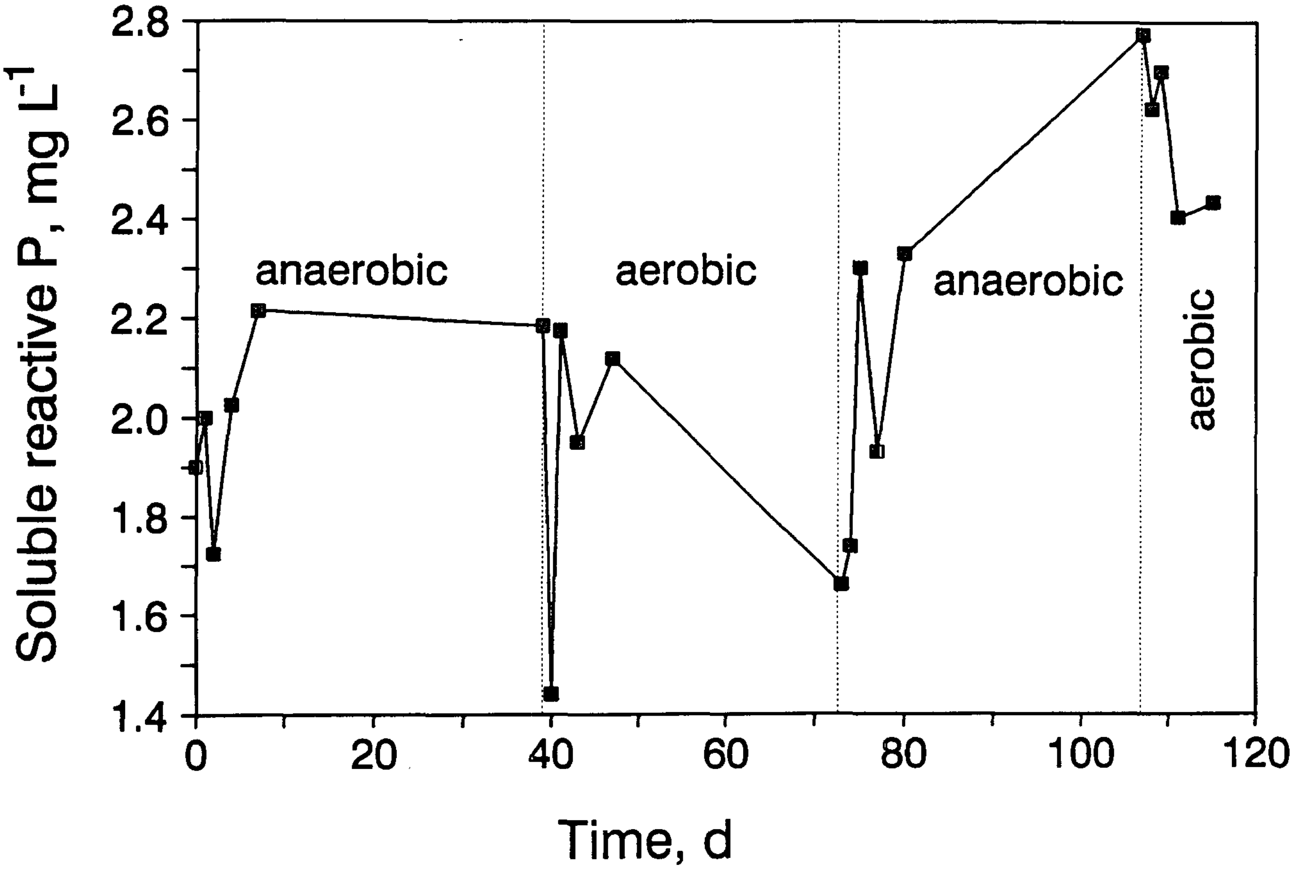
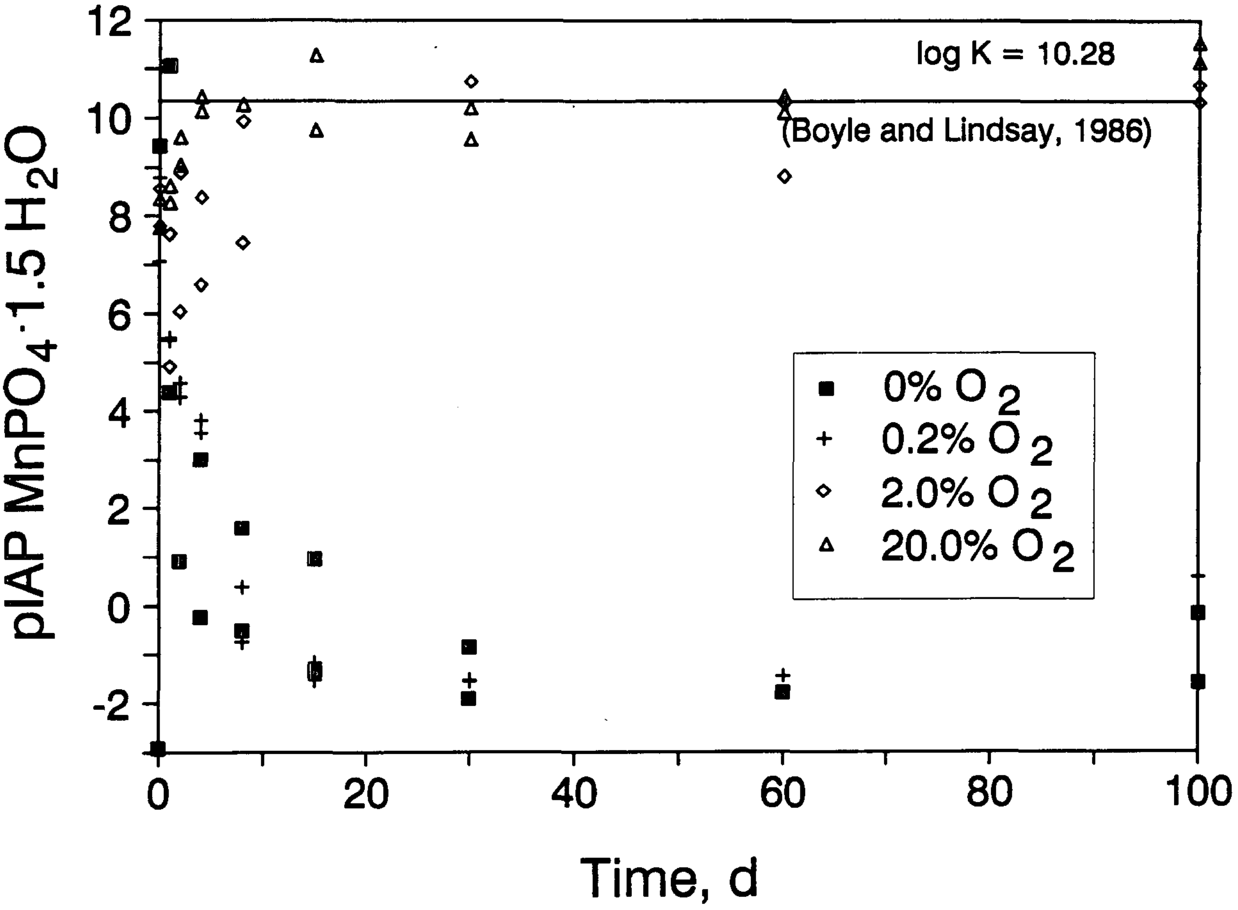


Fig. 5.1.14. Porewater soluble reactive P in sediments during decomposition of organic matter as influenced by alternate aerobic and anaerobic conditions.



5.1.15. Ion activity product of $MnPO_4 \cdot 1.5H_2O$ in sediments as influenced by O_2 supply.

The amount of P extracted with 0.1 M NaOH initially (days 1-10) increased in the 2 and 20% O_2 treatment, and decreased thereafter (Fig. 5.1.16). The increases under oxidized conditions occurred when SRP levels were decreasing, possibly due to the formation of $MnPO_4 \cdot 1.5H_2O$ as discussed above. Although NaOH has never been reported to be an extractant for Mn-bound P, it would be expected to work since Mn phosphates are similar to Fe and Al phosphates. The decreases in NaOH extractable P that occurred after day 8 may be due to the decomposition of organic matter, since NaOH will extract labile organic-bound P. The amount of HCl extractable P (Ca-bound P) increased, indicating that Ca is probably the ultimate sink for P in these sediments.

Porewater Ca decreased for the first few days in all the treatments (Fig. 5.1.17). These decreases were probably due to increases in pH, which affects the solubility of carbonate minerals. After the initial decreases, Ca levels increased steadily in the oxidized treatments, whereas they remained the same in the reduced treatments. The increases in Ca coincide with the onset of nitrification in the oxidized treatments, which affected the porewater pH. The relationship between porewater Ca and pH is shown in Fig. 5.1.18. The cause of the two outliers at day 100 is unknown.

Porewater Mg behaved almost identically to Ca, with initial decreases followed by increases in the oxidized treatments and decreases in the reduced treatments (Fig. 5.1.19). The relationship between porewater Mg and pH is shown in Fig. 5.1.20.

The precipitation of Ca and Mg carbonates in this experiment may have been artificially hastened due to the experimental set up. By stripping the CO_2 from the O_2/N_2 mixtures the pCO_2 in the microcosms was artificially lowered, causing the pH to increase and the Ca^{2+} and Mg^{2+} to decrease in the 0 and 0.2% O_2 treatments. This process was apparently counteracted by proton production from nitrification in the oxidized treatment since the pH decreased in these treatments. Under normal circumstances, porewater Ca^{2+} and Mg^{2+} concentrations in Lake Apopka sediment are above 75 and 25 mg L^{-1}, respectively, while the pH is usually between 6.8 and 7.5 except at the sediment-water interface where it may approach 8.

Oxidation of anaerobic sediments, such as that that occurs after dredging, can cause metal solubilities to increase under certain conditions (DeLaune and Smith, 1985; Khalid et al., 1978). However, this usually occurs in sediments with marine origins that contain some form of potential acidity, such as FeS_2, which releases sufficient sulfuric acid upon oxidation to significantly decrease the pH. Although the 2 and 20% O_2 treatments did cause a slight decrease in pH, the water soluble heavy metal concentrations remained low (Table 5.1.3). Arsenic was the only heavy metal that tended to be higher under oxidized conditions.

5.1.4. Conclusions

Varying O_2 concentrations strongly affected the redox status of the sediments, with 2.0 and 20.0% O_2 treatments resulting in oxidizing conditions, and 0 and 0.2%

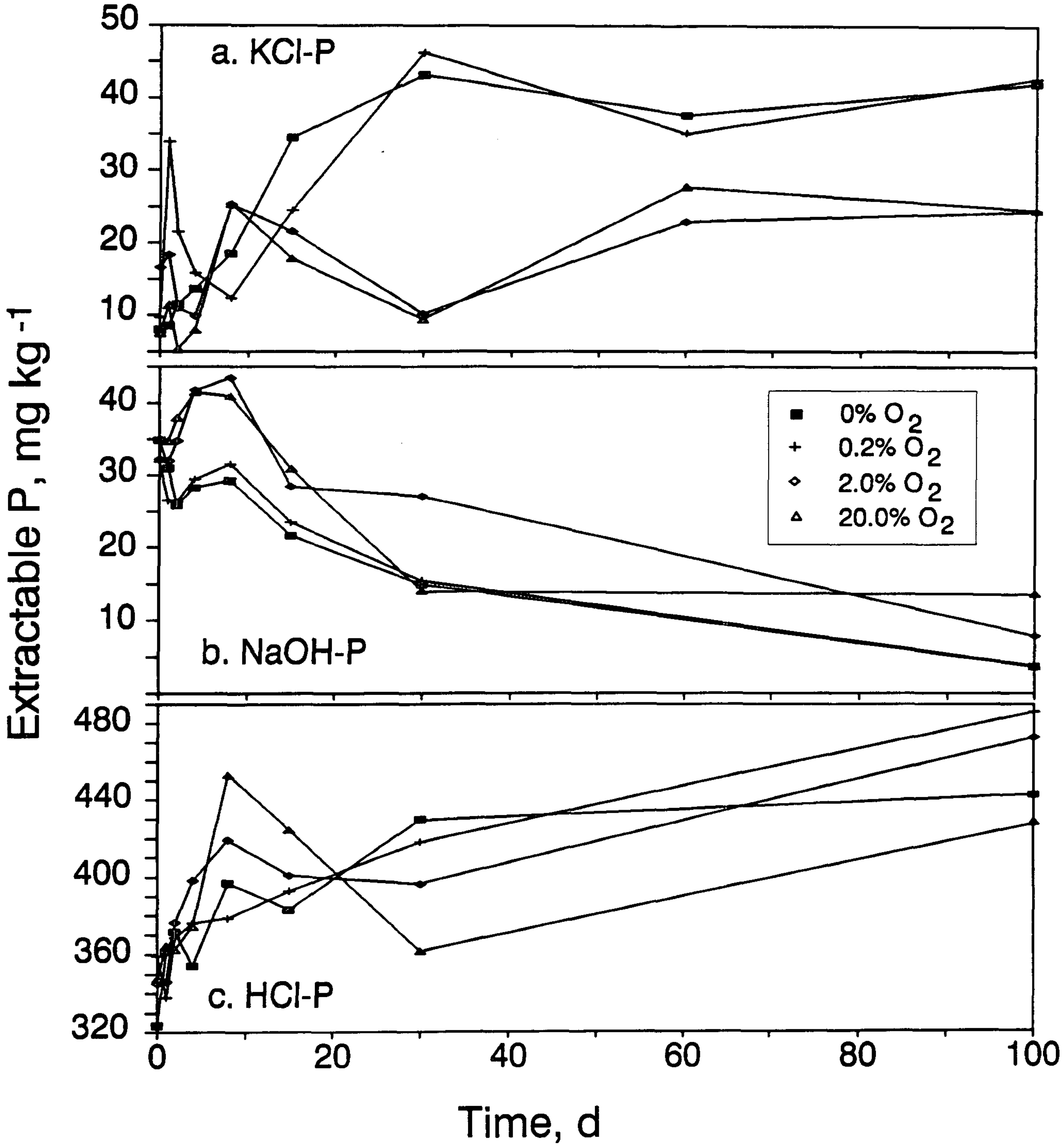


Fig. 5.1.16. Distribution of sediment inorganic P (as determined by chemical fractionation) during decomposition of organic matter, as influenced by O_2 supply.

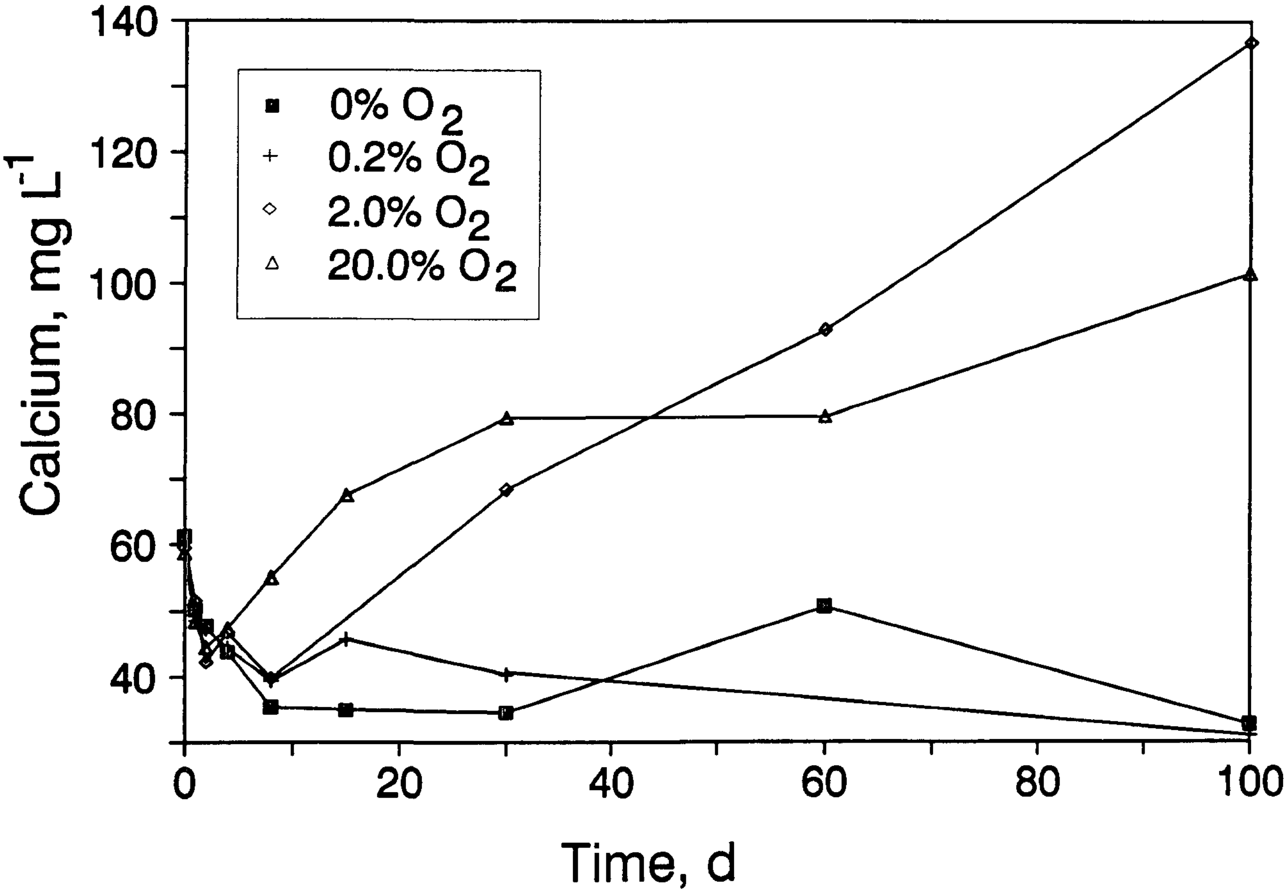


Fig. 5.1.17. Porewater calcium in sediments during decomposition of organic matter, as influenced by O_2 supply.

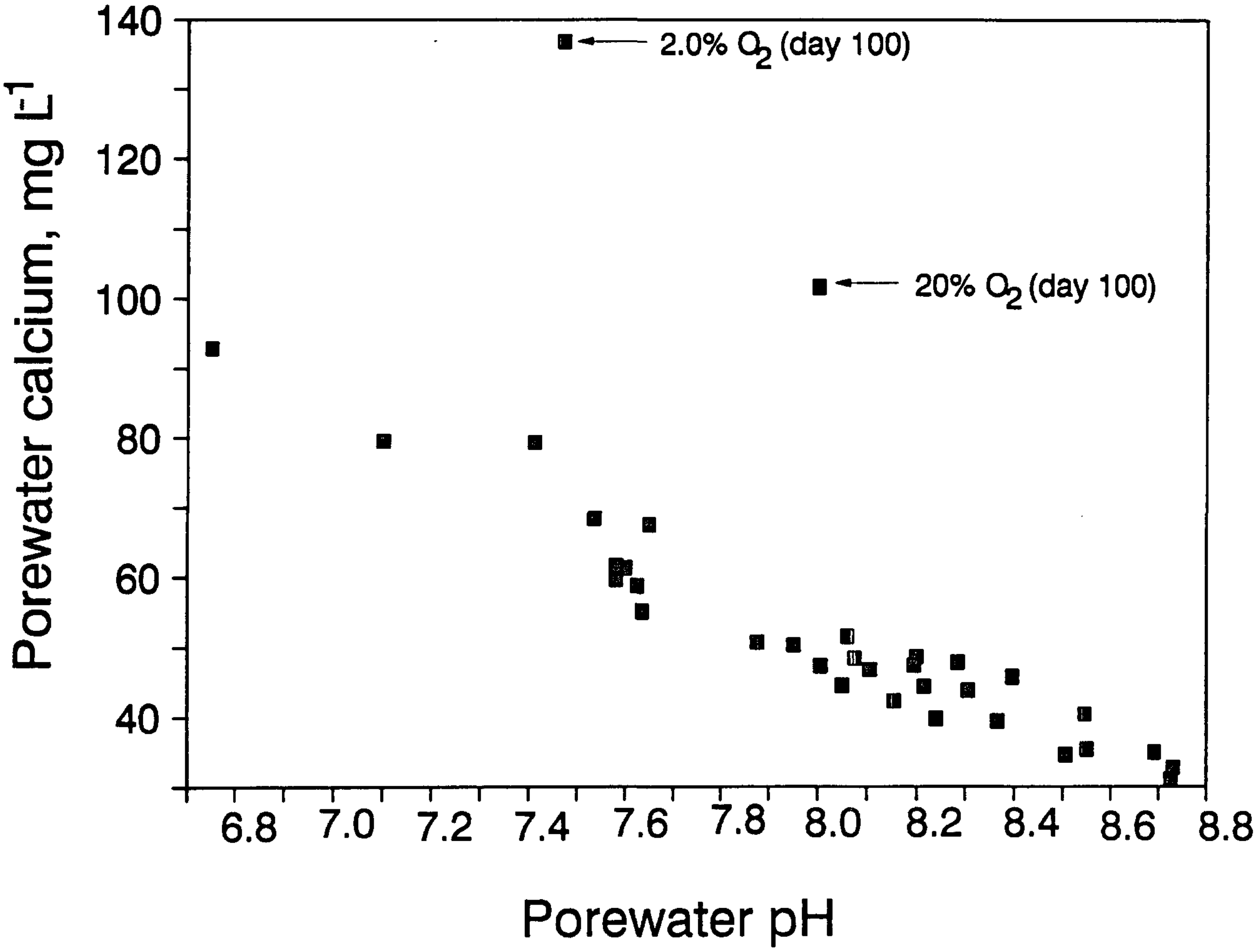


Fig. 5.1.18. The relationship between porewater Ca and pH in sediment during decomposition of organic matter, as influenced by O_2 supply.

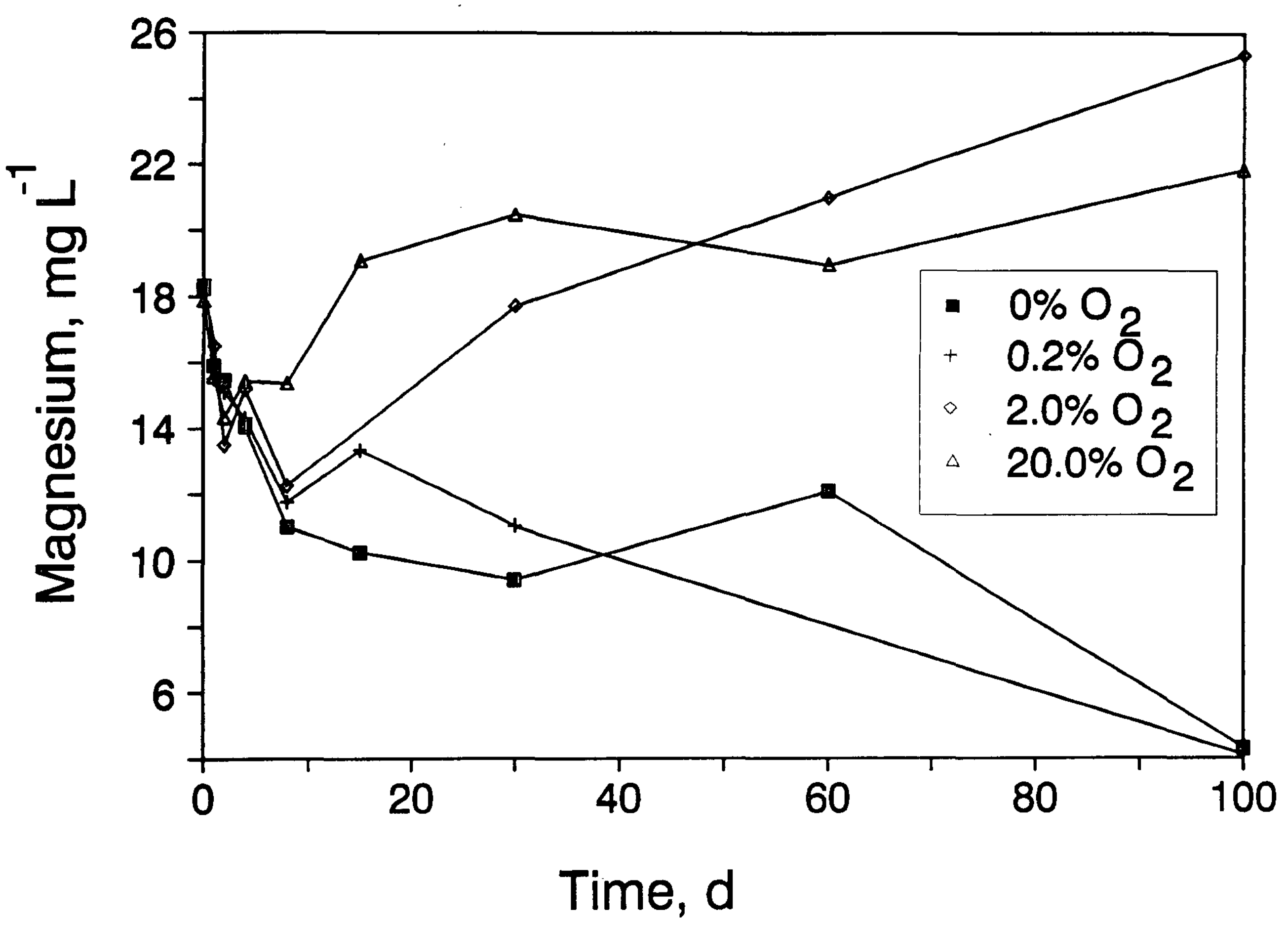


Fig. 5.1.19. Porewater magnesium in sediments during decomposition of organic matter, as influenced by O_2 supply.

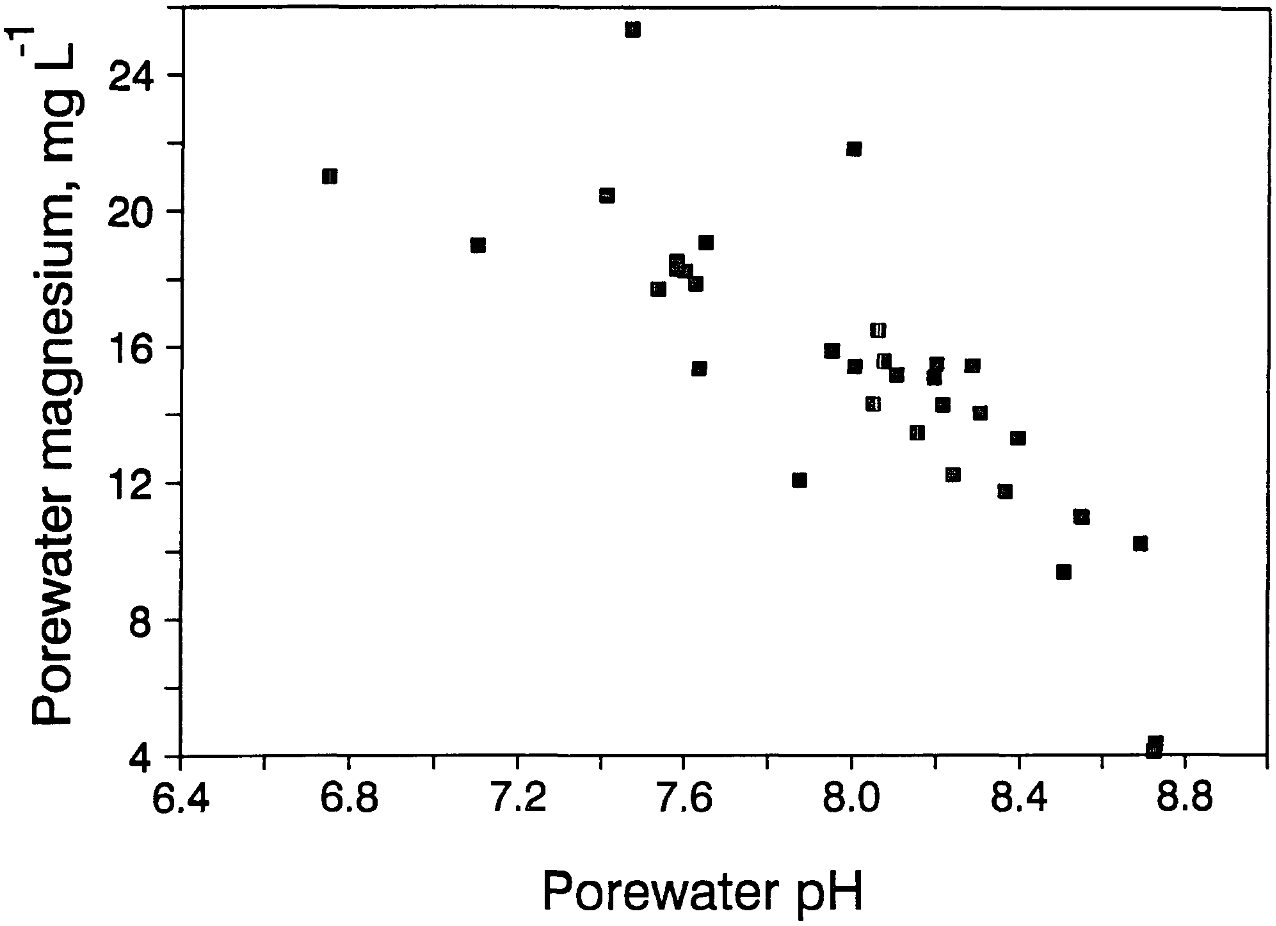


Fig. 5.1.20. The relationship between porewater Mg and pH in sediments during decomposition of organic matter, as influenced by O_2 supply.

Table 5.1.3. Mean porewater metal concentrations under different oxygen concentration.

Oxygen level	Fe	SD	Mn	SD	Cu	SD	Zu	SD	As	SD
—%—					mg L^{-1}					
0.0	0.09	0.12	0.02	0.01	0.03	0.07	0.05	0.05	0.02	0.02
0.2	0.09	0.13	0.03	0.01	0.01	0.02	0.05	0.06	0.03	0.04
2.0	0.04	0.06	0.001	0.003	0.006	0.009	0.03	0.04	0.06	0.02
20.0	0.09	0.13	0.003	0.004	0.009	0.01	0.06	0.07	0.08	0.02

O_2 treatments causing reducing conditions. The O_2 treatments also affected pH and alkalinity, with lower values for both noted in the oxidized treatments. Carbon dioxide evolution was very dependent on O_2 treatment, with first order rate constants of 0.00010, 0.00027, 0.00062, and 0.00068 d^{-1}, for the 0, 0.2, 2.0, and 20.0% O_2 treatments, respectively. However, production of SOC was greater under reduced conditions. Ammonium concentrations decreased rapidly in the oxidized treatments, with concurrent increases in NO_3-N, while they increased slowly in the reduced treatments. Although the ratio of N mineralized/CO_2 evolved was higher at low O_2 levels, the amount of N mineralized versus the sum of C metabolites (CO_2 + CH_4 + SOC) was relatively constant under all O_2 levels. Soluble reactive P levels decreased under oxidized conditions, possibly due to the precipitation of $MnPO_4 \cdot 1.5H_2O$.

The redox potential of the sediments was observed to be poorly buffered. This was believed to be due to a lack of electron acceptors such as Fe^{3+}, Mn^{4+}, or NO_3-N. Carbon dioxide evolution was much greater under aerobic conditions ($k = 0.005$ d^{-1}) than anaerobic ($k = 0.0004$ d^{-1}). Although NH_4-N concentrations decreased during the aerobic cycles, NO_3-N was undetectable at all times, indicating that nitrification may not have been the mechanism of NH_4-N loss. Soluble reactive P tended to decrease during the aerobic cycles and increase during the anaerobic cycles, indicating redox reactions may be important in governing P solubility.

5.1.5. References

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5.2 Kinetics of Sediment Organic Matter Decomposition Under Anoxic Conditions [Task 3.2]

5.2.1 Introduction

The eutrophication of a lake often involves increased inputs of nutrients into the body of water which results in an increase in primary production, fixation of CO_2, within the system (Henderson-Sellers and Markland, 1987). If the increases in primary production are not balanced by organic matter degradation and outflow, an accumulation of organic-rich sediments can occur. These conditions are generally observed in many hypereutrophic lakes, such as Lake Apopka in Florida (USEPA, 1979a) and Lake Balaton in Hungary (Somlyody and van Straten, 1986).

Several studies have shown the importance of phytoplankton and bacteria in the cycling of C in aquatic systems (Adams and van Eck, 1988; Boers and Boon, 1988; Billen, 1982; Jorgensen, 1983). In eutrophic lake systems, the production and degradation of particulate organic matter are regulated by physical and biogeochemical processes (Boers and Boon, 1988). Of the organic C deposited at the sediment surface, Adams and van Eck (1988) found that 60% was decomposed aerobically, 15% decomposed anaerobically, and 25% was buried. The cycling of depositional C is important in determining sediment accumulation and is inherently linked to other nutrient transformations. Work by Ali et al. (1988) found significant correlations between nutrient concentrations in the overlying water and sediment organic C levels in Lake Monroe, an eutrophic central Florida lake.

The rate of organic matter decomposition in sediments is governed by the quantity and quality of organic matter, and the supply of electron acceptors. The quality of organic matter refers to the chemical composition such as structural polysaccharides, ligno-cellulose, and C/N ratios (Capone and Kiene, 1988). Availability of electron acceptors such as O_2, NO_3^-, MnO_2, FeOOH, SO_4^{2-} and CO_2 dictates the type of microbial respiration functioning in sediments. In shallow lakes such as Lake Apopka, aerobic decomposition in the water column can play a major role, especially during periods of wind-driven sediment resuspension. Under quiescent conditions, facultative anaerobic and obligate anaerobic respiration control the decomposition of organic matter in the sediments. In recent years, several review articles have discussed the significance of aerobic and anaerobic metabolism in wetland soils and lake sediments (Reeburgh, 1983; Jorgensen, 1983; Reddy et al., 1986; Capone and Kiene, 1988; Lovely, 1987; Oremland, 1988). Depending on energy yield during microbial respiration, electron acceptor consumption will be in the order of $O_2 > NO_3^- > MnO_2 > FeOOH > SO_4^{2-} > CO_2$ (Claypool and Kaplan, 1974; Patrick, 1981; Reddy et al., 1986).

Environmental factors such as temperature have been shown to influence decomposition rates, with rate constants doubling for every 10°C rise in temperature (Pal et al., 1975; Nyhan, 1976; Volk, 1973). Although a vast amount of information is available on kinetics of organic matter decomposition for upland soils (Paul and van Veen, 1978), a very limited amount of data has been reported for lake sediments and wetlands (Vogels et al., 1988). Decomposition rate coefficients are useful in simulation models and nutrient budgets to describe quantitatively the nutrient flux from the sediment to the water column. Billen (1982) has indicated that an evaluation of the rates of microbial processes in an aquatic system are necessary for a complete description of the ecosystem.

The objectives of this research were to determine the kinetics of organic matter decomposition in Lake Apopka sediments under anoxic conditions. This was accomplished through the measurement of decomposition end-products such as CO_2, CH_4 and the water soluble C pools.

5.2.2 Materials and methods

A piston-type sediment core sampler, similar to that described by Livingstone (1955), was used to obtain the sediment samples. The UCF and CF sediments were collected at the same location about 100 m from the eastern shoreline at Fisherman's Paradise, while the peat samples were collected in the NE portion of the lake, near the pump house. These sites correspond to grid locations K-6 and H-2, respectively, in Fig. 3.1 of Chapter 3. The sediment samples were extruded on-site into 7-L polyurethane bottles and composited by sediment type. In all, approximately 8 cores of each sediment type were needed to fill the bottles. The UCF sample consisted of the top 27 cm (± 5 cm) of the UCF/CF cores. The CF samples were collected from the UCF/CF interface to a depth of 70 cm. The UCF/CF interface is recognized by a distinct change in consistency. The peat sediments were collected from the top 40 cm and at the location selected, these samples were not overlain by either UCF or CF deposits. After collection the bottles were kept on ice for transport to the laboratory.

Batch incubation experiments similar to those described by Lovley and Klug (1983) and Kelly and Chynoweth (1979), were conducted to determine the rate, extent and forms of C mineralized during sediment organic matter decomposition. Approximately 45 mL of field-moist sediment was placed into 150-mL serum bottles. The bottles were sealed and purged with prepurified N_2 gas (99.998% purity) to remove any O_2 and incubated in the dark at 15, 25, and 35°C. Sixty-three bottles of each sediment type were included to allow for seven destructive sampling times at each incubation temperature and three replications of all treatments.

Periodically a 500-μL portion of the sample head space was removed and analyzed for CO_2 and CH_4 evolved. The gas analysis was performed on a gas chromatograph (GC 5840 Hewlett-Packard, Avondale, PA) equipped with a thermal conductivity detector (TCD). Helium was the carrier gas and poropak N (Supelco, Bellefonte, PA) was used in a 1.8 m-stainless steel column. The column temperature was 50°C with a carrier flow rate of 0.4 mL s^{-1}. Working standards consisted of CH_4 and CO_2 diluted in prepurified N_2 gas. The detection limit of the TCD for either CO_2 or CH_4 was 1 μg C mL^{-1}. For greater sensitivity to CH_4 a flame ionization detector (FID) with N_2 as a carrier gas was used occasionally. After head space analysis of the samples, the bottles were purged with N_2 gas and returned to the respective incubators. Initially, gas analysis was performed on a weekly basis, however, since gas production was low, the sampling time was gradually increased to monthly intervals.

On days 0, 6, 21, 43, 104, 217, and 534, three replicates of each treatment were removed and analyzed in the following manner. After head space analysis, 50 mL of deionized water was added, the samples were mechanically shaken for 30 minutes, and vacuum filtered through Whatman #42 filter paper. The extract was acidified to pH < 2 with H_3PO_4 for analysis of water soluble organic C (WSOC) and volatile fatty acids (VFA). WSOC was measured using a total organic carbon (TOC) analyzer (OI Corp., College Station, TX) in accordance with method 415.2 (USEPA, 1979b). The procedures of Wilke et al. (1986) were used to determine concentrations of volatile fatty acids in the water extracts. This method employed a GC with a flame ionization detector (FID). Chromosorb W AW (Supelco, Bellefonte, PA) was used as the packing in a 1.8-m glass column with N_2 as the carrier gas. The column temperature was 100°C and the carrier flow rate was 0.4 mL $s^{-1.}$ With this set-up, the aliphatic acids of C-10 or less could be separated. Standards included a ready made VFA standard (Supelco Chromatography Supplies Cat.#4-6975, Bellefonte, PA) and water dilutions of reagent grade acetic, propionic and butyric acids. Initially, sediment samples were characterized as to bulk density, water content, and total C and N. The total C and N were determined using a Carlo Erba C, N and S analyzer (Milan, Italy) and water content and bulk density were measured by drying sediment subsamples to a constant weight.

5.2.3 Results and discussion

Selected physical and chemical properties of the sediments used in these incubations are presented in Table 5.2.1. All of the sediments were characterized by high water contents and low bulk densities. Since the C/N ratios of all of the sediments were below 20, N limitations of decomposition would not be expected to occur (Alexander, 1977).

The sediment types showed distinct differences in the amounts and rates of CO_2 and CH_4 evolution (Figs. 5.2.1-5.2.3). The UCF sediment was the most reactive overall with significant amounts of both CO_2 and CH_4 being produced at higher incubation temperatures (Fig. 5.2.1). At 35°C, CH_4 production from UCF sediment showed an initial lag period that lasted until day 280, while CH_4 evolution from the samples incubated at 25°C was linear throughout the incubation period. For both the 35 and 25°C incubations of UCF sediment, an initial flush of CO_2 was followed by a lower rate of CO_2 evolution. For the UCF samples incubated at 15°C, the initial flush of CO_2 was not as pronounced as that at the higher temperatures. The most striking difference was in CH_4 evolution. At the 15°C incubation temperature, noticeable CH_4 production did not occur until day 280 of the incubations. Total CH_4 evolved from the UCF sediments incubated at 15°C was less than one-tenth of that of the samples incubated at the higher temperatures. At the end of the 534-d incubation, at 25°C, 8.6% of the UCF sediment C had been evolved as either CO_2 or CH_4.

Table 5.2.1. Selected physical and chemical properties of the sediment samples used in the incubation experiments (UCF = unconsolidated flocculent material, CF = consolidated flocculent material).

Parameter	Units	UCF	CF	Peat
Bulk density	g (dw)[1] cm^{-3}	0.029	0.062	0.072
Water content	g kg^{-1}	971	938	928
Total C	g kg^{-1} (dw)	283.7	350.6	473.3
Total N	g kg^{-1} (dw)	23.6	26.1	29.3
C/N	—	12.0	13.4	16.2

[1] dw = dry weight

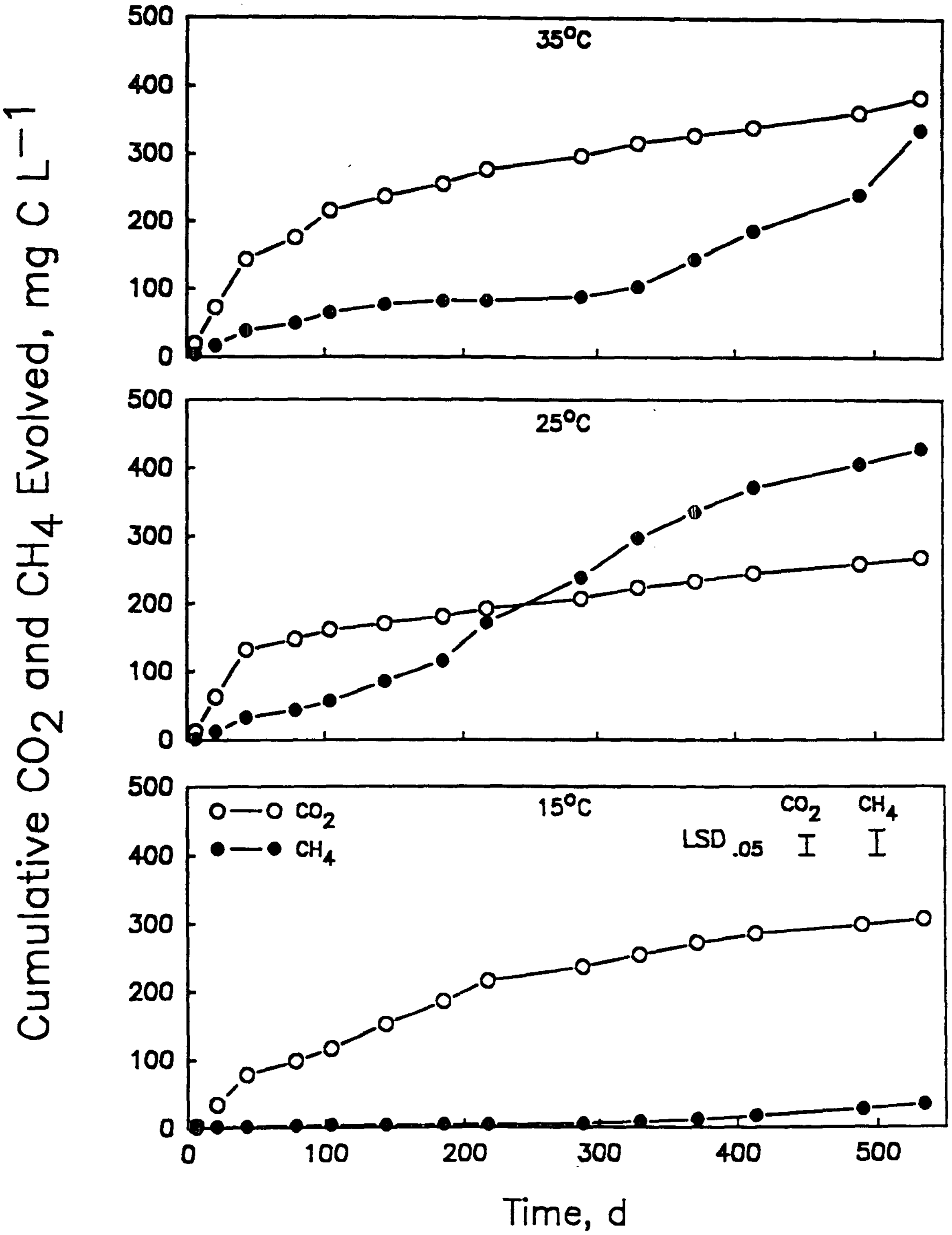

Fig. 5.2.1. Cumulative production of CO_2 and CH_4 evolved during the organic matter decomposition of unconsolidated flocculent material (UCF) at different incubation temperature.

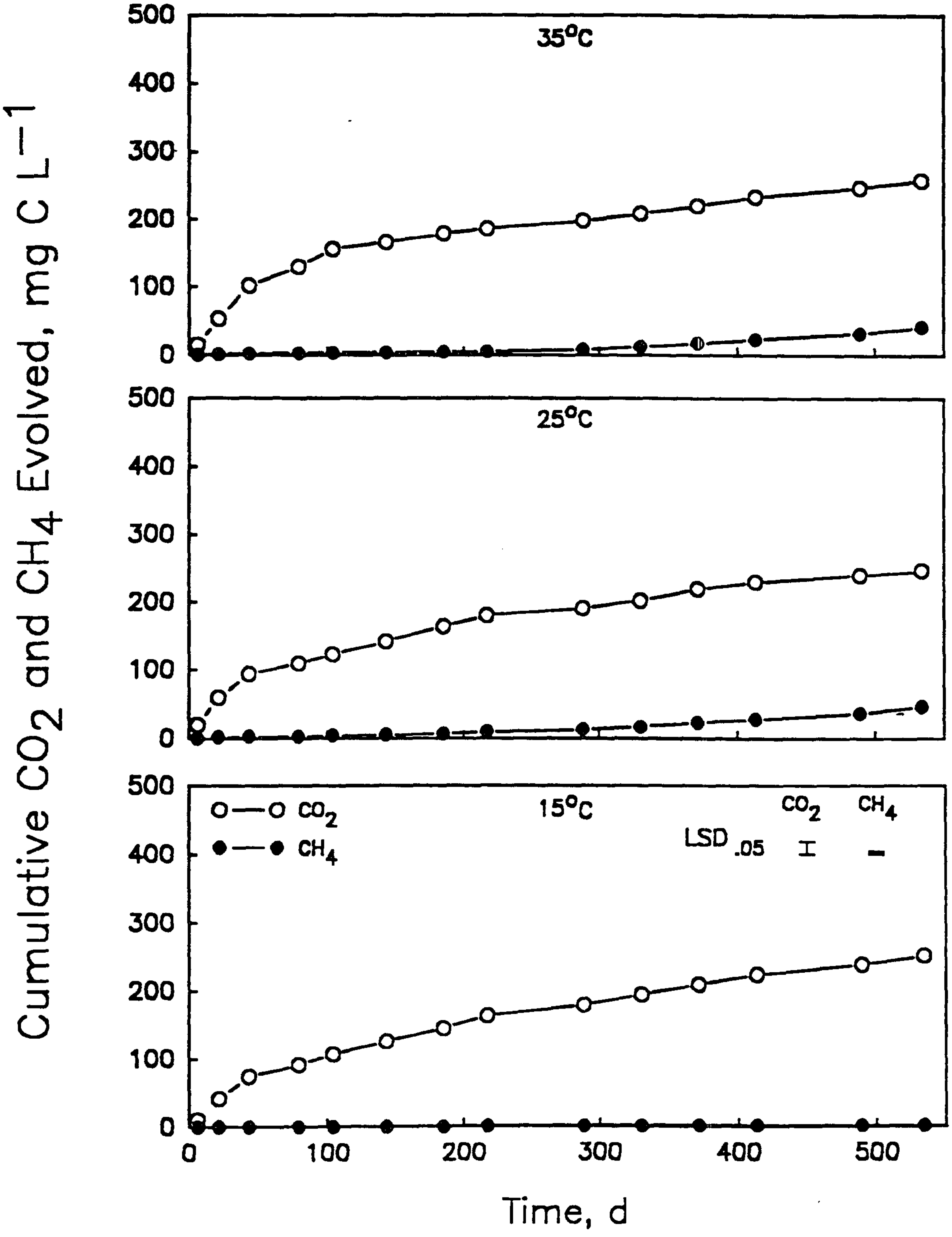

Fig. 5.2.2. Cumulative production of CO_2 and CH_4 evolved during the organic matter decomposition of consolidated flocculent material (CF) at different incubation temperature.

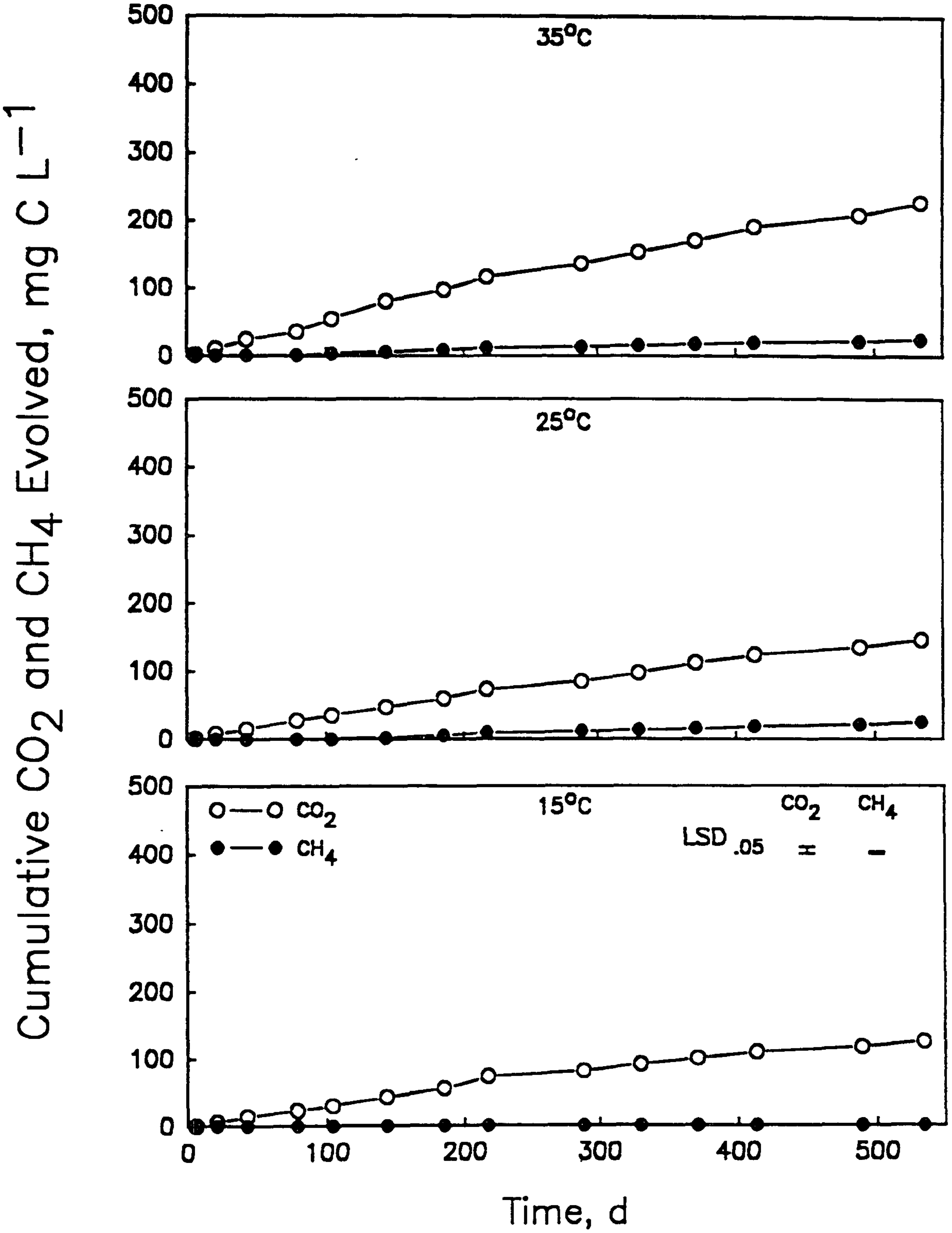

Fig. 5.2.3. Cumulative production of CO_2 and CH_4 evolved during the organic matter decomposition of peat sediment at different incubation temperature.

The evolution of CO_2 during the decomposition of the CF sediment was similar in rate and amount to that of the UCF sediment (Fig. 5.2.2). However, very little CH_4 was produced from the CF sediment during the incubations. The pronounced differences due to temperature noted in the UCF sediments (Fig. 5.2.1) were not evident in the CF sediments (Fig. 5.2.2). The evolution of CO_2 from the CF sediments was similar to that evolved from the UCF samples in that an initial flush was followed by a decreasing rate of evolution. However, very little CH_4 was evolved from any of the CF sediment samples. The extent of decomposition, as measured by the fraction of sediment C evolved as CO_2 or CH_4, in the CF sediment incubated at 25°C, was 1.3%.

The peat sediment was the most resistant to decomposition (Fig. 5.2.3). Even at 35°C, only 0.7% of the peat sediment C had decomposed during 534 days. The trend in CO_2 evolution from this sediment was also different. The initial flush of CO_2 noted in both the UCF and CF samples was not observed in the peat sediments.

The lack of significant CH_4 production from the CF and peat sediments is indicative of a substrate limited or by-product inhibited process. Methane formation during decomposition of organic matter is usually a two-step process (Acharya, 1935). The first step involves hydrolysis and fermentation of organic compounds (such as carbohydrates, lipids and proteins) by acid-forming bacteria to low molecular weight compounds such as organic acids and alcohols, H_2 and CO_2 (Chynoweth, 1987). Methanogenic bacteria convert these products to CH_4 and CO_2. The first step depends on the biodegradability of organic matter present in the sediments. In the UCF sediments, it is possible that acetate and H_2 production were high due to the ease of decomposition of organic substrates of the UCF sediment as compared to much more stable organic compounds in the CF and peat sediments. Low CH_4 and high CO_2 concentrations in CF and peat sediments clearly suggests that the first step, production of water soluble C compounds, was probably limiting CH_4 production. Cappenberg and Prins (1974) and Strayer and Tiedje (1978) have shown that approximately 70% of the CH_4 originates from the methyl position of acetate. This is in contrast to studies by Belyaev et al. (1975) who reported that 32-98% of the CH_4 produced was formed during reduction of CO_2 by H^+ and Winfrey et al. (1976) who found that CO_2 reduction by H^+ was the most significant process in methanogenesis of lake sediments. Winfrey and Zeikus (1977) and Westermann and Ahring (1988) have suggested that sulfate reducing microorganisms can inhibit methanogenesis. Their studies found that concentrations of sulfate as low as 0.2 mM can cause inhibition of CH_4 production. Sulfate concentrations in Lake Apopka water are in the range of 0.2 - 0.3 mM. Thus, it is possible that sulfate reducers can inhibit methanogenesis in the Lake Apopka sediments. However, it is not clear from these batch incubation experiments the extent of SO_4^{2-} inhibition upon methanogenesis.

Kelly and Chynoweth (1979) have proposed the use of CH_4 production alone as a measure of decomposition under anaerobic conditions. This approach is valid as long as methanogenesis is not limited. In our batch incubation experiments, the sum of both the CO_2 and the CH_4 evolved during anaerobic decomposition would be more indicative of the decomposition process than measuring CH_4 production alone (Gale and Gilmour, 1988). This is especially pertinent here since the samples were purged at the end of each gas analysis. Therefore, in order to calculate the amount of C mineralized (decomposed) in these incubations the sum of the CO_2-C and CH_4-C was used.

To estimate the rate constants for decomposition of sediment organic matter a simple first-order kinetic approach was used:

$$dC/dt = -kC \qquad [1]$$

Integrating the above equation one obtains:

$$C_t = C_o \exp(-kt) \qquad [2]$$

where:

C_t = organic C remaining in the sediment at time = t.
C_o = organic C present at the beginning of the study.
t = time, d
k = first-order rate constants, d^{-1}

Using Equation 2 and the CO_2 and CH_4 evolution data collected from the incubation experiments, first-order rate constants were calculated (Table 5.2.2). For this study C_t was calculated by subtracting the amount of C evolved as CO_2 and CH_4 from the initial amount of C present in each incubation vessel (C_o).

Low rate constants indicate the slow rate of decomposition of the physically protected soil organic matter (Paul and van Veen, 1978). At 25°C the rate constants for these sediments undergoing anoxic organic matter decomposition ranged from 1.67×10^{-4} d^{-1} for the UCF sediments, to 2.14×10^{-5} d^{-1} for the CF sediment organic matter and 8.57×10^{-6} d^{-1} for the peat sediments. In contrast, the rate constants of aerobic decomposition of the UCF sediments (see section 5.1) were found to be several-fold higher than the anaerobic decomposition rates measured in the present study. This is to be expected because of the high energy yields associated with aerobic respiration. Typically, the rate constants for steady state decomposition of various organic substrates under aerobic conditions were shown to be in the range of 7.0×10^{-4} to 9.6×10^{-3} d^{-1} (Reddy, et al., 1980).

Results of our study show the labile nature of the UCF sediments when compared to the CF and peat sediments. The UCF sediment is the most recently deposited and consists primarily of dead algal cells. On the other hand, the CF and peat sediments are composed of partially decomposed and compacted organic materials. Billen (1982) has indicated that adsorption by clay minerals or complexation by metal ions could protect proteins from enzymatic attack in aquatic systems. Yanze Kontchou and Blondeau (1990) found humic compounds to have a high resistance to degradation by heterotrophic bacteria both under aerobic and

Table 5.2.2. Rate constants for decomposition of sediment organic matter incubated under anoxic conditions at different temperatures (UCF = unconsolidated flocculent material, CF = consolidated flocculent material).

Sediment	Temperature	Rate Constant	Half-life
	—°C—	—d^{-1}—	—yr—
UCF	35	1.43×10^{-4} (0.941)[1]	13.3
UCF	25	1.67×10^{-4} (0.980)	11.4
UCF	15	7.86×10^{-5} (0.948)	24.2
CF	35	2.14×10^{-5} (0.881)	86.0
CF	25	2.14×10^{-5} (0.926)	84.6
CF	15	2.00×10^{-5} (0.930)	94.3
peat	35	1.29×10^{-5} (0.991)	133.0
peat	25	8.57×10^{-6} (0.996)	197.0
peat	15	7.14×10^{-6} (0.979)	263.0

[1] correlation coefficient

anaerobic conditions. Accordingly, Paul and van Veen (1978) stated that the production and stabilization of organic matter in soil is far greater than decomposition. The results of this study suggest that the organic matter found in these sediments is tending towards more recalcitrant C forms instead of degradative pathways.

Incubation temperature had little effect on the rate of organic matter decomposition with Q_{10} values for each sediment type in the range of 1.0-1.2. The Q_{10} is defined as the factor by which the rate constant changes with a 10 degree increase in temperature. Nyhan (1976) has stated that Q_{10} values of 1-2 are typical for biological systems. The lack of a Q_{10} relationship (values close to 1), as observed in this study, was probably limited by the quality of substrate (electron donor) and quantity of electron acceptors. Capone and Kiene (1988) have concluded that the most important aspect of C catabolism in sediments is the availability of electron acceptors. For the Lake Apopka sediments it is possible that anaerobic decomposition in our batch experiments were limited by the availability of electron acceptors within the system. However, under *in situ* conditions, the electron acceptors can be derived from external loading or through internal cycling. For example, nitrate can be derived through nitrification in the water column, and the nitrate formed can diffuse into underlying anaerobic sediments and function as electron acceptor during microbial respiration (Reddy and Patrick, 1984).

The amount and composition of the water soluble organic C pool (WSOC) was also evaluated during these incubations (Fig. 5.2.4). The trends in the concentration of the WSOC pool for the various incubations were the opposite of the trends observed in gas production. The UCF sediment which had the highest gas production maintained the lowest WSOC concentrations. The CF and peat sediment WSOC pools were characterized by fluctuations of 50-100 mg C L^{-1} throughout the incubations. These fluctuations are indicative of the transient nature of these C pools. Higher WSOC concentrations occur when consumption of this pool is limited or inhibited.

A portion of the WSOC pool could be attributed to volatile fatty acids (VFA). These compounds are known to be intermediates in anaerobic decomposition processes (Guenzi and Beard, 1981). Acetic, propionic, and butyric acids were the only VFA detected during these incubations (Figs. 5.2.5-5.2.7). The VFA concentrations were sporadic with variability between replicate samples ranging up to 200%. However, duplicate analyses of samples varied by only 5-10%. Acetic acid was found in the highest concentrations of the VFA's identified in these samples (Fig. 5.2.5). The UCF sediment samples had the highest acetic acid concentrations. Vogels et al. (1988) and Balch et al. (1979) have indicated that acetate is the most abundant substrate for methanogens in natural systems. They also noted that acetate is a significant precursor of cellular C. It is therefore not surprising that the highest concentrations of acetic acid are associated with the only sediment that was actively decomposing during these experiments. In the UCF sediment samples (Fig. 5.2.5) the acetic acid concentration peaked at day 6 and then leveled off to a concentration of 5 mg C L^{-1} (0.2 mM acid). This ensured a constant supply of acetate for CH_4 production.

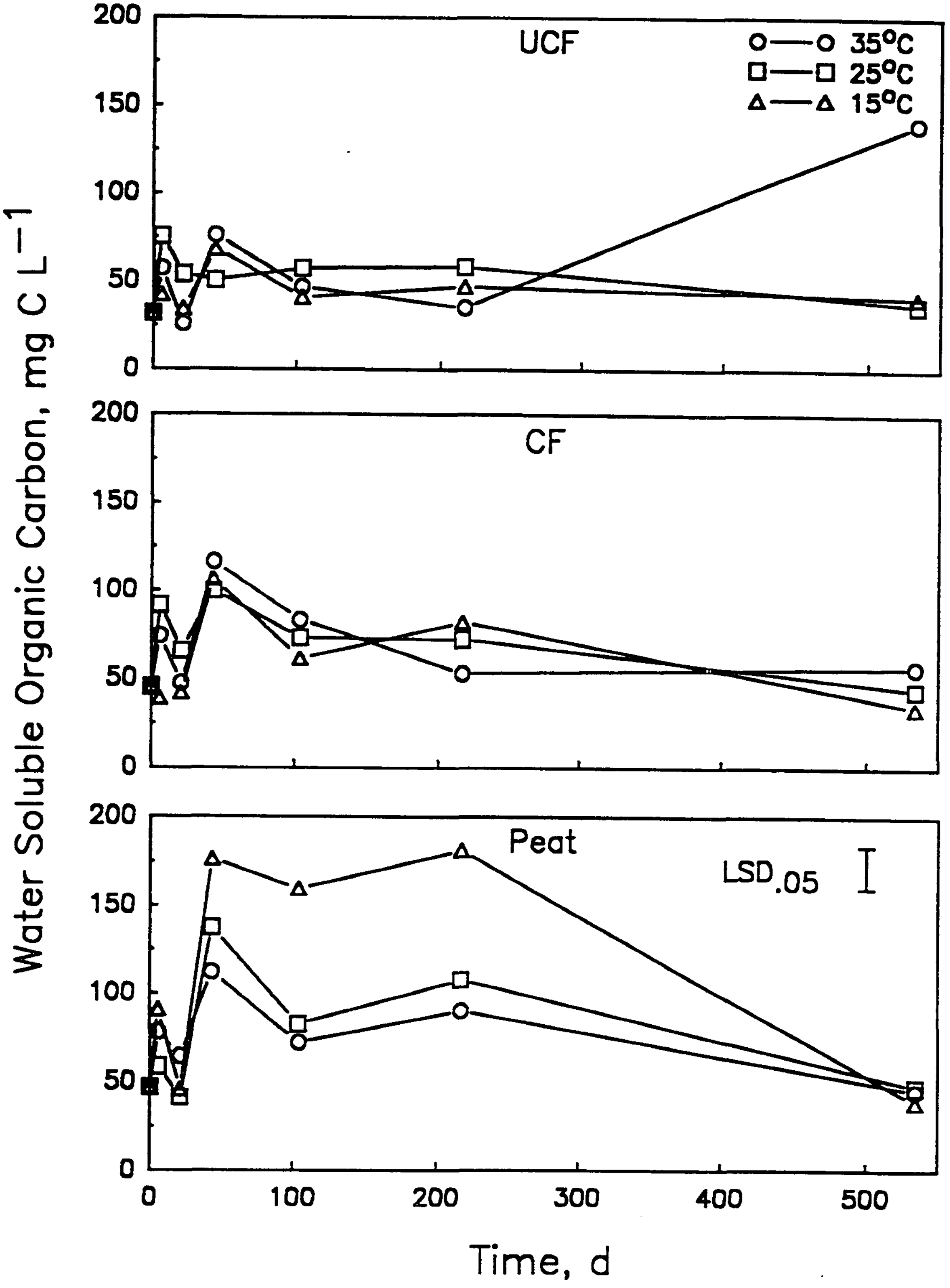

Fig. 5.2.4. Production of water soluble organic C (WSOC) during the decomposition of Lake Apopka sediments (UCF = unconsolidated flocculent material, CF = consolidated flocculent material).

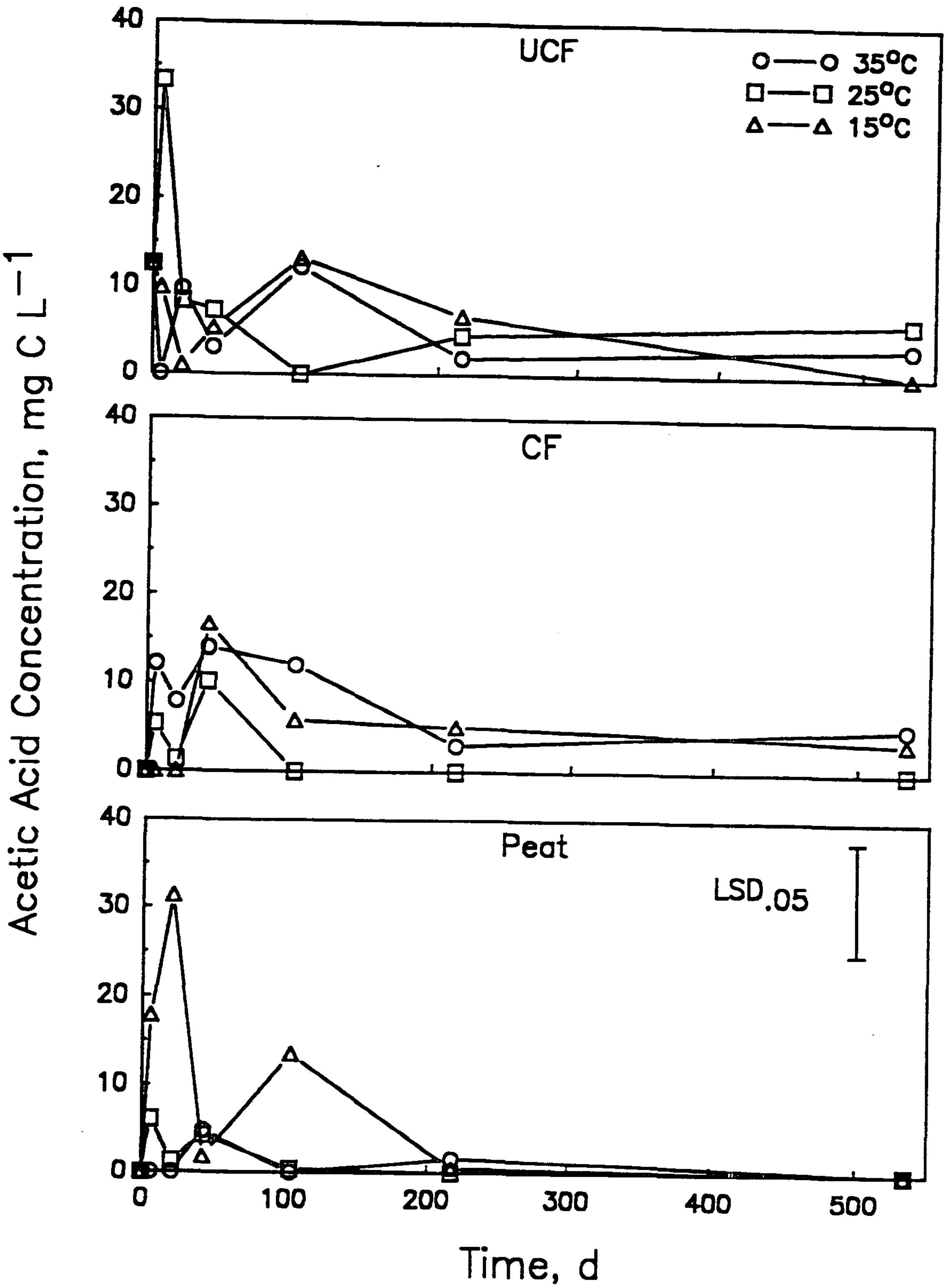

Fig. 5.2.5. Changes in acetic acid concentrations during decomposition of Lake Apopka sediments (UCF = unconsolidated flocculent material, CF = consolidated flocculent material).

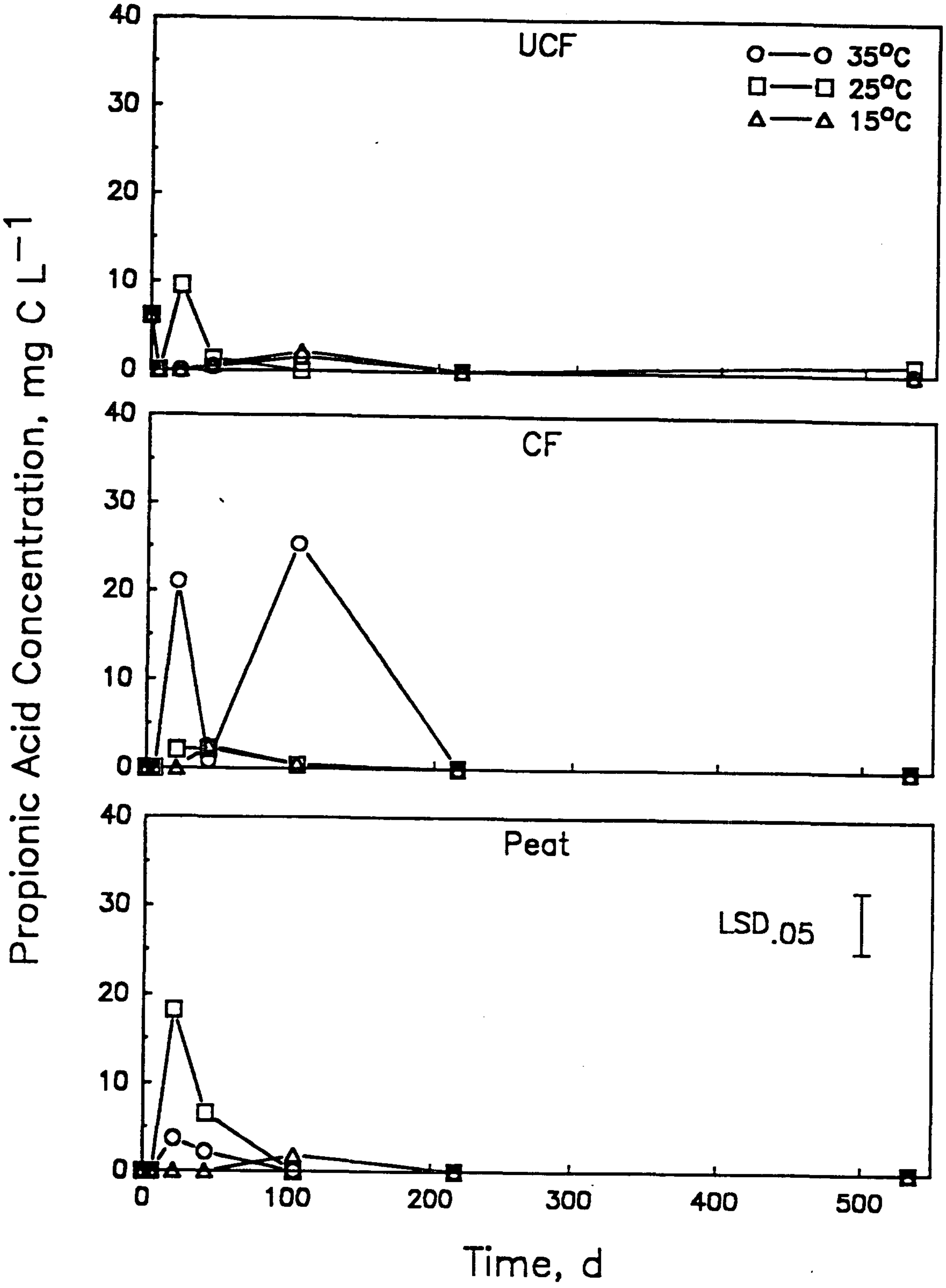

Fig. 5.2.6. Changes in propionic acid concentrations during decomposition of Lake Apopka sediments (UCF = unconsolidated flocculent material, CF = consolidated flocculent material).

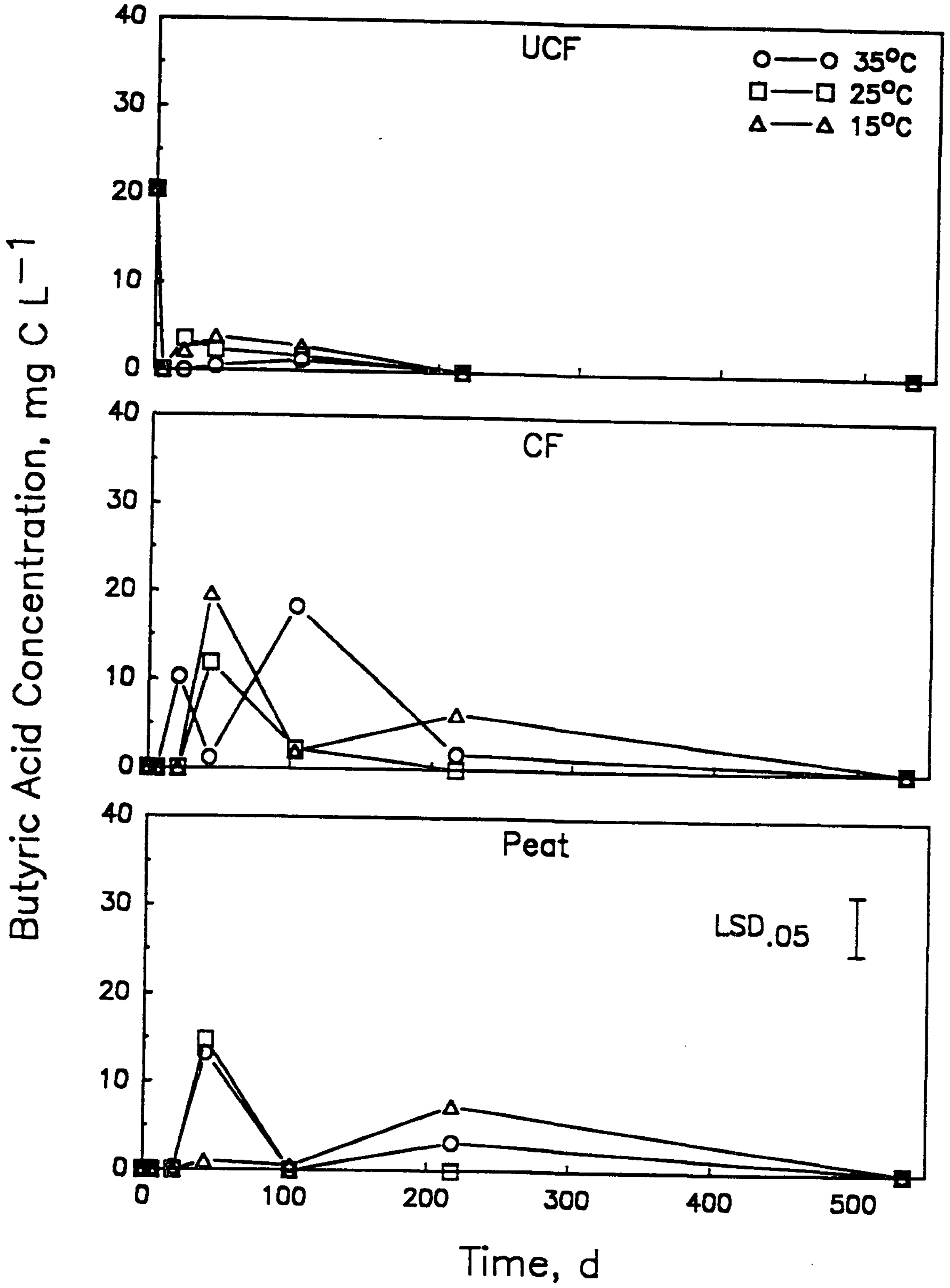

Fig. 5.2.7. Changes in butyric acid concentrations during decomposition of Lake Apopka sediments (UCF = unconsolidated flocculent material, CF = consolidated flocculent material).

Propionic and butyric acid concentrations (Figs. 5.2.6 and 5.2.7) peaked during the first 100 d of incubation and subsequently disappeared for all of the sediment samples. These peak concentrations could have been related to the flush of CO_2 observed at the beginning of the incubations. The lack of their continued production is most likely a function of the limited decomposition in these sediments. Cappenberg (1988) states that the initial exoenzyme hydrolysis is probably the rate limiting step for detrital organic C. The percent of the WSOC pool that could be attributed to VFA's ranged from 0-85%. Barcelona (1980) found that VFA's accounted for up to 50% of the measured *in situ* WSOC concentrations in marine sediments. It should be noted that both VFA and WSOC concentrations were low when compared to the total available C in the system and the C evolved gaseously as CO_2 and CH_4.

Cappenberg and Prins (1974) found the average CO_2/CH_4 ratio in the gas evolved from acetic acid spiked sediments to be 1.32. In the present study, the CO_2/CH_4 ratio ranged from approximately 20 to 0.25, during the period of active CH_4 production. Table 5.2.3 lists the CO_2/CH_4 ratios of the final gas samples analyzed at the end of the incubations. By this time all of the sediment samples were actively producing CH_4 at varying rates. The lowest CO_2/CH_4 ratios were observed in the UCF sediments which also supported a significant acetic acid pool. However, cleavage of the methyl group from acetate can only account for CO_2/CH_4 ratios above 1. Lower CO_2/CH_4 ratios are due to the reduction of CO_2 to CH_4 (Vogels et al., 1988).

5.2.4 Conclusions

The organic matter decomposition rates for Lake Apopka sediments under anoxic conditions are very slow. Of the sediment types studied, anaerobic decomposition of the UCF sediment resulted in approximately 10% of the C being evolved as gaseous end-products during the 534-d incubation. The percent decomposition for the CF and peat sediments were 10-fold lower having values of 1.5 and <1%, respectively. Slow decomposition rates in CF and peat sediments are probably due to the nature of the organic substrate and a limited supply of electron acceptors.

It is recognized that the rate constants determined in this experiment are most likely lower than those occurring naturally within the lake. This is especially true in regards to the UCF sediment which is most likely in contact with enough O_2 to undergo limited aerobic decomposition. Under field conditions, a steady supply of electron acceptors (such as nitrate and sulfate) from external and internal sources can also enhance the decomposition rates in the sediments. Future studies should be directed to evaluate the role of electron acceptors on organic matter decomposition in lake sediments and its impact on nutrient fluxes.

Table 5.2.3. Ratios of CO_2/CH_4 in gas samples collected during the final sampling (UCF = unconsolidated flocculent material, CF = consolidated flocculent material).

Sediment	Incubation Temperature		
	35°C	25°C	15°C
	mol CO_2/mol CH_4		
UCF	0.24	0.41	1.12
CF	1.18	0.64	10.70
Peat	8.87	2.97	3.13

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5.3 Diffusion of Organic Acids in the Sediment-Water Column [Task 3.3]

5.3.1 Introduction

Volatile fatty acids (VFA) are known intermediates of anaerobic decomposition processes (Klass, 1984). These compounds are the end products of the anaerobic catabolism of carbohydrates, proteins, and fats. The VFA's produced during fermentation are subsequently consumed by sulfate reducing and methanogenic microorganisms with the resulting production of CO_2 and CH_4. Guenzi and Beard (1981) found acetic, propionic and butyric acids to be dominant components of the VFA pool in cattle manure slurries. The turnover rate (consumption) of these compounds has been used to predict CH_4 production in anaerobic digesters (Smith and Mah, 1966). Barcelona (1980) has suggested that VFA's be used as indicators of diagenetic processes within marine sediments. In his study VFA concentration gradients were correlated with redox potential gradients and microbial populations. Volatile fatty acids are not detected in aerobic environments as they are readily consumed. However, these compounds are known to accumulate in anoxic environments. Recently, Michelson et al. (1989) cautioned that *in situ* measurements of VFA oxidation can be grossly overestimated if diffusion of these compounds is not considered. This idea is important as VFA produced in one area can diffuse and be consumed in another. Thus, diffusion is responsible for moving VFA from producers to consumers. The objective of this study was to measure the diffusion coefficients of selected volatile fatty acids (VFA) in anoxic sediments. These data can be used to estimate the diffusive flux of VFA from sediments to the overlying water column.

5.3.2 Materials and methods

To determine diffusion coefficients, sediment samples were incubated in contact with sediments spiked with known concentrations of the compound to be studied. After an incubation period, the sediment sample is sliced and the concentration of the compound under study is determined for each slice. The change in concentration with distance is then evaluated to determine the diffusion coefficient. In the present study, the diffusion half-cell A (Fig. 5.3.1) was filled with sediment spiked with a known concentration of a VFA. The sediment is half-cell B was filled with sediment treated only with water.

Bulk UCF sediments were collected with an Ekman dredge, from station K-6, a site just off Fisherman's Paradise, for use in these experiments. The sediments were stored at 4°C under anoxic conditions. Acetic and butyric acids were selected as the VFA's to be studied in these experiments. These compounds were selected based on: (1) their observed concentrations within these sediments, and (2) their significance as anaerobic decomposition intermediates (Capone and Kiene, 1988). Prior to filling the diffusion cells the sediment was divided into 3 portions. To each portion either deionized water or a 40 mM acid solution was added at a rate of 10% by volume. This resulted in a final concentration of 4 mM for the acid treated sediments and equivalent water content for the non-spiked sediment. After treatment half-cell B was packed with non-spiked sediment and half-cell A was

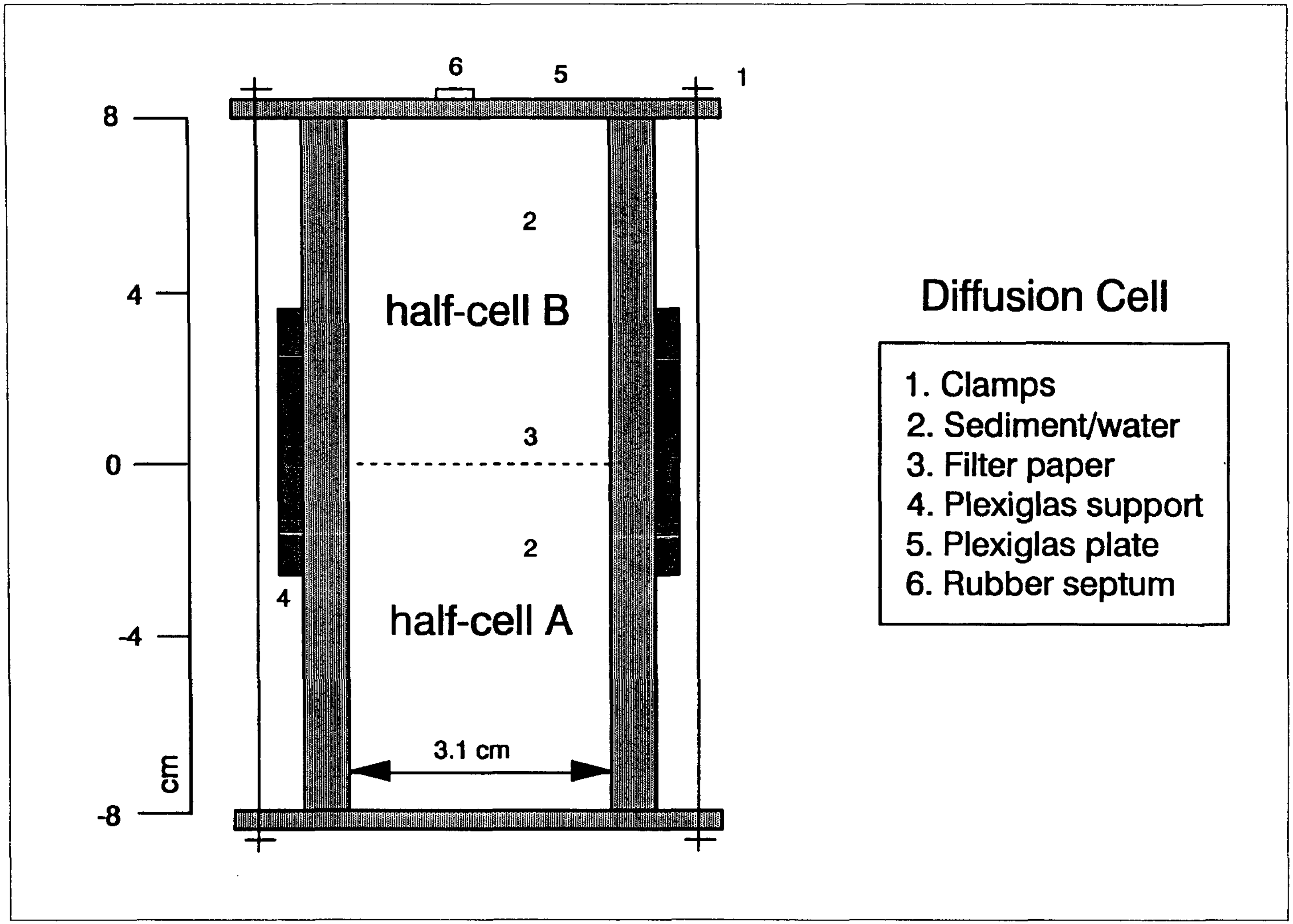

Fig. 5.3.1. Diffusion cell used for determination of VFA diffusion coefficients.

packed with sediment spiked with either acetic or butyric acid. The two cells were separated with a Whatman #45 filter paper. The diffusion cells were then sealed and incubated in the dark at 25°C for 72 h. Three replicate diffusion cells were used for each acid. Controls consisted of subsamples from each of the sediment treatments incubated in centrifuge tubes under the same conditions as the diffusion cells.

After 72 h, the diffusion cells were opened and the cells were sectioned in 1-cm increments using a pipette. The sediment was transferred to a 50-mL centrifuge tube and 5 mL of a 1% H_3PO_4 solution was added. The tubes were shaken for 15 min. and then centrifuged at 5000 rpm for 15 min. A portion of the supernatant was removed and analyzed for acetic, butyric and propionic acids using a gas chromatograph equipped with a flame ionization detector (FID). Chromosorb W AW was used as the packing in a 1.8-m glass column and N_2 was the carrier gas. The column temperature was 100°C and the carrier flow rate was 0.5 mL s^{-1}. This procedure has been previously described by Wilke et al. (1986).

5.3.3 Results and discussion

Measurement of the diffusion coefficients for butyric and acetic acids followed the same procedures as those described for ammonium in Chapter 5.7.2. The governing equations for diffusion of the organic acids in the sediment-sediment column is found in Case I of Section 5.7.2.1. Diffusion profiles for the two acids were very similar to one another (Fig. 5.3.2). Average (±SE) diffusion coefficients (D_s) using the estimated R values were 0.71 ± 0.19 (0.32 - 1.11, 95% CI) and 0.46 ± 0.14 (0.17 - 0.75, 95% CI) cm^2 d^{-1} for butyric and acetic acid, respectively. Retardation factors, based on measured K_ds of 14.1 for butyric acid and 16.4 for acetic acid, were 1.48 and 1.56, respectively. Diffusion coefficients for acetic acid at infinite dilution in water (25°C) have been reported at 1.05 cm^2 d^{-1} (Cussler, 1984); a value which is well above the 95% CI for D_s of acetic acid estimated for this lake sediment.

Background concentrations of acetic acid averaged 0.02 mM. Propionic and butyric acids were not detected in the deionized water or acetic acid treated sediments. The sediment sample treated with butyric acid had detectable amounts of both propionic and acetic acid at the end of the 72-h incubation. This indicates that decomposition of this compound occurred during the incubation. Based on the production of acetic and propionic acid produced in the butyric acid control approximately 2% of the added acid decomposed during the experiment. This was considered to have a negligible effect on the diffusion of this acid in this study.

5.3.4 Conclusions

Diffusion of the volatile fatty acids, acetic and butyric acid, were similar suggesting that movement was related to acidity gradients and not just mass transfer. Mass flow would suggest a greater movement of the butyric acid due to this compound's larger molecular size. Although on a total organic C basis both acetic and butyric acids are relatively small compounds.

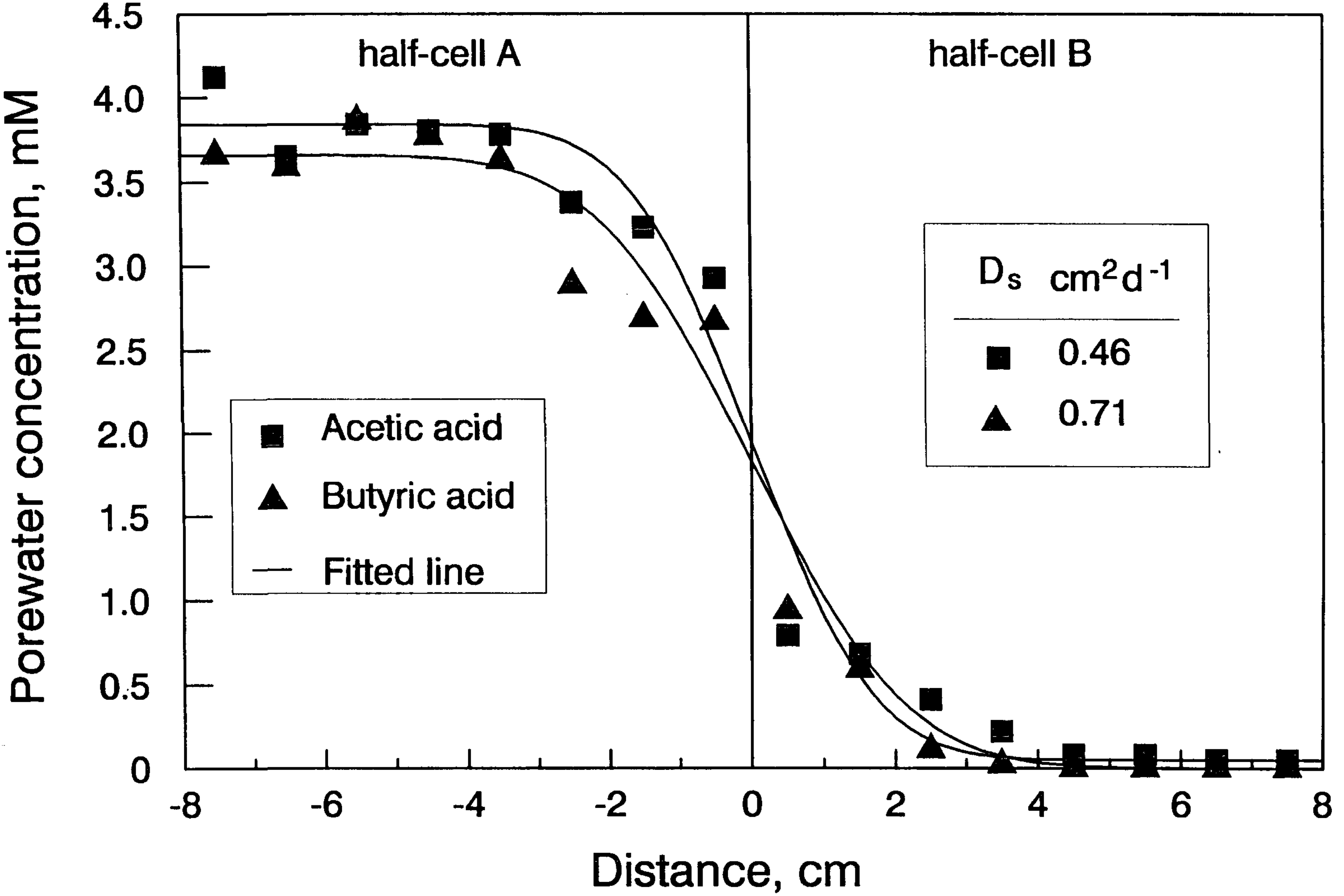

Fig. 5.3.2. Concentrations (measured and predicted) of acetic and butyric acid in K-6 sediments after 72-h incubation.

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5.4 Adsorption of Organic Acids Under Anoxic Conditions [Task 3.4]

5.4.1 Introduction

Volatile fatty acids (VFA) are important intermediate products of anaerobic decomposition in lake sediments. The concentration VFA in the porewater is governed to some extent by the capacity of the sediments to adsorb organic acids, thus the equilibrium relationship between solid phase and pore fluid. Billen (1982) has stated that adsorption of organic compounds by sediments can result in the physical protection of these compounds from further degradation. Michelson et al. (1989) have determined that adsorption was responsible for removing up to 30% of the acetic acid from the pore water of an anoxic estuarine sediment. To describe the movement of organic acids within the sediment profile and from the sediment to the overlying water column, it is critical to determine the partition coefficient or adsorption coefficient (ratio of VFA adsorbed to VFA in porewater) for sediments. The objective of this experiment was to determine the adsorption coefficients for selected organic acids in Lake Apopka sediments.

5.4.2 Materials and methods

Sediment collection and storage have been described previously in Chapter 5.3. Ten milliliters of sediment, spiked with 10 mL of solution of a known concentration of either acetic or butyric acid, was placed in a 50-mL centrifuge tube. Five different concentrations of each acid were used and all treatments were done in triplicate. The tubes were capped and flushed with N_2 to ensure anoxic conditions. The tubes were then shaken, in the dark, at room temperature for 24 h. At the end of 24 h the samples were centrifuged at 5000 rpm for 15 min. The supernatant was removed, acidified with 1 drop of 10% H_3PO_4 and analyzed for acetic and butyric acids using gas chromatography, as described in Chapter 5.3.

5.4.3 Results and discussion

For both acids, acetic and butyric, peak adsorption of the acid by the sediment was observed at a solution concentration of 4 mM (Fig. 5.4.1). Higher solution concentrations (VFA concentration far above nutrient levels present in sediments) resulted in a decrease in the amount of acid adsorbed.

Due to the observance of a maxima in the adsorption isotherm data, solution concentrations up to 4 mM only were used to calculate the adsorption coefficients. A simple linear adsorption isotherm as shown below was used in the calculations:

$$S = KC$$

where:

S = amount of acid adsorbed, mmol kg^{-1}
C = equilibrium concentration of acid in solution, mM
K = adsorption coefficient, L kg^{-1}

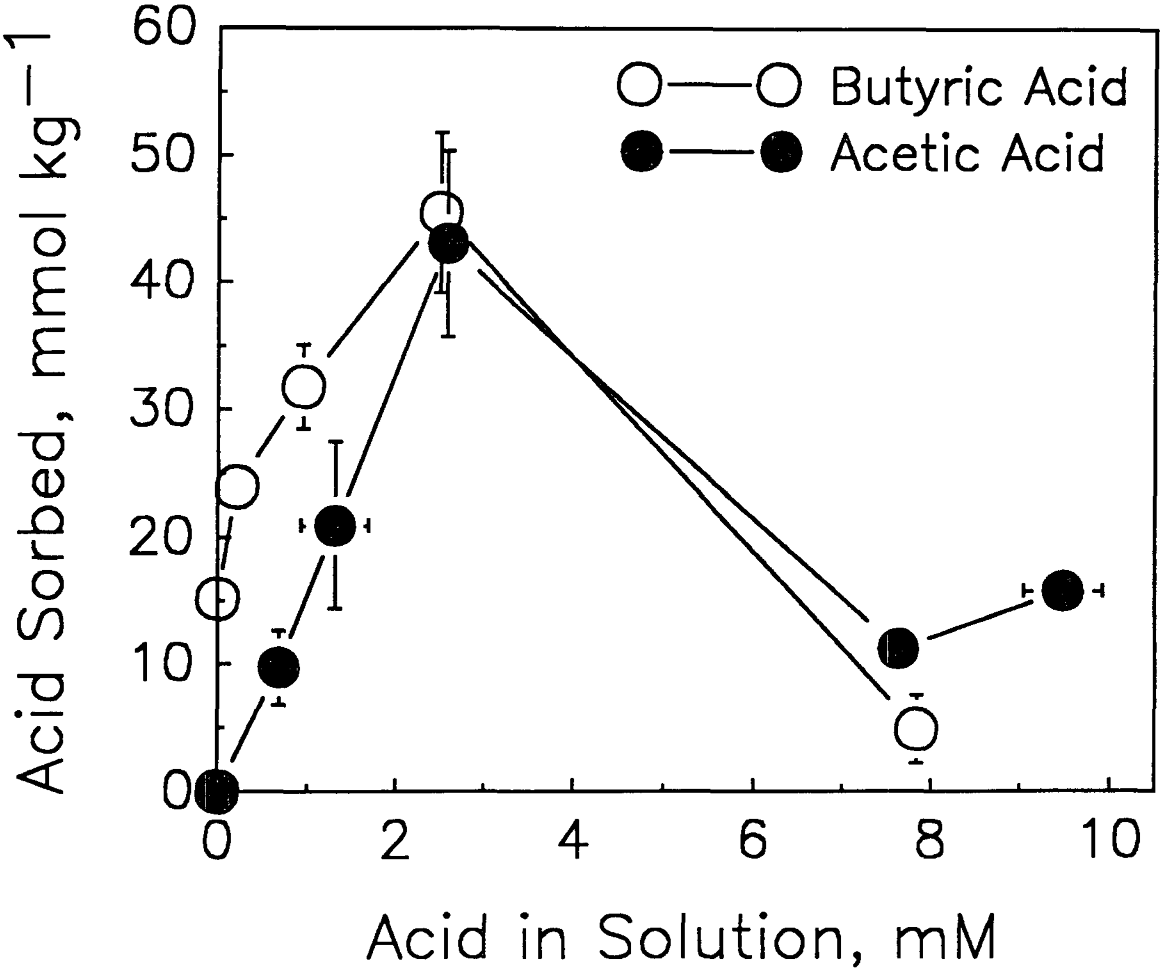

Fig. 5.4.1. Adsorption isotherms for acetic and butyric acid in Lake Apopka sediments.

These calculations were performed by regressing the amount of acid adsorbed (expressed as mmol acid per kg dry sediment) upon the solution concentration (mmol L^{-1}, mM). The slope of this relationship is the partition coefficient (K_d) and has units of L kg^{-1}. For acetic acid the value of K_d was 14.7 L kg^{-1} ($r^2 = 0.687$) and a value of 13.2 L kg^{-1} ($r^2 = 0.708$) was calculated for butyric acid. Although butyric acid (FW = 88.1 g mol^{-1}) is a larger molecule than acetic acid (FW = 60.1 g mol^{-1}) it is not surprising that they have similar K_d values and diffusion coefficients (measured in Chapter 5.3). Both of these organic acids have the same acid equivalents per mole and this factor would predominate in adsorption reactions. Mortland (1986) has stated that organic molecules in soils are mostly bound by the organic component of the soil. For both acetic and butyric acids, anion exchange reactions would predominate.

The observation of a peak in the adsorption for both of these acids was suspected to be a function of pH. To test this, sediment samples were spiked with the varying acid concentrations and shaken for 1 h. At the end of this period, the pH of the solution was measured. Since no significant changes in the solution pH occur around the 4 mM concentration (Fig. 5.4.2) it is unlikely that a pH effect is responsible for the observed maxima in the adsorption isotherms.

A portion of the measured adsorption could be due to degradation of the added compounds. In Chapter 5.3 it was determined that approximately 2% of the added acid decomposed during the 3-d incubation. In an attempt to remove the decomposition factor from the adsorption and diffusion coefficient determinations several sterilization techniques were tested on the sediments. Mercuric chloride, toluene, and autoclaving treatments were all found to greatly increase the soluble C pool of these sediments. While mercuric chloride was found to be the most effective and least damaging sterilizer of mineral soils (Wolf et al., 1989) the highly organic nature of the sediments used in this study inhibited its usefulness.

The volatile fatty acid data that appears in Chapter 5.2 are expressed as mg C L^{-1}. In the present study, the data are expressed on a mmol basis. For comparison of the data, 1 mmol butyric (FW = 88.1) acid is equivalent to 48 mg C and 1 mmol acetic (FW = 60.1) acid is equivalent to 24 mg C. The peak concentrations of these acids during the decomposition study (Chapter 5.2) ranged from 0.5-2 mM of volatile fatty acid.

5.4.4 Conclusions

The adsorption of organic acids by Lake Apopka sediments is a function of the acidic properties of these compounds. Adsorption of acetic acid by these sediments was responsible for removal of approximately 35% of the acid from the sediment porewater. This amount was similar to the 30% removal from estuarine sediment porewaters found in the study by Michelson et al. (1989). A wide range (10 - 80%) of adsorption percentages were found for butyric acid. For this acid the percent of the added acid adsorbed was highest at the lowest solution concentrations.

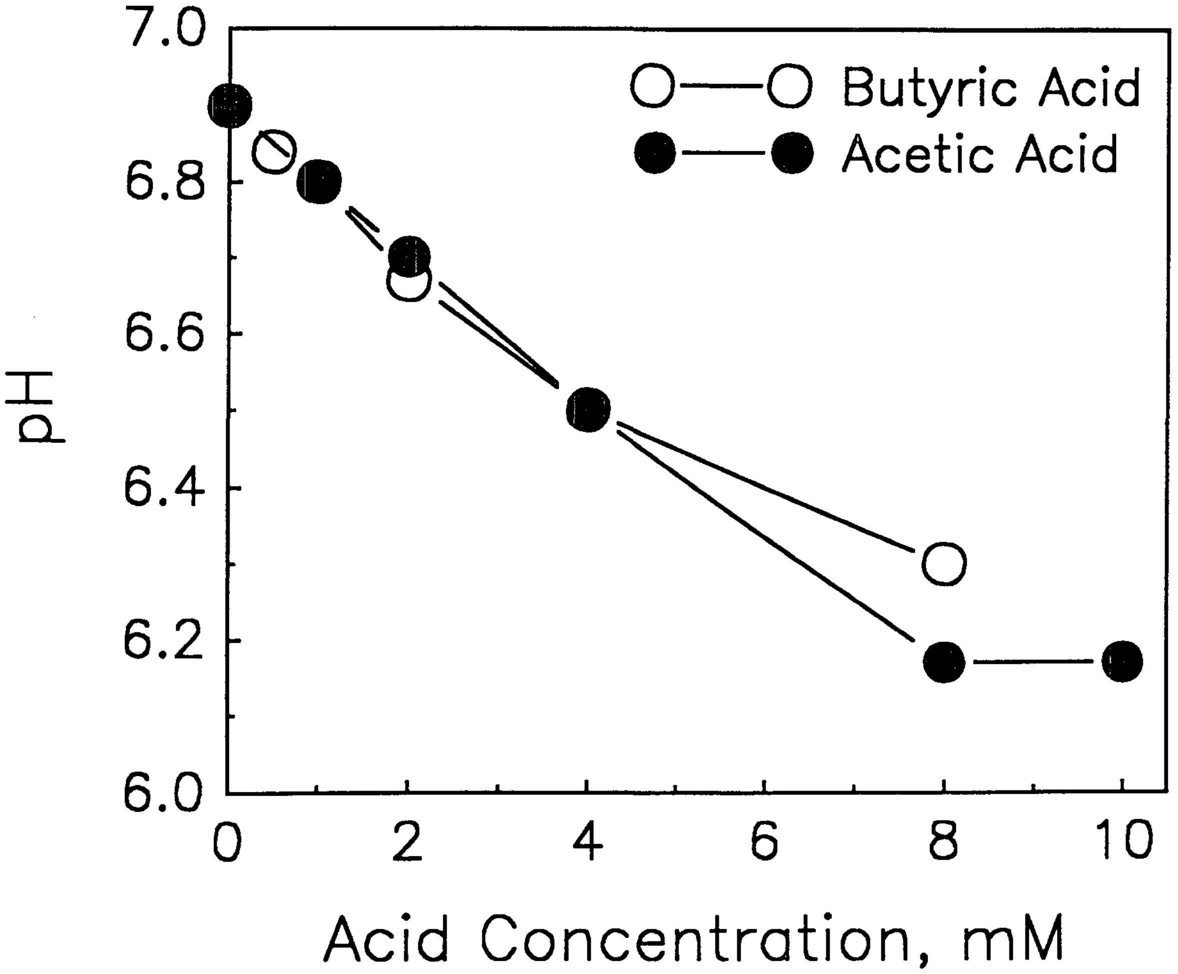

Fig. 5.4.2. Change in pH associated with acetic and butyric acid additions to Lake Apopka sediments.

5.4.5 References

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5.5 Kinetics of Organic Nitrogen Mineralization Under Anoxic Conditions [Task 3.6]

5.5.1 Introduction

Although nutrient loading from external sources contributes to the eutrophication of lakes, it is also known that organic-rich sediments can release nutrients to overlying waters (Gardner et al., 1989). In lake sediments, N occurs in inorganic and organic forms, with the latter predominating. More than 90% of the total N in sediments is in organic form. Thus, the N transformations regulating the breakdown of organic N forms are critical in supplying the nutrients to phytoplankton and other aquatic biota. Seitzinger (1988) estimated that 76-100% of freshwater N transformations are mediated by the sediments of the system. A series of biochemical and physico-chemical processes are involved in regulating the conversion of one form to another, and their mobility between the sediment and water columns. Conversion of organic N to inorganic N is the mineralization process. Under anoxic conditions the mineralization, the end product is NH_4-N. Ammonium formed will tend to diffuse into the water column where it is nitrified to NO_3^- or assimilated by aquatic biota (Reddy and Patrick, 1984). However, turbulent mixing of sediments with the water column accounts for the majority of sediment nutrient release (Keeney, 1973). The shallow depth of Lake Apopka and the flocculent nature of its sediments both contribute to sediment resuspension in this lake system (Pollman, 1983).

This exemplifies the importance of an understanding of the biochemical transformations of N and P in sediment studies (Reddy et al., 1988). Nutrient regeneration in sediments is controlled by the nature of the organic substrate and the supply of electron acceptors (Aller, 1982; Reddy et al., 1986). The kinetics of organic C decomposition in Lake Apopka are discussed in Chapter 5.2 of this report. Other researchers (Gallepp, 1979; Gardner et al., 1989) have shown that the metabolic activities of invertebrates may also be important to overall mineralization.

Since the inorganic N mobility in sediments is governed by the decomposition processes in the sediment, it is important to know the kinetics of mineralization under anoxic conditions. The objectives of this study were to study the transformations of N and P during decomposition of the organic Lake Apopka sediments under controlled anoxic conditions.

5.5.2 Materials and methods

Experiment 1

The sediment samples from the batch incubation experiments described in Chapter 5.2 were analyzed for porewater NH_4 and soluble reactive P (SRP) along with KCl extractable NH_4 and P. An autoanalyzer was used for the NH_4 and PO_4 determinations following EPA procedures (USEPA, 1979).

Experiment 2

In this experiment, the mineralization of organic N and the fate of added NH_4-N was evaluated under anoxic conditions. The distribution of N into the various porewater and exchange fractions were monitored periodically during a month-long experiment.

Bulk sediment samples collected from station K-6 were used in this experiment. Forty mL of wet sediment was placed into 150-mL serum bottles and spiked with 20 mL of an amending solution containing either NH_4Cl, the amino acid alanine, or deionized water. The serum bottles were sealed and purged with N_2 prior to incubation. The samples were incubated in the dark, at 25°C, for periods of up to 28 d. Enough replications were included to allow for triplication of all treatments and 8 sampling times.

Periodically, triplicate samples of each treatment were removed and analyzed in the following manner. Thirty mL of the sample was removed and filtered through Whatman #42 filter paper. The sediment remaining on the filter paper was dried and saved for analysis of total N. To the sediment remaining in the bottle, 30 mL of 4 M KCl was added and the samples were shaken. After 1-h the sediment-KCl solution was filtered and saved for later analysis. The filtrate from both the porewater and KCl extractions were analyzed for NH_4-N and NO_2-N plus NO_3-N by steam distillation (Keeney and Nelson, 1982) and total N using a micro Kjeldahl digestion (Bremner and Mulvaney, 1982).

5.5.3 Results and discussion

Experiment 1

Changes in the concentration of porewater NH_4-N with time are depicted in Fig. 5.5.1. The trends depicted in this figure are similar to observed C mineralization trends discussed in Chapter 5.2. All of the sediment samples were net mineralizers of N with the exception of the CF sediment incubated at 15°C. Figure 5.5.2 depicts the changes in KCl extractable NH_4-N with time. These data include both the porewater NH_4-N concentrations and the reversibly bound NH_4-N on the sediment exchange complex. As such, Figure 5.5.2 is a measure of the total N mineralization occurring during anoxic decomposition of these sediments.

Net N mineralization was defined as:

$$\text{N min} = \text{inorg. } N_t - \text{inorg. } N_0 \qquad [1]$$

where:

N_t = inorganic N concentration at time = t
N_o = initial inorganic N concentrations

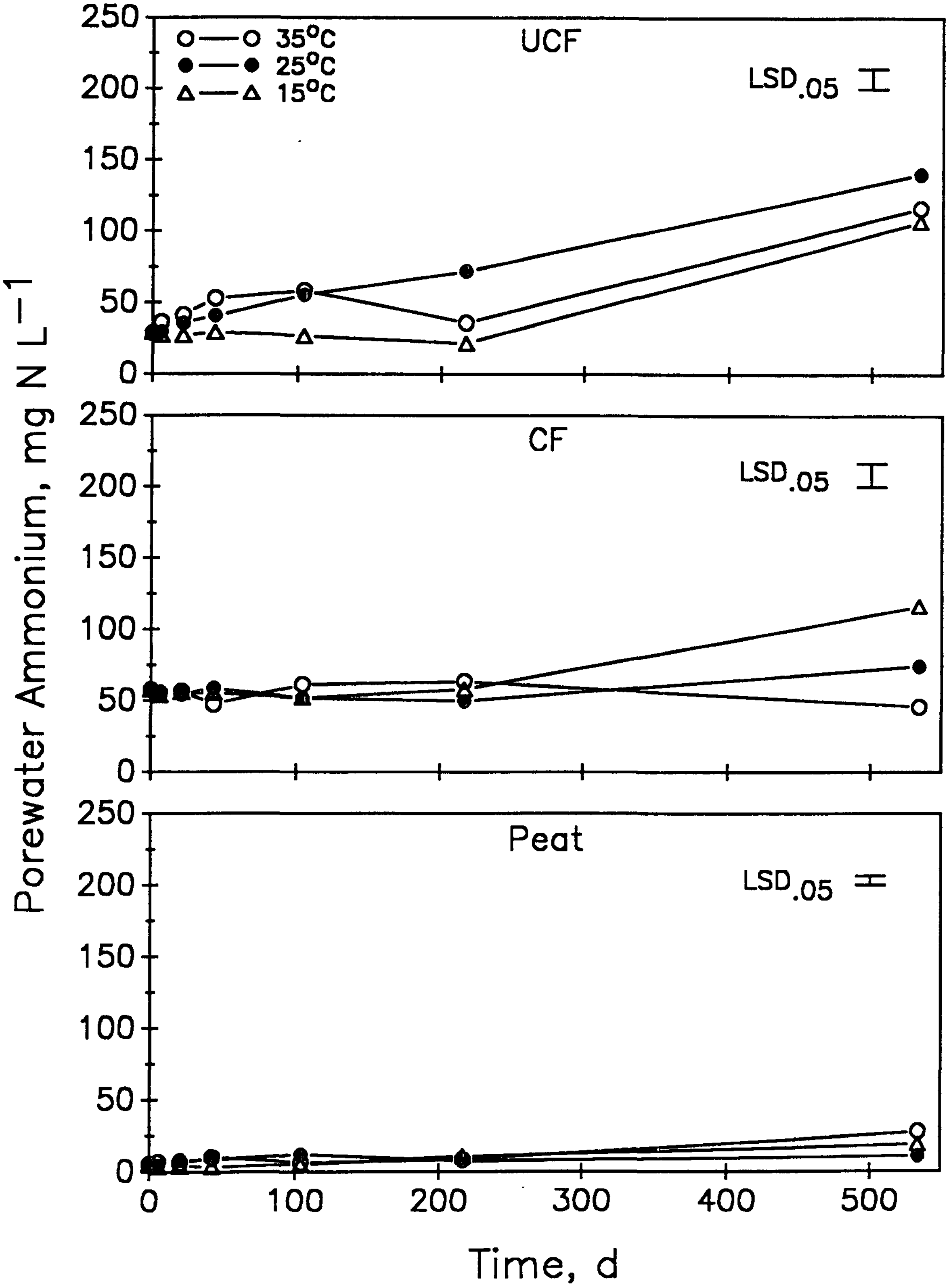

Fig. 5.5.1. Changes in porewater NH_4-N concentration with time for Lake Apopka sediments incubated under anoxic conditions at different temperatures.

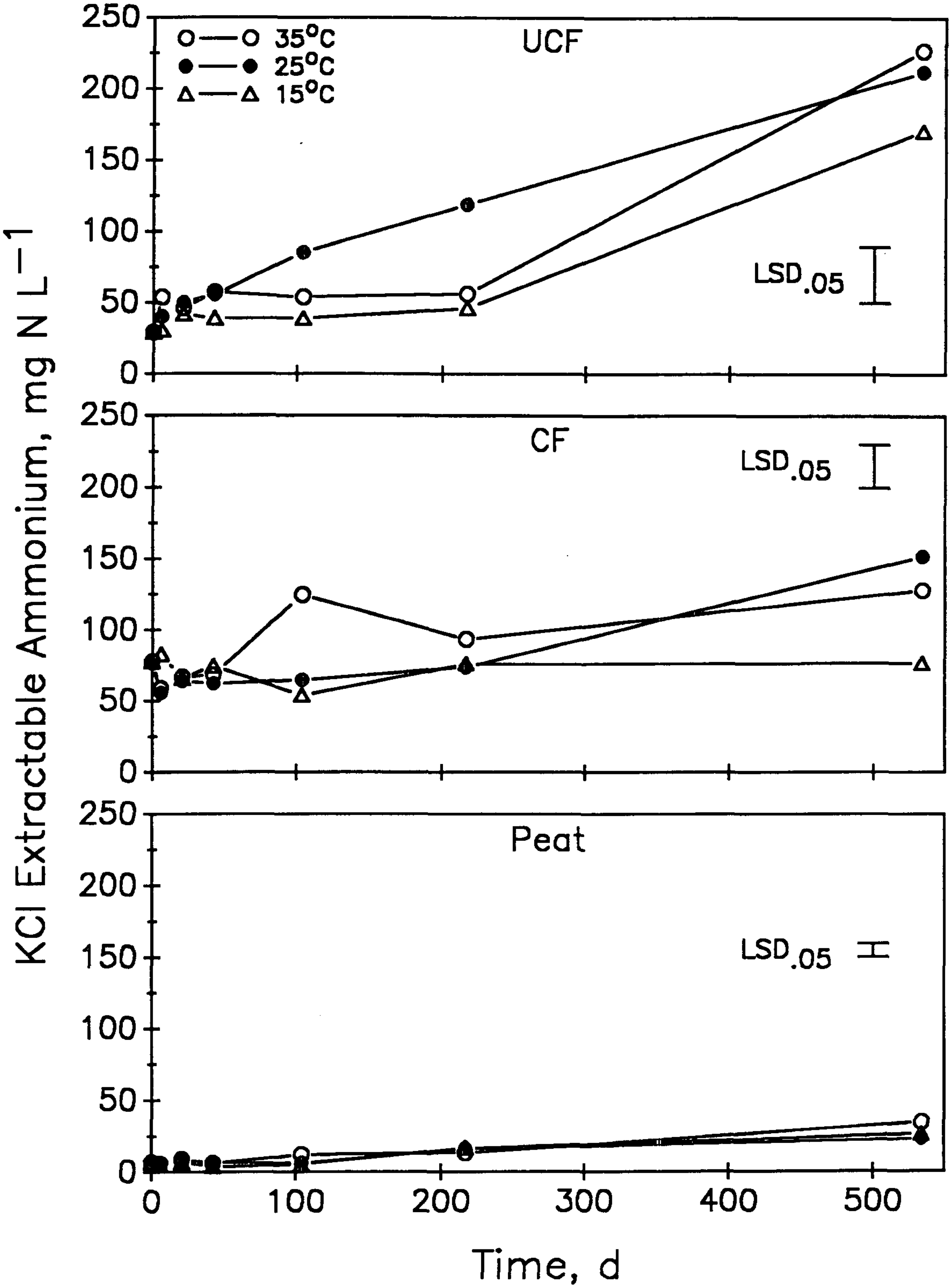

Fig. 5.5.2. Changes in exchangeable NH_4-N concentration with time for Lake Apopka sediments incubated under anoxic conditions at different temperatures.

All of the sediments, with the exception of the CF sediment incubated at 15°C, were net N mineralizers during the 534-d incubation. Nitrogen mineralization rates were calculated based upon the net N mineralized and the length of the incubation. Results of these calculations are presented in Table 5.5.1. These mineralization rates were similar in magnitude to those found by Gardner et al. (1989). In their study of N mineralization within sediments under substrate limiting conditions they calculated a high mineralization rate of 0.14 mg N L^{-1} d^{-1}. This adds support to the conclusions of Chapter 5.2 where anaerobic decomposition of these sediments is controlled by a substrate/electron acceptor limitation.

The N mineralization data were also expressed as a percent reduction in the initial organic N pool. The initial organic N pool is defined as the total N minus the initial inorganic N. For the UCF sediment, 16.9% of the organic N pool was mineralized. Values for the CF and peat sediments were 6.6 and 1.4%, respectively. When compared to the percent of the organic C mineralized (Chapter 5.2), N mineralization percentages were 2 times greater than C mineralization percentages in these incubations. Values for percent C mineralized during the 534-d incubation were 9% for the UCF sediment, 1.3% for the CF sediment, and 0.8% for the peat sediment.

Changes in SRP are depicted in Fig. 5.5.3. For the UCF and CF sediments, SRP values approached 5 mg P L^{-1} concentrations in the porewater. For the peat sediment, SRP levels remained around 1 mg P L^{-1} for most of the incubations. In the UCF sediments, porewater SRP concentrations increased from 1.3 mg P L^{-1} at d = 0 to 4.5 mg P L^{-1} at d = 534. This net increase in SRP concentrations was observed at all incubation temperatures for this sediment. Although SRP concentrations in the CF and peat sediments fluctuated during the 534-d incubation, no net changes in the SRP concentration was observed.

Phosphorus concentrations in the KCl extracts were slightly higher than the SRP observed in the same sediments (Fig. 5.5.4). Increases in soluble P concentrations with the addition of monovalent cations are thought to be associated with the dissolution of Ca-P compounds (see section 4.2 of this report). The elevated concentrations of SRP and KCl extractable P associated with the decomposition of the UCF sediment are potential P inputs to the water column (Syers et al., 1973).

Experiment 2

In Experiment 2, an organic and an inorganic form of N were added to samples of UCF sediment and incubated for 28 d. The concentrations of inorganic and organic N in the porewater of the samples were periodically determined and compared to those of non-amended sediment samples (Figs. 5.5.5-5.5.7).

The amino acid, alanine, was used as the organic N amendment. With this organic N addition, the only significant differences occurred as elevated levels of soluble organic N at time 0 (Fig. 5.5.7). Since this addition had no effect on the

Table 5.5.1. Nitrogen mineralization rates calculated for Lake Apopka sediments incubated under anoxic conditions at various temperatures.

Sediment type	Temperature	N mineralization rate
	——°C——	——mg N L^{-1} d^{-1}——
UCF	35	0.37
	25	0.32
	15	0.26
CF	35	0.09
	25	0.14
	15	0.00
Peat	35	0.05
	25	0.03
	15	0.04

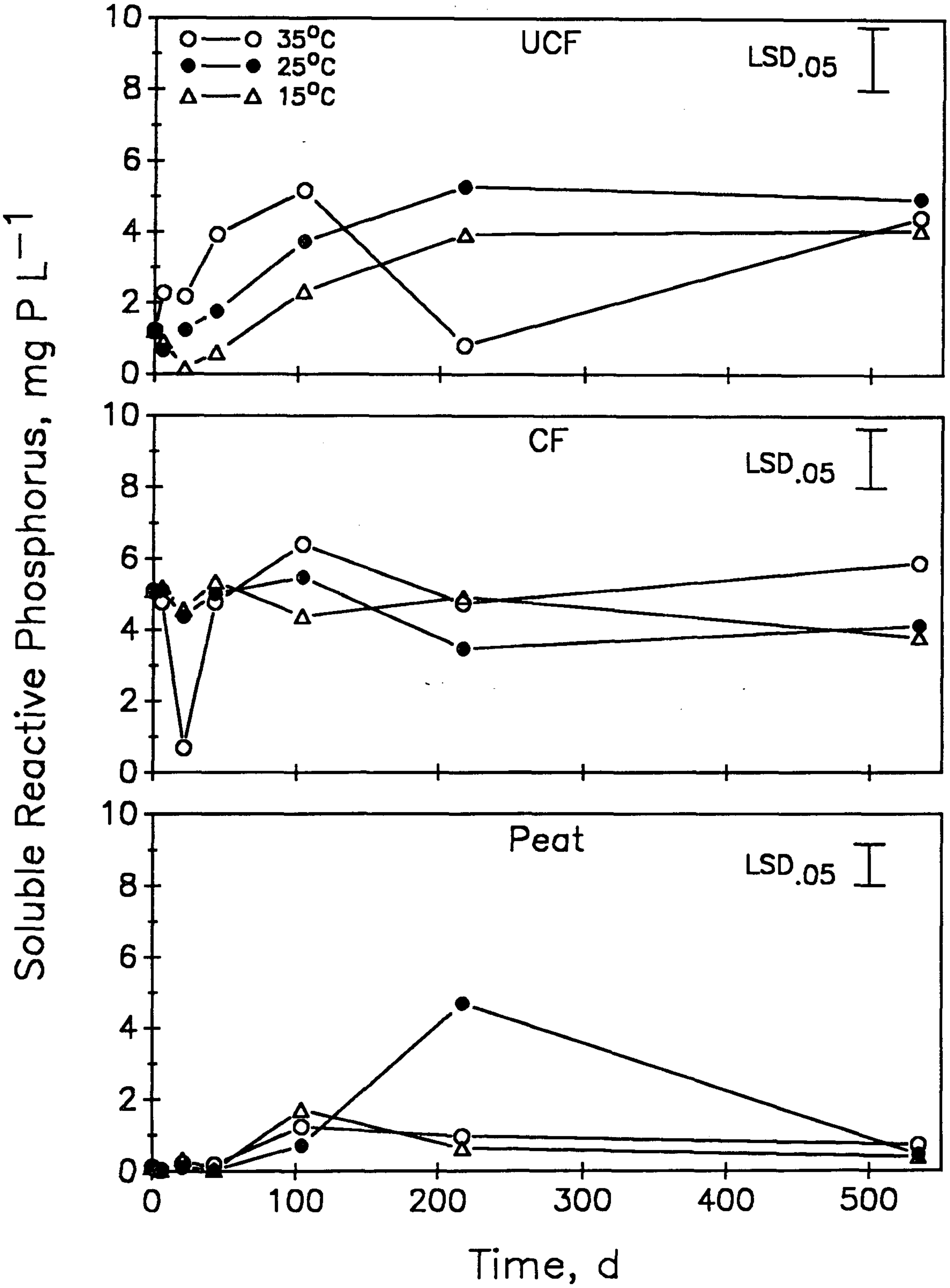

Fig. 5.5.3. Changes in soluble reactive P concentrations with time for Lake Apopka sediments incubated under anoxic conditions at different temperatures.

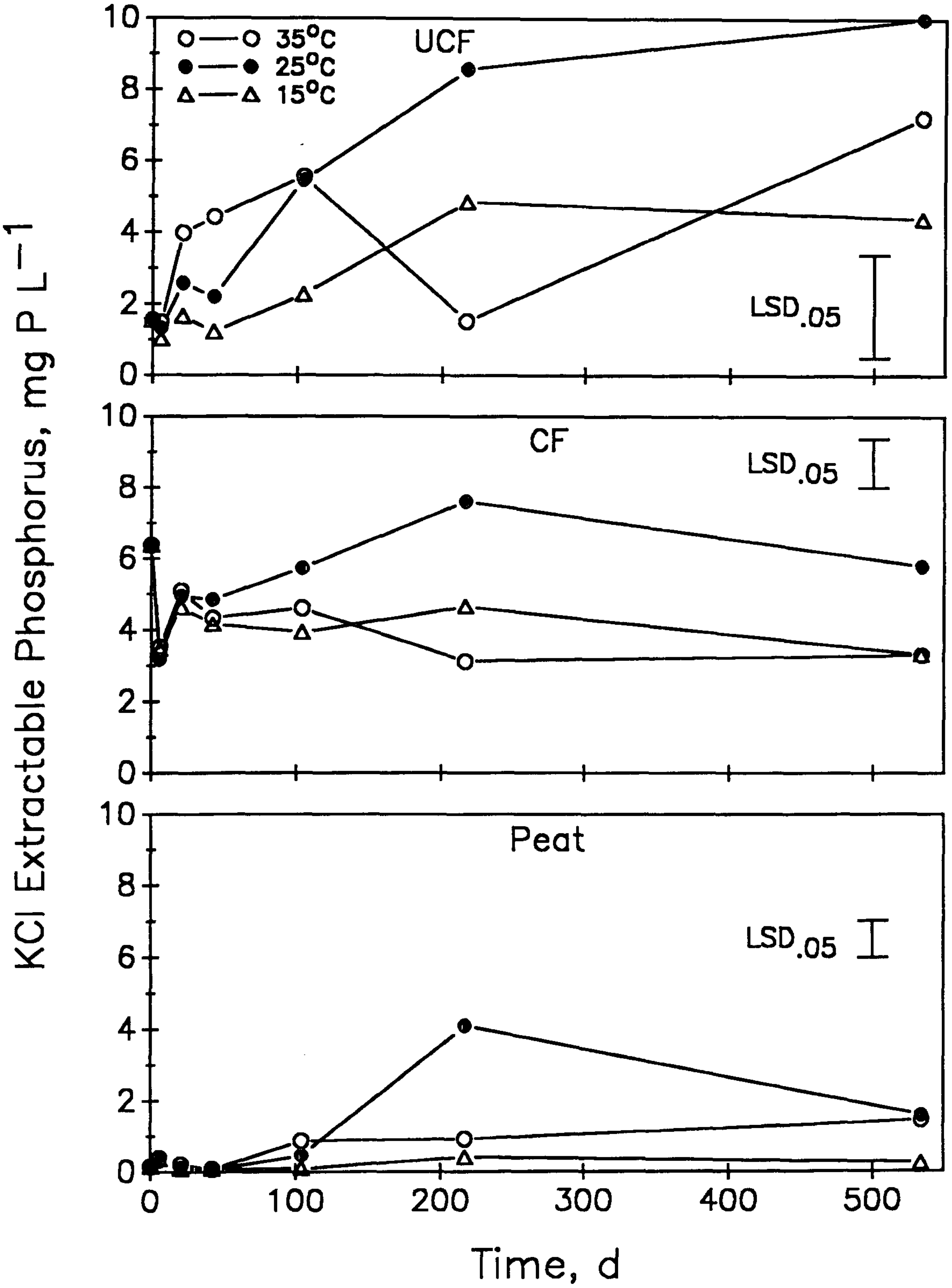

Fig. 5.5.4. Changes in KCl extractable P concentrations with time for Lake Apopka sediments incubated at different temperatures.

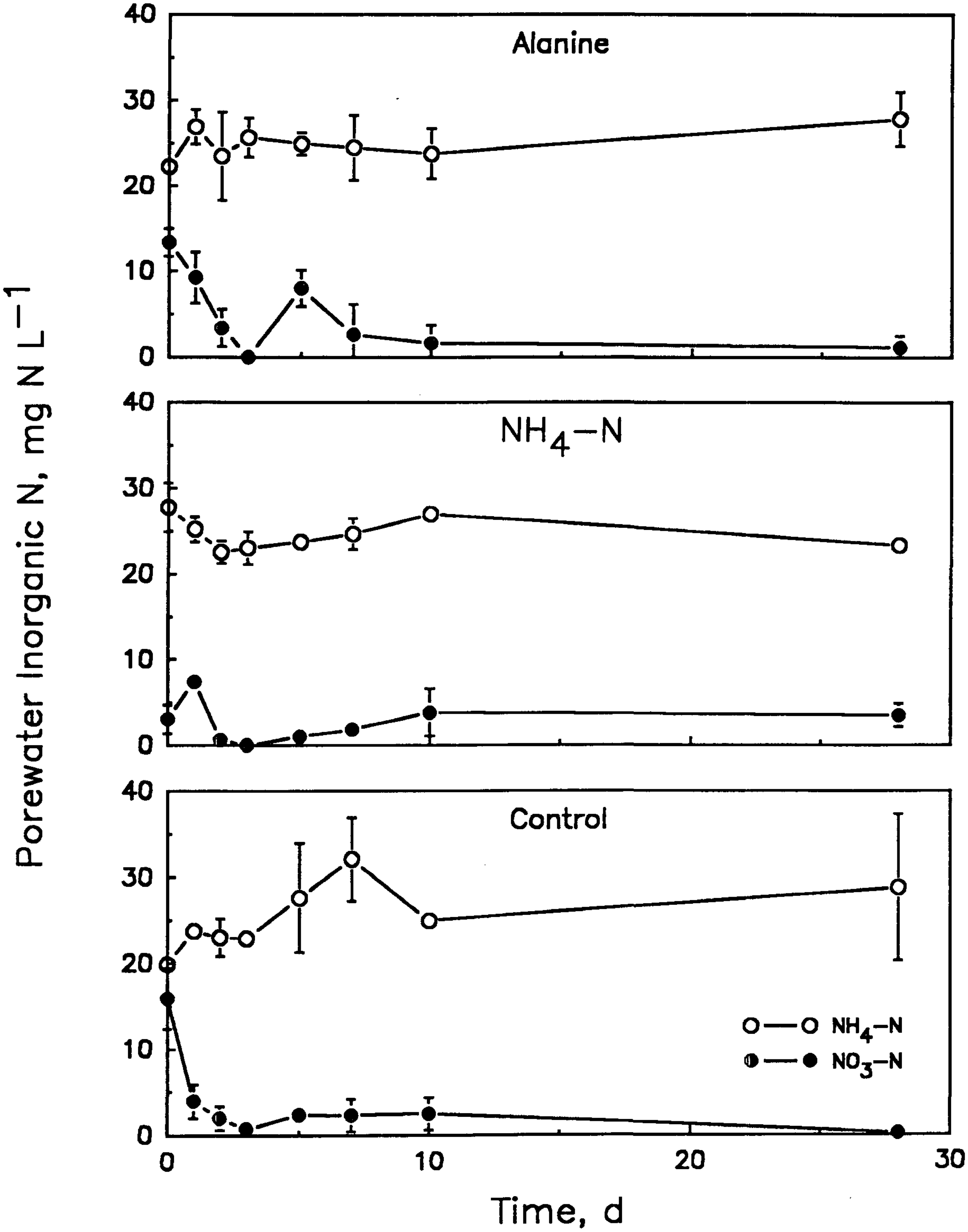

Fig. 5.5.5. Porewater inorganic N concentrations in UCF sediments after addition of N amendments.

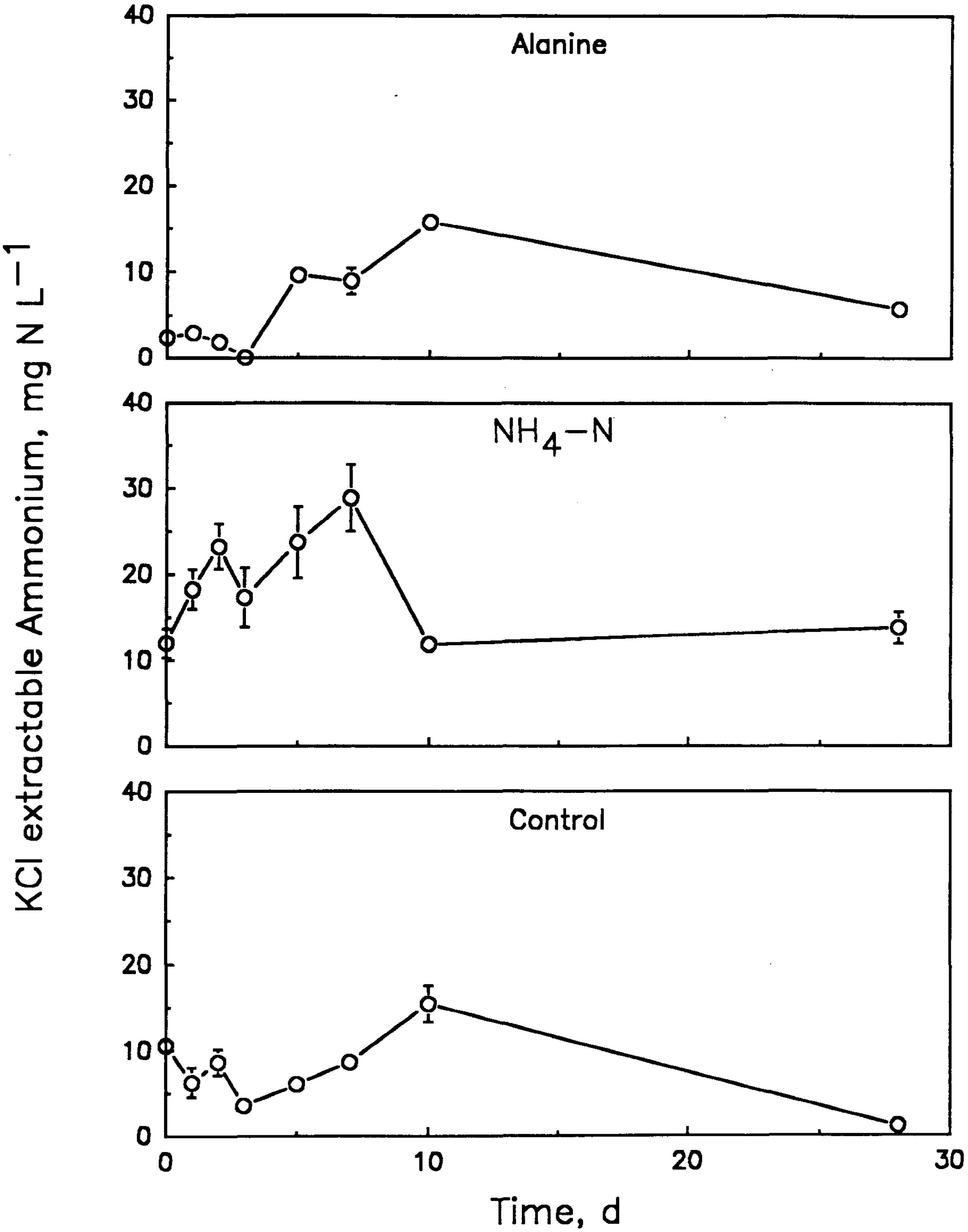

Fig. 5.5.6. Exchangeable ammonium concentrations in UCF sediment samples after receiving additions of N amendments.

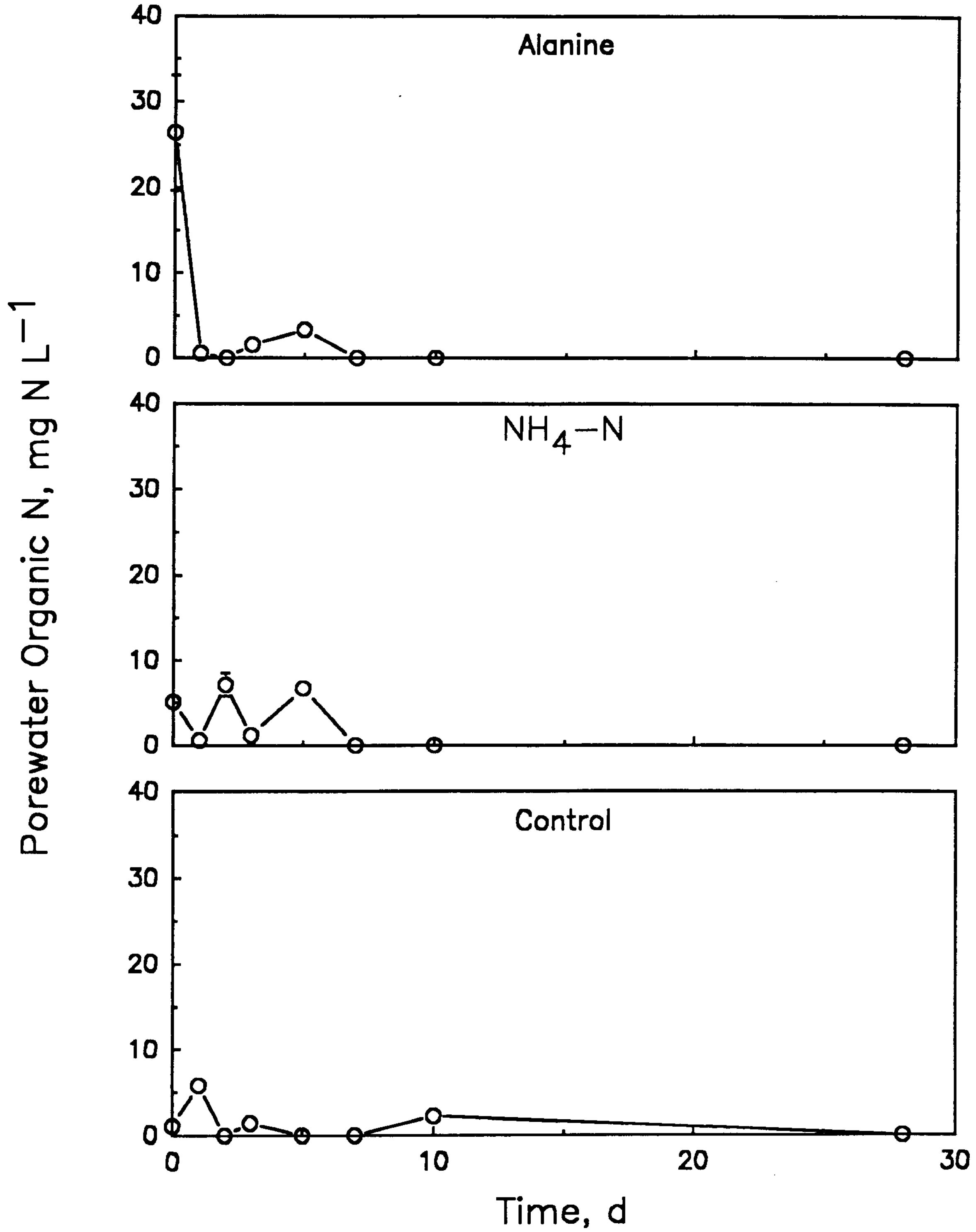

Fig. 5.5.7. Soluble organic N concentrations of UCF sediment incubated after N additions.

inorganic N pools (Figs. 5.5.5 and 5.5.6), this would imply that the amino acid was quickly incorporated into the microbial biomass (Moat, 1979).

In contrast, the addition of NH_4Cl resulted in an initial increase in the porewater inorganic N concentrations (Fig. 5.5.5). However, by day 2, the majority of the added NH_4 could be found in the exchangeable NH_4 fraction (Fig. 5.5.6). These results suggest that elevated NH_4 concentrations could be adsorbed through exchange reactions.

5.5.4 Conclusions

Mineralization of N and P during the anaerobic decomposition of the sediments was studied in these experiments. The N and P mineralized in the UCF sediment were in equilibrium with the water column. Nitrogen mineralization rates in UCF sediments were in the range of 0.26 - 0.37 mg N L^{-1} d^{-1}, in the temperature range of 15-35°C. Thus, N mineralization in the UCF fraction can be a likely nutrient input for the lake. Mineralization in the CF fraction involves more potential loss pathways and as such will contribute less to the nutrient load of the water. The peat sediments were resistent to decomposition, thus their contributions to nutrient loads will be minuscule.

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5.6 Diffusion of Ammonium N in the Sediment-Water Column [Task 3.7]

5.6.1 Introduction

Transport of dissolved nutrients from sediment to an overlying water column is due to: (1) sediment resuspension in the water column, and (2) diffusion and mass flow from the sediment to the water column. Diffusion of ammonium occurs in response to concentration gradients established across the sediment-water interface and plays a significant role in transport of dissolved substrates especially below the zone of bioturbation (Krom and Berner, 1980). The diagenetic models used to describe the transport of dissolved species from sediment to the overlying water column require an accurate estimate of the diffusion coefficient for ammonium N. The purpose of this study was to experimentally measure the diffusion coefficients of ammonium N in Lake Apopka sediments.

5.6.2 Materials and methods

Bulk sediment samples representing UCF and CF fractions were obtained from stations K-6 and B-2 using an Ekman dredge and stored under anoxic conditions at 4°C. Movement of ammonium was measured under two experimental conditions: (1) ammonium movement from sediment to an overlying water column, and (2) ammonium movement within different zones of the sediment. The experimental setup used was similar to the one described in Chapter 5.3, Fig. 5.3.1. This system consisted of two half-cells A and B. The length of each cell was 8 cm and the surface area of the cylinder was 7.6 cm^2.

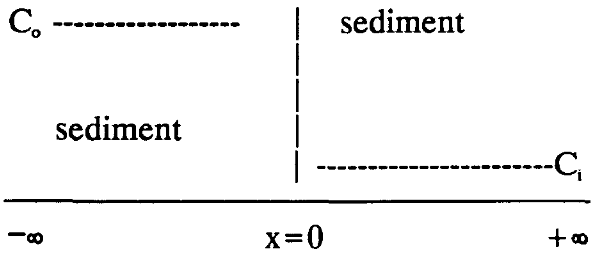
In the first experiment, cell A was packed with sediment, while filtered lake water was placed in cell B. The two cells were separated using a filter paper. The top of cell B was sealed with a Plexiglas plate and purged with a N_2 atmosphere. The sediment-water column was incubated in the dark at 25°C for a period of 72 h. Each treatment was replicated three times. At the end of incubation period, the water column in cell B was pipetted at 1 cm depth increments, while the sediment in cell A was sectioned at 1 cm depth increments. Sediment sections were transferred into 50-mL tubes and centrifuged at 5000 rpm for 15 min. Supernatant porewater was removed and acidified and stored under freezing conditions until analyzed. The residual sediment was treated with 1 M KCl, and mechanically shaken for 1 h, and then filtered. The filtered solutions were acidified and stored under freezing conditions until analyzed.

A second experiment measured ammonium diffusion within the sediment. The experimental set-up was similar to the one described above. Cell A was packed with sediment enriched with a known ammonium concentration, while cell B was packed with sediment with no added ammonium N. Each treatment was replicated three times and incubated for a period of 72 h in the dark at 25°C. At the end of the incubation period, sediments from each cell were sectioned at 1 cm depth increments and analyzed as described previously.

In independent experiments, ammonium adsorption coefficients were measured on the same sediments; these experiments are described in Chapter 5.7.

Governing diffusion equations:

Case I. Diffusion of ammonium N in different horizons of the sediment.



At t = 0 $\quad C = C_o \quad x < 0$
$\qquad\qquad\quad C = C_i \quad x > 0$

At all times $\quad C = C_o \quad x = -\infty$
$\qquad\qquad\qquad C = C_i \quad x = \infty$

The basic diffusion equation for this system is (Crank, 1956; Rao et al., 1984):

$$(\theta + \rho K_d) \frac{\partial C}{\partial t} = D\theta \frac{\partial^2 C}{\partial x^2} \qquad [1]$$

where:

C = solution concentration, $\mu g\ mL^{-1}$
θ = volumetric water content, $mL\ cm^{-3}$
ρ = bulk density, $g\ cm^{-3}$
K_d = partition coefficient, $mL\ g^{-1}$
D = diffusion coefficient, $cm^2\ d^{-1}$
x = distance, cm
t = time, d

Ammonium adsorption in the sediment was assumed to follow the linear relationship:

$$S = K_d C \qquad [2]$$

where S = ammonium adsorbed, $\mu g\ g^{-1}$.

Let the retardation factor, $R = (1 + \frac{\rho K_d}{\theta})$ [3]

then equation [1] can be written as

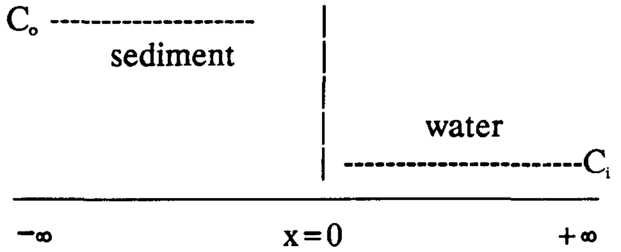
$$\frac{\partial C}{\partial t} = \frac{D}{R}\frac{\partial^2 C}{\partial x^2} \qquad [4]$$

Using the solutions presented by Crank (1956, p. 13-14), equation [4] can be transformed into:

$$C = (\frac{C_o - C_i}{2}) \text{ erfc } (\frac{x}{2\surd(D/R\ t)}) + C_i \qquad [5]$$

where erfc is the complentory error function (Crank, 1956, p. 14). Ammonium solution concentrations and x data obtained from the experiments can be fitted to equation [5] to yield D/R. Using the K_d value (obtained from separate experiments), D can be estimated.

Case II: Diffusion of ammonium nitrogen from sediment to overlying water column.



The basic diffusion equations for this system are as follows:

Sediment

$$\frac{\partial C_s}{\partial t} = \frac{D_s}{R}\frac{\partial^2 C_s}{\partial x^2} \qquad [6]$$

$t = 0$ $\qquad C_s = C_o$
$x = -\infty$ $\qquad C_s = C_o$

Water

$$\frac{\partial C_w}{\partial t} = D_w \frac{\partial^2 C_w}{\partial x^2} \qquad [7]$$

$t = 0$ $\qquad C_w = C_i$
$x = \infty$ $\qquad C_w = C_i$
At $x = 0$ $\qquad C_s = C_w$

where:

C_s = sediment porewater concentration, μg mL^{-1}
C_w = concentration in the water column, μg mL^{-1}
D_s = sediment-diffusion coefficient, cm^2 d^{-1}
D_w = water-diffusion coefficient, cm^2 d^{-1}

Using the solutions presented by Crank (1956, pp. 38-39), equation [6] and [7] can be transformed into:

$$C_w = \frac{C_o - C_i}{1 + \frac{1}{\theta R} \frac{\sqrt{D_w}}{\sqrt{(D_s/R)}}} \operatorname{erfc}\left(\frac{x}{2\sqrt{(D_w t)}}\right) + C_i \qquad [8]$$

$$C_s = \frac{C_o - C_i}{1 + \frac{1}{\theta R} \frac{\sqrt{D_w}}{\sqrt{(D_s/R)}}} \left[1 + \frac{1}{\theta R} \frac{\sqrt{D_w}}{\sqrt{(D_s/R)}} \operatorname{erf}\left(\frac{-x}{2\sqrt{(D_s/R\ t)}}\right)\right] + C_i \qquad [9]$$

where, C_w and C_s obtained from the experimental data can be fitted to equations [8] and [9] with the SAS non-linear program (SAS Institute Inc., 1982) to yield D values for water and sediment.

5.6.3 Results and discussion

5.6.3.1 Ammonium diffusion from sediment to the overlying water column:

Dissolved NH_4^+ profiles in the sediment (Stations B-2 and K-6) and the water column after 72 h of diffusion are presented in Fig. 5.6.1. The two diffusion profiles were very similar; however, D_s estimated for NH_4^+ from Eqs. [8] and [9] for the B-2 sediment was almost twice that for the K-6 sediment (Table 5.6.1). An average retardation factor, R, of 1.24 (K_d = 7.05 mL g^{-1}) was used in all calculations of D_s.

The diffusion of NH_4^+ into the overlying lake water (D_w) resulted in similar diffusion profiles for the two sediments (Fig. 5.6.1). Values of D_w for NH_4^+ (Table 5.6.1), however, were 25 to 30% lower than those reported in the literature (i.e., 1.71 cm^2 d^{-1} by Li and Gregory (1974) at 25°C).

5.6.3.2 Ammonium diffusion in the sediment:

Dissolved NH_4^+ profile when one cell was enriched with 40 mg L^{-1} NH_4^+ for the K-6 sediment is presented in Fig. 5.6.2. The average D_s value was 1.47 ± 0.21 cm^{-2} d^{-1}, which is higher than those obtained when NH_4^+ diffusion was measured from the sediment to the water column.

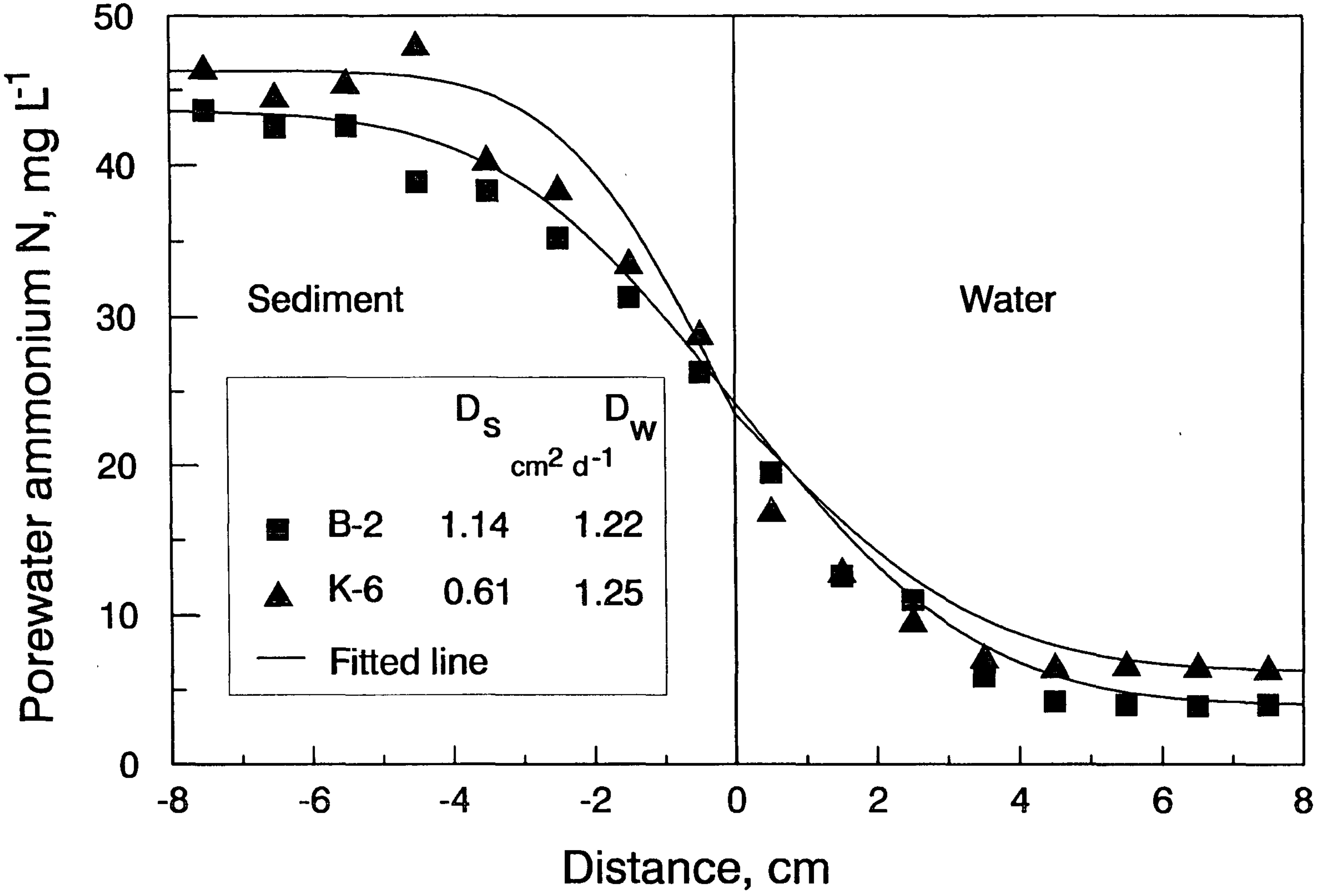


Fig. 5.6.1. Concentration profiles of porewater ammonium N in anoxic sediments and the overlying water column.

Table 5.6.1. Average diffusion coefficients (±SE) for ammonium measured in sediments and lake water.

	D_s cm^2 d^{-1} (95% CI)	D_w cm^2 d^{-1} (95% CI)
Sediment-Water Diffusion:		
B-2	1.14±0.23 (0.65-1.64)	1.22±0.24 (0.71-1.74)
K-6	0.61±0.20 (0.19-1.03)	1.25±0.46 (0.26-2.23)
Sediment-Sediment Diffusion:		
K-6 40 mg L^{-1}	1.47±0.21 (1.02-1.92)	

R = 1.25
θ = 0.964 mL cm^{-3}
ρ = 0.033 g cm^{-3}
K_d = 7.05 mL g^{-1}

where R = retardation factor
θ = water content
ρ = bulk density
K_d = partition coefficient

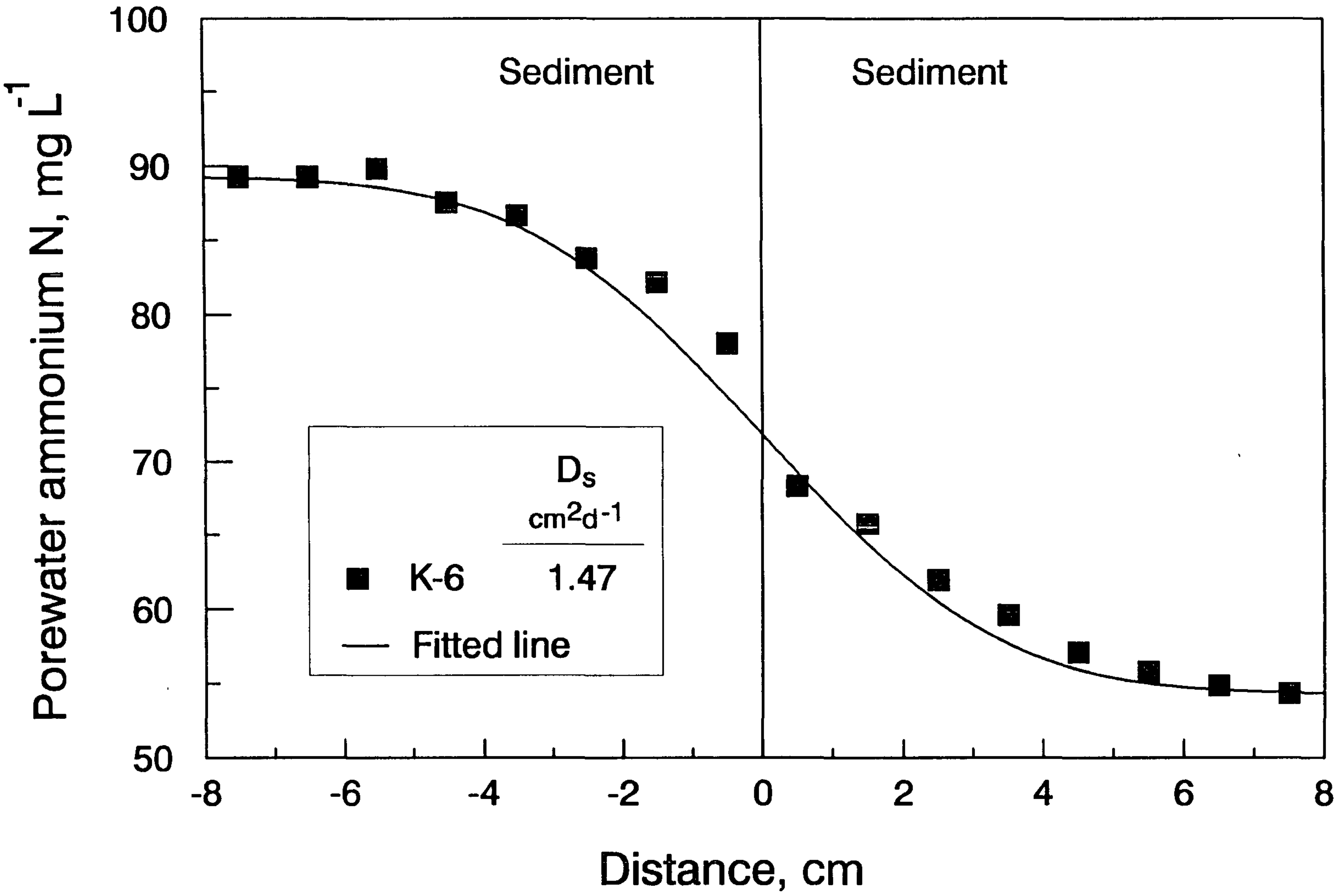


Fig. 5.6.2. Concentration profiles of porewater ammonium in the sediment column. Ammonium diffusion measured within the sediment column by spiking one half of the sediment with 40 mg NH_4-N L^{-1}.

Values of D_s for NH_4^+ in marine sediments were 0.84 ± 0.17 $cm^2\ d^{-1}$ at 20°C (Krom and Berner, 1980), a value comparable with those obtained in the B-2 sediment and the K-6 sediment-water experiment. For mineral silt loam flooded soils, Reddy et al. (1980) have measured a much lower D value in the range of 0.06 - 0.216 $cm^2\ d^{-1}$. Differences in experimental setup and analyses, temperature, ionic environment, and sediment type, however, may account for the differences between the higher D_s values from this study and that of Krom and Berner's study.

In Lake Apopka sediments, molecular diffusion of NH_4^+ plays a significant role in transporting NH_4^+ from the sediment to the water column. The D_s values developed can be used to calculate the flux of NH_4^+ from the sediment to the overlying water. The D_s values presented in this study have shown considerable variability. Some of the factors influencing D_s values include: ionic strength of porewater, cation exchange capacity of sediments, adsorption coefficients, temperature and microbial processes associated with the breakdown of organic matter. Further studies are needed to elucidate the influence of these factors on D_s in Lake Apopka sediments.

5.6.4 Conclusions

The diffusion coefficients (D_s) of NH_4^+ ions were determined for bulk sediments (UCF and CF) obtained from K-6 and B-2 stations of Lake Apopka. The estimated D_s values were in the range of 0.6 - 1.47 $cm^2\ d^{-1}$, showing considerable variability. The D_s values were adjusted for the effects of adsorption of NH_4^+, by using K_d (adsorption coefficients) determined in independent experiments for the same sediments. The diffusion coefficients (D_w) of NH_4^+ in the overlying water column of the sediments was 1.22-1.25 $cm^2\ d^{-1}$. The published D_w of NH_4^+ in water at infinite dilution was 1.71 $cm^2\ d^{-1}$ (at 25°C). The D_s and D_w values in the sediment-water column were probably influenced by ionic strength of the porewater along with associated biogeochemical processes. The D_s is an important parameter needed in diagenetic models to predict the NH_4^+ concentration profiles and to quantitatively describe the internal cycling of NH_4^+ in the sediment-water column.

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5.7 Ammonium Adsorption by Sediments [Task 3.8]

5.7.1 Introduction

Anaerobic sediments are characterized by the accumulation of NH_4-N, an end product of organic N mineralization. Mineralization of organic N under anaerobic environments is governed by the type and chemical composition of organic matter and the availability of electron acceptors. Ammonium N formed is present in: (1) water soluble form, primarily in porewater, (2) exchangeable fraction, NH_4^+ adsorbed on cation exchange complex, and (3) fixed in clay lattice. In Lake Apopka, sediment NH_4^+ is primarily present in the first two fractions, and clay fixed NH_4^+ is not significant in this organic-rich sediment.

The ability of anaerobic sediments to retain NH_4-N depends on physicochemical characteristics of the sediments and associated N transformations. It has been shown that NH_4-N added at concentrations considerably greater than those present in the sediment porewater can be retained on the cation exchange complex of the sediment. Ammonium present in adsorbed phase is in reversible equilibrium with the NH_4^+ present in the porewater. The ratio of NH_4^+ adsorbed to NH_4^+ in porewater is the adsorption coefficient which is controlled by sediment physicochemical properties such as organic matter content, pH, cation exchange capacity, intensity of soil reduction, and concentration of other cations.

The cation exchange complex of calcareous lake sediments such as Lake Apopka is generally dominated by calcium and magnesium. Under these conditions, NH_4^+ may not be the major cation occupying the exchange complex. At ambient NH_4^+ concentration for marine sediments, NH_4^+ adsorption behavior was shown to follow a linear, reversible, equilibrium isotherm (Rosenfeld, 1979; Berner, 1977; Boatman and Murray, 1982; Mackin and Aller, 1984). Since the movement of NH_4^+ is controlled by the adsorption and desorption processes, it is critical to determine the adsorption coefficients in order to determine the transport of NH_4^+ in the sediment-water column.

The objectives of this study were to determine: (1) adsorption coefficients under oxic and anoxic conditions of sediments, (2) adsorption coefficients as function of depth, and (3) rate of desorption of adsorbed NH_4^+.

5.7.2 Materials and methods

Bulk surface sediments (unconsolidated fraction) obtained at the K-6 station were used in batch incubations, while intact sediment cores obtained from F-6 station were used to determine adsorption coefficients as a function of depth.

For the batch experiments, sediments from K-6 were pre-incubated in stirred reactors (similar to the experimental set up described in Chapter 5.1) to obtain oxidized (Eh = 550 mV) or reduced (Eh = -250 mV) conditions.

A known amount of oxidized or reduced sediment was placed into centrifuge tubes (three replications) and flooded with filtered lake water containing one of several levels of NH_4^+ (0, 50, 100, 200, 500 and 1000 mg L^{-1}) as NH_4Cl. The tubes were capped and placed on a mechanical shaker for a 24 h equilibration period. Sediment samples were then centrifuged at 5000 rpm for 15 min, and the supernatant liquid was filtered through 0.45 μm filter paper. Filtered solutions were analyzed for NH_4-N. Ammonium not recovered in solution was assumed to be sorbed by the sediment.

Anaerobic sediments not amended with additional NH_4^+ were used in the desorption study. Initial porewater was removed by centrifuging a known amount of sediment as described above. After initial removal of porewater, the residual sediment was treated with filtered (0.45 μm) Lake Apopka water to attain the initial sediment-water ratio. The sediment suspensions were shaken on a mechanical shaker for a period of one hour, followed by centrifugation at 5000 rpm for 15 min and removal of supernatant liquid. The residual sediment was then treated with filtered lake water as described above for an additional 5 cycles. Filtered solutions and the lake water used in the extractions were analyzed for NH_4-N.

Ammonium sorbed by the sediment was calculated as follows:

$$[(C_o \cdot V) - (C_t \cdot V)] / M = S \qquad [1]$$

where:

C_o = concentration of NH_4^+ added, mg L^{-1}
C_t = concentration of NH_4^+ in solution after 24-h equilibration, mg L^{-1}
V = volume of liquid, L
M = mass of dry sediment, mg kg^{-1}
S = ammonium N retained by solid phase, mg kg^{-1}

The above equation does not take into account the amount of native sediment NH_4^+ present in the adsorbed phase. The total amount of NH_4^+ sorbed by the sediment can be calculated as follows:

$$S = S^1 + S_o \qquad [2]$$

where:

S = total amount of NH_4^+ sorbed, mg kg^{-1}
S^1 = amount of added NH_4^+ sorbed, mg kg^{-1}
S_o = initial sediment NH_4^+ present in sorbed phase, mg kg^{-1}

The S_o can be estimated using a least squares fit of S^1 measured at low equilibrium concentrations, C. At these concentrations, the relationship between S^1 and C was found to be linear, and can be described by the following equation.

$$S^1 = KC - S_o \qquad [3]$$

where:

S_o = the y axis intercept-representing the initial sediment NH_4^+ present in the adsorbed phase, mg kg^{-1}
C = ammonium in solution, mg L^{-1}
K = linear adsorption coefficient, L kg^{-1}

The sum of $(S^1 + S_o)$ as shown above represents the actual amount of NH_4^+ adsorbed at respective equilibrium NH_4^+ concentrations.

Adsorption parameters can be obtained by fitting the data to the following Freundlich adsorption isotherm equation:

$$S = K\,C^{1/n} \qquad [4]$$

where:

S = $(S^1 + S_o)$, mg kg^{-1}
K = adsorption coefficient, L kg^{-1}
C = solution NH_4^+ concentration measured after 24-h equilibration period, mg L^{-1}

Equation [4] is written in linear form as:

$$\log S = 1/n\,(\log C) + \log K \qquad [5]$$

Least squares fit of log S vs log C should yield a straight line with intercept, log K, and slope 1/n. At ambient NH_4^+ concentrations in the porewater of lake sediments, the adsorption process may follow simple linear, reversible equilibrium isotherms. Under these conditions, the exponent in equation [4] will be unity, resulting in the following simple relationship:

$$S = KC \qquad [6]$$

where the parameters S, C and K are the same as described in equation [4].

In a separate experiment, three intact sediment cores were obtained from station F-6 using a core sampler and transported to the laboratory. Sediment cores were extruded using a piston, and sectioned at depth increments of 0-2, 2-4, 4-8, 8-12, 12-16, 16-20, 20-25, 30-40, and 50-60 cm. Sectioned fractions of the sediment were immediately transferred into centrifuge tubes fitted with rubber septa. The tubes were purged with N_2 and centrifuged at 5000 rpm for 15 min at 15°C. Supernatant porewater was removed, acidified and frozen until analyzed. Residual sediment was homogenized and treated with 2 M KCl to obtain a wet sediment to solution ratio of 1:10. The samples were placed on a mechanical shaker and shaken for a period of one hour. This procedure was followed by filtration of the sediment suspension through Whatman #42 filters. Filtered solutions were acidified and frozen until analyzed. The concentration of NH_4^+ in the porewater was expressed in the units of mg L^{-1}, while NH_4^+ present on solids (exchangeable fraction) was expressed as mg NH_4-N kg^{-1} of dry sediment. Ammonium in the porewater and KCl extractions were analyzed using an autoanalyzer using the methods described in Table 3.1 (see Chapter 3).

The ratio between NH_4^+ concentration in the porewater (mg L^{-1}) and the exchangeable NH_4^+ as determined in KCl extracts (mg kg^{-1}) was calculated by using simple linear regression (see equation [6]). The resulting K values were plotted as a function of depth.

5.7.3 Results and discussion

Ammonium adsorption could be equally well described by Freundlich and linear isotherms (Table 5.7.1). The adsorption coefficient (K = volume of porewater/mass of dry weight of sediment) was found to be higher under oxic (aerobic) sediments than anoxic (anaerobic) sediments. Low K values under anaerobic conditions were probably due to the influence of other cations such as reduced Fe^{2+} and Mn^{2+}. At low NH_4^+ concentrations (< 50 mg L^{-1}, similar to those observed in sediments), the adsorption coefficients were the same (Fig. 5.7.1) under both aerobic and anaerobic conditions.

Repeated extraction of sediments resulted in the removal of more than 90% of soluble NH_4^+ in the first two extractions (Fig. 5.7.2). The concentration of NH_4^+ in sediment porewater before extraction was 29 mg L^{-1}. After five sequential extractions with filtered lake water, the concentration of NH_4^+ decreased to 0.31 mg L^{-1}, suggesting rapid mobility of NH_4^+ in these sediments. Ammonium desorption potential of these sediments have important implications, when these sediments are resuspended into the overlying water column. It is likely that during sediment resuspension, sediment bound NH_4^+ is rapidly released into the water column.

Soluble (porewater NH_4^+) and exchangeable NH_4^+ (KCl-extractable) of sediments showed similar trends as a function of depth (Fig. 5.7.3). Sediment porewater NH_4^+ levels were generally lowest at the surface and increased with depth to 20 cm. The concentrations remained constant or decreased below this level at depths > 20 cm. Exchangeable NH_4^+ also followed generally the same trend. Similarities in the profiles of soluble and exchangeable NH_4^+ of the sediments supports the linear reversible equilibrium isotherm presented in Table 5.7.1 and Figure 5.7.1. Steep gradients in soluble and exchangeable NH_4^+ is due to steady upward diffusion into the overlying water column where it is oxidized to NO_3^- or assimilated by algae. Low NH_4^+ levels at lower depth (> 20 cm) was due to high C/N ratio of sediment organic matter and slower decomposition rates as a result of low levels of electron acceptors, low microbial population and biologically resistant organic matter. Results presented in Chapter 5.2 indicate that the decomposition rates of sediment organic matter are higher in surface sediments as compared to

Table 5.7.1. Ammonium adsorption parameters for Lake Apopka sediment.

	Freundlich			Linear	
Sediment	K	1/n	r^2	K	r^2
	L kg^{-1}			———L kg^{-1}———	
Aerobic	15.49	0.909	0.973	7.75	0.861
	±1.26	±0.088		±0.88	
Anaerobic	12.94	0.904	0.982	6.89	0.975
	±1.19	±0.070		±0.34	

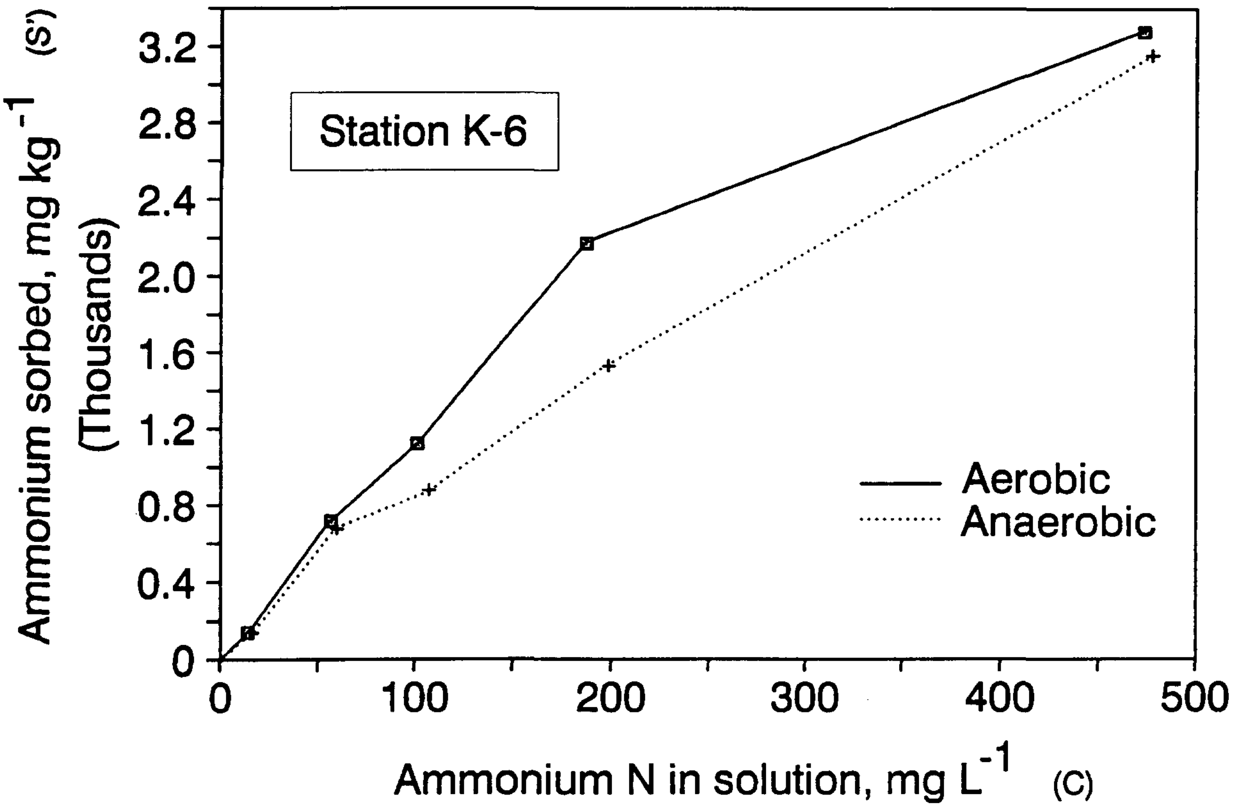

Fig. 5.7.1. Ammonium adsorption isotherms under aerobic (oxidized) and anaerobic (reduced) conditions of UCF sediments. Batch incubation experiment with equilibration period of 24 h.

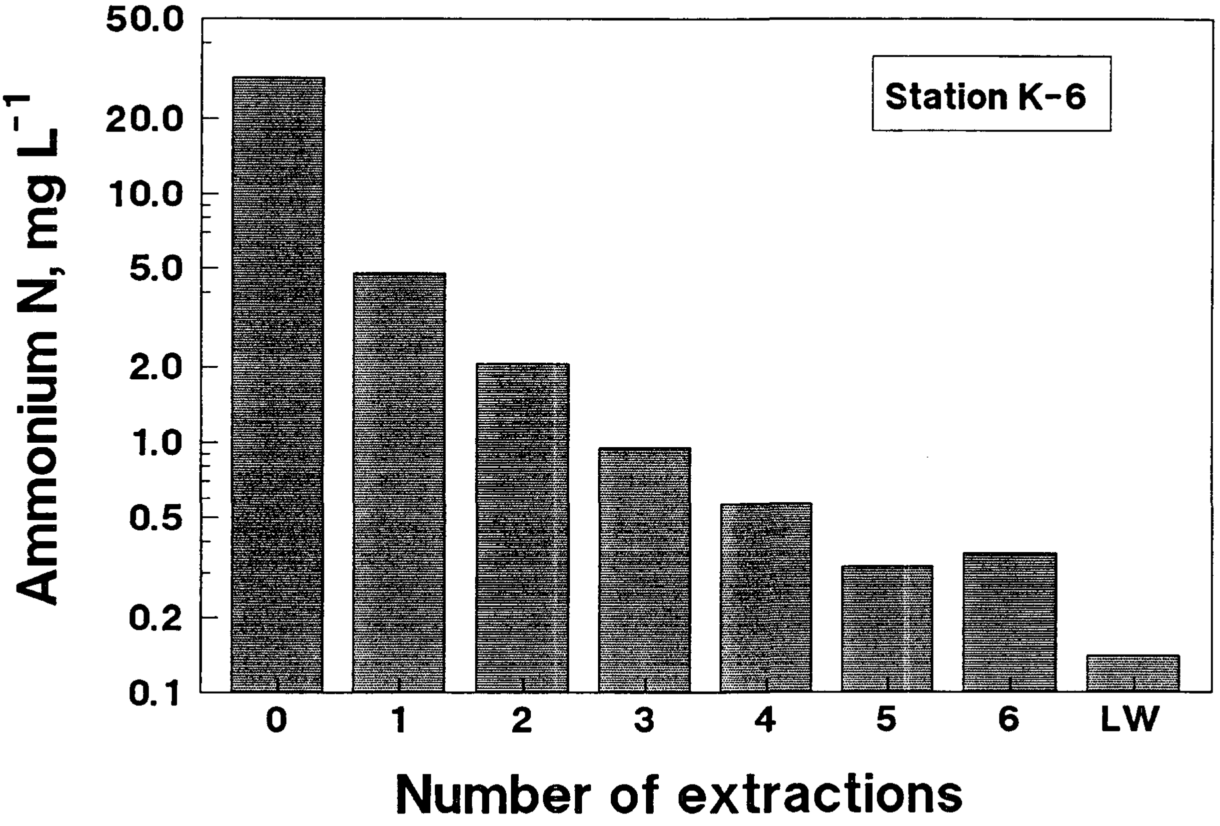

Fig. 5.7.2. Ammonium desorption by UCF sediments under anaerobic (reduced) conditions, as determined by repeated extractions.

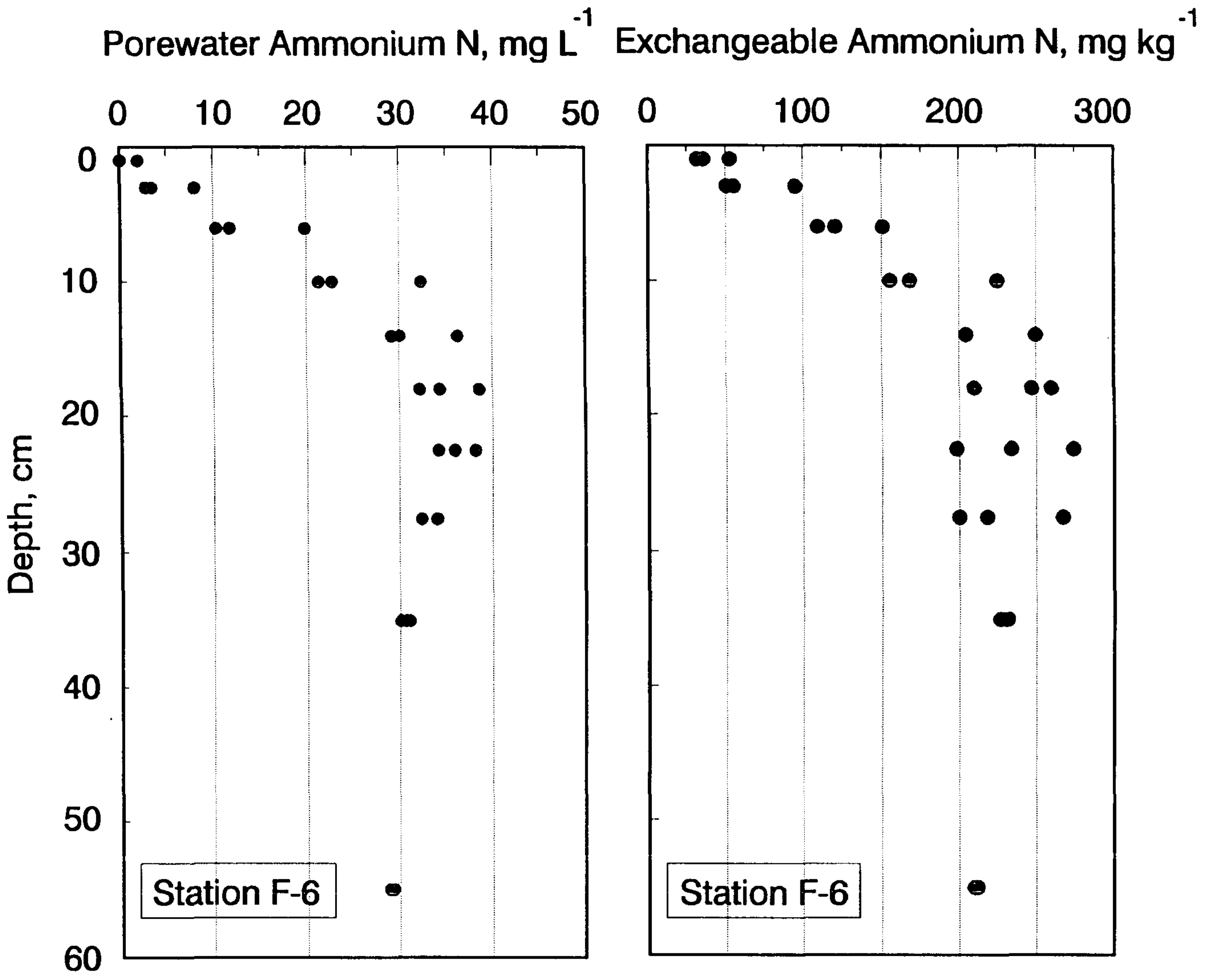

Fig. 5.7.3. Porewater and exchangeable NH_4^+ as a function of depth in intact cores obtained from station F-6 on July 10, 1989. Data points are from three intact cores.

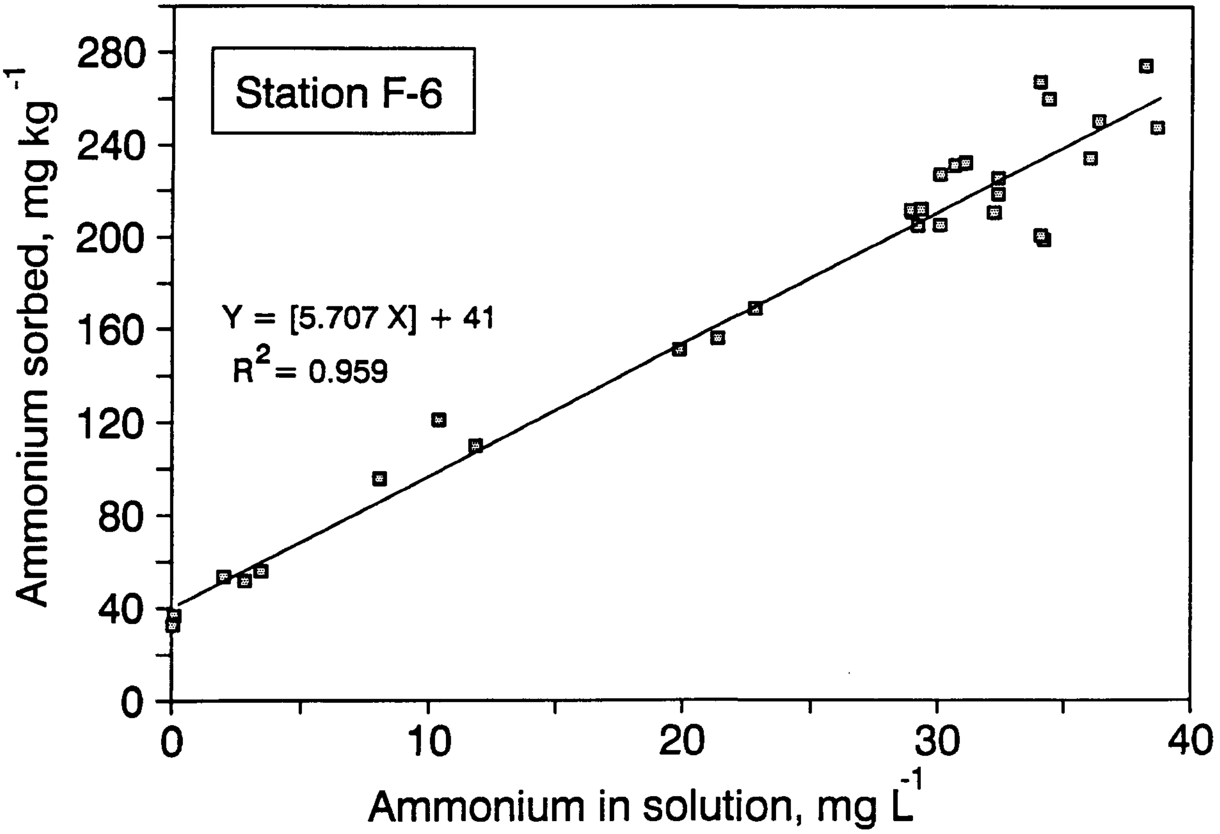

Fig. 5.7.4. Relationship between porewater NH_4^+ and exchangeable NH_4^+ of intact sediment cores obtained from station F-6 on July 10, 1989.

sediments obtained from lower depths. The sediment organic matter in surface layers is readily decomposable, thus can be subjected to rapid rate of decomposition.

A wide range in K ratio between exchangeable NH_4^+ and soluble NH_4^+ values (26 to 479 L kg^{-1}) were noted for replicate cores in the surface 0-2 cm depth followed by an exponential decrease in K values up to a depth of 10 cm. Below this depth, K values remained constant. Although rapid desorption of NH_4^+ can occur from surface sediments, it is apparent the NH_4^+ adsorptive capacity of surface sediments is higher than the sediments at lower depths, especially in the surface 1 cm depth. The adsorptive capacity of sediments below 1-cm depth were found to be relatively constant.

A linear relationship between porewater NH_4^+ and exchangeable NH_4^+ (data from Fig. 5.7.3) presented in Fig. 5.7.4 confirms the earlier data presented on linear isotherms. Best fit of the data was observed for the regression equation with an intercept value of 41 mg kg^{-1}. The NH_4^+ in the sorbed phase at zero concentration of porewater NH_4^+ can be assumed to be nonexchangeable NH_4^+ (Rosenfeld, 1979; Mackin and Aller, 1984). The K values obtained for Lake Apopka sediments were generally higher than those observed for marine sediments. For example, Mackin and Aller (1984) reported values in the range of 0.75 - 49 L kg^{-1} for marine sediments, while Rosenberg (1979) reported values in the range of 1.07 - 6.68 L kg^{-1}.

5.7.4 Conclusions

The results of this study indicate that the ability of sediments to adsorb NH_4^+ as determined by K (NH_4^+ in exchangeable fraction/porewater NH_4^+) was stronger under aerobic (oxidized) than anaerobic (reduced) conditions. More than 90% of soluble NH_4^+ was easily desorbable. The higher the K value, the stronger the NH_4^+ adsorption. Results presented in this study show that K values are depth dependent, especially in the surface sediments (<10 cm). The adsorption/desorption characteristics of the surface sediments need further investigation. The sorption characteristics of the surface sediments have important implications when sediments are resuspended into the water column during wind events. High adsorption capacity of surface sediments was probably also due to relatively less reduced conditions than deeper depths. It is critical to determine the redox potential or dissolved O_2 concentrations of the surface sediments, which may help to explain why surface sediments have higher adsorption capacities. Ammonium diffusing from lower depths can be readily retained by surface sediments, thus reducing overall NH_4^+ flux to the overlying water column.

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5.8 Fate of Inorganic Nitrogen in the Sediment-Water Column [Task 3.9]

5.8.1 Introduction

Nitrogen is one of the major elements that regulates the eutrophication of lakes and streams. Nitrogen is loaded to the system through external sources (point and nonpoint) and internal sources. Internal sources include: dinitrogen fixation in the water column and diffusion and mass flow of soluble N from the sediment to the overlying water column. Underlying organic-rich lake sediments can function as a source by releasing soluble N species into the overlying water or as a sink by assimilating inorganic N species diffusing from the overlying water to the sediments.

The objective of this study was to quantitatively evaluate selected N transformations influencing the fate of added inorganic N in the sediment-water column of Lake Apopka. These processes were evaluated in a series of batch incubation experiments.

5.8.2 Materials and methods

Intact sediment columns were obtained from K-6 and also a station near pumphouse #2 of Lake Apopka using the sediment core sampler. The bottom portion of the Plexiglas columns were sealed with a rubber stopper and transported to the laboratory. Sediment cores obtained from the K-6 station were extruded using a plunger to separate the upper unconsolidated, flocculent sediment. For sediment cores obtained from the pumphouse station, the upper unconsolidated sediment was removed and the underlying peat fraction was used in the following studies. These two fractions were placed in a cooler and transported to the laboratory and stored at 4°C until used. A description of each experiment is given below.

5.8.2.1 Fate of floodwater inorganic N:

This study was designed to evaluate the floodwater NH_4^+ and NO_3^- assimilation by the underlying sediment. Intact sediment columns obtained from Lake Apopka were placed in an incubator maintained at 28°C, and allowed to equilibrate for a period of 48 h. After this period, four columns were batch fed with 2.5 mg N L^{-1} wk^{-1} (5 μg N cm^{-2} d^{-1}) enriched with 99 atom % ^{15}N as NH_4Cl, while the second set of four columns was treated with 2.5 mg N L^{-1} wk^{-1}, enriched with 99 atom % ^{15}N as KNO_3. The floodwater in each column was continuously aerated with 15 mL min^{-1} ambient air. The sediment-water columns were incubated for a period of 10 weeks. At the end of incubation, the floodwater was removed, acidified, and frozen until analyzed for inorganic N. Sediment was extruded from the core, and sectioned into various depth increments. A known amount of the sectioned sample was extracted with 2 M KCl solution and filtered through Whatman #42 filter paper. Filtered solutions were acidified and frozen until analyzed. The residual sediment was dried at 60°C, ground and analyzed for total and labelled N content. Total N was analyzed by the procedures described by Bremner and Mulvaney (1982). Labelled N was determined using isotope ratio mass spectrometer (Hauck, 1982).

5.8.2.2 Fate of ammonium N in the sediment:

Two batch incubation experiments were conducted to determine the fate of NH_4 added to sediments. In the first experiment, $^{15}NH_4$-Cl (2.66 mg N bottle^{-1} enriched with 99 atom % ^{15}N) was added to either UCF or peat sediment contained in 125 mL serum bottles. All bottles were fitted with rubber septa and purged with N_2 gas to create anoxic conditions. In the second experiment, $^{15}NH_4Cl$ (as above) was added to UCF sediment contained in wide-mouth bottles. The sediment was then flooded with lake water to a depth of 5 cm and left open to the atmosphere.

For each experiment, 18 identical samples were set up. After incubation for 0, 7, 15, 30, 60 and 120 days in the dark at 28°C, triplicate samples were extracted with 2 M KCl. After filtration through Whatman #42 filter paper, extracts were acidified and frozen until analyzed for inorganic N. The residual soil, after extraction, was dried at 70°C and analyzed for total N content. All samples (extracts and residual soil) were analyzed for ^{15}N content as described above.

5.8.2.3 Fate of nitrate N in the sediment:

This study was designed to determine the fate of added NO_3^- in two sediment fractions. A known amount of wet sediment was weighed into 125 mL serum bottles and amended with K $^{15}NO_3$ (1.0 mg N bottle^{-1}) enriched with 99 atom % ^{15}N. All bottles were fitted with rubber septa and purged with N_2 gas to create anoxic conditions. All samples were incubated for 0, 8, 24, 48, 98 and 192 h in the dark at 28°C. At the end of each incubation period, three replicates of each treatment were extracted with 2 M KCl as described above. Filtered solutions and residual sediment N were analyzed for total and labelled N content as described above.

5.8.3 Results and discussion

5.8.3.1 Floodwater ammonium and nitrate N removal:

Floodwater of NH_4^+ and NO_3^- were rapidly lost from the system, as indicated by the mass balance of added N (Table 5.8.1). At the end of 10 weeks of inorganic N loading (loading rate = 5 μg N cm^{-2} d^{-1}) to the floodwater, about 86 and 90% of added NH_4^+ and NO_3^- were unaccounted for, suggesting rapid loss through related biogeochemical processes.

Distribution of floodwater $^{15}NH_4$ and $^{15}NO_3$ in the sediment profile at the end of a 10-wk incubation is shown in Figure 5.8.1. The largest fraction of added floodwater $^{15}NH_4$-N or $^{15}NO_3$-N was recovered in the surface 5-cm depth. When $^{15}NH_4$ was added to the floodwater, 5.8 and 7.7% of ^{15}N was recovered in inorganic and organic N fraction of the sediment, respectively. About 5% ^{15}N was recovered in each inorganic and organic N fraction of the sediment, when floodwater was loaded with NO_3^-. In both systems, ^{15}N was detected even at 42-52 cm depth, suggesting diffusion through the porewater as a result of ^{15}N concentration gradient between the floodwater and sediment.

Table 5.8.1. Mass balance of added nitrogen to the water column of Lake Apopka sediments. Nitrogen loading to the water column = 5 μg N cm^{-2} d^{-1}. Experimental period = 10 wk. Temperature = 28°C.

N-loading	Floodwater	Sediment Inorganic N	 Organic N	Total	N loss
		———% added N———			
Ammonium N	ND	5.82	7.73	13.55	86.45
Nitrate-N	ND	4.75	4.80	9.55	90.45

Total N added = 3990 μg N/column.
ND = not detected.

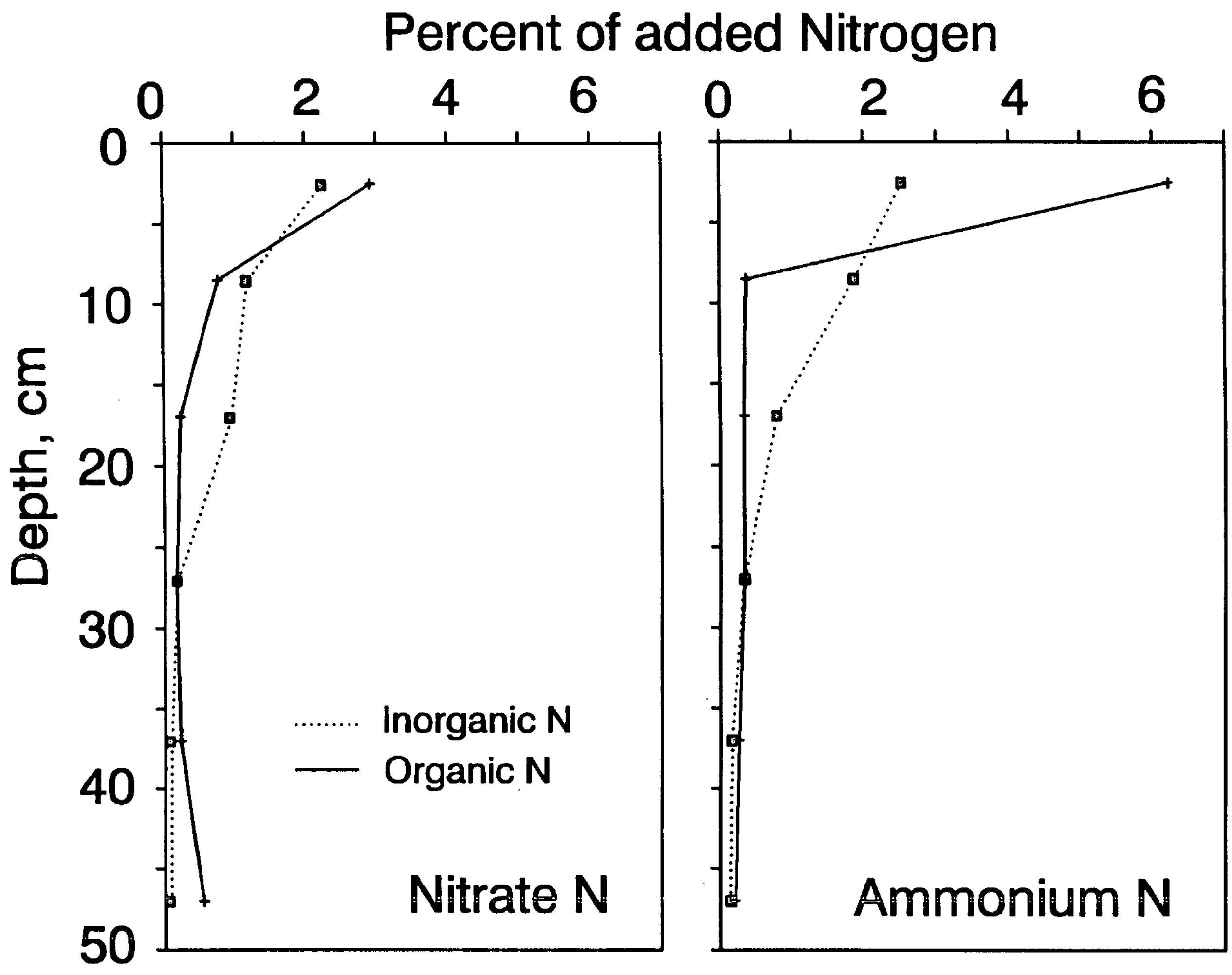

Fig. 5.8.1. Distribution of added floodwater $^{15}NH_4$-N and $^{15}NO_3$-N at the end of a 10-week incubation period. Floodwater was spiked with either $^{15}NH_4$-N or $^{15}NO_3$-N at a rate of 2.5 mg N L^{-1} $week^{-1}$.

Rapid loss of added NH_4^+ suggests nitrification in the water column and at the sediment-water interface, and downward movement of NO_3 from floodwater into the underlying sediment. Removal of NH_4^+ from floodwater of various aquatic systems was also observed by several researchers (Chen et al., 1972 and 1979; Curtis et al., 1975; Reddy and Graetz, 1981).

Recovery of ^{15}N in the sediment, even at depths of 42-52 cm, suggests the diffusion of $^{15}NH_4$ and $^{15}NO_3$ from floodwater to the sediment. Addition of inorganic N to the floodwater elevated the NH_4^+ and NO_3^- concentration to 2.5 mg L^{-1}. Nitrate diffusion from the water column to the sediment was expected because of the relatively high concentration in the water column, and a negligible concentration in the sediment porewater. Recovery of $^{15}NO_3$ at depths of 42-52 cm suggests that diffusion of NO_3^- was much faster than the rate of NO_3^- reduction in the sediment. Porewater NH_4^+ concentrations were generally higher than in the floodwater, especially at lower sediment depths. Even under these conditions $^{15}NH_4$ diffused to depths of 42-52 cm, suggesting some diffusion of $^{15}NH_4$ was also probably due to the concentration gradient of highly enriched isotopic ^{15}N added to the floodwater. Similar observations were also noted for pond sediments by Reddy and Reddy (1987).

5.8.3.2 Fate of added ammonium N:

Ammonium N added to the sediment was found to be stable (Figs. 5.8.2) under anaerobic conditions. At the end of 62 days of incubation, up to 20% of added ^{15}N was recovered in the organic N fraction of peat sediments, suggesting immobilization during microbial growth. In UCF sediments, incorporation of $^{15}NH_4$ into microbial tissue was less than 5% of added $^{15}NH_4$-N. When floodwater was exposed to air to allow O_2 diffusion through the water-column, rapid loss of sediment $^{15}NH_4$-N occurred (Fig. 5.8.2). More than 50% sediment $^{15}NH_4$-N was rapidly lost during the first 7 d of incubation, probably due to NH_3 volatilization and nitrification-denitrification reactions. Negligible concentrations of inorganic N was detected in this shallow sediment at the end of 30 d. Rapid transformations of inorganic N indicates the dynamic nature of N transformations functioning in Lake Apopka sediments.

5.8.3.3 Fate of added nitrate N:

Rapid loss of added $^{15}NO_3$ occurred in both sediment types, with about 80% of added $^{15}NO_3$ lost in 192 h (Fig. 5.8.3). In UCF sediment, added $^{15}NO_3$ was recovered in $^{15}NH_4$ and organic ^{15}N fractions, suggesting dissimilatory NO_3^- reduction to ammonia (DNRA) and assimilatory NO_3^- reduction (see Chapter 5.10 for a description of these processes functioning in the systems along with the denitrification. In peat sediments, $^{15}NO_3^-$ loss was primarily due to the denitrification process, where NO_3^- was used as electron acceptors during decomposition of sediment organic matter.

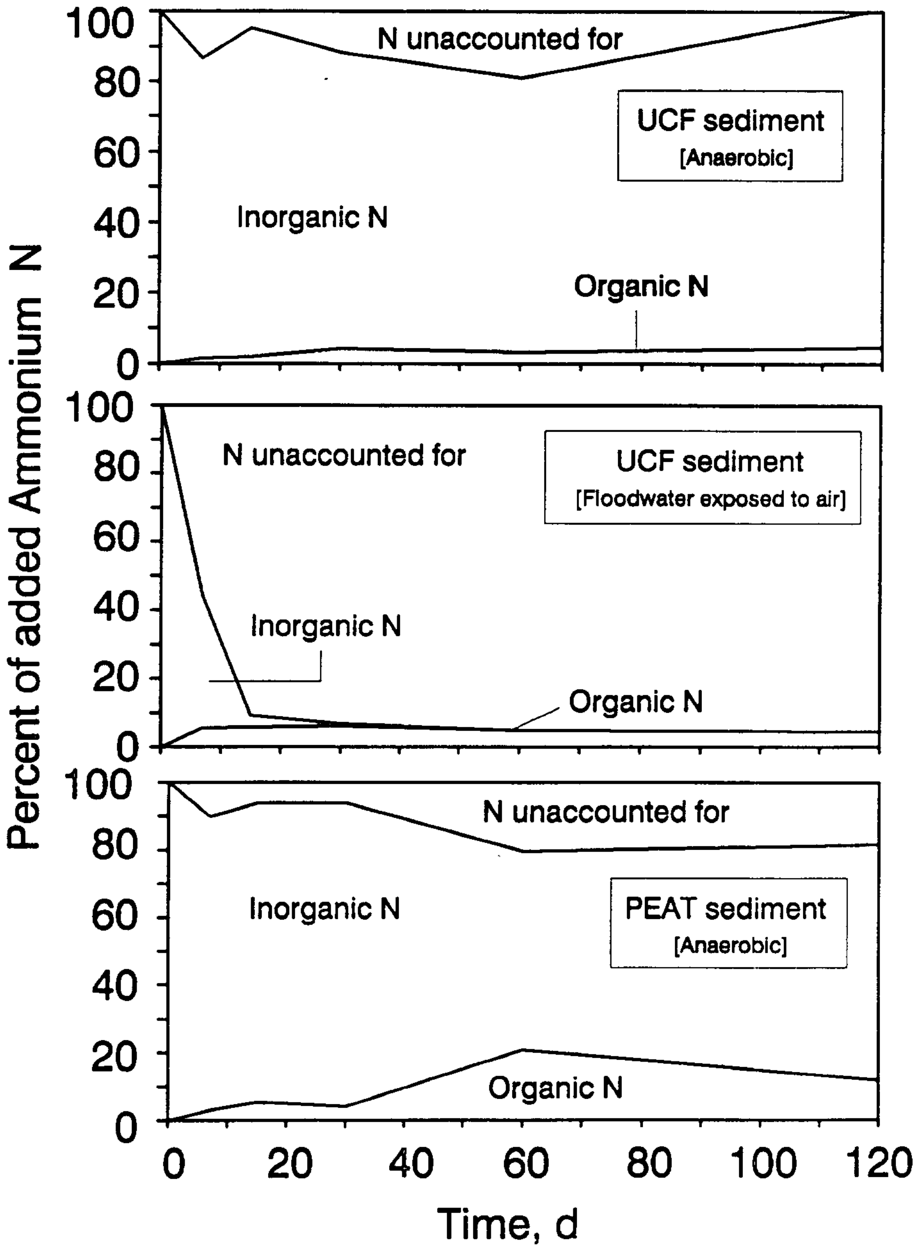

Fig. 5.8.2. Fate of added $^{15}NH_4$-N in UCF (unconsolidated floc) and peat sediments of Lake Apopka. Anaerobic sediments were spiked with $^{15}NH_4$-N at a rate of 2.66 mg N bottle^{-1}.

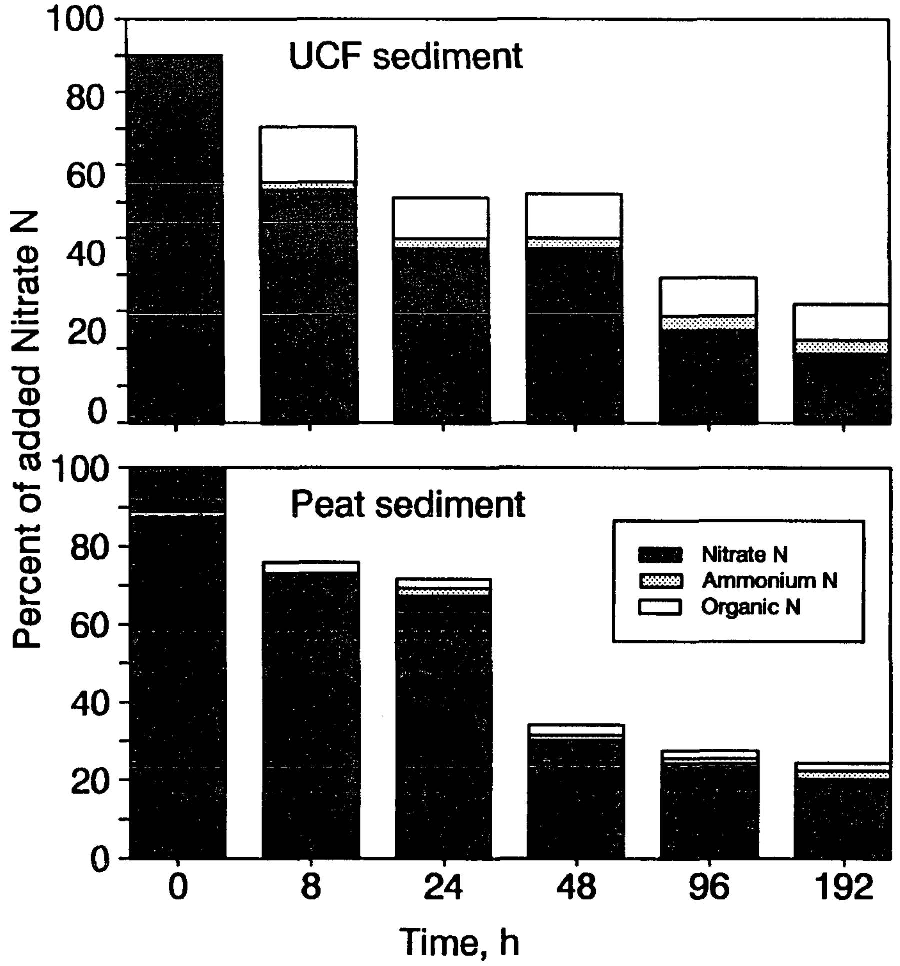

Fig. 5.8.3. Fate of added $^{15}NO_3$-N in UCF (unconsolidated floc) and peat sediments of Lake Apopka. Anaerobic sediments were spiked with $^{15}NO_3$-N at a rate of 1 mg N bottle^{-1}.

5.8.4 Conclusions

Ammonium and NO_3^- removal from floodwater was found to be equal to the loading rate (50 mg N m^{-2} d^{-1}). About 86 and 90% of floodwater NH_4^+ and NO_3^- were lost from the system as a result of associated N transformations, while the remaining 10-14% was incorporated into the sediment. Ammonium added to sediments and maintained under anoxic conditions was found to be stable. Up to 20% of added $^{15}NH_4$ to sediments was incorporated in cell biomass in peat sediments, while only 5% was incorporated in UCF sediments. In Lake Apopka, NH_4-N in the anaerobic sediments can only be lost through diffusion and mass flow or sediment resuspension to the sediment-water interface, where it is transformed to NO_3^-, and NO_3^- subsequently diffuses into sediments and is used as an electron acceptor during anaerobic respiration.

5.8.5 References

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5.9 Kinetics of Nitrification in the Sediment-Water Column [Task 3.9]

5.9.1 Introduction

Nitrification is defined as the biological conversion of reduced N forms (NH_4-N) to more oxidized states (NO_3^- or NO_2-N) (Alexander, 1965). The nitrifying bacteria are confined largely to aerobic chemoautotrophs of the genera *Nitrosomonas* ($NH_4^+ \rightarrow NO_2^-$) and *Nitrobacter* ($NO_2^- \rightarrow NO_3^-$). Nitrification is a key process in the N budget of lake systems, since the NO_3^- formed can be assimilated by many species. Perhaps more importantly, nitrification provides the substrate (NO_3^-) for denitrification, a major N removal mechanism in lake systems.

In a lake system, nitrification can occur (1) in the water column, (Curtis et al., 1975; Reddy and Graetz, 1981; Raune and Krenkel, 1978), and (2) the surface-oxidized sediments (Chen et al., 1972; Keeney, 1973). The objective of the present study was to determine the nitrification capacity of Lake Apopka sediment exposed to well-mixed, oxidized conditions which may occur at the sediment-water interface, especially during sediment resuspension.

5.9.2 Materials and methods

Bulk sediment samples were obtained by Ekman grab (APHA, 1985) from transect K-6 (LORAN coordinates 44497.1 μs, 62403.0 μs; about 300 m west of Fisherman's Paradise). Bulk sediment was stored at 15°C until used in the experiment.

A sediment slurry was made by mixing bulk sediment (600 g fresh weight) with filtered (0.45 μm) Lake Apopka water (1940 g) in a 3-L fernback flask. Selected physico-chemical properties of the bulk sediment, filtered lake water, and sediment slurry are shown in Table 5.9.1. A #13 rubber stopper inserted into the top of the flask was outfitted with 2 platinum redox electrodes, a salt bridge, glass aeration inlet and outlet ports, and a glass pH electrode (Fig. 5.9.1). The sediment slurry was continuously stirred with a magnetic stir plate, and was continuously bubbled with laboratory air using an aquarium pump (approx. 280 mL minute^{-1}), to maintain oxidized conditions favorable for nitrification. The air exiting from the flask was bubbled through 2 M H_2SO_4 to monitor NH_3 volatilization processes. The incubation was conducted in the dark at 31°C in triplicate.

The pH and redox potential (E_h) of the sediment slurry were continuously monitored over a period of 13 d (Fig. 5.9.2). At selected intervals over the 13-d period, 20-mL portions of the sediment slurry were extracted with 1 M KCl, shaken for 1 h, and filtered through #42 Whatman filter paper. The extracts were acidified (2 drops concentrated H_2SO_4) and frozen until analyzed for ammonium-N and (nitrate+nitrite)-N. Ammonium-N (NH_4-N) was determined with the salicylate-nitroprusside method, according to EPA 351.2 (USEPA, 1979). (Nitrate+nitrite)-N ((NO_3+NO_2)-N) was determined with the sulphanilamide/N-(1-naphthyl)-ethylenediamine method, according to method EPA 418.F (APHA, 1985).

Table 5.9.1. Selected properties of the bulk sediment, filtered lake water (0.45 μm), and sediment slurry of Lake Apopka (Transect K-6) used in the study. The sediment slurry consisted of 600 g bulk sediment mixed with 1940 g filtered lake water. Each value represents the mean of three replicates.

	Wet:dry weight ratio	pH	1 M KCl Extractable	
			NO_3-N	NH_4-N
Bulk sediment	22.4	6.70	4.52	18.91
Filtered lake water	—	7.75	2.41	ND
Sediment slurry	109.0	6.83	2.53	4.01

ND = not detectable.

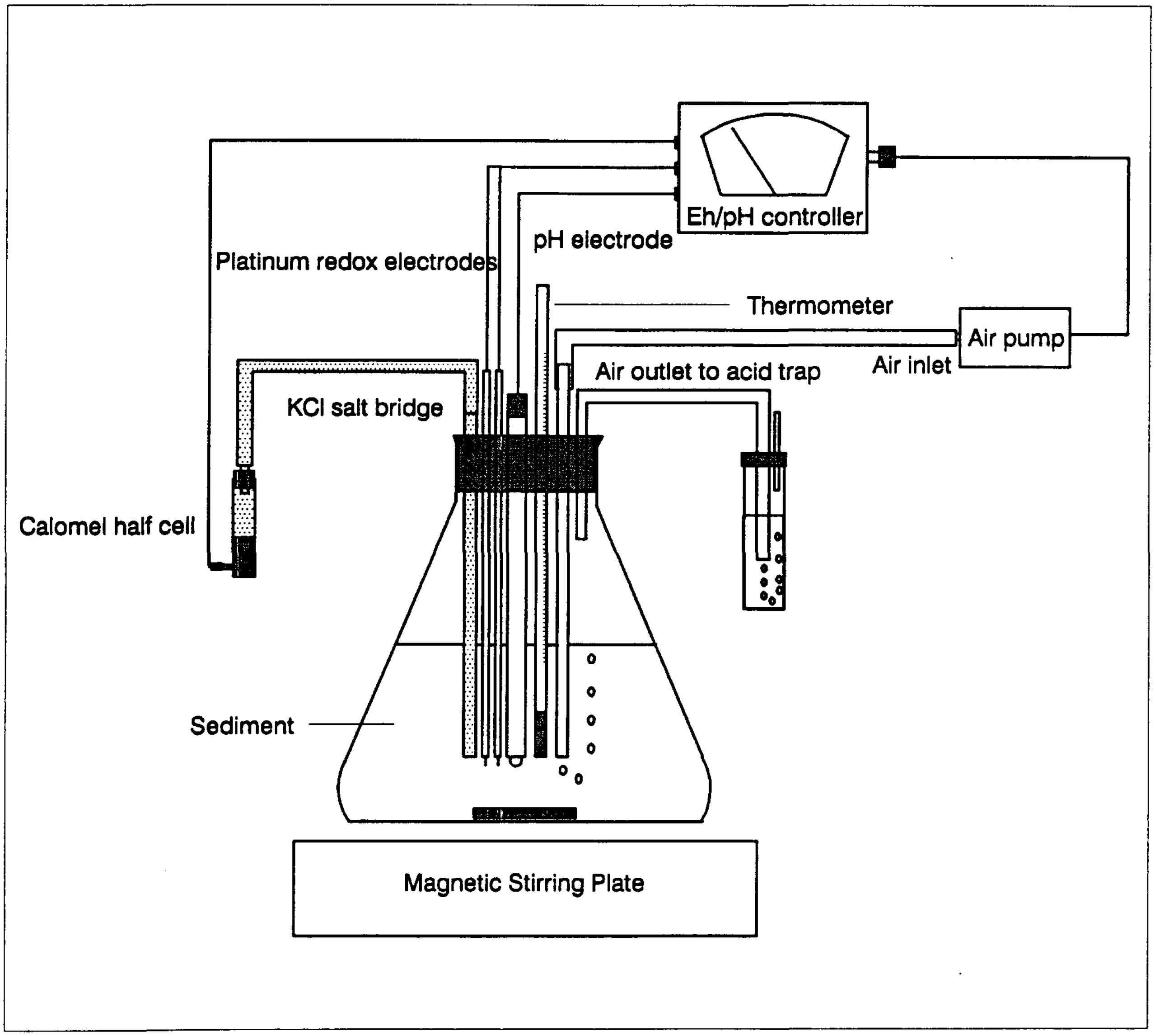

Fig. 5.9.1. Schematic representation of the incubation apparatus used in the nitrification experiment.

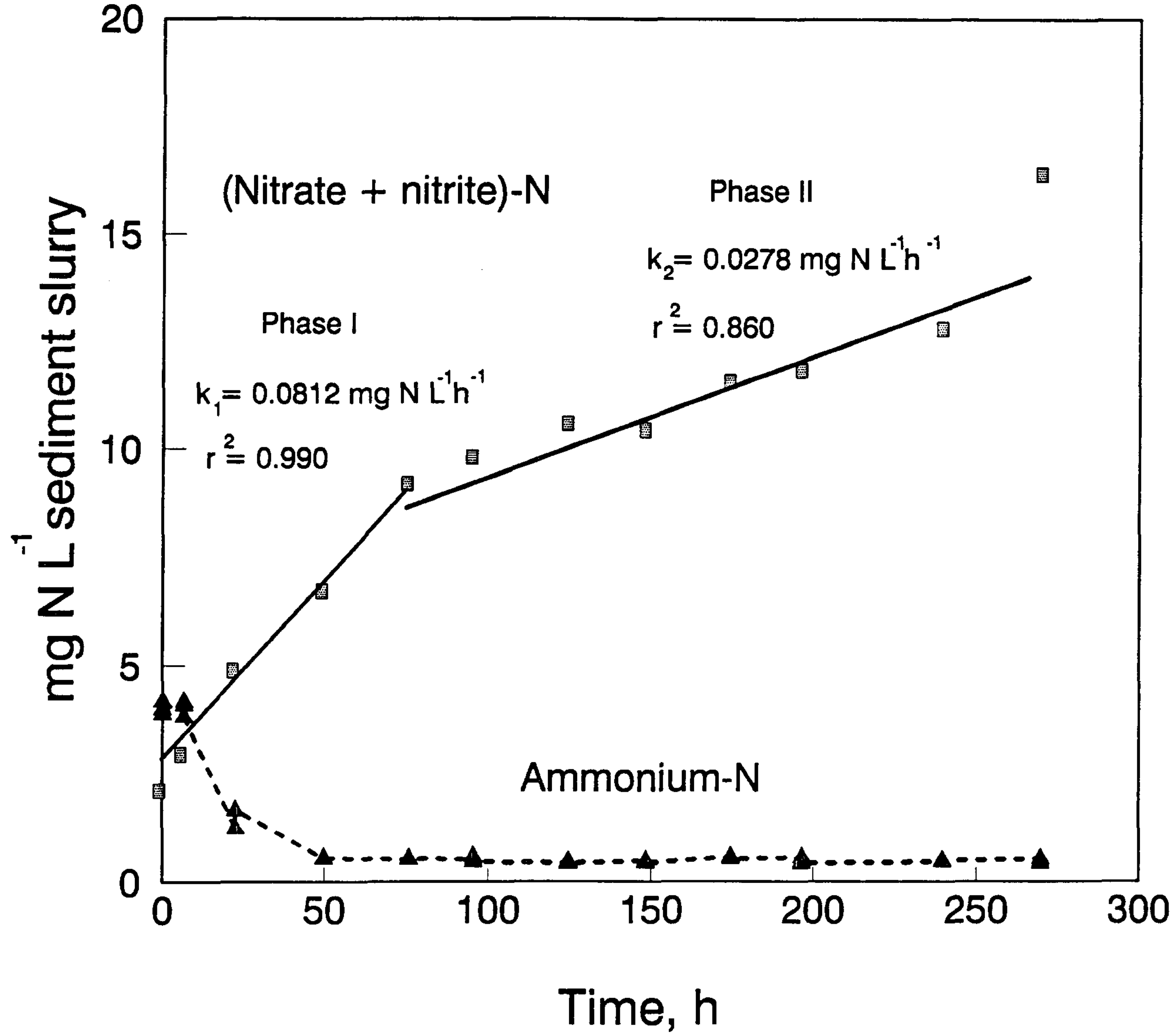

Fig. 5.9.2. Nitrification of a Lake Apopka sediment slurry incubated under well-mixed, oxidizing conditions. Sediment slurry consists of 600 g bulk sediment and 1940 g filtered lake water. Each value represents the mean of three replicates.

5.9.3 Results and discussion

The presence of indigenous NO_3-N in the bulk sediment and filtered lake water indicated the presence of an active population of nitrifiers under the aerobic storage conditions. These results explain the lack of the initial lag phase in NO_3^- production in the present study (Fig. 5.9.2), as compared to a similar nitrification study (Chen et al., 1972).

Two phases of nitrification of the sediment slurry were observed (Fig. 5.9.2). Between 0 and 76 h, nitrification followed zero-order kinetics with a rate constant (k_1) of 0.0812 mg L^{-1} h^{-1}; between 76 and 270 h the zero-order rate constant decreased to 0.0278 mg N L^{-1} h^{-1}. The initially rapid first stage of nitrification was due to the oxidation of NH_4^+ initially present in the sediment slurry. Nitrification showed linear accumulation of NO_3^-, suggesting that NH_4^+ was non-limiting during this period. Rapid decrease in the NH_4^+ of the sediment slurry was also attributable to a rapid nitrification rate. The initial decrease in the redox potential from 475 to 415 mV corresponded to the consumption of O_2 due to the combined processes of nitrification and heterotrophic respiration by microflora (Fig. 5.9.3). As the readily available NH_4^+ was depleted, the only source of NH_4^+ for nitrification was from the breakdown of organic compounds such as proteins and amino acids. The second phase of nitrification was therefore directly related to the ammonification of organic N. Ammonia volatilization was not a significant N loss mechanism, accounting for a mean of 0.0798 mg N L^{-1} in the H_2SO_4 acid traps. Multistage decomposition sequences have been observed during organic material decomposition, with stages representing the ease (or difficulty) with which organic compounds are degraded (Gilmour et al., 1977; Gilmour et al., 1985; Hunt, 1977; Moorhead et al., 1987; Reddy et al., 1980a).

The present study was conducted under optimum conditions of temperature (approximately 30°C; Frederick, 1956), pH (around neutrality; Keeney, 1973) and Eh (+500 to +350 mV; Turner and Patrick, 1968). In similar studies by Chen et al. (1972), a nitrification rate of 0.001 μg N mL^{-1} h^{-1} was measured in sediments under well-mixed and oxidized conditions. In a study by Reddy et al. (1980b), nitrification rates were measured between 0.046 to 0.117 μg N mL^{-1} h^{-1} in the aerobic layer of flooded soils. In pure cultures of nitrifiers, a nitrification rate of 36.8 μg N mL^{-1} h^{-1} was measured by Srinath et al. (1976). The potentially high rate suggested that nitrification may be limited by factors such as nitrifying bacteria populations.

In Lake Apopka, nitrification can potentially occur (1) in the water column (especially during sediment resuspension which results in NH_4^+ release), and (2) at the sediment-water interface where aerobic conditions may exist. Under both conditions, nitrification rates may be limited by the NH_4^+ concentration. In the water column and at the sediment surface, assimilation of NH_4-N by the autotrophs (see Chapter 5.10) may reduce the amount of substrate available for nitrification. Ammonium N may be increased in the water column through sediment resuspension (see Chapter 7.1 for release rates), caused by wind-induced wave action, currents, and bioturbation. In addition, NH_4^+ diffusion from the underlying anaerobic sediment to the sediment surface and the water column increases the NH_4^+ available

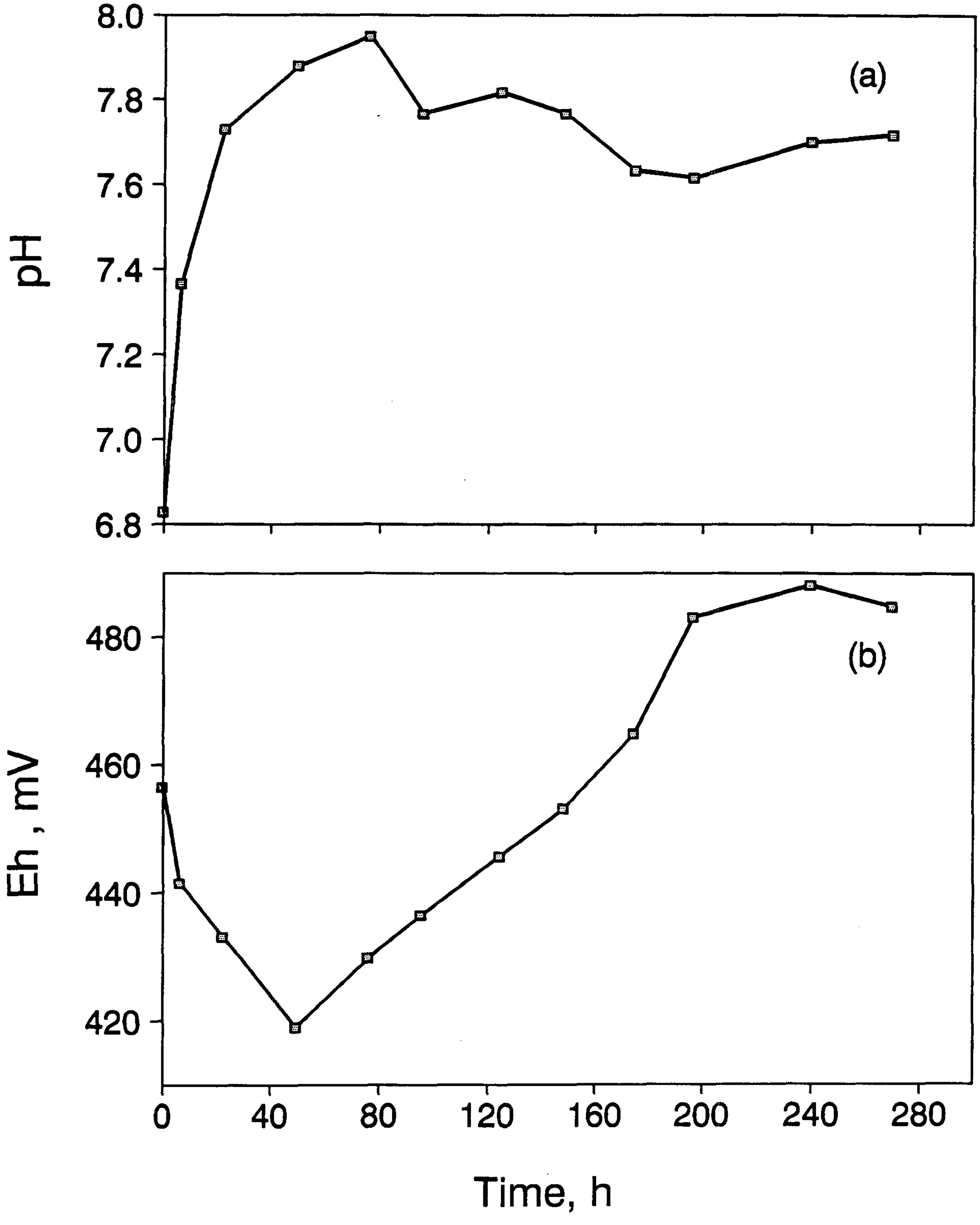

Fig. 5.9.3. The (a) pH and (b) Eh of a well-mixed sediment slurry continuously bubbled with laboratory air. The sediment slurry consists of 600 g fresh sediment and 1940 g filtered lake water. Each value represents the mean of three replicates.

for nitrification. The estimated NH_4^+ flux from the sediment to the water column was in the range of 30-40 mg N m^{-2} d^{-1} (see Chapter 4).

5.9.4 Conclusions

In the present study, NH_4-N in sediment slurries (4.01 mg N L^{-1}) exposed to O_2 was rapidly oxidized to NO_3^- at a maximum rate of 0.0812 mg N L^{-1} h^{-1}. The nitrification rate in Lake Apopka is limited by the substrate NH_4^+ concentration in the water column and at sediment-water interface, where NH_4-N concentrations are less than 1 mg N L^{-1}. Decreased N concentrations in the water column and at the sediment-water interface is caused primarily by rapid NH_4-N and NO_3-N assimilation, and gaseous N losses due to nitrification-denitrification (see Chapter 5.8). Increasing NH_4^+ in the water column (through sediment resuspension), and at the sediment water interface (through diffusion from the underlying sediment) would increase O_2 demand resulting from increased nitrification. Future studies should focus on the factors regulating nitrification in the water column, such as sediment resuspension during hydrodynamic events.

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5.10 Kinetics of Nitrate Reduction in Sediments [Task 3.9]

5.10.1 Introduction

Some of the most important processes which directly affect the rate of eutrophication in lake ecosystems include microbially-mediated N transformations in the sediment-water column. Understanding these metabolic processes enables us to confront, and possibly minimize detrimental changes to lake ecosystems resulting from excessive N loading. One of the major N removal mechanisms in a lake system is nitrate reduction in the sediments (Fig. 5.10.1). Denitrification (a nitrate reduction mechanism) is a respiratory process where facultative anaerobic bacteria use NO_3^- (or NO_2^-), in the absence of O_2, as the terminal electron acceptor during the oxidation of organic C, resulting in the production of gaseous end products such as N_2O and N_2 which are lost to the atmosphere.

A competing mechanism called dissimilatory NO_3^- reduction to ammonia (DNRA), is also a respiratory process used by facultative and obligate anaerobic bacteria which also use NO_3^- as the terminal electron acceptor (Tiedje, 1988). Both processes are beneficial to organisms living in the anaerobic, electron-rich environments such as lake sediment, since N oxide compounds act as an electron sink, which coupled to electron transport phosphorylation, produces energy for the organisms.

A third mechanism called assimilatory nitrate reduction conserves N within the lake ecosystem, since the organisms responsible utilize N in protein synthesis and other anabolic processes.

Physical, chemical, and biological conditions in the sediment determine which N transformation predominates. For example, denitrifying organisms are selected for when anoxia is temporary, or when the concentration of electron acceptors (i.e. NO_3^-) is high, since their utilization of NO_3^- (instead of O_2) is a secondary process. On the other hand, organisms responsible for DNRA are selected for in C and electron-rich environments that are continuously anoxic. Assimilatory NO_3^- reduction is repressed by large amounts of NH_4^+ which usually occur in anaerobic lake sediments.

Numerous field and laboratory studies have confirmed that each of the NO_3^- reduction processes occur in a variety of environments, including estuary sediments (Nedwell, 1975; Nishio et al., 1982), marine sediments (Koike and Hattori, 1978; Oremland et al., 1984; Oren and Blackburn, 1979; Seitzinger and Nixon, 1985; Sorensen, 1978 a,b,c), and lake sediments (Chan and Knowles, 1979; Chen et al., 1972; Kaspar, 1983, 1985; Keeney et al., 1971). A summary of literature data on denitrification rates and utilization of NO_3^- in three microbially mediated processes in various sediments is presented in Tables 5.10.1 and 5.10.2. The extent of denitrification, DNRA, and assimilatory NO_3^- reduction in hypereutrophic lakes has yet to be quantified. The objectives of this study were to: (1) evaluate the effectiveness of the C_2H_2 blockage and ^{15}N isotope techniques to simultaneously measure the NO_3^- reductive processes in anaerobic lake sediment, (2) estimate the partitioning between the three NO_3^- reductive processes in the bulk sediment and

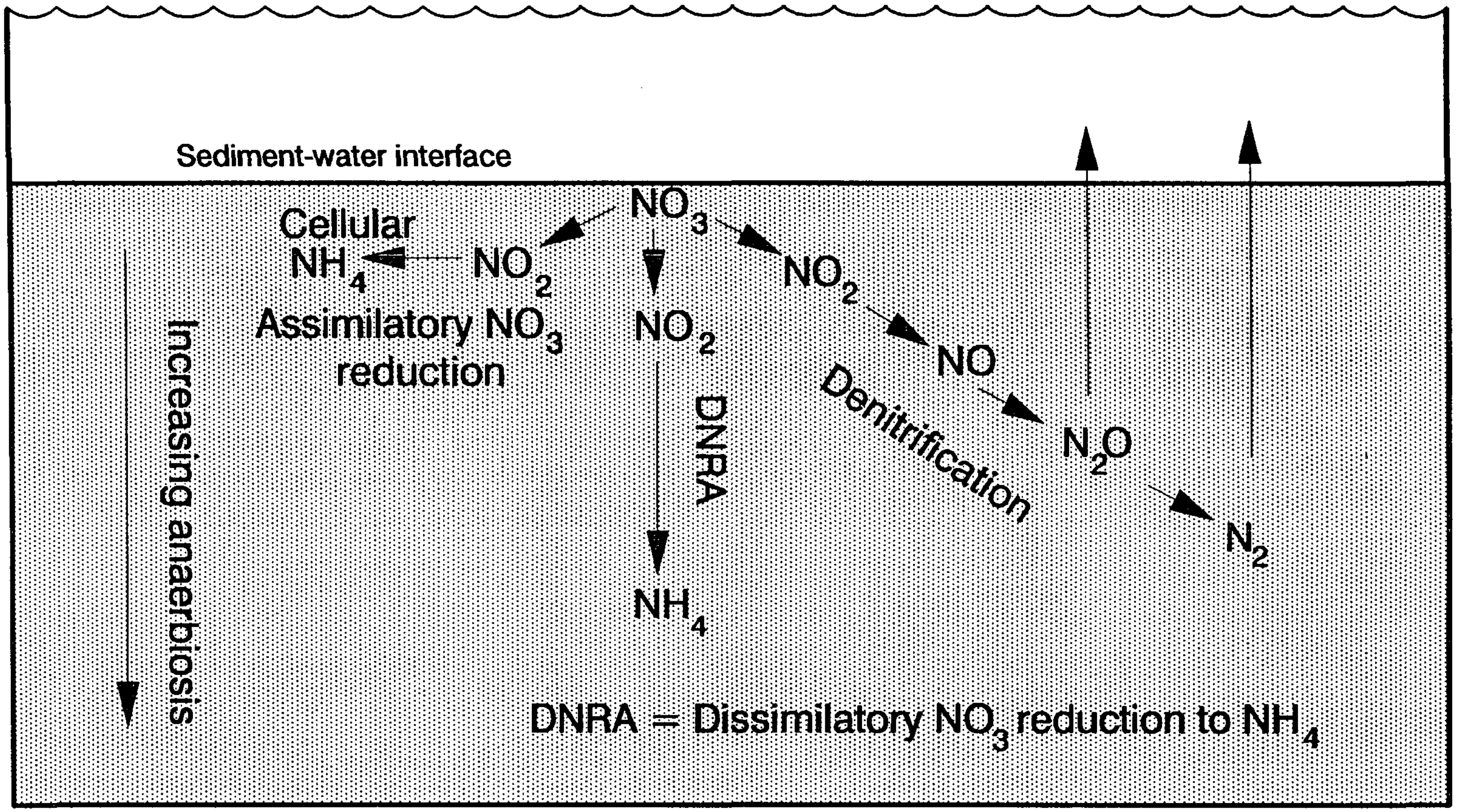

Fig. 5.10.1. Nitrate reduction processes in lake sediments (DNRA = dissimilatory nitrate reduction to ammonia).

Table 5.10.1. Estimates of denitrification rates of sediments reported by various researchers.

Type of sediment	Location	Experimental conditions	Rate	Reference
Lake sediment	Lake St. George, Ontario, Canada	Lab incubation using C_2H_2 blockage technique; surface 5 cm of lake sediment amended with 28 μg NO_3-N g^{-1}	0.408-0.618 μg N g^{-1} h^{-1}	Knowles, 1979
Coastal sediment	Kysing Fjord, Denmark	Lab incubation using ^{15}N technique; surface 3 cm of marine sediment amended with 0.147 NO_3-N mL^{-1}	0.00117-0.00729 μg N cm^{-3} h^{-1}	Oren and Blackburn, 1979
Coastal sediment	Limfjorden, Denmark	Lab incubation using the C_2H_2 blockage and ^{15}N techniques; surface 12 cm of marine sediment amended with 21 μg NO_3-N mL^{-1}	0.0583-0.508 μg N cm^{-3} h^{-1}	Sorensen, 1978a
Estuary sediment	Jutland, Denmark	Lab incubation using C_2H_2 blockage technique; surface 9 cm of marine sediment at *in situ* NO_3 concentrations of 0-2.24 μg N mL^{-1}	0.00382-0.0204 μg N cm^{-3} h^{-1}	Sorensen, 1978b
Coastal sediment	Kysing Fjord, Denmark	Lab incubation using C_2H_2 blockage technique; marine sediment cores	0-0.158 μg N mL^{-1} h^{-1}	Sorensen, 1978c

Table 5.10.2. Estimates of the partitioning of three nitrate reductive processes in sediments.

Type of sediment	Location	Experimental conditions	% NO_3-N Recovery NH_4-N (DNRA)*	 Organic N (assimilation)	 Denitrification	Reference
Four intertidal sediments	Nelson, New Zealand	Lab incubation using the C_2H_2 and ^{15}N techniques; Comparison of 4 intertidal sediment slurries amended with 0.42 μg NO_3-N mL^{-1}	2-20 (mb)**	0 (mb)	34.8	Kaspar, 1983
Lake sediment	Wintergreen Lake, Michigan	Lab incubation using the C_2H_2 and ^{15}N techniques; Pelagic sediment slurries from a hypereutrophic lake amended with 0.140 μg NO_3-N mL^{-1}	30-19 (mb)	0 (mb)	70-81	Kaspar, 1985
Lake sediment	Lake Mendota, Wisconsin	*In situ* studies using bulk lake sediment amended with 2.1 μg $^{15}NO_3$-N mL^{-1}	0.3-8	5-31	63 (mb)	Keeney et al., 1971
Lake sediment	Lake St. George, Ontario, Canada	Lab incubation using C_2H_2 blockage technique; Surface 5 cm of lake sediment amended with 28 μg NO_3-N g^{-1}	ne***	ne	38	Knowles, 1979
Estuary and bay sediments	Tama Estuary, Odana Bay, Tokyo Bay	Lab incubation using ^{15}N; Intact cores from coastal and estuarine sediments amended with $^{15}NO_3$-N	ne	ne	27-57	Nishio et al., 1982
Intertidal mud	San Francisco Bay, California	Lab incubation using C_2H_2 blockage; Intertidal sediment slurries amended with 9.3-37.3 μg NO_3-N mL^{-1}	ne	ne	8.5-18	Oremland et al., 1984
Coastal sediment	Limfjorden, Denmark	Lab incubation using depth C_2H_2 blockage and ^{15}N techniques; Depth segments of marine sediment amended with 21 μg NO_3-N mL^{-1}				Sorensen, 1978a
0-3 cm			22	40 (mb)	38	
3-6 cm			38	20 (mb)	42	
6-9 cm			33	34 (mb)	33	
9-12 cm			27	33 (mb)	13	

*DNRA = dissimilatory nitrate reduction to ammonia.

**mb = determined by mass balance.

***ne = not estimated.

Table 5.10.3. Selected physico-chemical parameters of the Lake Apopka bulk sediment used in the denitrification experiments.

Experiment	Dry bulk density	pH	Extractable NH_4-N	Total N	Total C
	–g cm^{-3}–		—μg cm^{-3}—	——mg g^{-1} (dw)——	
1					
(0,10% C_2H_2)	0.0300	6.75	45.7	27.4	323
(20,50,100% C_2H_2)	0.0288	6.80	31.4	28.1	335
2	0.0283	—	52.1	26.5	327

Table 5.10.4. Selected physico-chemical parameters of Lake Apopka sediments as a function of depth.

Depth	Dry bulk density	pH	Extractable NH_4-N	Total N	Total C	Porewater TOC
cm	-g cm^{-3}-		—μg cm^{-3}—	—mg g^{-1} (dw)—		-μg mL^{-1}-
0-2	0.0214	7.10	4.6	34.4	340	27.0
2-4	0.0218	7.05	10.5	33.1	340	28.8
4-6	0.0258	7.30	9.5	32.5	335	29.6
6-10	0.0285	7.00	13.5	32.5	337	28.5
10-15	0.0323	6.95	6.9	29.8	331	35.8
15-20	0.0437	6.89	8.5	27.0	327	34.1
20-25	0.0429	6.83	19.6	25.6	332	40.7
25-30	0.0503	6.70	32.2	24.9	373	44.3
30-35	0.0471	6.70	30.6	26.3	387	45.3
35-40	0.0492	6.80	32.5	24.3	378	48.6

with sediment depth, and (3) estimate the denitrification capacity of the bulk sediment.

5.10.2 Materials and methods

5.10.2.1 Study site and sampling:

Lake Apopka is a large (12,500 ha), hypereutrophic lake located in Central Florida, northwest of Orlando. The sediment sampling site (transect K-6) was located at LORAN coordinates 44497.1 μs, 62403.0 μs (about 300 m west of Fisherman's Paradise).

Bulk sediment samples were obtained with an Ekman grab (APHA, 1985). Samples were stored in Nalgene containers under N_2 atmosphere (anaerobic conditions), and refrigerated (4°C) until used in the experiments (less than 2 weeks). Depth sections of sediment were obtained by combining the contents of 3 intact sediment cores using 3 Plexiglas piston corers (6.35 cm I.D. x 1.5 m). From each of the cores, lake water was siphoned from the sediment surface, and the sediment was slowly extruded from the bottom using a plunger. The surface 40 cm of each core was fractionated into 10-depth sections, and the combined contents of each depth from all of the cores were immediately transferred to Nalgene Mason Jars outfitted with rubber septa on the lids. The headspace of the jars containing the sediment was immediately purged with N_2 to ensure anaerobic conditions. The samples were refrigerated (4°C) until they could be used in the experiments (less than 1 week).

The lake sediment was characterized by unconsolidated (98% water) and consolidated (93% water) flocculent layers totaling 84 cm, which consisted of recent and settled deposits of algal cells, and allochthanous particulate organic matter, respectively. Selected physico-chemical parameters of the sediments used in this study are presented in Tables 5.10.3 and 5.10.4.

The pH was obtained using a pH meter and combination glass electrode inserted directly into the fresh sediment. Sediment porewater was obtained by centrifugation of fresh sediment at 5,000 rpm for 20 min. in a refrigerated centrifuge. Porewater organic C was determined by digestion with $K_2S_2O_8$ under acidic conditions in sealed glass ampules at 130°C, after purging with O_2 to remove inorganic C. Organic C converted to CO_2 was analyzed by a non-dispersive infrared detector (Oceanographic International Corporation Model 0524B Total Carbon System). Extractable ammonium (NH_4^+) and nitrate (NO_3^-), and organic N of the sediment were obtained by treating the sediment with 2 M KCl, shaking for 1 h, and filtering the sediment slurry through #42 Whatman filter paper. The filtrate was analyzed for extractable NH_4^+ and NO_3^- by steam distillation (Keeney and Nelson, 1982). The residual sediment on the filter paper was oven-dried at 105°C, finely ground, and analyzed for organic N by an elemental analyzer (Carla Erba). Total N and C were also analyzed by the elemental analyzer.

5.10.2.2 Experiment I:

To determine the efficiency of acetylene (C_2H_2) to block nitrous oxide reductase (i.e., block the conversion of N_2O to N_2) in lake sediment, five C_2H_2 concentrations were evaluated. Fifty milliliters of bulk sediment were pipetted into each of 15 serum bottles (120 mL), and plugged with rubber septa. Each of the bottles was immediately purged with N_2 gas for at least 3 min. Portions of the headspace gas were removed with a syringe, and replaced with C_2H_2 (obtained by the reaction of water with CaC_2) to give headspace concentrations of 0, 10, 20, 50, and 100 (v/v) % C_2H_2 at 1 atm. Sediment samples were incubated in the dark at 25°C. Each treatment was replicated three times. One milliliter of a KNO_3 solution was then injected into the sediments, to obtain 1 μg N mL^{-1} sediment (99 atom % ^{15}N). Samples were vigorously swirled to accelerate the diffusion of the C_2H_2 and NO_3^- solution into the sediment, and to ensure equilibration of gaseous denitrification products (N_2O) between the gaseous and aqueous phases.

Gaseous N_2O production was measured by a gas chromatograph equipped with a ^{63}Ni electron capture detector (Shimadzu GC-14A). Injector, column and detector temperatures were 65, 40, and 340°C, respectively. Gas samples were passed through an in-line column packed with Porapak Q (80/100 mesh). The flow rate of the carrier gas (95% Argon + 5% methane) was 30 cm^3 min^{-1}. Total N_2O (headspace + solubilized) was calculated using the following equation as described by Tiedje (1982):

$$M = C_g (V_g + V_s a)$$

where M = total amount of N_2O produced, C_g = concentration of N_2O in the headspace, V_g = volume of headspace, V_s = volume of the sediment, and a = temperature-pressure dependant Bunsen adsorption coefficient of 0.544 (25°C, and 1 atm pressure), calculated by Wilhelm et al. (1977).

Isotopic N was analyzed by mass spectrophotometry (Hauck, 1982). Assimilatory nitrate reduction was indicated by the incorporation of $^{15}NO_3$-N into the organic ^{15}N fraction of the sediment. Dissimilatory nitrate reduction to ammonia (DNRA) was indicated by the presence of extractable $^{15}NH_4$-N in the sediment.

5.10.2.3 Experiment II:

To estimate the denitrification capacities of the lake sediment, bulk sediment samples with a 10% C_2H_2 - 90% N_2 (v/v) headspace were amended with 3 concentrations of NO_3^- (1, 10, or 100 μg N mL^{-1} sediment at 99 atom % ^{15}N) using the procedure described in Experiment I. The N_2O accumulated was measured over a period of 288 h. Sediment samples were immediately extracted with 2 M KCl and analyzed for inorganic and organic nitrogen and ^{15}N. There were 3 replications for each treatment. It was assumed that *in situ* denitrification rates could be estimated by amending the sediment with low concentrations of NO_3^- (1 μg N mL^{-1} sediment), while the denitrification capacity could be estimated by non-NO_3^- limiting conditions in the sediment (100 μg N L^{-1} sediment).

5.10.2.4 Experiment III:

To determine the denitrification activity of the upper 40 cm of the lake sediment, 0.255 mL of a KNO_3 solution (1 μg N mL^{-1} sediment at 99 atom % ^{15}N) was injected into each of 30 serum bottles (70 mL) containing 10 mL sediment (three replications for each of the 10 depth sections), and a 10% C_2H_2 - 90% N_2 (v/v) headspace and incubated in the dark at 25°C. Accumulated N_2O was measured over a period of 24 h. Identical incubations of the upper 40 cm of sediment were also conducted without C_2H_2 in the headspace, to determine the effects of C_2H_2 on the partitioning between dissimilatory and assimilatory NO_3^- reduction.

5.10.3 Results and discussion

5.10.3.1 Experiment I:

There was no initial N_2O gas measured in the headspace of the sediment, suggesting that no indigenous NO_3^- was available (Fig 5.10.2). A significant amount of N_2O temporarily accumulated in the headspace of the sediment untreated with C_2H_2, suggesting that in NO_3^- saturated sediments, the rate of N_2O reduction to N_2 (mediated by the enzyme nitrous oxide reductase) may be the rate-limiting step in the denitrification process (Betlach and Tiedje, 1981). The acetylene (C_2H_2) blockage of the enzymatic reduction of N_2O to N_2 was effective in estimating denitrification rates in NO_3^- amended sediments for short-term incubations (less than 25 h) with C_2H_2. A headspace concentration of at least 10% C_2H_2 resulted in the accumulation of 23.5 μg N_2O-N (46% of NO_3-N applied) over a period of 25 h after the addition of NO_3^- (Table 5.10.5). The mean rate of denitrification in the bulk sediment (calculated from the N_2O measurements between 0 to 25 h) was 0.0194 μg N mL^{-1} sediment h^{-1}. Higher headspace concentrations of C_2H_2 did not significantly increase the denitrification rate during the first 25 h, therefore the headspace concentration of 10% C_2H_2 was used in the determination of denitrification rates in the following experiments (Experiments II and III). Similar rates have been measured by other researchers using sediments with low concentrations of NO_3^- (<2.24 μg N mL^{-1}) (Table 5.10.1).

For longer incubation periods at low headspace concentrations of C_2H_2 (0 and 10%), and when NO_3^- in sediment became very low, reduction of N_2O to N_2 indicated the failure of C_2H_2 blockage (Fig 5.10.2). Reduction of N_2O to N_2 was an indication of denitrification in the sediment. Several researchers have also observed this phenomena in denitrification studies with sediments incubated with C_2H_2 (Chan and Knowles, 1979; Kaspar, 1982, 1983; Knowles, 1979; Oremland et al., 1984; Smith et al., 1978; Tam and Knowles, 1979; Van Raalte and Patriquin, 1979; Watanabe and deGuzman, 1980; Yeomans and Beauchamp, 1978), and has been attributed to many factors. The development of microorganisms in the sediment capable of decomposing C_2H_2 (possibly using C_2H_2 as a C source), or capable of reducing N_2O to N_2 in the presence of low amounts of C_2H_2 has been suggested. The presence of sulphide in the sediment was also reported to promote N_2O reduction in the presence of C_2H_2. In the presence of higher concentrations of C_2H_2 (20, 50, and 100%), N_2O accumulated to a maximum of 32.6 μg N mL^{-1} (63.9% of NO_3-N

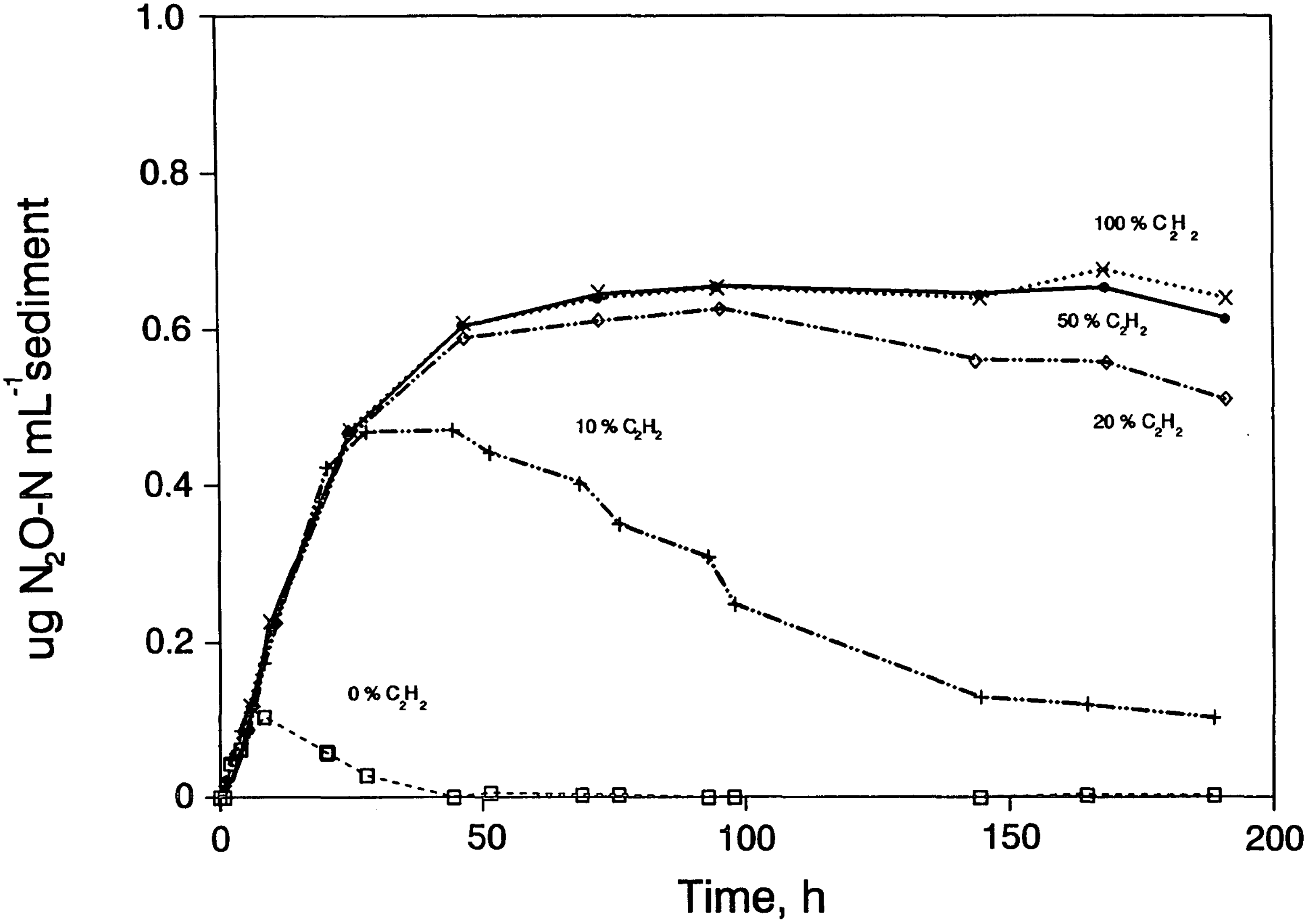

Fig. 5.10.2. Effect of headspace C_2H_2 concentration (v/v) on nitrous oxide (N_2O-N) gas production by denitrification after the addition of 1 μg NO_3-N mL^{-1} bulk sediment.

Table 5.10.5. Summary of percent ^{15}N recovery in the denitrification Experiment I. Soil N fractions were measured 190 h after NO_3^- addition. Each value represents the mean of 3 replications.

	Mean Percent ^{15}N Recovery					
Treatment	NH_4-N	Organic N	Total soil-N	Maximum N_2O-N	Unaccounted N	Denitrification rate
						N (mL sediment•h)$^{-1}$
0% C_2H_2	24.9a	4.46a	29.9a	10.2a	59.9	0.0123a
10% C_2H_2	22.0b	4.68b	27.0b	45.0b	28.0	0.0205b
20% C_2H_2	13.7c	3.86c	17.6c	61.3c	21.2	0.0190b
50% C_2H_2	13.3c	4.07d	17.4c	64.1c	18.5	0.0191b
100% C_2H_2	14.0c	4.22d	18.2c	66.3c	15.5	0.0188b

Means in the same column with the same letter are not significantly different at p=0.05.

applied), and remained for the duration of the experiment. Denitrification accounted for between 13 to 81% of the NO_3^- amended to sediments by other researchers, as summarized in Table 5.10.2.

The major fraction of total ^{15}N recovered in the sediment was $^{15}NH_4$-N resulting from DNRA (Table 5.10.3). Higher percentages of $^{15}NH_4$-N were recovered in the sediments treated with low C_2H_2 headspace concentrations (0 and 10% C_2H_2), than in sediments treated with higher concentrations of C_2H_2. Decreased $^{15}NH_4$-N in the treatments receiving C_2H_2 > 20% may be due to an inhibitory effect on organisms involved in DNRA. Differences in the rates of DNRA were also probably due to differences in the microbial activity of the two sediments used in the experiment. About 4.3% of the added ^{15}N was recovered in the organic ^{15}N fraction of the sediment resulting from assimilatory NO_3^- reduction. There were only small differences in the recoveries of organic ^{15}N fraction between the 5 treatments. No detectable amounts of NO_3^- remained in the sediment after 190 h for any of the treatments. Partitioning of the three NO_3^- reductive processes in sediments measured by other researchers are shown in Table 5.10.2.

5.10.3.2 Experiment II:

A maximum of 21.9 μg N_2O-N (51.7% of NO_3-N added) was recovered 24 h after the addition of 1 μg NO_3-N mL^{-1} sediment treated with C_2H_2 (Table 5.10.6). After 24 h, N_2O in the headspace began to decline, again indicating the ineffectiveness of the C_2H_2 blockage technique at low sediment NO_3^- and C_2H_2 concentrations (Fig. 5.10.3). In the treatment with 10 μg NO_3-N mL^{-1} sediment and C_2H_2, N_2O accumulated to maximum of 260.9 μg N (61.5% of NO_3-N added) after 72 h, and maintained a steady value for the duration of the experiment. In the treatment with 100 μg NO_3-N mL^{-1} sediment and C_2H_2, N_2O accumulated for the entire experiment, reaching a maximum of 1296 μg N (30.5% of NO_3-N added) after 288 h. In the treatments with 10 and 100 μg NO_3-N mL^{-1} sediment, significant NO_3^- remained in the sediment after 288 h (Table 5.10.6).

The estimated denitrification rate of the bulk sediment at an approximate *in situ* NO_3^- concentration was 0.0240 μg N mL^{-1} sediment h^{-1} (Table 5.10.6), determined by measuring the accumulated N_2O in the headspace of sediment amended with 1 μg NO_3-N mL^{-1} sediment and C_2H_2 (Fig. 5.10.3). The denitrification capacity of the bulk sediment was estimated by measuring the accumulated N_2O in the headspace of sediments amended with C_2H_2 and with NO_3^- concentrations of 10 and 100 μg N mL^{-1} sediment. The mean rates of denitrification were 0.0920 and 0.108 μg N mL^{-1} sediment h^{-1} for the treatments with 10 and 100 μg NO_3-N mL^{-1} sediment, respectively (Table 5.10.6), calculated from the linear portion of the curves shown in Fig. 5.10.3. The denitrification capacity of the bulk sediment was between 4 to 5 times higher than the denitrification rate measured at appropriate *in situ* concentrations.

Partitioning between the DNRA and denitrification reductive processes was affected by the amount of electron acceptor (NO_3^-) amended to the sediment. In the treatment with low NO_3^- (1 μg $^{15}NO_3$-N mL^{-1} sediment), the ratio of the percentages

Table 5.10.6. Summary of percent ^{15}N recovery in the denitrification Experiment 2. Each value represents the mean of 3 replications.

	Mean Percent ^{15}N Recovery						
Treatment	NH_4-N	NO_3-N	Organic N	Total soil-N	Maximum N_2O-N	Unaccounted N	Denitrification rate
							μg N (mL sediment·h)$^{-1}$
1 μg N mL^{-1}	33.6a	nd a	10.0a	43.7a	51.7	4.60	0.024a
10 μg N mL^{-1}	11.1b	9.76b	2.1b	22.8b	61.5	15.70	0.092b
100 μg N mL^{-1}	2.2c	47.5c	0.9c	50.7c	30.5	18.80	0.108c

nd = not detectable

Means in the same column with the same letter are not significantly different at p=0.05.

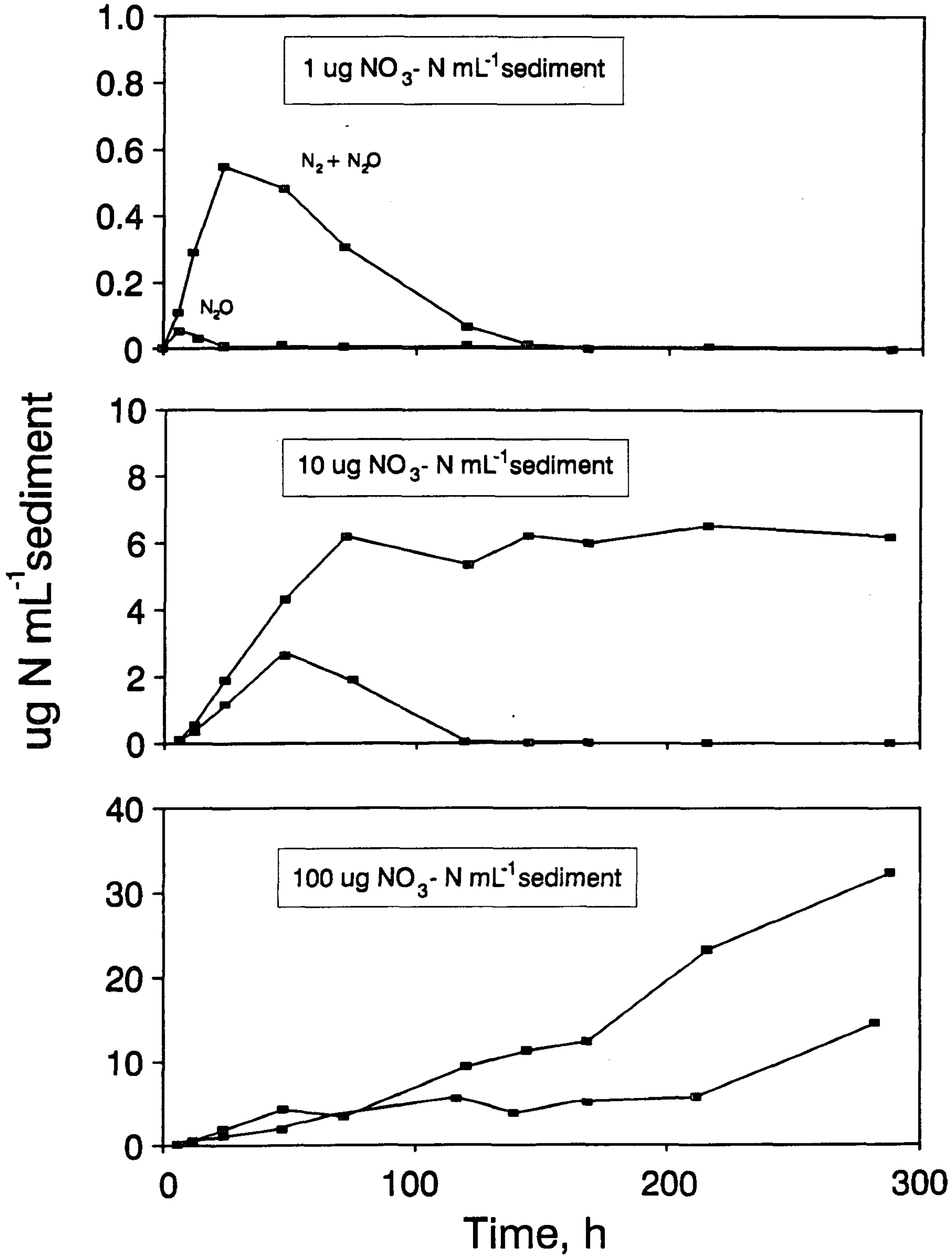

Fig. 5.10.3. Nitrous oxide (N_2O-N) and N_2-N gas production by denitrification after the addition of 1, 10, and 100 μg NO_3-N mL^{-1} bulk sediment.

of ^{15}N recovered from denitrification/DNRA was 1.54. In the treatments with 10 and 100 μg $^{15}NO_3$-N mL^{-1} sediment, the ratios increased to 5.54 and 13.6, respectively, suggesting the influence of NO_3^- concentration on the partitioning between the two processes. King and Nedwell (1985) also found that denitrification was increased in environments with low C/electron acceptor ratios. The DNRA became the dominant reductive process when the C/electron acceptor ratio became higher, which commonly occurs in extremely anaerobic lake sediment.

5.10.3.3 Experiment III:

The denitrification rate increased from 0.0370 μg N_2O-N mL^{-1} sediment h^{-1} at the sediment surface, to a maximum of 0.0546 μg N_2O-N mL^{-1} sediment h^{-1} at a depth of 15-20 cm (Table 5.10.7). The denitrification rate was reduced at sediment depths greater than 25 cm (Fig. 5.10.4). Denitrification was the major NO_3-N reductive process at all depths between 0-27 cm (Fig. 5.10.5).

A 24-h incubation period of sediments with a headspace concentration of 10% C_2H_2 - 90% N_2 (v/v) had no significant effect on the partitioning between assimilatory NO_3^- reduction and DNRA (Table 5.10.8). At the sediment surface 0-2 cm, 13.2% of the applied $^{15}NO_3$-N was recovered as the end-product of DNRA ($^{15}NH_4$-N), whereas assimilation of NO_3^- into the organic ^{15}N fraction accounted for over 21% of the applied $^{15}NO_3$-N. At sediment depths 2-40 cm, between 18-32% of applied $^{15}NO_3$-N was recovered as $^{15}NH_4$-N resulting from DNRA, while only about 8% of the applied $^{15}NO_3$-N was assimilated into the organic fraction. At sediment depths of 27-40 cm, DNRA surpassed denitrification as the major NO_3^- reductive process. Unaccounted ^{15}N was assumed to be unreacted $^{15}NO_3$-N remaining in the sediment, undetectable by the steam distillation method.

Sediment depth affected the partitioning between the NO_3^- reductive processes in several ways. Several researchers have shown a correlation between sediment exchangeable organic C content and the partitioning of NO_3-N in sediments (Knowles, 1982; Koike and Hattori, 1978; Tiedje, 1982). For example, assimilatory NO_3^- reduction was highest at the sediment surface 0-2 cm, where exchangeable NH_4-N was relatively low (>10 μg N mL^{-1}). Reduced denitrification activity was associated with increased C/N ratios between 13-16 at sediment depths of 27-40 cm. Other investigators have associated the pathway of NO_3^- reduction with sediment characteristic redox potentials, or indigenous NO_3^- concentrations, suggesting a correlation between NO_3^- reduction, anaerobiosis and nitrification (Kaspar, 1982). Increased redox potential and nitrification at the sediment surface may result from mixing of the relatively oxygenated lake water with the underlying sediments due to currents or to burrowing organisms (Henriksen et al., 1983). In addition, Tiedje (1982) suggested that high denitrification activity in the anaerobic lake sediment may be associated, with as yet, undiscovered populations of obligate anaerobes capable of respiratory denitrification.

Table 5.10.7. Estimation of the denitrification rates of depth sections of Lake Apopka sediment.

Depth	Denitrification rate
cm	μg N (mL sediment•h)$^{-1}$
0–2	0.0370e
2–4	0.0422d
4–6	0.0447c
6–10	0.0457c
10–15	0.0516b
15–20	0.0546a
20–25	0.0234f
25–30	0.0087g
30–35	0.0042h
35–40	0.0025h

Means followed by the same letter suffix are not significantly different at $p = 0.05$.

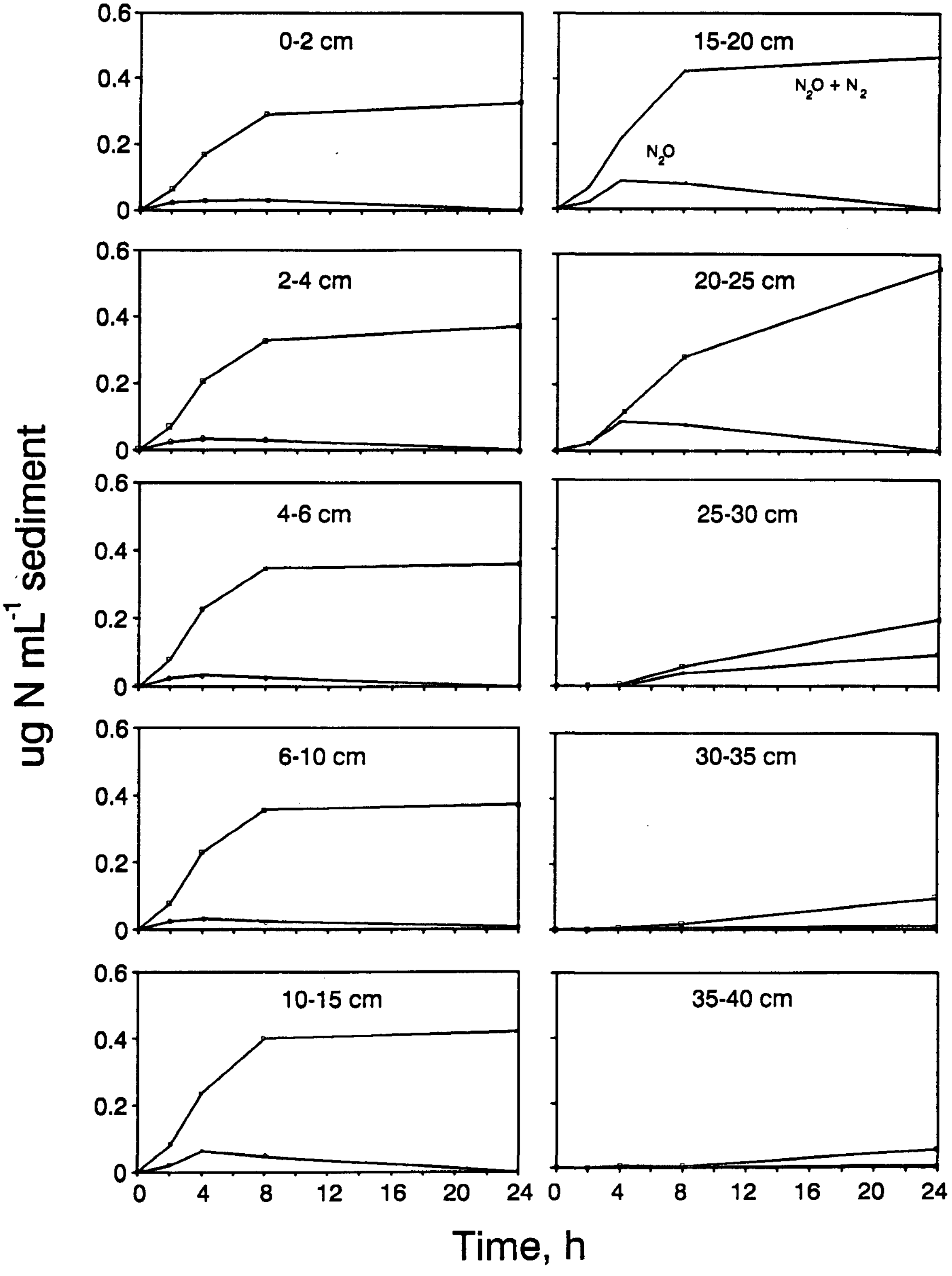

Fig. 5.10.4. Effect of sediment depth on N_2O-N and N_2-N gas production by denitrification after the addition of 1 μg NO_3-N mL^{-1} bulk sediment.

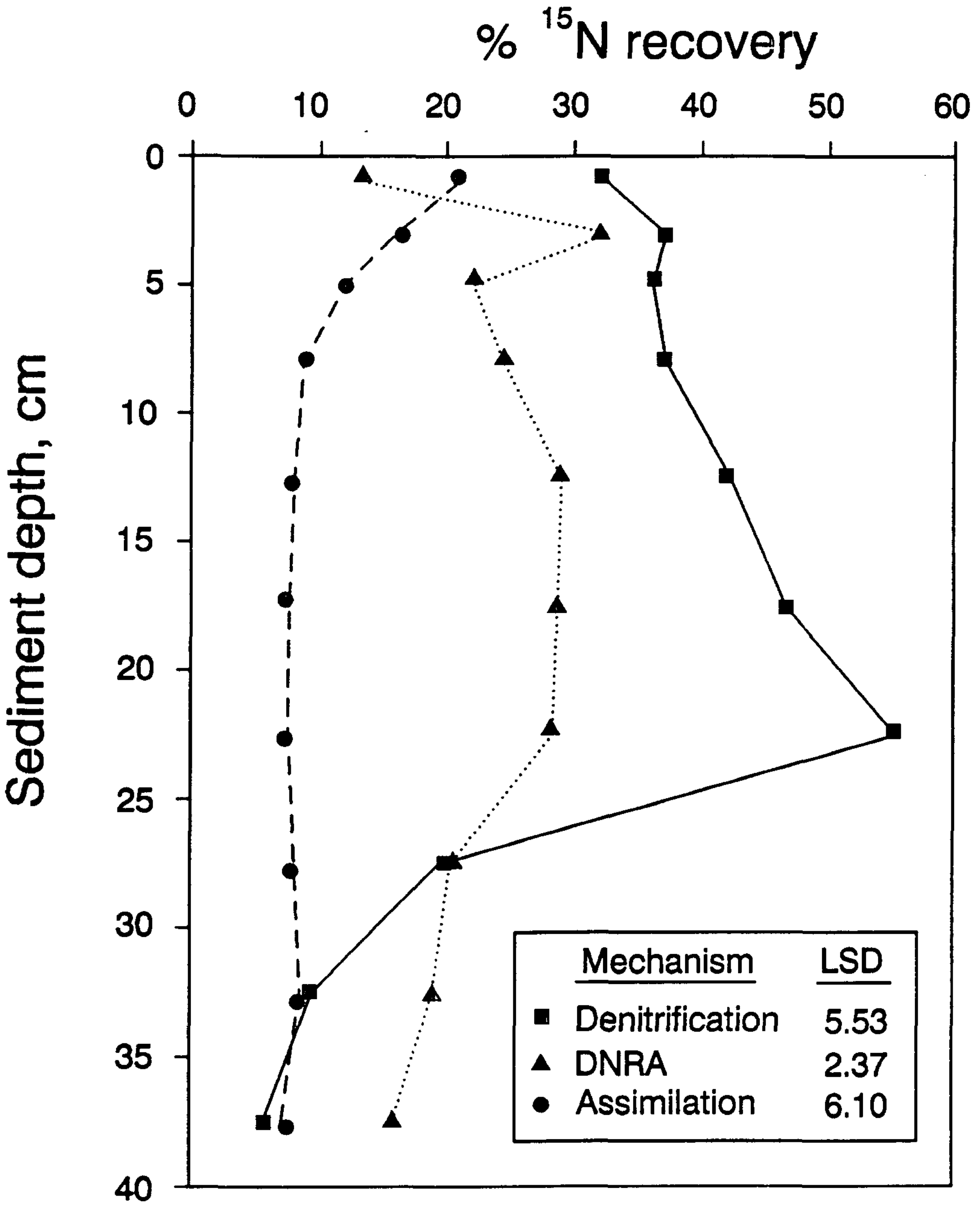

Fig. 5.10.5. Effect of sediment depth on the partitioning between the nitrate reductive processes of denitrification, dissimilatory nitrate reduction to ammonia (DNRA), and assimilation. Each value represents the mean of six replications.

Table 5.10.8. Effect of C_2H_2 on the end-product partitioning between DNRA and assimilatory NO_3^- reduction. Soil N fractions were measured 24 h after NO_3^- addition. Each value represents the mean of three repetitions.

	Mean Percent ^{15}N Recovery					
	NH_4-N		Organic N		Total sediment-N	
Depth	C_2H_2	w/o C_2H_2	C_2H_2	w/o C_2H_2	C_2H_2	w/o C_2H_2
cm						
0–2	10.2a	16.2a	18.6a	23.5a	28.8a	39.7a
2–4	30.8a	34.7a	17.2a	14.9a	47.9a	49.6a
4–6	27.6a	16.8a	12.1a	11.9a	39.6a	28.6b
6–10	28.9a	20.2a	8.3a	9.3a	37.2a	29.5b
10–15	29.5a	28.6a	10.0a	6.1b	39.5a	34.87a
15–20	29.9a	27.6a	7.5a	7.8a	37.4a	35.4a
20–25	28.5a	28.3a	8.0a	7.1a	36.5a	35.4a
25–30	18.3a	22.6a	7.6a	8.7a	25.9a	31.2a
30–35	17.6a	19.7a	8.9a	8.3a	26.5a	28.1a
35–40	13.4a	18.4a	7.1a	7.3a	25.6a	20.5a

For each N fraction, means in the same row followed by the same letter are not significantly different at $p=0.05$.

5.10.4 Conclusions

Changes in chemical, physical, and biological characteristics occurring with sediment depth significantly affected the partitioning of NO_3^- between the three reductive processes. Increased ^{15}N assimilation into the organic fraction was associated with low exchangeable NH_4-N (less than 10 μg N mL^{-1}) at the sediment surface (0-2 cm), accounting for over 21% of the total $^{15}NO_3$-N reduced. Denitrification was the major NO_3^- reductive process at sediment depths of 0-27 cm, accounting for up to 57% of the total. The high rates of denitrification suggested that *in situ* denitrification is restricted to the upper 27 cm of the sediment surface. Dissimilatory $^{15}NO_3$-N reduction to $^{15}NH_4$-N was reduced at the sediment surface (0-2 cm), accounting for about 13% of the total $^{15}NO_3$-N reduced. DNRA became the dominant NO_3^- reduction process at depths greater than 27 cm, where more reduced conditions and decreased microbial activity (evidenced by increased organic carbon levels in the porewater and in the sediment) restricted denitrification activity.

The denitrification rate was found to be directly affected by the amount of NO_3^- amended to the sediment. The denitrification capacity of the bulk sediment was between 4 to 5 times the denitrification rate measured at approximate *in situ* concentrations. Therefore, it was concluded that the denitrification rate was limited by the amount of NO_3^- in the lake sediment.

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5.11 Phosphorus Sorption by Lake Sediment [Task 3.10]

5.11.1 Introduction

There is increasing evidence that sediments play a major role in regulating dissolved P in lake waters. Several studies have shown that the rate and extent of P exchange between the sediment and the overlying water and the concentration of inorganic P in the water column depends on the capacity of sediments to either retain or release P (Williams et. al., 1970).

Adsorption and release of P by non-calcareous sediments and suspended particulate matter are controlled largely by solid phases containing iron and aluminum (Shukla et al., 1971; Lijklema, 1977; Manning and Jones, 1982; Manning et al, 1984; Lucotte and D'Anglejan, 1988) while P retention in calcareous sediments is associated with calcium carbonate (Wentz and Lee, 1969). Many studies indicated that inorganic P, when added at concentrations considerably greater than those present in the interstitial water of the sediment, is retained by a sorption rather than a precipitation mechanism (Syers et al., 1973). Results obtained from phosphate exchange studies using ^{32}P (Li et al., 1972; Furumai and Ohgaki, 1988) have provided further evidence of these mechanisms. Although sediments are less diverse than terrestrial soils in terms of mineralogical species which are potentially important in the sorption of inorganic P (Syers et al., 1973), they are heterogeneous enough to allow adsorption, precipitation, and partitioning to occur simultaneously. Because the concepts of both adsorption and precipitation imply a loss of material from an aqueous solution phase, the distinction between the two can be difficult. In addition, the chemical bonds formed in both cases may be similar (Sposito, 1984). However, the chemistry of phosphate adsorption can be demonstrated using optical methods such as magnetic resonance, x-ray photoelectron spectroscopy, infrared, and electron micrographs which can give direct evidence for the presence of an adsorbed species.

Results of P adsorption measurements, particularly those of the batch incubation method, have been shown to vary with several factors such as solid:solution ratio (Hope and Syers, 1976; Barrow and Shaw, 1979), ionic strength of background salt solution (Ryden et al., 1977), and cationic species of the supporting electrolyte (Barrow et al., 1980; Helyar et al., 1976). Nair et al. (1984) conducted an interlaboratory comparison of standard P adsorption procedures in four laboratories and found that the effect of the soil:solution ratio on P adsorption was rather inconsistent and generally smaller than the effect of the supporting electrolyte. Generally, P adsorption was found to be higher in $CaCl_2$ (0.01 M) than in KCl systems (Nair et al., 1984; Yuan and Lucas, 1982; Barrow et al., 1980; Helyar et al., 1976).

In their extensive study on equilibrating salt solutions and P adsorption, Singh and Tabatabai (1976) found that 0.01 M each of $CaCl_2$, $Ca(NO_3)_2$, $CaSO_4$, $MgCl_2$, KCl, LiCl, NaCl, and $KHCO_3$ consistently exceeded the amount of P sorbed in the soil-water system. The authors suggested the exclusion of salt solutions especially in P sorption studies related to water quality.

Adsorption and release of P is affected by, among other factors, pH and oxidation-reduction (Eh) state (Patrick and Khalid, 1974; Bostrom et al., 1982). In their study on flooded soils, Khalid et al. (1977) found that more P was released under anaerobic than under aerobic conditions. They observed that even though the anaerobic soils released more P, these were capable of sorbing high amounts of P from a high P solution.

Many of the lakes in Florida are shallow, with mean depths ranging from 1 to 8 m (Shannon and Brezonik, 1972). Lake Apopka, which is the biggest in the Oklawaha River Basin, is one of these shallow lakes and is susceptible to wind turbulence. Wind mixing of the water column in the lake can keep the sediment-water interface under aerobic conditions. However, depending on the O_2 demand and other factors, the redox potential of Lake Apopka sediments may vary seasonally. These redox changes, in turn, may regulate either retention or release of sediment phosphates into the overlying water.

The objective of this study was to determine the phosphate sorption characteristics of Lake Apopka sediments as affected by incubation period and O_2 supply.

5.11.2 Materials and methods

Bulk sediment samples (unconsolidated flocculent, UCF) were obtained from the K-6 station of Lake Apopka using an Ekman dredge. The samples were kept in large jars and refrigerated at 4°C. Prior to the phosphate sorption studies, the sediment was pre-incubated to obtain two Eh levels: anaerobic (-220 mV) and aerobic (+550 mV) conditions. To obtain an anaerobic system, the sediment was placed in duplicate 2800-mL flasks, sealed with rubber stoppers, and incubated with N_2 gas at room temperature. The sediment was stirred continuously with a magnetic stirrer. Two platinum electrodes and a reference electrode were inserted through the stopper to monitor the Eh of the sediment. The Eh readings were taken every 2 to 3 d. Aerobic conditions were obtained in the sediment using the same experimental set-up as described above, except that air (21% O_2) was bubbled through the sediment to obtain aerobic conditions. An equilibrium condition (i.e., constant Eh) in each case was attained after 24 to 30 d of incubation.

5.11.2.1 Phosphate sorption under anaerobic conditions:

Duplicate sets of 15-mL sediment samples from the anaerobic reactor were placed into sealed and deaerated centrifuged tubes. A syringe was used to withdraw the sediment from the large flask in order to maintain anaerobic conditions. Five mL of the pre-calculated standard P solution was added to the sediment to obtain final porewater P concentrations of 0, 0.05, 0.1, 0.5, 1, 2, 5 and 20 mg P L^{-1}. The final mixture had a solution: sediment (dry wt) ratio of about 250:1 based on the oven-dried weight of sediment.

Separate sets of sediment samples were shaken continuously for 12, 24, 48, 96, 192 and 384 h and then centrifuged at 5000 rpm for 15 min. The supernatant liquid was withdrawn anaerobically using a syringe and immediately injected into an anaerobic filtration apparatus. The filtrate was acidified with 1 drop of concentrated H_2SO_4 and stored at 4°C until analyzed for soluble reactive phosphorus (SRP).

To determine the effect of sediment-water ratio on P retention, a batch incubation experiment was conducted under anaerobic conditions at ambient sediment/water ratio. Sediments obtained were spiked with a known amount of P and equilibrated for 24 h as described above. After equilibration period, the sediments were centrifuged and the porewater was analyzed for SRP.

5.11.2.2 Phosphate sorption under aerobic conditions:

Adsorption isotherms from the aerobic reactor (+550 mV) were measured using the procedures described above except that the filtration was performed under an O_2 atmosphere. A 24-h shaking period was used in this set.

5.11.2.3 Effect of chloroform and toluene on P release:

Adsorption isotherm studies are usually conducted with the addition of either chloroform or toluene to suppress microbial growth. However, when used in sediments high in organic matter (algal population), these growth suppressants can cause microbial cell degradation which, in turn, could result in mineralization of organic P. This study was done in order to evaluate whether chloroform and toluene additions affect phosphate release by sediments within the 24-h equilibration period.

Triplicate 15-g wet sediment samples were added to centrifuge tubes containing 5 mL of filtered (0.45 μm) lake water to obtain a solution:sediment ratio similar to those used in the adsorption studies. Sediment samples received either 3- or 6-drop treatments of either chloroform or toluene. A control set (without chloroform or toluene) was also included.

The samples were equilibrated for 24 h and centrifuged at 5000 rpm for 15 min. The supernatant liquid was filtered using 0.45 μm filter paper, acidified with 1 drop of concentrated H_2SO_4, and analyzed for SRP.

5.11.2.4 Phosphate adsorption as influenced by oxygen supply:

In a separate study, bulk sediments obtained from the K-6 station were incubated for 100 d at 0, 0.2, 2.0 and 20% O_2. For details of the incubation procedures see Chapter 5.1 of this report. After 100 d of incubation under these controlled environments, sediment samples were withdrawn from each flask for phosphate adsorption isotherm studies as described above. The P isotherms for the 0, and 0.2% O_2 were performed under anaerobic conditions, while those for the 2 and 20% O_2 were done under aerobic conditions. Standard P solutions were added to the sediments to obtain final porewater P concentrations of 0, 0.05, 0.1, 0.5, 1.0, 2.0, 5.0, and 20.0 mg L^{-1}. The sediment samples were equilibrated for a period of 24 h and centrifuged at 5000 rpm. The porewater extracted was filtered and analyzed for SRP.

5.11.2.5 Phosphate desorption by sediment:

A batch incubation was conducted in order to determine the desorption characteristics of the K- sediments as affected by chloroform additions. Triplicate samples of the sediments, with or without chloroform (4 drops), were added with filtered water (0.45 μm) at a solution:sediment ratio of about 30:1. The sediments were incubated under anaerobic conditions in the dark. After 24 h, the samples were shaken for 1 h and centrifuged. The supernatant liquid was filtered under anaerobic condition and the filtrate was analyzed for SRP. The residual sediment was treated with filtered lake water (with or without 4 drops of chloroform) and incubated in the dark for 24 h and subsequently shaken for 1 h. The supernatant liquid was filtered and analyzed for SRP. This procedure was repeated daily for the first 10 d and every 2 to 3 d thereafter for a total period of 10 d. The filtrates were acidified with 1 drop of concentrated H_2SO_4 and analyzed for SRP. All extracted solutions were analyzed for SRP using an autoanalyzer (APHA, 1985).

Triplicate sediment samples obtained from the experiment reported in 5.11.2.1 and 5.11.2.2 were used to estimate P desorption of the sediments. After initial removal of porewater, the residual sediment was treated with filtered (0.45 μm) Lake Apopka water to attain an initial sediment water ratio. The sediment suspensions were shaken on a mechanical shaker for a period of 1 h, followed by centrifugation at 5000 rpm for 15 min and removal of supernatant liquid. The residual sediment was then treated with filtered lake water as described above for an additional 5 cycles. All filtrates were acidified and analyzed for SRP.

5.11.2.6 Calculations:

Phosphorus adsorbed by the sediments was calculated as follows:

$$(C_o \cdot V - C_t \cdot V) / M = S^1 \qquad [1]$$

where:

C_o = concentration of P added, mg L^{-1}
V = volume of liquid, L
C_t = concentration of P in solution after 24-h shaking period, mg L^{-1}
M = mass of dry sediment, kg
S^1 = P adsorbed, mg kg^{-1}

Equation [1] is used primarily to calculate the P lost (adsorbed) or released (desorbed), in relation to P added to the sediment. These calculations do not take into account the amount of native P in the adsorbed phase. The total amount of P sorbed by the sediment can be calculated as follows:

$$S = S^1 + S_o \qquad [2]$$

where:

S = total amount of P sorbed, mg kg^{-1}
S^1 = amount of added P sorbed, mg kg^{-1}
S_o = native sorbed P, mg kg^{-1}

The S_o can be estimated using a least squares fit of S^1 measured at low equilibrium concentrations. The y axis intercept represents S_o for the sediment. The sum of $(S^1 + S_o)$ represents the actual amount of P adsorbed at respective equilibrium P concentrations. The value of S_o can also be estimated by: (1) using an isotopic dilution method, and determining exchangeable P, and (2) extractable P measured using an anion exchange resin method. Adsorption parameters can be obtained by fitting the data to the two most commonly used adsorption isotherm equations.

Langmuir:

$$S = \frac{S_{max}\, k\, C}{1 + kC} \qquad [3]$$

where:

S = the total amount of P in adsorbed phase $(S^1 + S_o)$, mg kg^{-1}
S_{max} = adsorption maximum at which phosphate forms a monolayer on a solid surface, mg kg^{-1}
k = a constant related to bonding energy, L mg^{-1} P
C = solution P concentration measured after a 24-h shaking period, mg L^{-1}

Freundlich:

$$S = K\, C^{1/n} \qquad [4]$$

where:

S = same as in equation [3]
K = adsorption constant, L kg^{-1}
C = solution P concentration measured after 24-h equilibration period, mg L^{-1}

Equation [4] is written in linear form as

$$\log S = 1/n (\log C) + \log K \qquad [5]$$

Least squares fit of log S vs log C should yield a straight line with intercept, log K, and slope 1/n. For some systems the adsorption process may follow simple linear relationships and under these conditions, the exponent in equation [4] will be unity, hence,

$$S = KC \qquad [6]$$

where the parameters S, C and K are the same as described in equation [4].

5.11.2.7 Sediment characterization:

The sediments were analyzed for extractable Fe, Al, Ca, and Mg. Data from these analyses were tested for correlation with the sorption parameters.

A. $CuCl_2 \cdot 2H_2O$ extractable-Al (Juo and Kamprath, 1979)

Five grams of sediment samples were placed into centrifuge tubes and added with 15 mL of 1 N $CuCl_2 \cdot 2H_2O$ (pH 3.0). The samples were shaken for 2 h and centrifuged at 5000 rpm for 10 min. The supernatant liquid was filtered (0.45 μm) under anaerobic conditions and stored at 4°C for Al determination. Aluminum was measured using an atomic adsorption spectrophotometer.

B. Ammonium oxalate extractable-Fe/Al (McKeague and Day, 1966)

Fifteen mL of 0.2 M ammonium oxalate (acidified to pH 3.0 with oxalic acid) was added to 5-g samples and shaken for 4 h in the dark. The samples were centrifuged and filtered (0.45 μm) and stored at 4°C until analyzed for Fe and Al by atomic absorption spectrophotometry.

C. Citrate-dithionite-bicarbonate (CDB) extractable Fe and Al
(Mehra and Jackson, 1960)

Five grams of sediment samples were added to 20 mL of 0.3 M sodium citrate and 2.5 mL of 1 M $NaHCO_3$. The mixture was heated to 80°C in a water bath. About 1/2 g of solid $Na_2S_2O_4$ was added and the mixture was stirred constantly for 1 min, then occasionally for 15 min. At the end of the 15-min digestion period, 5 mL of saturated NaCl solution was added to promote flocculation. The suspension was then mixed, warmed in a water bath, and centrifuged at 5000 rpm for 10 min. The supernatant liquid was filtered (0.45 μm) and stored at 4°C until analyzed for Fe and Al by atomic absorption spectrophotometry.

D. HCL extractable Fe, Al, Ca, and Mg

Five grams of wet sediment were placed in 50-mL centrifuge tubes and treated with 15 mL of 1 N HCl. The mixture was shaken for 3 h, centrifuged and filtered (0.45 μm). The filtrate was stored at 4°C until analysis of the metals Fe, Al, Ca, and Mg by atomic absorption spectrometry.

E. KCl extractable Ca and Mg

Five grams of wet sediment was placed in 50-mL centrifuge tubes and treated with 15-mL of 1 N KCl. The mixture was shaken for 2 h, centrifuged and filtered (0.45 μm). The filtrate was stored at 4°C until analyzed for Ca and Mg using atomic absorption spectrometry.

5.11.3 Results and discussion

5.11.3.1 Phosphate adsorption as influenced by equilibrium period:

During the 24-h equilibrium period, addition of either chloroform or toluene showed no significant effect on P release as compared to the sediment not treated with microbial retardants (Table 5.11.1). These results suggest that within the 24-h shaking period, microbial activity had no significant effect on P concentration of the porewater.

The phosphate sorption isotherms measured under anaerobic conditions at various equilibration periods are shown in Figs. 5.11.1 - 5.11.3. The change in P concentration in porewater after a pre-determined equilibrium period was assumed to be due to P adsorption or desorption by the solid phase. Net loss of P from porewater after equilibrium period suggests that P is adsorbed by the solid phase, while net P increase in the porewater is due to desorption from solid phases. The change in P concentration of solution is normalized to the dry weight solid phase (y axis on Figs. 5.11.1 - 5.11.3).

Results show that P adsorption was affected by equilibrium period, especially at 8 and 16 d. For incubation periods up to 96 h, P adsorption did not occur at porewater P concentrations of less than 3.1 mg L^{-1}. As the incubation period increased, P retention by the sediments also increased.

Incubation time also affected the equilibrium P concentration (EPC_o). EPC_o is referred to as the concentration at which point adsorption by solid phases will be equal to desorption (the point of intersection of solution P concentration on x axis of Fig. 5.11.1 - 5.11.3). Under anaerobic conditions, the EPC_o value was 9.6 mg P L^{-1} for sediments equilibrated for 12 h and decreased to 3.7 mg P L^{-1} in 24 h, the standard equilibrium period used in many adsorption isotherm experiments. The EPC values drastically decreased to 0.2 mg L^{-1} at the end of 384 h, suggesting that at longer equilibrium periods, precipitation rather than adsorption is probably regulating P retention in Lake Apopka sediments. At a longer incubation period, it is also likely that microbial assimilation probably resulted in decreased EPC. The high EPC values of the sediments suggest that the direction of P release would be from sediment to water column, since lake water SRP concentrations are typically less than 0.1 mg P L^{-1}. EPC values for Lake Apopka are in the range of 0.2 - 4.5 mg P L^{-1} for equilibrium periods in the range of 24-384 h. Pollman (1983) reported EPC values of 0.08 - 0.52 mg P L^{-1} for Lake Okeechobee sediments and 0.47 - 2.0 mg P L^{-1} for Lake Apopka sediments. Nisson (1975) measured EPC values in the

Table 5.11.1. Effects of chloroform and toluene on soluble reactive P (SRP) release by lake sediments (K-6 Apopka).

Treatments	SRP*
	mg L^{-1}
Control	1.35
3 drops toluene	1.35
6 drops toluene	1.62
3 drops chloroform	1.57
6 drops chloroform	1.53

*Values are not significant at 0.05 level.

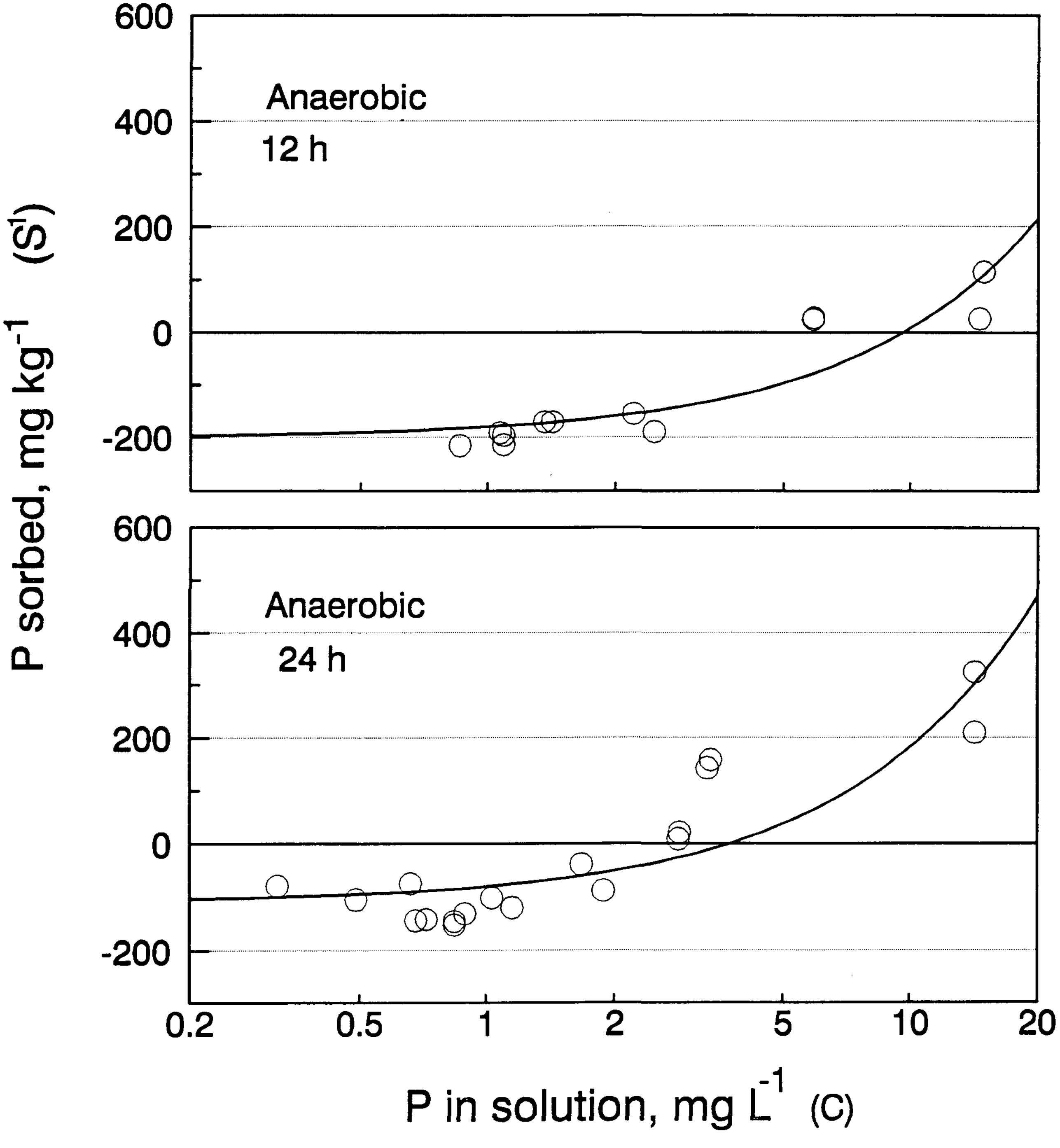

Fig. 5.11.1. Phosphate adsorption isotherms of Lake Apopka sediments equilibrated under anaerobic conditions for 12 and 24 h. S^1 = P sorbed and C = equilibrium P concentration (see Equation [1]).

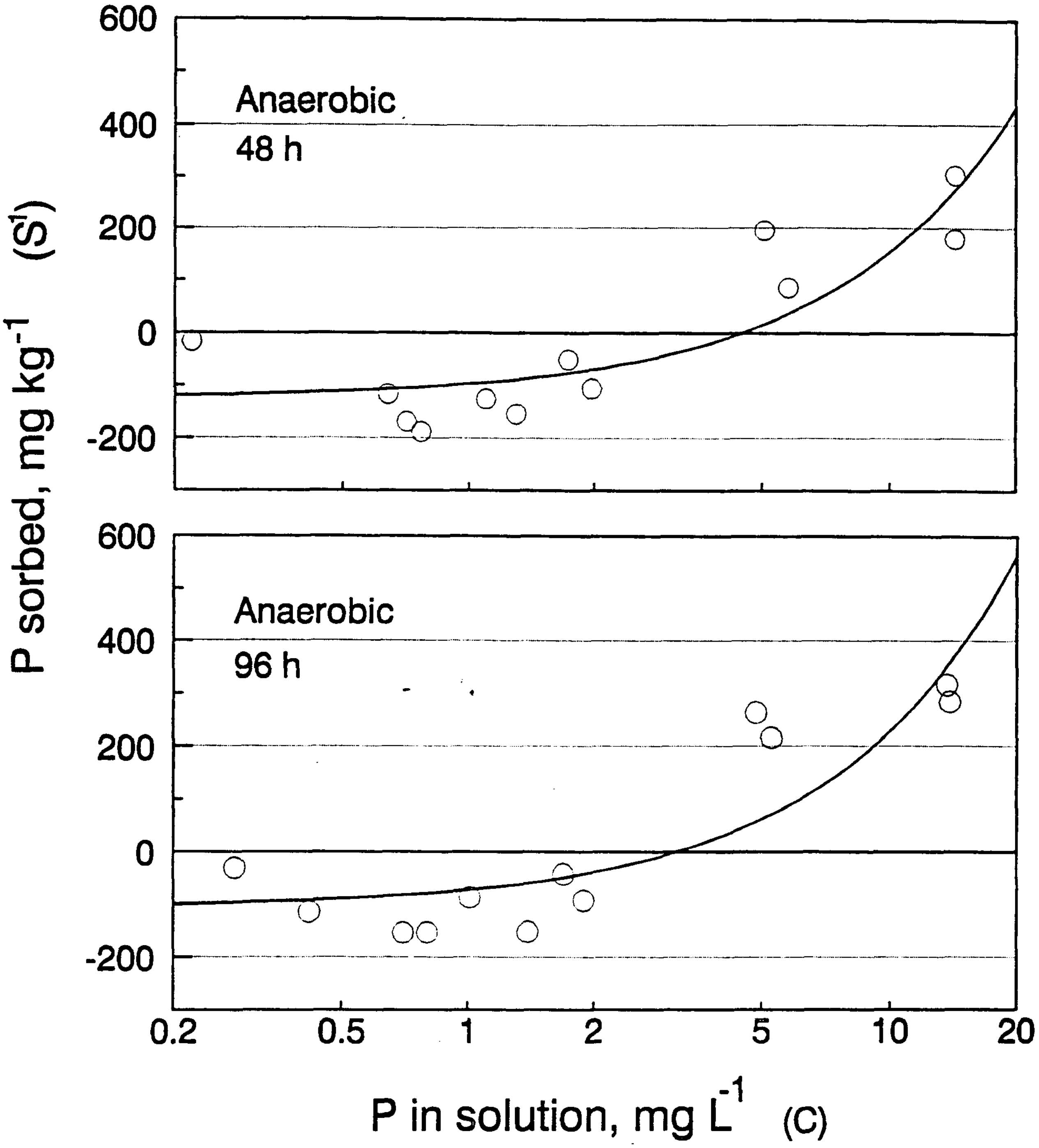

Fig. 5.11.2. Phosphate adsorption isotherms of Lake Apopka sediments equilibrated under anaerobic conditions for 48 and 96 h. S^1 = P sorbed and C = equilibrium P concentration (see Equation [1]).

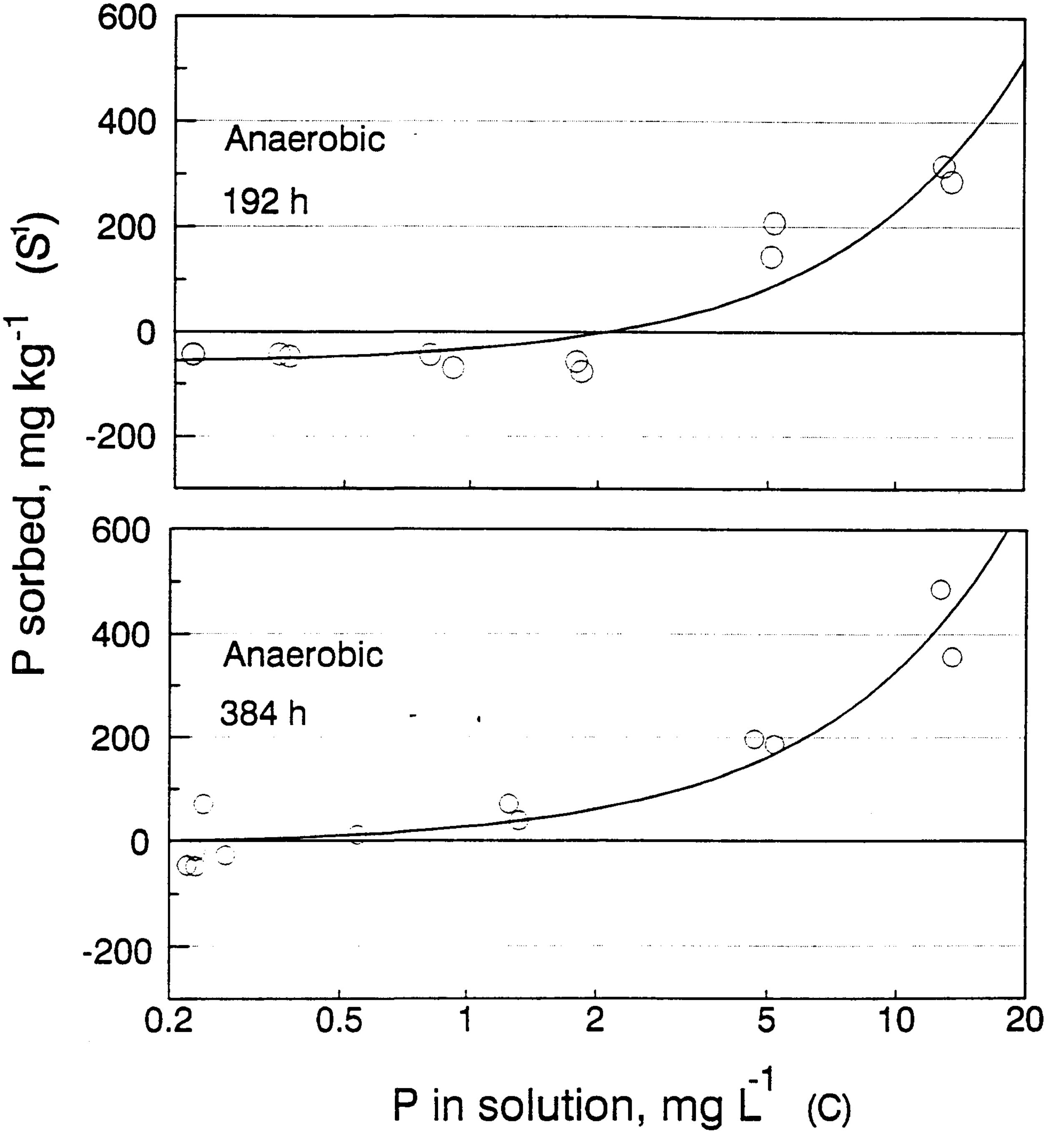

Fig. 5.11.3. Phosphate adsorption isotherms of Lake Apopka sediments equilibrated under anaerobic conditions for 192 and 384 h. S^1 = P sorbed and C = equilibrium P concentration (see Equation [1]).

range of 0.08 - 2.0 mg P L^{-1} for selected Florida lakes (Lakes Harney, Jessup and Monroe).

Adsorption isotherms presented in Figs. 5.11.1 - 5.11.3 were not corrected for initially adsorbed P. The initially adsorbed P was estimated using a linear regression between P adsorbed and P in porewater. The intercept of the resulting equation was assumed to be the P present in adsorbed phase (S_o) in sediments (Table 5.11.2). The value S_o was included in estimating adsorption parameters. Within the concentration ranges evaluated, P adsorption was evaluated by a simple linear isotherm as shown in Eq. [6]. Since the data did not fit well with the Langmuir or Freundlich equations (Eq. 3 and 4), the adsorption coefficient (K) increased with decrease in EPC values (Table 5.11.3). Because of low sorption capacity and high EPC values, no attempt was made to estimate adsorption maxima for Lake Apopka sediments.

Data on adsorption capacity of the sediments measured at ambient water content of the sediments are presented in Fig. 5.11.4. Phosphate adsorption showed different characteristics when solution to sediment ratio was 25:1 on dry weight basis. EPC_o values were significantly higher (13.8 mg P L^{-1} at ambient sediment/solution ratio = 25:1) than those measured at solution to sediment ratio of ≈250:1. Similarly, the adsorption coefficient was 7.03 L kg^{-1}, which is about three times lower than the values obtained at high sediment to water ratio. Practical implications on the effects of sediment-water ratio needs further evaluation.

Data presented in Fig. 5.11.5 compare P sorption behavior of the sediments under aerobic and anaerobic sediments. Under aerobic conditions, EPC was found to be 2-fold higher than the EPC values under anaerobic conditions. Low adsorption capacity of the oxidized sediment was due to large concentrations of initially adsorbed P (Table 5.11.2), probably due to mineralization of organic P. The linear adsorption coefficients were 21 and 35 L kg^{-1} for anaerobic and aerobic sediments, respectively. At low solution P concentrations (< 8 mg P L^{-1}), P adsorption by sediments was the same under both aerobic (oxidized, 550 mV) and anaerobic (reduced, -250 mV) conditions.

5.11.3.2 Phosphate adsorption as influenced by oxygen supply:

Adsorption behavior of the sediments exposed to varying levels of O_2 was similar to those observed for the sediments maintained under aerobic or anaerobic conditions (Figs. 5.11.6 - 5.11.8). At low O_2 levels (0 and 0.2% O_2), the Eh of sediments was low (-300 mV) and the pH was high (8.5). The P adsorbed initially (S_o and EPC values) for these sediments are given in Tables 5.11.4 and 5.11.5. The anaerobic sediment (0% O_2) in this experiment was allowed to equilibrate at constant temperature for 100 d under a CO_2-free atmosphere (sediments from experiments reported in Chapter 4). These conditions resulted in a significantly higher pH than normally encountered in Lake Apopka sediments. In the concentration range evaluated, the P adsorption behavior in the sediments exposed to varying levels of O_2 was best described by a simple linear relationship. Because

Table 5.11.2. Linear regression equations used to estimate initially adsorbed P (S_o) in sediments equilibrated for various incubation periods. The adsorption isotherms related to these equations are presented in Figs. 5.11.1 and 5.11.5.

Treatment	Incubation period	$S = KC - S_o$	r^2
	——h——		
Anaerobic	12	$S = 20.8C - 200$	0.797
	24	$S = 28.9C - 108$	0.747
	48	$S = 27.9C - 125$	0.754
	96	$S = 33.4C - 105$	0.752
	192	$S = 29.2C - 62$	0.887
	384	$S = 33.5C - 6$	0.915
Aerobic	24	$S = 34.7C - 289$	0.828

Table 5.11.3. Phosphate adsorption coefficients expressed as linear adsorption isotherms for sediments (K-6) equilibrated for various incubation periods. Approximate sediment-solution ratio = 250:1.

Equilibration period	pH	Eh	EPC_o	K	r^2
—h—		mV	mg L^{-1}	L kg^{-1}	
Sediment/Solution Ratio = 250:1:					
Anaerobic:					
12	7.2	-250	9.6	20.8	0.797
24	7.0	-250	3.7	28.9	0.747
48	7.0	-250	4.5	27.9	0.754
96	7.1	-250	3.1	33.4	0.751
192	—	—	2.1	29.2	0.887
384	—	—	0.2	33.5	0.915
Aerobic:					
24	7.3	500	8.3	34.7	0.828
Sediment/Solution Ratio = 25:1:					
Anaerobic:					
24	6.8	—	13.7	7.0	0.871

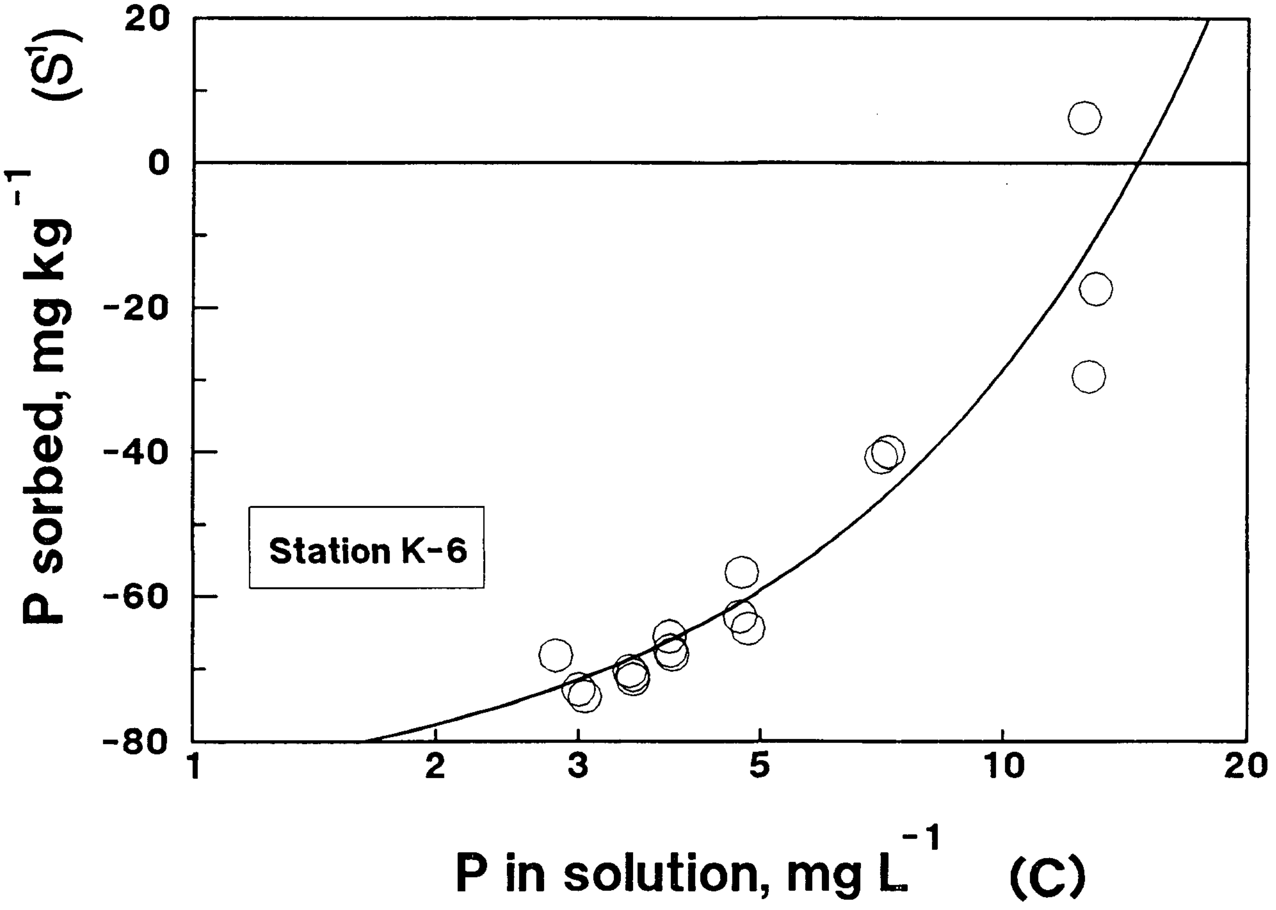

Fig. 5.11.4. Phosphate adsorption isotherms of Lake Apopka sediments (station K-6). Isotherms determined at ambient sediment/water ratio.

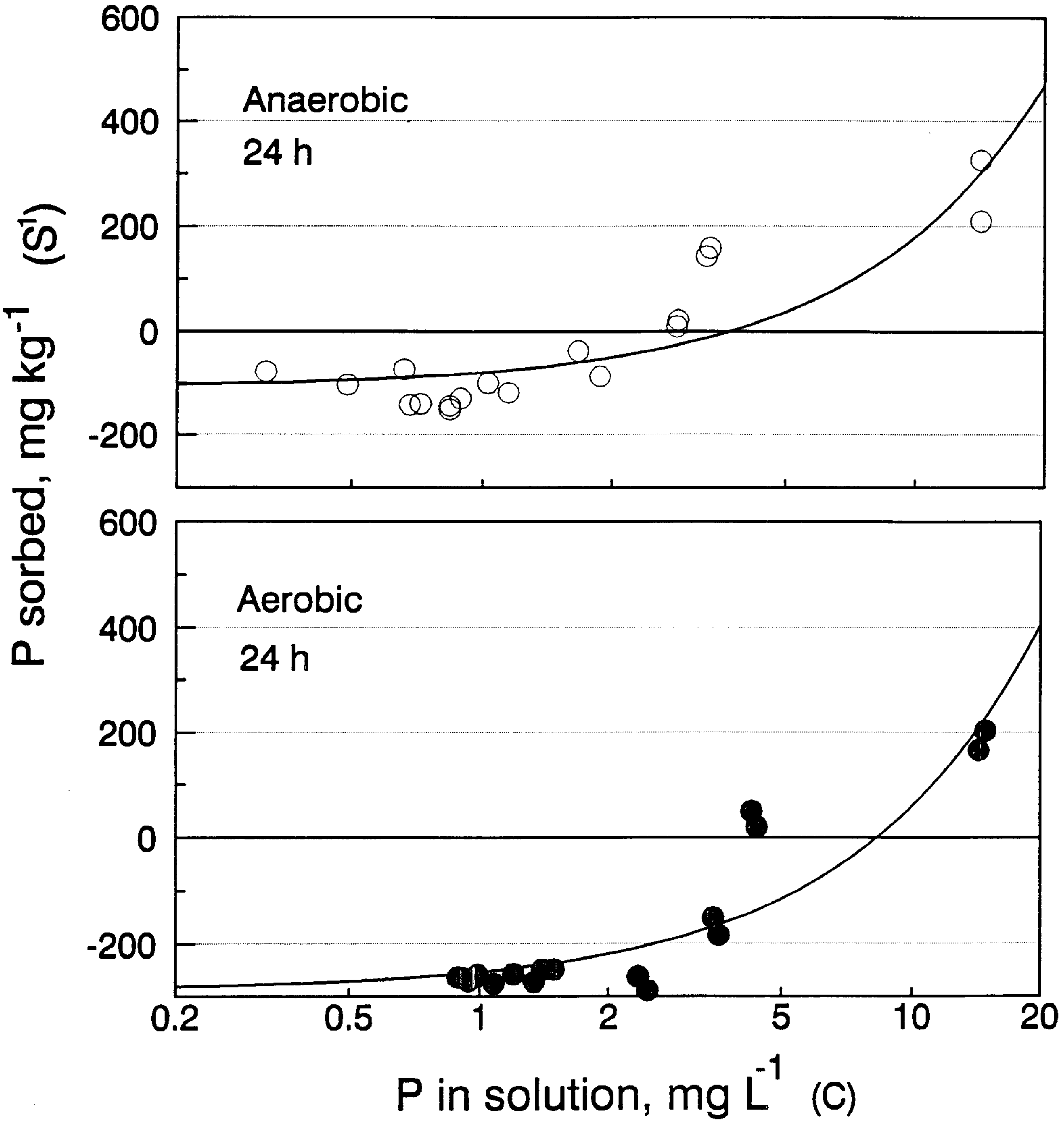

Fig. 5.11.5. Phosphate adsorption isotherms of Lake Apopka sediments measured under aerobic and anaerobic conditions. S^1 = P sorbed and C = equilibrium P concentration (see Equation [1]).

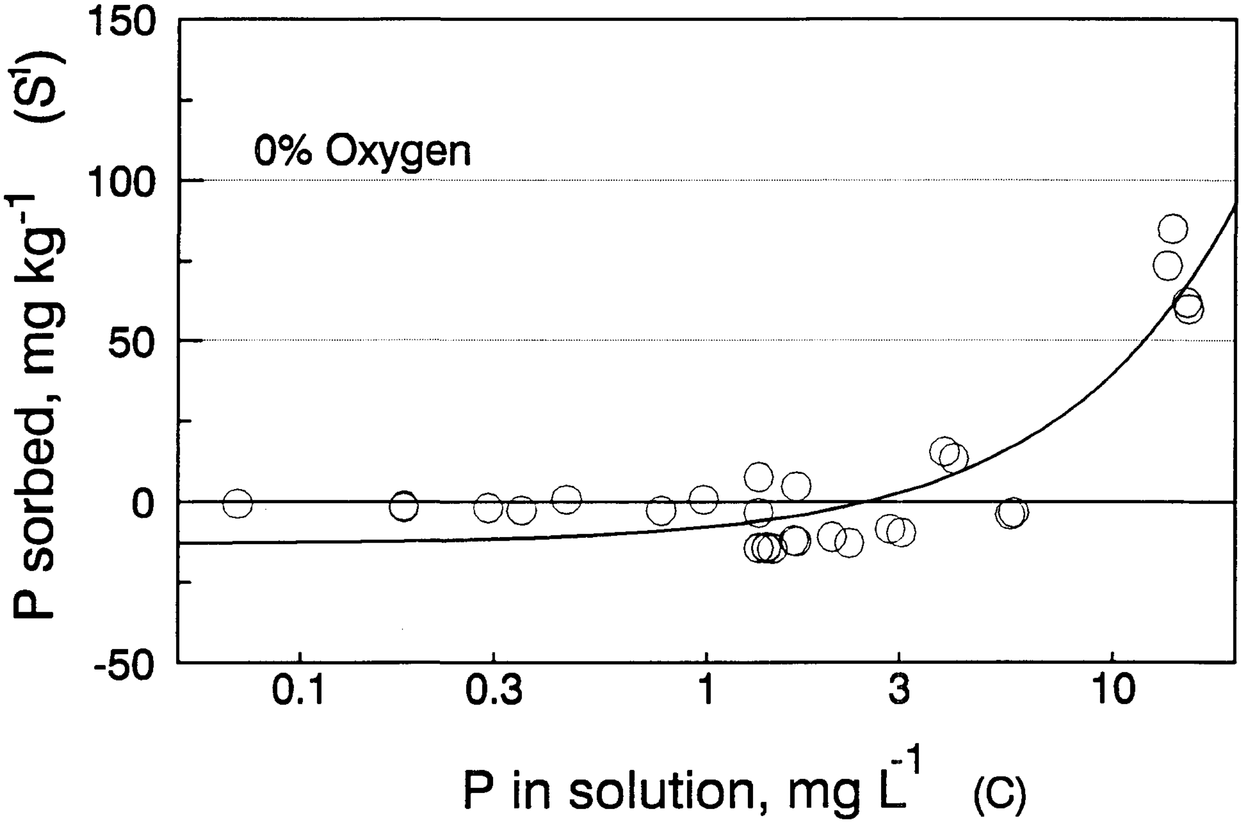

Fig. 5.11.6. Phosphate adsorption isotherms of Lake Apopka sediments incubated for 100 d under 0% O_2 level. S^1 = P sorbed and C = equilibrium P concentration (see Equation [1]).

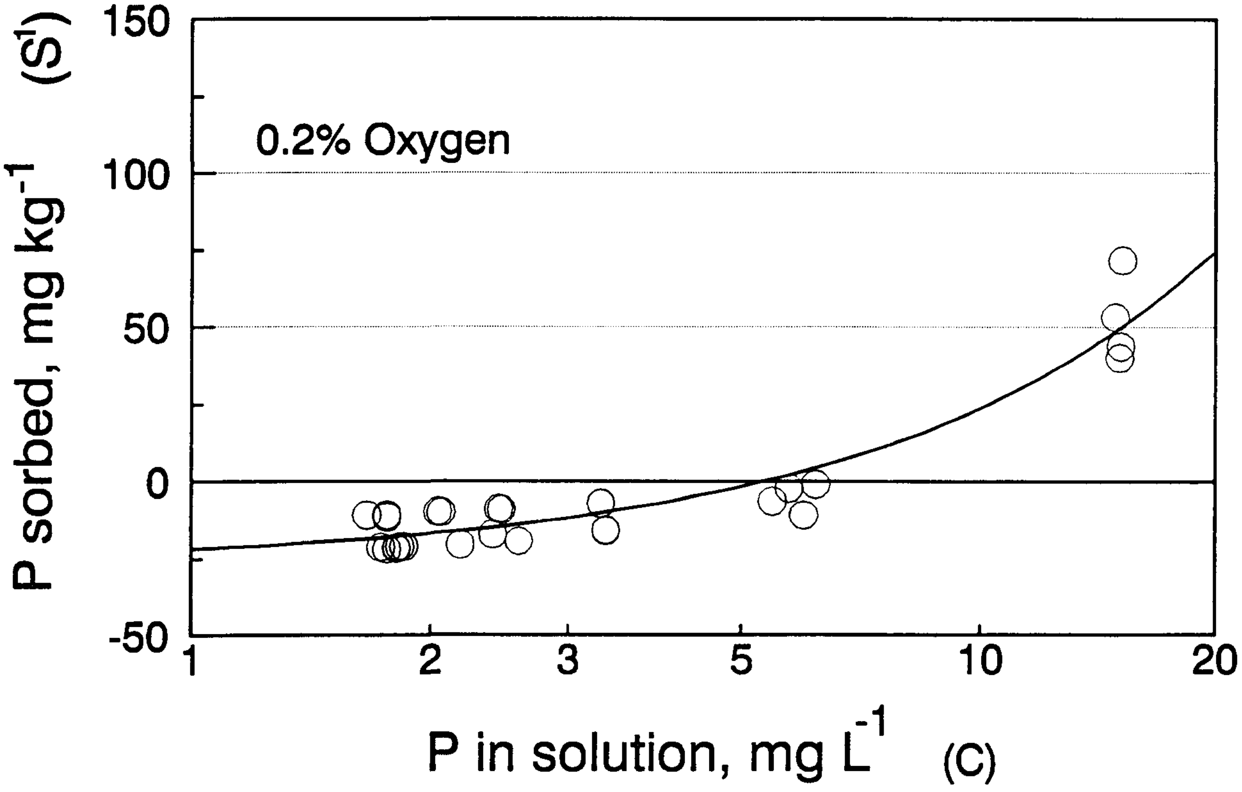

Fig. 5.11.7. Phosphate adsorption isotherms of Lake Apopka sediments incubated for 100 d under 0.2% O_2 level. S = P sorbed and C = equilibrium P concentration (see Equation [1]).

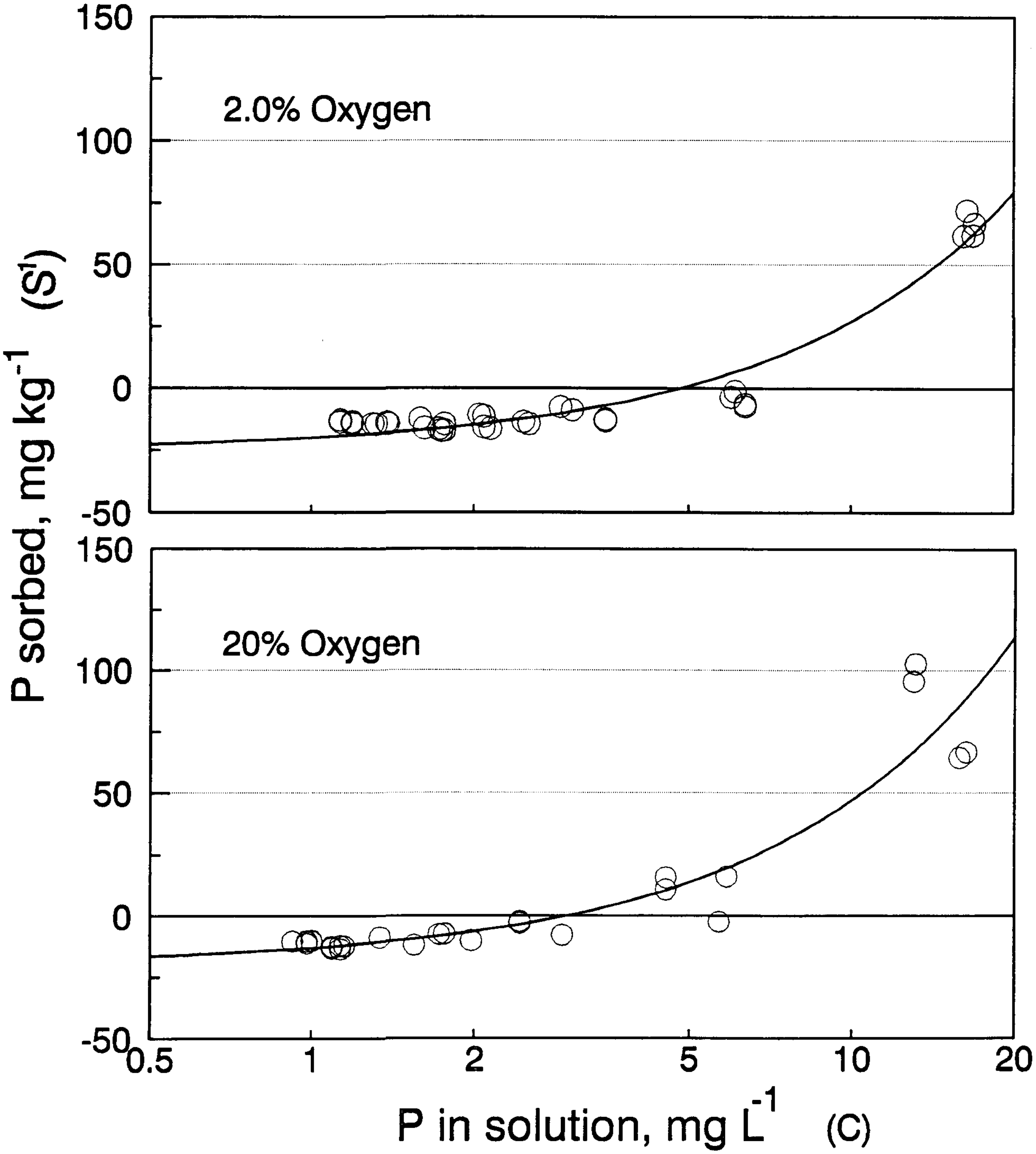

Fig. 5.11.8. Phosphate adsorption isotherms of Lake Apopka sediments incubated for 100 d under 2 or 20% O_2 level. S' = P sorbed and C = equilibrium P concentration (see Equation [1]).

Table 5.11.4. Linear regression equation used to estimate initially adsorbed P (S_o) in sediments (K-6) exposed to various levels of O_2 for 100 d. The adsorption isotherms related to these equations are presented in Figs. 5.11.6 - 5.11.8.

Oxygen supply	$S = KC - S_o$	r^2
%		
0	S = 5.31C - 13.2	0.815
0.2	S = 5.08C - 26.9	0.904
2.0	S = 5.22C - 25.2	0.950
20.0	S = 6.68C - 19.7	0.881

Table 5.11.5. Phosphate adsorption coefficients for a linear adsorption isotherm for sediments (K-6) exposed to various O_2 levels for 100 d.

Oxygen supply	pH	Eh	EPC	K	r^2
%		mv	mg L^{-1}	L kg^{-1}	
0	8.7	-300	2.5	5.31 ± 0.36	0.82
0.2	8.7	-300	5.3	5.08 ± 0.21	0.90
2.0	8.0	500	4.8	5.22 ± 0.16	0.95
20.0	7.5	500	2.9	6.68 ± 0.34	0.88

of high pH conditions in these sediments, at high solution P concentration, precipitation of P as calcium phosphates is a more likely retention mechanism than adsorption (Table 5.11.5).

Data on extractable Fe, Al, Ca and Mg in sediments are presented in Table 5.11.6. Extractable Ca was found to be several fold higher than Fe, Al and Mg. Porewater Ca and Mg concentrations (see Chapter 3) are also several fold higher than Fe and Al. Alkaline pH associated with high concentrations of Ca and Mg suggests that inorganic phosphate can form stable complexes. Iron and Al are in relatively insoluble forms under alkaline conditions, thus they may not play a significant role in P retention in Lake Apopka sediments. The experiments described here are preliminary and future research should be addressed to evaluate the factors regulating P retention, especially during sediment resuspension in the water column.

5.11.3.3 Desorption studies:

Figure 5.11.9 shows the desorption characteristics of the lake sediments (no chloroform added), when extracted sequentially over a period of 10 d. About 85% of the initially adsorbed P was desorbed on the first day of extraction, decreasing the porewater P concentration from 5 mg P L^{-1} to 1.5 mg P L^{-1}. At the end of two weeks, the concentration of P decreased to 0.5 mg L^{-1}. Addition of chloroform to suppress the microbial activity resulted in elevated levels of soluble P in the sediments. Because chloroform was added (4 drops) regularly together with the extracting solution (filtered lake water), its effect on P release was quite noticeable.

Phosphorus desorption potential of sediments was also estimated by repeated extractions with filtered lake water, by allowing 1 h equilibration time between each extraction (Fig. 5.11.10). During six successive extractions, porewater SRP concentrations decreased by more than 95%. The SRP concentrations of the porewater decreased by about 80% after the first extraction, followed by a much slower release during subsequent extractions. Desorption was similar under aerobic and anaerobic conditions. These results suggest that during repeated wind-driven resuspension events, the first resuspension is more likely to release more P than subsequent resuspension events.

5.11.4 Conclusions

Phosphate adsorption for Lake Apopka sediments was best described by a simple linear isotherm. The adsorption coefficient (K) decreased as a function of equilibration period. High P retention at longer incubation periods was probably due to precipitation of calcium phosphates, rather than adsorption. The EPC values under anaerobic conditions were in the range of 0.2 - 9.6 mg P L^{-1}, while the K values were in the range of 21-35 L kg^{-1} at sediment to solution ratio of 250:1. At ambient sediment-solution ratios, the EPC value was 13.8 mg L^{-1} and K was 7.03 L kg^{-1}, which is significantly different than those observed at high sediment-liquid ratios. High EPC values suggest that direction of P transport is from sediment to

Table 5.11.6. Extractable aluminum, iron, calcium and magnesium in Lake Apopka sediments (Station K-6) under aerobic and anaerobic conditions.

Extractant	Element	Anaerobic	Aerobic
		mg kg^{-1}	
Ammonium oxalate (0.2 M, pH 3.0)	Al Fe	552 129	649 140
Citrate dithionite bicarbonate (CDB)	Al Fe	498 533	471 564
1 N $CuCl_2$ H_2O	Al Fe	103 ND	112 ND
1 N HCl	Al Fe	604 252	— —
Mehlich I (0.05 N HCl + 0.025 N H_2SO_4)	Al Fe Ca Mg	— — — —	156 24 20,620 1,716

ND = not detected.

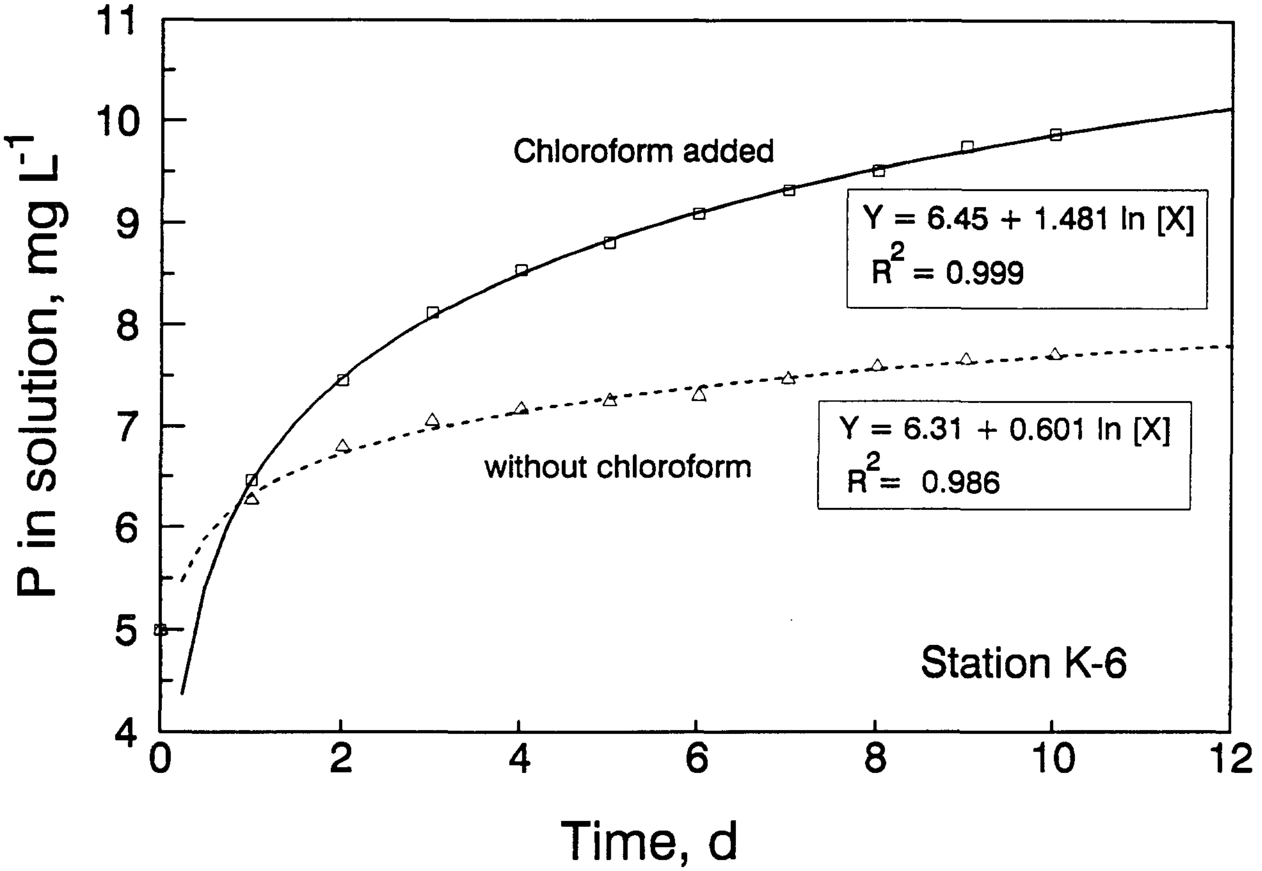

Fig. 5.11.9. Cumulative phosphate release from Lake Apopka during sequential extraction with filtered lake water during a 10 day incubation period.

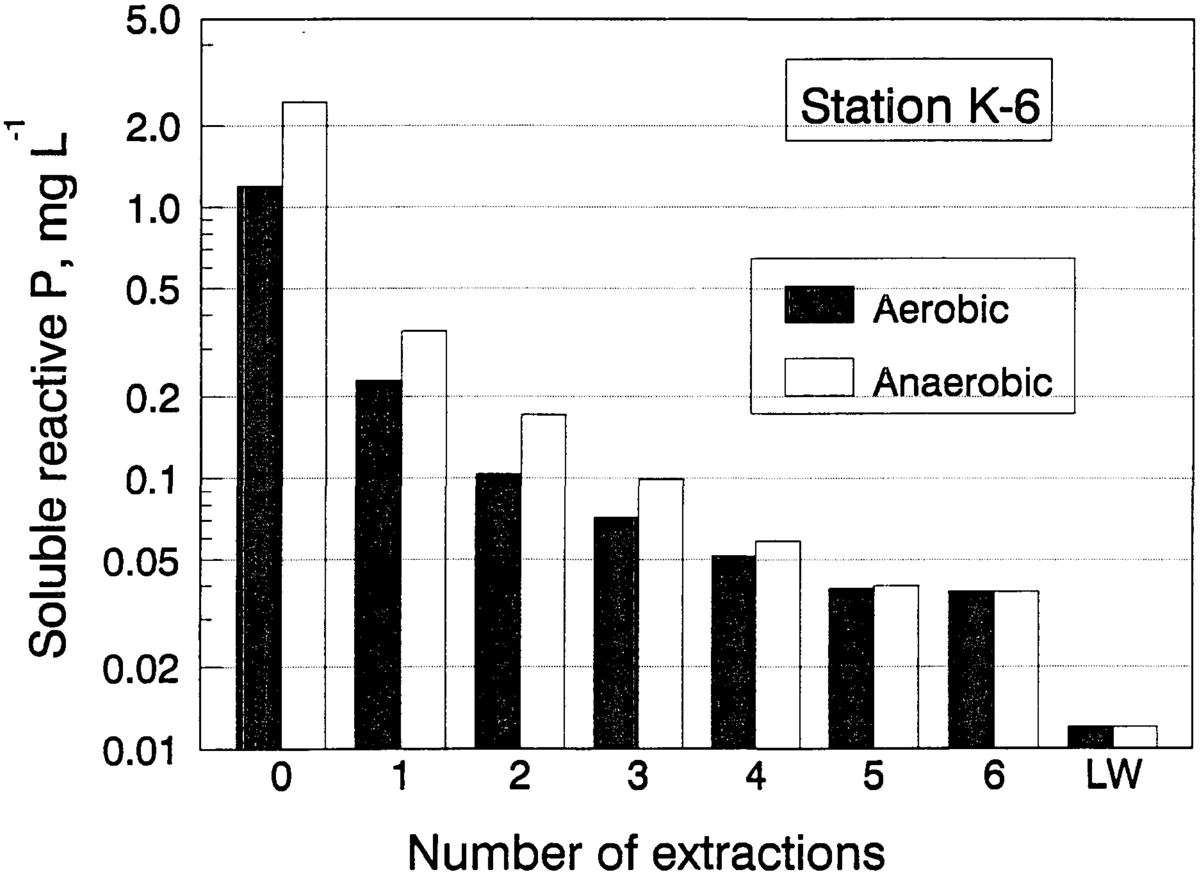

Fig. 5.11.10. Phosphate desorption by Lake Apopka sediments during repeated extraction with filtered (0.45 μm) lake water. LW = lake water.

water column, since lake water SRP values were usually lower than the EPC of sediment.

The phosphate adsorption isotherms obtained at different levels of O_2 did not follow either Freundlich or Langmuir equations, but could be best described by linear relationships. The mechanism by which the added phosphate was lost from the solution is not yet well understood, but the results suggest that at high solution P concentration, precipitation is a likely mechanism retaining P. A linear correlation existed between the phosphate removed from solution and the solution P concentration with K values in the range of 5.1 - 6.7 L kg^{-1}, while EPC values were in the range of 2.5 - 5.3 mg P L^{-1}, respectively, for various O_2 levels.

The results presented are preliminary and further evaluation is needed to quantitatively evaluate the P retention mechanisms in different horizons of sediments. Some of the critical data needed are: (1) P retention coefficients as a function of depth, especially on micro-scale sections in surface sediments, (2) short-term P retention/release mechanisms at the sediment-water interface, (3) P retention/release kinetics during sediment resuspension, and (4) long-term stability of phosphate complexes in the sediment-water column. These data are needed to evaluate whether the sediments are functioning as a source of P to the water column or as a sink.

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5.12 Diffusion of Soluble Phosphorus in the Sediment-Water Column [Task 3.11]

5.12.1 Introduction

One of the important sources of soluble reactive P (SRP) to the overlying water column is the transport from the underlying anaerobic sediments. Phosphate from sediment can be transported by means of: (1) desorption of P from sediment particles during sediment resuspension as a result of hydrodynamic events, and (2) molecular diffusion of phosphate from the sediment to the water column. The SRP concentration gradients in the sediment profile (see Chapters 4.2 and 7.2) below 8 cm depth suggest that molecular diffusion may be an important mechanism in controlling the transport of SRP across the sediment-water interface (Thibodeaux, 1979; Vanderborght et al., 1977; Berner, 1977; Murray et al., 1978; Lasaga and Holland, 1976). Li and Gregory (1974) reported $H_2PO_4^-$ diffusion coefficients (D) of 0.634 - 0.731 $cm^2\ d^{-1}$ measured at infinite dilution. these values, however, will be lower in consolidate sediments, as a result of tortuosity and adsorption effects. Krom and Berner (1980) reported D value of 0.311 $cm^2\ d^{-1}$ for bulk marine sediments, after making corrections for tortuosity and adsorption effects.

To develop diagenetic models for Lake Apopka, it is important to determine the D values for bulk sediments. Very limited information is available on D measurements in freshwater sediments and none in Florida lakes. The objective of this study was to experimentally measure the diffusion coefficients of phosphate in anaerobic Lake Apopka sediments.

5.12.2 Materials and methods

Bulk sediment samples representing UCF and CF fractions were obtained from stations K-6 and B-2 using an Ekman dredge and stored under anoxic conditions at 4°C. Movement of phosphate was measured under two experimental conditions: (1) phosphate movement from the sediment to the water column, and (2) phosphate movement within the sediment. The experimental set-up used was similar to the one described in Chapter 5.3, Fig. 5.3.1. This system consisted of two half-cells A and B. The length of each cell was 8 cm and the cross-sectional area of the cylinder was 7.6 cm^2.

In the first experiment, cell A was packed with sediment, while filtered lake water was placed in cell B. The two cells were separated using a filter paper. The top of cell B was sealed with a Plexiglas plate and purged with N_2 atmosphere. The sediment-water column was incubated in the dark at 25°C for a period of 72 h. Each treatment was replicated three times. At the end of the incubation period, floodwater was pipetted at 1 cm depth increments, while the sediment was sectioned at 1 cm depth increments. The sediment was transferred into 50 mL tubes and centrifuged at 5000 rpm for 15 min. Porewater was removed, filtered, acidified and stored under freezing conditions until analyzed for SRP.

A second experiment measured phosphate diffusion within the sediment. The experimental set-up was similar to the one described above. In this experiment, cell A was packed with sediment enriched with a known phosphate concentration, while cell B was packed with sediment with no added phosphate. Each treatment was replicated three times and incubated for a period of 72 h in the dark at 25°C. At the end of the incubation period, sediments from each cell were sectioned at 1 cm depth increments and analyzed as described previously in section 5.6. In independent experiments, phosphate adsorption coefficients were also measured. Details of these experiments are presented in Chapter 5.11.

5.12.3 Results and discussion

Concentration profile data for phosphate in sediment-sediment (Fig. 5.12.1) and sediment-water columns (Fig. 5.12.2) appeared to agree well with the fitted simulation lines. An average K_d value (based on K-6 sediment) of 703 mL g^{-1} was used in calculating diffusion coefficients for phosphate in sediments (D_s). Values of D_s from the B-2 and K-6 sediments in the sediment-water column were 2 and 8 times lower, respectively, than that for the K-6 sediment in the sediment-sediment study (Table 5.12.1). The differences in D_s values may be reduced if K_d values were calculated for each sediment under the experimental conditions. Phosphorus sorption coefficients are also strongly influenced by non-equilibrium and precipitation reactions; factors which can affect K_d values and hence diffusion coefficients. Krom and Berner (1980) estimated a D_s of 0.31 cm^2 d^{-1} for phosphate in marine sediments which agrees well with those estimates of D_s in the sediment-water study.

Estimates of D_w for the B-2 sediment were two times that for the K-6 sediment (Table 5.12.1). Diffusion coefficients of various forms of P in water range from 0.63 to 0.77 cm^2 d^{-1} (Li and Gregory, 1974); these values are within the 95% CI for the estimates of D_w in this study. One of the difficulties in calculating D_w by this technique is that the non-linear procedure fits both D_s and D_w to the data at the same time; hence, any discrepancy in the data for the sediment half-cell can affect the estimated value of D_w for the water half-cell, or vice-versa.

A wide range of D_s values were obtained for Lake Apopka bulk sediments. The D_s values were lower for phosphate diffusing from the sediment to the overlying water column, while higher D_s values were measured for phosphate within two layers of sediments. We expected that diffusion of phosphate would be more rapid from the sediment to the water column, because of less tortuosity effects. But, apparently, the diffusion of phosphate was retarded by the overlying column. Some factors regulating phosphate diffusion needs careful evaluation in order to determine more accurate D_s values. Phosphate diffusion can be retarded by complex non-equilibrium and precipitation reactions. Other factors such as ionic strength of sediment porewater and the overlying water column, concentration of Ca, Mg, Fe and Mn which control phosphate retention/release, temperature, and sediment type. The experiments presented in this report take a simplistic approach, and provide a first approximation of D_s value for Lake Apopka sediments.

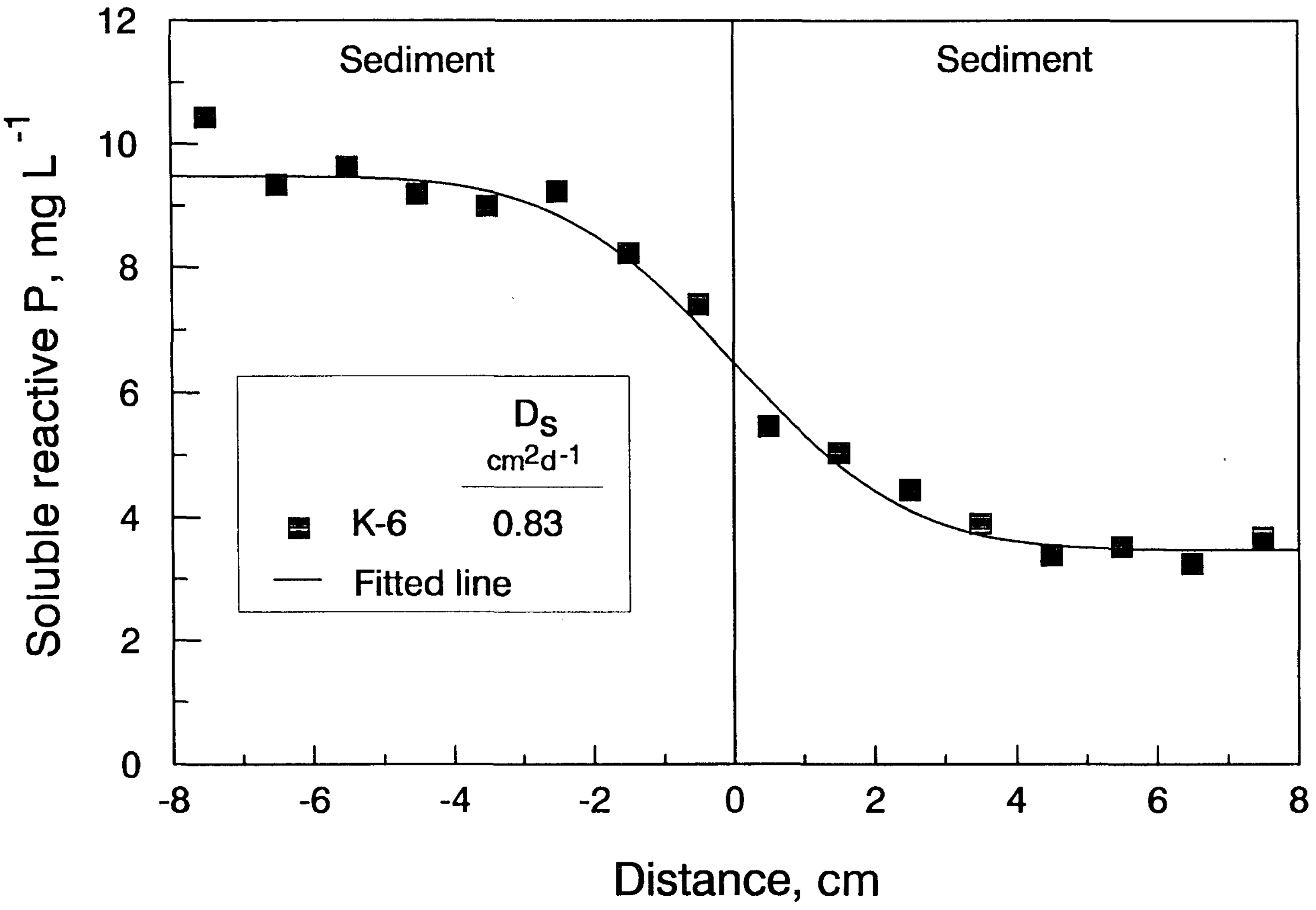

Fig. 5.12.1. Concentration profiles of phosphate diffusing from sediment (spiked with phosphate) to sediment (no P added).

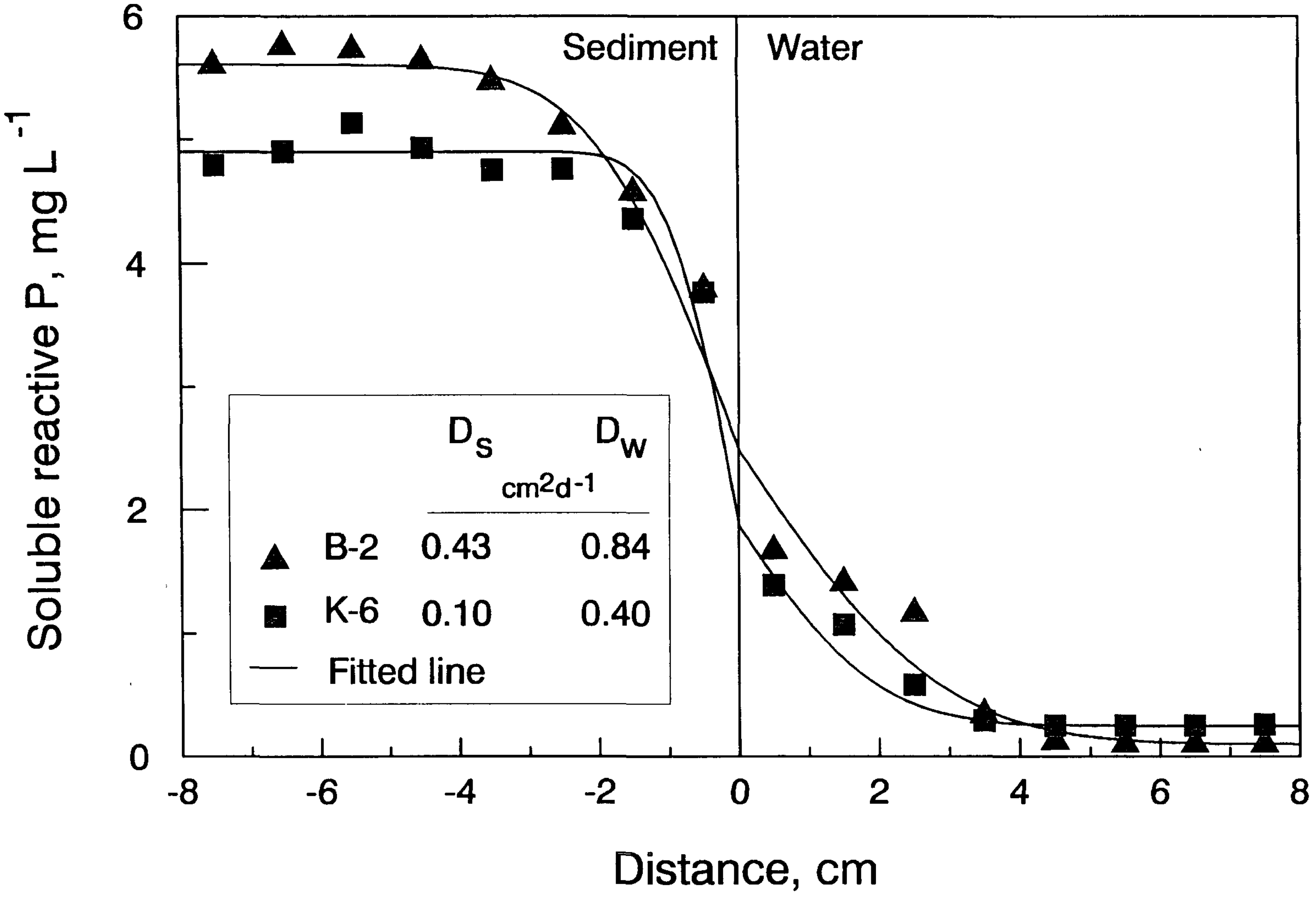

Fig. 5.12.2. Concentration profiles of phosphate diffusing from sediment to the overlying water column.

Table 5.12.1. Average diffusion coefficients (±SE) for phosphorus measured in sediments and lake water.

	D_s' cm^2 d^{-1} (95% CI)	D_w cm^2 d^{-1} (95% CI)
Sediment-Water Diffusion:		
B-2	0.43±0.10 (0.23-0.64)	0.84±0.21 (0.39-1.29)
K-6	0.10±0.03 (0.03-0.17)	0.40±0.17 (0.03-0.78)
Sediment-Sediment Diffusion:		
K-6	0.83±0.18 (0.44-1.21)	

5.12.4 Conclusions

The diffusion coefficients (D_s) for phosphate ions were determined for bulk sediments (unconsolidated UCF) obtained from K-6 and B-2 stations of Lake Apopka. The estimated D_s values were highly variable (0.10 -0.83 $cm^2\ d^{-1}$). The D_s values were adjusted for the effects of phosphate adsorption, by using K_d values determined in independent experiments for the same sediments. The diffusion coefficients (D_w) of phosphate in the overlying water column were impacted by the underlying sediments with values in the range of 0.40 - 0.84 $cm^2\ d^{-1}$. Further studies are needed to evaluate the factors governing the D_s and D_w values in Lake Apopka. This is an important parameter, critical in diagenetic models to predict the phosphate flux in the sediment-water column.

5.12.5 References

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Chapter 6

SEASONAL CHANGES IN CARBON AND NITROGEN FIXATION IN LAKE APOPKA

6.0 SEASONAL CHANGES IN CARBON AND NITROGEN FIXATION IN LAKE APOPKA

6.1 Photosynthetic Fixation Rates of Carbon in Lake Apopka [Task 4.1]

6.1.1 Introduction

The capacity of an ecosystem to convert radiant and chemical energy into simple organic compounds is termed primary production (Vollenweider, 1969). Although this process is an essential part of any ecosystem, if the process is not kept in check through nutrient limitations and organic matter degradation, enhancement of eutrophic conditions of a lake can occur.

Lake Apopka, located in central Florida, is an example of a system where the primary producers thrive unchecked. The highly productive algal community in this lake has resulted in the buildup of a sediment consisting primarily of undecomposed algal cells (USEPA, 1979a). Since the sediment consists almost exclusively of algal biomass the growth rate of this community deserves investigation. The objectives of this study were to determine primary productivity rates and measure related water quality parameters in Lake Apopka periodically throughout a year.

6.1.2 Materials and methods

Three locations on Lake Apopka were selected for the *in situ* measurements, Apopka Spring, the Center Lake Station, and Apopka-Beauclair Canal. These sites corresponded to the inflow, central, and outflow portions of the lake, respectively. On the grid map of Lake Apopka (Chapter 3, Fig. 3.1), these sites are found at grid locations B-12, F-6, and B-2.

The O_2 method using light and dark bottles was employed for the productivity measurements (APHA, 1985). The selection of this method was based upon the hypereutrophic status of the lake. The *in situ* incubations were conducted in triplicate for a period of 2-4 h. All incubations were initiated during the mid-morning and completed by mid-afternoon. One potential problem with the selected incubation method is that the incubation vessels inhibit the natural mixing of the waters. Vollenweider (1969) concludes that this problem only becomes significant when incubation times approach 24 h. Therefore, for these experiments, it was assumed that this effect was negligible. The *in situ* productivity measurements were conducted monthly (weather permitting) for a period of 1 yr starting in December 1988 and continuing through November 1989. Bad weather during Feb. 1989 inhibited measurement of productivity during this month and, as a result, measurements of this parameter were not made until the first week in March and then only at the entrance to Apopka-Beauclair canal. In March 1989, diel measurements were conducted. For these incubations, productivity measurements were conducted every 2 h during the period from sunrise to sunset.

Oxygen measurements were made with a portable YSI meter (Yellow Springs Instrument Co., Yellow Springs, OH). At the time of the incubations, the water and air temperatures, *in situ* dissolved O_2, and weather conditions were noted (Table 6.1.1). Along with the incubations to measure primary productivity, incubations were conducted to determine the dinitrogen fixation potential of the Lake Apopka system (Chapt. 6.2). Lake water samples were also taken for analysis of chl a, NH_4-N, SRP, TKN, and TP. In the laboratory the water samples were filtered through glass-fiber filters. The residue and filters were analyzed for chlorophyll a (APHA, 1985). The filtrate was analyzed for NH_4-N, SRP, TKN, and TP using standard methods found in USEPA (1979b).

In November 1988, *in situ* incubations were conducted to test the selected procedures. These incubations were conducted at depths of 30 cm and 1 m. The gross productivity measured at 1 m (64 mg C m^{-3} h^{-1}) was 85% less than that measured at 30 cm (431 mg C m^{-3} h^{-1}). However, respiration during this period was the same at both depths (38 mg C m^{-3} h^{-1}). The extreme reduction in productivity with depth was most likely due to inadequate light penetration of the water column. On two occasions, photometer readings through the water column were made on the lake (Fig. 6.1.1). This graph indicates that at least a 50% reduction in light penetration occurs within the upper 0.5 m of the water column. However, on a sunny day in the center of the lake, a 50% reduction in light penetration occurred at less than 20 cm.

6.1.3 Results and discussion

One advantage of the O_2 method for determining primary productivity is that gross productivity, respiration, and net productivity can all be measured with this technique. Figures 6.1.2 - 6.1.4 include the results of the primary productivity measurements for the three locations on Lake Apopka. Both gross productivity (Fig. 6.1.2) and net productivity (Fig. 6.1.3) were characterized by variability throughout the year. In contrast, respiration rates (Fig. 6.1.4) were less variable. At Apopka Spring, peak productivity rates were observed in March and August and corresponded to high *in situ* DO concentrations (Table 6.1.1). At the Center Lake Station and Apopka-Beauclair Canal, gross productivity rates (Fig. 6.1.2) seemed to follow a seasonal trend with maxima occurring through the months of March to October. However, this trend was not observed in the net productivity rate measurements (Fig. 6.1.3) The correlation between the Apopka Springs productivity data and *in situ* DO was not observed at the other locations.

Changes in measured chlorophyll a concentrations at the time of productivity measurements are presented in Fig. 6.1.5. In general, Chl a concentrations were highly variable both within the replicate samples and between the sampling times. The average Chl a concentrations were 37±19 mg m^{-3} at Apopka Spring, 38±23 mg

Table 6.1.1 Weather and water conditions during monthly experiments.

Date	Loc	Julian	Temperature		DO in situ	pH in situ	Weather
			Air	Water			
			C		mg O_2 L^{-1}		
1/17/89	AS	17	19.3	20.8	5.9	8.5	sunny
1/17/89	CLS	17	19.5	20.2	10.4	9.2	sunny
1/17/89	ABC	17	20.0	21.8	10.0	9.2	sunny
3/8/89	ABC	67	12.0	17.8	8.5	8.9	overcast
3/27/89	AS	86	28.8	25.0	10.1	8.8	sunny/pc
3/27/89	CLS	86	29.6	23.5	10.5	9.0	sunny/pc
3/27/89	ABC	86	30.4	26.7	12.7	9.4	sunny/pc
4/25/89	AS	115	27.3	24.3	4.5	8.3	sunny
4/25/89	CLS	115	24.7	23.6	10.7	9.2	sunny
4/25/89	ABC	115	26.4	26.7	11.2	9.1	sunny
5/18/89	ABC	138	29.1	28.8	11.8	9.4	cloudy
5/23/89	AS	143	28.1	27.3	8.5	8.3	sunny
5/23/89	CLS	143	29.6	28.6	10.0	9.1	sunny
6/20/89	AS	171	31.2	30.9	8.4	8.9	pcloudy
6/20/89	CLS	171	30.7	29.5	8.0	8.9	pcloudy
6/20/89	ABC	171	32.1	30.1	8.9	9.0	pcloudy
7/25/89	AS	206	29.8	28.1	8.8	8.9	pcloudy
7/25/89	CLS	206	30.7	27.9	7.9	9.2	pcloudy
7/25/89	ABC	206	31.7	28.8	9.4	9.3	pcloudy
8/8/89	AS	220	28.3	29.6	10.5	9.1	rain
8/8/89	CLS	220	29.9	29.3	9.7	9.2	rain
8/8/89	ABC	220	31.5	30.1	8.5	9.1	rain
9/13/89	AS	256	28.8	29.1	8.4	8.9	sunny
9/13/89	CLS	256	29.1	29.5	9.3	9.5	sunny
9/13/89	ABC	256	29.9	30.9	9.9	9.4	sunny
10/27/89	AS	300	21.2	22.3	4.7	8.1	overcast
10/27/89	CLS	300	22.0	19.9	9.2	9.0	overcast
10/27/89	ABC	300	22.5	20.6	9.5	9.2	overcast
11/10/89	AS	314	21.0	23.1	3.3	8.0	sunny
11/10/89	CLS	314	21.1	22.0	9.1	9.0	sunny
11/10/89	ABC	314	22.0	23.5	9.6	9.1	sunny
11/30/89	AS	334	15.1	19.4	7.0	8.5	sunny
11/30/89	CLS	334	15.8	17.2	9.2	9.0	sunny
11/30/89	ABC	334	16.1	18.3	9.2	9.1	sunny

AS = Apopka Spring
CLS = Center Lake Station
ABC = Apopka-Beauclair Canal

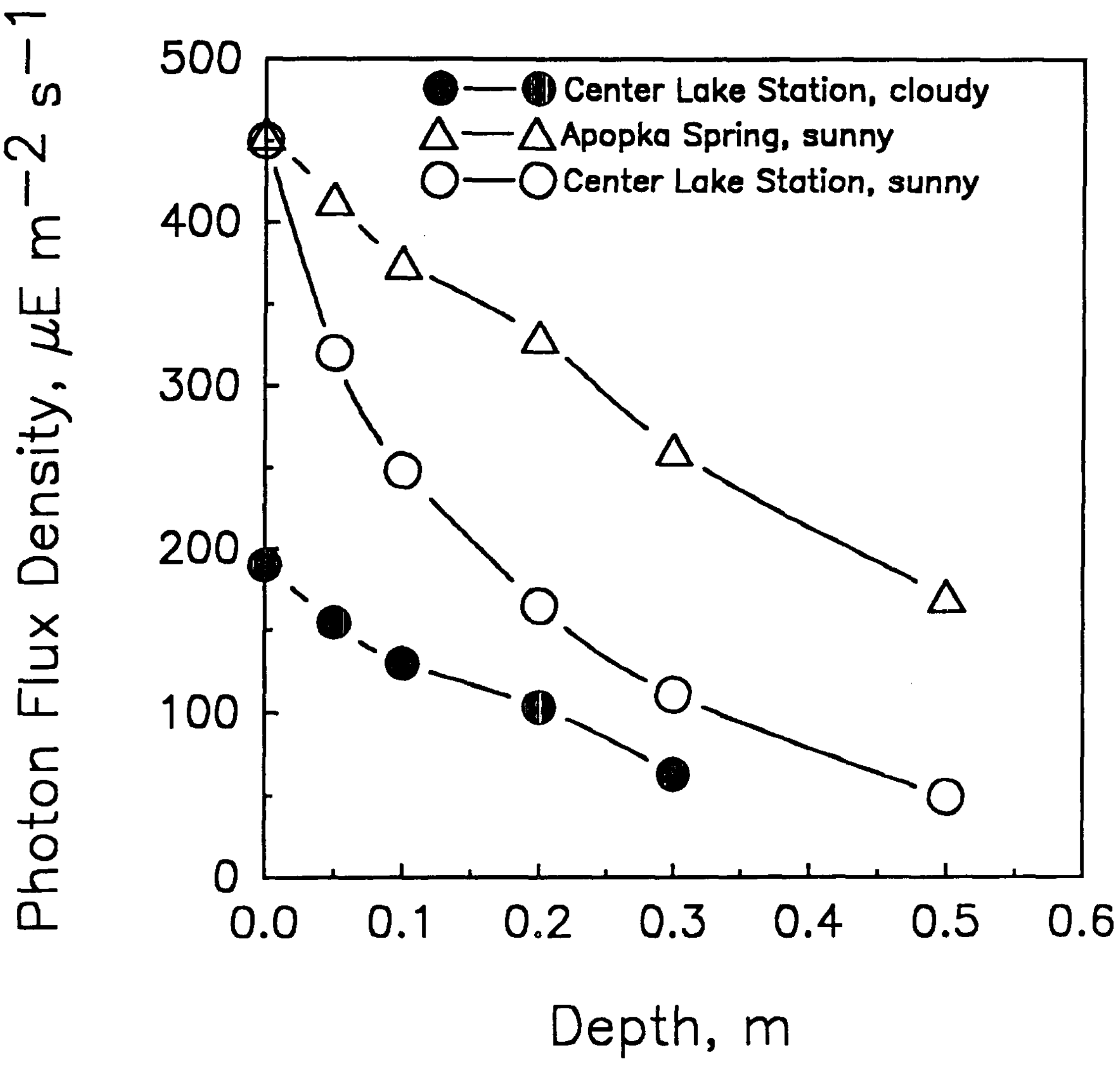

Fig. 6.1.1. Photon flux density readings with depths (a measure of light intensity) at two locations on Lake Apopka.

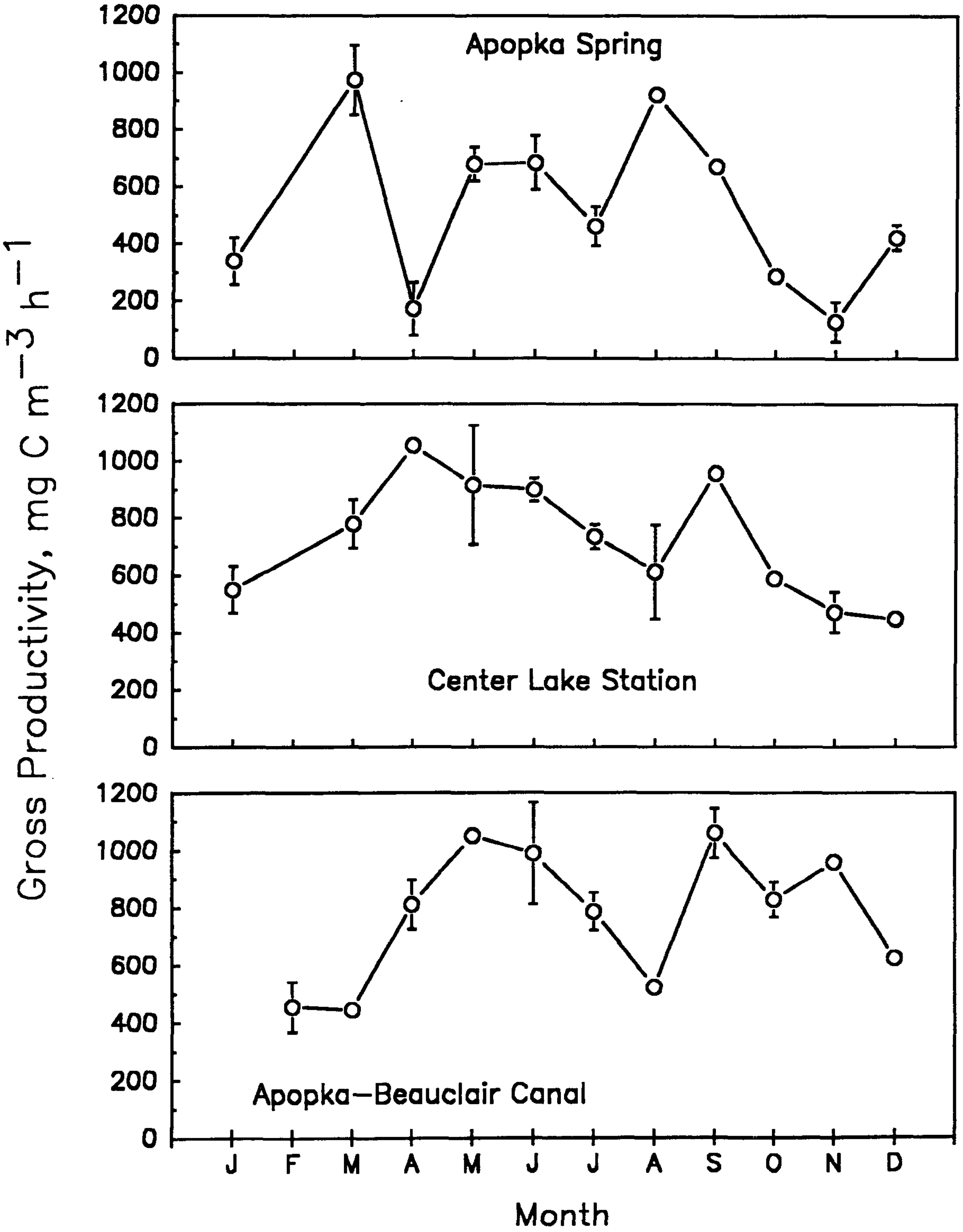

Fig. 6.1.2. Monthly measurements of gross primary productivity at three locations on Lake Apopka.

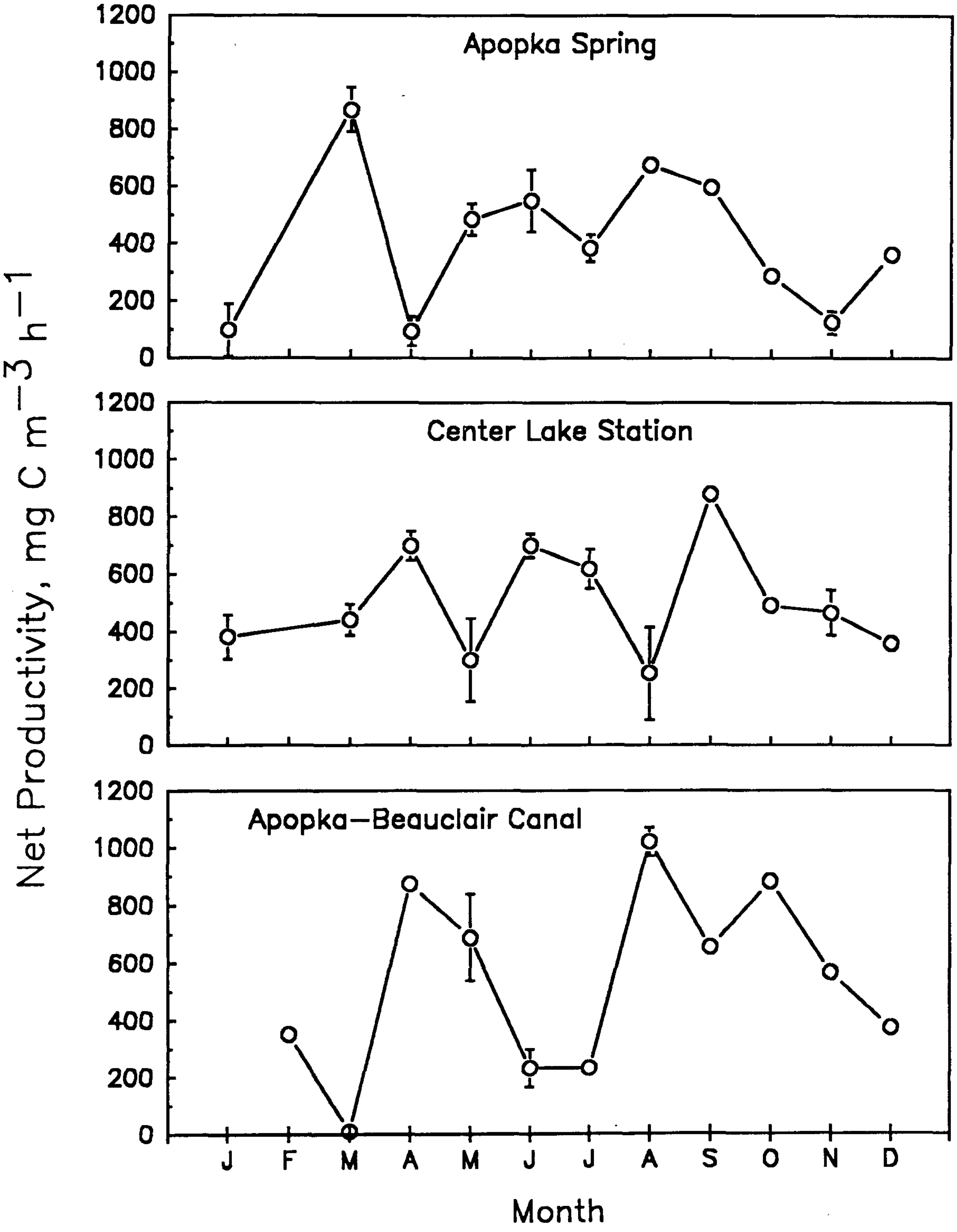

Fig. 6.1.3. Monthly measurements of net primary productivity at three locations on Lake Apopka.

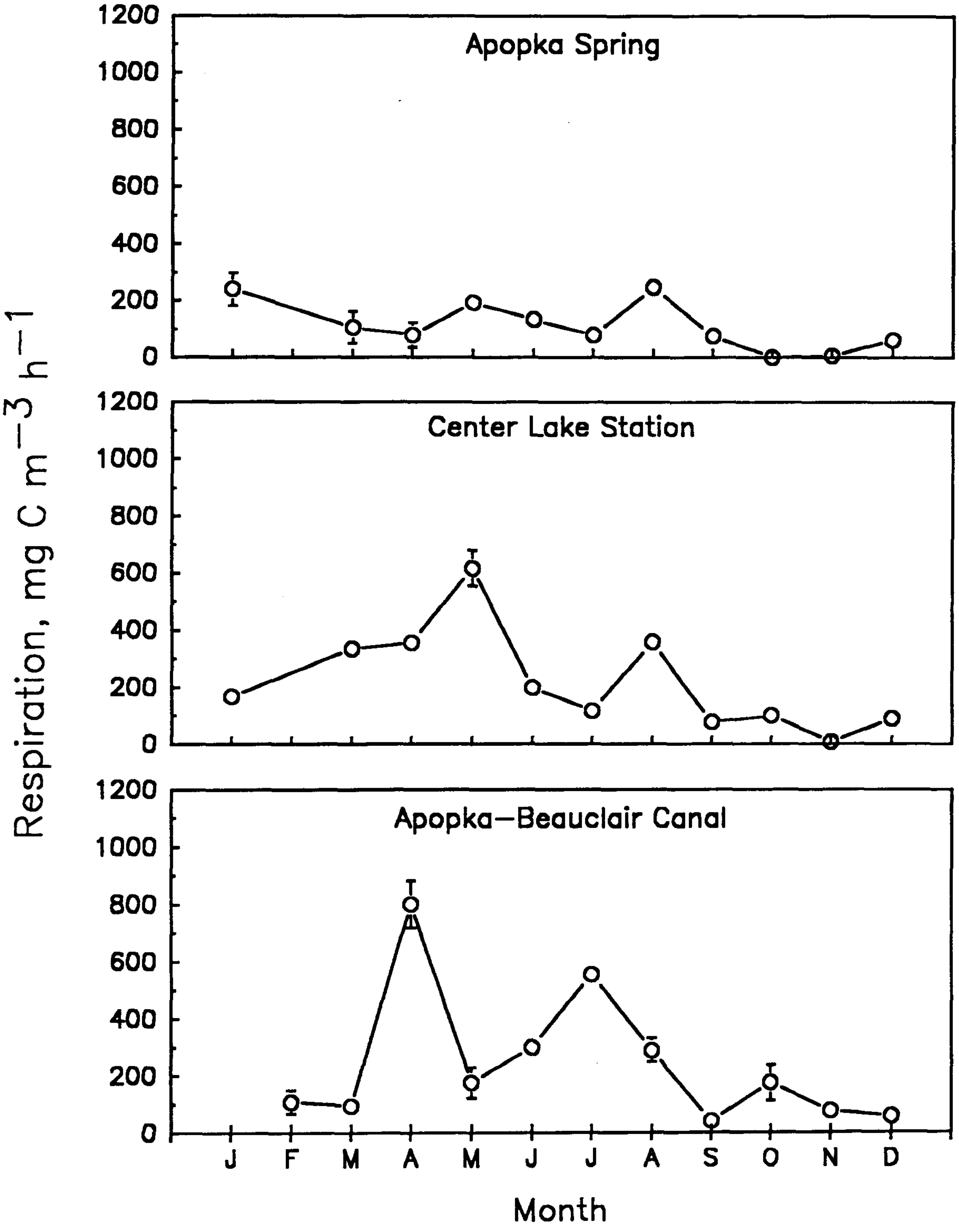

Fig. 6.1.4. Monthly measurements of respiration at three locations on Lake Apopka.

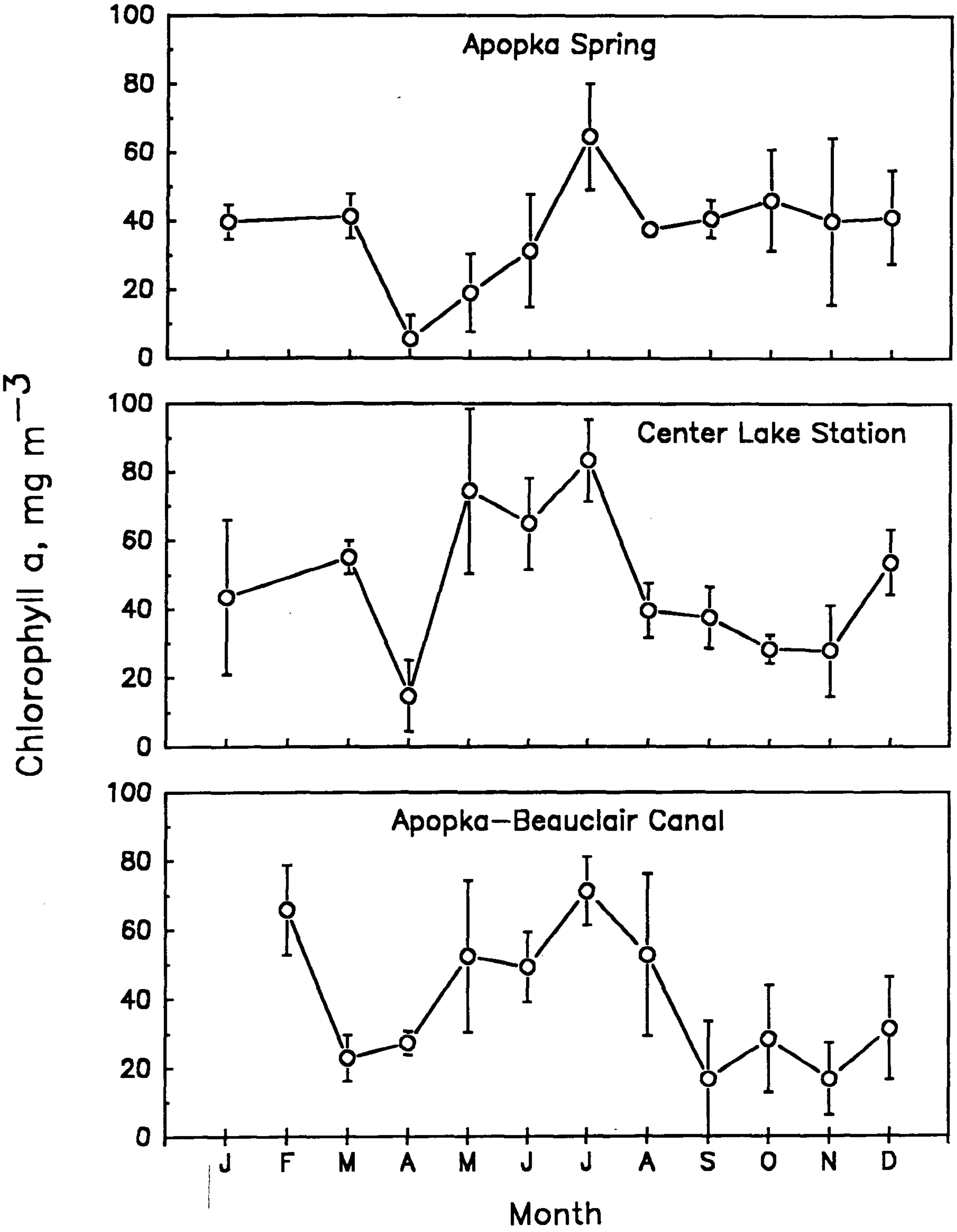

Fig. 6.1.5. Chlorophyll a concentrations of water samples collected from three sites on Lake Apopka during 1989.

m^{-3} at Apopka-Beauclair Canal, and 47±24 mg m^{-3} at the Center Lake Station. These averages imply that the phytoplankton community is at its maximum achievable density (Agusti et al., 1990). In relation to the amount of C fixed through primary production, a C:Chl a ratio of 14 was found for the Lake Apopka system. This value is at the lower end of the ranges determined by Welschmeyer and Lorenzen (1984) in field measurements of specific growth rates. In laboratory experiments also conducted by the aforementioned authors, the C:Chl a was found to decrease with decreasing light intensity. In regards to the current study, this would support the assumption that light is limiting primary production in Lake Apopka.

Figures 6.1.6 and 6.1.7 depict monthly measurements of lake water concentrations of NH_4-N and soluble reactive P (SRP). The NH_4-N concentrations showed little seasonal variation with the exception of the Apopka Spring site. The variations in NH_4-N concentrations at this site are most likely due to variations in flow from the spring itself. Soluble reactive P concentrations (Fig. 6.1.7) showed a definite peak in June 1989 at all locations.

Dissolved total N (Fig. 6.1.8) and dissolved total P (Fig. 6.1.9) concentrations of the water samples were also measured. The greatest variability in dissolved total N (Fig. 6.1.8) was observed at the Apopka Spring location. This variability was also observed in the NH_4-N concentrations (Fig. 6.1.6). For dissolved total P (Fig. 6.1.9), concentrations varied little throughout the year. The peak values observed for SRP in June 1989 (Fig. 6.1.7) were not observed in the total P pool.

A correlation matrix was constructed to test for significant interactions between the measured parameters. These comparisons were made individually for each of the lake stations. At the Center Lake Station, the location most representative of the lake system, the only significant correlations were found between the time of year (Julian Date) and respiration (correlation coefficient = 0.669) and time of year and dissolved total P (correlation coeff. = 0.672). At the Apopka-Beauclair Canal site, the time of year was also correlated with two parameters. These were NH_4-N (correlation coeff = 0.843) and dissolved total N (correlation coeff. = 0.632). At Apopka Spring, gross and net productivity and respiration were found to be correlated with both *in situ* DO concentrations and dissolved total N. For the *in situ* DO interaction, the correlation coefficients were 0.912, 0.825, and 0.601 for gross productivity, net productivity, and respiration, respectively. The correlation coefficients for dissolved total N and the above-listed productivity parameters were 0.773, 0.787, and 0.763, respectively.

Results of chemical analyses of the diel measurements were similar to those described by Reddy (1981). Gross productivity rates as measured during the diel, conducted at the Center Lake Station, are depicted in Fig 6.1.10. The mean productivity rates for each time were then modeled over the daylight period (solid line in Fig. 6.1.10). The second order equation that described these data was:

$$y = -17x^2 + 179x + 260 \quad (r^2 = 0.977)$$

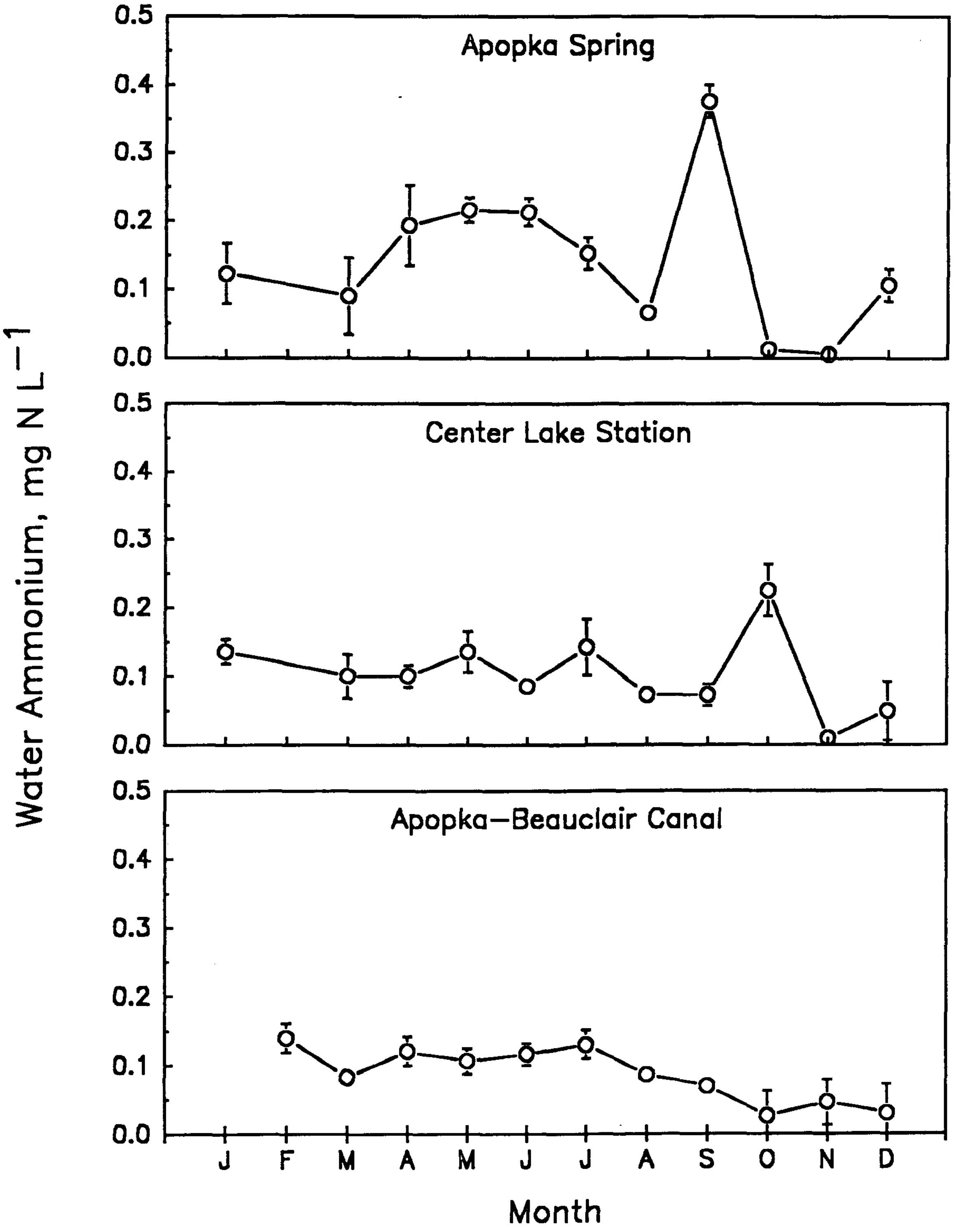

Fig. 6.1.6. Concentration of ammonium-N on water samples collected from three sites on Lake Apopka during 1989.

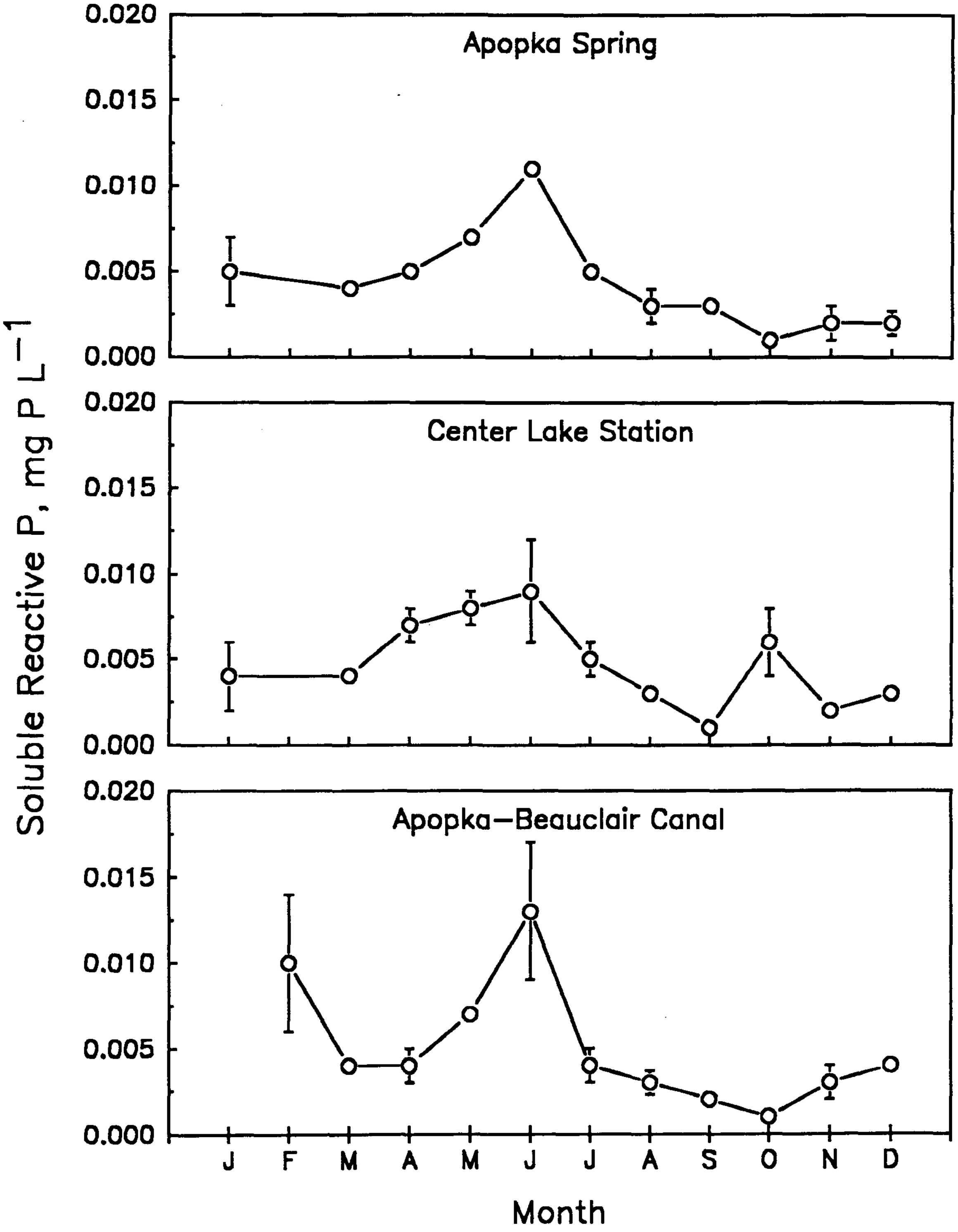

Fig. 6.1.7. Soluble reactive P concentrations of water samples collected from three sites on Lake Apopka during 1989.

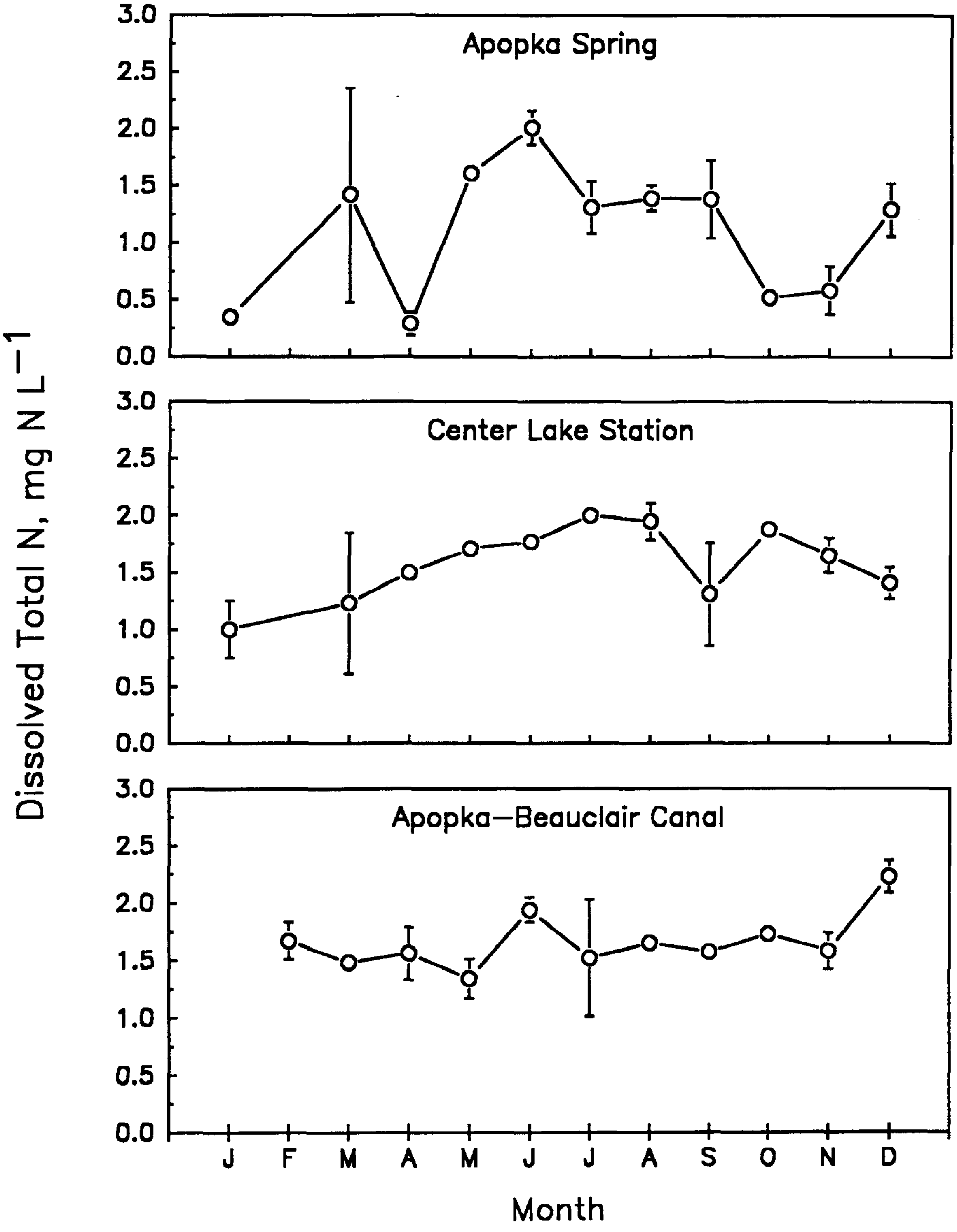

Fig. 6.1.8. Dissolved total N in water samples collected from three sites on Lake Apopka during 1989.

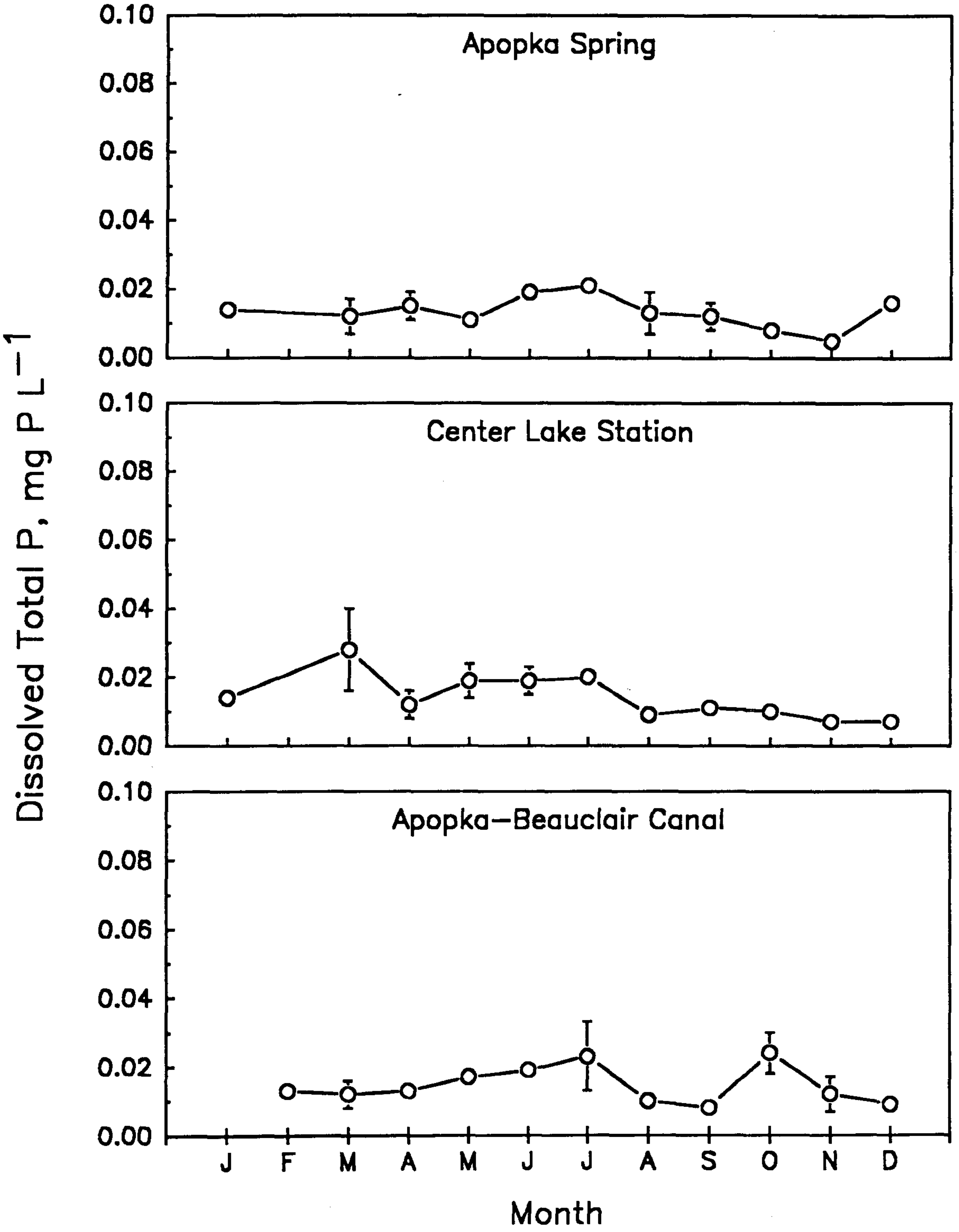

Fig. 6.1.9. Dissolved total P in water samples collected from three sites on Lake Apopka during 1989.

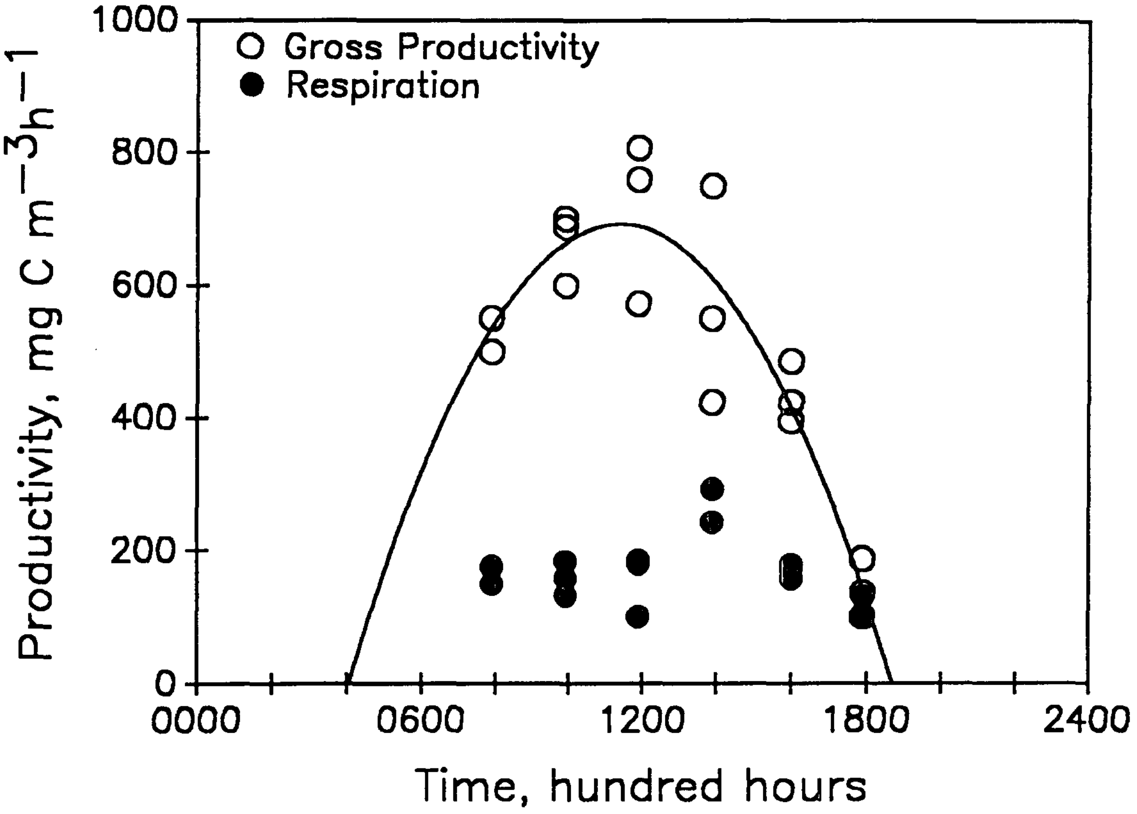

Fig. 6.1.10. Gross productivity and respiration rates measured during diel observations at the Center Lake Station on March 1990.

This equation was integrated over the daylight period in order to determine the total amount of C fixed during the diel period (6.2 g C m^{-3} d^{-1}). Using the maximum productivity for the diel as a reference (723 mg C m^{-3} h^{-1}), productivity rates for each of the other determinations were converted to daily amounts. The daily values were then summed over the time interval between monthly measurements in order to get a yearly estimate for gross primary productivity. Since analyses in Dec. 1988 determined that the rate of primary production was reduced to 80% of its surface value at a 1-m depth, an effective productivity depth was calculated to be equal to 1.25 m. In this manner, the gross amount of C fixed in the system was found to be 1.4 ± 0.3 kg C m^{-2} yr^{-1}.

6.1.4 Conclusions

The phytoplankton community of Lake Apopka is very active. Measurement of lake water NH_4-N and SRP concentrations indicate that limitations of primary production by the lack of either of these nutrients is unlikely. This situation is not uncommon in Florida (Agusti et al., 1990) where several lakes have been shown to support maximum phytoplankton densities. The lack of nutrient limitations on primary production implies that a physical factor such as light intensity may be limiting production.

The average yearly net amount of C fixed by the Lake Apopka system is 110 g C m^{-2} $year^{-1}$. This value is at the lower end of the 10 to 1000 g C m^{-2} $year^{-1}$ reported by Mitsch and Gosselink (1986) for net primary productivity in wetland systems. However, when compared to temperate forested ecosystems, the value for Lake Apopka is ten to twenty times lower (Whittaker, 1975).

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6.2 Nitrogen Fixation in Lake Apopka Water and Sediment [Task 4.2]

6.2.1 Introduction

Lake Apopka is a shallow, hypereutrophic lake located in central Florida. The phytoplankton community of Lake Apopka is comprised mainly of blue-green algae (T. Crisman, personal communication). The blue-green algae are prokaryotic microorganisms, some of which have the ability to fix atmospheric N. These microorganisms can be an important source of fixed N in ecosystems where they proliferate (Delwiche, 1970). Fixation of N involves the uptake of atmospheric N_2 and its reduction to NH_3, a form of N which can be used metabolically by microorganisms. In N-limited systems, N_2 fixation plays a key role in the cycling of this nutrient (Paerl et al., 1981). In eutrophic systems, Ashton (1981) found that up to 47% of N inputs were due to N_2 fixation.

The acetylene (C_2H_2) reduction technique has been used by many authors to indirectly estimate the rate of N_2 fixation in a system (Burris, 1974; Hardy and Holsten, 1977; Dierberg and Scheinkman, 1987). The stoichiometry of the reduction of acetylene (C_2H_2) to ethylene (C_2H_4) implies that 3 moles of C_2H_2 will be reduced for every potential mole of N_2 fixed. However, Peterson and Burris (1976) recognized that this is not always the case in natural systems. They proposed the use of a ^{15}N labeling technique to determine the ratio between the amount of C_2H_2 reduced and the amount of N_2 fixed for a given system.

Since the potential for N_2 fixation in Lake Apopka is great, a nutrient budget for this lake must include a measure of this important potential N input into the system. The objectives of this study were to measure *in situ* N_2 fixation rates in Lake Apopka using the acetylene reduction technique. A secondary objective was to determine the C_2H_2/N_2 ratio for N_2 fixation in this system.

6.2.2 Materials and methods

The *in situ* incubation studies for these experiments were conducted concurrently with the primary productivity measurements (see Chapter 6.1). A modification of the acetylene reduction technique as described by Burris (1974) and Hardy and Holsten (1977) was used to measure this process. Serum bottles (150-mL capacity) were filled with 130 mL of lake water, collected from the 30-cm depth, and capped. Two milliliters of the sample head space were removed and replaced with 2 mL of acetylene (C_2H_2). The samples were then incubated *in situ* for a period of 2 to 4 h. Three replications were used at each of the sites studied. At the end of the incubation period, 2 mL of the sample head space was removed and stored in a Vacutainer for later GC analysis. The water samples were stored on ice, in the dark, for transport to the laboratory.

The amount of ethylene (C_2H_4) produced from the reduction of acetylene (C_2H_2) was quantitated using a gas chromatograph with a flame ionization detector.

The 1.8-m stainless steel column was packed with poropak N and operated at a temperature of 70°C. Nitrogen was used as the carrier gas at a rate of 0.4 mL s^{-1}. Standards consisted of C_2H_4 and C_2H_2 diluted in air and sample values were corrected for ethylene present in the acetylene used.

In August 1989, the procedures of Peterson and Burris (1976) were used to determine the C_2H_2/N_2 ratio. This was accomplished by including an extra triplicate set of samples in the incubations. For these samples, 10 mL of the sample headspace was replaced with 99 atom% labeled $^{15}N_2$, instead of the C_2H_2 treatment. All of the other incubation conditions were kept the same. At the end of the incubation, the samples were filtered and the % enrichment, total N contents, and weight of the algal cells collected were determined. The filtrates from these samples were saved for analysis as described below. With this information, the amount of N_2 fixed by the algae could be calculated and compared to the amount of C_2H_2 reduced in the companion samples.

6.2.3 Results and discussion

The results of the ^{15}N labeling study indicated that an average of 6.78 moles of C_2H_2 were reduced for every mole of N_2 fixed. This value was the average of measurements made at the Center Lake Station (6.85 n=3) and Apopka-Beauclair Canal (6.71 n=3). Enrichment of the samples incubated at Apopka Spring was not significant. The mean value determined here (6.78) was similar to the value of 6.88 found by Peterson and Burris (1976). Their study included both pure cultures and field measurements. They found that while pure cultures will approach the 3:1 ratio of C_2H_2/N_2 reduction determination of this ratio for a given field situation is a must.

Some seasonal variation in the measured N_2 fixation rates was noted (Fig. 6.2.1). Peak N_2 fixation rates were observed at all three locations in May and September. The minimum N_2 fixation rates occurred in December and January. Dugdale and Dugdale (1965) found similar seasonal variation in N_2 fixation rates. However, their rates were 10 times higher than those found in the present study.

Although it is known that N fertilizers can have an inhibitory effect on the development of rhizobia in association with legumes (Alexander, 1977), studies in aquatic systems have found that nitrogenase activity is independent of NH_3 concentration but has very high P requirements (Dugdale and Dugdale, 1965; Paerl et al., 1981; Vanderhoef et al., 1975). Correlations between N_2 fixation rates and the water quality data presented in Chapter 6.1 were found to be insignificant in the present study. The lack of a correlation between P and N_2 fixation rates in this study is most likely due to the ambient levels of P in the lake. Both Dugdale and Dugdale (1965) and Vanderhoef et al. (1975) have indicated that N_2 fixation is dependant upon the phytoplankton population. Howarth et al. (1988) found such factors as turbulence, light intensity, and water residence time to be physical controls of N_2 fixation.

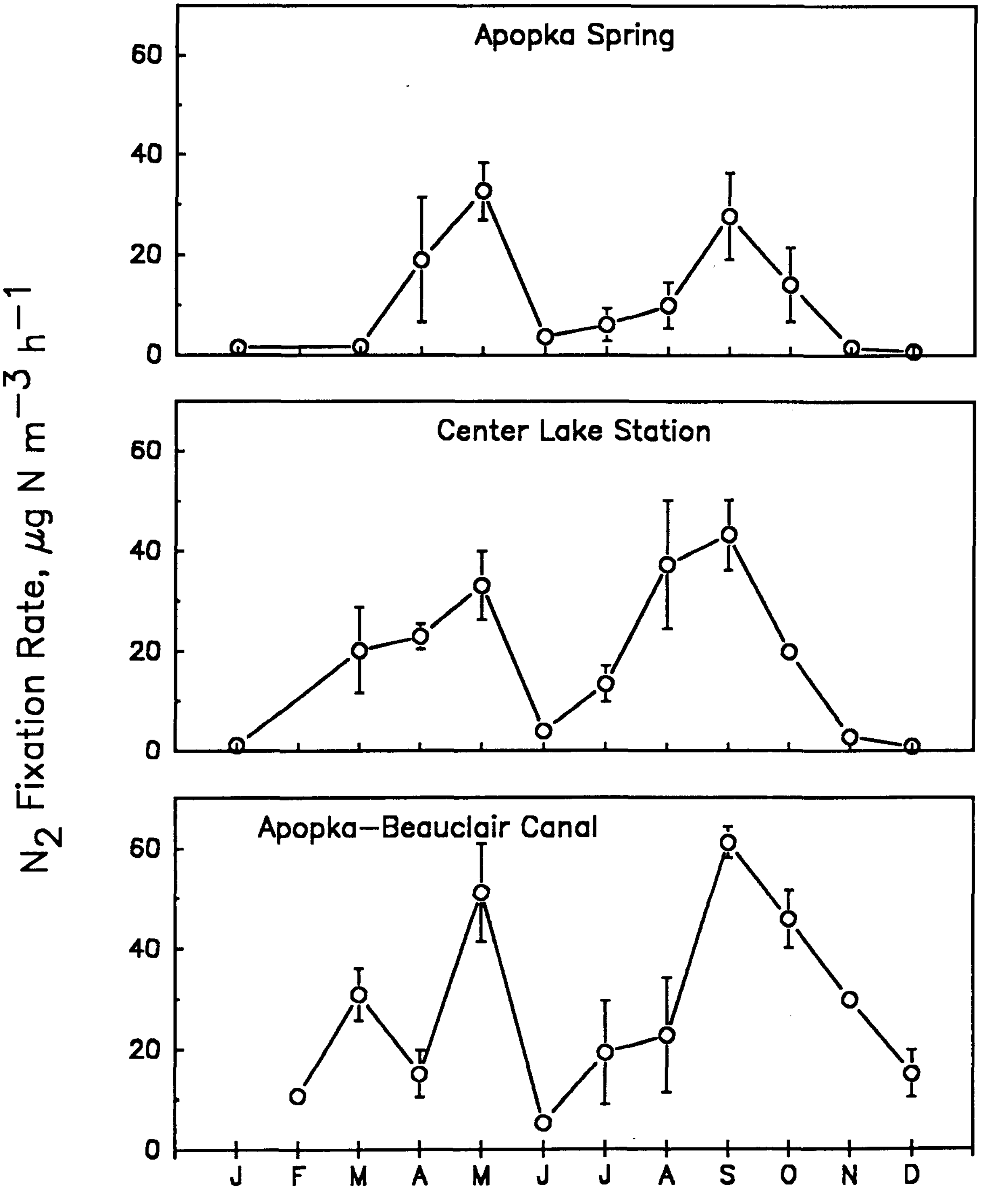

Fig. 6.2.1. Monthly measurements of dinitrogen fixation, as measured by acetylene reduction method.

The average annual N_2 fixation rate found in this study was 18.5 $\mu g\ N\ m^{-3}\ h^{-1}$. Extrapolation of this rate over a year results in an annual input of 0.16 $g\ N\ m^{-2}\ yr^{-1}$. This value is on the lower end of a range of values for N_2 fixation presented by Dierberg and Scheinkman (1987). Their values for N_2 fixation ranged from 0.06 to 5.4 $g\ N\ m^{-2}\ yr^{-1}$ in a comparison of N_2 fixation rates in eutrophic lakes.

6.2.4 Conclusions

The ability of the phytoplankton community to fix atmospheric N_2 suggests that N limitations to growth would be unlikely. The lack of a correlation between nutrient concentrations and N_2 fixation rates indicates that these elements are not limiting algal growth and metabolism in this system.

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6.3 Sedimentation Rates as Determined by ^{210}Pb [Task 1.3]

6.3.1 Introduction

^{210}Pb is a naturally occurring radioisotope that is a member of the ^{238}U decay series. ^{210}Pb in lake sediments arises by two principal mechanisms. First, some radioactive Pb is formed in lacustrine muds when intrinsic ^{226}Ra decays through a series of short-lived daughter products. ^{210}Pb formed in this manner (*in situ*) is referred to as "supported" ^{210}Pb. Alternatively, ^{226}Ra in watershed soils and rocks decays to the daughter radionuclide, ^{222}Rn, which enters the atmosphere as a gas. ^{222}Rn ($t_{1/2}$ = 3.8 d) quickly decays through a series of four intermediate radionuclides to form ^{210}Pb that has a half-life of 22.26 ± 0.22 years (El-Daoushy, 1988). ^{210}Pb has a short residence time in the atmosphere, on the order of several weeks (Robbins, 1978), and is returned to land and lake surfaces by aerosol scavenging and in atmospheric precipitation. The mean global fallout rate for ^{210}Pb is about 0.5 pCi cm^{-2} yr^{-1} (Turekian et al., 1977; Nozaki et al., 1978; Appleby and Oldfield, 1978, 1983). After deposition to the lake, atmospherically-derived ^{210}Pb adsorbs to fine particulates and is incorporated into bottom deposits by sedimentation processes. ^{210}Pb delivered to the lake sediments in this manner is referred to variously as "unsupported", "fallout", or "excess" ^{210}Pb. Some additional sedimentary ^{210}Pb may be attributable to soil erosion or tributary inputs, but the amount delivered via these pathways is generally negligible compared with the atmospherically-derived fraction.

The distribution of unsupported ^{210}Pb activity throughout a lake sediment profile can be used to establish a chronology extending back about 150 yr. In addition to radioactive decay, a number of processes or sediment characteristics control the distribution of ^{210}Pb activity over depth in the sediment profile, including: ^{210}Pb fallout rate, bulk sedimentation rate, sediment bulk density, and post-depositional mixing. A number of factors influence the resolution, accuracy and precision of the dating method, including: sediment mixing (by wind, bioturbation, or during coring), length of core intervals sectioned, ^{210}Pb activity and counting time, accurate measurement of relevant sediment variables (e.g., bulk density), selection of the appropriate dating model, etc.

The purpose of Task 1.3 was to: (1) establish the feasibility of dating sediment cores from Lake Apopka, and (2) calculate sedimentation rates and assess changes that have occurred during the last century.

6.3.2 Materials and methods

Sediment cores were collected at sites D-3 and D-7 (Fig. 3.1, see Chapter 3) in Lake Apopka on January 6, 1989. Coring was done with a modified Livingstone piston corer (Deevey, 1965) equipped with a meter-long, clear acrylic core barrel. Cores were sectioned immediately at 2-cm intervals to a depth of 60 cm, and sediments were stored in preweighed, labelled plastic jars. Samples were returned to the laboratory where the jars were again weighed and then placed in the drying oven at 100°C. After drying, jars were reweighed allowing calculation of percent water content and bulk density. Sediment samples were then ground with a mortar and pestle and stored in plastic scintillation vials.

Dried, ground sediments from core D-7 were sealed with Duco cement in plastic counting chambers (petri dishes) for 14 d to establish equilibrium between intrinsic ^{226}Ra and supported ^{210}Pb. Dry weight of counted samples was low, varying between 0.67 and 5.3 g. ^{210}Pb activity was measured by gamma counting (Appleby et al., 1986) at 46.5 keV on a thin-window, planar Germanium detector, with count times ranging from 50400 to 86400 seconds. Supported ^{210}Pb activity was determined indirectly from other uranium series peaks: ^{226}Ra (186.2 keV), ^{214}Pb (351.9 keV), and ^{214}Bi (609.3 keV) (Nagy, 1988). Unsupported ^{210}Pb activity was calculated by subtracting supported levels from the total ^{210}Pb activity, and unsupported ^{210}Pb activity at uncounted intervals was estimated by interpolation. Lake Apopka sediments are poorly compacted and possess low bulk density ($<$0.1 g dry cm^{-3} wet) above 60 cm. As a consequence, low concentrations of unsupported ^{210}Pb were measured at all sampled levels in the D-7 core. Because numerous stratigraphic levels were analyzed and they required long counting times, it was not feasible to analyze the second core from site D-3.

Dates were calculated using the Constant Rate of Supply (CRS) Model (Goldberg, 1963; Krishnaswami et al., 1971; Appleby and Oldfield, 1978). The model assumes that the flux of unsupported ^{210}Pb to the sediments has remained constant through time. Consequently, an increase in bulk sediment accumulation rate will dilute the concentration of ^{210}Pb being deposited. Conversely, a slower rate of sediment deposition will concentrate ^{210}Pb in the accruing sediment. Mathematically, dates were computed by the CRS Model in the following manner:

$$t_x = 1/k \ln (A_o/A_x)$$

where t_x is the age in years at depth x, k is the decay constant for ^{210}Pb (0.03114 yr^{-1}), A_o is the total integrated, unsupported ^{210}Pb in the core (pCi cm^{-2}), and A_x is the integrated ^{210}Pb activity below depth x.

6.3.3 Results and discussion

The bulk density profile from core D-7 was typical of mid-lake cores from Lake Apopka (Fig. 6.3.1). Surface sediments (0-2 cm) are nearly 99% water by weight and contain only 9 mg dry material per cm^3 wet volume. Bulk density increases gradually with depth in the core to about 36 cm. Higher values registered from 36-42 cm and from 52-56 cm are probably attributable to small shell fragments. The maximum bulk density value was recorded at 54-56 cm (87 mg cm^{-3}).

Unsupported ^{210}Pb concentration (pCi g^{-1}) shows a general decline with depth in the profile (Table 6.3.1). Unsupported ^{210}Pb activity (log scale) is plotted against cumulative mass in Figure 6.3.2. This plot should be linear if the following CRS assumptions are valid: (1) ^{210}Pb delivery to the sediments has proceeded at a constant rate, (2) there has been no post-depositional migration of ^{210}Pb or sediment mixing, and (3) bulk sedimentation rates have not varied through time. Non-linearity of the plot suggests that one or more of the criteria were not met. Sediment mixing in Lake Apopka is probable because of the lake's shallow depth and flocculent bottom deposits. Additionally, fine shell fragments at some stratigraphic levels may not offer sites for the adsorption of atmospherically-derived ^{210}Pb, thereby violating

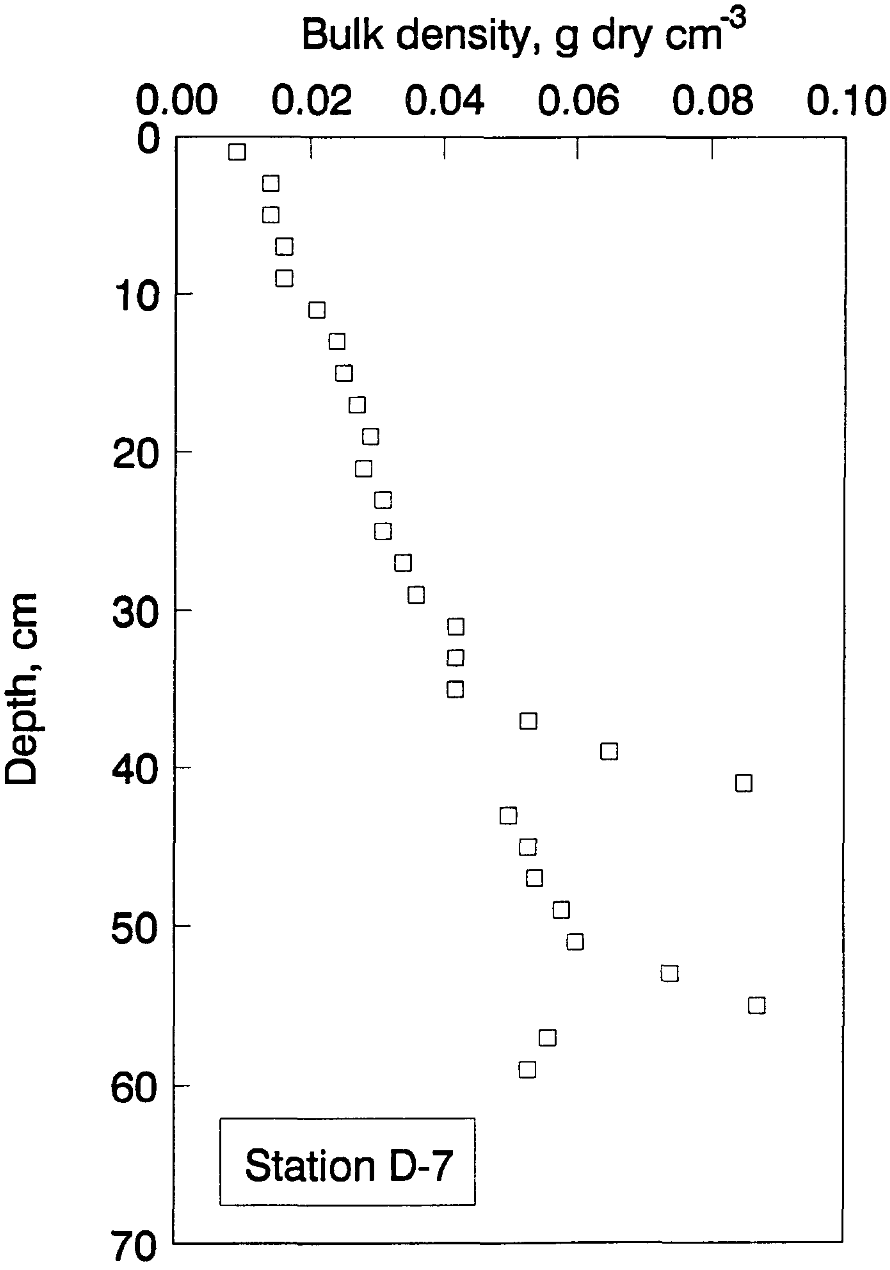

Fig. 6.3.1. Bulk density (g dry cm^{-3} wet) versus depth (cm) in the core from station D-7 in Lake Apopka.

Table 6.3.1. Selected characteristics of the sediment core collected from station D-7 in Lake Apopka.

Depth interval	Bulk density	Mass in depth interval	Cumulative mass	Unsupported Pb-210		Cumulative residual unsupported Pb-210	Age	Sedimentation rate
cm	mg dry cm^{-3} wet	mg cm^{-2}		pCi g^{-1}	pCi cm^{-2} in depth interval	pCi cm^{-2}	yr before 1989	g cm^{-2} yr^{-1}
0 - 2	9.0	18	18	8.08	0.15	9.61	0.0	0.037
2 - 4	14.0	28	46	13.90	0.39	9.47	0.5	0.021
4 - 6	14.0	28	74	11.66	0.33	9.08	1.8	0.024
6 - 8	16.0	32	106	9.42	0.30	8.75	3.0	0.029
8 - 10	16.0	32	138	7.18	0.23	8.45	4.1	0.037
10 - 12	21.0	42	180	4.94	0.21	8.22	5.0	0.052
12 - 14	24.0	48	228	5.80	0.28	8.01	5.8	0.043
14 - 16	25.0	50	278	6.65	0.33	7.74	7.0	0.036
16 - 18	27.0	54	332	7.51	0.41	7.40	8.4	0.031
18 - 20	29.0	58	390	8.36	0.48	7.00	10.2	0.026
20 - 22	28.0	56	446	5.65	0.32	6.51	12.5	0.036
22 - 24	31.0	62	508	8.16	0.51	6.20	14.1	0.024
24 - 26	31.0	62	570	10.67	0.66	5.69	16.8	0.017
26 - 28	34.0	68	638	2.99	0.20	5.03	20.8	0.052
28 - 30	36.0	72	710	4.01	0.29	4.83	22.1	0.037
30 - 32	42.0	84	794	4.16	0.35	4.54	24.1	0.034
32 - 34	42.0	84	878	4.30	0.36	4.19	26.7	0.030
34 - 36	42.0	84	962	4.45	0.37	3.83	29.6	0.027
36 - 38	53.0	106	1068	3.81	0.40	3.45	32.9	0.028
38 - 40	65.0	130	1198	3.18	0.41	3.05	36.9	0.030
40 - 42	85.0	170	1368	2.54	0.43	2.64	41.5	0.032
42 - 44	50.0	100	1468	1.90	0.19	2.20	47.3	0.036
44 - 46	53.0	106	1574	2.21	0.23	2.01	50.2	0.028
46 - 48	54.0	108	1682	2.28	0.25	1.78	54.1	0.024
48 - 50	58.0	116	1798	2.36	0.27	1.53	58.9	0.020
50 - 52	60.0	120	1918	2.43	0.29	1.26	65.2	0.016
52 - 54	74.0	148	2066	2.50	0.37	0.97	73.7	0.012
54 - 56	87.0	174	2240	1.86	0.32	0.60	89.1	0.010
56 - 58	56.0	112	2352	1.21	0.14	0.28	114.0	0.007
58 - 60	53.0	106	2458	1.33	0.14	0.14	135.6	0.003

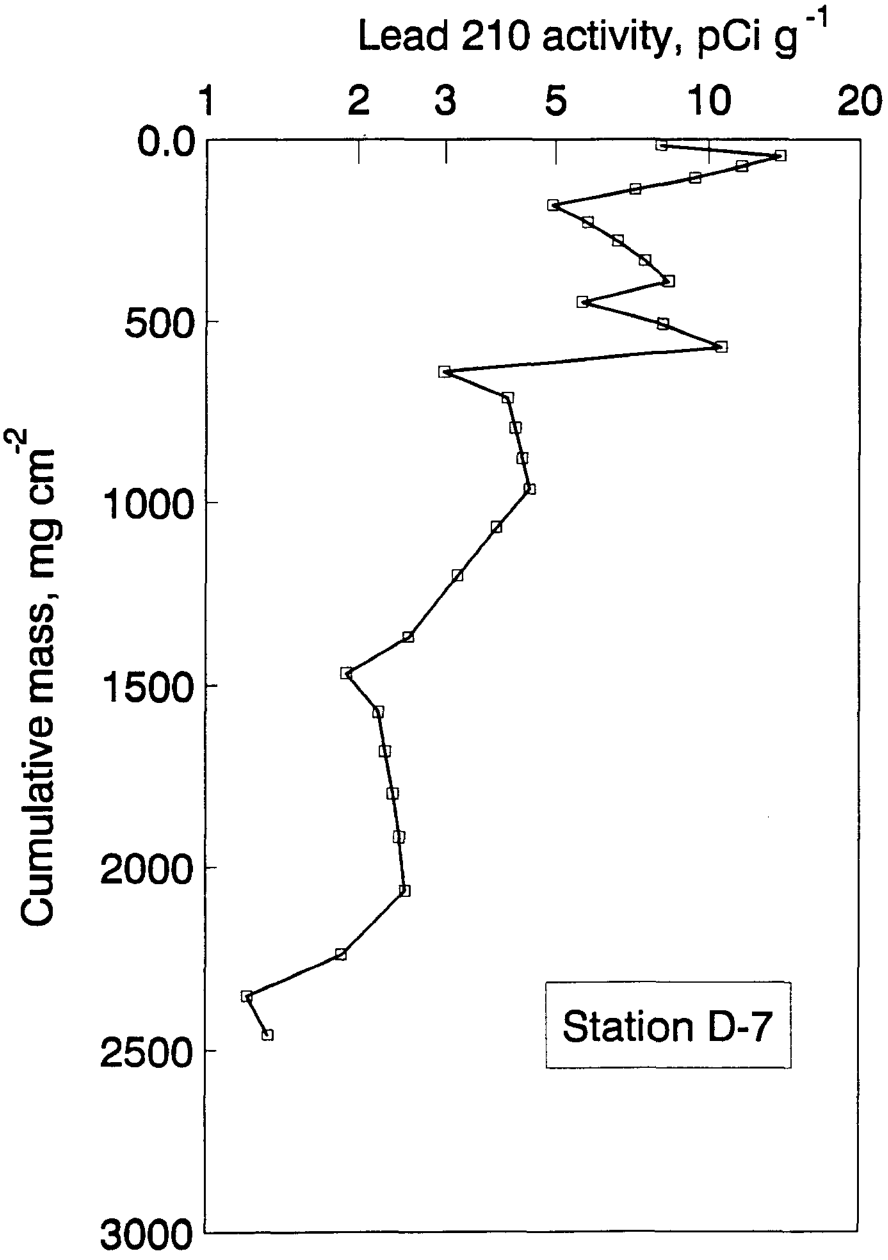

Fig. 6.3.2. Unsupported ^{210}Pb activity (pCi g^{-1}) versus cumulative mass (mg cm^{-2}) in the core from station D-7 in Lake Apopka.

the assumption of constant ^{210}Pb flux to the sediments. Finally, and perhaps most importantly, bulk sediment accumulation rates have probably changed in response to historical shifts in riparian land use.

The cumulative unsupported (total residual) ^{210}Pb activity in the Apopka D-7 core is 9.61 pCi cm^{-1} (Table 6.3.1). The ^{210}Pb supply rate is calculated from the equation:

$$P = kA_o$$

where: P = the ^{210}Pb supply rate, k = the ^{210}Pb decay constant (0.03114 yr^{-1}), and A_o = the cumulative residual ^{210}Pb activity (pCi cm^{-2}). The supply rate computed from the D-7 core (0.30 pCi cm^{-2} yr^{-1}) is comparable to the mean of 0.46 pCi cm^{-2} yr^{-1} based on profiles from nine other Florida lakes (Binford and Brenner, 1986). The rate computed for Lake Apopka is lower because the cumulative residual ^{210}Pb activity is underestimated. Some unsupported ^{210}Pb is present at the deepest analyzed level in the core (58-60 cm), suggesting that the ^{210}Pb profile is truncated.

For purposes of age calculation, it was assumed that the misestimate of A_o is small and contributes little to dating error. Ages were computed for each sampled horizon in the core (Table 6.3.1), and data were used to construct an age versus depth plot (Fig. 6.3.3). The slope of the line is an expression of net sedimentation rate (cm yr^{-1}). The age/depth curve shows a smooth, regular shift to greater sediment accumulation (by depth) through time, up to the present. The trend is most clearly seen by comparing the high sedimentation rates in the topmost portion of the core with the lower values at the base of the core. In the uppermost 10 cm of the core, sediment accumulated at a mean rate of 2.0 cm yr^{-1}. In the bottom 10 cm of the core, the mean rate is 0.13 cm yr^{-1}.

Shifts in bulk density and mass-based sediment accumulation rate influence the shape of the age/depth profile. Depth-based (cm yr^{-1}) expressions of sedimentation rate are controlled in part by variable compaction of muds over the length of the core. Surface deposits are high in water content and have low bulk densities, whereas deeper sediments have undergone some compaction and thus display higher bulk density. With the exception of several high values that likely contain shell fragments, the bulk density varies about five-fold over the length of the core. Because the topmost 10 cm accrued at a rate more than an order of magnitude higher than that recorded for the bottommost sediments, greater mass accumulation is implied for recent times.

Mass-based net sediment accumulation rate (g cm^{-2} yr^{-1}) is plotted against age (yr) in Figure 6.3.4. Starting 136 years ago with a net sediment accumulation rate of 0.003 g cm^{-2} yr^{-1}, the rate rose continuously to 0.036 g cm^{-2} yr^{-1} in 1942. For the past half century, net sediment accumulation rate has been variable (range = 0.017 - 0.052 g cm^{-2} yr^{-1}), but generally faster than rates recorded in older deposits. The mean bulk sedimentation rate for the past 30 years (1959-1989) was 0.030 g cm^{-2} yr^{-1}, about twice as high as the average recorded for the previous 106 years (1853-1959 = 0.014 g cm^{-2} yr^{-1}).

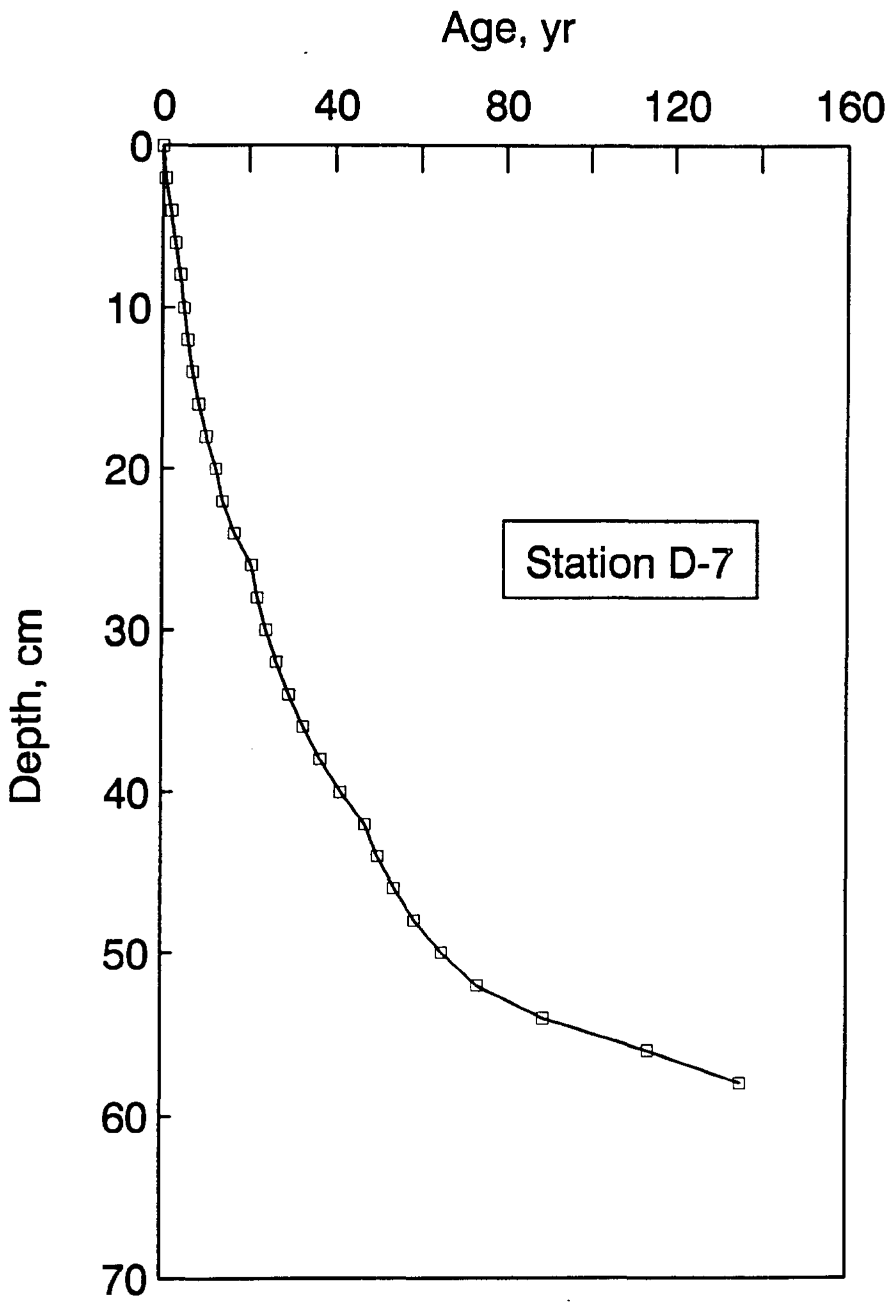

Fig. 6.3.3. Age/depth curve for the core from station D-7 in Lake Apopka.

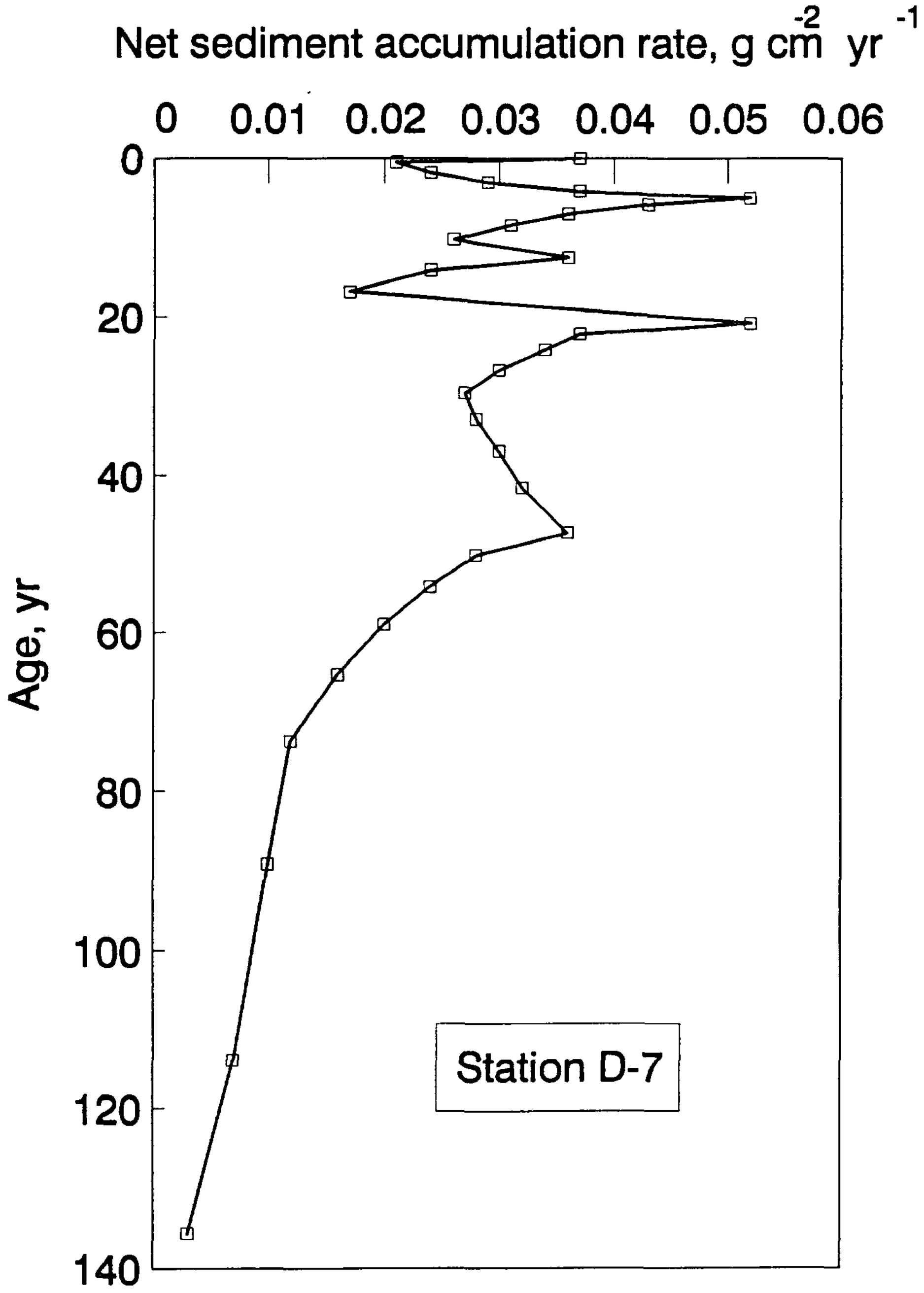

Fig. 6.3.4. Net sediment accumulation rate (g cm^{-2} yr^{-1}) versus age for the core from station D-7 in Lake Apopka.

6.3.4 Conclusions

Data from site D-7 suggest that ^{210}Pb dating of sediments from Lake Apopka is feasible despite their flocculent nature. Results demonstrate that during the past 140 years, net sediment accumulation rates in Lake Apopka have increased, whether expressed on a depth or mass basis. When expressed on a depth basis (cm yr^{-1}), sedimentation rates are seen to have increased by more than an order of magnitude. This is attributed to the effects of compaction and increasing mass deposition. When mass accumulation alone is considered, it is also clear that there has been an increase in net sedimentation. During the past three decades, the mean sediment accumulation rate was about twice that recorded for the previous century.

Some error was introduced into age determination because coring failed to reach "supported" levels (A_o was underestimated), and because counted samples contained low dry weight and required long counting times. The core was sectioned in the field at 2-cm depth intervals to provide high-resolution dating of the sediment column. Despite the use of a large-diameter core barrel, the low bulk density of the muds leaves little dry material for counting. Age differences between contiguous stratigraphic levels in the top 20 cm of the core are less that two years, and probably not statistically real. Future ^{210}Pb-dated profiles from Lake Apopka should be taken to a depth of 80-100 cm to guarantee retrieval of the full unsupported ^{210}Pb record. Furthermore, cores can probably be sampled at somewhat broader intervals, on the order of 5-10 cm, to provide sufficient material for gamma counting. Cores need not be sampled at regular intervals. Sediments near the top of the profile accumulated rapidly and have low bulk density, and therefore can be sectioned at broad intervals. Deeper in the profile, where sediment accumulation proceeded more slowly and there has been some compaction, closer-interval sampling should be done.

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Chapter 7

SEDIMENT RESUSPENSION EFFECTS ON NITROGEN AND PHOSPHORUS FLUX ACROSS THE SEDIMENT-WATER INTERFACE

7.0 SEDIMENT RESUSPENSION EFFECTS ON NITROGEN AND PHOSPHORUS FLUX ACROSS THE SEDIMENT-WATER INTERFACE

[Tasks 5.1 and 5.2]

7.1 Laboratory Microcosm Study to Determine the Sediment Resuspension Effects on Water Quality

7.1.1 Introduction

Resuspension of unconsolidated surface sediments in shallow lakes during the periods of heavy winds can have a major influence on quality of the overlying water. Some of the parameters which can have a major influence include turbidity and nutrient release. The conditions can significantly affect the light penetration, thus influencing algal productivity. Many studies conducted on sediment resuspension primarily dealt with the physical processes (Mehta and Partheniade, 1975, 1979 and 1982; Wolanski et al., 1988). None of these studies have discussed the impact of sediment resuspension on water quality.

In shallow lakes, dissolved oxygen of the water column remains relatively high due to: (1) a low density of oxygen consuming organisms; (2) photosynthetic oxygen production by algae, and (3) wind induced mixing in the water column. Under most conditions oxygen demand in the water column is low and the demand is usually high in the bottom sediments, especially by the sediments with high organic matter content. Because of high oxygen levels in the water, the sediment water interface is usually oxidized (Mortimer, 1941). The thickness of this oxidized sediment layer is determined by the oxygen consumption rate of the sediment and oxygen removal rate in the water column. The surface oxidized sediment layer is often disrupted by: (1) wind induced resuspension of sediment, and (2) bioturbation, thus altering the redox conditions at the sediment water interface.

The amount of sediment resuspended into the water column can deplete the dissolved oxygen and result in anaerobic conditions, especially during night time, when respiration rates are high. However, when wind events occur during daytime, sediment can be resuspended into the oxygenated water column. These conditions can create fluctuating aerobic and anaerobic environments in the water column, thus can have a significant impact on P release. Under these conditions, it is possible that ligand exchange can occur between hydroxide and phosphate on metal (such as ferric iron) containing compounds (Anderson, 1975; Lijkelma, 1977). However, in calcareous sediments, increased pH of the overlying water column was shown to decrease net P flux from sediments, as a result of sorption and coprecipitation with calcite (Gunatilaka, 1982).

The depth of the surface sediment layer involved in mixing with the overlying water column may be highly variable depending on shear stress and sediment structure (Lee, 1970). Other researchers (Tessenow, 1972; Schindler et al., 1977) have estimated the depth of this layer to be about 10 cm, and the sediment in this depth is actively involved in exchange reactions.

Wind-induced mixing of the surface sediment layers was shown to increase nutrient exchange across the sediment-water interface (Anderson, 1974). Holdren and Armstrong (1980) measured increased soluble P release from sediments when the water column was maintained under continuous stirring. Similarly, wind-induced sediment resuspension was shown to increase P release in other lakes (Ryding and Forsberg, 1977; Ahlgren, 1977).

Simultaneous measurements of wind/waves, suspended solids and total P in the water column recently obtained in the Lake Okeechobee Phosphorus Dynamics Study (Sheng et al., 1990) seem to show significant correlations, suggesting that wind-induced waves resuspend bottom fine sediment which in turn releases P. Using a laboratory test column, Reddy and Fisher (1990) have shown that sediment resuspension significantly increased soluble P in the water column of Lake Okeechobee. Sediment resuspension was shown to be the major mechanism for cycling of NH_4^+ between the bottom sediment and the overlying water column in the transition zone of the Potomac River Estuary (Simon, 1988a,b).

In Lake Apopka, the surface unconsolidated (UCF) sediments are 98% water and about 2% solids (by dry weight basis) (see Chapter 3 for specific characteristics of UCF sediments), thus offering a greater potential for rapid resuspension during hydrodynamic events. The objectives of this study were to determine: (1) the rate of NH_4^+ and SRP release during sediment resuspension under simulated conditions, and (2) the potential NH_4^+ and SRP desorption from solid phase to liquid phase in recently settled suspended sediments.

7.1.2 Materials and methods

7.1.2.1 Laboratory sediment resuspension study:

Intact sediment cores obtained from Center Lake station (near F-6) were used in the study. Three columns with 30 cm water depth were used as control, while the second set of three columns were used to simulate sediment resuspension. Sediment resuspension was generated in Plexiglas cylinders (6.35 i.d. and 60 cm high) by oscillating grids (Fig. 7.1.1), an experimental set-up similar to the one described by Wolanski et al. (1989). Using this apparatus, the surface 10 cm sediment was resuspended into the water column for a period of one hour. During this period, sediment/water samples were obtained at 0, 15, 30 and 60 minutes, and filtered through 0.45 μm filter paper. After one hour, sediment resuspension was stopped, and sediment particles were allowed to settle. During sediment settling, water samples were obtained after 1, 2, 4, 8, 12 and 24 h and analyzed for NH_4-N and SRP after filtration through 0.45 μm filter paper. At the same time, water samples were also obtained from control sediment-water columns.

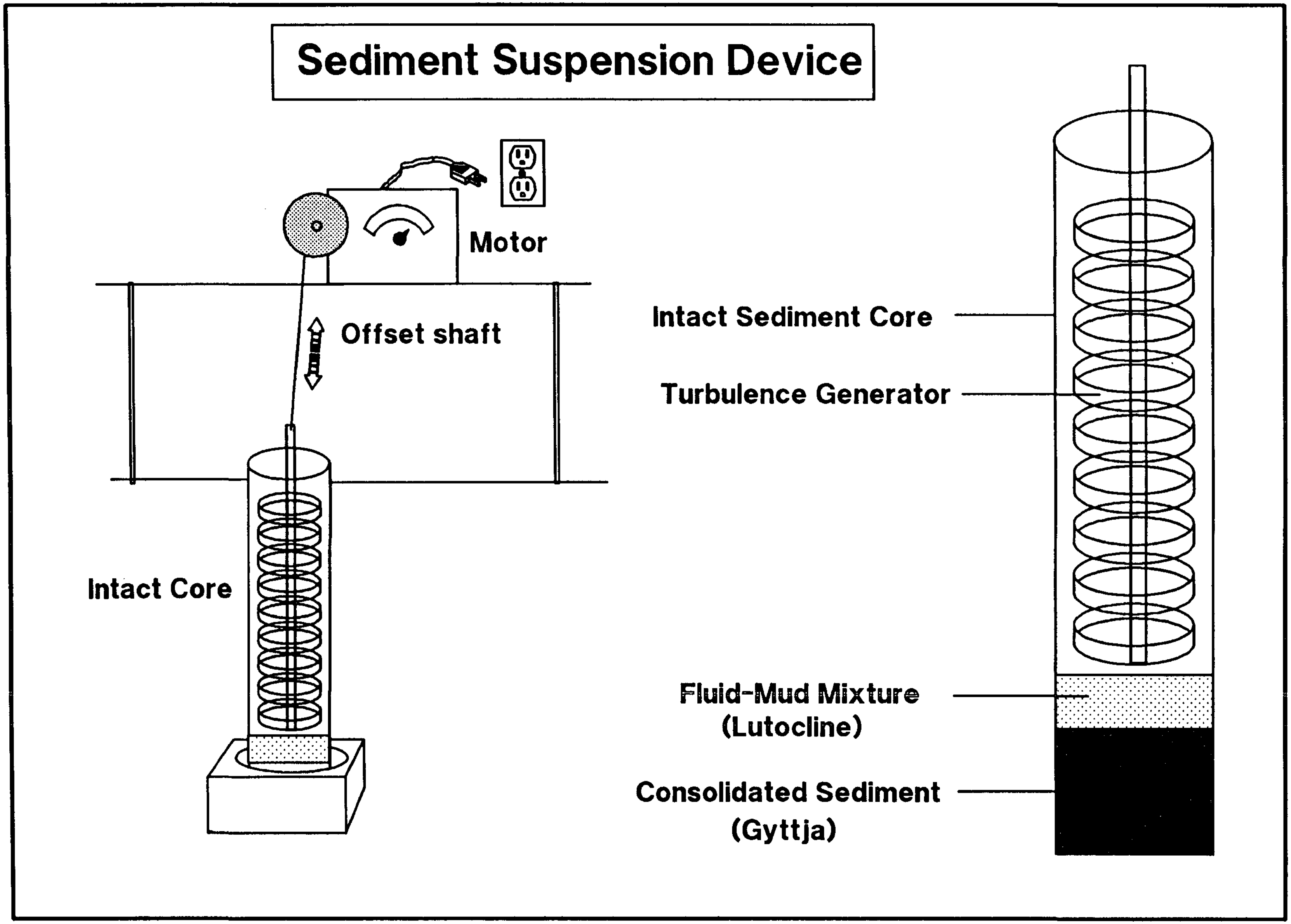


Fig. 7.1.1. Schematic presentation of sediment resuspension apparatus used in the study.

7.1.2.2 Laboratory incubation study:

In order to determine the NH_4^+ and SRP release from recently deposited sediments (after one hour resuspension event), the surface sediments resuspended into the water column for one hour (see Sec. 7.2.2.1) were allowed to settle for 24 h. The surface 10 cm sediment core was sectioned and placed in a flask containing filtered lake water (total solids = 10 g L^{-1}) and stirred continuously with a magnetic stirrer under oxygenated conditions at 25°C. Sediment slurry samples were withdrawn at 0, 15, 30 minutes, and 1, 2, 4, 8, 12 and 24 h and filtered through 0.45 μm filter paper. Filtered solutions were analyzed for NH_4-N and SRP.

7.1.3 Results and discussion

7.1.3.1 Sediment resuspension effects:

Resuspension of surface 10 cm flocculent sediment into the overlying water column for a period of one hour resulted in rapid release of soluble NH_4^+ within the first 15 minutes (Fig. 7.1.2). Ammonium concentration in the water column increased from 0.215 mg L^{-1} to 3.8 mg L^{-1} in 15 minutes. After this period, NH_4^+ concentration in the water column did not change significantly during one hour of resuspension. Ammonium concentration of the water column remained at the same level (3.5 - 3.8 mg L^{-1}) after one hour of sediment resuspension and the remaining 23-h settling period (Fig. 7.1.3). In the control sediment-water column, diffusive flux of NH_4^+ resulted in no significant change in NH_4^+ levels of the water column. Initial NH_4^+ release rates during the sediment resuspension event were in the range of 0.403 - 0.508 mg cm^{-2} h^{-1} (Table 7.1.1). These are potential release rates measured under laboratory conditions, and should be used with caution.

One hour sediment resuspension did not have an immediate effect on SRP release as was observed for NH_4^+. Peak SRP release was noted three hours after the resuspension event was stopped (Fig. 7.1.4). Soluble P concentrations were low (7 μg L^{-1}) in the water column before the resuspension event. Resuspension of sediment increased the water column SRP levels to 26 μg L^{-1}, three hours after the sediment resuspension event was stopped (Fig. 7.1.5). Diffusive flux of SRP in control sediment cores was not significant. Calculated SRP release rates were 0.05 - 0.33 μg cm^{-2} h^{-1} for the water column with sediment resuspension event, and -0.02 - 0.05 μg cm^{-2} h^{-1} for the water column without resuspension (Table 7.1.1). Slow SRP release by surface 10 cm is due to low levels of porewater SRP (see Chapter 7.3 for porewater SRP profiles of sediment cores).

7.1.3.2 Desorption of soluble ammonium and phosphorus:

Short-term NH_4^+ and SRP desorption rates were measured using recently settled surface sediments obtained from cores used in the experiment of sediment resuspension (Sec. 7.2.2.1). The surface 10 cm sediments which underwent resuspension (Sec. 7.1.3.1) and settling were used to prepare sediment slurries. The sediment slurries were continuously mixed in batch reactors, and NH_4^+ and SRP

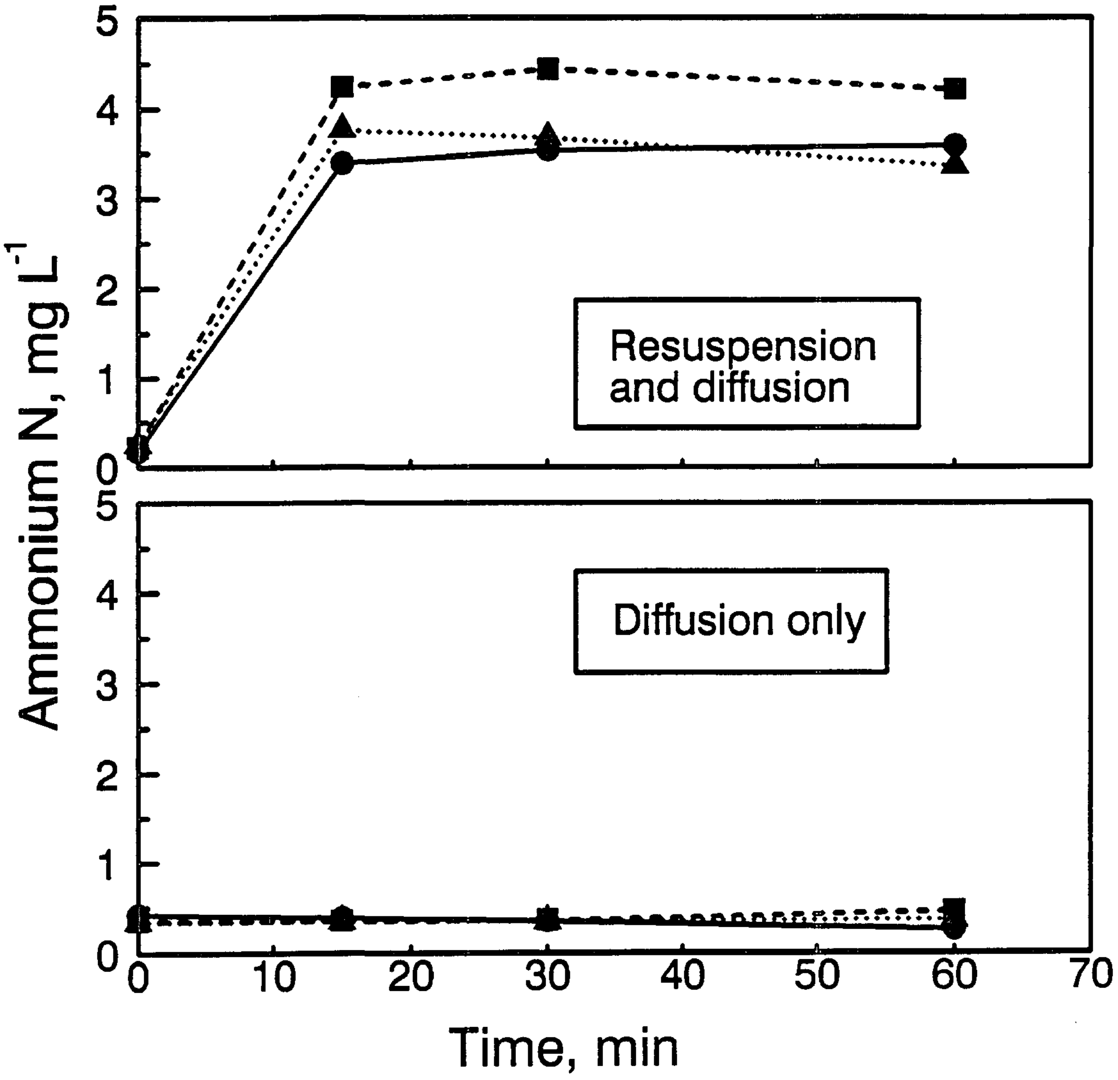


Fig. 7.1.2. Ammonium N release into the water column during one hour of sediment (surface 10 cm) resuspension. Different data lines represent replicate cores.

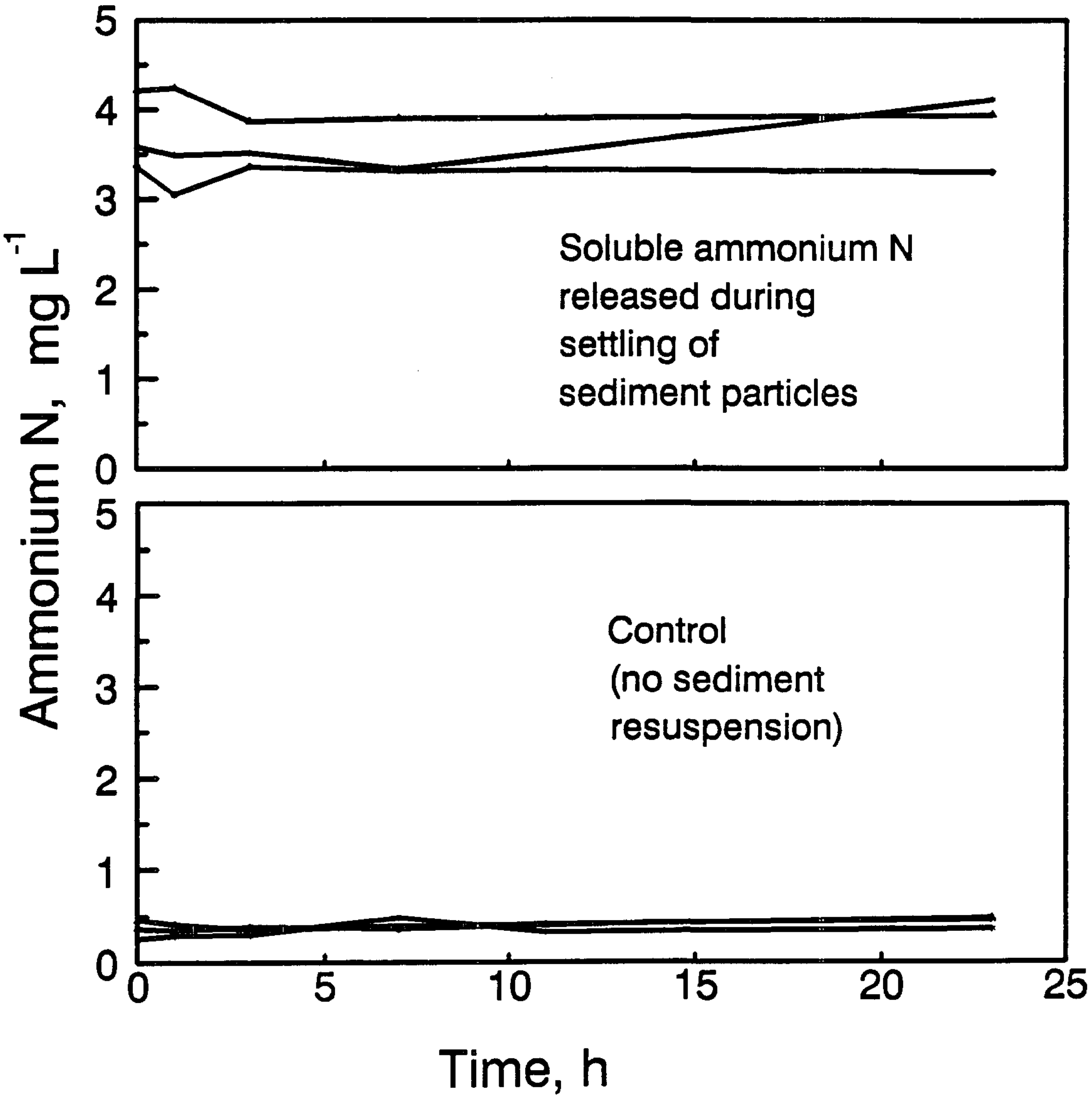


Fig. 7.1.3. Soluble ammonium N release into the water column during settling of suspended sediment particles.

Table 7.1.1. Ammonium N and soluble P release during sediment resuspension.

	NH_4-N	SRP
	------μg cm^{-2} h^{-1}------	
Resuspended Cores		
Core I	403	-0.016
Core II	508	0.113
Core III	443	0.483
Control Cores		
Core I	-4.8	0.041
Core II	0.5	-0.016
Core III	0.5	0.047

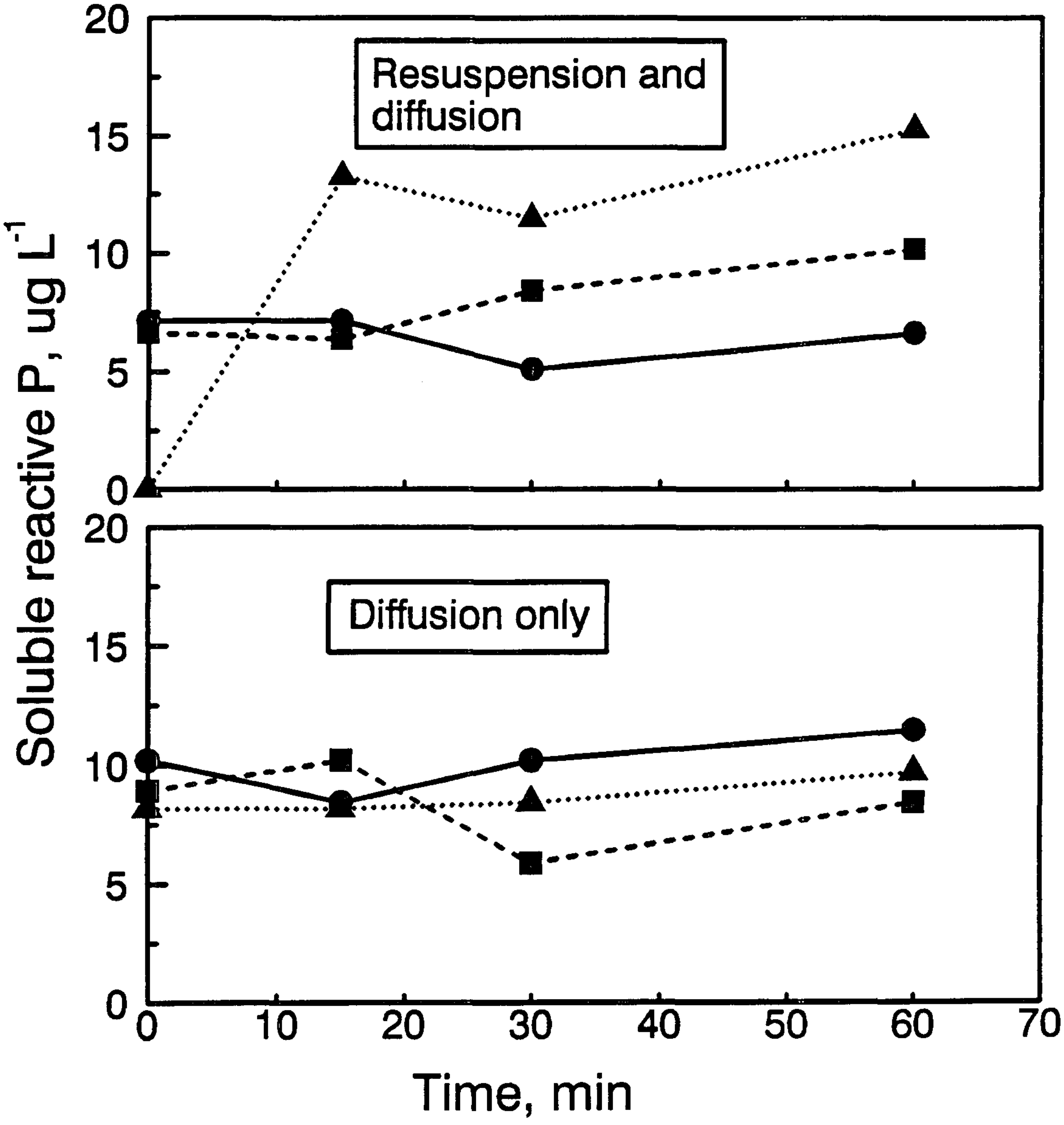


Fig. 7.1.4. Soluble reactive P release into the water column during one hour of sediment (surface 10 cm) resuspension. Different data lines represent replicate cores.

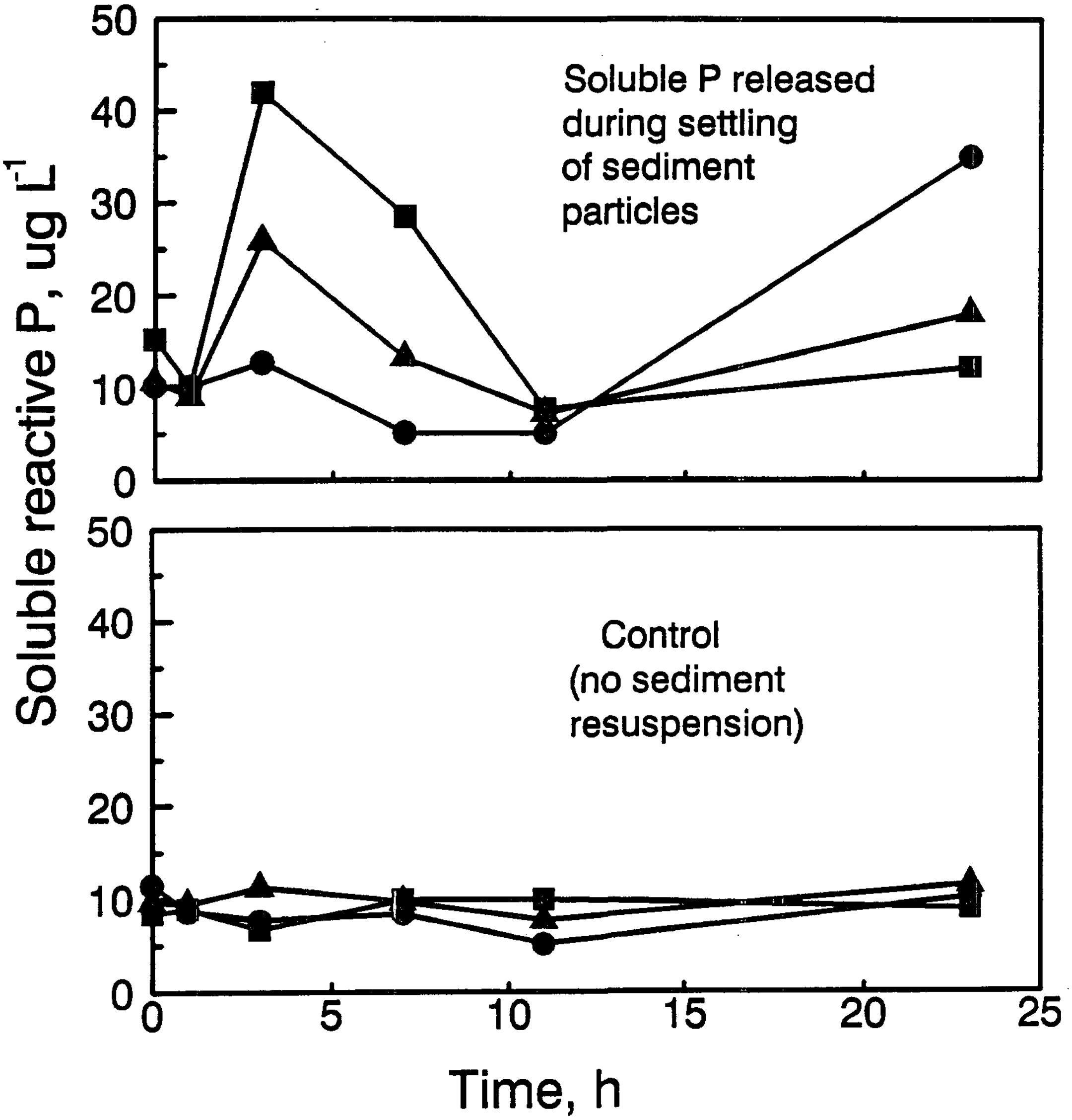


Fig. 7.1.5. Soluble reactive P release into the water column during settling of suspended particles.

release under these conditions were measured. Results are presented in Figs. 7.1.6 and 7.1.7. In recently settled sediments, NH_4^+ concentration in solution was low, compared to the sediments which did not have resuspension. Under both types of sediments, NH_4^+ decreased during a 24-h incubation period. This is probably due to reabsorption of NH_4^+ on solid particles and nitrification. In recently settled sediments, NH_4^+ decreased from 1.6 mg L^{-1} to 0.75 mg L^{-1}, while in 'control' sediments, NH_4^+ decreased from 3.7 mg L^{-1} to 2.3 mg L^{-1}. Since these batch reactions were maintained under oxidized conditions, it is possible that significant amounts of NH_4-N was probably nitrified. Ammonium adsorption was shown to be stronger under aerobic conditions than anaerobic conditions (see Chapter 5.8).

Soluble P in sediment slurries was decreased during continuous mixing, suggesting stronger adsorption of P under aerobic conditions than anaerobic conditions. Soluble reactive P concentrations decreased from 12 μg L^{-1} to 10 μg L^{-1} in recently settled sediments, and 22 μg L^{-1} to 9 μg L^{-1} in 'control' sediments. These results suggest that the sorbed P in surface sediments is strongly bound and is slowly desorbed into the water column.

An example of P exchange processes before, during and after resuspension events are schematically shown in Fig. 7.1.8 (Reddy and Fisher, 1990). Similar exchange processes can also function in a shallow lake in cycling of N between the sediment and the water column. Both biotic and abiotic processes appear to regulate N and P release during these events.

The results clearly indicate that, NH_4^+ release is rapid during resuspension events, with flux of up to 500 μg N cm^{-2} h^{-1}. The flux of NH_4^+ during resuspension events is considerably higher in our laboratory experiments, primarily due to resuspension of the top 10 cm sediment. Resuspension flux is several-fold higher than diffusive flux, with respect to cycling of NH_4^+. Similar results were also observed by Simon (1988a,b) for the Potomac River and Estuary. Decrease in NH_4^+ concentration in the water column can be attributed to nitrification of NH_4^+. In a lake system, NO_3^- will rapidly diffuse into bottom sediments where it is subjected to various NO_3^- reductive processes.

A high degree of variability was measured in P release rates during sediment resuspension. The chemical processes associated with the sediment resuspended into the water column are the same as those functioning within the sediment profile, except the resuspended sediments are interacting with the water containing usually low P concentration. As the particles are resuspended, soluble P desorption occurs until a new equilibrium is reached. The equilibrium P concentration is regulated by the amount of sediment resuspended (total suspended solids concentration of the water), O_2 demand of the suspended sediment, soluble P concentration of the water column before resuspension, ionic strength, pH and sorptive characteristics of the sediment particles (Lijklema et al., 1986).

Results obtained from this laboratory experiment show the relative significance of flux due to resuspension and diffusion. Under field conditions, several complex

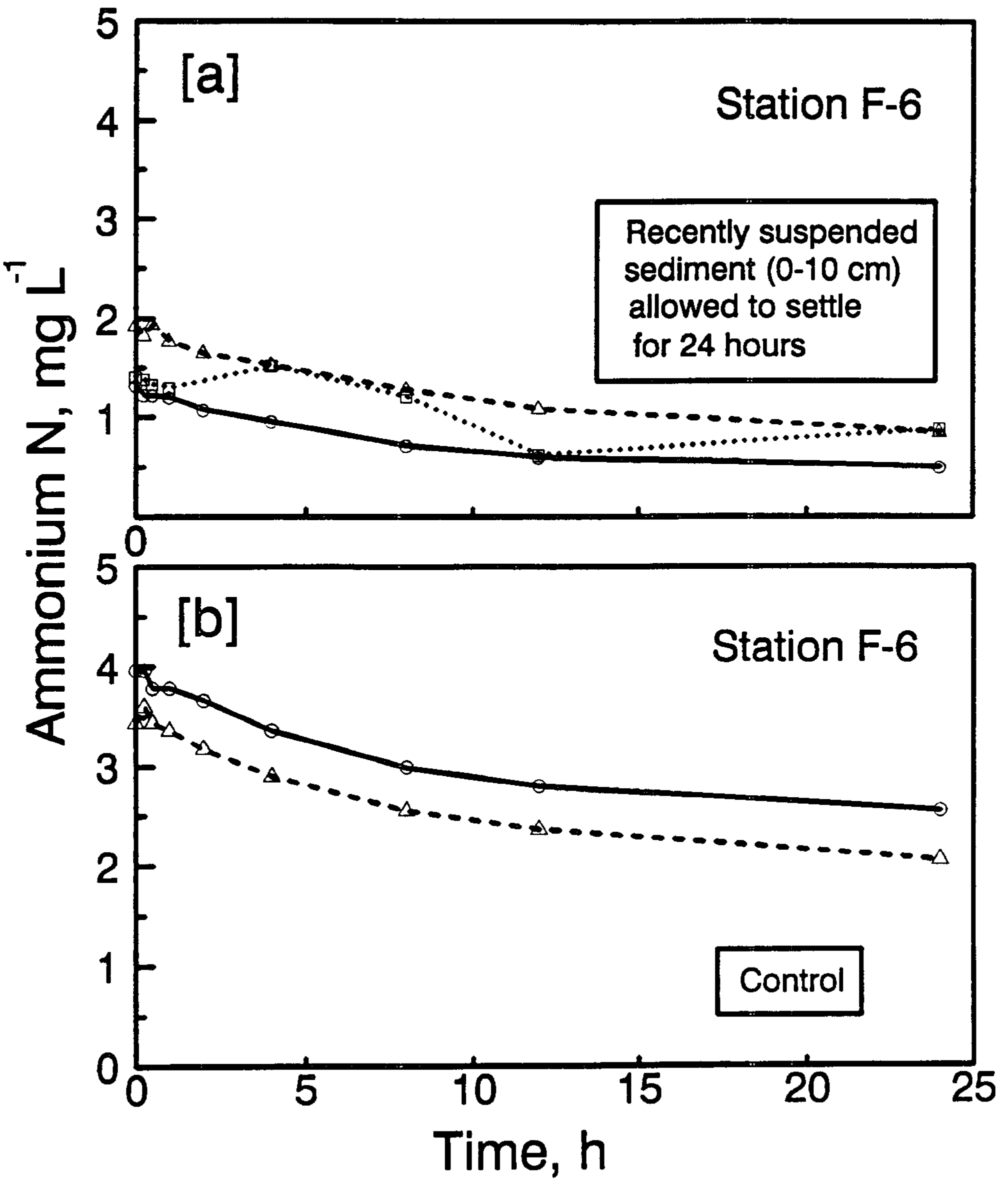


Fig. 7.1.6. Soluble ammonium N desorption in a continuously stirred sediment (surface 10 cm) in batch reactions. In [a], ammonium N release potential of recently settled sediment was measured. Different data lines represent replicate cores.

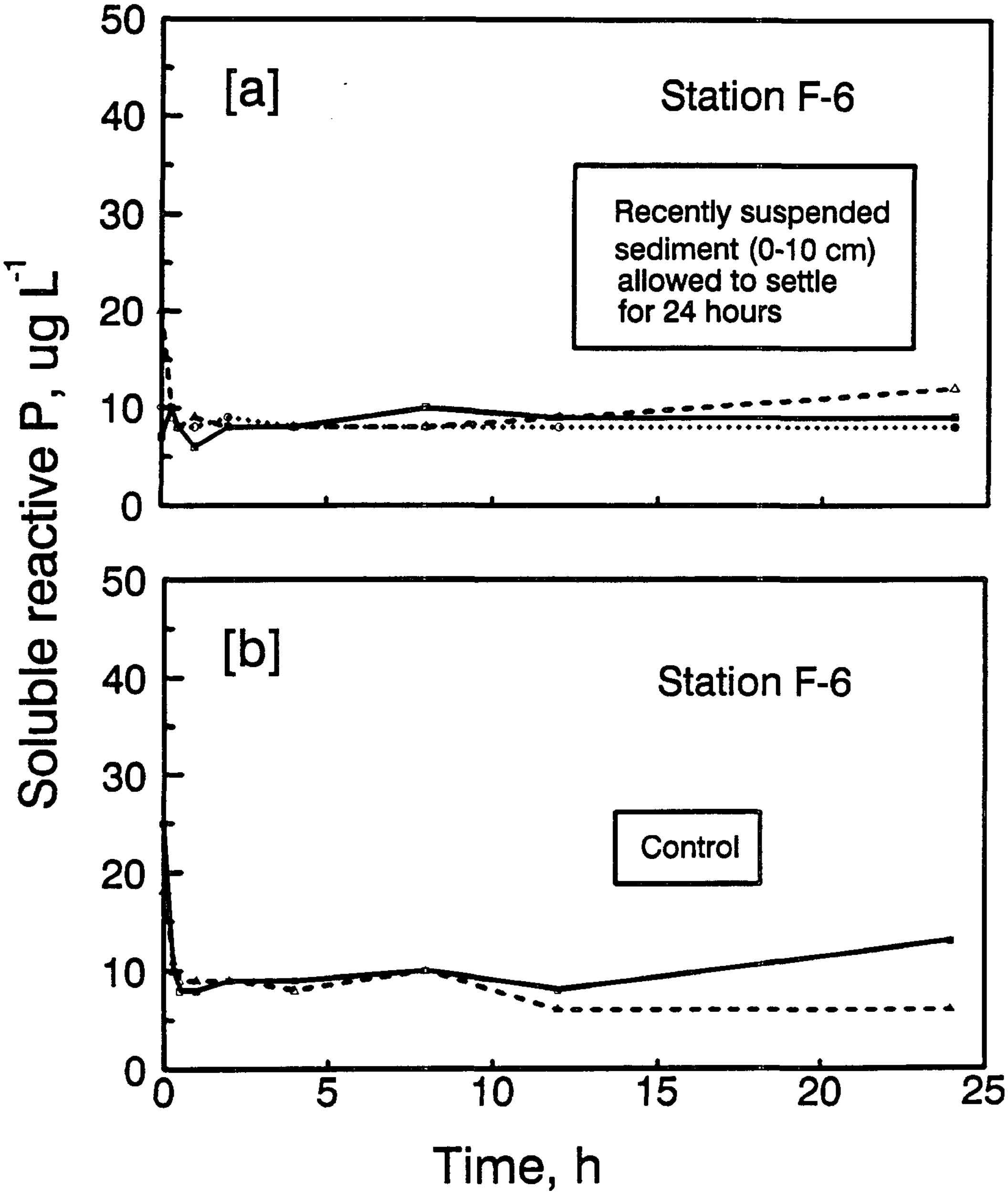
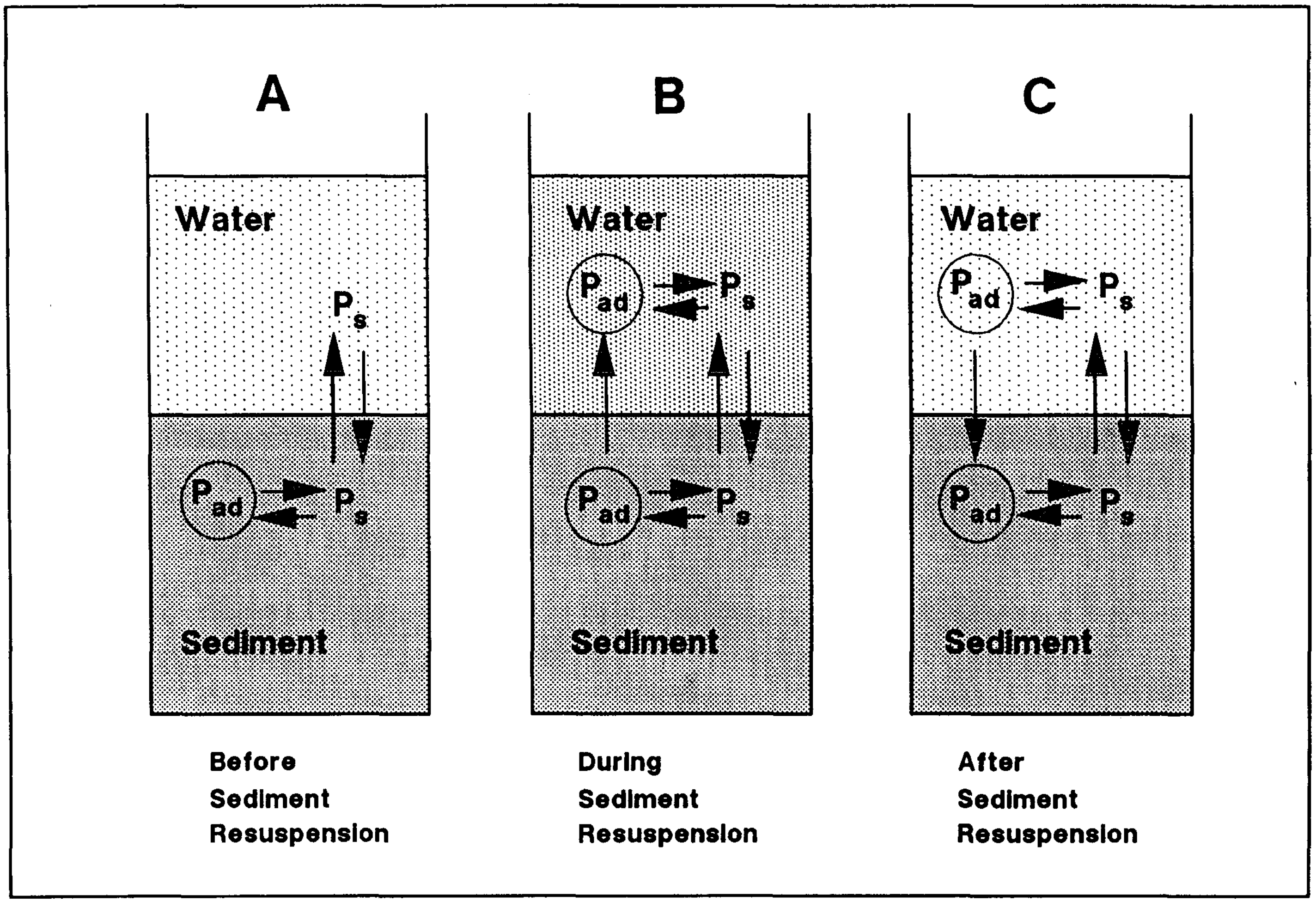


Fig. 7.1.7. Soluble reactive P desorption in a continuously stirred sediment (surface 10 cm). In [a], phosphorus release potential of recently settled sediment was measured. Different data lines represent replicate cores.



Before Sediment Resuspension

During Sediment Resuspension

After Sediment Resuspension

Fig. 7.1.8. Schematic presentation of the adsorption-desorption processes regulating soluble P concentration in the overlying water column as a result of resuspension and diffusive flux in lake sediments. P_s = soluble P; P_{ad} = adsorbed P.

hydrodynamic and biogeochemical processes simultaneously regulate the N and P cycling between sediment and the overlying water column. Caution should be exercised in the application of laboratory results to predict the behavior under field conditions.

7.1.4 Conclusions

The results presented in this study clearly document the potential effects of sediment resuspension on NH_4^+ and soluble reactive P release into the water column. Ammonium N release during sediment resuspension was rapid with release rates of 403 - 508 $\mu g\ cm^{-2}\ h^{-1}$, as compared to SRP release rates of 0.05 - 0.33 $\mu g\ cm^{-2}\ h^{-1}$. Ammonium concentrations remained high even after a 24-h settling period of suspended sediment, while SRP levels reached near background levels. It should be noted that the release rates were measured under laboratory conditions (and caution should be exercised when using these values under field conditions. The hydrodynamic processes functioning in Lake Apopka are complex and the biogeochemical processes associated with N and P release are dynamic and need further investigation to quantitatively evaluate the effects of sediment resuspension on water quality.

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7.2 Sediment Resuspension Effects on Water Quality: In-Situ Studies

7.2.1 Introduction

The surface sediments of Lake Apopka contain about 98% water and are flocculent in consistency. This sediment can be easily suspended into the water column during wind events resulting in the release of dissolved nutrients into the water column. The objectives of this study were to: (1) evaluate the effect of wind-driven sediment resuspension on water quality, and (2) determine the spatial and temporal variations in sediment porewater NH_4^+ and soluble P.

7.2.2 Materials and methods

7.2.2.1 Water sampling:

Water samples from the Center Lake Station (near F-6 station) were collected 3 times a week by SJRWMD staff. The water sampling was initiated on July 13, 1988 and was continued for a period of 24 months, until June 30, 1990. One portion of the water sample was filtered on-site through 0.45 μm filter paper. Filtered water samples were acidified and frozen until analyzed. Both filtered and unfiltered water samples were placed on ice and shipped to the Wetland Soils Research Laboratory for chemical analysis. Filtered samples were analyzed for ammonium N, nitrate + nitrite N, soluble reactive P (SRP), while the unfiltered samples were analyzed for total Kjeldahl N (TKN), total P (TP), total organic C (TOC), dissolved solids and total solids, using standard methods (APHA, 1985).

7.2.2.2 Sediment sampling:

Triplicate intact sediment cores were obtained from seven locations (stations B-2, G-2, D-5, K-6, G-7, H-10 and D-11) on February 12, 1988 to determine the spatial variation in porewater concentrations of NH_4^+ and SRP as a function of depth. To determine the temporal variations, triplicate sediment cores were obtained quarterly from the same location (station F-6) as water samples. Sediment cores were obtained on October 7, 1988 and January 10, April 10, and July 10, 1989, using a piston corer fitted with 1 m Plexiglas (6.35 cm ID) tube. Sediment cores were then sectioned into 0-2, 2-4, 4-8, 8-12, 12-16, 16-20, 20-25, 25-30, 35-40, and 50-60 cm intervals and transferred into centrifuge tubes followed by thorough purging with N_2 gas. Samples were placed on ice and transported to the laboratory. Porewater was extracted by centrifuging the sediments at 5000 rpm for 15 min., followed by filtration under anaerobic conditions. Filtered solutions were analyzed for pH, alkalinity, ammonium N, nitrate + nitrite N, and SRP.

7.2.3 Results and discussion

7.2.3.1 Water chemistry:

Measured water quality parameters of the samples collected from the Center Lake station during the two-year period are given in Appendix 7.2.1. Examples of the data collected for the year of 1989 are shown in Fig. 7.2.1. Results show significant fluctuations in the concentrations of water quality parameters suggesting an influence from both external and internal factors.

Total suspended solid concentrations were in the range of 29-170 mg L^{-1}, with the low concentration measured on November 21, 1988, and the maximum recorded on April 6, 1989. Total N and P concentrations on November 21, 1988 were 3.4 and 0.10 mg L^{-1}, respectively, while on April 6, 1989, TKN and TP concentrations were 7.15 and 0.27 mg L^{-1}. Although TKN and TP concentrations were not at their maximum when highest TSS values were measured, generally there was a positive relationship between these elemental concentrations and total suspended solids (Figs. 7.2.2 and 7.2.3). No significant relationship was observed between total solids and SRP or NH_4-N. Maximum TP values were recorded during the months of August and September, 1988. Similar trends were also observed with TKN concentrations, with peak concentrations also observed during the month of July. The water chemistry data collected over a two-year period from Center Lake Station will be used by SJRWMD staff in developing predictive models.

7.2.3.2 Sediment chemistry:

(a) Spatial variability studies.

Profiles of NH_4^+ concentration of the porewater sediment cores collected from various locations in Lake Apopka are presented in Table 7.2.1 and Figs. 7.2.4a and b. Ammonium concentration in the porewater showed significant spatial variability, with the concentrations ranging from about 20 to 140 mg L^{-1} at depths greater than 30 cm. Ammonium concentration in the surface layers showed less variability and concentration was less than 5 mg L^{-1}. Porewater NH_4^+ concentration was lowest in the sediment cores obtained from G-2 and D-11, while highest concentrations were measured in the cores obtained from station G-7.

Ammonium profiles at all stations showed steep gradients up to the 20 cm depth, indicating rapid interchange between the sediment and the overlying water column. The NH_4^+ flux from the sediment to the water column was estimated to be in the range of 10-39 mg N m^{-2} d^{-1} (see Chapter 4 for procedures used in calculation of flux). The average NH_4^+ flux was estimated to be 25.2 ± 11.2 mg N m^{-2} d^{-1} (Table 7.2.2).

Soluble P concentrations were very low in the surface layers, indicating the effects of sediment resuspension and subsequent release into the water column (Figs. 7.2.5a and b). It is interesting to note that SRP levels in the surface sediment layers

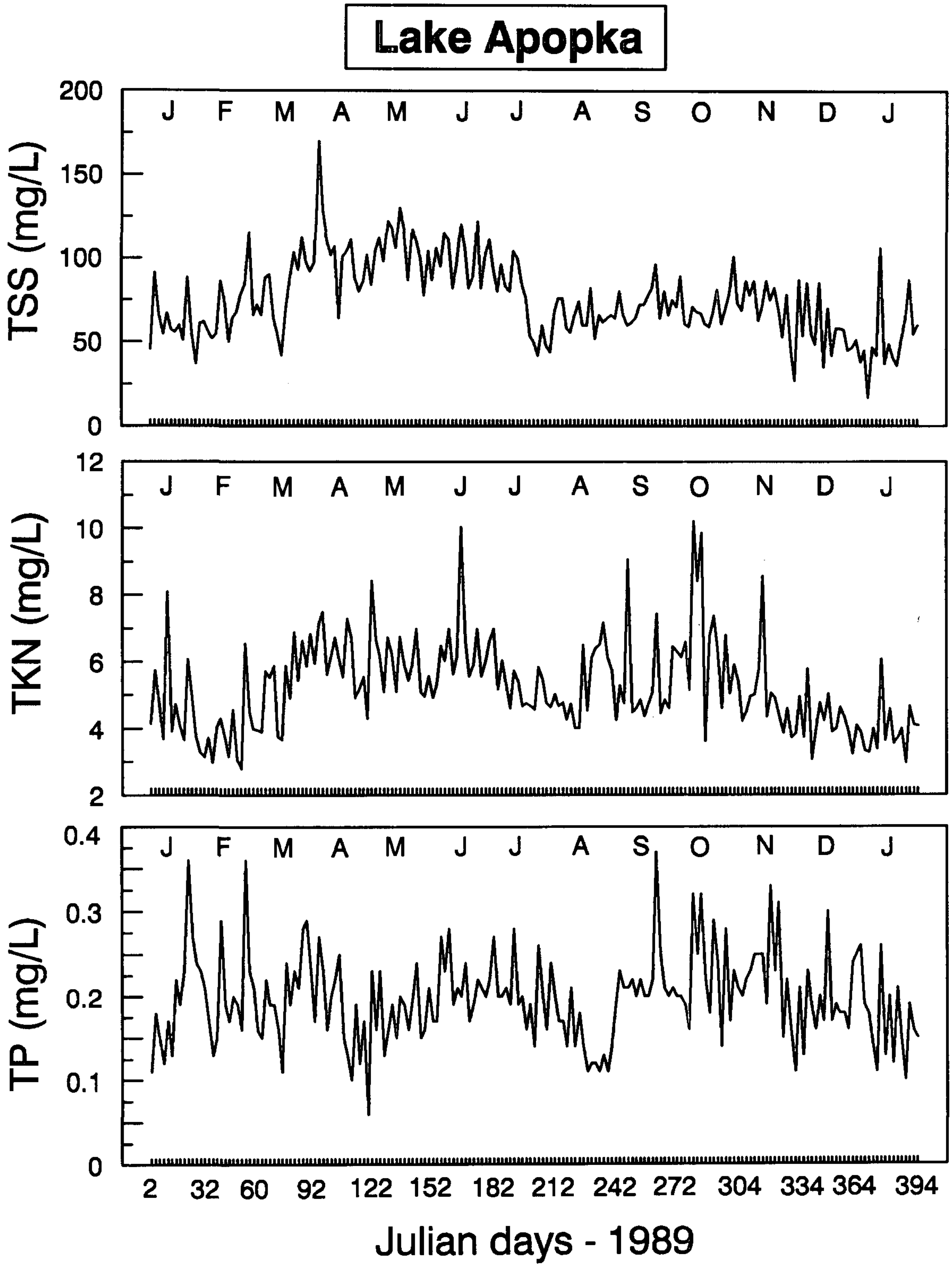

Fig. 7.2.1. Seasonal changes in total suspended solids, total N and total P in the water column at Center Lake Station.

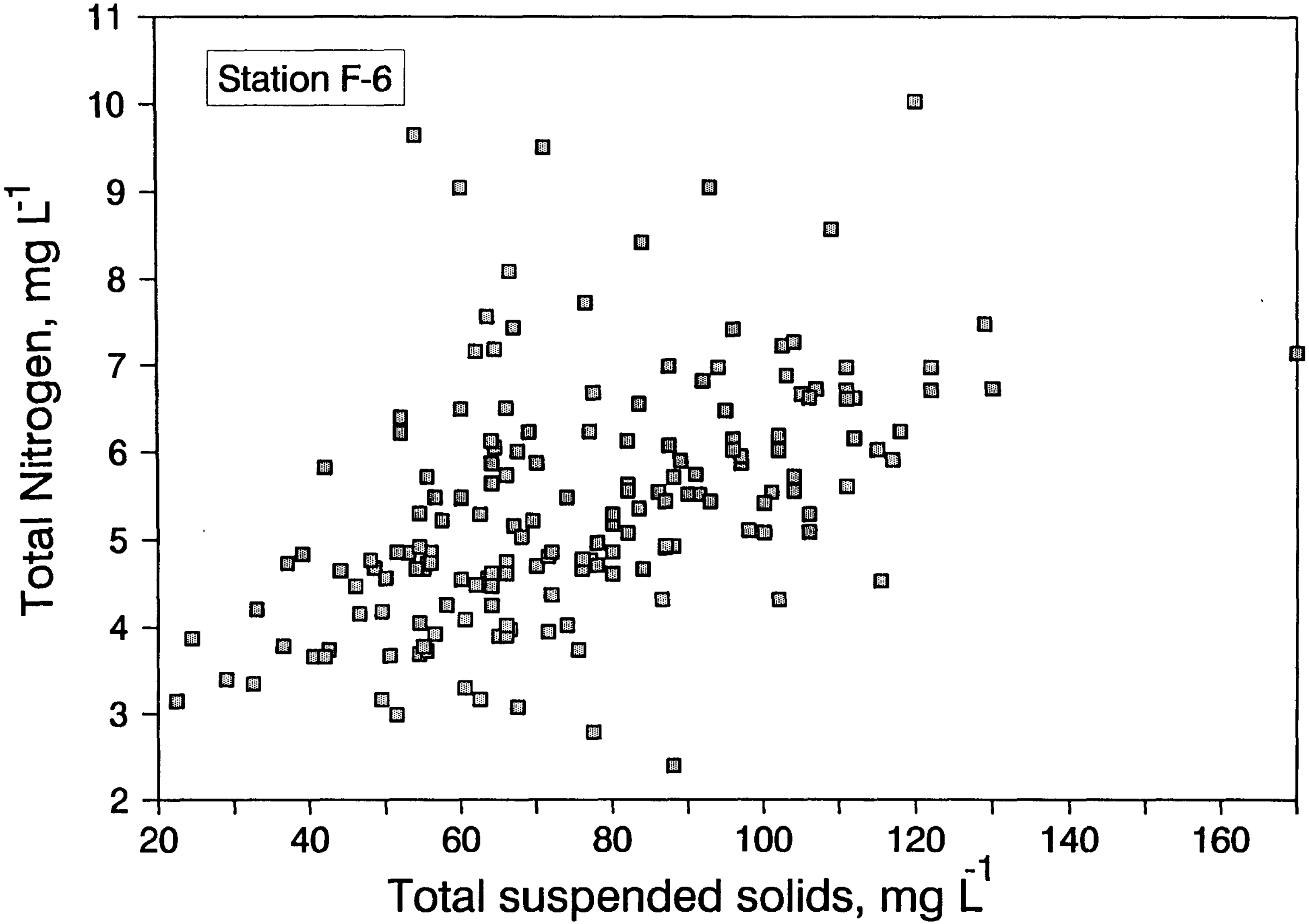

Fig. 7.2.2. Relationship between total suspended solids and total nitrogen content of the water samples obtained at station F-6 ($r = 0.493^{**}$; $n = 174$).

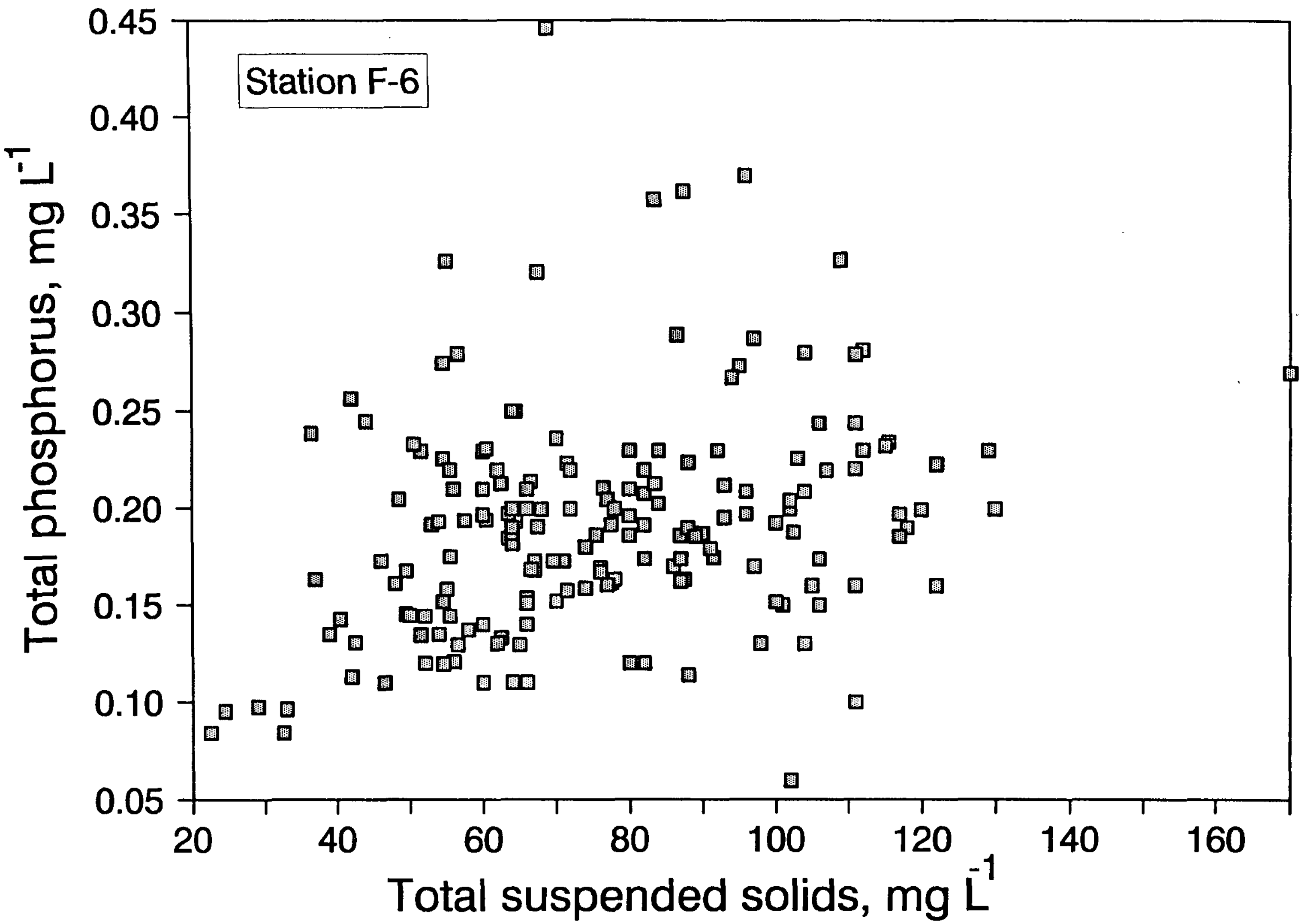

Fig. 7.2.3. Relationship between total suspended solids and total phosphorus content of the water samples obtained at station F-6 ($r = 0.345^{**}$; $n = 172$).

Table 7.2.1. Selected physico-chemical properties of the porewater of sediment cores obtained from selected stations on February 12, 1988.

Sampling station	Depth	Dry bulk density	pH	EC	NH_4-N	SRP
	cm	g cm^{-3}		μS cm^{-1}	mg L^{-1}	
Station G-7	0-2	0.052	7.45	587	3.33	0.020
	2-4	0.053	7.58	647	6.32	0.024
	4-8	0.074	7.21	737	14.87	0.017
	8-12	0.087	7.12	850	27.13	0.114
	12-16	0.095	7.13	927	32.27	0.927
	16-20	0.112	7.08	1020	37.47	2.350
	20-25	0.120	7.04	1150	46.93	4.583
	25-30	0.136	7.07	1267	49.63	5.173
	35-40	0.150	6.98	1363	101.83	10.313
	45-50	0.184	6.97	1650	127.30	14.980
	55-60	0.195	7.38	1683	134.67	14.673
Station D-5	0-2	0.051	7.39	475	1.19	0.015
	2-4	0.056	7.37	540	4.28	0.005
	4-8	0.072	7.16	660	7.07	0.035
	8-12	0.082	7.14	733	15.77	0.562
	12-16	0.089	7.15	793	17.40	0.873
	16-20	0.093	7.10	833	22.00	1.623
	20-25	0.098	7.10	870	23.17	1.970
	25-30	0.101	7.01	893	29.17	2.137
	35-40	0.105	7.13	917	28.47	2.677
	45-50	0.110	7.02	947	35.03	3.503
	55-60	0.111	7.06	953	34.87	3.287
Station K-6	0-2	0.049	7.78	560	2.96	0.019
	2-4	0.047	7.63	623	6.32	0.012
	4-8	0.074	7.38	767	13.31	0.642
	8-12	0.089	7.32	902	25.03	2.463
	12-16	0.100	7.12	1013	38.93	4.587
	16-20	0.110	7.18	1107	45.23	5.430
	20-25	0.120	7.05	1140	49.63	6.137
	25-30	0.119	7.03	1160	52.17	6.957
	35-40	0.122	7.02	1207	49.53	6.333
	45-50	0.130	7.12	1168	50.73	6.020
	55-60	0.126	7.23	1110	53.30	5.150
Station B-2	0-2	0.053	7.46	533	6.59	0.021
	2-4	0.062	7.37	598	0.35	0.014
	4-8	0.075	7.11	682	6.48	0.052
	8-12	0.083	7.05	738	12.80	0.228
	12-16	0.088	7.07	802	25.27	1.833
	16-20	0.095	7.01	843	30.73	2.877
	20-25	0.106	6.93	920	36.10	3.523
	25-30	0.107	6.91	963	40.23	3.903
	35-40	0.113	6.96	990	45.87	4.560
	45-50	0.117	6.93	995	45.97	4.130
	55-60	0.113	6.97	992	44.67	3.883
Station G-2	0-2	0.057	7.28	533	2.99	0.012
	2-4	0.060	7.22	560	5.45	0.013
	4-8	0.066	7.07	610	7.41	0.015
	8-12	0.069	7.08	633	7.40	0.226
	12-16	0.074	7.08	677	11.10	0.850
	16-20	0.081	7.02	707	14.20	1.627
	20-25	0.082	7.03	730	17.70	2.093
	25-30	0.084	6.98	737	14.70	1.590
	35-40	0.084	7.00	747	19.23	2.087

Table 7.2.1 (cont'd.)

Sampling station	Depth	Dry bulk density	pH	EC	NH_4-N	SRP
	cm	—g cm^{-3}—		µS cm^{-1}	mg L^{-1}	
Station D-11	0–2	0.045	7.50	467	2.53	0.021
	2–4	0.049	7.24	542	4.34	0.019
	4–8	0.060	7.22	660	6.28	0.016
	8–12	0.070	7.29	692	8.35	0.121
	12–16	0.073	7.37	702	12.67	0.377
	16–20	0.073	7.32	702	12.87	0.467
	20–25	0.068	7.20	716	15.63	0.544
	25–30	0.071	7.15	715	16.67	0.616
	35–40	0.069	7.05	667	16.43	0.509
	45–50	0.069	7.17	672	18.37	0.599
	55–60	0.072	7.30	712	20.27	0.570
Station H-10	0–2	0.066	7.37	577	5.74	0.008
	2–4	0.074	7.32	653	8.85	0.007
	4–8	0.084	7.07	747	12.87	0.317
	8–12	0.097	7.03	847	18.40	1.247
	12–16	0.107	7.05	927	30.73	2.697
	16–20	0.118	7.00	1007	39.57	3.913
	20–25	0.127	6.92	1067	48.00	4.853
	25–30	0.134	6.95	1143	48.87	4.173
	35–40	0.140	6.87	1173	51.23	4.400
	45–50	0.143	6.87	1200	54.23	4.587
	55–60	0.144	6.85	1220	51.10	3.730

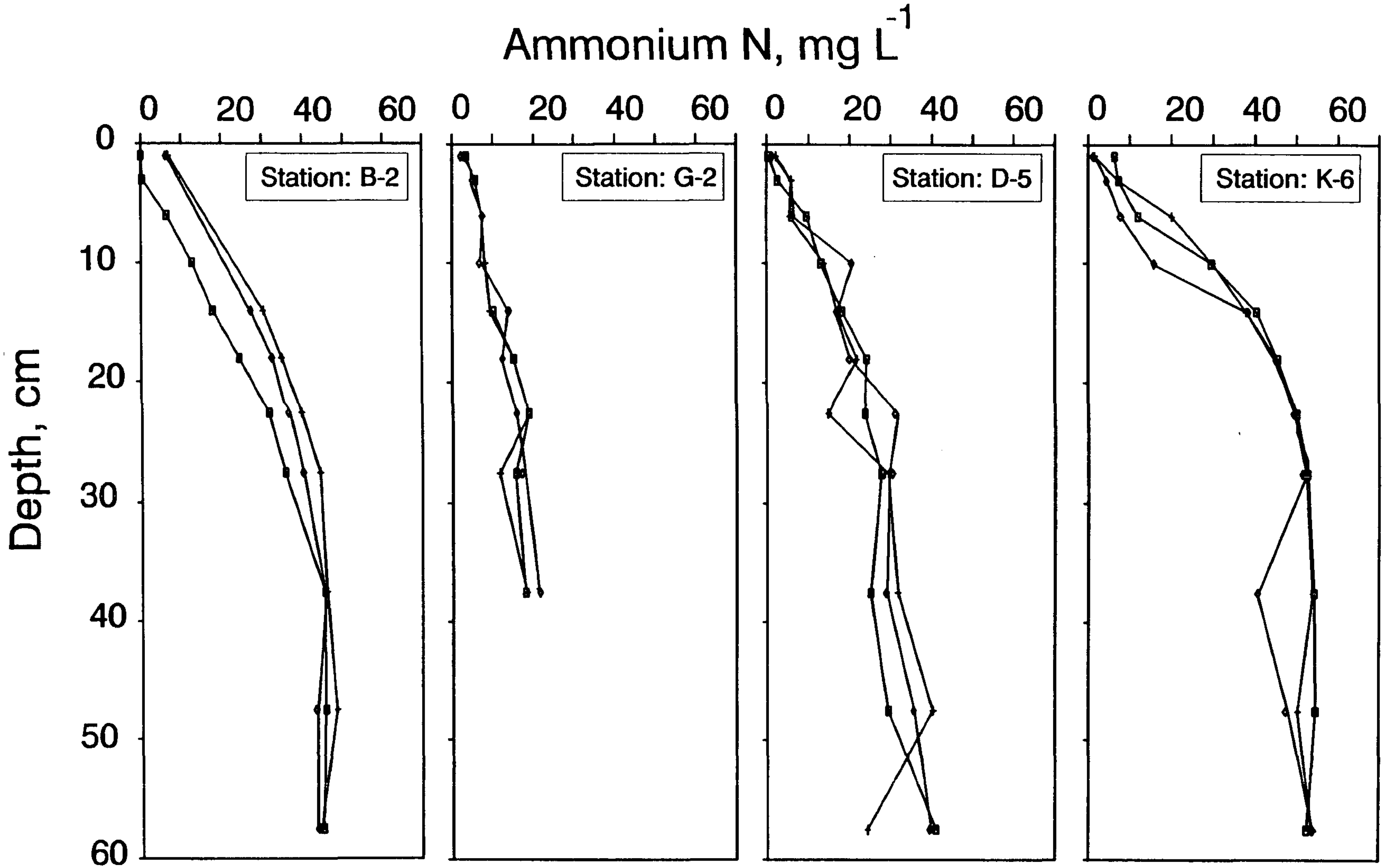

Fig. 7.2.4a. Ammonium N concentration of the sediment porewater as a function of depth in triplicate sediment cores obtained from selected locations on February 12, 1988.

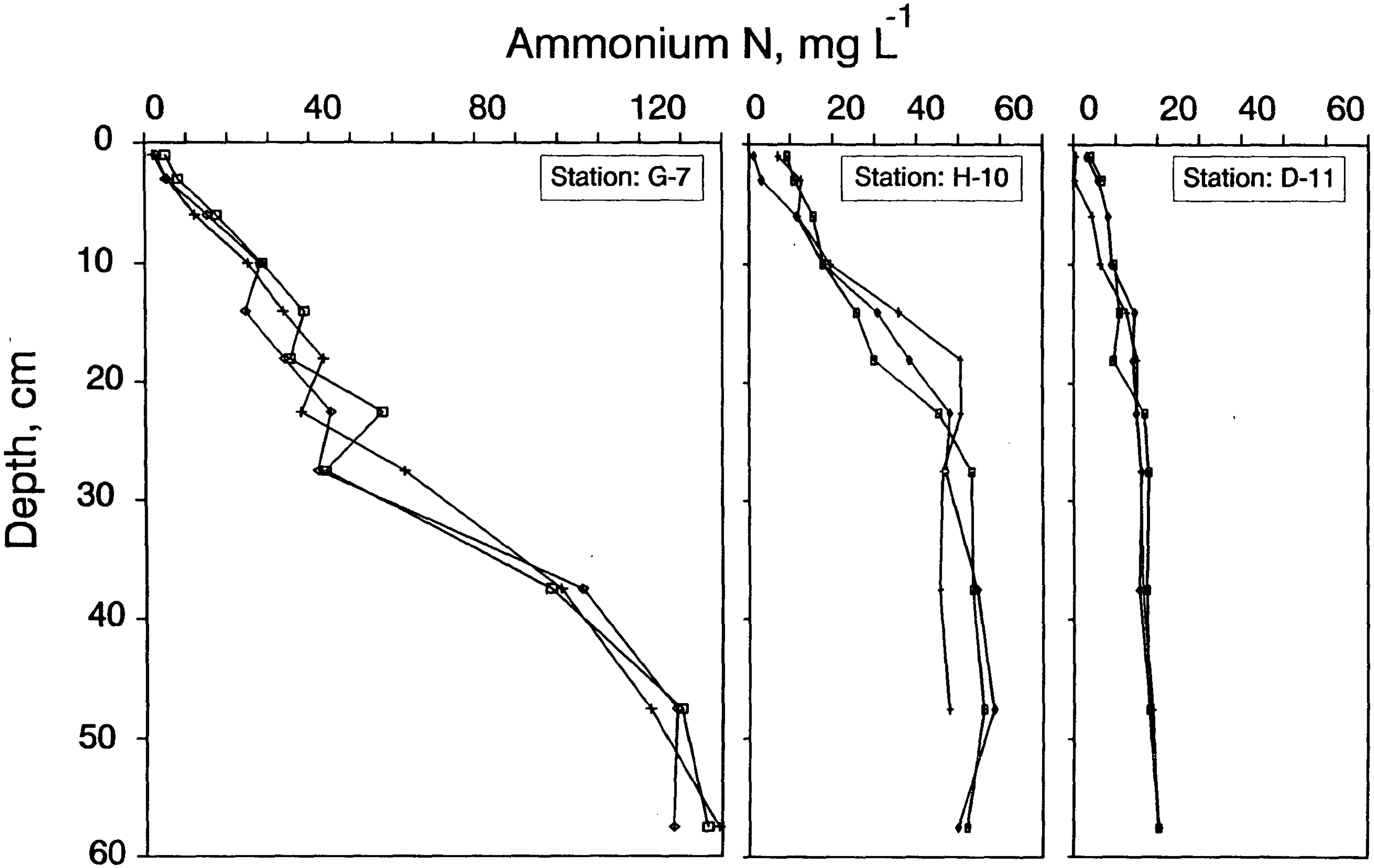

Fig. 7.2.4b. Ammonium N concentration of the sediment porewater as a function of depth in triplicate sediment cores obtained from selected locations on February 12, 1988.

Table 7.2.2. Diffusive flux of ammonium N and soluble P as calculated from porewater concentration gradients (D NH_4 = 1.47 cm^2 d^{-1}; D PO_4 = 0.683 cm^2 d^{-1}.

Station	NH_4-N	SRP	NH_4-N/SRP ratio
	-----μg cm^{-2} d^{-1}-----		
G-7	3.85	0.140	27.5
D-5	2.13	0.056	38.0
K-6	3.85	0.189	20.4
B-2	2.32	0.094	24.7
G-2	0.98	0.050	19.6
D-11	1.26	0.016	28.8
H-10	3.23	0.137	23.6
Mean	2.52	0.097	
S.D.	1.12	0.059	

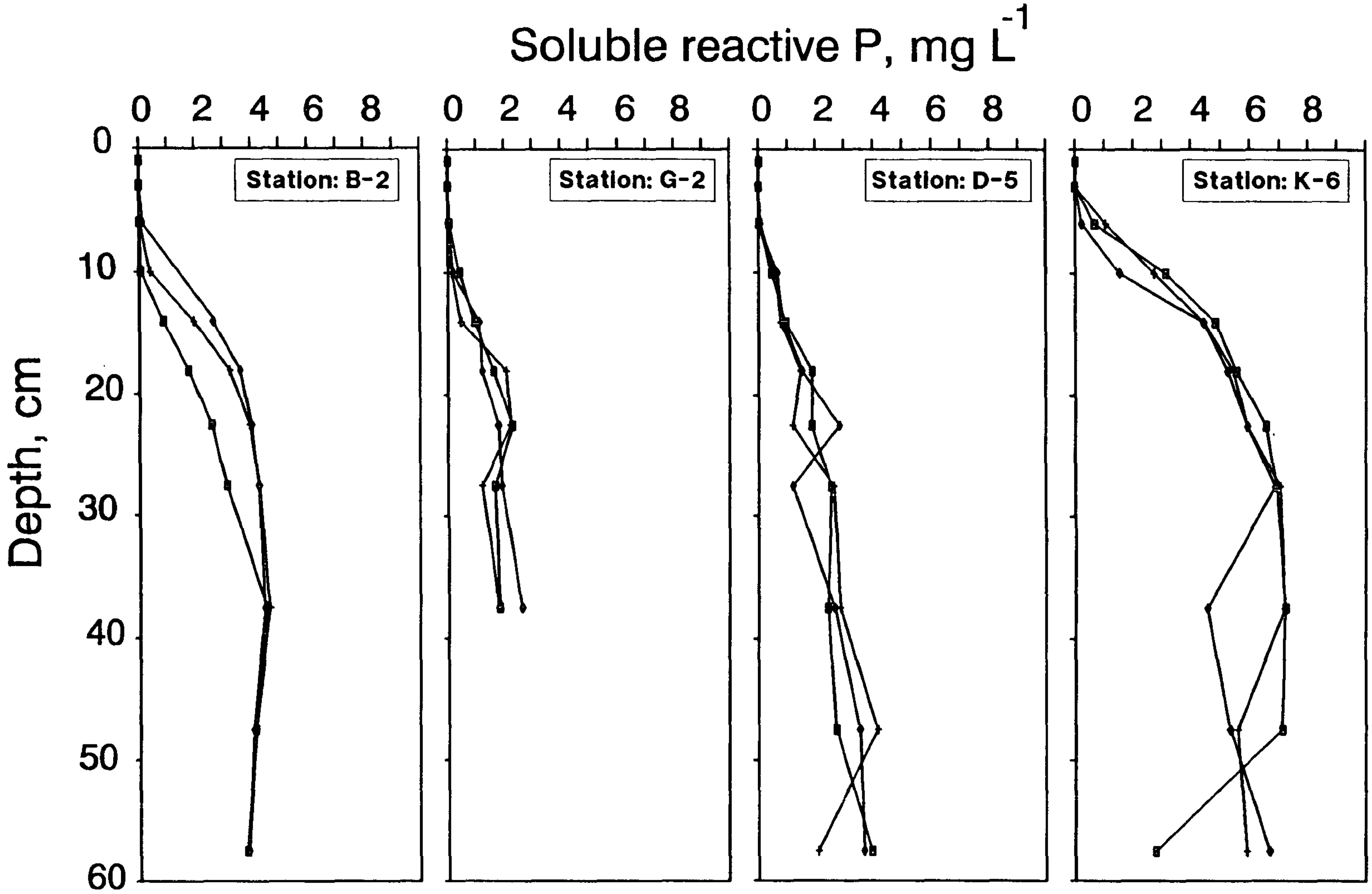

Fig. 7.2.5a. Soluble reactive P concentration of the sediment porewater as a function of depth in triplicate sediment cores obtained from selected locations on February 12, 1988.

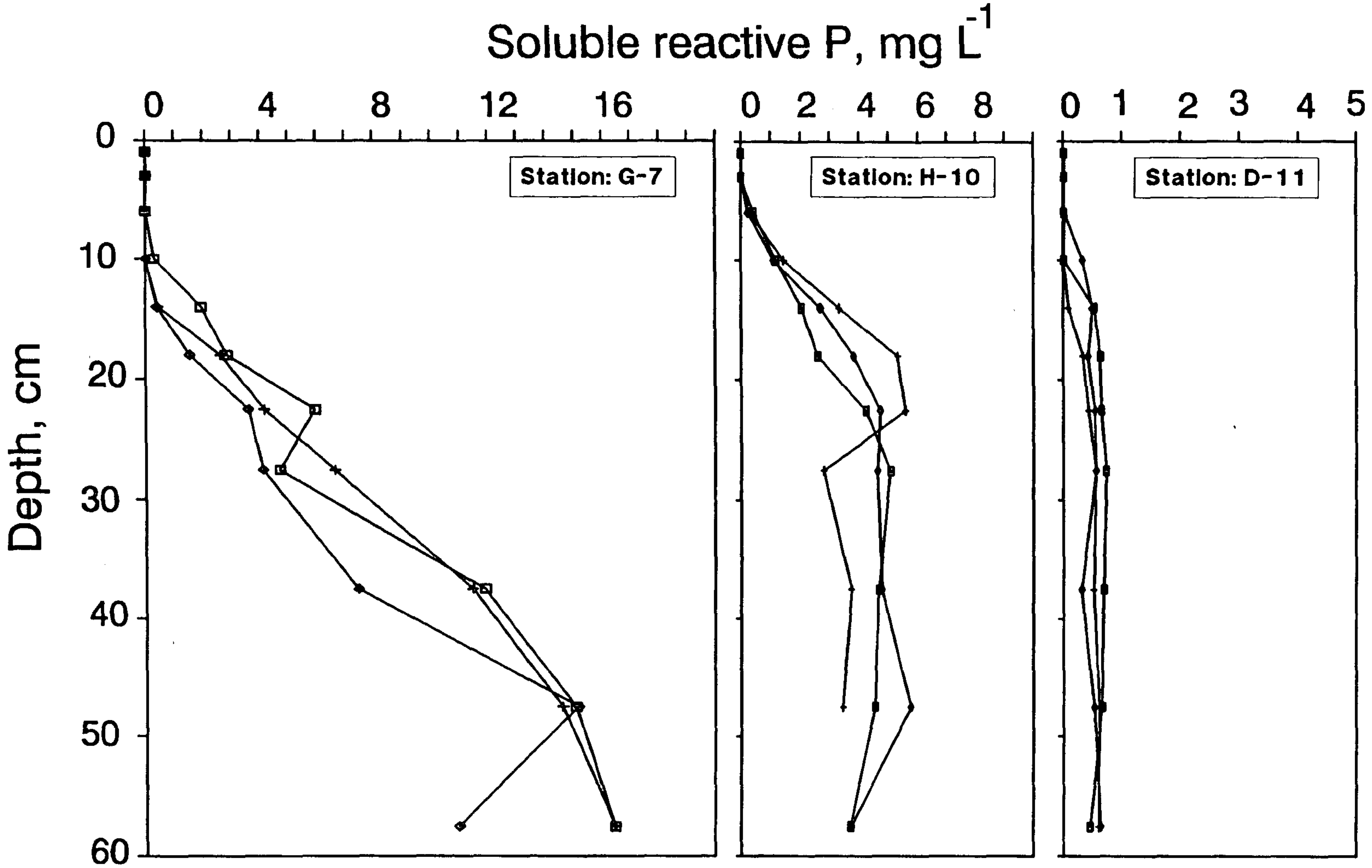

Fig. 7.2.5b. Soluble reactive P concentration of the sediment porewater as a function of depth in triplicate sediment cores obtained from selected locations on February 12, 1988.

(0-8 cm) were low (0.012-0.026 mg L^{-1}) and were approximately in the same range as those found in the water column. It is apparent from these results that the surface 8 cm sediments are resuspended into the water column more frequently, as indicated by depletion of SRP. Below 8 cm depth, there is a steep gradient in SRP levels of the porewater as a function of depth. Phosphorus mobility from sediments below 8 cm is primarily associated with diffusive flux, as indicated by the porewater SRP gradients. Diffusive flux of P for sediment profiles presented in Figs. 7.2.5a and b is in the range of 0.2-1.9 mg P m^{-2} d^{-1} (Table 7.2.2). Low P flux was observed at stations G-2 and D-11, while high flux was observed at stations K-6 and G-7. Triplicate cores obtained at each location showed minimum variability for both porewater NH_4^+ and SRP.

(b) Temporal variability studies.

Ammonium and SRP concentrations were low in surface sediment porewaters, but increased with depth (Figs. 7.2.6-7.2.7). Ammonium and SRP flux were in the same range as reported for the spatial variability study (Table 7.2.3). Diffusive flux of NH_4^+ and SRP were 18.7 ± 5.6 and 0.64 ± 0.16 mg m^{-2} d^{-1}, respectively. Soluble P concentrations showed a clear break at 8 cm depth, indicating the impact of possible sediment resuspension effects. Soluble P concentrations in 0-8 cm depth were in the range of 0.003 - 0.021 mg P L^{-1}, which are typical concentrations observed in the Lake Apopka water column. The SRP levels of the water column sampled during the same sampling period were in the range of 0.028 - 0.047 mg P L^{-1}. The elevated SRP levels in the water column suggest external inputs of P or microbial breakdown of algal cells and/or desorption of P from the resuspended sediments. Short-term N and P dynamics at the sediment-water interface need further evaluation to quantitatively describe the N and P release or retention by sediments.

7.2.4 Conclusions

A significant relationship was observed between total suspended solids (TSS) and TKN and TP, but no relationship with SRP and NH_4^+. The water quality data presented needs further evaluation to determine the relationship with rainfall, wind speed and other related parameters associated with sediment resuspension.

Soluble NH_4^+ and SRP concentration profiles showed spatial variability, but showed very little or no temporal variability, indicating steady-state conditions in the lake. The NH_4^+ flux from the sediment to the overlying water column was estimated to be 28-40 mg N m^{-2} d^{-1}, while SRP flux were 0.8 - 2.7 mg P m^{-2} d^{-1}. The average ratio of ammonium to SRP flux was 17.9, suggesting that slow P release can potentially limit the productivity of the lake (Fig. 7.2.8). Soluble P concentrations in the surface 8 cm sediment layer was approximately in the same range as the concentrations of the overlying water column. These results suggest that the surface 8 cm sediments are frequently resuspended during wind-driven resuspension. It can be concluded from these observations that NH_4^+ and SRP transport from the surface 8 cm sediment is due to release during sediment resuspension, while below 8 cm

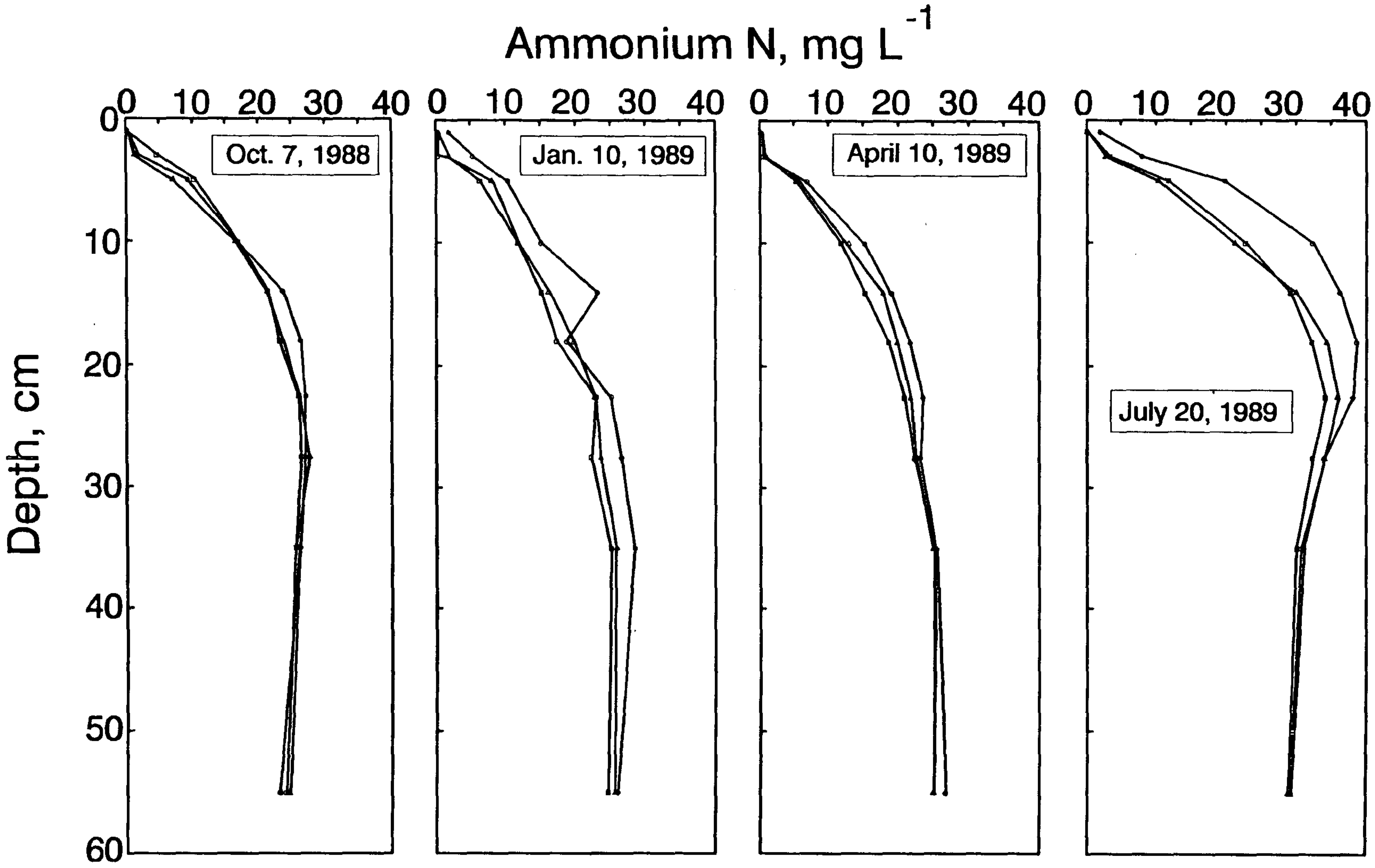

Fig. 7.2.6. Ammonium concentration of the sediment porewater as a function of depth in triplicate sediment cores obtained quarterly during the year 1988-89 from station F-6 of Lake Apopka.

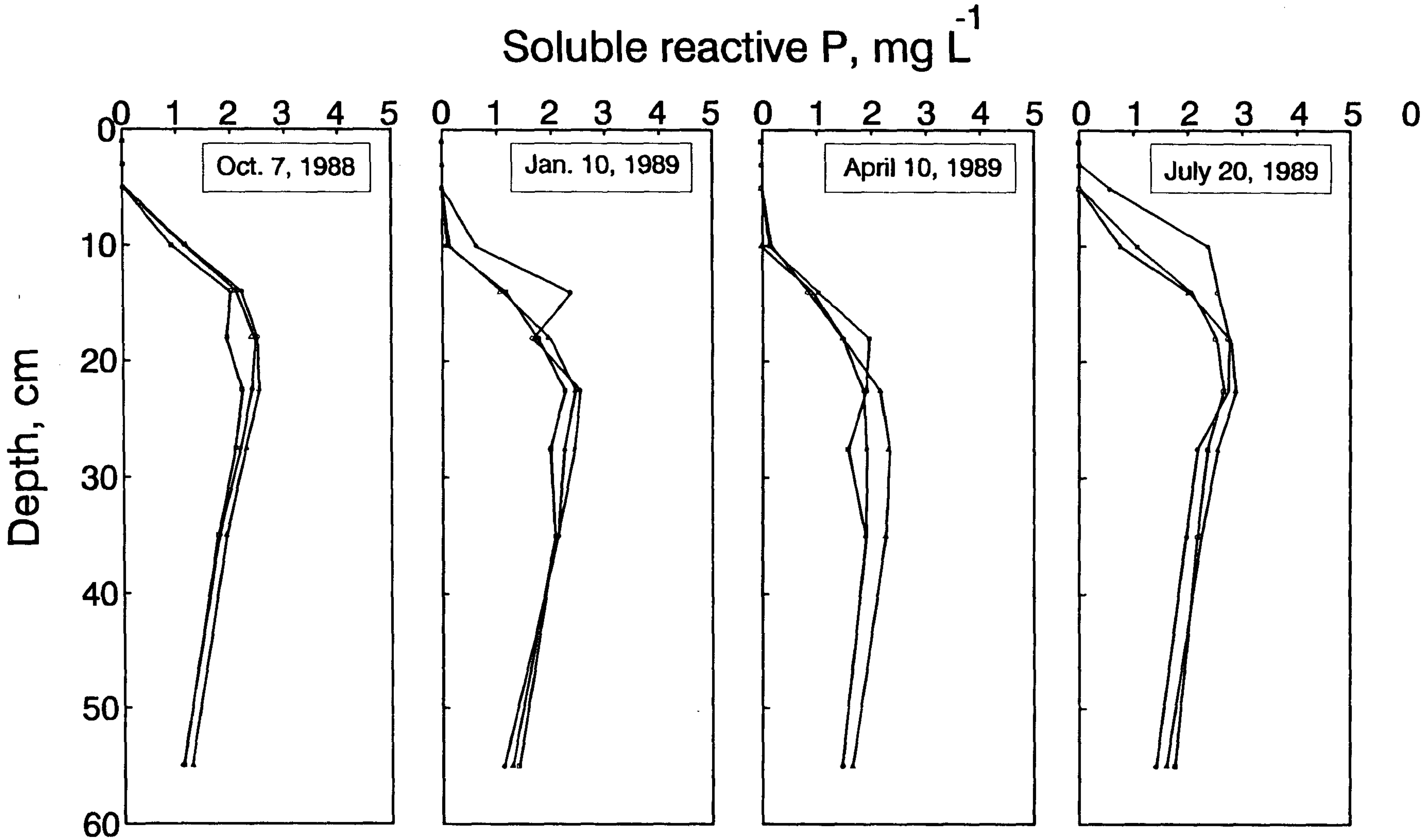

Fig. 7.2.7. Soluble reactive P concentration of the sediment porewater as a function of depth in triplicate sediment cores obtained quarterly during the year 1988-89 from station F-6 of Lake Apopka.

Table 7.2.3. Diffusive flux of ammonium N and soluble P as calculated from porewater concentration gradients (D NH_4 = 1.47 cm^2 d^{-1}; D PO_4 = 0.683 cm^2 d^{-1}. Station F-6.

Sampling period	NH_4-N	SRP	NH_4-N/SRP ratio
	-----$\mu g\ cm^{-2}\ d^{-1}$-----		
10/7/88	3.85	0.140	27.5
1/10/89	1.58	0.057	27.7
4/10/89	1.41	0.046	30.7
7/20/89	2.68	0.046	31.9
Mean	2.52	0.097	
S.D.	1.12	0.059	

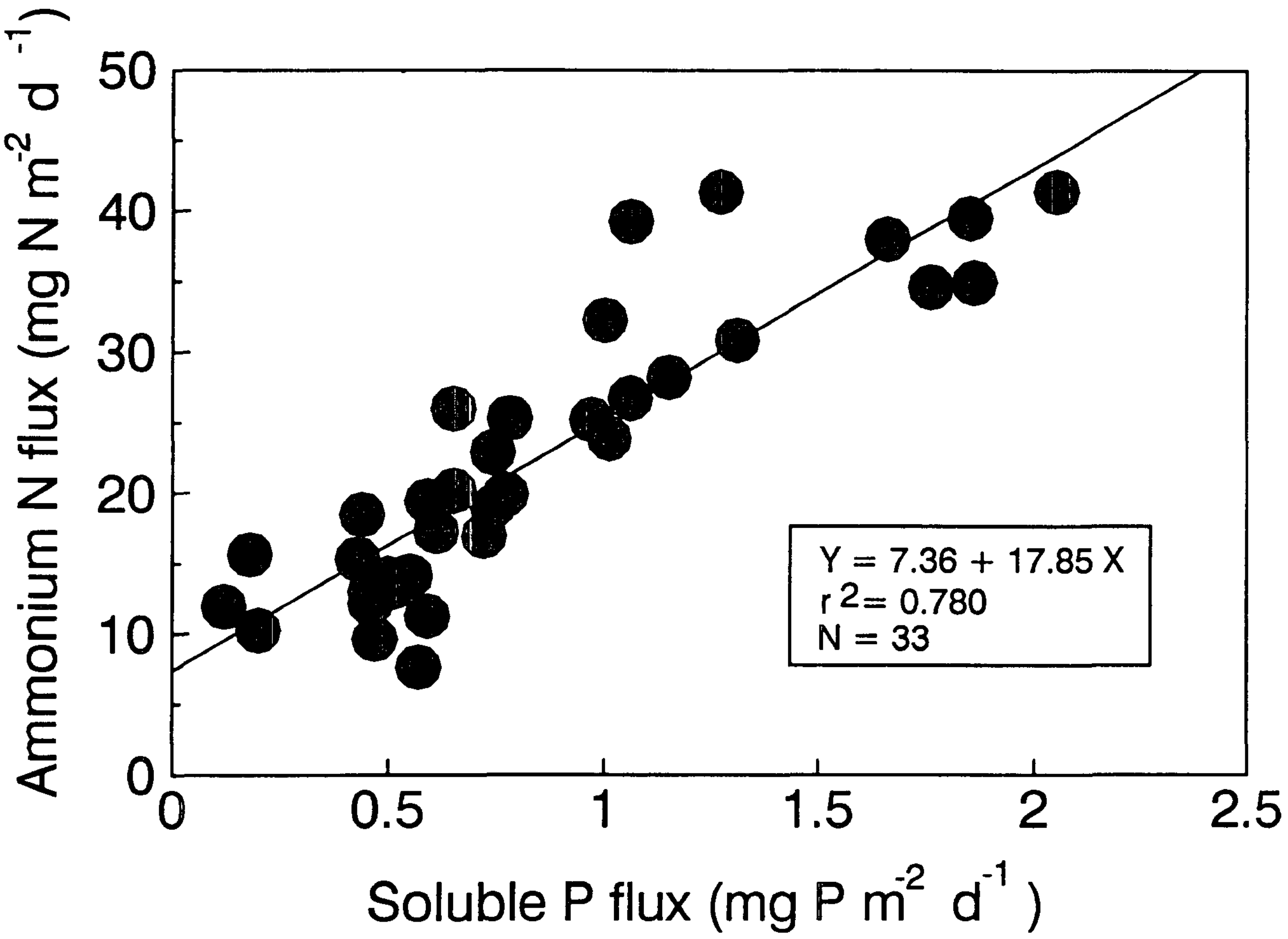

Fig. 7.2.8. Relationship between ammonium and soluble P flux from bottom sediments of Lake Apopka.

sediment depth, upward mobility of NH_4^+ and SRP is governed by diffusion related processes. The biogeochemical processes functioning at the sediment-water interface need further investigations to quantitatively evaluate the impact of sediments on water quality.

7.2.5 References

American Public Health Association (APHA). 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed. Amer. Publ. Health Assoc., Washington, D.C. 1268 pp.

APPENDIX

Table A-1: Lake Apopka INB station LORAN coordinates.
Group repetition interval (GRI): 7980, Southeast USA.
Time Delay, usecs.

Station	Y	Z	Station	Y	Z
1 C	44573.2	62439.2	6 I	44509.0	62414.3
2 A	44579.5	62450.8	J	44503.0	62408.1
B	44573.5	62445.5	K	44497.1	62403.0
C	44567.5	62440.2	7 J	44497.1	62409.5
D	44561.8	62435.3	I	44503.2	62415.5
E	44556.0	62430.0	H	44509.2	62420.9
F	44549.8	62424.8	G	44515.1	62426.0
G	44543.8	62419.8	F	44521.0	62431.0
H	44539.6	62416.0	E	44527.0	62436.3
3 A	44573.8	62452.0	D	44532.8	62441.5
B	44567.7	62446.8	C	44538.8	62446.8
C	44561.8	62441.5	B	44544.8	62452.0
D	44556.2	62436.5	8 C	44533.0	62448.0
E	44550.0	62431.3	D	44527.2	62442.9
F	44544.0	62426.2	E	44521.0	62437.7
G	44538.3	62421.0	F	44515.2	62432.5
H	44532.5	62415.8	G	44509.5	62427.4
4 A	44568.0	62453.3	H	44503.4	62422.2
B	44562.0	62448.0	I	44497.3	62417.0
C	44556.5	62442.8	J	44493.0	62412.6
D	44550.2	62437.8	9 I	44491.5	62418.2
E	44544.0	62432.5	H	44497.4	62423.5
F	44538.4	62427.4	G	44503.8	62428.8
G	44532.6	62422.3	F	44509.8	62433.8
H	44527.0	62417.0	E	44515.5	62439.0
I	44521.0	62411.8	D	44521.5	62444.2
5 K	44503.0	62401.8	10 I	44488.2	62419.6
J	44509.0	62407.0	D	44515.8	62445.5
I	44515.1	62413.0	E	44510.0	62440.2
H	44521.0	62418.2	F	44504.0	62435.2
G	44527.0	62423.6	G	44497.8	62430.0
F	44532.5	62428.8	H	44491.6	62424.8
E	44538.5	62433.8	11 G	44494.5	62432.2
D	44544.5	62439.0	F	44498.4	62436.4
C	44550.3	62444.2	E	44504.3	62441.5
B	44556.7	62449.4	C	44516.3	62450.8
A	44562.4	62454.8	D	44511.2	62445.9
6 A	44556.8	62456.0	c	44513.3	62448.3
B	44550.5	62450.8	a	44523.3	62458.4
C	44544.6	62445.5	12 c	44510.0	62450.2
D	44538.7	62440.3	C	44514.6	62452.5
E	44532.8	62435.0	b	44506.0	62455.3
F	44527.0	62430.0	B	44520.0	62456.7
G	44521.0	62424.8	13 C	44512.8	62452.8
H	44515.2	62419.5	b	44514.6	62454.8

Table B-1: Water and sediment depth at selected locations in Lake Apopka.

Station		Water Depth	Sediment Depth	Sediment Component Thickness 1968 UCF	1987 UCF	1968 CF	1987 CF	P	S	C	M	Depth of retrieved core
		cm										
1	C	[illegible]	305	8	40	89	0	117			3	160
2	A	[illegible]	225	13	42	3	32	10				84
	B	[illegible]	254	13	38	84	132					[illegible]
	C	[illegible]	153	13	9	89	74	20	42			[illegible]
	D	176	106	3	35	28	44		27			[illegible]
	E	172	76	3	16	0	0	2	3	16		[illegible]
	F	177	128	15	5	0	0	15				20
	G	139	121	3	8	43	30	11				49
	H	130	[illegible]	0	0	0	0	23				23
3	A	100	[illegible]	64	46	64	110					156
	B	144	298	8	47	74	128					175
	C	144	263	5	36	71	134				2	172
	D	164	148	13	32	79	48		37			117
	E	171	124	5	46	74	44		[illegible]			111
	F	163	10	[illegible]	0	20	0					
	G	151	91	[illegible]	15	46	28	11				54
	H	115	73	3	0	0	0	[illegible]				16
4	A	130	442	20	[illegible]	64	120					149
	B	142	359	25	38	76	116					154
	C	170	324	20	[illegible]	71	135					161
	D	172	130	15	[illegible]	69	[illegible]				27	115
	E	167	135	15	43	79	[illegible]				42	120
	F	157	198	23	23	[illegible]	[illegible]	23		3		160
	G	160	195	25	27	[illegible]	63	10				100
	H	200	80	13	16	[illegible]	10	6				32
	I	170	26	5	14	[illegible]	0			3		17
5	A	117	600	15	50	76	[illegible]					167
	B	124	238	13	[illegible]	89	[illegible]				7	156
	C	160	222	8	[illegible]	94	[illegible]				20	178
	D	165	167	10	[illegible]	61	[illegible]				28	148
	E	167	135	[illegible]	26	84	[illegible]				33	120
	F	165	127	[illegible]	33	84	84				3	120
	G	170	470	[illegible]	31	79	110				10	151
	H	156	234	[illegible]	18	86	63			13		94
	I	154	96	8	30	53	45			15		90
	J	138	[illegible]	13	36	58	53	[illegible]		5		106
	K	66	[illegible]	8	40	33	25	24				89
6	A	104	[illegible]	3	51	74	148	23				222
	B	193	[illegible]	5	18	71	112					130
	C	148	427	3	70	99	90				15	175
	D	320	190	5	28	46	36				25	89
	E	[illegible]	305	8	32	94	111				11	154
	F	[illegible]	49	5	28	91	13				8	49
	G	[illegible]	205	3	37	79	60				8	105
	H	[illegible]	213	3	23	71	61		11	[illegible]		112
	I	142	145	3	33	99	38			[illegible]		89
	[illegible]	220	60	8	20	81	21		5		[illegible]	56
	[illegible]	120	252	5	42	91	84	23				149

[illegible]e B-1 (cont'd): Water and sediment depth at selected locations in Lake Apopka.

Stati[illegible]		Water Depth	Sediment Depth	1968 UCF	1987 UCF	1968 CF	1987 CF	P	S	C	M	Depth of retrieved core
		Sediment Component Thickness										
							cm					
7	B	[illegible]	600	5	21	76	88					101
	C	[illegible]	600	15	28	61	114					142
	D	170	600	13	27	64	123	15	5		13	183
	E	[illegible]	384	8	28	53	116					[illegible]
	F	254	13	13	0	51	0				4	[illegible]
	G	157	130	25	25	46	91			8		[illegible]
	H	235	35	1	22	51	12			8		30
	I	245	[illegible]	5	20	23	0			10		30
	J	144	[illegible]	8	46	71	82	23				151
8	C	162	600	3	50	99	85					135
	D	174	[illegible]	5	76	97	48				10	134
	E	281	[illegible]	5	4	97	62				8	74
	F	172	180	3	7	99	112				8	127
	G	230	36	3	12	74	17				5	17
	H	175	88	5	32	66	48			8		88
	I	213	114	[illegible]	31	18	37	19		3		90
	J	86	222	[illegible]	57		97	10				164
9	D	263	267	[illegible]	20	61	107					127
	E	175	305	8	25	94	125					150
	F	150	300	5	26	97	108					134
	G	143	207	5	29	97	111				3	139
	H	132	158	10	39	91	[illegible]				8	154
	I	110	336	5	[illegible]	97	[illegible]	13				132
10	D	150	410	5	37	97	[illegible]					104
	E	175	600	5	27	[illegible]	[illegible]	34				111
	F	146	188	8	23	[illegible]	116	20				159
	G	146	600	13	29	[illegible]	130					159
	H	106	600	10	37	[illegible]	63					100
	I	70	392		48	[illegible]	125		15			188
11	C	ND	107	5	[illegible]	15	[illegible]					107
	D	125	225	20	21	81	[illegible]	18				143
	E	136	600	15	[illegible]	86	116					149
	F	335	104	5	30	97	[illegible]					104
	G	402	600	[illegible]	44		[illegible]					85
	a	171	600	[illegible]	107	86	36					143
	c	159	600	[illegible]	23	81	127					150
12	B	152	600	30	108	71	47					155
	C	180	600	18	24	84	114					138
	b	96	600	15	41	86	80					121
	c	131	600	18	31	84	124					155
13	C	155	[illegible]	15	41	86	51					92
	b	127	[illegible]	30	79	71	71	5				155
Mean		163.8	276.0	10.4	32.3	69.2	81.8	20.1	18.[illegible]	[illegible]9.5	12.4	117.4
St.Dev.		60.[illegible]	189.6	9.0	18.8	26.6	35.3	21.0	14.3	[illegible]	10.8	48.9
n		[illegible]	90.0	87	90.0	87	90	25.0	9	[illegible]	25	89.0
C.V.(%)		[illegible]	68.7	87	58.3	38	43	104.5	78	[illegible]	0.86	41.6
Max.		402	600.0	64	108.0	99	148	117.0	42	[illegible]	42	254.0
Min.		30	10.0	0	0.0	0	0	2.0	0	[illegible]	0	13.0

UCF [illegible]nconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; [illegible] Clay; M[illegible]l; ND = Not Determined.

Table B-2a

Bulk density (g dry/cm3) of sediment at selected stations in Lake Apopka.

Station		UCF	CF	P	S	C	M
		g (dry)/cm3					
1	C	0.024		0.024			0.068
2	A	0.024	0.063	0.065			
	B	0.032	0.116				
	C	0.010	0.073		0.291		
	D	0.024	0.104		0.230		
	E	0.107			1.426	0.781	
	F	0.010		0.021			
	G	0.045	0.069	0.164			
	H			0.092			
3	A	0.028	0.067				
	B	0.024	0.088				
	C	0.033	0.067				
	D	0.035	0.097		0.542		
	E	0.054	0.097		0.246		
	G	0.027	0.079	0.143			
	H			0.065			
4	A	0.024	0.101				
	B	0.026	0.079				
	C	0.050	0.107				
	D	0.034	0.104				0.397
	E	0.046	0.087				0.428
	F	0.037	0.090				
	G	0.036	0.097	0.093			
	H	0.046	0.130	0.145			
	I	0.056				0.299	
5	A	0.030	0.093				
	B	0.028	0.073				
	C	0.031	0.065				
	D	0.031	0.117				
	E	0.032	0.086				
	F	0.040	0.102				
	G	0.040	0.116				
	H	0.039	0.065				
	I	0.043	0.094				
	J	0.031	0.077	0.114			
	K	0.033	0.061	0.069			
6	A	0.034	0.073				
	B	0.031	0.090				
	C	0.026	0.073				
	D	0.065	0.118				0.302
	E	0.038	0.101				
	F	0.030	0.087				
	G	0.026	0.050				
	H	0.031	0.082				
	I	0.037	0.117				
	J	0.017	0.100		0.754		
	K	0.033	0.067				
7	B	0.030	0.061				
	C	0.040	0.071				
	D	0.022	0.069				
	E	0.027	0.052				
	G	0.014	0.067				
	H	0.025	0.205				
	I	0.004					
	J	0.026	0.071				
8	C	0.027	0.069				
	D	0.044	0.020				
	E	0.086	0.122				
	F	0.057	0.113				
	G	0.049	0.154				
	H	0.030	0.072				
	I	0.056	0.144	0.181			
	J	0.024	0.108				
9	D	0.036	0.061				
	E	0.023	0.077				
	F	0.031	0.081				
	G	0.037	0.089				
	H	0.041	0.109				
	I	0.027	0.079				
10	D	0.044	0.085				
	E	0.028	0.075	0.069			
	F	0.027	0.069				
	G	0.040	0.075				
	H	0.031	0.065				
	I	0.036	0.097				
11	D	0.044	0.196				
	E	0.028	0.071				
	F		0.071				
	G	0.046	0.065				
	a	0.034	0.044				
	c	0.033	0.078				
12	B	0.029	0.054				
	C	0.030	0.078				
	b	0.016	0.057				
	c	0.036	0.078				
13	C	0.035	0.066				
	b	0.033	0.064				
Mean		0.035	0.086	0.096	0.582	0.54	0.299
Std. Dev.		0.014	0.029	0.051	0.461	0.241	0.163
n		84	80	13	6	2	4
C.V.(%)		41.6	33.8	53.1	79.3	44.6	54.5
Max.		0.107	0.205	0.181	1.426	0.781	0.428
Min.		0.004	0.020	0.021	0.230	0.299	0.068

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-2b

Bulk density (g wet/cm3) of sediment at selected stations in Lake Apopka.

Station		UCF	CF	P	S	C	M
		g wet/cm3					
1	C	0.862		1.087			
2	A	0.764	1.072	0.876			
	B	1.046	1.032				
	C	0.620	1.074		1.133		1.248
	D	0.933	1.115		1.075		
	E	0.991		2.945	2.100	1.318	
	F	1.145		0.427			
	G	1.061	1.066	1.239			
	H			1.146			
3	A	1.077	1.063				
	B	1.070	1.033				
	C	1.026	1.067				
	D	1.086	1.055				1.739
	E	0.924	0.930				1.547
	F						
	G	1.009	1.107	1.173			
	H			1.091			
4	A	1.119	1.030				
	B	1.039	1.069				
	C	1.065	1.049				
	D	1.007	1.107				1.301
	E	1.007	0.970				1.325
	F	1.021	1.079				
	G	0.953	1.079	1.029			
	H	1.012	0.995	1.117			
	I	0.925				1.992	
5	A	1.078	1.045				
	B	1.066	1.045				
	C	1.096	1.038				
	D	1.031	1.074				
	E	1.032	1.089				
	F	1.007	1.109				
	G	0.965	1.077				
	H	1.027	0.965				
	I	1.120	1.066				
	J	1.056	1.045	1.017			
	K	0.982	0.949	1.080			
6	A	1.183	1.046				
	B	1.085	1.045				
	C	1.053	1.060				
	D	1.182	0.921				1.172
	E	1.126	1.049				
	F	0.963	1.287				
	G	1.046	1.057				
	H	1.030	1.065				
	I	1.056	1.085				
	J	0.724	1.214		1.629		
	K	0.956	0.959				
7	B	0.977	1.047				
	C	1.002	1.063				
	D	0.996	1.048				
	E	1.087	1.013				
	F						
	G	0.823	1.039				
	H	1.062					
	I	1.047					
	J	1.098	1.016				
8	C	1.048	1.052				
	D	1.038	1.002				
	E	1.190					
	F	0.935	1.013				
	G						
	H	1.010	1.020				
	I	0.948	1.127	1.072			
	J	0.921	1.067				
9	D	1.017	1.053				
	E	1.013	1.032				
	F	1.108	1.037				
	G	0.962	1.063				
	H	0.999	1.043				
	I	1.054	1.067				
10	D	1.153	1.042				
	E	1.038	1.060	1.111			
	F	1.124	0.997				
	G	1.072	1.048				
	H	1.108					
	I	1.056	1.077				
11	C						
	D	1.311	0.991				
	E	1.084	1.033				
	F		1.018				
	G	1.028	1.040				
	a	1.011	0.973				
	c	1.217	1.022				
12	B	1.048	1.030				
	C	1.095	1.058				
	b	0.571	0.980				
	c	1.103	1.038				
13	C	1.097	1.041				
	b	0.920	1.023				
	Mean	1.024	1.048	1.172	1.484	1.655	1.388
	Std. Dev.	0.112	0.054	0.526	0.416	0.337	0.194
	C.V.(%)	10.9	5.1	44.9	28.0	20.4	14.0
	n	83	77	14	4	2	6
	Max.	1.311	1.287	2.945	2.100	1.992	1.739
	Min.	0.571	0.921	0.427	1.075	1.318	1.172

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-2c

Water content of sediment at selected stations in Lake Apopka.

Station		UCF	CF	P	S	C	M
				%			
1	C	87.8		93.9			
2	A	96.9	94.1	92.5			
	B	97.0	88.7				
	C	98.5	93.0		73.8		
	D	97.4	90.6		78.6		
	E	89.2		52.1	32.1	41.5	
	F	91.0		80.6			
	G	95.7	93.5	86.7			
	H			92.0	76.4		
3	A	97.4	93.7				
	B	97.8	91.5				
	C	96.8	93.8				
	D	96.8	90.8		68.9		
	E	94.1	89.6		84.1		
	F						
	G	97.3	92.8	87.8			
	H			94.0			
4	A	97.8	90.2				
	B	97.5	92.6				89.8
	C	95.3	89.8				
	D	96.7	90.6				69.5
	E	95.4	91.1				67.7
	F	96.4	91.6			44.8	
	G	96.2	91.0	91.0			
	H	95.5	87.0	87.0			
	I	94.0				41.9	
5	A	96.6	93.5				
	B	91.1	93.0				46.5
	C	97.2	93.8			84.8	84.8
	D	97.0	89.1				87.4
	E	96.9	92.1				66.7
	F	96.1	90.8				57.1
	G	95.8	89.3				83.4
	H	96.2	93.3			37.2	
	I	96.1	91.2			37.0	
	J	97.0	92.7	88.8		40.8	
	K	96.7	93.6	93.6			
6	A	97.1	93.0				
	B	97.2	91.4				
	C	97.5	93.2				85.1
	D	94.5	87.2				74.3
	E	96.6	90.4				80.4
	F	96.9	93.2				78.0
	G	97.5	95.3				42.4
	H	97.0	92.3			37.8	39.2
	I	96.5	89.2			69.7	
	J	97.7	91.8		53.7		34.0
	K	96.6	93.0	92.3			
7	B	97.0	94.2				
	C	96.0	93.4				
	D	97.8	93.4	91.2	83.0		74.6
	E	97.5	94.8				85.4
	F	75.5					32.5
	G	98.3	93.6			44.8	32.5
	H	97.6				43.5	
	I	99.6				37.3	
	J	97.6	93.1	93.6			
8	C	97.4	93.4				
	D	95.8	94.0				70.0
	E	94.1	88.6				80.3
	F	95.2	88.8				68.2
	G	94.8	86.7				46.0
	H	97.0	93.0			37.6	
	I	94.1	87.2	83.1		51.1	
	J	97.4	89.9	90.6			
9	D	96.4	94.2				
	E	97.7	92.6				
	F	97.2	92.2				
	G	96.1	91.6				46.6
	H	95.9	89.5				45.0
	I	97.4	92.6	92.4			
10	D	96.2	91.9				
	E	97.3	92.9	93.8			
	F	97.6	93.1	94.3			
	G	96.2	92.9				
	H	97.2	93.8				
	I	96.6	91.0		58.3		
11	C	96.2					
	D	96.7	80.3	73.7			
	E	97.4	93.2				
	F	96.2	93.1				
	G	95.5	93.7				
	a	96.7	95.5				
	c	97.3	92.4				
12	B	97.2	94.8				
	C	97.3	92.6				
	b	97.3	94.2				
	c	96.7	92.5				
13	C	96.8	93.7				
	b	96.4	93.7	93.6			
	Mean	96.1	91.9	88.1	67.7	46.4	64.1
	Std. Dev.	2.9	2.4	9.5	16.9	14.0	19.3
	n	87	79	22	9	14	26
	C.V.(%)	3.0	2.6	10.8	25.0	30.1	30.1
	Max.	99.6	95.5	94.3	84.1	84.8	89.8
	Min.	75.5	80.3	52.1	32.1	37.0	32.5

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-3: Sediment porewater alkalinity and pH at selected stations in Lake Apopka.

Station		Alkalinity						pH					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg CaCO3/l											
1	C	380		820			720	7.2		7.1			7.1
2	A	524	596	540				6.9	6.8	7.8			
	B	480	320					6.8	7.9				
	C	240	370		370			7.4	7.2		7.3		7.3
	D	340	300		360			7.1	7.5		7.3		
	E	320		240	310	290		7.4		7.6	7.8	7.9	
	F	300		160				7.3		7.8			
	G	290	340	140				7.3	7.4	7.8			
	H			180						8.1			
3	A	530	400					6.8	7.0				
	B	480	640					6.8	7.0				
	C	550	720					6.8	7.2				
	D	460	500		320			7.1	7.9		8.0		
	E	460	420		320			7.1	7.4		8.1		
	F												
	G	320	364	60				7.3	7.1	7.6			
	H			120						7.6			
4	A	460	520					7.0	7.1				
	B	556	964					6.8	6.7				
	C	480	480					6.9	7.0				
	D	490	540				540	6.8	6.9				7.8
	E	390	420				420	6.9	7.3				7.9
	F	420	420					6.9	7.2				
	G	380	900	260				6.9	7.0	7.9			
	H	260	280	140				7.2	7.8	7.3			
	I	320				480		7.0				7.1	
5	A	460	790					6.8	7.0				
	B	440	520					6.8	7.0				
	C	540	1320					6.8	7.0				
	D	420	520					6.9	7.5				
	E	360	560					7.0	7.5				
	F	420	460					6.9	7.1				
	G	400	440					6.9	7.0				
	H	300	400					7.1	6.9				
	I	460	680					7.0	6.9				
	J	360	420	150				6.8	7.0	7.9			
	K	490	620	330				6.8	6.8	7.9			
6	A	460	440					7.4	7.5				
	B	440	460					7.1	7.2				
	C	460	960					7.2	7.0				
	D	420	520				500	7.3	7.3				7.4
	E	440	520					6.8	7.0				
	F	420	770					6.8	7.0				
	G	520	900					6.9	6.7				
	H	440	680					6.9	6.7				
	I	480	1440					6.9	6.9				
	J	320	460		460			7.0	6.9		7.2		
	K	540	560					6.7	7.0				

Table B-3: Sediment porewater alkalinity and pH at selected stations in Lake Apopka.

Station		Alkalinity						pH					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg CaCO3/l											
	D	440	620					6.9	7.1				
	E	500	1820					6.9	7.4				
	F												
	G	420	1170					6.9	7.0				
	H	320	540					7.1	7.0				
	I	140						7.3					
	J	500	610					6.7	6.9				
8	C	480	200					6.9	6.9				
	D	740	1030					7.1	7.0				
	E	280	390					7.2	7.4				
	F	380	560					7.1	6.9				
	G	360	380					7.1	7.2				
	H	460	440					6.9	7.2				
	I	400	460	140				6.9	6.8	7.8			
	J	580	310					6.9	6.9				
9	D	580	540					6.9	6.9				
	E	260	290					7.0	7.1				
	F	340	187					7.1	7.2				
	G	380	350					7.0	7.2				
	H	440	260					7.0	7.0				
	I	260	470					7.2	6.8				
10	D	410	313					6.9	7.0				
	E	420	390	200				7.0	7.5	8.0			
	F	360	360					7.1	7.1				
	G	490	390					7.0	7.3				
	H	600	635					7.0	7.2				
	I	500	640					6.7	6.9				
11	C												
	D	420	300					6.8	6.7				
	E	350	580					7.0	6.9				
	F		690					7.6	6.9				
	G	490	320					7.0	7.0				
	a	280	200					6.6	6.7				
	c	370	360					6.9	6.9				
12	B	460	380					6.9	6.8				
	C	300	260					7.0	6.9				
	b	510	420					6.9	6.7				
	c	360	630					6.9	6.9				
13	C	360	290					6.9	6.7				
	b	650	630					6.7	6.7				
Mean		423	540	249	357	385	545	6.98	7.06	7.73	7.62	7.50	7.50
Std. Dev.		100	279	202	56	134	127	0.19	0.27	0.27	0.40	0.57	0.34
n		84	80	14	6	2	4	85	80	14	6	2	5
C.V.(%)		24	52	81	16	35	23	3	4	3	5	8	5
Max.		740	1820	820	460	480	720	7.60	7.90	8.10	8.10	7.90	7.90
Min.		140	187	60	310	290	420	6.60	6.65	7.10	7.20	7.10	7.10

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-4: Sediment porewater conductivity at selected stations in Lake Apopka.

Station		UCF	CF	P	S	C	M
		uS/cm					
1	C	660		980			910
2	A	1040	1240	1180			
	B	900	800				
	C	600	710		700		
	D	700	630		680		
	E	620		550	610	610	
	F	550		460			
	G	550	610	340			
	H			510			
3	A	1100	760				
	B	990	1120				
	C	1160	1350				
	D	950	720		630		
	E	820	760		630		
	F						
	G	700	800	320			
	H			380			
4	A	980	1080				
	B	1100	950				
	C	750	800				
	D	730	940				820
	E	700	820				820
	F	800	790				
	G	640	760	570			
	H	620	590	490			
	I	620					
5	A	770	1200				
	B	800	990				
	C	980	1900				
	D	750	900				
	E	810	1200				
	F	680	840				
	G	740	820				
	H	640	770				
	I	830	990				
	J	720	730	340			
	K	790	990	580			
6	A	830	680				
	B	770	750				
	C	850	1470				
	D	800	970				910
	E	810	950				
	F	840	900				
	G	970	1480				
	H	870	1110				
	I	860	1050				
	J	620	880		730		
	K	900	960				
7	B	900	690				
	C	760	840				
	D	800	1150				
	E	880	2700				
	F						
	G	850	1800				
	H	700	980				
	I	380					
	J	820	880				
8	C	850	400				
	D	1200	1300				
	E	600	780				
	F	700	1140				
	G	680	810				
	H	840	950				
	I	790	880	300			
	J	1040	700				
9	D	1170	980				
	E	790	690				
	F	750	400				
	G	770	650				
	H	830	780				
	I	550	810				
10	D	770	600				
	E	880	790	450			
	F	750	700				
	G	700	690				
	H	1150	1150				
	I	800	990				
11	C						
	D	800	550				
	E	780	1000				
	F	640	1200				
	G	980	650				
	a	565	345				
	c	780	680				
12	B	780	790				
	C	690	510				
	b	1000	800				
	c	600	375				
13	C	780	535				
	b	1060	1230				
Mean		801	908	532	663	610	865
St.Dev.		158	348	253	47		52
n		85	80	14	6	1	4
C.V.(%)		20	38	48	7		6
Max.		1200	2700	1180	730	610	910
Min.		380	345	300	610	610	820

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-5: Sediment porewater soluble reactive phosphorus (SRP) and total phosphorus (TP) at selected stations in Lake Apopka. (Detection limit = 0.005 mg/l)

Station		SRP						TP					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/l											
1	C	4.135		5.919				5.382		6.845			
2	A	3.209	1.040	7.449				4.794	1.127	7.626			
	B	1.080	0.300					2.110	1.788				
	C	0.546		0.136				1.450		0.608			
	D	0.506			0.141			0.961			0.330		
	E	0.243				0.014		1.173				0.523	
	F	0.360		0.118				1.467		0.365			
	G	0.414		1.006				0.972		0.959			
	H			0.100	0.260					0.488			
3	A	1.438						3.780	0.404				
	B	1.889	1.035					3.087	3.192				
	C	0.212						3.628	4.347				0.658
	D	0.330	1.324		0.081			2.594	1.921		0.108		
	E	0.825	0.654		0.115			1.708	1.038		0.847		
	F												
	G	0.669		0.190				1.761	0.691	0.345			
	H			0.020						0.347			
4	A	1.895	0.389					3.116	1.200				
	B	5.050	10.424					6.056	18.764				
	C	0.955	0.439					2.234	4.511				
	D	1.647	5.486		0.555		0.196	8.618	7.639		0.702		0.272
	E	0.084	0.547				0.188	0.356	1.061		0.699		0.234
	F	0.301	0.370	0.190				1.172	1.731	3.665			
	G	0.428	0.536	1.283				1.484	1.196	2.590			
	H	0.554		0.257				2.160	0.874	0.404			
	I	0.156						0.170					
5	A	1.220	2.745					3.116	3.323				
	B	1.100	2.174				0.030	2.168	2.070				0.355
	C	3.600	9.056				1.556	3.524	8.272				1.700
	D	0.820	2.417				0.359	1.750	0.500				0.622
	E	0.180	0.266				0.199	1.362	0.646				0.418
	F	0.180	0.425				0.078	1.750	1.000				0.075
	G	0.020	0.138				0.072	1.144	0.453				0.359
	H	0.275	0.099					0.802	2.688				
	I	2.784	2.274					4.604	19.076				
	J	1.540	1.076	0.246		0.016		1.694	1.209	0.544			
	K	3.280	0.664	1.251				4.310	3.884	0.943			
6	A	1.304	0.215					2.698	0.296				
	B	1.063	0.548					2.452	0.498				
	C	1.971	4.776				0.485	3.562	7.290				0.540
	D	0.092	0.190				0.190	1.550	0.578				0.290
	E	2.251	0.463				0.185	3.182	0.698				0.252
	F	0.625	0.547		2.512		0.231	1.760	1.200		0.729		0.247
	G	0.133	0.674				0.172	0.830	3.625				0.386
	H	3.102	2.750				0.230	3.946	4.002				0.528
	I	2.212	4.544			0.215		3.182	3.861			0.441	
	J	0.529	0.256				0.033	0.754	2.820				0.504
	K	4.080	1.220	1.670				4.926	4.575	3.640			

Table B-5: Sediment porewater soluble reactive phosphorus (SRP) and total phosphorus (TP) at selected stations in Lake Apopka. (Detection limit = 0.005 mg/l)

Station		SRP						TP					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/l											
7	B	0.144	0.426					0.274	1.578				
	C	1.804	0.356					1.253	1.023				
	D	1.488	0.289	0.816	0.070		0.428	2.016	1.520	3.341	0.095		0.459
	E	3.622	8.381					7.882	17.313				
	F						0.032	1.230					0.379
	G	2.625	4.304			1.67		4.836	15.312				
	H	0.044				0.121		0.680	1.449				
	I	0.026				0.12		0.954				0.075	
	J	0.978	1.864	1.330				1.024	4.779	1.710			
8	C	2.187	0.200					2.494	1.100				
	D	2.431	4.786				0.672	5.806	5.480				
	E	1.250	0.116				0.075	0.643	0.376				1.214
	F	0.527	0.517				0.750	1.558	4.230				1.023
	G	0.190						0.856	0.404				
	H	0.191	2.002			0.02		0.827	1.897			0.025	
	I	0.548	0.660	0.260		0.457		0.594	0.025	0.196		4.170	
	J	2.251	0.405	0.410				3.094	0.380	0.266			
9	D	4.818	3.649					6.692	3.240				
	E	0.360	0.713					1.098	0.215				
	F	0.360	0.595					0.742	0.309				
	G	0.860	0.017				0.022	1.324	0.340				
	H	1.376	0.441				0.037	1.886	0.720				0.322
	I	0.106	0.056	0.536				0.846	0.419	1.177			
10	D	1.082	0.311					1.716	0.520				
	E	0.918	0.094	0.771				1.360	0.407	17.560			
	F	0.208	0.142	0.520				0.686	0.413	7.550			
	G	0.664	0.057					1.258	0.762				
	H	1.796	1.982					2.542	3.080				
	I	1.160	1.958					1.329	7.234				
11	C	0.431	0.098					0.432	0.218				
	D	0.792	0.255	0.030				3.003	0.400	0.304			
	E	0.170	0.300					1.982	0.814				
	F	1.364	0.217					3.528	0.847				
	G	3.874	4.718					7.028	5.125				
	a	4.000	2.817					8.305	2.198				
	c	0.237	0.687					0.386	0.595				
12	B	0.488	0.814					2.312	0.174				
	C	0.272	0.549					2.015	5.848				
	b	0.407	0.354					1.460	0.500				
	c	0.742	0.180					2.107	15.225				
13	C	0.072	0.316					1.136	3.042				
	b	1.960	0.490	0.995				4.360	0.573	0.075			
Mean		1.26	1.47	1.11	0.53	0.33	0.28	2.42	3.00	2.68	0.50	1.05	0.52
Std. Dev.		1.24	2.14	1.84	0.076	0.56	0.35	1.89	4.23	4.03	0.32	1.76	0.38
n		86	72	23	7	8	22	87	78	23	7	5	21
C.V.(%)		99	145	166	1	171	124	78	141	151	63	168	73
Max.		5.05	10.42	7.45	2.51	1.67	1.56	8.62	19.08	17.56	0.85	4.17	1.70
Min.		0.02	0.02	0.02	0.07	0.01	0.02	0.17	0.03	0.08	0.10	0.03	0.08

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-6: Porewater and exchangeable ammonium N of sediment collected at selected stations in Lake Apopka. (Detection limit = 0.01 mg NH4-N/l)

Station		Porewater Ammonium N						Exchangeable Ammonium N					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/l						mg/kg					
1	C	35.30		83.81				97.3		670.0			
2	A	40.94	61.98	45.11				444.4	287.6				
	B	35.63	48.52					115.0	116.8				
	C	17.87		20.72				105.6		24.8			
	D	12.03			8.84			99.7			25.1		
	E	14.86				20.33		10.3				23.5	
	F	11.60		7.02				32.4		223.1			
	G	17.03		6.87				140.3		702.9			
	H			5.26						39.3			
3	A	40.71	38.90					508.1					
	B	47.02	55.63					389.9	305.7				
	C	45.01	63.60				38.60	307.8	248.5				249.5
	D	31.40	22.07		14.06			219.9	154.5		41.5		
	E	33.75	24.12		20.32			99.1	190.2		83.6		
	F												
	G	18.76	5.34	11.95				146.8	41.5	111.9			
	H			3.47						13.4			
4	A	40.71	21.52					277.7	365.4				
	B	51.99	38.99					257.8	461.8				
	C	24.74	24.74					152.1	161.0				
	D	95.65	92.36		20.97			529.8	212.6				
	E	12.42	15.42		16.03			156.5	43.7				
	F	18.16	21.00	20.13		19.99		236.7	64.1	138.8		107.1	
	G	16.68	19.35	25.10				64.6	140.8	140.4			
	H	14.69	11.98	6.49				87.6	110.8	74.5			
	I	7.42				0.78		73.0					
5	A	29.57	61.16					180.1	548.0				
	B	38.63	38.47					275.6	253.1				
	C	62.16	119.67					535.6	637.4				
	D	21.04	29.52					227.9	253.1				
	E	19.50	21.40					155.4	41.8				
	F	19.37	23.45					157.3	69.6				
	G	3.39	17.89					162.3	64.4				
	H	13.80	17.87			20.12		155.5	88.8			150.1	
	I	34.27	34.20			44.37		352.9	75.2			240.4	
	J	18.96	20.80	10.27		9.55		173.4	137.6	186.2		71.0	
	K	38.70	47.25	20.65				329.7	303.5	116.2			
6	A	32.26	32.69					235.5	187.3				
	B	25.41	22.19					150.1					
	C	41.99	104.89					292.2	482.6				
	D	14.97	19.89				25.27	96.5	72.7				
	E	29.67	27.81					46.4	87.6				
	F	18.83	21.23		25.13			112.7	21.4		50.0		
	G	15.46	18.40					143.6	190.9				
	H	31.32	39.22			12.45		190.1	307.6			25.6	
	I	35.95	58.25			44.24		365.5	333.3			228.4	
	J	14.27	18.68				27.04	134.3	111.2				
	K	23.60	51.56	14.37				164.1	250.7	474.8			

Table B-6: Porewater and exchangeable ammonium N of sediment collected at selected stations in Lake Apopka. (Detection limit = 0.01 mg NH4-N/l)

Station		Porewater Ammonium N						Exchangeable Ammonium N					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/l						mg/kg					
7	B	24.23	36.83					230.6	381.8				
	C	24.32	26.30					116.7	228.7				
	D	30.04	18.46	41.76	21.10		37.89	239.7	647.1	333.5	247.1		
	E	110.21	178.15					55.7	185.7				
	F	17.18					10.92	12.3					
	G	59.78	139.74			68.90		754.9	632.9			845.3	
	H	13.05	29.31			21.00		100.2	157.9			196.2	
	I	14.50				2.00		40.7				141.1	
	J	26.55	43.00	29.73				123.3	392.7	230.6			
8	C	30.58	17.60					253.8	296.7				
	D	66.93	83.76					1018.3	84.8				
	E	14.80	16.60				16.59	160.8	125.0				
	F	4.10	43.06				47.78	419.4	145.3				
	G	30.44	24.76						92.4				
	H	2.98	27.26			19.20		103.6	90.6			297.0	
	I	13.56	18.20	8.87		8.27		133.4	152.9	332.1		134.1	
	J	48.53	20.59	5.10				120.0	18.2	152.5			
9	D	69.21	82.63					621.8	540.7				
	E	16.72	10.63					250.4	119.6				
	F	14.84	12.92					116.6	103.8				
	G	17.39	12.65				0.97	111.7	123.6				
	H	19.53	27.73				9.54	102.8	147.3				
	I	14.57	13.28	3.16				95.0	96.5	714.9			
10	D	23.70	20.27					139.7	83.6				
	E	21.55	8.91	18.10				196.9	121.7	82.9			
	F	15.24	20.81	11.15				165.2	84.1	379.7			
	G	21.15	21.55					160.7	115.0				
	H	43.83	97.66					264.2	418.1				
	I	54.84	49.37		20.00			157.1	827.4		335.6		
11	C	18.19	5.51					233.8					
	D	22.89	10.74	3.18				175.9	29.2	100.0			
	E	24.10	28.33					78.2	279.2				
	F	45.98	31.12					309.0	308.4				
	G	93.24	115.40					154.9	786.3				
	a	56.46	37.60					394.3	751.6				
	c	4.73	42.21					259.0	191.2				
12	B	35.91	30.27					266.9	449.4				
	C	18.19	21.28					126.1	116.4				
	b	16.89	18.52					199.1	234.1				
	c	21.55	12.65					165.9	163.5				
13	C	18.19	20.31					157.8	219.6				
	b	41.55	28.92	11.27				355.7	201.8	650.3			
Mean		29.31	37.40	17.98	18.31	22.40	23.84	213.2	234.2	267.9	130.5	205.0	249.5
Std. Dev.		19.87	31.95	18.44	5.29	19.36	15.60	161.9	190.0	233.0	129.1	218.5	
n		87	78	23	8	13	9	86	75	22	6	12	1
C.V.(%)		68	85	103	31	86	65	76	81	87	99	107	
Max.		110.21	178.15	83.81	25.13	68.90	47.78	1018.3	827.4	714.9	335.6	845.3	249.5
Min.		2.98	5.34	3.16	8.84	0.78	0.97	10.3	18.2	13.4	25.1	23.5	249.5

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-7: Sediment porewater total Kjeldahl nitrogen (TKN) and total organic nitrogen (TON) at selected stations in Lake Apopka. (Detection limits = 0.1 mg TKN,TON/l)

Station		TKN						TON					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/l											
1	C	46.52		89.08				11.22		5.27			
2	A	54.74	67.73	66.19				13.80	5.75	21.09			
	B	38.64	50.20					3.01	1.68				
	C	30.60		86.19				12.73		65.47			
	D	27.85			60.59			15.82			51.75		
	E	30.39				23.86		15.53				3.53	
	F	21.33		22.40				9.73		15.38			
	G	19.37		40.74				2.34		33.86			
	H			21.60						16.34			
3	A	44.20	56.00					3.49	17.10				
	B	48.66	83.44					1.64	27.81				
	C	48.48	120.20				48.23	3.47	56.60				9.63
	D	35.76	39.30					4.36	17.23		10.59		
	E	36.25	28.48					2.50	4.36		17.14		
	F												
	G	21.04	28.92	46.58				2.28	23.58	34.63			
	H			22.25						18.78			
4	A	43.30	64.82					2.59	43.30				
	B	59.58	180.28					7.59	141.29				
	C	29.62	127.84					4.88	103.10				
	D	75.30	103.05		46.06		52.60		10.69				13.29
	E	19.42	24.48		59.30		25.13	7.00	9.06				8.45
	F	19.42	36.92	34.50		29.90		1.26	15.92	14.37		9.91	
	G	23.50	37.19	28.85				6.82	17.84	12.12			
	H	32.64	45.75	28.45				17.95	33.77	21.96			
	I	11.44				52.74		4.02				52.74	
5	A	33.00	87.42					3.43	26.26				
	B	39.64	45.52				49.76	1.01	7.05				35.64
	C	73.99	149.20				131.79	11.83	29.53				113.23
	D	25.23	22.18					4.19	0.00				
	E	20.84	30.86				29.19	1.34	9.46				8.62
	F	26.16	34.01					6.79	10.56				
	G	21.55	32.05				31.72	18.16	14.16				12.62
	H	17.24	50.02			34.79		3.44	32.15			14.67	
	I	36.80	53.17			46.74		2.53	18.97			2.37	
	J	23.39	29.09	35.97		22.28		4.43	8.29	25.71		12.73	
	K	43.14	56.09	36.14				4.44	8.84	15.50			
6	A	44.50	44.50					12.24	11.81				
	B	33.50	33.53					8.09	11.34				
	C	46.36	125.25				107.51	4.37	20.36				88.00
	D	41.81	28.87				38.00	26.84	8.98				12.73
	E	60.60	33.95				31.14	30.93	6.14				11.50
	F	25.23	37.35		27.63		32.40	6.40	16.12		2.50		9.70
	G	19.72	29.08				108.28	4.26	10.68				87.91
	H	35.15	46.35				34.35	3.83	7.13				26.65
	I	39.01	66.20			61.72		3.06	7.95			17.48	
	J	19.99	29.60				45.70	5.72	10.92				18.66
	K	37.63	65.05	45.73				14.03	13.49	31.36			

Table B-7: Sediment porewater total Kjeldahl nitrogen (TKN) and total organic nitrogen (TON) at selected stations in Lake Apopka. (Detection limits = 0.1 mg TKN,TON/l)

Station		TKN						TON					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/l											
7	B	31.48	48.03					7.25	11.20				
	C	30.75	35.78					6.43	9.48				
	D	36.35	64.12	55.20			53.68	6.31	45.66	13.44			15.79
	E	96.22	217.91						39.76				
	F	38.87					18.35	21.69					7.43
	G	74.03	158.79					14.25	19.05				
	H	34.77	36.50					21.72				22.00	
	I	52.03						37.53					
	J	34.88	53.47	63.63				8.33	10.47	33.90			
8	C	39.02	29.31					8.44	11.71				
	D	80.74	103.61				59.99	13.81	19.85				19.15
	E	35.06	24.26				36.73	20.26	7.66				20.14
	F	37.20	62.70				66.30	33.10	19.64				18.52
	G	31.56	43.98					1.12	9.02				
	H	46.14	36.28			34.40		43.16	9.02			15.20	
	I	23.13	25.70	36.43		27.43		9.57	7.50	14.63		19.16	
	J	61.52	27.24	20.46				12.99	6.65	7.77			
9	D	62.00	95.69					0.00	13.06				
	E	26.12	20.18					9.40	9.55				
	F	21.86	18.97					7.02	6.05				
	G	25.72	26.72					8.33	14.07				
	H	29.58	29.17				23.40	10.05	1.44				13.86
	I	25.34	37.77	15.66				10.77	24.49	12.50			
10	D	33.26	30.13					9.56	9.86				
	E	34.42	30.74	109.20				12.87	21.83	91.10			
	F	24.86	26.42	48.50				9.62	5.61	8.10			
	G	31.22	36.58					10.07	15.03				
	H	63.36	106.37					19.53	8.71				
	I	51.03	60.96					0.00	11.59				
11	C	17.28	12.22					0.00	6.71				
	D	27.39	26.23	13.58				4.50	15.49	10.40			
	E	28.66	52.09					4.56	23.76				
	F	49.42	41.52					3.44	10.40				
	G	115.08	140.26					21.84	24.86				
	a	65.20	61.57					8.74	23.97				
	c	8.88	56.03					4.15	13.82				
12	B	40.52	39.84					4.61	9.57				
	C	21.93	34.06					3.74	12.78				
	b	23.71	28.17					6.82	9.65				
	c	27.47	18.69						6.04				
13	C	23.22	34.16					5.03	13.85				
	b	46.35	40.82	51.25				4.80	11.90	14.25			
Mean		37.82	55.09	44.29	48.40	37.10	51.21	9.30	17.79	23.39	20.50	16.98	27.58
Std. Dev.		18.36	39.90	24.89	15.32	13.68	30.86	8.42	20.23	19.70	21.68	14.06	30.77
n		87	78	23	4	9	20	84	77	23	4	10	20
C.V.(%)		49	72	56	32	37	60	91	114	84	106	83	112
Max.		115.08	217.91	109.20	60.59	61.72	131.79	43.16	141.29	91.10	51.75	52.74	113.23
Min.		8.88	12.22	13.58	27.63	22.28	18.35	0.00	0.00	5.27	2.50	2.37	7.43

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-8: Dissolved total Kjeldhal nitrogen (DTKN) and organic nitrogen (DON) of sediment porewater at selected stations in Lake Apopka. (Detection limits = 0.1 mg DON,DTKN/l)

Station		DTKN						DON					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/l											
1	C	44.25		100.37			30.14	8.95		16.56			
2	A	46.38	68.88	35.44				5.44	6.90	2.99			
	B	36.99	41.68					1.36					
	C	26.78		29.33				8.91		8.61			
	D	20.96			19.89			8.93			11.05		
	E	28.00				22.97		13.14				2.64	
	F	12.30		13.50				0.70		6.48			
	G	18.97		19.89				1.94		13.01			
	H			18.43						13.17			
3	A	41.70	38.90					0.99	0.00				
	B	46.94	67.06					0.00	11.43				
	C	48.43	72.40				45.09	3.42	8.50				
	D	32.19	34.13		15.04			0.79	12.06		0.98		
	E	33.53	31.60		40.10			0.00	7.48		19.78		
	F												
	G	20.21	13.47	28.20				1.45	8.13	16.26			
	H			10.70						7.23			
4	A	40.61	61.13					0.00	39.61				
	B	58.91	117.96					6.92	78.97				
	C	26.32	41.47					1.58	16.73				
	D	71.57	97.38		30.98		47.40	0.00	5.02		10.01		8.09
	E	16.30	31.09		43.98		15.87	3.88	15.67		27.95		
	F	19.38	28.08	35.87		27.05		1.22	7.08	15.74		7.06	
	G	19.47	29.83	26.28				2.79	10.48	1.18			
	H	20.69	34.21	14.50				6.00	22.23	8.01			
	I	9.08				11.30		1.66					
5	A	31.19	31.24					1.62					
	B	39.10	47.19				17.15	0.47	8.72				3.03
	C	64.22	144.89				105.84		25.22				87.28
	D	24.99	37.86				43.93	3.95	8.34				
	E	21.68	28.90				20.88	2.18	7.50				0.31
	F	25.80	30.09					6.43	6.64				
	G	4.30	32.57				30.92	0.91	14.68				11.82
	H	15.79	25.04			37.20		1.99	7.17			17.08	
	I	35.97	46.24			4.02		1.70	12.04				
	J	21.58	31.52	20.02		24.85		2.62	10.72	9.75		15.30	
	K	39.27	52.39	23.86				0.57	5.14	3.21			
6	A	34.36	36.13					2.10	3.44				
	B	29.21	27.82					3.80	5.63				
	C	44.48	117.44				77.24	2.49	12.55				57.73
	D	22.05	32.08				30.52	7.08	12.19				
	E	31.93	40.88				23.63	2.26	13.07				3.99
	F	23.15	39.41				26.96	4.32	18.18				4.26
	G	18.05	30.70				27.03	2.59	12.30				6.66
	H	32.80	40.44			21.46		1.48	1.22			9.01	
	I	37.86	62.81			57.65		1.91	4.56			13.41	
	J	17.40	27.12				31.93	3.13	8.44				
	K	35.01	58.19	30.50				11.41	6.63	16.13			

Table B-8: Dissolved total Kjeldhal nitrogen (DTKN) and organic nitrogen (DON) of sediment porewater at selected stations in Lake Apopka. (Detection limits = 0.1 mg DON,DTKN/l)

Station		DTKN						DON					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
							mg/l						
7	B	26.09	49.76					1.86	12.93				
	C	29.16	33.84					4.84	7.55				
	D	30.50	62.91	50.68			45.69	0.46	44.45	8.92			
	E	97.76	196.40					0.00	18.25				
	F	24.76					22.21	7.58					
	G	65.71	142.60					5.93	2.86				
	H	20.00	34.81					6.95	5.50				
	I	22.12						7.62					
	J	30.59	55.82	55.18				4.04	12.82	25.44			
8	C	33.18	27.36					2.60	9.76				
	D	67.82	87.40				51.58	0.89	3.64				10.74
	E	23.80	29.12				24.10	9.00	12.52				
	F	29.12	126.23				59.40	25.02	83.17				
	G	97.07	29.92					67.07	5.16				
	H	21.74	33.48			30.45		18.76	6.22				
	I	21.89	21.41	19.87				8.33	3.21	6.12			
	J	76.84	35.90	16.97				28.31	15.31	8.86			
9	D	68.84	98.08					0.00	15.45				
	E	19.70	29.88					2.98	19.25				
	F	16.71	25.40					1.87	12.48				
	G	19.19	27.46					1.80	14.81				
	H	21.45	30.44				19.13	1.92	2.71				
	I	17.63	33.28	17.95				3.06	20.00	14.79			
10	D	26.82	30.30					3.12	10.03				
	E	24.53	25.88	81.25				2.98	16.97	63.15			
	F	18.09	30.06	40.40				2.85	9.25	29.25			
	G	26.13	33.96					4.98	12.41				
	H	56.14	98.17					12.31	0.51				
	I	25.35	56.22						6.85				
11	C	22.27	9.21					4.08	3.70				
	D	24.99	15.25					2.10	4.51				
	E	27.33	38.06					3.23	9.73				
	F	75.77	55.08					29.79	23.96				
	G	112.96	134.56					19.72	19.16				
	a	61.04	34.57					4.58	5.87				
	c	6.83	39.02					2.10	2.10				
12	B	39.51	47.18					3.60	16.91				
	C	21.31	39.08					3.12	17.80				
	b	20.89	25.67					4.00	7.15				
	c	22.23	21.22					0.68	8.57				
13	C	22.92	33.69					4.73	13.38				
	b	24.19	55.31	22.45					13.76	22.45			
Mean		33.69	49.54	32.35	30.00	26.33	37.94	5.52	12.96	14.42	13.95	10.75	19.39
Std. Dev.		20.43	34.53	22.30	12.49	15.32	22.01	8.95	13.58	13.04	10.27	5.48	29.06
n		87	78	22	5	9	21	84	76	22	5	6	10
C.V.(%)		61	70	69	42	58	58	162	105	90	74	51	150
Max.		112.96	196.40	100.37	43.98	57.65	105.84	67.07	83.17	63.15	27.95	17.08	87.28
Min.		4.30	9.21	10.70	15.04	4.02	15.87	0.00	0.00	1.18	0.98	2.64	0.31

UCF = Unconsoliated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-9: Total organic carbon (TOC) of sediment porewater at selected stations in Lake Apopka. (Det. lim. = 0.1 mg C/l).

Station		TOC					
		UCF	CF	P	S	C	M
		mg/l					
1	C	47.80		10.67			
2	A	28.84		69.93			
	B	31.34	20.65				
	C	19.28		226.61			
	D	38.85			81.25		
	E	100.52				30.85	
	F	53.40		55.54			
	G	17.85		91.63			
	H			37.14	54.38		
3	A	27.63					
	B	29.67	87.94				71.41
	C	17.00					
	D	20.10			38.50		
	E	18.62			37.23		
	F						
	G	24.15		65.52			
	H			68.08			
4	A	25.37	24.80				
	B	37.34	40.00				40.24
	C	22.78	35.08				
	D	22.79	32.67				50.40
	E	18.29	24.46				41.92
	F	23.67	27.41	48.00		39.24	
	G	34.78	23.05	52.56			
	H	123.04		76.94			
	I	19.19				82.14	
5	A	36.33	33.92				
	B	23.96	28.54				67.49
	C	35.35	46.44				118.06
	D	22.82	24.37				30.91
	E	28.09	30.40				37.08
	F	32.12	40.98				55.87
	G	30.19	47.09				99.91
	H	24.06	42.04			63.12	
	I	30.48	44.96			65.56	
	J	26.67	36.09	101.30			
	K	30.26	19.63	55.71			
6	A	23.70	25.07				
	B	27.02	27.73				
	C	29.59	31.24				50.74
	D	61.56	41.92				61.47
	E	25.34	29.97				53.48
	F	24.00	39.76				41.55
	G	25.68	28.22				51.83
	H	27.36	27.58			44.98	55.50
	I	24.84	32.78				
	J	29.48	36.43				584.43
	K	84.74	33.81	92.33			
7	B	25.99	21.51				
	C	29.59	32.59				
	D	28.48	29.94	47.13	47.01		100.66
	E	32.89	52.51				
	F	114.55					460.67
	G	27.44	48.82			77.77	
	H	85.64					
	I	62.14				37.80	
	J	29.00	40.22	47.84			
8	C	22.58	22.28				
	D	41.79	36.16				28.90
	E		23.97				74.60
	F	25.21	43.95				93.43
	G	39.56					55.67
	H	59.23	24.00			24.88	
	I	29.58	26.78	71.66	57.20	39.60	
	J	20.28	24.70	62.94			
9	D	30.50	23.05				
	E	18.47	20.75				
	F	18.61	23.70				
	G	28.28	31.50				48.67
	H	27.50	26.60				317.83
	I	22.29	31.23	24.88			
10	D	26.15	29.20				
	E	25.86	23.21	1046.80			
	F	25.03	29.67	32.82			
	G	22.02	17.09				
	H	31.74	34.45				
	I	35.91	17.38		64.05		
11	C	16.88	16.39				
	D	16.66	25.24	23.04			
	E	23.07	190.07				
	F	26.52	19.25				
	G	42.29	27.77				
	a	20.91	53.68				
	c	12.87	35.26				
12	B	23.74	24.83				
	C	21.55	29.24				
	b	21.20	28.92				
	c	13.73	24.80				
13	C	27.35	31.35				
	b	35.73	39.09				
Mean		32.50	34.00	109.50	54.23	50.59	107.71
St.Dev.		20.03	21.99	213.68	15.40	20.03	138.01
n		86	69	22	7	10	25
C.V.(%)		62	65	195	28	40	128
Max.		123.04	190.07	1046.80	81.25	82.14	584.43
Min.		12.87	16.39	10.67	37.23	24.88	28.90

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-10: Dissolved inorganic carbon content of sediment porewater at selected stations in Lake Apopka. (Detection limit = 0.1 mg C/l).

Station		UCF	CF	P	S	C	M
		mg/l					
1	C	84.46		119.90			
2	A	74.55	92.69	16.11			
	B	69.36	81.60				
	C	7.39		28.66			
	D	41.52			19.56		
	E	30.58				32.01	
	F	45.55		4.91			
	G	36.96		5.57			
	H			12.21			
3	A	50.88	0.00				
	B	72.52	46.06				
	C	68.96	110.66				
	D	48.68	46.87		21.89		
	E	76.10	7.12		42.98		
	G	39.36	34.28	7.24			
	H			2.79			
4	A	63.64	71.34				
	B	68.10	152.03				
	C	9.68	58.83				
	D	95.88	119.19				28.96
	E	52.66	97.52				31.37
	F	48.84	55.86	94.94		23.56	
	G	44.96	68.94	1.93			
	H	49.22	54.60	2.93			
	I	25.76				50.46	
5	A	58.04	61.17				
	B	63.28	78.51				12.74
	C	128.56	204.87				75.68
	D	51.72	79.35				79.72
	E	46.32	13.63				47.46
	F	58.20	60.88				
	G	7.35	54.55				16.16
	H	32.20	53.20			13.93	
	I	72.28	75.44			129.34	
	J	43.72	18.52	0.19		9.42	
	K	56.04	99.78	4.69			
6	A	57.04	37.62				
	B	46.84	35.94				
	C	76.04	154.59				59.46
	D	23.85	57.84				30.99
	E	13.02	86.50				28.14
	F	55.66	73.74				56.50
	G	45.56	100.59				23.77
	H	13.97	80.72			25.18	
	I	61.83	110.78			62.49	
	J	11.61	66.22				24.77
	K	46.15	110.89	6.61			
7	B	40.03	69.51				
	C	1.50	63.84				
	D	68.61	82.88	70.06			27.37
	E	106.45	231.30				
	F	46.45					20.00
	G	97.67	163.10				
	H	68.77				42.16	
	I	39.14					
	J	11.21	135.36	36.00			
8	C	63.94	29.72				
	D	100.48	130.47				56.48
	E	115.83	11.70				20.28
	F	68.03	96.34				30.91
	G	93.18					
	H	40.97	61.21				
	I	71.81		0.00		7.17	
	J	11.98	29.09	1.96			
9	D	99.29	130.82				
	E	51.70	41.06				
	F	43.40	30.99				
	G	51.84	46.85				
	H	58.25	59.83				22.30
	I	54.50	45.04				
10	D	6.66	38.11				
	E	52.02	49.71	10.96			
	F	44.41	56.77	29.14			
	G	41.12	48.06				
	H	76.94	119.83				
	I	10.31	64.84				
11	C	33.89	10.16				
	D	57.09	14.05	11.91			
	E	66.76	46.68				
	F	81.15	63.72				
	G	105.67	159.04				
	a	72.97	21.58				
	c	21.31	37.08				
12	B	56.02	2.97				
	C	48.57	51.17				
	b	49.77	22.66				
	c	38.27	9.17				
13	C	54.86	23.29				
	b	66.89	37.82				
Mean		53.62	68.65	22.32	28.14	39.57	36.48
St.Dev.		26.38	46.31	32.92	12.90	36.28	19.95
n		87	75	21	3	10	19
C.V.(%)		112	67	147	46	92	55
Max.		128.56	231.30	119.90	42.98	129.34	79.72
Min.		1.50	0.00	0.00	19.56	7.17	12.74

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-11: Concentration of major cations in the unconsolidated flocculent (UCF) sediment at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		mg/l							
1	C	140.83	63.33	16.67	0.83	0.17	0.00	0.00	19.17
2	A	130.00	42.50	16.00	0.50	0.15	0.00	0.00	20.50
	B	134.98	30.71	10.71	0.36	0.11	0.00	0.00	17.50
	C	112.50	23.75	12.50	1.25	0.13	0.00	0.00	21.25
	D	102.50	25.63	11.88	0.00	0.06	0.00	0.00	18.75
	E	64.29	20.00	10.00	0.00	0.00	0.00	0.00	17.14
	F	71.50	24.00	11.50	0.50	0.05	0.00	0.00	17.00
	G	87.85	27.14	12.50	0.00	0.04	0.00	0.00	18.21
3	A	132.39	24.21	13.16	0.26	0.13	0.00	0.00	18.95
	B	135.75	30.75	12.25	0.25	0.10	0.00	0.00	21.50
	C	125.25	32.75	12.50	0.00	0.08	0.00	0.00	18.50
	D	111.77	33.57	13.21	0.00	0.04	0.00	0.00	19.64
	E	120.00	26.88	11.88	0.63	0.06	0.00	0.00	20.63
	G	105.77	31.92	14.23	0.00	0.08	0.00	0.00	19.61
4	A	119.00	28.50	12.60	0.20	0.05	0.00	0.00	16.60
	B	128.52	38.33	15.21	0.00	0.10	0.00	0.00	20.83
	C	112.00	36.00	14.10	0.10	0.09	0.00	0.00	19.30
	D	127.00	43.50	16.10	0.10	0.15	0.00	0.00	19.00
	E	97.25	31.00	12.00	0.00	0.05	0.00	0.00	17.25
	F	102.28	31.66	13.96	0.00	0.06	0.00	0.04	18.54
	G	97.25	29.75	13.00	0.00	0.03	0.00	0.00	19.00
	H	63.84	24.61	11.54	0.77	0.08	0.00	0.00	18.46
	I	84.57	28.75	9.79	0.21	0.08	0.00	0.00	17.71
5	A	104.00	29.50	12.80	0.10	0.09	0.00	0.00	17.20
	B	121.00	32.30	14.50	0.10	0.11	0.00	0.00	17.20
	C	141.85	43.74	15.00	0.00	0.10	0.00	0.00	18.12
	D	93.65	30.58	11.35	0.00	0.06	0.00	0.00	16.35
	E	100.00	28.60	12.60	0.00	0.06	0.00	0.00	17.80
	F	111.00	32.50	13.75	0.50	0.10	0.00	0.00	18.50
	G	17.70	5.10	2.40	0.00	0.00	0.00	0.00	3.40
	H	83.94	27.08	11.87	0.00	0.04	0.00	0.00	17.71
	I	117.00	37.00	13.60	0.10	0.09	0.00	0.00	19.60
	J	88.06	26.67	12.50	0.00	0.03	0.00	0.00	18.06
	K	117.83	34.35	13.48	0.00	0.17	0.00	0.00	19.35
6	A	129.00	27.30	13.20	0.00	0.12	0.00	0.00	16.50
	B	103.00	28.20	12.30	0.20	0.09	0.00	0.00	16.40
	C	115.00	34.50	14.10	0.10	0.14	0.00	0.00	18.50
	D	70.25	24.61	12.82	0.00	0.00	0.00	0.00	21.02
	E	117.00	35.00	13.70	0.10	0.09	0.00	0.00	18.50
	F	112.00	34.60	13.30	0.00	0.09	0.00	0.00	18.30
	G	102.00	32.50	13.00	0.10	0.12	0.00	0.00	18.40
	H	108.00	34.20	12.20	0.10	0.08	0.00	0.00	17.50
	I	119.15	35.20	14.16	0.21	0.15	0.00	0.00	17.91
	J	98.20	28.90	12.10	0.30	0.13	0.00	0.02	17.60
	K	134.00	34.10	14.90	0.10	0.15	0.00	0.00	18.30

Table B-11: Concentration of major cations in the unconsolidated flocculent (UCF) sediment at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		mg/l							
7	B	104.23	24.74	12.63	0.00	0.05	0.00	0.00	16.84
	C	106.40	28.80	12.00	0.00	0.04	0.00	0.00	16.80
	D	115.00	30.60	12.90	0.10	0.13	0.00	0.00	16.70
	E	119.00	38.80	16.40	0.10	0.14	0.00	0.00	18.70
	F	74.70	27.65	11.18	0.00	0.06	0.00	0.00	17.06
	G	118.00	36.80	15.80	0.80	0.17	0.00	0.03	17.90
	H	69.81	22.54	11.27	0.00	0.04	0.00	0.00	17.82
	I	89.11	29.12	11.76	0.29	0.09	0.00	0.00	18.53
	J	118.11	31.25	13.54	0.00	0.15	0.00	0.00	17.50
8	C	117.00	23.50	11.20	0.00	0.12	0.00	0.00	14.10
	D	136.00	37.40	14.90	0.10	0.21	0.00	0.02	18.20
	E	92.50	33.50	11.00	0.50	0.05	0.00	0.00	17.50
	F	113.00	31.10	13.30	0.00	0.11	0.00	0.00	17.70
	G	91.79	32.31	12.31	0.00	0.10	0.00	0.00	19.49
	H	92.06	26.14	11.37	0.00	0.07	0.00	0.02	17.05
	I	75.93	23.71	12.59	0.00	0.04	0.00	0.00	17.78
	J	140.50	22.50	8.75	0.00	0.15	0.00	0.00	14.25
9	D	124.00	34.80	12.80	0.10	0.17	0.00	0.00	15.50
	E	107.00	24.40	14.00	0.50	0.09	0.00	1.30	19.10
	F	102.00	21.50	11.00	0.00	0.08	0.00	0.00	15.10
	G	101.00	36.60	12.90	0.10	0.08	0.00	0.00	18.10
	H	108.00	35.90	13.00	0.00	0.13	0.00	0.00	18.90
	I	107.00	25.30	11.60	0.10	0.10	0.00	0.00	17.20
10	D	107.00	29.30	12.40	0.10	0.10	0.00	0.00	17.40
	E	115.70	31.07	13.57	0.00	0.14	0.00	0.00	18.21
	F	110.00	30.65	12.39	0.00	0.13	0.00	0.00	16.74
	G	107.00	26.50	11.40	0.10	0.06	0.00	0.01	16.10
	H	135.00	39.20	15.30	0.10	0.21	0.10	0.00	17.90
	I	122.00	37.20	14.40	0.40	0.23	0.10	0.00	17.90
11	C	91.30	11.60	4.00	0.10	0.04	0.10	0.00	8.00
	D	112.00	16.70	8.90	0.10	0.09	0.00	0.00	13.20
	E	118.00	30.50	13.10	0.00	0.15	0.00	0.00	17.50
	F	130.00	34.80	14.80	0.10	0.21	0.10	0.00	16.10
	G	118.00	36.00	15.80	0.20	0.12	0.10	0.00	16.00
	a	121.40	24.45	8.33	0.28	0.06	0.00	0.00	13.61
	c	87.91	24.31	12.65	0.00	0.03	0.00	0.00	17.98
12	B	113.00	26.40	10.80	0.30	0.12	0.10	0.01	13.60
	C	99.57	22.08	11.04	0.00	0.06	0.00	0.00	15.83
	b	87.32	22.66	10.67	0.33	0.03	0.00	0.00	15.33
	c	99.61	18.65	8.27	0.38	0.06	0.00	0.02	12.11
13	C	101.38	25.46	11.37	0.45	0.07	0.00	0.02	16.14
	b	120.47	28.19	12.05	0.23	0.16	0.00	0.00	15.68
Mean		107.2	29.9	12.5	0.2	0.1	0.0	0.0	17.4
Std. Dev.		20.5	7.4	2.2	0.2	0.1	0.0	0.1	2.5
n		87	87	87	87	87	87	87	87
C.V.(%)		19	25	18	146	52	370	810	15
Max.		141.9	63.3	16.7	1.3	0.2	0.1	1.3	21.5
Min.		17.7	5.1	2.4	0.0	0.0	0.0	0.0	3.4
Det.lim.		0.10	0.10	0.10	0.10	0.010	0.10	0.010	0.1

Table B-12: Concentration of major cations in the consolidated flocculent (CF) sediment at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		mg/l							
2	B	131.80	31.20	10.00	0.20	0.12	0.00	0.00	17.40
4	A	125.66	21.74	7.39	0.43	0.04	0.00	0.00	11.30
	B	152.80	38.40	13.60	0.40	0.04	0.00	0.00	22.80
	C	97.89	24.74	10.53	0.00	0.05	0.00	0.00	19.47
	D	131.67	44.76	17.86	0.00	0.07	0.00	0.00	21.67
	E	110.44	29.09	14.09	0.45	0.05	0.00	0.00	19.09
	F	111.50	23.50	13.00	0.50	0.10	0.00	0.00	20.00
	G	110.20	25.96	11.06	0.43	0.04	0.00	0.00	17.02
5	A	114.00	21.50	9.10	0.10	0.03	0.00	0.01	13.10
	B	141.12	20.37	10.74	0.37	0.07	0.00	0.00	15.19
	C	156.67	46.67	14.44	1.11	0.11	1.11	0.11	23.33
	D	136.89	39.31	11.03	0.69	0.07	0.00	0.00	20.69
	E	108.00	28.50	11.50	0.25	0.03	0.00	0.00	18.50
	F	120.29	24.93	11.23	0.27	0.05	0.00	0.00	16.99
	G	92.86	20.48	10.00	0.00	0.05	0.00	0.00	17.14
	H	102.84	21.81	10.13	0.26	0.08	0.00	0.31	18.70
	I	135.20	37.60	10.80	0.00	0.08	0.00	0.00	22.80
	J	91.60	24.40	11.20	0.00	0.00	0.00	0.00	18.00
	K	109.00	34.50	10.40	0.00	0.07	0.00	0.00	19.30
6	A	115.62	11.89	10.12	0.25	0.08	0.00	0.03	10.88
	B	83.79	16.23	7.71	0.00	0.03	0.00	0.00	10.37
	C	144.50	37.76	10.41	0.00	0.04	0.00	0.00	16.94
	D	87.20	30.00	11.20	0.00	0.04	0.00	0.00	20.00
	E	126.25	35.00	10.63	0.00	0.06	0.00	0.00	18.75
	F	115.29	35.29	12.35	0.00	0.06	0.00	0.00	18.82
	G	118.14	33.95	11.63	0.00	0.09	0.00	0.05	19.07
	H	130.00	35.10	10.20	0.00	0.04	0.00	0.00	18.10
	I	137.55	36.14	12.98	0.35	0.07	0.00	0.00	19.30
	J	102.40	26.40	10.00	0.00	0.08	0.00	0.00	17.60
	K	150.65	32.00	13.33	0.33	0.13	0.00	0.00	19.33
7	B	131.20	14.40	7.20	0.00	0.08	0.00	0.00	9.20
	C	100.00	15.60	7.20	0.00	0.00	0.00	0.00	10.40
	D	133.42	26.00	8.57	0.00	0.06	0.00	0.00	14.57
	E	164.00	52.00	16.30	0.10	0.04	0.00	0.00	19.50
	G	180.00	54.50	20.50	0.10	0.19	0.00	0.00	21.90
	J	129.09	27.27	11.82	0.91	0.09	0.00	0.00	22.73

Table B-12: Concentration of major cations in the consolidated flocculent (CF) sediment at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		mg/l							
8	C	33.60	10.40	4.40	0.40	0.00	0.00	0.00	10.00
	D	158.62	50.00	9.45	0.28	0.11	0.00	0.00	19.45
	E	89.76	33.95	7.44	0.47	0.05	0.00	0.00	14.42
	F	109.45	24.45	10.00	0.00	0.06	0.00	0.00	19.45
	H	112.62	28.57	10.00	0.24	0.12	0.00	0.00	16.67
	I	90.40	23.40	12.80	0.20	0.02	0.00	0.00	17.80
	J	46.15	6.15	5.64	0.00	0.00	0.00	0.00	8.72
9	D	142.77	20.00	7.59	0.00	0.07	0.00	0.00	8.97
	E	65.00	12.50	5.63	0.00	0.00	0.00	0.00	10.00
	F	61.00	9.50	5.00	0.50	0.00	0.00	0.00	11.50
	G	65.40	34.05	6.49	0.00	0.00	0.00	0.00	13.51
	H	87.04	38.65	8.65	0.00	0.03	0.00	0.00	21.89
	I	76.40	12.00	8.40	0.40	0.00	0.00	0.00	13.20
10	D	67.04	16.30	6.30	0.00	0.00	0.00	0.00	11.11
	E	83.42	16.57	9.43	0.29	0.03	0.00	0.00	13.71
	F	93.62	18.61	10.00	0.00	0.06	0.00	0.00	15.56
	G	107.36	12.65	8.98	0.41	0.04	0.00	0.00	12.25
	H	147.64	27.65	9.12	0.29	0.06	0.00	0.00	14.41
	I	121.00	34.60	15.40	0.20	0.08	0.00	0.00	20.00
11	C	34.14	6.25	1.01	0.00	0.00	0.00	0.00	4.39
	D	26.50	5.00	1.50	0.25	0.00	0.00	0.05	6.75
	E	96.28	14.00	5.71	0.29	0.03	0.00	0.00	10.00
	F	83.42	14.86	4.00	0.00	0.06	0.00	0.00	9.71
	G	136.00	29.00	10.00	0.20	0.08	0.00	0.00	11.60
	a	25.152	6.288	3.144	0	0	0	0	7.074
	c	96.60	14.28	7.35	0.02	0.02	0.00	0.02	13.23
12	B	44.14	9.66	4.83	0.00	0.00	0.00	0.00	10.35
	C	69.14	8.00	5.14	0.00	0.00	0.00	0.00	9.14
	b	43.74	6.93	5.50	0.00	0.02	0.00	0.02	9.32
	c	28.48	5.42	2.03	0.00	0.00	0.00	0.00	5.76
13	C	37.33	8.44	4.89	0.44	0.00	0.00	0.00	9.78
	b	46.74	10.34	5.62	0.22	0.02	0.00	0.00	10.34
Mean		102.29	24.23	9.29	0.19	0.05	0.02	0.01	15.15
Std. Dev.		37.45	12.32	3.72	0.23	0.04	0.13	0.04	4.87
n		68	68	68	68	68	68	68	68
C.V.(%)		37	51	40	126	82	825	461	32
Max.		180.00	54.50	20.50	1.11	0.19	1.11	0.31	23.33
Min.		25.15	5.00	1.01	0.00	0.00	0.00	0.00	4.39
Det.lim.		0.10	0.10	0.10	0.10	0.010	0.10	0.010	0.1

Table B-13: Concentration of major cations in the peat (P) at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		----------------------------			mg/l			----------------------------	
2	A	19.6	5.3	11.7	0.0	0.0	0.0	0.0	13.2
	B	76.0	11.3	8.1	0.0	0.0	0.0	0.0	16.8
	F	32.7	9.8	10.4	0.0	0.0	0.0	0.0	14.7
	G	22.0	4.9	12.1	0.0	0.0	0.0	0.1	14.8
	H	29.8	12.8	10.4	0.5	0.0	0.0	0.0	15.1
3	G	32.6	6.9	7.5	0.2	0.0	0.0	0.0	14.5
	H	23.8	10.5	16.5	0.4	0.0	0.0	0.0	19.0
4	F	105.3	17.3	10.7	1.3	0.1	0.0	0.1	17.3
	G	11.4	2.1	4.7	0.5	0.0	0.0	0.0	8.8
	H	20.9	5.3	8.8	0.3	0.0	0.0	0.0	12.7
5	J	16.6	3.7	7.0	0.3	0.0	0.6	0.0	11.8
	K	10.0	4.1	7.5	0.2	0.0	0.0	0.0	14.5
	SI	32.9	9.5	1.7	0.0	0.0	0.0	0.1	5.2
6	K	14.1	2.4	6.3	0.0	0.0	0.0	0.0	10.2
7	D	72.0	12.0	3.2	0.0	0.0	0.0	0.0	8.8
8	I	18.2	3.8	5.3	0.0	0.0	0.0	0.0	12.0
	J	7.1	2.1	2.3	0.0	0.0	0.2	0.0	7.3
10	E	62.6	10.4	6.3	4.2	0.0	0.0	0.0	12.5
	F	44.0	8.0	7.0	0.0	0.0	0.0	0.0	9.0
11	D	20.0	4.5	0.9	0.0	0.0	0.0	0.0	5.5
Mean		33.59	7.33	7.42	0.39	0.007	0.04	0.02	12.19
Std. Dev.		25.97	4.21	3.89	0.95	0.03	0.13	0.04	3.85
n		20	20	20	20	20	20	20	20
C.V.(%)		130	21	19	5	0	1	0	19
Max.		105.33	17.33	16.54	4.177	0.133	0.56	0.13	18.96
Min.		7.10	2.06	0.91	ND	ND	ND	ND	5.20
Det.lim.		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table B-14: Concentration of major cations in the clay (C) at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		mg/l							
2	E	69.2	16.9	7.7	0.0	0.0	0.0	0.0	14.9
4	F	68.8	10.4	9.2	0.3	0.0	0.0	0.0	14.4
	I	87.3	25.7	14.4	0.0	0.0	0.0	0.0	24.6
5	H	38.8	6.3	6.3	0.0	0.0	0.0	0.1	12.6
	I	77.3	18.6	12.4	0.0	0.0	0.0	0.2	21.6
	J	29.9	6.4	10.5	0.0	0.0	0.0	0.0	11.1
6	H	60.4	13.0	6.5	0.0	0.0	0.0	0.0	14.9
	I	100.0	27.2	7.2	0.0	0.1	0.0	0.0	16.2
7	H	104.4	25.5	18.2	0.0	0.0	0.0	0.1	23.1
8	I	14.3	3.4	5.5	0.0	0.0	0.0	0.0	11.6
Mean		65.0	15.3	9.8	0.0	0.0	0.0	0.0	16.5
Std. Dev.		29.8	8.8	4.1	0.1	0.0	0.0	0.1	4.9
n		10	10	10	10	10	10	10	10
C.V.(%)		46	57	42	316	229		149	30
Max.		104.4	27.2	18.2	0.3	0.1	0.0	0.2	24.6
Min.		14.3	3.4	5.5	0.0	0.0	0.0	0.0	11.1
Det.lim.		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table B-15: Concentration of major cations in the sand (S) at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		mg/l							
2	D	56.5	9.8	8.6	0.0	0.0	0.0	0.1	17.2
3	D	51.2	20.6	6.6	0.2	0.0	0.0	0.0	16.7
7	D	39.8	6.0	2.8	0.0	0.0	0.0	0.0	7.2
Mean		49.2	12.1	6.0	0.1	0.0	0.0	0.0	13.7
Std. Dev.		8.5	7.6	2.9	0.1	0.0	0.0	0.0	5.6
n		3	3	3	3	3	3	3	3
C.V.(%)		17	62	49	173	173	0	173	41
Max.		56.5	20.6	8.6	0.2	0.0	0.0	0.1	17.2
Min.		39.8	6.0	2.8	0.0	0.0	0.0	0.0	7.2
Det.lim.		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table B-16: Concentration of major cations in the marl (M) at selected stations in Lake Apopka.

Station		Ca	Mg	K	Fe	Mn	Al	Cu	Na
		mg/l							
4	D	48.66	24.65	13.90	0.32	0.00	0.00	0.03	19.28
	E	80.18	15.60	11.45	0.00	0.03	0.00	0.03	16.43
5	B	45.06	5.63	6.50	0.43	0.00	0.00	0.04	9.53
	C	66.22	19.76	10.68	0.00	0.00	0.00	0.00	17.62
	D	86.76	25.29	9.71	0.59	0.03	0.00	0.00	15.59
	E	75.30	24.96	8.46	0.00	0.02	0.00	0.00	18.88
	G	48.74	9.59	7.19	0.00	0.00	0.00	0.08	14.38
6	C	57.20	18.80	5.20	0.00	0.00	0.00	0.00	13.60
	D	55.92	22.30	6.40	0.02	0.02	0.00	0.02	20.34
	E	61.92	24.48	6.48	0.00	0.00	0.00	0.00	18.00
	F	95.00	40.80	8.32	0.00	0.00	0.00	0.02	17.05
	G	62.43	16.46	6.52	0.00	0.00	0.00	0.07	19.21
	J	51.40	11.58	9.05	0.00	0.00	0.00	0.00	13.76
7	D	47.40	7.80	3.18	0.00	0.00	0.00	0.03	11.56
	F	61.21	22.09	15.78	0.00	0.00	0.00	0.06	16.41
8	D	90.68	44.82	4.48	0.00	0.03	0.00	0.00	16.21
	E	37.86	15.03	4.91	0	0	0	0	11.56
	F	32.11	6.28	5.93	0.00	0.00	0.00	0.03	13.61
9	H	30.92	18.86	7.34	0.00	0.00	0.00	0.05	15.72
Mean		59.7	19.7	8.0	0.1	0.0	0.0	0.0	15.7
Std. Dev.		18.9	10.4	3.2	0.2	0.0	0.0	0.0	2.9
n		19	19	19	19	19	19	19	19
C.V.(%)		40	59	48	250	179		112	30
Max.		95.0	44.8	15.8	0.6	0.0	0.0	0.1	20.3
Min.		30.9	5.6	3.2	0.0	0.0	0.0	0.0	9.5
Det.lim.		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Table B-17a: Sediment double acid extractable (0.05N HCl+0.025N H2SO4) phosphorus at selected stations in Lake Apopka. (Detection limit = 0.01 mg P/g)

Station		UCF	CF	P	S	C	M			UCF	CF	P	S	C	M
		mg/kg								mg/kg					
1	C	116.3		277.1				7	B	1415.1	89.6				
2	A	211.4		125.4					C	158.8	55.9				
	B	187.0	168.4						D	200.2	120.9	56.8	10.6		13.1
	C	137.3		37.5					E	388.1	154.4				53.5
	D	72.9			41.3				F	43.0					0.0
	E	92.0				53.3			G	231.7	197.5			37.7	
	F	84.1		11.9					H	92.2				0.0	
	G	137.1		39.4					I	95.1				39.4	
	H			27.5	39.4				J	394.6	125.9	154.1			
3	A	168.4			70.5			8	C	323.6	140.0				
	B	197.1	105.8						D	326.0	163.6				2.4
	C	173.2					54.5		E	84.8	12.9				6.7
	D	135.8			4.8				F	148.8	49.0				29.6
	E	154.5			8.8				G	53.3					10.8
	F								H	176.7	125.4			48.5	
	G	145.0		132.6					I	199.4	169.6	74.0	87.7		
	H	36.1		25.1					J	381.0	112.7	51.4			
4	A	268.0	123.5					9	D	200.2	149.3				
	B	376.2	168.4				51.4		E	199.4	80.3				2.4
	C	191.6	108.7						F	58.5	102.5		130.2		
	D	336.3	94.3				8.1		G	108.9		171.7			1.4
	E	136.9	34.6				12.2		H	187.5	82.4				279.5
	F	139.5	103.7	114.4		3.6			I	211.4	279.0	14.1			
	G	151.7	96.5	47.1				10	D	255.6	75.0				
	H	199.2		75.0					E	201.8	187.3	15.5			
	I	309.1				37.7			F	124.9	129.5	28.7			
5	A	314.3	197.1						G	185.1	100.3				
	B	474.1	126.5				32.2		H	290.1	137.3				
	C		132.1				32.2		I	384.1	924.3		1397.2		
	D	150.3	80.0				19.8	11	C	181.8	146.9				
	E	96.7	32.2				5.0		D	195.4	149.3	206.6			
	F	440.7	21.0				6.0		E	306.7	93.2				
	G	80.0	70.0				19.8		F	92.0	194.9				
	H					63.8			G	312.8	89.6				
	I	91.7	77.6			69.3			a	265.1	88.1				
	J	187.5	78.6	139.7					c	158.8	173.2			93.2	
	K	120.6	204.0	22.6				12	B	471.7	93.9				
6	A	244.6	80.5						C	275.6	76.2				
	B	289.0	48.2						b	190.1	90.0				
	C	202.3	120.4				15.5		c	148.3	44.2				
	D	60.2	61.4				11.0	13	C	199.7	70.5				
	E	187.3	48.7				6.0		b	308.1	75.2	13.4			
	F	255.6	16.7				16.7								
	G	370.2	80.0				8.4	Mean		218.9	119.8	79.5	181.1	50.7	27.9
	H	204.2	136.1		20.3	55.2		Std. Dev.		166.0	112.3	70.6	429.2	31.2	54.8
	I	364.2	130.4			106.3		n		86	67	24	10	12	25
	J	139.7	27.2					C.V.(%)		76	94	89	237	62	196
	K	166.0	106.8	46.1				Max.		1415.1	924.3	277.1	1397.2	106.3	279.5
								Min.		36.1	12.9	11.9	4.8	0.0	0.0

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; M = Marl; C = Clay.

Table B-17b: Sediment double acid extractable (0.5N HCl+0.25N H2SO4) phosphorus at selected stations in Lake Apopka.
(Detection limit = 0.01 mg P/g)

Station		UCF	CF	P	S	C	M			UCF	CF	P	S	C	M
				mg/kg								mg/kg			
1	C	418.4		406.9				7	B	578.8	170.9				
2	A	503.2		193.8					C	464.2	260.2				
	B	365.7	315.4	223.6					D	370.2	299.2	386.3	152.5		143.4
	C	285.5							E	654.4	718.6				
	D	317.5			241.9				F	111.3	571.9				5.9
	E	97.5				81.5			G	1075.6	239.6			207.5	
	F	166.3		70					H	280.9				97.5	
	G	292.3		106.7					I	120.5				51.7	
	H			51.7					J	584.2		161.7			
3	A	294.6						8	C	428.8	235				
	B	555.1	486.1						D	739.2	418.4				51.7
	C	590.2							E	280.9	237.3				40.2
	D	372.5			40.2				F	253.4	258				118.2
	E	326.7			235				G	258					67.7
	F								H	299.2	280.9			74.6	
	G	342.7		235					I	283.2	315.2	120.5		51.7	
	H			51.7					J	660.7	223.6	79.2			
4	A	455	193.8					9	D	636.1	349.6				
	B	784.3	464.2						E	395.4	189.2				
	C	730	28.8						F	264.8	182.3				
	D	743.8	532.9				216.7		G	349.6	558.2				40.2
	E	441.3	303.8				47.1		H	574.2	237.3				258
	F	349.6	319.8	186.9		106.7			I	292.3	326.7	70			
	G	464.2	214.4	17.3				10	D	624.6	230.5				
	H	897.3		113.6					E	632.2	292.3	86.1			
	I	487.1				95.2			F	429.8	333.6	74.6			
5	A	471.1	514.6						G	482.5	303.8				
	B	1291.8	306.1				269.4		H	1000.5	363.4				
	C	739.2	727.7				315.2		I				1632.9		
	D	487.1	523.8				212.1	11	C	482.5	496.3				
	E	489.4	269.4				47.1		D	397.7	164	329			
	F	624.6	258				74.6		E	436.7	269.4				
	G	532.9	372.5				331.3		F	645.2	283.2				
	H	253.4	209.8			345			G	720.9	638.4				
	I	510	189.2			93			a	292.3	166.3				
	J	271.7	182.3	138.8		93			c	349.6	248.8				
	K	636.4	555.9	74.6				12	B	1099.3	212.1				
6	A	280.9	303.8						C	510	253.4				
	B	528.4	326.7						b	276.3	209.8				
	C	615	725.4				131.9		c	381.7	131.9				
	D	262.5	1082.9				97.5	13	C	1151.7	145.7				
	E	601.7	253.4				63.2		b	670.4	180	39.3			
	F	372.5	235				50.8								
	G	303.8	93				647.5	Mean		488.3	318.2	141.1	394.3	160.3	146.8
	H	607.4	109		63.2	532.9		Std. Dev.		230.5	180.7	110.7	612.6	141.7	150.2
	I	395.4	216.7			253.4		n		86	68	23	6	13	22
	J	532.9	143.4				0.74	C.V.(%)		47	57	78	155	88	102
	K	363.1	184.6	28.8				Max.		1291.8	1082.9	406.9	1632.9	532.9	647.5
								Min.		97.5	28.8	17.3	40.2	51.7	0.7

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; M = Marl; C = Clay.

Table B-17c. Concentration of selected cations in unconsolidated flocculent (UCF) sediment extracted with 0.025N H2SO4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		mg/kg							
1	C	NA	386	5186	4	46	5	0	56
2	A	22340	924	3028	2	8	1	0	22
	B	23200	498	1982	16	128	2.2	0	36
	C	27060	494	2576	18	172	1.6	0	52
	D	27860	446	2252	2	4	0	0	18.2
	E	NA	240	564	10	92	6.2	0.2	17
	F	26740	290	1510	0	6	0	0	34
	G	27420	520	3306	2	38	1.8	0	48
3	A	NA	570	1318	12	112	2.8	0	28
	B	25500	618	2274	6	62	1.6	0	32
	C	26500	552	1660	8	68	1.8	0	24
	D	32320	592	3140	2	4	0.4	0	26
	E	29600	386	1702	12	106	1.6	0	30
4	A	28660	782	2358	2	22	1	0	22
	B	26560	962	2290	2	2	0.2	0	22
	C	18428	818	3018	0	0	0	0	13.4
	D	30918	798	3102	6	30	9	19.8	42
	E	28506	762	2034	6	12	4.8	6.6	18
	F	26268	852	3138	6	12	2.4	2.4	18
	G	27216	774	2886	6	24	3	1.2	33
	H	25194	468	2892	6	12	0.6	0.6	35.4
	I	24378	378	1962	6	54	1.8	0.6	39
5	A	25880	46	126	0	6	0	0.2	2.2
	B	25326	1386	4758	90	594	18	1.2	96
	D	31040	668	1968	2	4	0	0.2	17.2
	E	29760	660	2788	2	4	0	0.2	17.8
	F	28206	810	2052	6	12	1.2	0	20.4
	G	32480	574	2784	2	4	0	0.2	9.4
	I	27340	944	3006	2	4	0	0.2	12.2
	J	26088	654	2220	6	30	4.2	7.2	36.6
	K	31908	1572	3234	6	12	4.2	1.8	28.2
6	A	28220	712	1856	2	6	0	0.4	17.8
	B	25860	1026	2682	2	4	0	0.4	8.6
	C	27140	1000	2496	2	6	0.2	0.2	18.4
	D	24240	476	2104	2	4	0	0.2	10.8
	E	25300	838	3262	2	6	0	0.2	24
	F	26860	908	2706	2	6	0	0.2	19.4
	G	25320	922	2440	12	14	1.6	0.4	22
	H	25640	1132	3366	2	4	0	0.2	9.8
	I	26380	1060	2298	4	30	2	0.2	32
	J	26780	654	2040	6	52	6.8	3	26
	K	20620	634	1716	24	156	8.2	5.2	42
7	B	27900	756	2052	8	102	5.6	0.4	44
	C	25740	846	2562	2	4	0	0.4	16.8
	D	27140	818	2548	2	26	1.4	0.4	32
	E	23980	1052	2854	2	4	0	0.2	11.4
	F	30000	294	748	2	4	0	0.2	10.6
	G	25660	1282	2478	4	22	2.2	0.4	30
	H	30320	518	1516	2	4	0	0.2	7.8
	I	NA	344	876	16	90	5	0.4	16.2
	J	27660	1190	3032	4	18	2.2	0.6	28

Table B-17c. Concentration of selected cations in unconsolidated flocculent (UCF) sediment extracted with 0.025N H2SO4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		----------------------	----------------------	----------------------	---------------------- mg/kg	----------------------	----------------------	----------------------	----------------------
8	C	NA	728	1952	6	72	3.8	0.4	40
	D	26860	1054	2464	2	8	1.2	0.2	28
	E	29500	498	2568	2	6	0.4	0.2	20
	F	31680	786	2776	2	4	0	0.2	17
	G	35560	416	2458	2	4	0	0.2	9.2
	H	NA	718	2052	2	12	1.6	0.2	26
	I	NA	708	2248	10	90	8	0.4	28
	J	33200	1006	1936	2	4	0.6	0.2	17.8
9	D	38100	780	2604	2	6	0	0.2	18
	E	26720	708	1946	2	18	1.8	0.2	28
	F	36860	558	1190	0	4	0	0.2	7.2
	G	31480	650	3052	2	4	0	0.2	17.8
	H	33060	764	2912	2	4	0	0.2	14.4
	I	NA	548	1616	2	10	3.4	0.2	24
10	D	31100	950	2656	2	4	0	0.2	16.6
	E	NA	850	2038	2	4	0.2	0.2	19.4
	F	26640	770	2100	2	4	0	0	9.8
	G	NA	762	2674	2	28	1.8	0	36
	H	31140	1174	2580	2	4	0	0.2	8.8
	I	37520	1214	2962	44	266	58	0.8	52
11	C	28840	454	1198	2	4	0.2	0.2	10.8
	D	32960	516	1706	2	4	0	0.2	16.8
	E	34000	970	2132	2	4	0	0.2	18.6
	F	33600	1022	2612	2	4	0	0.2	24
	G	33240	882	3012	2	6	0	0	28
	a	NA	536	2120	10	90	6.2	0.4	20
	c	26220	650	2128	2	4	0.6	0	22
12	B	29720	962	2284	6	48	1.8	0	34
	C	NA	656	2590	8	122	2.8	0.2	42
	b	28100	762	2578	12	72	2	0.2	38
	c	23840	464	1672	10	152	4.8	0.2	30
13	C	25200	726	2748	2	10	1.6	0.2	26
Mean		28290	736	2365	6	40	3	1	25
Std.Dev.		3741	269	760	11	78	7	2	14
n		71	83	83	83	83	83	83	83
C.V.(%)		13	36	32	183	195	263	321	55
Max.		38100	1572	5186	90	594	58	20	96
Min.		18428	46	126	0	0	0	0	2

Table B-17d. Concentration of selected cations in consolidated flocculent (CF) sediment extracted with 0.025N H_2SO_4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		mg/kg							
2	B	23980	544	2632	20.0	164.0	6.2	0.2	48.0
3	A	4030	184	242	36.0	80.0	1.0	0.0	9.2
	B	30480	236	2016	2.0	6.0	0.0	0.0	16.4
4	A	23840	330	1898	34.0	34.0	1.2	0.0	40.0
	B	23180	452	2046	10.0	10.0	3.0	0.0	36.0
	C	29700	324	1948	10.0	10.0	1.4	0.0	34.0
	D	36012	480	2178	24.0	12.0	8.4	9.0	17.4
	E	30174	450	2172	0.0	6.0	3.6	3.6	13.8
	F	28590	408	1974	12.0	102.0	2.4	1.8	33.6
	G	27258	408	2310	12.0	120.0	1.2	0.6	38.4
5	A	23180	422	2044	20.0	168.0	3.2	0.2	40.0
	B	17736	408	1446	42.0	210.0	2.4	0.0	31.2
	C	26040	382	1782	2.0	4.0	0.0	0.2	14.0
	D	31180	478	2410	2.0	4.0	0.0	0.2	8.8
	E	30558	408	1698	6.0	12.0	0.6	0.6	9.6
	F	30186	396	1458	0.0	6.0	0.6	0.0	6.6
	G	33036	354	1896	6.0	24.0	2.4	0.0	25.8
	I	NA	276	1140	6.0	36.0	12.0	19.2	11.4
	J	16590	408	1992	30.0	162.0	3.6	3.0	42.6
	K	NA	372	3744	42.0	282.0	1.8	1.2	84.0
6	A	35560	418	2620	2.0	8.0	0.2	0.4	26.0
	B	30660	334	1372	2.0	4.0	0.0	0.2	10.4
	C	28540	374	1644	2.0	4.0	0.0	0.2	8.0
	D	28040	380	1996	2.0	4.0	0.0	0.2	11.6
	E	32940	378	1916	2.0	6.0	0.2	0.2	12.8
	F	33680	380	2462	30.0	158.0	3.2	0.2	34.0
	G	30160	480	2260	2.0	6.0	0.0	0.2	18.0
	H	29060	426	2220	2.0	34.0	2.0	0.2	36.0
	I	28340	374	1698	2.0	6.0	0.2	0.2	30.0
	J	29160	328	1350	2.0	4.0	1.0	1.6	22.0
	K	17242	438	1622	30.0	178.0	4.2	4.6	40.0
7	B	25160	394	1302	36.0	172.0	2.4	0.6	34.0
	C	27800	316	1196	2.0	4.0	0.0	0.2	17.6
	D	25500	348	1514	30.0	116.0	1.8	0.4	30.0
	E	29180	520	1906	2.0	4.0	0.0	0.4	5.2
	G	28400	602	2132	2.0	6.0	0.4	0.4	24.0
	J	20320	480	2194	48.0	246.0	3.6	0.4	44.0
8	C	19356	428	1928	388.0	854.0	6.6	0.6	62.0
	D	27740	282	1730	2.0	4.0	0.0	0.2	7.4
	E	36600	316	2328	2.0	4.0	0.0	0.6	22.0
	F	43400	336	1592	2.0	4.0	0.0	0.2	11.6
	H	29700	374	1888	26.0	138.0	4.6	1.4	44.0
	I	NA	460	2214	40.0	264.0	5.4	1.0	36.0
	J	17160	292	2448	396.0	628.0	9.2	2.0	30.0
9	D	43760	332	1632	28.0	190.0	4.6	0.4	40.0
	E	16820	280	1462	46.0	186.0	3.8	1.0	34.0
	F	20480	284	1368	78.0	226.0	3.8	0.8	34.0
	G	28960	282	3888	2.0	4.0	0.4	0.2	22.0
	H	33940	326	2496	16.0	104.0	2.0	0.4	20.0
	I	30640	394	2616	330.0	822.0	4.6	0.8	56.0
10	D	10704	278	1418	54.0	152.0	2.2	0.8	32.0
	E	NA	356	1688	30.0	178.0	2.4	0.2	28.0

Table B-17d. Concentration of selected cations in consolidated flocculent (CF) sediment extracted with 0.025N H_2SO_4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		-------------------------------			mg/kg	---------------------------			
10	F	36220	398	1776	30.0	158.0	2.2	0.2	32.0
	G	15742	270	1038	40.0	188.0	1.6	0.2	30.0
	H	25700	346	1612	44.0	194.0	3.8	0.2	32.0
	I	NA	550	2270	106.0	586.0	192.0	4.2	58.0
11	C	13164	274	1062	66.0	210.0	3.8	0.4	28.0
	D	NA	186	638	88.0	298.0	3.2	0.2	8.4
	E	12528	288	1034	48.0	170.0	2.6	0.4	28.0
	F	NA	330	1374	28.0	128.0	5.0	0.4	32.0
	G	10440	232	1132	58.0	188.0	3.4	0.4	26.0
	a	10380	282	1808	112.0	358.0	3.4	0.2	14.4
	c	17978	206	1814	62.0	344.0	8.0	0.4	7.0
12	B	9990	248	1278	82.0	246.0	3.4	0.2	19.2
	C	12050	294	1062	72.0	240.0	3.6	0.2	20.0
	b	NA	446	1898	2.0	4.0	0.0	0.2	8.0
	c	12044	230	1244	76.0	272.0	3.2	0.4	13.0
13	C	12056	280	1530	76.0	210.0	5.0	0.6	26.0
Mean		24884	361	1819	43.3	146.5	5.4	1.0	26.8
Std.Dev.		8683	88	592	76.1	178.0	22.9	2.6	15.0
n		60	68	68	68	68	68	68	68
C.V.(%)		35	24	33	176	121	424	254	56
Max.		43760	602	3888	396.0	854.0	192.0	19.2	84.0
Min.		4030	184	242	0.0	4.0	0.0	0.0	5.2

Table B-17e. Concentration of selected cations in the peat sediment extracted with 0.025N H_2SO_4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		mg/kg							
1	C	22800	534	3242	4.0	54.0	5.8	0.2	28.0
2	A	13950	480	1956	6.0	82.0	1.0	0.0	36.0
	C	29420	186	396	0.0	4.0	0.0	0.0	10.6
	F	21020	362	3318	8.0	140.0	0.8	0.0	62.0
	G	18536	334	2214	18.0	90.0	1.6	0.0	58.0
	H	23880	492	4176	20.0	294.0	3.8	0.2	96.0
3	H	NA	576	4206	20.0	520.0	1.2	0.0	24.0
4	F	19488	402	1788	102.0	318.0	6.0	3.0	48.6
	G	NA	432	2898	186.0	144.0	4.2	1.2	66.0
	H	NA	474	3330	90.0	114.0	1.2	0.6	84.0
5	J	23370	402	3450	324.0	636.0	4.8	2.4	84.0
	K	10404	432	3060	156.0	144.0	2.4	0.6	60.0
6	K	16706	398	1872	180.0	132.0	5.0	2.4	50.0
7	D	33060	248	1282	2.0	6.0	0.4	0.2	18.0
	J	NA	390	2106	328.0	276.0	3.2	0.4	42.0
8	I	NA	314	3138	166.0	160.0	1.8	0.6	56.0
	J	NA	264	2372	378.0	1660.0	2.2	1.0	18.4
9	I	13634	248	1500	206.0	162.0	2.4	0.8	14.4
10	E	NA	360	1622	34.0	48.0	2.4	0.2	20.0
	F	NA	354	2104	150.0	148.0	3.2	0.4	32.0
11	D	7610	188	678	64.0	202.0	2.2	0.4	4.0
13	b	9812	226	1550	230.0	444.0	3.4	0.4	14.2
Mean		18835	368	2375	121.5	262.6	2.7	0.7	42.1
Std.Dev.		7148	107	1013	115.3	343.8	1.7	0.8	25.7
n		14	22	22	22	22	22	22	22
C.V.(%)		38	29	43	95	131	62	122	61
Max.		33060	576	4206	378.0	1660.0	6.0	3.0	96.0
Min.		7610	186	396	0.0	4.0	0.0	0.0	4.0

Table B-17f. Concentration of selected cations in the sand sediment extracted with 0.025N H2SO4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		mg/kg							
2	D	28520	182	366	0.0	4.0	0.0	0.0	11.0
3	D	30420	182	1612	2.0	4.0	0.0	0.0	42.0
	E	29060	232	812	0.0	4.0	0.0	0.0	22.0
6	H	32680	230	378	0.0	4.0	0.0	0.2	5.0
7	D	33280	226	1452	2.0	6.0	0.0	0.4	28.0
Mean		30792	210	924	1	4	0	0	22
Std.Dev.		1900	23	524	1	1	0	0	13
n		5	5	5	5	5	5	5	5
C.V.(%)		6	11	57	122	18	NA	133	60
Max.		33280	232	1612	2	6	0	0	42
Min.		28520	182	366	0	4	0	0	5

Table B-17g. Concentration of selected cations in the clay sediment extracted with 0.025N H_2SO_4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		mg/kg							
2	E	10936	586	1906	44.0	324.0	1.0	0.4	26.0
4	F	29970	372	870	6.0	12.0	1.8	1.8	15.6
	I	NA	552	2676	36.0	330.0	1.8	0.0	30.0
5	H	29082	282	2832	0.0	6.0	0.0	0.0	22.8
	I	9300	378	1626	42.0	198.0	5.4	7.2	25.8
	J	NA	372	1902	36.0	216.0	1.8	1.8	44.4
6	H	11902	296	1966	30.0	306.0	0.6	0.6	28.0
	I	NA	314	2298	12.0	176.0	15.0	0.6	50.0
7	G	24800	388	1642	2.0	6.0	0.4	0.2	12.2
	H	28340	442	1776	2.0	4.0	0.0	0.2	14.0
	I	13944	444	2522	30.0	212.0	0.8	0.8	22.0
8	H	NA	286	1636	42.0	368.0	1.4	2.2	15.8
	I	3382	206	372	146.0	128.0	2.0	0.6	7.4
Mean		17962	378	1848	32.9	175.8	2.5	1.3	24.2
Std.Dev.		9499	104	657	36.4	129.9	3.9	1.8	11.8
n		9	13	13	13	13	13	13	13
C.V.(%)		53	27	36	111	74	157	147	49
Max.		29970	586	2832	146.0	368.0	15.0	7.2	50.0
Min.		3382	206	372	0.0	4.0	0.0	0.0	7.4

Table B-17h. Concentration of selected cations in the marl sediment extracted with 0.025N H2SO4+0.05N HCl.

Station		Ca	K	Mg	Fe	Al	Zn	Cu	Mn
		mg/kg							
4	D	29352	210	1422	6.0	12.0	15.0	29.4	44.4
	E	29970	210	1608	6.0	6.0	2.4	4.2	66.0
5	B	30480	180	276	6.0	12.0	5.4	0.0	4.8
	C	27840	832	2056	2.0	4.0	0.0	0.2	16.2
	D	31540	312	1668	2.0	4.0	0.0	0.2	11.6
	E	32010	234	1698	6.0	6.0	2.4	0.6	66.0
	F	33360	238	1760	2.0	4.0	0.0	0.2	62.0
	G	34554	276	1716	0.0	6.0	0.0	0.0	25.8
6	C	30620	224	1318	2.0	4.0	0.0	0.2	18.4
	D	28000	196	1404	2.0	4.0	0.0	0.0	26.0
	E	30040	198	1070	2.0	4.0	0.0	0.2	12.0
	F	29120	234	1498	2.0	6.0	0.0	0.2	13.6
	G	29440	196	808	0.0	4.0	0.8	0.0	18.2
	J	30080	298	1224	2.0	8.0	0.2	1.0	11.2
7	D	35800	232	602	2.0	4.0	0.0	0.4	15.2
	F	31200	314	1424	2.0	6.0	0.0	0.2	7.4
8	D	30700	232	1686	2.0	6.0	0.0	0.2	2.0
	E	35240	210	1872	2.0	4.0	0.0	0.2	24.0
	F	39220	188	806	0.0	4.0	0.0	0.2	11.6
	G	39440	200	640	0.0	4.0	0.0	0.2	7.4
9	G	33680	180	2040	2.0	4.0	0.0	0.2	5.4
	H	16558	260	2294	46.0	248.0	3.6	1.2	18.2
Mean		31284	257	1404	4.4	16.5	1.4	1.8	22.2
Std.Dev.		4494	131	510	9.3	50.6	3.3	6.1	19.1
n		22	22	22	22	22	22	22	22
C.V.(%)		14	51	36	213	306	243	342	86
Max.		39440	832	2294	46.0	248.0	15.0	29.4	66.0
Min.		16558	180	276	0.0	4.0	0.0	0.0	2.0

Table B-18: Volatile solids of sediment samples collected from selected stations in Lake Apopka.

Station		UCF	CF	P	S	C	M	Station		UCF	CF	P	S	C	M
				%									%		
1	C	81.55		76.28				7	B	59.97	68.14				
2	A	68.37		91.80					C	60.54	62.92				
	B	70.54	71.68						D	61.70	66.29	55.94	28.50		15.09
	C	68.97		17.25					E	59.46	51.99				33.38
	D	59.00			7.76				F	3.79					8.53
	E	6.50							G	63.31	33.81			6.20	
	F	21.10		73.88					H	11.31				5.27	
	G	62.47		87.27					I	4.23				4.48	
	H			88.34	29.90				J	65.34	68.78	78.98			
3	A	39.24			5.98			8	C	57.18	67.85				
	B	68.17	52.26						D	62.35	44.85				12.17
	C	64.18					28.83		E	52.19	51.53				18.83
	D	61.65			10.08				F	56.72	47.76				12.16
	E	55.01			9.88				G	43.04					6.71
	F								H	40.41	54.90			5.64	
	G	57.76		90.69					I	38.12	27.62	64.54		3.73	
	H			85.09	30.09				J	64.61	70.11	66.46			
4	A	65.13	61.09					9	D	59.47	63.90				
	B	63.05	65.75						E	63.44	71.96				
	C	57.80	66.90						F	44.61	71.00				
	D	45.61	50.35				9.73		G	56.29	56.11				16.58
	E	51.85	50.03				7.98		H	59.77	63.73				6.03
	F	56.97	64.08	39.77		8.97			I	46.94	67.31	80.56			
	G	59.32	67.73	90.82				10	D	62.81	60.67				
	H	40.59		80.08					E	61.72	65.65	90.42			
	I	16.73				1.94			F	56.95	67.37	93.11			
5	A	61.55	67.39						G	57.99	81.98				
	B	64.43	66.96				5.99		H	62.76	66.49				
	C	61.47	53.07				41.18		I	39.64	33.37		6.78		
	D	60.43	52.24				38.61	11	C	62.90	56.20				
	E	59.98	65.32				11.50		D	41.66	12.92	17.79			
	F	62.11	47.28				13.68		E	54.51	67.08				
	G	53.49	63.34				37.68		F	64.17	62.11				
	H	61.56	38.28			10.18			G	53.75	83.98				
	I	59.79	35.93			5.26			a	71.68	76.96				
	J	62.14	70.17	74.32		9.62			c	60.21	50.28				
	K	63.04	65.15	93.98				12	B	65.42	72.37				
6	A	59.04	67.74						C	61.02	73.15				
	B	59.65	56.36						b	64.02	67.94				
	C	62.10	48.83						c	60.68	58.41				
	D	30.76	44.72			12.45	26.21	13	C	58.30	65.75				
	E	58.80	61.87				17.34		b	64.02	61.91	86.11			
	F	57.68	65.16				17.45								
	G	57.03	58.87				16.74	Mean		54.68	58.98	72.90	11.40	16.29	28.83
	H	63.45	56.25		5.42		4.74	St.Dev.		14.58	14.19	24.13	8.57	10.87	
	I	60.75	19.17			23.72	8.40	n		85	65	19	6	21	1
	J	47.80	32.88					C.V.(%)		27	24	33	75	67	
	K	63.10	68.49	85.52			13.94	Max.		71.68	86.15	93.98	28.5	41.18	28.83
								Min.		3.79	12.92	17.25	5.42	4.74	28.83

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-19: Total and inorganic carbon concentration of sediment at selected stations in Lake Apopka.
(Sensitivity > 0.1 ug C. Sample range 5 - 7000 ug C)

Station		Total Carbon						Total Inorganic Carbon					
		UCF	CF	P	C	S	M	UCF	CF	P	C	S	M
		%						%					
1	C	48.41		36.18				0.32		0.24			
2	A	37.25		51.02				1.19		0.04			
	B	39.57	39.68					0.26	0.29				
	C	39.73				6.65		0.17				3.97	
	D	32.48						1.35					
	E	3.09			4.15			0.22			0.01		
	F	9.64		46.89				0.37		0			
	G	34.28		46.42				0.62		0			
	H			49.87						0.12			
3	A	17.79	3.58					0.19	0				
	B	37.98	26.1					0.54	1.99				
	C	34.9						1.16					
	D	38.07				13.18		0.96				10.54	
	E	27.25				3.73		0.84				1.27	
	G	27.44		41.81				0.68		0.02			
	H			44.22						0.07			
4	A	35.41	39.81					0.65	0.34				
	B	34.81	36.18					1.14	0.71				
	C	31.77	39.21					1.53	0.53				
	D	30.98	29.43				13.49	1.68	3.33				10.5
	E	26.88	26.46				11.33	3.38	4.11				8.61
	F	31.82	35.9	24.64	5.4			1.04	0.55	1.64	3.06		
	G	33.58	37.78	50.99				1.07	0.48	0			
	H	23.86		47.65				0.85		0			
	I	13.74			3.11			0.54			0.01		
5	A	32.94	38.09					1.06	0.37				
	B	33.94	31.93				2.45	0.99	0.16				0.8
	C	32.31	31.93				24.57	1.67	1.84				4.08
	D	32.42	29.45				30.54	1.92	2.24				3.01
	E	39.76	26.59				12.93	0.17	5.95				10.03
	F	32.26	29.36					2.02	3.89				
	G	29.43	34.78				21.44	3.24	1.06				4.29
	H	32.04	23.33		3.2			0.77	1.1		0.49		
	I	32.18	4.38		2.55			0.68	0.53		0.01		
	J	34.04	42.87	30.83	5.48			0.74	0.1	0.01	0		
	K	32.94	34.78	53.6				2.09	0.67	0			
6	A	33.01	38.15					1.23	0.07				
	B	32.65	32.67					1.46	1.66				
	C	33.51	36.66				19.13	1.19	0.99				6.07
	D	31.28	23.8				13.5	3.37	2.68				6.6
	E	33.3	34.85				15.8	1.53	2.13				8.2
	F	33.92	38.37				15.64	1.41	1.01				7.06
	G	34.26	31.83				4.59	1.23	1.59				2.72
	H	31.57	29.39		2.37	2.3		1.19	1.15		0.12	1.02	
	I	34.83	29.62		12.47			1.05	1.1		0.13		
	J	34.53	29.62			3.48		0.99	0.46			0.58	
	K	34.51	36.93	47.93				0.93	0.27	0.02			

Table B-19: Total and inorganic carbon concentration of dried sediment at selected stations in Lake Apopka. (Sensitivity > 0.1 ug C. Sample range 5 - 7000 ug C)

Station		Total Carbon						Total Inorganic Carbon					
		UCF	CF	P	C	S	M	UCF	CF	P	C	S	M
		%						%					
7	B	33.91	40.03					0.51	0.24				
	C	34.81	34.4					1.09	1.59				
	D	35.48	35.46	33.26		18.27	14.97	0.79	0.61	1.71		5.25	8.03
	E	33.37	29.69					1.29	2.19				
	F	3.19					9.37	1.85					8.37
	G	33.64	17.11		2.03			1.23	1.02		0.69		
	H	4.64			3.16			1.48			1.49		
	I	2.5			1.3			0.36			0.27		
	J	33.48	39.69	43.53				0.6	0.09	0.01			
8	C	29.85	36.96					0.41	0.02				
	D	34.85	29.06				11.39	0.96	2.04				6.56
	E	29.11	28.82				13.94	1.78	2.21				8.8
	F	33.02	29.65				11.43	0.92	1.53				6.15
	G	25.19						2.06					
	H	20.74	31.43		2.03			0.8	0.53		0.04		
	I	17.43	15.38	31.32				0.39	0.04	0.01			
	J	33.97	35.81	25.96				1.28	0.02	0.02			
9	D	32.83	34.28					1.31	0.71				
	E	35.38	38.38					0.84	0.03				
	F	29.76	40.79					3.58	0.03				
	G	31.45	41.48					2.07	0.08				
	H	29.73	32.59				2.93	2.77	0.14				0.15
	I	21.18	36.8	41.53				0.71	0.01	0			
10	D	32.81	32.22					0.95	0.01				
	E	32.29	37.95	46.25				1.58	0.66	2.68			
	F	30.84	36.79	54.09				1.97	1.05	0			
	G	29.42	40.46					1.04	0.26				
	H	32.46	36.17					1.5	0.16				
	I	18.65				2.86		1.35				0.06	
11	C	33.04	26.42					1.51	0				
	D	21.51	9.57	10.44				0.64	0.01	0.01			
	E	27.06	39					1.06	1.71				
	F	33.81	33.23					1.01	0.01				
	G	29.42	29.72					1.19	0.54				
	a	39.22	41.36					0.32	0.03				
	c	31.14	28.54					1.03	0.01				
12	B	36.12	40.79					0.57	0.01				
	C	28.9	38.57					0.97	0.01				
	b		33.51						0				
	c	31.67	34.65					0.58	0.01				
13	C	31.6	37.88					0.43	0.01				
	b	31.69	34.64					0.91	0				
Mean		30.16	32.50	40.88	3.94	7.21	13.86	1.16	0.88	0.31	0.53	3.24	6.11
Std. Dev.		8.26	7.97	11.22	2.98	6.16	7.12	0.72	1.15	0.73	0.91	3.74	3.02
n		86	69	21	12	7	18	86	69	21	12	7	18
C.V.(%)		27	25	27	76	85	51	62	130	234	172	115	49
Max.		48.41	42.87	54.09	12.47	18.27	30.54	3.58	5.95	2.68	3.06	10.54	10.50
Min.		2.50	3.58	10.44	1.30	2.30	2.45	0.17	ND	ND	ND	0.06	0.15

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl; ND = Not Detected.

Table B-20: Total nitrogen and phosphorus content (dry wt. basis) of sediment samples collected from selected stations in Lake Apopka.(Det. lim. = 0.035 mg N/g, 0.02 mg P/g)

Station		Total Nitrogen						Total Phosphorus					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/g											
1	C	23.05		34.81				0.12		1.03			
2	A	22.76		32.92				1.19		0.47			
	B	22.44	22.93					0.71	0.74				
	C	22.23		11.44				0.37		0.56			
	D	20.69			6.01			0.36			0.24		
	E	2.25				6.76		0.14				0.66	
	F	9.69		22.47		5.11		0.19		0.20		0.68	
	G	22.63		30.60				0.58		0.32			
	H			21.72	15.31					0.23	0.43		
3	A	18.98						0.64	1.02				
	B	33.45	20.23					0.77					
	C	22.18					15.39	0.98					1.41
	D	21.62			5.69			0.63			0.24		
	E	20.24			6.87			0.64			0.37		
	F												
	G	21.17		33.79				0.67		0.38			
	H			33.93	6.49					0.22	0.52		
4	A	34.69	23.86					1.16	0.67				
	B	21.48	20.34				19.04	1.66	1.01				0.72
	C	19.61	23.41					1.32	0.63			0.37	
	D	22.55	21.53				5.45	1.84	0.68				0.25
	E	21.46	20.35				6.02	0.89	0.91				1.49
	F	21.38	21.27	18.99		5.11		0.88	0.54	0.48			
	G	22.08	23.45	23.56				1.03	0.41	1.04			
	H	17.39		24.29				0.93		0.43			
	I	8.68				5.93		1.42				0.50	
5	A	33.56	24.66					1.20	0.65				
	B	30.28	23.90				5.37		0.20				0.25
	C	21.95	19.86				16.76	0.10	0.11				0.98
	D	22.12	20.54				18.96	1.05	0.95				0.45
	E	32.83	24.14				6.91	0.84	0.64				0.22
	F	22.27	20.16				6.49	1.33	0.62				0.19
	G	19.62	22.91				17.73	0.68	0.21				0.40
	H	22.06	18.84			6.13		0.40	0.30			0.38	
	I	21.66	3.19			5.78		1.11	0.21			0.17	
	J	20.97	23.93	22.90		7.05		0.72	0.44	0.56		0.13	
	K	33.56	23.30	30.69				1.53	0.52	0.21			
6	A	22.67	23.58					0.87	0.52				
	B	22.67	22.56					0.92	0.58				
	C	32.29	21.94				14.77	1.17	0.66				0.44
	D	14.51	21.07			7.05	8.78	0.94	0.64			0.41	0.36
	E	22.32	23.78				12.24	1.07	0.46				0.31
	F	21.32	24.81				10.63	0.69	0.46				0.30
	G	21.75	22.14				4.33	0.86	0.66				0.29
	H	33.10	21.96		0.01	1.55		1.58	0.77		0.06	0.14	
	I	31.26	21.93			10.64		1.14	0.64			0.16	
	J	19.86	13.54				0.01	0.35	0.28		0.20		0.19
	K	32.87	21.94	37.58	0.01			1.36	0.57	0.24			

Table B-20: Total nitrogen and phosphorus content (dry wt. basis) of sediment samples collected from selected stations in Lake Apopka. (Det. lim. = 0.035 mg N/g, 0.02 mg P/g)

Station		Total Nitrogen						Total Phosphorus					
		UCF	CF	P	S	C	M	UCF	CF	P	S	C	M
		mg/g											
7	B	21.96	24.00					0.90	0.58				
	C	32.38	21.53					1.00	0.46				
	D	32.64	24.00	21.46	11.09		5.11	0.93	0.65	0.44	0.35		0.60
	E	33.52	21.45				12.96	1.69	1.25				0.63
	F	1.35					11.33	0.20					0.10
	G	34.24	15.51			0.96		1.52	1.09			0.24	
	H	3.34				0.01		0.41				0.15	
	I	3.08				0.01		0.50				0.12	
	J	31.53	33.92	34.31				1.12	0.48	0.16			
8	C	22.58	27.20					0.97	0.52				
	D	33.85	19.57				4.51	1.35	1.15				0.20
	E	19.67	18.57				8.84	0.51	0.45				0.39
	F	21.03	18.83				4.46	0.89	0.51				0.44
	G	18.08					0.95	0.57					0.28
	H	18.44	21.93			0.43		0.61	0.62			0.14	
	I	17.42	20.76	20.83		0.45		0.69	0.42	0.18		0.05	
	J	34.71	27.00	20.66				1.52	0.56	0.21			
9	D	22.71	32.75					1.36	0.62				
	E	27.10	22.41					1.00	0.40				0.40
	F	26.42	22.59					1.11	0.37				
	G	28.43	20.48				0.93	0.76	0.86				0.21
	H	20.87	21.73				0.91	1.17	0.43				0.25
	I	30.79	26.40	21.84				0.93	0.72	0.23			
10	D	30.99	21.79					1.25	0.35				
	E	30.40	20.95	37.63				0.44	0.70	0.29			
	F	27.30	22.15	23.26				1.12	0.54	0.21			
	G	29.62	21.54					1.01	0.57				
	H	30.70	33.68					1.76	0.55				
	I	21.65	17.60		2.49			2.26	2.91		1.36		
11	C	30.83	20.59					1.01	0.45				
	D	18.14	20.78	6.25				0.70	0.27	0.33			
	E	23.57	23.34					1.11	0.49				
	F	22.62	22.11					1.36	0.42				
	G	20.58	22.50					1.44	1.06				
	a	33.58	35.19					0.87	0.39				
	c	21.32	24.60					0.90	0.52				
12	B	34.16	23.36					1.92	0.44				
	C	22.29	23.46					0.88	0.39				
	b	22.11	23.50					0.86	0.38				
	c	22.16	21.75					0.88	0.29				
13	C	20.81	21.81					1.54	0.34				
	b	33.83	21.43	34.81				1.60	0.30	0.22			
Mean		23.69	22.39	26.12	6.00	4.20	8.76	0.97	0.60	0.38	0.42	0.29	0.45
Std. Dev.		7.51	4.29	8.28	4.97	3.34	5.93	0.43	0.37	0.24	0.38	0.20	0.35
n		87	69	23	9	15	25	86	69	23	9	15	26
C.V.(%)		32	19	32	83	80	68	45	61	64	90	71	78
Max.		34.71	35.19	37.63	15.31	10.64	19.04	2.26	2.91	1.04	1.36	0.68	1.49
Min.		1.35	3.19	6.25	0.01	0.01	0.01	0.10	0.11	0.16	0.06	0.05	0.10

UCF = Unconsolidated Flocculent; CF = Consolidated Flocculent; P = Peat; S = Sand; C = Clay; M = Marl.

Table B-21

Concentration of major cations in unconsolidated flocculent (UCF) sediment at selected stations in Lake Apopka. Analyses performed after perchloric acid digestion of dried sediment.

Station		K	Ca	Mg	Fe	Mn	Cu	Al	Station		K	Ca	Mg	Fe	Mn	Cu	Al
		------------------			mg/g			------------------			------------------			mg/g			------------------
1	C	3.28	9.6	6.36	14.84	0.09	0.02	32.32	7	B	1.17	30.3	4.44	5.84	0.08	0.02	10.60
2	A	0.96	55.9	4.91	4.82	0.11	0.04	9.68		C	1.25	46.8	5.29	6.63	0.10	0.02	11.69
	B	0.82	30.4	4.58	6.17	0.08	0.09	10.17		D	1.10	41.6	4.95	6.15	0.10	0.03	10.55
	C	0.87	32.4	4.58	6.94	0.09	0.01	10.74		E	1.14	50.0	5.33	5.23	0.10	0.03	9.23
	D	0.69	52.0	3.73	5.54	0.08	0.01	7.84		F	0.28	55.6	0.98	0.79	0.02	0.01	0.93
	E	0.39	11.7	0.58	1.11	0.02	0.01	1.54		G	0.85	59.5	4.85	4.85	0.08	0.03	9.15
	G	0.70	54.7	4.40	5.19	0.13	0.01	6.97		H	0.55	63.4	3.54	4.55	0.06	0.01	8.46
3	A	0.68	25.0	2.91	4.17	0.06	0.01	7.27		I	0.51	14.0	0.98	1.40	0.02	0.01	2.37
	B	0.89	33.0	4.64	6.67	0.08	0.02	11.36		J	1.26	29.3	4.47	5.83	0.09	0.02	10.40
	C	0.97	60.1	5.14	6.54	0.09	0.01	11.29	8	C	1.07	22.8	4.35	5.28	0.09	0.03	9.63
	D	0.89	65.6	5.58	7.06	0.10	0.01	10.96		D	1.24	52.0	5.00	5.10	0.10	0.02	9.66
	E	0.75	52.0	4.25	7.15	0.08	0.02	10.65		E	0.83	102.7	6.95	7.63	0.15	0.02	12.48
	G	0.84	40.0	4.60	6.33	0.10	0.01	9.05		F	1.13	54.6	4.99	7.34	0.12	0.04	10.68
4	A	1.08	34.1	4.75	5.63	0.09	0.02	10.37		G	0.68	86.1	3.57	5.14	0.07	0.01	6.31
	B	1.23	41.0	5.51	5.02	0.10	0.02	10.53		H	0.83	27.0	2.98	3.67	0.06	0.07	6.65
	C	0.88	63.7	4.43	5.79	0.09	0.01	8.27		I	0.74	23.0	2.85	4.12	0.06	0.02	7.16
	D	1.20	62.5	5.40	5.00	0.11	0.02	9.50		J	1.09	34.7	3.62	4.23	0.08	0.03	8.09
	E	1.16	117.8	5.68	6.19	0.13	0.02	10.71	9	D	1.10	57.0	5.15	5.55	0.11	0.31	10.35
	F	1.00	50.32	4.75	6.27	0.09	0.02	10.04		E	1.07	41.7	4.74	6.74	0.09	1.17	11.28
	G	0.69	55.5	4.44	5.22	0.13	0.01	7.07		F	1.00	116.0	3.85	5.20	0.09	0.03	8.25
	H	0.39	64.0	2.39	2.49	0.09	0.01	2.59		G	1.00	57.8	4.92	6.12	0.09	0.03	9.37
	I	1.68	80.1	9.55	8.70	0.19	0.02	23.79		H	1.18	74.0	5.39	6.27	0.10	0.03	10.78
5	A	1.17	34.6	4.65	5.40	0.09	0.03	10.34		I	0.73	32.0	2.40	4.31	0.06	0.03	7.44
	D	1.05	64.5	5.30	6.05	0.10	0.02	9.95	10	D	1.17	44.9	4.55	5.18	0.09	0.03	9.63
	E	0.91	66.3	4.42	5.38	0.09	0.02	9.17		E	0.93	29.6	2.89	3.24	0.06	0.02	6.08
	F	1.10	60.0	4.90	5.25	0.11	0.03	9.35		F	1.07	63.8	4.29	5.41	0.09	0.03	8.85
	G	0.75	112.0	4.35	5.05	0.11	0.02	7.00		G	0.88	18.6	3.97	7.06	0.07	0.02	11.42
	H	0.85	29.5	4.65	5.60	0.09	0.02	9.20		H	1.46	59.3	5.15	4.86	0.10	0.03	9.62
	I	0.90	44.8	4.75	5.75	0.10	0.03	9.25		I	1.62	37.3	4.12	5.47	0.09	0.08	28.36
	J	1.05	43.3	4.70	5.55	0.12	0.02	9.25	11	C	0.85	47.5	3.20	5.65	0.06	0.03	9.35
	K	1.15	63.0	4.45	3.65	0.10	0.02	7.00		D	0.72	31.5	2.35	3.79	0.06	0.03	6.82
	A	0.95	48.5	4.60	5.65	0.09	0.02	10.05		E	1.20	37.3	3.88	4.64	0.08	0.03	8.33
6	B	1.10	45.7	4.95	5.75	0.09	0.02	10.05		F	1.30	48.0	4.90	5.70	0.11	2.55	9.95
	C	1.13	39.9	5.13	5.72	0.10	0.02	10.90		G	1.55	48.9	4.70	4.95	0.10	0.04	9.10
	D	0.64	194.7	3.85	4.74	0.08	0.01	6.57		a	0.95	18.5	3.25	4.75	0.05	0.04	8.20
	E	1.02	72.5	5.01	5.50	0.09	0.02	9.54		c	0.95	41.3	3.80	5.70	0.07	0.02	9.65
	F	0.84	62.8	4.40	5.04	0.08	0.02	8.70	12	B	1.15	22.9	3.80	4.30	0.08	0.04	7.95
	G	0.87	78.7	4.88	5.93	0.08	0.02	9.71		C	1.04	31.1	3.81	3.44	0.07	0.02	9.37
	H	1.25	52.5	5.00	5.35	0.11	0.06	9.50		b	1.03	47.4	4.73	5.67	0.08	0.13	9.31
	I	1.14	45.1	4.95	5.19	0.10	0.03	9.66		c	0.90	37.6	3.85	4.70	0.07	0.03	10.65
	J	0.84	39.5	3.69	4.20	0.07	0.01	8.40	13	C	1.00	31.3	3.80	5.45	0.08	0.05	9.05
	K	1.25	40.9	4.75	4.70	0.10	0.05	8.90		b	1.07	41.0	4.20	4.35	0.09	0.02	8.98
Detection Limits		0.05	0.05	0.05	0.05	0.005	0.005	0.05	Mean		1.01	50.47	4.37	5.36	0.09	0.07	9.61
									Std.Dev.		0.35	26.68	1.21	1.66	0.02	0.30	4.20
									n		84	84	84	84	84	84	84
									C.V.(%)		35.2	52.9	27.6	30.9	27.8	409.2	43.7
									Max.		3.28	194.66	9.55	14.84	0.19	2.55	32.32
									Min.		0.28	9.59	0.58	0.79	0.02	0.01	0.93

Table B-22

Concentration of major cations in the consolidated flocculent (CF) sediment at selected stations in Lake Apopka. Analyses performed after perchloric acid digestion of dried sediment.

Station		K	Ca	Mg	Fe	Mn	Cu	Al
		mg/g						
2	B	0.96	24.4	4.18	3.99	0.08	0.03	9.28
3	B	0.87	90.2	5.63	6.26	0.09	0.01	12.95
4	A	1.05	34.5	4.90	5.25	0.09	0.02	11.65
	B	1.25	41.0	5.33	5.86	0.10	0.02	12.44
	C	0.87	52.0	5.20	7.56	0.10	0.01	11.13
	D	0.85	105.0	4.30	4.95	0.08	0.02	7.70
	E	0.78	141.1	4.64	4.74	0.11	0.01	6.88
	G	0.90	38.0	4.20	5.95	0.09	0.02	8.90
5	A	1.12	40.0	4.97	7.11	0.09	0.02	12.32
	B	0.97	31.0	4.21	6.82	0.07	0.02	11.08
	C	0.70	118.0	4.30	5.50	0.09	0.02	8.25
	D	0.90	105.0	4.85	6.50	0.10	0.02	9.65
	E	0.50	167.0	3.40	4.60	0.09	0.01	7.30
	F	0.48	163.7	3.14	4.33	0.06	0.01	6.47
	G	0.58	64.5	4.41	6.16	0.09	0.01	9.31
	H	0.43	92.0	4.41	3.61	0.06	0.01	5.50
	I	0.70	29.3	2.66	2.99	0.06	0.02	6.95
	J	0.65	29.6	4.40	5.90	0.09	0.01	9.60
	K	0.54	23.7	3.66	3.66	0.08	0.02	6.54
6	A	0.70	57.2	4.93	6.51	0.07	0.01	10.33
	B	0.60	97.5	3.95	5.45	0.08	0.01	9.15
	C	0.64	110.1	4.57	6.29	0.09	0.01	10.23
	D	0.66	132.7	5.85	6.52	0.09	0.01	9.35
	E	0.70	75.0	4.90	6.15	0.07	0.02	9.75
	F	0.84	58.2	5.64	7.18	0.08	0.01	11.32
	G	1.09	39.2	5.04	5.88	0.09	0.02	9.98
	H	0.79	59.8	5.14	6.35	0.11	0.02	11.25
	I	0.59	56.8	3.06	4.00	0.06	0.01	6.97
	K	0.86	25.5	4.08	6.05	0.07	0.02	10.33
Detection Limits		0.05	0.05	0.05	0.05	0.005	0.005	0.05
7	B	1.00	56.0	4.65	7.55	0.09	0.02	13.20
	C	0.73	77.4	4.55	7.26	0.10	0.01	11.23
	D	0.80	51.0	4.21	6.41	0.08	0.01	10.57
	E	0.90	99.5	4.53	5.14	0.09	0.02	9.29
	G	1.26	41.5	4.76	4.27	0.09	0.04	8.01
	J	1.10	24.2	4.65	6.60	0.07	0.03	11.20
8	D	0.85	125.2	5.62	6.62	0.11	0.02	10.21
	E	0.80	71.4	4.54	5.58	0.08	0.02	7.95
	F	0.80	90.0	3.25	4.95	0.07	0.02	7.00
	H	0.78	44.1	4.20	5.91	0.10	0.02	9.51
	I	0.78	12.8	1.76	2.70	0.03	0.01	4.31
9	D	0.95	47.7	4.35	7.05	0.09	0.03	12.05
	E	0.99	25.5	4.64	7.06	0.07	0.02	11.50
	F	0.93	27.1	4.09	6.58	0.07	0.02	10.19
	H	2.36	59.1	7.31	7.28	0.09	0.01	0.05
10	D	1.72	18.6	4.95	7.12	0.08	0.01	0.05
	E	0.85	35.9	4.15	6.30	0.08	0.02	9.75
	F	3.94	54.4	5.79	8.15	0.11	0.01	0.05
	G	1.18	56.9	4.26	5.39	0.09	0.03	9.90
	H	2.91	37.2	5.95	8.15	0.10	0.01	0.05
	I	2.63	30.3	4.71	14.74	0.12	0.01	0.05
11	C	2.12	18.2	3.80	6.08	0.07	0.01	0.05
	D	0.38	5.5	0.81	1.34	0.01	0.02	2.59
	E	3.20	46.2	5.22	7.82	0.10	0.01	0.05
	F	2.52	17.7	4.34	7.06	0.07	0.01	0.05
	G	1.87	56.1	4.90	6.90	0.10	0.01	0.05
	a	2.31	13.9	4.12	6.41	0.03	0.01	0.05
	c	2.08	18.5	3.87	5.22	0.03	0.01	0.05
12	B	2.29	17.9	3.42	7.09	0.04	0.01	0.05
	C	2.79	22.4	4.13	6.63	0.06	0.01	0.05
	b	2.07	15.1	4.53	7.12	0.06	0.01	0.05
	c	1.99	16.9	4.56	5.77	0.04	0.01	0.05
13	C	2.10	16.0	4.23	6.48	0.06	0.01	0.05
	b	1.85	22.0	3.86	5.86	0.05	0.01	0.05
Mean		1.24	55.1	4.42	6.07	0.08	0.01	6.85
Std.Dev		0.78	38.8	0.96	1.74	0.02	0.01	4.59
n		63	63	63	63	63	63	63
C.V.(%)		62.9	70.4	21.6	28.6	27.0	61.1	67.0
Max.		3.94	167.0	7.31	14.74	0.12	0.04	13.20
Min.		0.38	5.5	0.81	1.34	0.01	0.01	0.05

Table B-23

Concentration of major cations in the peat (P) at selected stations in Lake Apopka. Analyses performed after perchloric acid digestion of dried sediment.

Station		K	Ca	Mg	Fe	Mn	Cu	Al
		mg/g						
1	C	0.84	31.3	4.15	2.61	0.09	0.05	6.66
2	A	0.63	16.2	2.28	0.87	0.04	0.02	0.78
	C	0.50	190.5	1.95	2.40	0.08	0.02	3.60
	F	0.60	21.2	3.20	2.30	0.10	0.02	3.80
	H	0.52	24.1	3.47	0.67	0.10	0.01	1.14
3	G	0.54	31.3	3.40	2.02	0.08	0.01	2.81
	H	0.82	16.9	3.73	1.84	0.03	0.01	4.90
4	F	0.87	19.2	3.77	6.20	0.06	0.01	11.26
	G	0.45	15.6	2.15	0.60	0.06	0.02	0.75
	H	0.50	18.0	2.70	1.25	0.08	0.01	0.70
5	K	0.29	11.0	2.33	1.41	0.05	0.01	0.68
6	K	0.34	30.4	1.72	1.63	0.04	0.01	0.84
7	D	0.80	71.5	4.80	6.10	0.11	0.02	10.85
	J	0.58	8.7	1.25	0.48	0.02	0.02	0.63
8	I	0.45	20.9	1.85	3.00	0.05	0.02	0.80
	J	0.40	11.8	1.65	1.70	0.06	0.02	3.00
10	E	1.68	11.7	1.96	1.32	0.04	0.01	0.05
	F	2.12	9.6	2.13	0.88	0.03	0.01	0.05
13	b	1.10	11.4	4.06	3.31	0.04	0.01	0.05
Mean		0.74	30.06	2.77	2.14	0.06	0.02	2.81
Std.Dev.		0.45	40.24	0.99	1.58	0.02	0.01	3.34
C.V.(%)		61.0	133.8	35.9	74.1	39.7	66.3	119.2
n		19	19	19	19	19	19	19
Max.		2.12	190.50	4.80	6.20	0.11	0.05	11.26
Min.		0.29	8.65	1.25	0.48	0.02	0.01	0.05
Det.Lim.		0.05	0.05	0.05	0.05	0.005	0.005	0.05

Table B-24

Concentration of major cations in the sand at selected stations in Lake Apopka. Analyses performed after perchloric acid digestion of dried sediment.

		K	Ca	Mg	Fe	Mn	Cu	Al
		mg/g						
2	D	0.38	63.0	0.96	1.10	0.03	0.01	1.72
3	D	0.28	359.2	10.20	1.20	0.29	0.01	1.11
	E	1.29	120.8	4.03	5.37	0.13	0.01	10.07
6	H	0.45	48.5	0.95	1.50	0.03	0.03	2.70
7	D	1.05	174.0	7.38	6.57	0.18	0.01	13.04
10	I	1.27	12.6	1.55	5.94	0.06	0.01	0.05
Mean		0.79	129.68	4.18	3.61	0.12	0.02	4.78
Std.Dev.		0.43	115.09	3.52	2.37	0.09	0.01	4.93
C.V.(%)		54.3	88.7	84.3	65.7	78.0	48.2	103.1
n		6	6	6	6	6	6	6
Max.		1.29	359.19	10.20	6.57	0.29	0.05	13.04
Min.		0.28	12.57	0.95	1.10	0.03	0.01	0.05
Det.Lim.		0.05	0.05	0.05	0.05	0.005	0.005	0.05

Table B-25

Concentration of major cations in the clay at selected stations in Lake Apopka. Analyses performed after perchloric acid digestion of dried sediment.

		K	Ca	Mg	Fe	Mn	Cu	Al
		mg/g						
2	E	0.58	45.7	4.97	2.03	0.12	0.08	3.14
4	F	2.14	157.1	8.41	11.87	0.14	0.02	24.76
	I	1.28	10.2	7.81	14.75	0.11	0.02	29.63
5	H	0.78	49.1	10.98	8.50	0.11	0.01	16.42
	I	1.12	15.3	10.77	16.93	0.12	0.01	31.06
	J	1.39	13.0	5.66	10.12	0.08	0.02	20.71
6	H	1.23	15.8	8.86	16.59	0.10	0.02	33.98
	I	0.85	20.2	5.65	6.40	0.08	0.03	12.20
7	G	0.65	43.4	18.35	17.20	0.13	0.02	32.50
	H	0.95	63.5	10.60	13.35	0.11	0.02	25.35
	I	1.07	20.8	11.92	18.06	0.12	0.02	33.80
8	H	0.85	11.4	5.70	12.75	0.07	0.02	25.65
	I	0.37	3.5	0.32	0.56	0.01	0.01	0.60
Mean		1.02	36.07	8.46	11.47	0.10	0.02	22.29
Std.Dev.		0.43	39.14	4.19	5.50	0.03	0.02	10.77
C.V.(%)		42.1	108.5	49.5	47.9	33.7	68.2	48.3
n		13	13	13	13	13	13	13
Max.		2.14	157.10	18.35	18.06	0.14	0.08	33.98
Min.		0.37	3.47	0.32	0.56	0.01	0.01	0.60
Det.Lim.		0.05	0.05	0.05	0.05	0.005	0.005	0.05

Table B-26

Concentration of major cations in the marl at selected stations in Lake Apopka. Analyses performed after perchloric acid digestion of dried sediment.

Station		K	Ca	Mg	Fe	Mn	Cu	Al
		mg/g						
4	D	0.24	397.6	5.19	0.99	0.22	0.01	0.90
	E	0.35	311.0	13.50	1.10	0.48	0.02	1.15
5	B	0.34	52.3	0.67	1.20	0.02	0.01	1.25
	C	0.50	140.6	5.91	5.82	0.12	0.01	9.43
	D	0.39	157.0	3.20	4.53	0.08	0.01	6.40
	E	0.09	328.1	14.47	1.34	0.46	0.01	1.34
	F	0.15	324.2	0.93	0.29	0.07	0.01	1.13
	G	0.50	161.0	5.85	6.75	0.16	0.01	11.05
6	C	0.59	214.9	5.84	6.19	0.16	0.01	9.55
	D	0.54	233.4	6.33	3.96	0.17	0.01	6.73
	E	0.29	258.8	3.53	2.84	0.10	0.01	4.56
	F	0.40	262.0	4.85	2.55	0.10	0.01	4.10
	G	0.29	125.4	4.08	2.64	0.07	0.01	4.47
	J	1.05	184.9	7.47	9.43	0.19	0.01	18.73
7	D	0.50	319.0	2.35	2.85	0.10	0.02	4.60
	F	0.57	298.3	20.31	4.42	0.15	0.01	8.90
8	D	0.58	197.1	13.17	6.54	0.14	0.02	10.10
	F	0.47	254.9	2.54	2.21	0.05	0.01	3.20
	G	0.29	216.5	3.04	1.69	0.04	0.01	1.45
9	G	2.10	115.3	40.61	5.91	0.17	0.01	0.05
	H	1.18	34.5	6.50	4.89	0.04	0.01	0.05
Mean		0.54	218.42	8.11	3.72	0.15	0.01	5.20
Std.Dev.		0.43	92.83	8.73	2.35	0.12	0.00	4.63
C.V.(%)		79.0	42.5	107.6	63.2	79.9	49.8	89.2
n		21	21	21	21	21	21	21
Max.		2.10	397.64	40.61	9.43	0.48	0.02	18.73
Min.		0.09	34.45	0.67	0.29	0.02	0.01	0.05
Det.Lim.		0.05	0.05	0.05	0.05	0.005	0.005	0.05

Table B-27

Water chemistry (June 1987) at selected stations in Lake Apopka.

Station		Total					Dissolved					
		TKN	ON	TP	TOC	TIC	NH4	NO3	TKN	SRP	TP	GTOC
		mg/l										
1	C	5.684	5.524	0.330		8.960	0.160	<.01	3.673	0.003	0.070	33.010
2	A	5.632	5.501	0.190		16.090	0.131	<.01	2.043	0.008	0.113	24.940
	B	6.094	5.835	0.240		19.540	0.259	<.01	3.558	0.002	0.065	29.530
	C	6.052	5.945	0.440		18.640	0.107	<.01	2.476	<.001	0.047	30.740
	D	5.768	5.651	0.279		19.350	0.117	<.01	3.023	<.001	0.064	32.120
	E	5.586	5.416	0.407		17.840	0.170	<.01	3.518	<.001	0.073	34.560
	F	5.667	5.336	0.354		18.960	0.331	<.01	4.047	0.002	0.076	30.620
	G	5.609	5.584	0.239		17.400	0.025	<.01	3.873	<.001	0.081	29.820
	H	4.270	4.132	0.186		19.270	0.138	<.01	2.703	<.001	0.063	33.490
3	A	5.457	5.337	0.258		17.330	0.120	<.01	3.424	0.003	0.082	30.750
	B	4.113	3.986	0.175		15.080	0.127	<.01	2.695	0.005	0.071	31.160
	C	6.231	6.039	0.330		16.990	0.192	<.01	3.256	<.001	0.054	30.510
	D	5.234	5.127	0.221		19.050	0.107	<.01	2.250	<.001	0.104	32.090
	E	4.698	4.570	0.358		16.860	0.128	<.01	2.700	<.001	0.081	31.170
	F	6.558	6.420	0.188		15.420	0.138	<.01	3.037	0.002	0.061	27.040
	G	4.892	4.764	0.376		16.330	0.128	<.01	2.988	0.003	0.051	32.630
	H	5.365	5.242	0.231		18.220	0.123	<.01	2.849	0.001	0.057	31.140
4	A	4.949	4.832	0.326		16.360	0.117	<.01	2.416	0.002	0.051	30.300
	B	5.164	5.026	0.215		16.960	0.138	<.01	2.664	0.003	0.080	31.520
	C	4.747	4.571	0.221		19.250	0.176	<.01	3.036	0.002	0.067	32.850
	D	4.602	4.453	0.212		14.100	0.149	<.01	2.366	0.003	0.056	32.830
	E	5.077	4.913	0.176		15.770	0.164	<.01	3.378	0.003	0.138	32.210
	F	5.254	5.091	0.282		14.650	0.163	<.01	2.510	0.002	0.049	31.990
	G	5.616	5.488	0.314		15.510	0.128	<.01	2.395	0.002	0.255	33.190
	H	5.360	5.224	0.280		14.590	0.136	<.01	3.662	0.002	0.078	31.470
	I	5.353	5.225	0.221		15.330	0.128	<.01	2.307	0.002	0.067	NA
5	A	4.281	4.123	0.294		13.690	0.158	<.01	3.579	0.002	0.061	30.810
	B	4.099	3.982	0.372		14.720	0.117	<.01	3.436	<.001	0.073	36.850
	C	4.314	4.181	0.325		18.890	0.133	<.01	3.191	0.003	0.056	31.510
	D	3.998	3.881	0.230		13.350	0.117	<.01	2.356	0.001	0.059	35.580
	E	4.393	4.249	0.168		15.980	0.144	<.01	2.826	0.008	0.057	31.280
	F	4.406	4.297	0.173		12.410	0.109	<.01	2.473	0.002	0.051	NA
	G	4.888	4.793	0.190		13.690	0.095	<.01	2.607	0.002	0.052	32.990
	H	4.406	4.261	0.179		13.902	0.145	<.01	2.311	0.001	0.046	32.700
	I	4.727	4.613	0.177		12.660	0.114	<.01	2.207	0.001	0.041	32.240
	J	4.430	4.315	0.159		11.680	0.115	<.01	2.534	0.001	0.052	33.010
	K	4.393	4.264	0.145		15.720	0.129	<.01	2.623	0.001	0.064	31.210
6	A	4.270	4.167	0.164		14.230	0.103	<.01	2.876	0.003	0.073	32.970
	B	4.468	4.333	0.154		17.390	0.135	<.01	2.801	0.003	0.086	38.490
	C	7.337	7.205	0.283		25.180	0.132	<.01	2.233	0.002	0.164	32.910
	D	5.877	5.747	0.199		21.076	0.130	<.01	3.137	0.003	0.075	33.760
	E	5.395	5.205	0.204		15.504	0.190	<.01	3.130	0.001	0.061	34.540
	F	5.877	5.749	0.225		16.142	0.128	<.01	2.896	0.002	0.055	30.300
	G	5.952	5.819	0.256		15.134	0.133	<.01	2.657	0.003	0.044	29.580
	H	6.125	5.963	0.345		14.458	0.162	<.01	3.425	0.003	0.048	29.290
	I	5.754	5.629	0.208		15.102	0.125	<.01	2.845	0.003	0.061	30.620
	J	5.506	5.371	0.199		18.090	0.135	<.01	2.731	0.002	0.060	29.140
	K	6.273	5.798	0.254		21.456	0.475	<.01	3.868	0.004	0.055	30.060

Table B-27

Water chemistry (June 1987) at selected stations in Lake Apopka.

	Total					Dissolved					
Station	TKN	ON	TP	TOC	TIC	NH4	NO3	TKN	SRP	TP	GTOC
	mg/l										
7 B	4.653	4.512	0.184		14.300	0.141	<.01	2.631	0.005	0.056	31.980
C	4.628	4.462	0.164		16.195	0.166	<.01	3.994	0.003	0.058	30.480
D	4.851	4.741	0.187		21.328	0.110	<.01	3.432	0.003	0.094	29.860
E	4.975	4.865	0.177		13.778	0.110	<.01	2.507	0.002	0.049	32.090
F	5.135	4.984	0.203		16.228	0.151	<.01	3.287	0.003	0.058	30.270
G	4.826	4.716	0.215		15.898	0.110	<.01	2.900	0.003	0.054	29.100
H	5.012	4.851	0.199		14.304	0.161	<.01	2.876	0.001	0.048	30.120
I	5.346	5.146	0.185		15.446	0.200	<.01	3.407	0.003	0.045	31.340
J	4.579	4.398	0.166		13.528	0.181	<.01	3.512	0.003	0.053	32.620
8 C	4.740	4.563	0.311		19.898	0.177	<.01	3.205	0.007	0.068	32.540
D	4.443	4.258	0.148		16.042	0.185	<.01	3.957	0.006	0.059	32.200
E	5.259	5.125	0.210		16.328	0.134	<.01	3.434	0.005	0.047	33.420
F	4.740	4.602	0.173		14.940	0.138	<.01	2.884	0.009	0.044	31.320
G	4.616	4.499	0.175		15.956	0.117	<.01	2.423	0.004	0.042	30.070
H	4.665	4.536	0.163		15.080	0.129	<.01	3.724	0.005	0.068	31.110
I	5.346	5.237	0.216		15.172	0.109	<.01	2.641	0.006	0.057	29.540
J	4.369	4.260	0.163		14.886	0.109	<.01	3.070	0.005	0.054	31.820
9 D	4.752	4.645	0.168		14.740	0.107	<.01	2.649	0.003	0.055	32.270
E	4.443	4.337	0.161		14.882	0.106	<.01	3.128	0.003	0.054	31.130
F	5.853	5.715	0.351		16.212	0.138	<.01	3.948	0.004	0.056	32.110
G	4.740	4.615	0.177		13.788	0.125	<.01	3.363	0.005	0.050	31.830
H	4.591	4.440	0.185		15.006	0.151	<.01	2.727	0.004	0.041	31.780
I	6.397	6.288	0.265		16.092	0.109	<.01	2.334	0.003	0.055	31.770
10 D	5.098	4.972	0.310		15.658	0.126	<.01	2.638	0.003	0.048	32.010
E	4.146	4.032	0.172		13.674	0.114	<.01	2.297	0.003	0.035	32.200
F	3.874	3.755	0.143		15.234	0.119	<.01	1.553	0.003	0.079	32.550
G	4.727	4.589	0.177		13.016	0.138	<.01	2.939	0.002	0.053	32.750
H	3.948	3.786	0.151		15.304	0.162	<.01	2.915	0.005	0.057	31.800
I	3.577	3.416	0.151		13.034	0.161	0.304	3.128	0.004	0.083	29.640
11 D	4.158	4.003	0.151		14.616	0.155	<.01	2.566	0.005	0.071	33.110
E	5.543	5.185	0.198		14.628	0.358	<.01	2.496	0.004	0.048	31.760
F	5.457	5.276	0.197		17.102	0.181	<.01	3.554	0.003	0.056	32.810
G	3.800	3.670	0.125		17.026	0.130	<.01	2.465	0.003	0.060	32.380
a	4.146	3.999	0.148		16.024	0.147	1.095	2.389	0.003	0.047	21.430
C	4.369	4.254	0.152		24.406	0.115	<.01	2.841	0.003	0.070	30.550
c	5.123	4.948	0.189		18.896	0.175	<.01	2.612	0.012	0.064	31.370
12 B	4.307	4.095	0.155		15.828	0.212	0.487	2.435	0.003	0.098	25.820
b	4.072	3.970	0.141		16.250	0.102	0.355	2.043	0.003	0.057	26.570
C	4.418	4.323	0.163		18.362	0.095	0.029	2.460	0.004	0.059	32.180
c	3.973	3.870	0.132		16.586	0.103	<.01	2.464	0.003	0.064	32.890
13 b	4.801	4.620	0.186		17.846	0.181	<.01	2.655	0.003	0.065	31.790
C	4.084	3.974	0.148		16.376	0.110	<.01	2.772	0.004	0.071	31.770
GNS	0.622	0.530	0.067		12.386	0.092	3.499	2.023	0.005	0.062	8.860
Mean	4.92	4.77	0.22		16.12	0.14	0.06	2.89	0.00	0.07	31.20
Stdv.	0.85	0.84	0.07		2.53	0.06	0.39	0.52	0.00	0.03	3.27
C.V.(%)	17	18	33	ERR	16	39	612	18	68	43	10
n	91	91	91	1	91	91	91	91	91	91	89
Max.	7.34	7.21	0.44	0.00	25.18	0.48	3.50	4.05	0.01	0.26	38.49
Min.	0.62	0.53	0.07	0.00	8.96	0.03	0.00	1.55	0.00	0.04	8.86

GNS = Gourd Neck Springs; GTOC & GTIC = Glass-Fiber Filtered; Dissolved = 0.2um Filtered.

Table B-28

Water chemistry (June 1987) at selected stations in Lake Apopka.

Station		Dissolved				
		K	Ca	Mg	Na	Cl
		mg/l				
1	C	9.50	26.80	14.90	13.00	33.80
2	A	11.80	31.40	19.60	16.90	43.10
	B	10.30	28.30	17.50	14.90	30.50
	C	10.60	28.90	17.70	15.10	38.30
	D	10.30	27.90	17.20	14.70	37.90
	E	10.40	28.70	17.70	15.20	38.10
	F	10.90	28.00	17.60	15.40	38.30
	G	10.70	27.50	17.40	15.00	36.80
	H	10.40	27.50	17.60	15.20	37.20
3	A	10.60	29.30	18.10	15.30	40.00
	B	10.50	29.40	18.10	15.40	37.50
	C	9.40	24.40	15.10	13.10	34.90
	D	10.40	27.50	17.80	15.40	40.50
	E	11.10	28.60	18.30	15.90	39.60
	F	10.60	27.30	17.40	15.20	38.50
	G	10.10	26.80	17.20	14.80	37.20
	H	10.60	27.80	17.60	15.50	37.50
4	A	10.60	28.90	17.90	15.30	37.90
	B	10.60	29.10	17.80	15.10	37.50
	C	10.90	28.80	18.00	15.50	38.50
	D	10.50	27.90	17.30	14.80	32.70
	E	11.00	28.40	18.00	15.60	35.30
	F	11.10	28.60	18.20	15.70	39.00
	G	10.70	28.20	17.50	14.90	35.30
	H	10.70	29.40	17.90	15.20	37.70
	I	10.50	28.60	17.80	15.20	35.70
5	A	10.50	28.60	17.50	14.90	33.30
	B	11.00	29.90	18.30	15.60	37.90
	C	10.80	29.10	17.90	15.30	39.60
	D	9.00	25.50	15.50	13.10	35.30
	E	10.60	29.60	18.00	15.40	36.60
	F	11.00	29.30	18.10	15.50	39.60
	G	10.40	28.40	17.80	15.10	37.90
	H	10.80	28.60	18.30	15.50	38.10
	I	10.90	28.10	18.00	15.50	40.70
	J	10.80	28.00	17.80	15.20	34.20
	K	10.40	28.20	17.90	15.10	38.70
6	A	10.20	28.60	17.70	14.90	39.60
	B	10.80	31.30	19.20	16.10	34.90
	C	10.20	29.40	17.60	14.90	38.70
	D	10.50	29.00	17.50	14.90	39.20
	E	10.40	29.20	17.60	14.90	39.00
	F	10.40	29.20	17.60	15.00	38.50
	G	9.60	28.20	17.00	14.40	37.00
	H	10.50	28.40	17.50	15.00	40.50
	I	10.20	29.30	17.30	14.70	37.90
	J	10.70	29.70	17.80	15.20	38.10
	K	11.10	31.90	18.90	15.90	42.00

Table B-28

Water chemistry (June 1987) at selected stations in Lake Apopka.

Station		Dissolved K	Dissolved Ca	Dissolved Mg	Dissolved Na	Dissolved Cl
		mg/l	mg/l	mg/l	mg/l	mg/l
7	B	10.40	29.40	17.60	14.90	40.00
	C	7.80	22.70	13.60	11.50	31.00
	D	10.20	29.20	17.30	14.50	37.50
	E	9.90	29.10	17.40	14.50	40.30
	F	9.70	29.20	17.20	14.40	37.00
	G	10.00	28.80	17.10	14.40	36.60
	H	9.80	28.40	17.00	14.60	37.00
	I	10.30	28.70	17.40	15.10	36.60
	J	11.10	29.90	17.70	15.60	38.10
8	C	10.50	28.60	17.30	14.90	36.20
	D	10.20	28.50	17.20	14.90	35.30
	E	11.50	31.60	19.00	16.50	42.60
	F	11.20	27.70	16.60	14.30	30.30
	G	10.50	29.60	18.10	15.40	38.70
	H	10.20	29.20	17.60	15.10	38.70
	I	10.10	28.20	16.30	14.20	34.90
	J	10.20	28.40	16.60	14.50	35.50
9	D	9.90	27.70	16.70	14.10	35.50
	E	9.90	27.40	16.70	14.20	35.50
	F	9.50	26.00	15.60	13.50	36.20
	G	9.80	27.90	16.60	14.00	31.20
	H	10.00	27.70	16.80	14.40	36.20
	I	9.70	26.40	16.50	14.20	32.30
10	D	10.00	27.70	17.10	14.60	36.60
	E	10.10	27.90	17.00	14.50	36.60
	F	9.70	28.00	17.10	14.60	35.90
	G	10.10	28.00	17.10	14.70	35.50
	H	10.50	28.60	17.90	15.30	37.00
	I	9.90	29.60	15.50	13.70	29.20
11	D	10.10	27.20	16.90	14.40	36.20
	E	10.10	27.20	16.80	14.40	33.30
	F	10.10	27.50	17.30	14.90	35.10
	G	10.40	27.60	17.30	15.00	35.50
	a	6.50	28.60	13.10	10.90	23.80
	C	9.40	28.20	16.70	14.10	36.80
	c	10.40	28.70	17.30	14.90	35.70
12	B	8.20	28.20	14.80	12.60	27.50
	b	8.50	28.40	15.40	13.20	26.20
	C	9.90	28.10	16.70	14.40	34.00
	c	10.50	28.10	17.40	15.00	34.90
13	b	9.40	27.20	16.40	13.60	29.40
	C	9.90	29.30	17.60	14.60	35.70
	GNS	1.80	27.00	8.10	5.70	9.50
	Mean	10.15	28.38	17.16	14.66	36.09
	Stdv.	1.15	1.30	1.41	1.31	4.37
	C.V.(%)	11	5	8	9	12
	n	91	91	91	91	91
	Max.	11.80	31.90	19.60	16.90	43.10
	Min.	1.80	22.70	8.10	5.70	9.50

GNS = Gourd Neck Springs; Dissolved = 0.2um Filtered.

Appendix 4.1. Average ammonium, nitrate, SRP, pH, and SOC in the overlying water.

	Dark					Light				
Time	pH	Ammonium	Nitrate	SRP	SOC	pH	Ammonium	Nitrate	SRP	SOC
weeks		mg L^{-1}					mg L^{-1}			
1		0.22	0.008	0.000	25.93		0.22	0.012	0.000	29.53
2		0.05	0.008	0.000	29.50		0.07	0.005	0.000	31.73
3		0.05	0.057	0.002	32.45		0.28	0.057	0.003	32.17
4		0.93	0.007	0.007	30.00		0.28	0.013	0.006	30.20
5		3.06	0.053	0.002	25.80		0.61	0.073	0.004	30.13
6		5.30	0.009	0.002	27.53		0.99	0.002	0.013	31.85
7		4.37	0.029	0.000	28.80		1.76	0.061	0.000	32.23
8		2.67	2.225	0.022	27.27		2.42	0.008	0.000	30.63
9		0.30	3.593	0.059	30.20		3.26	0.007	0.001	31.45
10		0.34	3.083	0.113	25.57		3.01	0.010	0.004	28.17
11		0.22	2.880	0.060	25.97		4.05	0.137	0.001	29.90
12		0.09	2.440	0.196	25.13		4.31	0.010	0.007	27.60
13		0.19	1.503	0.148	23.37		4.05	0.010	0.009	25.60
14		0.63	2.567	0.295	19.60		4.58	0.010	0.012	22.87
15		0.25	1.760	0.299	21.97		2.78	0.000	0.073	24.27
16		0.12	1.307	0.338	23.27		1.71	0.034	0.065	25.83
17		0.36	1.330	0.239	21.75		0.46	1.323	0.061	26.97
18		0.25	1.620	0.349	23.57		0.78	0.602	0.041	28.53
19		0.27	1.870	0.554	23.25		0.27	0.350	0.005	26.93
20		0.40	2.485	0.595	23.70		0.46	0.407	0.027	27.25
21		0.28	2.200	0.608	25.63		0.37	0.190	0.028	24.40
22					26.27					27.07
23		0.19	2.030	0.623	27.63		0.40	0.447	0.031	27.90
24		0.19	2.070	0.655	26.80		0.22	0.567	0.021	29.73
25	8.16	0.79	1.640	0.553	25.30	8.64	0.19	0.030	0.031	28.40
26	7.97	0.25	1.530	0.612	26.40	8.57	0.08	0.033	0.018	26.00
27	8.01	0.11	1.410	0.727		8.54	0.10	0.007	0.007	
28	8.02	0.12	0.657	0.472		8.32	0.12	0.003	0.011	
29	8.00	0.15	1.173	0.540		8.49	0.21	0.003	0.010	
30	7.95	0.14	1.613	0.728		8.49	0.12	0.004	0.011	
31	7.92	0.20	1.723	0.767		8.55	0.19	0.000	0.012	17.80
32	8.23	0.13	1.580	0.757		8.32	0.18	0.002	0.008	
33	8.25	0.29	1.500	0.821	20.37	8.33	0.20	0.040	0.023	20.53
34	8.17	0.08	1.430	0.801	18.53	8.43	0.08	0.057	0.025	20.43
35	8.13	0.16	1.240	0.781		8.43	0.18	0.033	0.029	22.60
36	8.27	0.12	1.037	0.756		8.48	0.09	0.020	0.026	
37	8.28	0.20	1.060	0.599	19.37	8.48				20.05
38	8.38	0.17	1.127		21.33	8.58	0.20	0.030	0.013	20.37
39	8.28	0.16	1.173		19.70	8.45	0.21	0.037	0.020	18.05
40	8.32	0.18	1.137	0.820	21.53	8.45	0.19	0.030	0.017	20.60
41	8.28	0.18	1.187	0.807	22.67	8.46	0.16	0.030	0.017	20.73
42	8.30	0.21	1.000	0.830	20.93	8.50	0.21	0.027	0.010	20.57
43	8.22	0.17	1.027	0.900	21.53	8.43	0.12	0.030	0.014	22.07
44	8.48	0.13	1.010	0.707	21.83	8.50	0.13	0.027	0.014	19.37
45	8.44	0.18	0.907	0.820	20.15	8.78	0.12	0.023	0.016	21.40
46	8.30	0.12	0.857	0.917	21.95	8.54	0.07	0.020	0.006	21.35
47	8.20	0.10	0.883	0.990	19.50	8.51	0.05	0.020	0.005	20.35
48	8.18	0.15	0.823	1.033	22.35	8.36	0.10	0.030	0.020	20.40
49	8.08	0.12	0.470	0.920	19.93	8.39	0.11	0.030	0.086	20.57
50	8.07	0.26	0.663	1.030	23.55	8.42	0.10	0.030	0.012	21.50
51	8.32	0.18	0.573	1.050	22.03	8.45	0.05	0.023	0.004	19.20
52	8.32	0.14	0.613	1.047	23.93	8.17	0.06	0.030	0.004	20.30
53	8.22	0.10	0.593	1.060	18.60	8.36	0.05	0.023	0.005	20.93
54	8.29	0.13	0.540	1.063	26.10	8.33	0.07	0.030	0.007	25.70

Appendix 4.2. Porewater soluble organic carbon concentrations.

Depth	Time, months					
	0	1	2	4	7	12
—cm—	—mg L^{-1}—					
Dark:						
0-1	33.6	30.7	24.6	20.5	24.1	25.2
1-3	28.1	33.8	23.2	19.9	27.6	25.6
3-6	28.8	30.2	21.2	17.3	24.2	25.8
6-12	28.0	25.5	19.8	19.7	28.3	26.8
12-24	31.7	30.5	21.4	21.1	32.7	29.6
24-40	34.8	40.1	23.2	21.8	29.6	34.0
40-54	na	41.7	27.4	22.5	35.5	24.6
Light:						
0-1	31.4	33.6	27.5	20.4	27.3	24.4
1-3	33.9	32.5	25.3	22.0	27.4	22.9
3-6	29.8	26.1	23.8	21.7	29.2	23.3
6-12	25.0	26.8	21.1	21.3	30.3	27.7
12-24	32.5	28.1	23.7	21.5	27.3	28.8
24-40	26.1	33.6	25.2	25.1	35.6	34.4
40-54	na	43.7	25.2	25.4	31.9	36.3

Appendix 4.3. Porewater concentrations of Fe, Mn, Ca, and Mg.

Time	Depth	Dark				Light			
		Fe	Mn	Ca	Mg	Fe	Mn	Ca	Mg
(month)	(cm)	mg L^{-1}							
0	1	na	na	na	na	0.042	0.101	73.8	24.3
0	3	0.032	0.125	74.5	21.8	na	na	na	na
0	6	0.030	0.157	90.2	25.8	0.022	0.143	81.8	23.7
0	12	0.028	0.165	97.9	25.5	0.021	0.143	98.6	23.1
0	24	0.027	0.161	110.1	25.2	0.023	0.129	104.3	21.6
0	40	0.042	0.148	125.9	26.7	0.030	0.143	127.9	25.7
0	54	na	na	na	na	na	na	na	na
1	1	0.278	0.095	68.6	24.2	0.038	0.138	82.7	28.0
1	3	0.040	0.111	80.4	25.3	0.037	0.138	89.2	27.5
1	6	0.030	0.144	94.3	27.8	0.059	0.184	101.5	29.5
1	12	0.047	0.179	99.6	29.8	0.039	0.187	99.2	30.7
1	24	0.083	0.181	125.0	30.1	0.031	0.189	115.4	31.3
1	40	0.030	0.164	128.2	29.8	0.028	0.129	118.8	24.1
1	54	0.049	0.139	124.5	28.4	0.034	0.143	127.9	28.9
2	1	0.048	0.107	67.8	22.9	0.023	0.069	64.9	23.5
2	3	0.037	0.107	68.3	20.9	0.036	0.118	80.9	23.7
2	6	0.020	0.132	92.7	22.2	0.046	0.152	93.6	26.1
2	12	0.022	0.190	97.2	29.3	0.021	0.151	94.3	24.8
2	24	0.026	0.192	118.3	30.5	0.025	0.167	117.5	29.7
2	40	0.025	0.163	126.0	28.9	0.024	0.142	124.6	26.2
2	54	0.033	0.140	127.4	27.9	0.038	0.132	122.6	27.5
4	1	0.017	0.053	59.2	20.6	0.018	0.065	63.0	21.9
4	3	0.026	0.073	64.2	21.7	0.030	0.081	70.0	22.9
4	6	0.032	0.114	79.9	24.9	0.018	0.126	84.2	25.7
4	12	0.019	0.160	95.6	28.2	0.026	0.163	95.6	28.9
4	24	0.026	0.185	113.8	30.6	0.023	0.187	118.1	31.2
4	40	0.018	0.156	121.8	29.5	0.046	0.155	121.6	29.3
4	54	0.023	0.132	122.1	28.1	0.051	0.136	116.4	27.7
7	1	0.034	0.090	74.8	21.4	0.034	0.062	66.4	21.5
7	3	0.034	0.100	81.4	22.7	0.030	0.072	77.1	23.6
7	6	0.030	0.134	90.7	24.5	0.025	0.094	84.9	25.0
7	12	0.027	0.164	108.4	26.0	0.023	0.123	92.9	26.8
7	24	0.026	0.185	118.4	29.9	0.030	0.173	111.1	28.4
7	40	0.030	0.159	128.0	29.4	0.035	0.178	134.2	31.6
7	54	0.034	0.129	127.7	27.0	0.042	0.134	119.7	27.3
12	1	0.049	0.087	55.9	19.4	0.088	0.057	72.9	20.6
12	3	0.085	0.088	60.9	20.1	0.047	0.063	76.7	21.2
12	6	0.073	0.118	71.3	21.7	0.059	0.082	82.2	22.9
12	12	0.026	0.149	88.1	24.6	0.035	0.121	88.6	24.2
12	24	0.091	0.145	103.6	26.7	0.038	0.142	98.2	24.9
12	40	0.044	0.112	112.0	26.1	0.039	0.125	110.3	25.0
12	54	0.045	0.074	101.7	23.3	0.031	0.084	102.6	24.2

Appendix 4.4. Lake water K, As, Fe, Na and B concentrations under light and dark conditions.

Time	Dark					Light				
	K	As	Fe	Na	B	K	As	Fe	Na	B
weeks	mg L^{-1}									
1	12.95	0.0052	0.0332	18.73	0.0385	13.09	0.0086	0.0287	18.85	0.0515
2	13.52	0.0482	0.3374	16.73	0.0675	13.19	0.0031	0.1552	19.11	0.0170
3	18.19	0.0434	0.3374	16.39	0.0257	18.54	0.0505	0.3621	16.53	0.0557
4	14.20	0.0303		18.31	0.1267	14.01	0.0202	0.1473	17.21	0.0761
5	14.11	0.0162		19.12	0.1017	14.32	0.0241	0.0181	19.28	0.1184
6	14.79	0.0133		19.22	0.1363	14.36	0.0128		19.61	0.1018
7	14.13	0.0144	0.0277	18.07	0.0858	15.04	0.0150	0.0283	19.33	0.0776
8	14.60	0.0201	0.0187	17.91	0.0816	12.81	0.0266	0.0225	16.03	0.0628
9	14.88	0.0224	0.0659	17.61	0.1253	14.58	0.0268	0.0289	18.58	0.0987
10	16.49	0.0216	0.0191	18.60	0.1338	9.70	0.0053	0.0209	12.10	0.0450
11	16.05	0.0359	0.0519	17.72	0.1679	14.37	0.0367	0.0762	17.70	0.1243
12	16.57	0.0276	0.0181	16.37	0.1266	18.07	0.0299	0.0324	16.43	0.0981
13	11.13	0.0236	0.0194	11.57	0.0579	13.40	0.0256	0.0201	16.65	0.1042
14	14.49	0.0214	0.2156	19.30	0.1764	12.36	0.0268	0.0522	18.28	0.1763
16	9.97	0.0195	0.0092	14.44	0.1042	11.02	0.0236	0.0107	16.91	0.0862
17	11.62	0.0161	0.0229	16.78	0.1455	12.94	0.0208	0.0398	18.51	0.0877
18	12.54	0.0222	0.0168	15.28	0.0890	9.97	0.0179	0.0165	14.99	0.0966
19	20.83	0.0337	0.0384	19.51	0.1371	13.66	0.0309	0.0141	15.21	0.1095
20	16.09	0.0479	0.0187	18.19	0.1195	10.37	0.0436	0.0163	14.99	0.1047
21	15.83	0.0438	0.0158	18.50	0.1121	11.18	0.0368	0.0084	15.45	0.1036
22	14.22	0.1086	0.0114	17.51	0.0699	11.61	0.0982	0.0105	15.15	0.0018
23	17.21	0.0098	0.0078	17.98	0.1196	34.57	0.0003	0.0035	16.05	0.0548
24	26.91	0.0178	0.0128	17.54	0.1752	15.67	0.0355	0.0499	17.33	0.1194
25	11.45	0.0229	0.0950	12.27	0.0970	10.69	0.0101	0.0526	13.60	0.0554
26	13.08	0.0205	0.0160	16.32	0.1594	13.95	0.0121	0.0427	16.57	0.0849
31	13.82	0.0000	0.0151	16.49	0.0977					
32	11.95	0.0000	0.0520	14.98	0.0836					
33	15.28	0.0056	0.0755	16.66	0.1578					
34	14.97	0.0149	0.0959	17.38	0.1859					
35	15.59	0.0061	0.0778	17.25	0.1864					
36	15.81	0.0000	0.1214	16.36	0.1030					
37	15.60	0.0107	0.2154	17.88	0.1061					
38	17.36	0.0119	0.0650	17.28	0.0000	13.33	0.0028	0.0232	17.53	0.0481
39	17.38	0.0128	0.0968	17.17	0.0000	13.81	0.0032	0.0194	17.48	0.0678
40	13.99	0.0000	0.3791	17.85	0.1241	13.64	0.0151	0.1889	18.55	0.0583
41	13.69	0.0025	0.0991	18.70	0.0676	12.68	0.0000	0.0598	15.70	0.0000
42	13.61	0.0020	0.0320	19.07	0.0721	10.63	0.0107	0.0783	15.29	0.0756
43	14.17	0.0024	0.0080	18.69	0.0723	14.03	0.0396	0.0515	20.05	0.0944
44	28.73	0.0335	0.0111	17.87	0.1060	10.40	0.0180	0.0615	17.23	0.1229
45	13.91	0.0461	0.0099	18.10	0.1156	12.43	0.0000	0.0114	16.29	0.0000
46	14.05	0.0148	0.0178	16.49	0.1242	15.63	0.0000	0.0143	18.44	0.0000
47	14.51	0.0106	0.0175	18.11	0.1135	16.01	0.0390	0.0130	18.90	0.0000
48	14.25	0.0000	0.0327	17.62	0.1610	14.83	0.0007	0.1228	18.43	0.0000
49	14.88	0.0000	0.0314	18.19	0.0688	15.37	0.0000	0.0261	18.56	0.0000
50	15.84	0.0044	0.0864	19.07	0.1669	15.98	0.0000	0.0343	18.96	0.0000
51	14.88	0.0033	0.0100	18.09	0.0922	16.18	0.0000	0.0193	19.47	0.0000
52	14.33	0.0022	0.0155	17.48	0.0459	15.24	0.0010	0.0090	17.93	0.0194
53	13.92	0.0000	0.0206	16.72	0.0089	14.90	0.0068	0.0292	18.11	0.0193
54	14.20	0.0000	0.0096	17.02	0.0827	16.47	0.0033	0.0164	18.14	0.0000

Appendix 4.5. Lake water Mn, Ca, Mg, Si, and dissolved P under light and dark conditons.

	Dark					Light				
Time	Mn	Ca	Mg	Si	P	Mn	Ca	Mg	Si	P
weeks	mg L^{-1}									
1	0.0037	36.71	19.19	7.129	0.0436	0.0426	37.18	19.56	6.462	0.0728
2	0.0121	35.01	18.96	2.613	0.1270	0.0017	43.31	20.18	2.924	0.0405
3	0.0049	36.48	19.00	0.739	0.0970	0.0073	47.77	20.07	1.239	0.1084
4	0.0348	38.46	21.05	3.088	0.1032	0.0081	42.29	19.59	3.690	0.0674
5	0.0170	43.23	21.26	1.217	0.0682	0.0270	47.24	21.59	1.230	0.0838
6	0.0220	47.40	21.46	5.180	0.0630	0.0088	50.44	21.60	3.878	0.0713
7	0.0060	48.18	20.57	5.043	0.0533	0.0184	53.11	21.76	3.304	0.0751
8	0.0089	48.45	20.80	5.684	0.0853	0.0058	49.54	19.29	2.337	0.0719
9	0.0041	52.01	20.24	4.924	0.1263	0.0038	53.66	21.50	0.766	0.0676
10	0.0010	51.77	21.54	3.674	0.1812	0.0013	51.85	14.44	0.165	0.0362
11	0.0059	51.78	21.47	6.706	0.2664	0.0040	54.86	21.83	0.148	0.1059
12	0.0025	50.41	19.67	6.204	0.3110	0.0012	47.90	20.36	0.164	0.0870
13	0.0109	44.93	13.32	4.584	0.2057	0.0039	51.36	19.97	0.118	0.0745
14	0.0032	50.06	20.87	7.308	0.3609	0.0022	47.06	20.68	0.390	0.0730
16	0.0009	49.02	15.53	0.380	0.3102	0.0009	45.66	19.59	0.051	0.0432
17	0.0031	49.30	17.74	0.512	0.3889	0.0031	43.06	20.67	0.165	0.0607
18	0.0055	48.78	17.00	0.490	0.4342	0.0003	37.23	17.27	0.062	0.0364
19	0.0000	53.49	21.66	8.372	0.8506	0.0000	36.60	17.95	0.083	0.0950
20	0.0014	50.42	20.30	4.435	0.7185	0.0044	33.08	16.84	0.086	0.0391
21	0.0022	52.38	20.85	6.869	0.7736	0.0029	32.92	17.89	0.205	0.0725
22	0.0032	50.72	19.21	7.891	0.7403	0.0032	38.69	17.87	0.369	0.0475
23	0.0000	50.45	20.49	9.033	0.7591	0.0000	38.53	18.27	0.564	0.0508
24	0.0000	51.52	19.99	9.402	0.7836	0.0000	41.83	19.34	0.542	0.0722
25	0.0010	47.86	14.00	7.479	0.5759	0.0000	33.07	14.99	0.364	0.0342
26	0.0020	51.04	18.18	8.074	0.7406	0.0007	37.82	18.19	0.222	0.0720
31	0.0001	46.73	18.69	8.874	0.7452					
32	0.0001	45.30	17.59	8.512	0.7266					
33	0.0001	47.90	19.14	7.720	0.8456					
34	0.0001	49.13	20.15	7.225	0.8866					
35	0.0021	49.22	20.14	8.693	0.8856					
36	0.0001	46.85	19.64	7.401	0.7287					
37	0.0000	47.87	19.69	7.778	0.8014					
38	0.0019	48.21	19.43	2.570	0.7825	0.0000	38.13	18.62	0.847	0.0226
39	0.0000	48.18	19.38	2.516	0.8051	0.0001	38.95	18.87	0.843	0.0344
40	0.0032	49.02	20.04	1.051	0.8099	0.0004	41.32	19.82	0.373	0.0863
41	0.0000	47.66	20.16	1.063	0.8355	0.0000	37.66	16.57	0.321	0.0131
42	0.0000	48.58	20.53	1.338	0.8237	0.0000	40.33	16.01	0.352	0.0518
43	0.0000	47.01	20.22	1.508	0.9655	0.0000	42.16	20.66	0.638	0.0910
44	0.0000	43.48	19.49	3.219	0.7736	0.0000	37.75	19.32	0.603	0.0970
45	0.0000	45.72	19.81	3.285	0.8383	0.0000	36.23	16.89	0.457	0.0061
46	0.0000	47.65	18.59	1.331	0.9235	0.0000	38.32	19.00	0.493	0.0612
47	0.0000	48.05	19.99	1.986	1.0160	0.0000	35.49	19.14	2.898	0.0573
48	0.0000	47.57	19.49	2.246	1.0007	0.0000	38.91	19.03	0.774	0.0538
49	0.0000	46.23	20.39	1.617	0.8914	0.0000	38.65	19.01	0.548	0.0472
50	0.0006	47.47	20.63	2.244	1.0321	0.0000	34.55	19.78	0.644	0.0491
51	0.0000	47.29	20.33	2.215	1.0480	0.0000	39.57	20.74	0.507	0.0515
52	0.0000	46.38	19.84	2.072	1.0072	0.0000	39.45	19.22	0.474	0.0222
53	0.0000	44.87	19.12	2.233	0.9794	0.0000	40.67	19.58	0.460	0.0297
54	0.0000	44.73	18.95	2.699	0.9504	0.0000	40.58	19.64	0.553	0.0565

Appendix 5.2a. Gaseous evolution of C02 and CH4 from unconsolidated flocculent sediments (UCF) incubated under anoxic conditions at 25°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			——mg C L^{-1}——		——avg mg C——		——total mg C——	
UCF-25	A	6	21.27	2.52				
UCF-25	B	6	0.00	0.00				
UCF-25	C	6	15.47	1.95	12.25	1.49	12.25	1.49
UCF-25	A	21	53.46	13.40				
UCF-25	B	21	48.88	10.50				
UCF-25	C	21	50.19	9.48	50.85	11.13	63.09	12.62
UCF-25	A	43	75.51	23.03				
UCF-25	B	43	70.02	20.37				
UCF-25	C	43	59.95	15.39	68.49	19.60	131.58	32.21
UCF-25	A	78	22.25	12.30				
UCF-25	B	78	14.31	7.22				
UCF-25	C	78	12.13	13.77	16.23	11.10	147.82	43.31
UCF-25	A	104	11.05	14.27				
UCF-25	B	104	13.13	12.11				
UCF-25	C	104	16.07	12.80	13.42	13.06	161.23	56.37
UCF-25	A	141	14.90	29.93				
UCF-25	B	141	6.29	19.37				
UCF-25	C	141	7.76	37.70	9.65	29.00	170.88	85.37
UCF-25	A	182	15.41	34.03				
UCF-25	B	182	5.49	21.84				
UCF-25	C	182	9.07	35.91	9.99	30.59	180.87	115.96
UCF-25	A	217	14.32	72.13				
UCF-25	B	217	6.22	18.30				
UCF-25	C	217	13.48	77.29	11.34	55.90	192.21	171.87
UCF-25	A	288	15.62	60.36				
UCF-25	B	288	13.35	53.27				
UCF-25	C	288	15.75	86.84	14.91	66.82	207.12	238.69
UCF-25	A	330	16.40	58.87				
UCF-25	B	330	15.20	51.63				
UCF-25	C	330	16.72	64.54	16.11	58.35	223.23	297.04
UCF-25	A	371	12.85	47.87				
UCF-25	B	371	6.37	33.62				
UCF-25	C	371	10.53	36.92	9.92	39.47	233.15	336.51
UCF-25	A	413	14.95	46.43				
UCF-25	B	413	13.29	38.91				
UCF-25	C	413	6.94	19.57	11.73	34.97	244.87	371.48
UCF-25	A	489	12.72	24.66				
UCF-25	B	489	15.19	42.30				
UCF-25	C	489	12.64	36.54	13.51	34.50	258.39	405.98
UCF-25	A	534	10.36	23.48				
UCF-25	B	534	11.52	27.66				
UCF-25	C	534	6.69	17.59	9.52	22.91	267.91	428.89

Appendix 5.2b. Gaseous evolution of CO2 and CH4 from unconsolidated flocculent sediments (UCF) incubated under anoxic conditions at 15°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			mg C L^{-1}		avg mg C		total mg C	
UCF-15	A	6	0.39	1.16				
UCF-15	B	6	3.64	0.13				
UCF-15	C	6	2.95	0.26	2.32	0.52	2.32	0.52
UCF-15	A	21	29.89	4.11				
UCF-15	B	21	32.23	0.00				
UCF-15	C	21	32.44	0.39	31.52	1.50	33.84	2.02
UCF-15	A	43	45.88	0.00				
UCF-15	B	43	40.59	0.52				
UCF-15	C	43	46.80	0.00	44.42	0.17	78.27	2.19
UCF-15	A	78	18.20	0.00				
UCF-15	B	78	16.73	3.55				
UCF-15	C	78	25.25	0.00	20.06	1.18	98.33	3.37
UCF-15	A	104	16.02	0.50				
UCF-15	B	104	13.70	2.94				
UCF-15	C	104	22.48	0.00	17.40	1.14	115.73	4.51
UCF-15	A	141	65.64	0.00				
UCF-15	B	141	29.56	0.00				
UCF-15	C	141	12.75	0.00	35.98	0.00	151.71	4.51
UCF-15	A	182	70.19	0.00				
UCF-15	B	182	17.18	0.00				
UCF-15	C	182	12.62	0.25	33.33	0.08	185.05	4.60
UCF-15	A	217	66.12	0.00				
UCF-15	B	217	19.71	0.00				
UCF-15	C	217	6.87	0.12	30.90	0.04	215.95	4.64
UCF-15	A	288	17.64	1.56				
UCF-15	B	288	28.24	0.67				
UCF-15	C	288	13.94	1.74	19.94	1.33	235.89	5.97
UCF-15	A	330	16.93	2.99				
UCF-15	B	330	20.71	2.55				
UCF-15	C	330	16.18	1.87	17.94	2.47	253.83	8.44
UCF-15	A	371	15.79	4.41				
UCF-15	B	371	16.67	3.36				
UCF-15	C	371	19.67	2.37	17.38	3.38	271.21	11.81
UCF-15	A	413	14.37	6.40				
UCF-15	B	413	13.18	5.92				
UCF-15	C	413	15.06	3.24	14.20	5.18	285.41	17.00
UCF-15	A	489	13.80	8.25				
UCF-15	B	489	11.43	9.01				
UCF-15	C	489	12.57	11.70	12.60	9.65	298.01	26.65
UCF-15	A	534	6.83	12.38				
UCF-15	B	534	7.66	4.71				
UCF-15	C	534	10.58	5.35	8.36	7.48	306.37	34.13

Appendix 5.2c. Gaseous evolution of C02 and CH4 from unconsolidated flocculent sediments (UCF) incubated under anoxic conditions at 35°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			mg C L^{-1}		avg mg C		total mg C	
UCF-35	A	6	22.54	3.92				
UCF-35	B	6	13.72	2.34				
UCF-35	C	6	22.38	3.65	19.55	3.30	19.55	3.30
UCF-35	A	21	52.76	13.19				
UCF-35	B	21	49.49	11.68				
UCF-35	C	21	57.61	15.15	53.29	13.34	72.83	16.65
UCF-35	A	43	60.55	15.80				
UCF-35	B	43	76.02	24.93				
UCF-35	C	43	75.40	25.56	70.65	22.10	143.49	38.74
UCF-35	A	78	41.47	11.71				
UCF-35	B	78	18.99	13.05				
UCF-35	C	78	37.74	7.71	32.73	10.82	176.22	49.57
UCF-35	A	104	42.68	13.60				
UCF-35	B	104	35.85	17.59				
UCF-35	C	104	39.71	15.70	39.41	15.63	215.63	65.20
UCF-35	A	141	33.14	14.51				
UCF-35	B	141	17.75	9.83				
UCF-35	C	141	13.04	11.02	21.31	11.79	236.94	76.98
UCF-35	A	182	36.59	8.36				
UCF-35	B	182	11.79	4.90				
UCF-35	C	182	6.97	2.16	18.45	5.14	255.39	82.13
UCF-35	A	217	31.89	0.00				
UCF-35	B	217	28.66	0.00				
UCF-35	C	217	3.12	0.00	21.23	0.00	276.62	82.13
UCF-35	A	288	19.98	5.82				
UCF-35	B	288	14.78	8.02				
UCF-35	C	288	26.08	3.97	20.28	5.94	296.90	88.06
UCF-35	A	330	12.64	10.25				
UCF-35	B	330	29.59	14.30				
UCF-35	C	330	15.87	21.57	19.37	15.37	316.26	103.44
UCF-35	A	371	10.97	29.40				
UCF-35	B	371	13.48	38.72				
UCF-35	C	371	9.61	55.17	11.35	41.10	327.62	144.53
UCF-35	A	413	10.06	40.25				
UCF-35	B	413	8.96	37.77				
UCF-35	C	413	15.13	46.00	11.38	41.34	339.00	185.87
UCF-35	A	489	23.53	49.75				
UCF-35	B	489	17.55	60.52				
UCF-35	C	489	27.24	54.72	22.77	55.00	361.77	240.87
UCF-35	A	534	22.19	94.58				
UCF-35	B	534	27.48	95.02				
UCF-35	C	534	17.55	96.36	22.41	95.32	384.18	336.19

Appendix 5.2d. Gaseous evolution of CO2 and CH4 from consolidated flocculent sediments (CF) incubated under anoxic conditions at 25°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			mg C L^{-1}		avg mg C		total mg C	
CF-25	A	6	14.83	0.53				
CF-25	B	6	25.88	0.70				
CF-25	C	6	19.28	0.50	20.00	0.58	20.00	0.58
CF-25	A	21	44.28	1.64				
CF-25	B	21	36.29	1.09				
CF-25	C	21	38.01	1.78	39.53	1.50	59.52	2.08
CF-25	A	43	29.72	1.57				
CF-25	B	43	31.98	0.91				
CF-25	C	43	41.85	0.00	34.52	0.83	94.04	2.91
CF-25	A	78	13.07	0.00				
CF-25	B	78	18.45	0.21				
CF-25	C	78	14.65	0.79	15.39	0.34	109.43	3.25
CF-25	A	104	11.25	0.33				
CF-25	B	104	13.30	0.64				
CF-25	C	104	14.96	1.79	13.17	0.92	122.60	4.17
CF-25	A	141	5.58	2.79				
CF-25	B	141	31.22	0.00				
CF-25	C	141	19.51	0.57	18.77	1.12	141.37	5.29
CF-25	A	182	8.99	3.72				
CF-25	B	182	40.18	1.98				
CF-25	C	182	18.34	0.00	22.50	1.90	163.87	7.19
CF-25	A	217	8.68	4.65				
CF-25	B	217	19.16	0.00				
CF-25	C	217	21.94	3.78	16.59	2.81	180.46	10.00
CF-25	A	288	9.34	4.84				
CF-25	B	288	8.80	1.90				
CF-25	C	288	11.88	1.88	10.01	2.87	190.47	12.87
CF-25	A	330	16.60	6.57				
CF-25	B	330	9.66	2.59				
CF-25	C	330	8.96	3.54	11.74	4.23	202.21	17.11
CF-25	A	371	29.39	8.30				
CF-25	B	371	12.77	3.28				
CF-25	C	371	8.13	6.46	16.76	6.01	218.97	23.12
CF-25	A	413	14.52	7.26				
CF-25	B	413	8.11	3.80				
CF-25	C	413	7.92	3.75	10.18	4.94	229.16	28.06
CF-25	A	489	8.30	11.76				
CF-25	B	489	14.15	6.73				
CF-25	C	489	7.09	5.42	9.85	7.97	239.00	36.02
CF-25	A	534	9.68	16.60				
CF-25	B	534	5.52	7.25				
CF-25	C	534	5.00	7.71	6.74	10.52	245.74	46.54

Appendix 5.2e. Gaseous evolution of CO2 and CH4 from consolidated flocculent sediments (CF) incubated under anoxic conditions at 15°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			——mg C L^{-1}——		——avg mg C——		——total mg C——	
CF-15	A	6	5.10	0.21				
CF-15	B	6	4.57	0.18				
CF-15	C	6	21.16	0.35	10.28	0.25	10.28	0.25
CF-15	A	21	25.03	0.72				
CF-15	B	21	37.00	1.08				
CF-15	C	21	29.25	0.00	30.43	0.60	40.71	0.85
CF-15	A	43	24.67	0.00				
CF-15	B	43	47.95	0.00				
CF-15	C	43	24.38	0.00	32.33	0.00	73.04	0.85
CF-15	A	78	19.00	0.00				
CF-15	B	78	21.41	0.00				
CF-15	C	78	11.96	0.00	17.46	0.00	90.50	0.85
CF-15	A	104	15.89	0.00				
CF-15	B	104	19.49	0.00				
CF-15	C	114	11.85	0.00	15.74	0.00	106.24	0.85
CF-15	A	141	18.55	0.44				
CF-15	B	141	25.49	0.65				
CF-15	C	141	10.04	1.07	18.03	0.72	124.27	1.57
CF-15	A	182	21.55	0.00				
CF-15	B	182	23.06	0.22				
CF-15	C	182	11.74	1.30	18.78	0.51	143.05	2.07
CF-15	A	217	19.53	0.44				
CF-15	B	217	14.44	0.65				
CF-15	C	217	18.14	2.81	17.37	1.30	160.42	3.37
CF-15	A	288	16.65	2.11				
CF-15	B	288	11.90	1.42				
CF-15	C	288	11.11	2.40	13.22	1.97	173.63	5.35
CF-15	A	330	15.80	1.69				
CF-15	B	330	9.76	1.24				
CF-15	C	330	14.59	1.96	13.39	1.63	187.02	6.98
CF-15	A	371	15.17	1.05				
CF-15	B	371	11.54	1.07				
CF-15	C	371	15.03	0.65	13.91	0.92	200.93	7.90
CF-15	A	413	10.96	2.32				
CF-15	B	413	13.67	0.36				
CF-15	C	413	15.46	1.31	13.36	1.33	214.30	9.23
CF-15	A	489	11.59	1.69				
CF-15	B	489	11.90	0.89				
CF-15	C	489	16.12	0.87	13.20	1.15	227.50	10.38
CF-15	A	534	13.49	1.90				
CF-15	B	534	9.59	0.36				
CF-15	C	534	12.85	1.09	11.97	1.11	239.47	11.49

Appendix 5.2f. Gaseous evolution of CO2 and CH4 from consolidated flocculent sediments (CF) incubated under anoxic conditions at 35°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			——mg C L^{-1}——		——avg mg C——		——total mg C——	
CF-35	A	6	19.67	0.41				
CF-35	B	6	17.87	0.47				
CF-35	C	6	7.47	0.29	15.01	0.39	15.01	0.39
CF-35	A	21	40.98	1.10				
CF-35	B	21	32.56	1.72				
CF-35	C	21	41.42	0.85	38.32	1.22	53.33	1.62
CF-35	A	43	49.02	0.00				
CF-35	B	43	49.16	0.86				
CF-35	C	43	46.75	0.66	48.31	0.51	101.64	2.12
CF-35	A	78	19.12	0.49				
CF-35	B	78	50.78	2.36				
CF-35	C	78	13.03	0.00	27.64	0.95	129.28	3.07
CF-35	A	104	15.97	0.74				
CF-35	B	104	52.37	0.00				
CF-35	C	104	12.40	0.42	26.91	0.39	156.19	3.46
CF-35	A	141	8.48	0.00				
CF-35	B	141	8.40	0.70				
CF-35	C	141	12.89	0.42	9.92	0.37	166.11	3.83
CF-35	A	182	14.75	0.17				
CF-35	B	182	13.15	0.35				
CF-35	C	182	9.95	0.62	12.62	0.38	178.73	4.21
CF-35	A	217	5.76	0.66				
CF-35	B	217	4.51	0.87				
CF-35	C	217	12.88	1.04	7.72	0.85	186.45	5.06
CF-35	A	288	13.96	3.01				
CF-35	B	288	11.17	1.44				
CF-35	C	288	8.67	4.44	11.27	2.96	197.71	8.03
CF-35	A	330	10.67	3.28				
CF-35	B	330	13.27	2.51				
CF-35	C	330	8.93	6.59	10.96	4.13	208.67	12.16
CF-35	A	371	13.04	2.99				
CF-35	B	371	10.81	4.96				
CF-35	C	371	12.13	7.74	11.99	5.23	220.66	17.39
CF-35	A	413	20.91	6.79				
CF-35	B	413	6.73	5.49				
CF-35	C	413	10.67	5.86	12.77	6.05	233.44	23.43
CF-35	A	489	22.00	11.14				
CF-35	B	489	10.98	8.15				
CF-35	C	489	10.25	7.32	14.41	8.87	247.85	32.30
CF-35	A	534	13.85	11.95				
CF-35	B	534	13.11	9.04				
CF-35	C	534	5.44	6.49	10.80	9.16	258.65	41.48

Appendix 5.2g. Gaseous evolution of CO2 and CH4 from peat sediments incubated under anoxic conditions at 25°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			———mg C L^{-1}———		———avg mg C———		———total mg C———	
Peat-25	A	6	2.07	0.00				
Peat-25	B	6	0.00	0.00				
Peat-25	C	6	1.16	0.00	1.08	0.00	1.08	0.00
Peat-25	A	21	8.59	0.00				
Peat-25	B	21	3.48	0.00				
Peat-25	C	21	6.98	0.00	6.35	0.00	7.43	0.00
Peat-25	A	43	7.25	0.00				
Peat-25	B	43	8.98	0.00				
Peat-25	C	43	6.06	0.00	7.43	0.00	14.86	0.00
Peat-25	A	78	5.86	0.00				
Peat-25	B	78	21.19	0.00				
Peat-25	C	78	9.58	0.00	12.21	0.00	27.07	0.00
Peat-25	A	104	5.86	0.00				
Peat-25	B	104	6.81	0.00				
Peat-25	C	104	9.58	0.00	7.42	0.00	34.49	0.00
Peat-25	A	141	6.67	0.95				
Peat-25	B	141	19.80	3.30				
Peat-25	C	141	9.07	1.23	11.85	1.83	46.34	1.83
Peat-25	A	182	9.45	2.12				
Peat-25	B	182	18.86	6.21				
Peat-25	C	182	10.29	1.47	12.87	3.27	59.21	5.09
Peat-25	A	217	7.81	0.95				
Peat-25	B	217	19.95	9.97				
Peat-25	C	217	12.75	1.72	13.50	4.21	72.71	9.31
Peat-25	A	288	9.64	2.47				
Peat-25	B	288	14.51	1.29				
Peat-25	C	288	11.68	1.60	11.94	1.79	84.66	11.10
Peat-25	A	330	13.60	2.72				
Peat-25	B	330	15.48	1.29				
Peat-25	C	330	8.47	2.06	12.52	2.02	97.17	13.12
Peat-25	A	371	15.08	1.48				
Peat-25	B	371	17.74	2.58				
Peat-25	C	371	10.76	2.06	14.53	2.04	111.70	15.16
Peat-25	A	413	9.39	2.72				
Peat-25	B	413	13.22	3.55				
Peat-25	C	413	11.68	2.52	11.43	2.93	123.13	18.09
Peat-25	A	489	12.11	2.22				
Peat-25	B	489	10.97	3.55				
Peat-25	C	489	10.76	2.75	11.28	2.84	134.41	20.93
Peat-25	A	534	8.16	2.97				
Peat-25	B	534	15.80	4.52				
Peat-25	C	534	8.47	3.44	10.81	3.64	145.22	24.57

Appendix 5.2h. Gaseous evolution of CO2 and CH4 from peat sediments incubated under anoxic conditions at 15°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			mg C L^{-1}		avg mg C		total mg C	
Peat-15	A	6	2.15	0.00				
Peat-15	B	6	1.54	0.00				
Peat-15	C	6	0.53	0.00	1.41	0.00	1.41	0.00
Peat-15	A	21	5.26	0.00				
Peat-15	B	21	5.45	0.00				
Peat-15	C	21	3.17	0.00	4.62	0.00	6.03	0.00
Peat-15	A	43	6.74	0.00				
Peat-15	B	43	6.52	0.00				
Peat-15	C	43	11.33	0.00	8.20	0.00	14.23	0.00
Peat-15	A	78	7.41	0.00				
Peat-15	B	78	5.57	0.00				
Peat-15	C	78	12.87	0.00	8.62	0.00	22.85	0.00
Peat-15	A	104	7.11	0.00				
Peat-15	B	104	4.99	0.00				
Peat-15	C	104	9.28	0.00	7.13	0.00	29.97	0.00
Peat-15	A	141	12.43	0.00				
Peat-15	B	141	13.17	6.76				
Peat-15	C	141	5.42	0.00	10.34	2.25	40.31	2.25
Peat-15	A	182	12.40	0.80				
Peat-15	B	182	15.46	0.00				
Peat-15	C	182	5.76	4.17	11.21	1.66	51.52	3.91
Peat-15	A	217	19.02	1.19				
Peat-15	B	217	12.60	3.60				
Peat-15	C	217	6.34	10.70	12.65	5.16	64.17	9.08
Peat-15	A	288	6.72	0.22				
Peat-15	B	288	8.43	0.97				
Peat-15	C	288	6.85	0.24	7.33	0.48	71.51	9.55
Peat-15	A	330	8.89	0.00				
Peat-15	B	330	11.67	1.62				
Peat-15	C	330	7.83	0.49	9.46	0.70	80.97	10.26
Peat-15	A	371	8.89	0.22				
Peat-15	B	371	7.13	0.00				
Peat-15	C	371	8.81	1.47	8.28	0.56	89.24	10.82
Peat-15	A	413	4.55	2.17				
Peat-15	B	413	9.07	4.54				
Peat-15	C	413	5.87	0.24	6.50	2.32	95.74	13.13
Peat-15	A	489	3.25	1.74				
Peat-15	B	489	7.78	2.92				
Peat-15	C	489	7.58	1.47	6.20	2.04	101.95	15.17
Peat-15	A	534	4.77	2.17				
Peat-15	B	534	8.10	1.62				
Peat-15	C	534	5.14	1.96	6.00	1.92	107.95	17.09

Appendix 5.2i. Gaseous evolution of CO2 and CH4 from peat sediments incubated under anoxic conditions at 35°C.

Sample	Rep	Day	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved	CO_2 evolved	CH_4 evolved
			mg C L^{-1}		avg mg C		total mg C	
Peat-35	A	6	1.51	0.00				
Peat-35	B	6	2.87	0.00	2.42	0.00	2.42	0.00
Peat-35	C	6	2.89	0.00				
Peat-35	A	21	8.88	0.00				
Peat-35	B	21	4.20	0.00				
Peat-35	C	21	8.35	0.00	7.14	0.00	9.56	0.00
Peat-35	A	43	16.05	0.41				
Peat-35	B	43	15.94	0.78				
Peat-35	C	43	10.00	0.00	14.00	0.40	23.56	0.40
Peat-35	A	78	15.01	0.59				
Peat-35	B	78	8.71	0.21				
Peat-35	C	78	10.71	0.21	11.48	0.34	35.04	0.73
Peat-35	A	104	18.72	1.75				
Peat-35	B	104	13.47	4.00				
Peat-35	C	104	23.80	0.83	18.66	2.20	53.70	2.93
Peat-35	A	141	29.40	3.03				
Peat-35	B	141	25.38	3.67				
Peat-35	C	141	22.85	1.50	25.88	2.73	79.58	5.66
Peat-35	A	182	21.54	4.90				
Peat-35	B	182	13.93	1.68				
Peat-35	C	182	16.26	2.11	17.24	2.90	96.82	8.56
Peat-35	A	217	21.86	1.78				
Peat-35	B	217	18.73	3.87				
Peat-35	C	217	18.92	2.25	19.84	2.63	116.65	11.20
Peat-35	A	288	21.00	2.08				
Peat-35	B	288	17.55	1.77				
Peat-35	C	288	20.06	1.46	19.54	1.77	136.19	12.96
Peat-35	A	330	18.54	2.65				
Peat-35	B	330	14.31	3.10				
Peat-35	C	330	19.58	1.29	17.48	2.35	153.67	15.31
Peat-35	A	371	19.11	3.41				
Peat-35	B	371	16.52	0.59				
Peat-35	C	371	15.37	2.27	17.00	2.09	170.67	17.40
Peat-35	A	413	23.28	2.08				
Peat-35	B	413	16.82	2.07				
Peat-35	C	413	19.25	2.10	19.78	2.08	190.45	19.48
Peat-35	A	489	18.54	3.22				
Peat-35	B	489	16.82	1.62				
Peat-35	C	489	19.90	2.27	18.42	2.37	208.87	21.85
Peat-35	A	534	20.06	2.08				
Peat-35	B	534	16.37	2.36				
Peat-35	C	534	20.22	1.94	18.89	2.13	227.76	23.98

Appendix 5.2j. Concentrations of various forms of carbon found in unconsolidated flocculent sediments during anoxic incubations.

Sample	Rep	Day	Sample wt.	Dry wt.	TC sed	TOC sed	Acetic acid	Butyric acid	Propionic evolved	Total VFA evolved
			g		%	μg C mL^{-1}				
UCF	A	0	45.46	1.50		—	36.75	23.73	15.54	76.02
UCF	B	0	45.25	1.49	32.95	33.89	0.00	26.52	0.00	26.52
UCF	C	0	46.73	1.54	23.78	34.36	0.00	17.80	0.00	17.80
UCF	D	0	44.81	1.48	—	32.37	0.00	9.73	0.00	9.73
UCF	E	0	46.25	1.53	—	29.76	31.01	0.00	0.00	31.01
UCF	F	0	45.88	1.51	—	29.26	7.11	24.87	15.05	47.02
UCF-25	A	6	44.77	1.48	29.31	—	—	—	—	—
UCF-25	B	6	45.70	1.51	29.78	54.45	37.90	0.00	0.00	37.90
UCF-25	C	6	45.84	1.51	30.47	—	28.64	0.00	0.00	28.64
UCF-25	A	21	45.83	1.51	26.57	53.53	0.00	0.00	7.11	7.11
UCF-25	B	21	45.96	1.52	27.85	45.10	0.00	0.00	7.31	7.31
UCF-25	C	21	45.63	1.51	24.44	63.29	25.15	10.69	14.25	50.09
UCF-25	A	43	42.99	1.42	26.17	59.92	0.43	0.00	0.87	1.30
UCF-25	B	43	45.36	1.50	25.94	31.74	3.36	4.84	3.15	11.35
UCF-25	C	43	46.36	1.53	32.93	60.07	18.08	2.08	0.00	20.16
UCF-25	A	104	45.52	1.50	30.11	70.70	0.00	3.15	0.00	3.15
UCF-25	B	104	46.51	1.53	28.21	57.69	0.00	1.87	0.00	1.87
UCF-25	C	104	46.32	1.53	25.46	43.75	0.00	0.00	0.00	0.00
UCF-25	A	217	45.76	1.51	27.28	58.59	0.00	0.00	0.00	0.00
UCF-25	B	217	45.78	1.51	20.72	51.47	0.00	0.00	0.00	0.00
UCF-25	C	217	46.68	1.54	29.84	65.03	13.46	0.00	0.00	13.46
UCF-25	A	534	43.14	1.42	—	37.80	12.98	0.00	3.20	16.17
UCF-25	B	534	42.70	1.41	—	37.37	5.21	0.00	0.00	5.21
UCF-25	C	534	45.55	1.50	—	35.44	0.00	0.00	0.00	0.00
UCF-15	A	6	45.01	1.49	29.36	45.38	0.00	0.00	0.00	0.00
UCF-15	B	6	45.98	1.52	30.17	39.45	29.43	0.00	0.00	29.43
UCF-15	C	6	45.27	1.49	30.26	42.09	0.00	0.00	0.00	0.00
UCF-15	A	21	44.05	1.45	30.16	36.72	2.99	4.27	0.00	7.26
UCF-15	B	21	46.38	1.53	33.52	—	0.00	0.00	0.00	0.00
UCF-15	C	21	45.68	1.51	—	32.26	0.00	0.00	0.00	0.00
UCF-15	A	43	45.08	1.49	27.15	54.84	1.48	1.90	0.00	3.37
UCF-15	B	43	46.30	1.53	26.52	64.89	5.62	6.66	0.00	12.27
UCF-15	C	43	45.03	1.49	21.36	84.63	8.86	2.74	1.69	13.30
UCF-15	A	104	46.57	1.54	21.98	41.68	12.65	0.83	1.04	14.52
UCF-15	B	104	43.26	1.43	21.29	42.47	3.23	0.00	0.43	3.66
UCF-15	C	104	45.94	1.52	23.33	38.63	23.81	7.52	5.01	36.34
UCF-15	A	217	45.65	1.51	21.89	36.46	0.00	0.00	0.00	0.00
UCF-15	B	217	45.75	1.51	25.69	49.39	20.09	0.00	0.00	20.09
UCF-15	C	217	46.11	1.52	27.60	55.44	0.00	0.00	0.00	0.00
UCF-15	A	534	41.70	1.38	—	63.96	0.00	0.00	0.00	0.00
UCF-15	B	534	44.02	1.45	—	28.60	0.00	0.00	0.00	0.00
UCF-15	C	534	46.52	1.54	—	30.52	0.00	0.00	0.00	0.00
UCF-35	A	6	44.57	1.47	29.78	61.53	0.00	0.00	0.00	0.00
UCF-35	B	6	46.00	1.52	30.90	64.70	0.00	0.00	0.00	0.00
UCF-35	C	6	44.80	1.48	29.18	45.71	0.00	0.00	0.00	0.00
UCF-35	A	21	45.49	1.50	27.98	19.73	25.82	0.00	0.00	25.82
UCF-35	B	21	45.83	1.51	29.37	35.97	1.05	0.00	0.00	1.05
UCF-35	C	21	44.78	1.48	30.56	22.22	2.33	0.00	0.00	2.33
UCF-35	A	43	46.64	1.54	21.08	56.77	7.67	1.45	1.24	10.36
UCF-35	B	43	43.95	1.45	26.25	98.97	0.43	0.00	0.00	0.43
UCF-35	C	43	45.85	1.51	23.10	72.33	1.05	0.00	0.00	1.05
UCF-35	A	104	44.24	1.46	34.02	47.93	2.77	0.00	0.43	3.20
UCF-35	B	104	45.23	1.49	24.52	53.69	0.00	0.00	0.00	0.00
UCF-35	C	104	44.14	1.46	25.37	38.60	33.91	3.63	4.27	41.80
UCF-35	A	217	39.10	1.29	27.96	36.23	0.00	0.00	0.00	0.00
UCF-35	B	217	46.65	1.54	21.58	34.39	5.59	0.00	0.00	5.59
UCF-35	C	217	45.21	1.49	21.79	—	0.00	0.00	0.00	0.00
UCF-35	A	534	47.36	1.56	—	44.35	4.93	0.00	0.00	4.93
UCF-35	B	534	44.82	1.48	—	184.94	2.54	0.00	0.00	2.54
UCF-35	C	534	45.27	1.49	—	190.71	2.53	0.00	0.00	2.53

Appendix 5.2k. Concentrations of various forms of carbon found in consolidated flocculent sediments during anoxic incubations.

Sample	Rep	Day	Sample wt.	Dry wt.	TC sed	TOC sed	Acetic acid	Butyric acid	Propionic evolved	Total VFA evolved
			g		%	μg C mL^{-1}				
CF	A	0	27.30	1.83	35.14	45.74	0.00	0.00	0.00	0.00
CF	B	0	33.69	2.26	34.97	38.78	0.00	0.00	0.00	0.00
CF	C	0	34.19	2.29	—	41.06	0.00	0.00	0.00	0.00
CF	D	0	29.42	1.97	—	51.80	0.00	0.00	0.00	0.00
CF	E	0	30.00	2.01	—	—	—	—	—	—
CF	F	0	29.31	1.96	—	49.02	0.00	0.00	0.00	0.00
CF-25	A	6	33.52	2.25	30.84	142.08	0.00	0.00	0.00	0.00
CF-25	B	6	33.81	2.27	31.34	74.32	15.81	0.00	0.00	15.81
CF-25	C	6	34.88	2.34	31.31	58.35	0.00	0.00	0.00	0.00
CF-25	A	21	30.56	2.05	25.07	80.61	3.92	0.00	0.28	4.20
CF-25	B	21	33.31	2.23	18.49	65.39	0.00	0.00	5.85	5.85
CF-25	C	21	33.90	2.27	27.04	51.26	0.00	0.00	0.00	0.00
CF-25	A	43	34.69	2.32	24.41	95.17	0.00	0.00	3.10	3.10
CF-25	B	43	33.53	2.25	24.62	89.52	30.37	35.65	3.43	69.45
CF-25	C	43	33.11	2.22	28.01	115.10	0.00	0.00	0.00	0.00
CF-25	A	104	35.35	2.37	26.49	78.28	0.00	5.12	0.00	5.12
CF-25	B	104	29.19	1.96	22.90	59.25	0.00	0.00	0.00	0.00
CF-25	C	104	31.35	2.10	30.83	81.77	0.00	1.66	1.10	2.76
CF-25	A	217	21.09	1.41	—	75.33	0.00	0.00	0.00	0.00
CF-25	B	217	31.14	2.09	21.40	101.40	0.00	0.00	0.00	0.00
CF-25	C	217	31.81	2.13	22.48	40.49	0.00	0.00	0.00	0.00
CF-25	A	534	19.20	1.29	—	36.62	0.00	0.00	0.00	0.00
CF-25	B	534	34.27	2.30	—	45.16	0.00	0.00	0.00	0.00
CF-25	C	534	29.16	1.95	—	50.02	0.00	0.00	0.00	0.00
CF-15	A	6	29.72	1.99	31.69	61.00	0.00	0.00	0.00	0.00
CF-15	B	6	34.66	2.32	—	55.86	0.00	0.00	0.00	0.00
CF-15	C	6	19.71	1.32	29.92	0.00	0.00	0.00	0.00	0.00
CF-15	A	21	34.78	2.33	29.41	47.02	0.00	0.00	0.00	0.00
CF-15	B	21	29.99	2.01	27.77	30.75	0.00	0.00	0.00	0.00
CF-15	C	21	30.64	2.05	28.48	48.25	0.00	0.00	0.00	0.00
CF-15	A	43	30.96	2.07	26.45	178.98	3.76	5.37	0.00	9.14
CF-15	B	43	29.60	1.98	16.77	48.71	20.35	26.36	0.00	46.71
CF-15	C	43	34.23	2.29	25.30	91.63	25.55	27.21	7.50	60.26
CF-15	A	104	29.19	1.96	26.34	66.35	4.64	1.45	0.00	6.08
CF-15	B	104	29.30	1.96	25.60	63.77	6.64	3.46	1.44	11.54
CF-15	C	104	33.40	2.24	25.65	53.80	5.83	0.80	0.00	6.63
CF-15	A	217	29.77	1.99	18.60	60.64	2.00	0.00	0.00	2.00
CF-15	B	217	29.93	2.01	26.15	71.69	8.25	0.00	0.00	8.25
CF-15	C	217	30.08	2.02	25.39	113.94	4.84	18.80	0.00	23.64
CF-15	A	534	29.84	2.00	—	36.72	6.84	0.00	0.00	6.84
CF-15	B	534	34.09	2.28	—	30.63	0.00	0.00	0.00	0.00
CF-15	C	534	29.40	1.97	—	34.34	3.48	0.00	0.00	3.48
CF-35	A	6	28.84	1.93	30.29	58.99	0.00	0.00	0.00	0.00
CF-35	B	6	25.93	1.74	31.93	83.87	36.30	0.00	0.00	36.30
CF-35	C	6	38.33	2.57	30.33	79.80	0.00	0.00	0.00	0.00
CF-35	A	21	27.68	1.85	29.72	46.79	0.00	0.00	0.00	0.00
CF-35	B	21	35.03	2.35	28.39	53.42	4.65	0.00	0.00	4.65
CF-35	C	21	28.12	1.88	27.56	42.01	18.77	30.99	63.16	112.92
CF-35	A	43	28.15	1.89	25.93	136.29	8.57	0.00	1.18	9.76
CF-35	B	43	29.05	1.95	22.99	86.05	2.32	3.48	1.45	7.24
CF-35	C	43	28.74	1.93	24.05	126.79	31.11	0.00	0.00	31.11
CF-35	A	104	25.62	1.72	28.39	80.73	15.26	17.48	13.67	46.40
CF-35	B	104	11.68	0.78	25.27	85.27	20.60	36.05	62.38	119.03
CF-35	C	104	29.22	1.96	30.93	83.89	0.00	1.45	0.00	1.45
CF-35	A	217	35.46	2.38	25.34	49.56	2.55	5.11	0.00	7.66
CF-35	B	217	34.01	2.28	25.69	41.96	0.00	0.00	0.00	0.00
CF-35	C	217	29.62	1.98	18.08	67.95	6.02	0.00	0.00	6.02
CF-35	A	534	23.08	1.55	—	69.26	8.13	0.00	0.00	8.13
CF-35	B	534	32.79	2.20	—	52.60	3.22	0.00	0.00	3.22
CF-35	C	534	28.44	1.91	—	48.04	3.54	0.00	0.00	3.54

Appendix 5.21. Concentrations of various forms of carbon found in peat sediments during anoxic incubations.

Sample	Rep	Day	Sample wt.	Dry wt.	TC sed	TOC sed	Acetic acid	Butyric acid	Propionic evolved	Total VFA evolved
			g		%	μg C mL^{-1}				
Peat	A	0	26.64	2.45	49.23	48.46	0.00	0.00	0.00	0.00
Peat	B	0	27.71	2.55	45.43	47.09	0.00	0.00	0.00	0.00
Peat	C	0	26.44	2.43	—	49.98	0.00	0.00	0.00	0.00
Peat	D	0	23.17	2.13	—	52.32	0.00	0.00	0.00	0.00
Peat	E	0	26.07	2.40	—	38.04	0.00	0.00	0.00	0.00
Peat	F	0	26.35	2.42	—	46.17	0.00	0.00	0.00	0.00
Peat-25	A	6	19.01	1.75	35.91	103.81	0.00	0.00	0.00	0.00
Peat-25	B	6	21.15	1.95	27.06	72.82	0.00	0.00	0.00	0.00
Peat-25	C	6	27.19	2.50	37.06	—	18.43	0.00	0.00	18.43
Peat-25	A	21	18.48	1.70	33.62	115.43	3.97	0.00	37.01	40.97
Peat-25	B	21	27.82	2.56	30.04	—	0.00	0.00	0.00	0.00
Peat-25	C	21	20.90	1.92	36.09	8.42	0.00	0.00	17.64	17.64
Peat-25	A	43	20.04	1.84	28.96	145.02	1.25	1.67	9.58	12.50
Peat-25	B	43	16.70	1.54	38.23	151.58	11.55	42.83	10.11	64.48
Peat-25	C	43	20.67	1.90	22.89	115.72	0.00	0.00	0.00	0.00
Peat-25	A	104	20.94	1.93	39.88	77.71	0.00	0.00	0.00	0.00
Peat-25	B	104	19.06	1.75	38.15	81.39	1.27	0.00	0.00	1.27
Peat-25	C	104	20.35	1.87	37.62	88.87	0.00	0.00	0.00	0.00
Peat-25	A	217	21.18	1.95	26.99	142.53	1.26	0.00	0.00	1.26
Peat-25	B	217	19.35	1.78	22.66	82.98	0.00	0.00	0.00	0.00
Peat-25	C	217	18.02	1.66	29.82	97.88	0.00	0.00	0.00	0.00
Peat-25	A	534	17.72	1.63	—	44.76	0.00	0.00	0.00	0.00
Peat-25	B	534	14.73	1.36	—	52.21	0.00	0.00	0.00	0.00
Peat-25	C	534	19.02	1.75	—	45.09	0.00	0.00	0.00	0.00
Peat-15	A	6	15.36	1.41	37.68	84.36	0.00	0.00	0.00	0.00
Peat-15	B	6	20.19	1.86	40.14	99.69	53.36	0.00	0.00	53.36
Peat-15	C	6	17.36	1.60	38.89	88.58	0.00	0.00	0.00	0.00
Peat-15	A	21	14.51	1.33	32.28	60.27	93.87	0.00	0.00	93.87
Peat-15	B	21	16.51	1.52	32.90	35.24	0.00	0.00	0.00	0.00
Peat-15	C	21	18.72	1.72	37.58	42.22	0.00	0.00	0.00	0.00
Peat-15	A	43	16.77	1.54	31.07	172.95	1.45	0.00	0.00	1.45
Peat-15	B	43	19.36	1.78	31.41	144.14	3.84	2.99	0.00	6.82
Peat-15	C	43	13.79	1.27	29.12	211.56	0.00	0.00	0.00	0.00
Peat-15	A	104	15.97	1.47	33.70	163.49	7.97	1.50	0.00	9.47
Peat-15	B	104	21.62	1.99	33.37	115.54	5.88	0.00	1.18	7.05
Peat-15	C	104	14.46	1.33	38.62	199.42	26.73	0.00	4.28	31.01
Peat-15	A	217	12.28	1.13	26.96	200.91	0.00	22.12	0.00	22.12
Peat-15	B	217	13.48	1.24	34.24	205.13	0.00	0.00	0.00	0.00
Peat-15	C	217	22.33	2.05	37.12	138.36	1.52	0.00	0.00	1.52
Peat-15	A	534	20.45	1.88	—	40.12	0.00	0.00	0.00	0.00
Peat-15	B	534	14.52	1.34	—	39.64	0.00	0.00	0.00	0.00
Peat-15	C	534	18.55	1.71	—	35.73	0.00	0.00	0.00	0.00
Peat-35	A	6	25.85	2.38	39.97	120.67	0.00	0.00	0.00	0.00
Peat-35	B	6	26.94	2.48	39.49	61.45	0.00	0.00	0.00	0.00
Peat-35	C	6	26.78	2.46	35.95	52.26	0.00	0.00	0.00	0.00
Peat-35	A	21	22.57	2.08	34.53	52.75	0.00	0.76	0.00	0.76
Peat-35	B	21	30.66	2.82	34.36	28.34	0.00	0.00	0.00	0.00
Peat-35	C	21	25.85	2.38	35.76	112.14	0.00	0.00	11.01	11.01
Peat-35	A	43	20.73	1.91	30.84	—	0.00	0.00	0.00	0.00
Peat-35	B	43	21.59	1.99	20.52	93.25	11.36	20.77	0.00	32.13
Peat-35	C	43	23.91	2.20	28.62	130.67	2.91	5.82	4.37	13.10
Peat-35	A	104	21.19	1.95	27.57	78.34	0.00	0.00	0.00	0.00
Peat-35	B	104	19.97	1.84	25.59	61.45	0.00	0.00	0.00	0.00
Peat-35	C	104	20.04	1.84	32.05	76.78	0.00	0.00	0.00	0.00
Peat-35	A	217	23.09	2.12	26.01	121.23	0.00	0.00	0.00	0.00
Peat-35	B	217	25.81	2.37	32.64	81.86	4.84	9.67	0.00	14.51
Peat-35	C	217	26.44	2.43	28.49	67.44	0.00	0.00	0.00	0.00
Peat-35	A	534	21.69	2.00	—	43.01	0.00	0.00	0.00	0.00
Peat-35	B	534	26.24	2.41	—	47.54	0.00	0.00	0.00	0.00
Peat-35	C	534	24.43	2.25	—	44.23	0.00	0.00	0.00	0.00

Appendix 5.3.1. Acetic acid concentrations in sediments as a function of depth. Sediment in diffusion half-cell A was spiked with 4 mM acetic acid.

Depth	Concentration			
	rep I	rep II	rep III	Mean
—cm—	mM			
half-cell B				
-8 - -7	0.06	0.02	0.06	0.05
-7 - -6	0.06	0.03	0.06	0.05
-6 - -5	0.10	0.03	0.10	0.07
-5 - -4	0.05	0.05	0.13	0.07
-4 - -3	0.18	0.18	0.29	0.21
-3 - -2	0.38	0.40	0.45	0.41
-2 - -1	0.69	0.72	0.62	0.68
-1 - 0	0.75	0.83	0.80	0.79
half-cell A				
0 - 1	2.96	2.88	2.94	2.93
1 - 2	3.26	3.17	3.26	3.23
2 - 3	3.14	3.58	3.41	3.38
3 - 4	3.76	3.82	3.76	3.78
4 - 5	4.00	3.82	3.58	3.80
5 - 6	3.60	3.95	3.97	3.84
6 - 7	3.78	3.60	3.58	3.65
7 - 8	4.21	4.05	4.11	4.12

Appendix 5.3.2. Organic acid concentration in sediments as influenced by the addition of butyric acid in diffusion cell A. Sediment in diffusion half-cell B was spiked with 4 mM butyric acid.

Depth	Concentration			
	rep I	rep II	rep III	Mean
—cm—	—mM—			
	Butyric Acid			
half-cell B				
-8 - -7	0.00	0.00	0.00	0.00
-7 - -6	0.00	0.00	0.00	0.00
-6 - -5	0.00	0.00	0.00	0.00
-5 - -4	0.00	0.00	0.00	0.00
-4 - -3	0.01	0.01	0.03	0.02
-3 - -2	0.12	0.12	0.09	0.11
-2 - -1	0.49	0.66	0.62	0.59
-1 - 0	0.84	0.82	1.17	0.94
half-cell A				
0 - 1	2.43	2.53	3.05	2.67
1 - 2	2.55	3.05	2.48	2.69
2 - 3	3.02	3.21	2.43	2.89
3 - 4	3.74	3.58	3.56	3.63
4 - 5	3.85	3.75	3.72	3.77
5 - 6	3.87	3.88	3.84	3.86
6 - 7	3.17	3.91	3.69	3.59
7 - 8	3.58	3.70	—	3.64
	Acetic Acid			
half-cell B				
-8 - -7	0.03	0.02	0.00	0.02
-7 - -6	0.03	0.02	0.00	0.02
-6 - -5	0.00	0.00	0.00	0.00
-5 - -4	0.00	0.02	0.00	0.01
-4 - -3	0.05	0.00	0.05	0.03
-3 - -2	0.02	0.02	0.05	0.03
-2 - -1	0.03	0.02	0.02	0.02
-1 - 0	0.05	0.05	0.03	0.04
half-cell A				
0 - 1	0.02	0.03	0.03	0.03
1 - 2	0.03	0.03	0.02	0.03
2 - 3	0.05	0.06	0.02	0.04
3 - 4	0.05	0.06	0.02	0.04
4 - 5	0.06	0.06	0.06	0.06
5 - 6	0.03	0.03	0.03	0.03
6 - 7	0.00	0.02	0.05	0.02
7 - 8	0.00	0.00	—	0.00

Appendix 5.3.2 (cont'd.)

Depth	Concentration rep I	rep II	rep III	Mean
—cm—	—mM—			
	Propionic Acid			
half-cell B				
-8 - -7	0.00	0.00	0.00	0.00
-7 - -6	0.00	0.00	0.00	0.00
-6 - -5	0.00	0.00	0.00	0.00
-5 - -4	0.00	0.00	0.00	0.00
-4 - -3	0.00	0.00	0.00	0.00
-3 - -2	0.00	0.00	0.00	0.00
-2 - -1	0.00	0.00	0.01	0.00
-1 - 0	0.00	0.00	0.02	0.01
half-cell A				
0 - 1	0.03	0.01	0.02	0.02
1 - 2	0.08	0.07	0.00	0.05
2 - 3	0.04	0.04	0.03	0.03
3 - 4	0.00	0.00	0.02	0.01
4 - 5	0.00	0.00	0.04	0.01
5 - 6	0.08	0.04	0.04	0.05
6 - 7	0.03	0.03	0.03	0.03
7 - 8	0.00	0.03	—	0.02

Appendix 5.3.3. Volatile fatty acid concentrations in control samples after 72-h incubation.

Treatment	Volatile Fatty Acids		
	Acetic	Propionic	Butyric
	mM		
DI water	0.04	ND	ND
DI water	0.02	ND	ND
DI water	ND	ND	ND
4 mM Acetic	4.11	ND	ND
4 mM Acetic	4.09	ND	ND
4 mM Acetic	4.26	ND	ND
4 mM Butyric	0.02	ND	3.91
4 mM Butyric	0.04	0.02	3.84
4 mM Butyric	0.06	0.01	3.69

ND = not detected.

Appendix 5.4.1. Solution and adsorbed concentrations of butyric and acetic acid in anaerobic sediments (K-6). Equilibrium period = 24 h.

Butyric Acid			Acetic Acid		
Acid added	Acid in solution	Acid adsorbed	Acid added	Acid in solution	Acid adsorbed
mM	mM	mmol kg^{-1}	mM	mM	mmol kg^{-1}
0.0	0.00	0.0	0.0	0.00	0.0
0.0	0.00	0.0	0.0	0.00	0.0
0.0	0.00	0.0	0.0	0.00	0.0
0.5	0.00	15.2	1.0	0.86	4.2
0.5	0.00	15.2	1.0	0.38	18.8
0.5	0.00	15.2	1.0	0.80	6.1
1.0	0.15	25.8	2.0	1.44	17.0
1.0	0.19	24.5	2.0	1.61	11.8
1.0	0.29	21.5	2.0	0.88	33.9
2.0	0.83	35.5	4.0	2.38	49.1
2.0	0.98	30.9	4.0	2.55	43.9
2.0	1.04	29.1	4.0	2.81	36.1
4.0	2.36	49.7	8.0	7.91	2.7
4.0	2.74	38.2	8.0	7.50	15.2
4.0	2.40	48.5	8.0	7.48	15.8
8.0	7.87	3.9	10.0	9.01	30.0
8.0	7.74	3.9	10.0	9.56	13.3
8.0	7.91	2.7	10.0	9.87	3.9

Appendix 5.5a. Porewater N and P concentrations in unconsolidated flocculent sediments incubated under anoxic conditions.

			Water Soluble		KCl Exchangeable	
Day	Samp wt	Dry wt	NH_4-N	PO_4-P	NH_4-N	PO_4-P
	g		mg L^{-1}			
25°C						
0	45.46	1.50	30.03	1.55	29.26	2.08
0	45.25	1.49	28.63	1.09	31.10	1.15
0	46.73	1.54	28.98	1.24	33.79	1.65
6	44.77	1.48	30.27	0.89	50.33	1.85
6	45.70	1.51	29.74	0.65	34.03	1.00
6	45.84	1.51	28.85	0.48	35.52	1.11
21	45.83	1.51	36.38	1.15	51.76	2.53
21	45.96	1.52	35.70	1.59	50.75	2.95
21	45.63	1.51	34.37	0.96	47.96	2.22
43	42.99	1.42	42.40	1.69	57.47	2.33
43	45.36	1.50	41.20	1.77	54.95	2.12
43	46.36	1.53	38.66	1.85	54.15	2.12
104	45.52	1.50	55.40	3.46	85.03	4.05
104	46.51	1.53	51.46	3.24	78.77	7.09
104	46.32	1.53	58.64	4.51	92.00	5.20
217	45.76	1.51	74.12	6.82	105.89	11.07
217	45.78	1.51	84.11	3.79	111.71	6.14
217	46.68	1.54	57.16	5.24	139.54	8.51
534	43.14	1.42	141.24	4.25	229.39	8.47
534	42.70	1.41	154.38	4.88	225.59	12.17
534	45.55	1.50	124.98	5.71	181.48	10.09
15°C						
6	45.01	1.49	26.81	0.68	31.23	1.12
6	45.98	1.52	26.51	0.56	29.07	0.78
6	45.27	1.49	28.62	1.45	31.01	1.15
21	44.05	1.45	28.82	0.47	42.22	2.17
21	46.38	1.53	24.69	0.02	43.32	0.85
21	45.68	1.51	27.44	0.02	39.84	1.93
43	45.08	1.49	29.11	0.57	38.67	0.58
43	46.30	1.53	28.91	0.46	39.91	2.02
43	45.03	1.49	29.55	0.80	38.27	1.05
104	46.57	1.54	27.99	1.80	37.58	1.55
104	43.26	1.43	30.40	1.92	40.30	1.72
104	45.94	1.52	21.34	3.26	38.63	3.52
217	45.65	1.51	20.85	4.04	47.45	4.97
217	45.75	1.51	22.08	3.12	46.08	3.82
217	46.11	1.52	22.03	4.65	44.76	5.72
534	41.70	1.38	112.74	4.53	216.34	6.34
534	44.02	1.45	102.63	3.18	175.72	3.64
534	46.52	1.54	105.05	4.47	119.97	3.15
35°C						
6	44.57	1.47	36.92	2.46	54.59	1.60
6	46.00	1.52	36.52	1.73	53.35	1.42
6	44.80	1.48	35.55	2.62	53.86	1.45
21	45.49	1.50	41.14	1.95	46.90	4.05
21	45.83	1.51	40.15	2.11	43.98	4.00
21	44.78	1.48	42.75	2.41	47.92	3.85
43	46.64	1.54	50.77	3.96	55.02	4.29
43	43.95	1.45	53.66	3.98	57.35	4.57
43	45.85	1.51	54.14	3.87	59.34	4.39
104	44.24	1.46	55.81	4.45	51.21	5.03
104	45.23	1.49	60.85	5.79	58.79	6.24
104	44.14	1.46	58.01	5.25	51.53	5.40
217	39.10	1.29	37.51	1.60	66.93	1.70
217	46.65	1.54	34.16	1.26	52.87	0.74
217	45.21	1.49	36.24	2.53	48.24	2.13
534	47.36	1.56	125.26	1.90	208.37	3.74
534	44.82	1.48	126.81	4.81	256.86	5.53
534	45.27	1.49	96.66	6.54	215.90	12.40

Appendix 5.5b. Porewater N and P concentrations in consolidated flocculent sediments incubated under anoxic conditions.

			Water Soluble		KCl Exchangeable	
Day	Samp wt	Dry wt	NH_4-N	PO_4-P	NH_4-N	PO_4-P
	g		mg L^{-1}			
25°C						
0	27.30	1.83	58.46	5.03	87.98	7.12
0	33.69	2.26	56.98	5.09	80.84	5.88
0	34.19	2.29	57.54	5.18	67.03	6.13
6	33.52	2.25	52.32	5.23	58.27	3.59
6	33.81	2.27	53.24	5.14	51.09	2.44
6	34.88	2.34	54.72	5.21	57.82	3.52
21	30.56	2.05	56.82	4.65	66.13	4.75
21	33.31	2.23	55.02	4.57	62.41	4.94
21	33.90	2.27	54.94	4.47	63.96	5.19
43	34.69	2.32	55.34	5.40	62.71	4.86
43	33.53	2.25	61.00	5.68	63.28	4.48
43	33.11	2.22	50.21	4.97	60.56	5.21
104	35.35	2.37	57.81	4.91	63.32	5.78
104	29.19	1.96	50.58	4.13	65.54	5.06
104	31.35	2.10	47.79	4.09	65.51	6.36
217	21.09	1.41	57.58	5.98	39.02	9.65
217	31.14	2.09	59.01	4.72	91.66	7.35
217	31.81	2.13	57.48	4.05	91.51	5.83
534	19.20	1.29	131.53	2.97	215.31	8.44
534	34.27	2.30	75.91	4.11	132.06	5.01
534	29.16	1.95	141.37	4.32	108.89	3.92
15°C						
6	29.72	1.99	54.12	4.93	55.50	3.46
6	34.66	2.32	54.31	4.63	58.57	3.21
6	19.71	1.32	57.40	4.79	134.97	3.73
21	34.78	2.33	53.48	0.67	64.33	4.94
21	29.99	2.01	60.36	0.51	68.08	4.84
21	30.64	2.05	56.10	0.87	65.72	4.14
43	30.96	2.07	47.57	4.60	60.65	3.65
43	29.60	1.98	37.83	4.47	94.38	4.21
43	34.23	2.29	57.48	5.25	69.05	4.62
104	29.19	1.96	60.18	4.35	53.72	3.09
104	29.30	1.96	59.21	7.04	58.76	4.46
104	33.40	2.24	64.93	7.84	49.64	4.26
217	29.77	1.99	54.35	4.12	87.90	3.88
217	29.93	2.01	68.51	5.97	67.05	5.89
217	30.08	2.02	68.02	4.13	74.09	4.21
534	29.84	2.00	54.07	1.73	70.08	2.04
534	34.09	2.28	32.96	3.58	79.15	4.38
534	29.40	1.97	50.53	12.36	81.44	3.56
35°C						
6	28.84	1.93	53.17	5.23	55.65	3.87
6	25.93	1.74	57.27	5.29	60.17	3.55
6	38.33	2.57	52.71	4.86	60.23	3.17
21	27.68	1.85	54.89	4.53	67.01	4.86
21	35.03	2.35	53.16	4.03	65.39	5.33
21	28.12	1.88	54.82	4.56	68.04	5.07
43	28.15	1.89	58.53	5.00	68.96	4.67
43	29.05	1.95	61.43	5.39	67.73	4.01
43	28.74	1.93	56.06	4.67	68.30	4.33
104	25.62	1.72	51.81	5.98	119.89	4.26
104	11.68	0.78	49.21	4.75	146.46	4.90
104	29.22	1.96	54.68	5.70	107.78	4.68
217	35.46	2.38	53.54	2.91	96.34	2.79
217	34.01	2.28	41.51	3.36	92.23	2.71
217	29.62	1.98	54.44	4.19	91.99	3.89
534	23.08	1.55	63.69	4.74	138.96	3.59
534	32.79	2.20	69.62	4.06	132.21	3.54
534	28.44	1.91	90.07	3.56	113.13	2.81

Appendix 5.5c. Porewater N and P concentrations in peat sediments incubated under anoxic conditions.

Day	Samp wt	Dry wt	Water Soluble		KCl Exchangeable	
			NH_4-N	PO_4-P	NH_4-N	PO_4-P
	g		mg L^{-1}			
25°C						
0	26.64	2.45	5.46	0.17	8.34	0.18
0	27.71	2.55	4.97	0.13	6.26	0.23
0	26.44	2.43	5.14	0.10	8.45	0.18
6	19.01	1.75	3.46	0.04	5.19	0.32
6	21.15	1.95	4.92	0.04	5.44	0.29
6	27.19	2.50	4.19	0.03	5.00	0.29
21	18.48	1.70	8.81	0.22	15.62	0.08
21	27.82	2.56	6.88	0.09	5.59	0.23
21	20.90	1.92	8.02	0.04	2.60	0.07
43	20.04	1.84	5.42	0.04	2.32	0.08
43	16.70	1.54	10.11	0.05	8.06	0.09
43	20.67	1.90	9.54	0.04	9.23	0.08
104	20.94	1.93	12.04	1.29	2.23	0.59
104	19.06	1.75	11.02	0.04	8.60	0.08
104	20.35	1.87	12.35	0.86	8.20	0.68
217	21.18	1.95	7.32	2.35	10.86	1.95
217	19.35	1.78	5.49	6.64	20.15	5.97
217	18.02	1.66	9.25	5.05	17.89	4.34
534	17.72	1.63	9.34	0.77	17.43	2.38
534	14.73	1.36	11.69	0.22	30.86	1.08
534	19.02	1.75	10.66	0.35	20.73	1.32
15°C						
6	15.36	1.41	3.07	0.05	5.04	0.49
6	20.19	1.86	2.90	0.04	3.91	0.31
6	17.36	1.60	3.69	0.05	4.66	0.26
21	14.51	1.33	4.27	0.05	7.30	0.10
21	16.51	1.52	2.90	0.77	4.90	0.09
21	18.72	1.72	4.35	0.22	8.78	0.08
43	16.77	1.54	3.85	0.05	3.11	0.09
43	19.36	1.78	2.99	0.04	1.99	0.08
43	13.79	1.27	3.38	0.06	6.26	0.11
104	15.97	1.47	5.58	1.05	6.40	0.10
104	21.62	1.99	4.47	1.14	4.17	0.07
104	14.46	1.33	5.08	2.94	4.91	0.10
217	12.28	1.13	11.18	0.55	17.13	0.24
217	13.48	1.24	7.64	0.46	16.24	0.11
217	22.33	2.05	13.15	0.84	16.41	0.84
534	20.45	1.88	8.16	0.56	12.49	0.56
534	14.52	1.34	34.80	0.27	52.58	0.10
534	18.55	1.71	13.68	0.35	14.48	0.08
35°C						
6	25.85	2.38	9.28	0.03	5.09	0.31
6	26.94	2.48	5.34	0.07	6.09	0.41
6	26.78	2.46	4.69	0.03	5.64	0.42
21	22.57	2.08	5.69	0.04	9.69	0.35
21	30.66	2.82	5.49	0.03	9.97	0.26
21	25.85	2.38	6.85	0.65	6.99	0.06
43	20.73	1.91	8.50	0.08	4.94	0.07
43	21.59	1.99	7.84	0.24	4.47	0.07
43	23.91	2.20	12.99	0.25	9.53	0.07
104	21.19	1.95	7.95	1.11	10.04	0.88
104	19.97	1.84	4.21	1.47	16.01	0.85
104	20.04	1.84	6.64	1.12	10.73	0.85
217	23.09	2.12	10.82	1.04	16.82	1.22
217	25.81	2.37	5.53	1.14	10.33	0.98
217	26.44	2.43	8.26	0.71	12.78	0.54
534	21.69	2.00	28.24	0.90	36.42	1.43
534	26.24	2.41	18.43	0.44	39.43	1.02
534	24.43	2.25	35.93	0.83	28.06	1.90

Appendix 5.5d. Mineralization of added N to unconsolidated flocculent sediment incubated at 25°C under anoxic conditions.

		Water Soluble			KCl Extractable			
Sample	Day	NH_4-N	NO_3-N	TKN	NH_4-N	TKN	TN dry	N-15
		mg L^{-1}					%	A%
Alanine	0	22.42	15.00	42.59	22.25	40.13	2.83	0.408
Alanine	0	20.83	13.94	65.83	26.84	42.25	2.71	0.398
Alanine	0	23.47	11.12	37.47	24.72	45.42	2.77	0.377
Alanine	1	28.06	5.12	28.42	31.07	34.60	2.68	0.450
Alanine	1	28.59	10.41	26.47	37.78	30.37	2.63	0.445
Alanine	1	24.00	12.18	27.36	20.48	27.54	2.52	0.448
Alanine	2	17.12	0.71	25.59	22.25	28.22		
Alanine	2	23.47	6.00	19.77	26.84	27.54		
Alanine	2	29.83	3.53	22.59	26.84	34.60		
Alanine	3	27.65	0.00	30.18	26.48	14.83		
Alanine	3	26.94	0.00	22.77	25.78	23.30		
Alanine	3	22.42	0.00	28.77	21.54	25.78		
Alanine	5	26.65	5.29	26.83	33.90	44.14	2.79	0.379
Alanine	5	24.71	10.41	28.95	32.13	42.37	2.55	0.413
Alanine	5	23.47	8.30	28.95	37.78	26.48	2.69	0.376
Alanine	7	29.65	0.00	23.47	37.43	39.55	2.71	0.375
Alanine	7	20.47	7.59	22.42	25.42	36.02	2.73	0.378
Alanine	7	23.30	0.18	17.47	37.43	29.31	2.69	0.376
Alanine	10	19.77	0.18	17.12	41.67	31.43	2.64	0.431
Alanine	10	24.71	0.00	19.94	39.55	41.67	2.75	0.389
Alanine	10	26.83	4.59	32.30	37.43	58.97	2.63	0.378
Alanine	28	31.59	0.00	31.06	40.61	33.19	2.76	0.444
Alanine	28	23.83	3.00	24.71	31.07	38.13	2.65	0.447
Alanine	28	28.06	0.35	5.59	28.95	45.55	2.68	0.430
NH_4Cl	0	24.71	0.71	32.30	32.84	30.37	2.94	0.487
NH_4Cl	0	31.59	4.41	33.71	46.26	40.96	2.66	0.480
NH_4Cl	0	27.00	4.06	32.65	40.25	33.54	2.65	0.476
NH_4Cl	1	23.47	5.65	25.77	50.85	40.25	2.74	0.406
NH_4Cl	1	25.06	8.30	25.24	41.31	22.95	2.68	0.397
NH_4Cl	1	27.00	8.30	26.30	38.13	34.25	2.54	0.384
NH_4Cl	2	24.36	0.00	34.42	48.37	53.67		
NH_4Cl	2	26.47	1.94	33.01	50.49	40.25		
NH_4Cl	2	16.77	0.00	21.53	38.49	28.60		
NH_4Cl	3	21.18	0.00	25.42	40.24	28.71		
NH_4Cl	3	23.77	0.00	21.71	40.24	26.84		
NH_4Cl	3	24.12	0.00	25.42	40.48	41.31		
NH_4Cl	5	25.77	1.94	25.77	52.97	77.68	2.90	0.375
NH_4Cl	5	21.18	1.06	33.01	35.66	48.73	2.66	0.386
NH_4Cl	5	24.18	0.00	32.48	53.67	35.31	2.69	0.377
NH_4Cl	7	24.89	1.94	26.47	43.43	43.08	2.73	0.377
NH4Cl	7	24.00	0.35	24.53	58.97	30.72	2.53	0.376
NH_4Cl	7	25.06	3.18	17.47	58.26	46.96	2.57	0.380
NH_4Cl	10	24.53	6.35	18.18	44.49	38.49	2.66	0.402
NH_4Cl	10	27.53	5.12	25.95	36.37	36.37	2.73	0.418
NH_4Cl	10	28.77	0.00	28.59	35.66	37.78	2.66	0.413
NH_4Cl	28	23.47	1.59	24.00	30.72	30.01	2.59	0.421
NH_4Cl	28	22.77	4.06	25.59	38.13	36.02	2.62	0.419
NH_4Cl	28	23.77	4.77	13.77	42.73	26.48	2.58	0.418
Control	0	18.36	16.94	22.06	26.84	18.01	2.74	0.377
Control	0	21.36	19.59	20.12	25.78	19.42	2.69	0.376
Control	0	19.94	11.12	20.83	38.84	31.07	2.70	0.379
Control	1	23.83	3.88	27.00	33.19	23.66	2.66	0.378
Control	1	22.42	1.59	32.12	38.13	46.61	2.64	0.374
Control	1	24.89	6.35	29.48	18.71	37.08	2.65	0.374
Control	2	23.47	0.00	22.42	24.01	33.54		
Control	2	20.12	3.00	15.00	36.37	21.89		
Control	2	25.42	2.82	24.36	34.60	27.74		
Control	3	22.30	0.00	25.06	28.42	29.42		
Control	3	23.36	2.12	23.65	23.06	22.95		
Control	3	23.00	0.00	24.18	28.01	23.42		
Control	5	22.77	3.00	23.30	36.02	32.49	2.61	0.372

Appendix 5.5d (cont'd.)

Sample	Day	Water Soluble NH_4-N	Water Soluble NO_3-N	Water Soluble TKN	KCl Extractable NH_4-N	KCl Extractable TKN	TN dry	N-15
		mg L^{-1}					%	A%
Control	5	23.47	1.06	20.65	35.66	29.66	2.63	0.375
Control	5	36.54	3.00	22.77	29.31	42.73	2.71	0.376
Control	7	38.12	4.94	24.18	35.31	33.54	2.70	0.378
Control	7	26.30	1.06	13.41	41.67	34.96	2.73	0.374
Control	7	31.77	0.88	32.12	45.20	44.14	2.67	0.381
Control	10	25.42	4.59	28.24	48.02	49.08	2.63	0.372
Control	10	24.53	0.00	23.30	37.43	43.43	2.84	0.375
Control	10	24.89	2.82	30.01	35.66	61.79	2.68	0.373
Control	28	33.71	0.00	19.42	33.90	11.30	2.61	0.370
Control	28	16.77	0.71	17.12	29.31	16.24	2.20	0.368
Control	28	35.83	0.00	12.18	26.48	22.60	2.63	0.369

Appendix 6.1a. Data collected during monthly measurements of primary productivity and dinitrogen fixation at Apopka Spring.

Date	Julian date	Initial DO	Time in	C Fix Gross	C Fix Net	C Fix Resp.	Chl a	Phe	NH_4-N	PO_4-P	TKN	TP	N fix
		mg O_2 L^{-1}		mg C m^{-3} h^{-1}			mg m^{-3}		mg N L^{-1}	mg P L^{-1}	mg N L^{-1}	mg P L^{-1}	μg m^{-3} h^{-1}
1/17/89	17	7.1	10.5	268	27	295	33.89	7.80	0.07	0.002	0.29	0.012	2.41
1/17/89	17	7.1	10.5	455	188	268	46.21	1.95	0.18	0.008	0.41	0.014	1.02
1/17/89	17	7.1	10.5	295	134	161	39.02	4.11	0.12	0.005	0.36	0.017	1.11
3/27/89	86	9.75	11.0	873	777	95	50.32	17.25	0.05	0.005	1.29	0.005	2.27
3/27/89	86	9.75	11.0	900	859	41	34.92	34.09	0.17	0.004	0.34	0.018	1.61
3/27/89	86	9.75	11.0	1145	968	177	39.02	20.64	0.05	0.004	2.64	0.014	1.32
4/25/89	115	5.20	10.3	216	130	86	15.40	38.51	0.24	0.007	0.17	0.014	2.40
4/25/89	115	5.20	10.3	43	21	21	1.03	24.13	0.23	0.008	0.29	0.021	22.19
4/25/89	115	5.20	10.3	257	129	129	0	35.94	0.11	0.001	0.42	0.011	32.36
5/23/89	143	9.40	10.7	669	523	145	19.51	66.75	0.23	0.007	1.71	0.008	24.59
5/23/89	143	9.40	10.7	610	407	203	32.86	49.81	0.23	0.007	1.58	0.014	37.41
5/23/89	143	9.40	10.7	756	523	233	5.13	84.72	0.19	0.007	1.54	0.010	36.03
6/20/89	171	9.10	11.7	750	600	150	52.37	1.54	0.19	0.012	2.17	0.021	5.02
6/20/89	171	9.10	11.7	750	650	100	12.11	76.61	0.24	0.011	2.05	0.017	3.29
6/20/89	171	9.10	11.7	550	400	150	29.78	54.32	0.21	0.011	1.80	0.019	2.77
7/25/89	206	8.90	9.9	556	444	111	50.32	25.16	0.17	0.005	1.61	0.017	10.63
7/25/89	206	8.90	9.9	444	375	69	57.51	11.50	0.17	0.005	1.29	0.025	4.04
7/25/89	206	8.90	9.9	389	333	56	86.26	53.91	0.12	0.005	1.04	0.020	3.46
8/8/89	220	10.20	10.5	916	663	253	35.94	15.10	0.07	0.003	1.54	0.009	9.74
8/8/89	220	10.20	10.5	932	679	253	36.97	18.38	0.06	0.003	1.29	0.021	4.48
8/8/89	220	10.20	10.5	916	679	237	40.05	27.52	0.07	0.003	1.36	0.009	15.70
9/13/89	256	8.60	10.7	676	606	69	47.24	7.70	0.35	0.001	1.73	0.009	36.24
9/13/89	256	8.60	10.7	658	589	69	33.88	56.89	0.41	0.004	0.92	0.010	15.96
9/13/89	256	8.60	10.7	676	589	87	41.07	59.06	0.37	0.004	1.48	0.017	31.02
10/27/89	300	4.80	10.5	293	293	0	59.56	11.71	0.02	0.001	0.54	0.009	8
10/27/89	300	4.80	10.5	276	276	0	53.40	89.34	0.02	0.001	0.42	0.010	9.74
10/27/89	300	4.80	10.5	293	293	0	25.67	40.72	0	0.001	0.61	0.005	24.55
11/10/89	314	3.90	10.9	226	178	48	6.16	10.37	0	0.003	0.54	0.005	2.48
11/10/89	314	3.90	10.9	81	113	32	62.64	13.09	0	0.003	0.36	0.006	1.44
11/10/89	314	3.90	10.9	81	81	0	51.35	12.32	0.02	0.001	0.86	0.004	0.69
11/30/89	334	7.60	10.5	483	400	83	22.18	34.40	0.10	0.002	1.04	0.009	0.87
11/30/89	334	7.60	10.5	400	350	50	53.40	15.33	0.14	0.004	1.60	0.028	0.71
11/30/89	334	7.60	10.5	383	333	50	48.27	15.25	0.08	0.001	1.23	0.011	0.71

Appendix 6.1b. Data collected during monthly measurements of primary productivity and dinitrogen fixation at Apopka-Beauclair Canal.

	Julian	Initial	Time	C Fix									
Date	date	DO	in	Gross	Net	Resp.	Chl a	Phe	NH_4-N	PO_4-P	TKN	TP	N fix
		mg O_2 L^{-1}		—mg C m^{-3} h^{-1}—			—mg m^{-3}—		mg N L^{-1}	mg P L^{-1}	mg N L^{-1}	mg P L^{-1}	μg m^{-3} h^{-1}
1/17/89	17	7.1	10.5	268	27	295	33.89	7.80	0.07	0.002	0.29	0.012	2.41
1/17/89	17	9.65	12	400	337	63	13.97	13.14	0.13	0.001	0.89	0.018	1.13
1/17/89	17	9.65	12	575	413	163	35.94	10.72	0.13	0.009	1.36	0.014	1.30
1/17/89	17	9.65	12	388	288	100	22.59	6.16	0.17	0.007	0.54	0.009	1.13
3/8/89	67	8.7	11.7	444	389	56	74.97	33.58	0.13	0.010	1.67	0.013	11.16
3/8/89	67	8.7	11.7	444	333	111	74.97	28.55	0.12	0.010	1.48	0.013	10.78
3/8/89	67	8.7	11.7	444	333	111	47.24	45.49	0.17	0.010	1.86	0.013	10.01
3/27/89	86	11.9	12.2	933	33	900	27.73	6.78	0.08	0.004	1.48	0.010	24.71
3/27/89	86	11.9	12.2	733	33	700	13.35	8.74	0.08	0.004	1.39	0.009	37.18
3/27/89	86	11.9	12.2	767	33	800	27.73	6.78	0.09	0.004	1.56	0.017	30.71
4/25/89	115	11.4	11.8	1025	900	125	31.83	17.77	0.11	0.010	1.29	0.014	16.02
4/25/89	115	11.4	11.8	1100	850	250	23.62	37.48	0.10	0.001	1.86	0.012	20.26
4/25/89	115	11.4	11.8	1025	875	150	26.70	24.34	0.15	0.001	1.54	0.012	8.75
5/18/89	143	11.2	11.5	767	500	267	34.92	11.33	0.12	0.008	1.12	0.020	63.56
5/18/89	143	11.2	11.5	1200	867	333	83.18	37.89	0.12	0.008	1.54	0.017	39.66
5/18/89	143	11.2	11.5	1000	700	300	39.02	19.92	0.08	0.007	1.36	0.015	50.23
6/20/89	171	9.2	12.5	696	161	536	47.24	8.11	0.10	0.014	1.80	0.019	3.71
6/20/89	171	9.2	12.5	857	321	536	62.64	9.96	0.11	0.012	1.98	0.017	7.42
6/20/89	171	9.2	12.5	804	214	589	38.01	28.52	0.14	0.014	2.05	0.020	4.45
7/25/89	206	9.1	11.7	500	267	233	85.23	69.42	0.10	0.003	2.23	0.039	11.66
7/25/89	206	9.1	11.7	533	200	333	63.67	16.84	0.14	0.005	1.29	0.017	33.83
7/25/89	206	9.1	11.7	533	233	300	64.70	15.10	0.15	0.004	1.04	0.015	12.12
8/8/89	220	8.2	11.7	960	960	0	85.23	60.79	0.08	0.003	1.67	0.009	37.20
8/8/89	220	8.2	11.7	1050	1020	30	30.81	27.42	0.10	0.003	1.67	0.009	21.82
8/8/89	220	8.2	11.7	1170	1080	90	42.10	26.19	0.08	0.004	1.61	0.013	9.14
9/13/89	256	10.4	12.1	741	654	87	0	8.12	0.05	0.002	1.49	0.010	57.10
9/13/89	256	10.4	12.1	872	654	218	40.05	13.62	0.08	0.001	1.54	0.005	61.78
9/13/89	256	10.4	12.1	872	654	218	10.27	8.03	0.08	0.003	1.67	0.009	64.65
10/27/89	300	9.8	12.0	943	853	90	50.32	17.25	0.08	0.001	1.80	0.019	43.56
10/27/89	300	9.8	12.0	943	898	45	20.54	7.58	0	0.002	1.67	0.021	53.67
10/27/89	300	9.8	12.0	988	898	90	14.38	10.57	0	0.001	1.73	0.032	40.14
11/10/89	314	9.7	12.4	577	543	34	31.83	11.52	0.08	0.005	1.45	0.014	32.39
11/10/89	314	9.7	12.4	645	577	68	9.24	9.76	0	0.001	1.80	0.005	27.70
11/10/89	314	9.7	12.4	645	577	68	9.24	9.76	0.06	0.003	1.48	0.017	29.41
11/30/89	334	9.6	11.8	529	396	132	15.40	6.87	0.09	0.005	2.17	0.009	16.02
11/30/89	334	9.6	11.8	529	396	132	51.35	12.47	0	0.005	2.09	0.011	20.26
11/30/89	334	9.6	11.8	430	330	99	27.73	13.84	0	0.003	2.42	0.008	8.75

Appendix 6.1c. Data collected during monthly measurements of primary productivity and dinitrogen fixation at the Center Lake Station.

Date	Julian date	Initial DO	Time in	C Fix Gross	C Fix Net	C Fix Resp.	Chl a	Phe	NH_4-N	PO_4-P	TKN	TP	N fix
		mg O_2 L^{-1}		——mg C m^{-3} h^{-1}——			——mg m^{-3}——		mg N L^{-1}	mg P L^{-1}	mg N L^{-1}	mg P L^{-1}	μg m^{-3} h^{-1}
1/17/89	17	9.6	11.5	436	273	164	13.35	8.42	0.11	0.007	1.04	0.015	1.04
1/17/89	17	9.6	11.5	614	436	177	67.78	42.81	0.15	0.005	0.67	0.012	1.13
1/17/89	17	9.6	11.5	600	436	164	49.29	31.01	0.15	0.001	1.29	0.016	1.13
3/27/89	86	10	11.5	894	519	375	58.53	26.19	0.14	0.004	1.98	0.012	12.69
3/27/89	86	10	11.5	750	404	346	48.27	14.99	0.06	0.005	0.46	0.042	15.69
3/27/89	86	10	11.5	692	404	288	58.53	16.94	0.10	0.004	1.25	0.029	32.18
4/25/89	115	10.6	11.2	1096	755	341	23.62	28.14	0.10	0.008	1.48	0.012	21.85
4/25/89	115	10.6	11.2	1023	633	390	20.54	51.35	0.08	0.009	1.48	0.012	26.40
4/25/89	115	10.6	11.2	1047	706	341	0	39.54	0.12	0.005	1.54	0.012	20.58
5/23/89	143	10.2	11.5	1200	500	700	56.48	52.06	0.12	0.007	1.61	0.024	42.80
5/23/89	143	10.2	11.5	850	250	600	58.53	37.07	0.18	0.010	1.84	0.017	28.80
5/23/89	143	10.2	11.5	700	150	550	108.7	71.36	0.11	0.007	1.67	0.015	27.79
6/20/89	171	8.3	12.2	850	650	200	74.97	22.08	0.10	0.011	1.73	0.015	2.77
6/20/89	171	8.3	12.2	950	750	200	73.94	31.73	0.08	0.012	1.86	0.017	3.64
6/20/89	171	8.3	12.2	900	700	200	46.21	29.27	0.08	0.005	1.73	0.024	5.37
7/25/89	206	8	10.9	729	604	125	100.6	10.78	0.09	0.004	1.98	0.019	9.53
7/25/89	206	8	10.9	688	542	146	74.97	48.30	0.19	0.007	2.05	0.021	18.26
7/25/89	206	8	10.9	792	708	83	74.97	50.83	0.15	0.004	1.97	0.020	12.56
8/8/89	220	9.5	11	820	460	360	43.13	14.38	0.07	0.003	2.17	0.009	39.21
8/8/89	220	9.5	11	600	240	360	47.24	28.96	0.07	0.005	1.77	0.012	20.71
8/8/89	220	9.5	11	420	60	360	28.75	42.41	0.08	0.003	1.92	0.005	52.17
9/13/89	256	10.1	11.4	931	879	52	40.05	37.59	0.08	0.002	1.36	0.010	36.64
9/13/89	256	10.1	11.4	957	879	78	25.67	9.82	0.05	0.002	0.73	0.009	53.04
9/13/89	256	10.1	11.4	983	879	103	47.24	55.56	0.09	0.001	1.84	0.014	40.31
10/27/89	300	9.2	11.5	573	464	109	22.59	13.91	0.28	0.005	1.92	0.009	20.41
10/27/89	300	9.2	11.5	573	491	82	30.8	10.73	0.21	0.010	1.80	0.012	18.61
10/27/89	300	9.2	11.5	627	518	109	31.83	14.11	0.19	0.005	1.92	0.009	20.69
11/10/89	314	9.1	10.8	572	572	0	9.24	9.47	0	0.002	1.54	0.006	1.09
11/10/89	314	9.1	10.8	434	434	0	39.02	38.61	0.02	0.003	1.54	0.005	3.96
11/10/89	314	9.1	10.8	412	389	23	35.84	34.84	0.01	0.003	1.86	0.010	3.57
11/30/89	334	9.2	11.2	448	358	90	56.48	14.68	0.01	0.003	1.58	0.008	0.80
11/30/89	334	9.2	11.2	425	358	67	41.08	54.53	0.11	0.004	1.23	0.007	1.06
11/30/89	334	9.2	11.2	470	358	112	63.67	26.29	0.03	0.003	1.42	0.005	0.80

Appendix 7.2.1. Selected chemical parameters of the water samples collected from the Center Lake Station of Lake Apopka.

Sample	Date	TSS	TS	TDS	TOC	NH4-N	NO3-N	SRP	TKN	TP
#		mg/L	mg/L	mg/L	mg/L			mg/L		
1	13-Jul-88				21.02	0.428	<.01	0.029	8.10	0.24
2	15-Jul-88				45.21	0.690	0.04	0.011	8.15	0.17
3	18-Jul-88				25.50	0.438	<.01	0.046	8.20	0.19
4	20-Jul-88				32.56	0.212	<.01	0.052	7.34	0.25
5	22-Jul-88		Sample #s		34.41	0.554	<.01	0.049	5.83	0.16
6	25-Jul-88		1-23		26.17	0.221	<.01	0.023	6.56	0.14
7	27-Jul-88		were not		35.82	0.358	<.01	0.011	5.56	0.12
8	29-Jul-88		processed		48.35	0.467	<.01	0.006	8.26	0.20
9	31-Jul-88		for Solids		51.12	0.531	<.01	0.013	6.26	0.13
10	03-Aug-88				50.07	0.336	<.01	0.021	8.15	0.20
11	05-Aug-88				37.18	0.347	<.01	0.011	7.74	0.21
12	08-Aug-88				49.89	0.126	<.01	0.013	10.52	0.26
13	10-Aug-88				31.37	0.183	<.01	0.013	7.96	0.15
14	12-Aug-88				38.45	0.414	<.01	0.005	10.44	0.22
15	15-Aug-88				32.50	0.331	<.01	0.011	9.76	0.16
16	18-Aug-88				16.74	0.084	<.01	0.005	5.01	0.12
17	20-Aug-88				22.60	0.241	<.01	0.016	7.32	0.13
18	22-Aug-88				19.09	0.307	<.01	0.011	5.01	0.12
19	26-Aug-88				19.48	0.120	<.01	0.005	5.65	0.18
20	29-Aug-88				21.08	0.060	<.01	0.024	6.72	0.11
21	31-Aug-88				46.61	0.141	<.01	0.015	6.34	0.15
22	02-Sep-88				18.92	0.099	<.01	0.024	7.81	0.35
23	04-Sep-88				48.50	0.174	<.01	0.054	7.07	0.14
24	06-Sep-88	NA	346	NA	23.34	0.153	<.01	0.041	8.20	0.18
25	08-Sep-88	69	369	300	18.82	0.049	<.01	0.015	6.23	0.45
26	11-Sep-88	63	335	272	18.75	0.066	<.01	0.014	7.56	0.18
27	13-Sep-88	64	345	281	21.75	0.086	0.02	0.020	7.18	0.19
28	15-Sep-88	67	341	274	16.89	0.083	0.02	0.015	7.44	0.17
29	17-Sep-88	46	300	254	35.75	0.553	<.01	0.052	4.47	0.17
30	19-Sep-88	37	277	240	29.16	0.990	0.02	0.081	4.73	0.16
31	21-Sep-88	53	326	273	28.37	0.186	0.02	0.030	4.85	0.19
32	23-Sep-88	48	135	87	31.55	0.667	0.06	0.026	4.68	0.20
33	26-Sep-88	52	173	121	28.09	0.301	0.03	0.064	4.86	0.23
34	28-Sep-88	55	297	243	32.18	0.072	0.03	0.013	5.30	0.23
35	30-Sep-88	55	378	323	30.88	0.322	0.02	0.017	4.67	0.33
36	03-Oct-88	60	347	287	32.32	0.656	0.06	0.096	5.47	0.23
37	05-Oct-88	67	390	323	25.62	0.101	0.04	0.020	6.01	0.32
38	07-Oct-88	77	299	222	24.70	0.519	0.02	0.027	7.73	0.21
39	10-Oct-88	71	274	203	26.79		0.05	0.028	9.51	0.17
40	12-Oct-88	56	313	257	25.16	0.931	0.09	0.023	5.72	0.14
41	14-Oct-88	77	299	222	39.88	0.279	0.05	0.026	6.23	0.20
42	17-Oct-88	88	326	239	29.27	0.942	0.05	0.022	6.99	0.16
43	19-Oct-88	63	268	205	24.39	0.533	0.04	0.037	5.29	0.13
44	21-Oct-88	70	336	266	21.18	0.649	0.02	0.027	4.70	0.15
45	24-Oct-88	67	335	268	25.64	0.599	0.02	0.040	5.16	0.17
46	26-Oct-88	70	308	238	18.56	0.806	0.02	0.037	5.22	0.17
47	28-Oct-88	52	236	184	18.44	0.666	0.02	0.014	6.22	0.14
48	31-Oct-88	88	323	235	13.08	0.200	0.02	0.029	2.40	0.11
49	02-Nov-88	92	333	242	32.17	0.690	0.03	0.045	5.52	0.17
50	04-Nov-88	102	292	190	29.61	0.473	0.02	0.071	7.23	0.19
51	07-Nov-88	78	330	253	19.99	0.393	0.02	0.052	6.68	0.19
52	09-Nov-88	54	312	258	27.62	0.335	0.02	0.019	9.65	0.13
53	11-Nov-88	39	316	277	22.98	0.312	0.02	0.006	4.84	0.13
54	14-Nov-88	93	256	163	30.97	0.553	0.02	0.022	9.06	0.20
55	18-Nov-88	56	334	278	28.54	0.074	0.02	0.028	4.86	0.12
56	21-Nov-88	29	388	359	29.44	0.025	0.02	0.039	3.40	0.10
57	23-Nov-88	109	352	243	37.55	0.109	<.01	0.003	8.58	0.33
58	28-Nov-88	74	396	322	29.79	0.024	0.01	0.034	5.48	0.16
59	30-Nov-88	57	304	248	28.87	0.144	0.09	0.277	5.48	0.28
60	02-Dec-88	64	372	308	32.16	0.015	0.01	0.021	5.64	0.18
61	05-Dec-88	57	370	312	29.81	0.013	0.01	0.022	5.22	0.19
62	07-Dec-88	42	228	186	29.27	0.012	0.01	0.052	3.74	0.13
63	14-Dec-88	71	240	169	28.31	<.010	0.01	0.027	4.81	0.22

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Sample #	Date	TSS mg/L	TS mg/L	TDS mg/L	TOC mg/L	NH4-N	NO3-N	SRP mg/L	TKN	TP
64	16-Dec-88	49	270	221	30.34	<.010	0.01	0.013	4.18	0.15
65	19-Dec-88	65	306	241	28.20	0.014	0.01	0.037	3.90	0.13
66	21-Dec-88	32	346	313	23.80	0.036	0.04	0.043	3.35	0.08
67	23-Dec-88	23	304	282	26.86	<.010	<.01	0.012	3.14	0.08
68	26-Dec-88	25	242	217	27.02	<.010	0.10	0.029	3.87	0.10
69	28-Dec-88	40	314	273	27.30	0.031	<.01	0.020	3.66	0.14
70	30-Dec-88	33	280	247	28.64	0.017	<.01	0.034	4.21	0.10
71	02-Jan-89	46	312	265	28.89	0.042	<.01	0.033	4.16	0.11
72	04-Jan-89	91	400	309	30.98	0.018	0.03	0.025	5.74	0.18
73	06-Jan-89	66	332	266	29.92	0.030	0.01	0.043	4.70	0.15
74	09-Jan-89	55	400	345	39.74	0.014	0.01	0.025	3.69	0.12
75	11-Jan-89	67	308	241	35.41	0.034	0.01	0.096	8.09	0.17
76	13-Jan-89	57	226	169	29.68	0.058	<.01	0.032	3.92	0.13
77	16-Jan-89	56	266	211	20.06	0.227	0.01	0.032	4.73	0.22
78	18-Jan-89	60	364	304	19.23	0.233	0.01	0.022	4.09	0.19
79	20-Jan-89	51	373	322	15.34	0.288	<.01	0.047	3.67	0.23
80	23-Jan-89	88	287	200	11.87	0.215	0.01	0.036	6.08	0.36
81	25-Jan-89	55	259	205	15.99	0.228	<.01	0.049	4.92	0.27
82	27-Jan-89	37	220	183	21.20	0.261	<.01	0.036	3.78	0.24
83	30-Jan-89	61	358	298	14.52	0.410	<.01	0.023	3.29	0.23
84	01-Feb-89	62	285	223	14.78	0.126	<.01	0.018	3.16	0.21
85	03-Feb-89	56	311	256	17.75	0.149	<.01	0.022	3.73	0.17
86	06-Feb-89	52	234	182	10.58	0.186	<.01	0.034	2.98	0.13
87	08-Feb-89	55	242	188	14.36	0.321	<.01	0.021	4.05	0.15
88	10-Feb-89	86	364	278	24.94	0.200	<.01	0.023	4.32	0.29
89	13-Feb-89	75	357	281	17.73	0.188	<.01	0.019	3.74	0.19
90	15-Feb-89	50	274	224	16.16	0.104	0.02	0.019	3.17	0.17
91	17-Feb-89	64	262	198	9.25	0.086	<.01	0.030	4.56	0.20
92	20-Feb-89	68	240	173	18.38	0.067	<.01	0.016	3.08	0.19
93	22-Feb-89	78	316	238	15.99	0.276	<.01	0.042	2.79	0.16
94	24-Feb-89	84	359	275	13.68	0.100	<.01	0.033	6.55	0.36
95	27-Feb-89	115	359	243	10.93	0.030	<.01	0.009	4.53	0.23
96	01-Mar-89	66	403	337	14.48	0.179	<.01	0.012	3.98	0.21
97	03-Mar-89	72	350	279	13.46	0.158	<.01	0.020	3.95	0.16
98	06-Mar-89	66	379	313	19.42	0.557	0.02	0.101	3.90	0.15
99	08-Mar-89	88	403	315	25.73	0.057	<.01	0.016	5.71	0.22
100	10-Mar-89	90	293	203	20.93	0.282	<.01	0.040	5.52	0.19
101	13-Mar-89	64	328	264	27.20	0.229	<.01	0.039	5.87	0.19
102	15-Mar-89	55	257	202	26.96	0.239	<.01	0.019	3.78	0.16
103	17-Mar-89	42	313	271	15.48	0.478	0.01	0.130	3.66	0.22
104	20-Mar-89	70	291	221	22.29	0.094	0.02	0.038	5.88	0.24
105	22-Mar-89	87	366	279	26.71	0.136	0.01	0.039	4.91	0.19
106	24-Mar-89	103	368	265	20.03	0.268	0.02	0.042	6.88	0.23
107	27-Mar-89	93	321	228	24.27	0.321	0.01	0.062	5.44	0.21
108	29-Mar-89	112	400	288	24.19	0.086	0.01	0.019	6.62	0.28
109	31-Mar-89	97	397	300	20.12	0.127	<.01	0.094	5.88	0.29
110	02-Apr-89	92	358	266	20.42	0.306	0.01	0.062	6.82	0.23
111	04-Apr-89	97	356	259	19.48	0.256	<.01	0.045	5.96	0.17
112	06-Apr-89	170	426	256	20.60	0.150	<.01	0.076	7.15	0.27
113	08-Apr-89	129	359	230	20.07	0.167	0.01	0.053	7.48	0.23
114	10-Apr-89	111	369	258	15.38	0.182	<.01	0.033	5.61	0.16
115	12-Apr-89	102	355	253	25.29	<.010	<.01	0.025	6.19	0.20
116	14-Apr-89	107	355	248	18.20	0.118	<.01	0.037	6.72	0.22
117	16-Apr-89	64	349	284	16.86	0.619	<.01	0.074	6.05	0.25
118	18-Apr-89	101	368	267	33.77	0.153	<.01	0.025	5.54	0.15
119	20-Apr-89	104	336	232	19.64	0.058	<.01	0.033	7.28	0.13
120	22-Apr-89	111	328	217	21.13	0.170	<.01	0.053	6.71	0.10
121	24-Apr-89	88	318	230	16.02	0.155	0.01	0.048	4.93	0.19
122	26-Apr-89	80	366	286	15.58	0.236	0.01	0.035	5.18	0.12
123	28-Apr-89	86	361	275	20.11	0.062	0.02	0.022	5.55	0.17
124	30-Apr-89	102	358	256	18.54	0.140	0.01	0.027	4.32	0.06
125	02-May-89	84	392	308	17.44	0.044	0.01	0.021	8.42	0.23
126	04-May-89	105	366	261	20.50	0.124	0.01	0.087	6.67	0.16
127	06-May-89	112	383	271	17.60	0.276	0.01	0.071	6.16	0.23
128	08-May-89	98	360	262	26.62	0.041	<.01	0.025	5.11	0.13

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Sample #	Date	TSS mg/L	TS mg/L	TDS mg/L	TOC mg/L	NH4-N	NO3-N	SRP mg/L	TKN	TP
129	10-May-89	122	381	259	21.47	0.103	<.01	0.039	6.71	0.16
130	12-May-89	118	353	235	16.40	0.031	<.01	0.039	6.24	0.19
131	14-May-89	106	350	244	18.06	0.058	<.01	0.027	5.10	0.15
132	16-May-89	130	377	247	18.81	0.049	<.01	0.020	6.73	0.20
133	18-May-89	117	369	252	31.36	0.376	0.03	0.115	5.91	0.19
134	20-May-89	87	378	291	30.61	0.524	0.02	0.100	5.44	0.16
135	22-May-89	117	311	194	32.25	0.184	0.01	0.064	5.91	0.20
136	24-May-89	111	425	314	31.73	0.173	0.01	0.053	6.98	0.24
137	26-May-89	100	402	302	31.83	0.513	0.01	0.083	5.09	0.15
138	28-May-89	78	378	300	29.88	0.225	<.01	0.088	4.97	0.16
139	30-May-89	104	365	261	33.41	0.213	<.01	0.058	5.56	0.21
140	01-Jun-89	87	390	303	30.92	0.220	0.01	0.069	4.93	0.17
141	03-Jun-89	106	402	296	28.96	0.253	0.01	0.106	5.30	0.17
142	05-Jun-89	95	416	321	28.94	0.147	0.01	0.040	6.48	0.27
143	07-Jun-89	115	416	301	28.61	0.173	0.01	0.042	6.03	0.23
144	09-Jun-89	111	424	313	34.19	0.260	0.01	0.098	6.98	0.28
145	11-Jun-89	82	361	279	30.32	0.226	<.01	0.087	5.63	0.19
146	13-Jun-89	96	399	303	30.22	0.180	0.01	0.075	6.15	0.21
147	15-Jun-89	120	447	327	32.06	0.088	<.01	0.014	10.04	0.20
148	17-Jun-89	106	425	319	33.21	0.056	<.01	0.007	6.62	0.24
149	19-Jun-89	82	427	345	35.74	0.015	<.01	0.002	5.56	0.17
150	21-Jun-89	89	445	356	42.03	0.015	<.01	0.002	5.90	0.19
151	23-Jun-89	122	433	311	29.91	0.028	<.01	0.005	6.98	0.22
152	25-Jun-89	82	399	317	29.90	0.260	0.03	0.037	5.56	0.21
153	27-Jun-89	102	423	321	31.77	0.021	<.01	0.004	6.02	0.20
154	29-Jun-89	111	429	318	29.96	0.226	<.01	0.047	6.61	0.22
155	01-Jul-89	94	429	335	38.55	0.037	<.01	0.007	6.98	0.27
156	03-Jul-89	80	371	291	34.19	<.010	<.01	0.002	5.18	0.20
157	05-Jul-89	96	408	312	28.93	0.046	<.01	0.005	6.03	0.20
158	Field Blank	5	14	9	0.00	0.172	<.01	0.031	0.27	0.03
159	Field Blank	1	25	24	0.00	<.010	0.01	<.001	0.27	0.03
160	07-Jul-89	83	368	285	31.15	0.184	0.01	0.047	5.36	0.21
161	09-Jul-89	80	386	306	32.62	0.287	<.01	0.106	4.62	0.19
162	11-Jul-89	104	411	307	33.29	0.151	0.01	0.055	5.73	0.28
163	13-Jul-89	100	403	303	32.13	0.249	<.01	0.065	5.42	0.19
164	17-Jul-89	84	393	309	33.96	0.092	<.01	0.062	4.67	0.20
165	19-Jul-89	77	459	382	36.23	0.332	<.01	0.068	4.77	0.16
166	Field Blank	0	58	58	0.90	<.010	<.01	0.005	0.09	0.05
167	21-Jul-89	54	348	294	35.10	0.148	<.01	0.027	4.67	0.19
168	23-Jul-89	50	418	368	26.05	0.215	0.01	0.039	4.57	0.14
169	25-Jul-89	42	422	380	27.63	0.143	<.01	0.042	5.83	0.26
170	27-Jul-89	60	365	305	29.74	0.075	<.01	0.032	5.48	0.20
171	29-Jul-89	48	369	321	26.74	0.165	0.01	0.040	4.77	0.16
172	31-Jul-89	44	359	315	32.01	0.345	0.02	0.071	4.65	0.24
173	02-Aug-89	68	378	310	30.89	0.020	0.01	0.000	5.03	0.20
174	04-Aug-89	76	388	312	32.59	0.045	<.01	0.010	4.67	0.17
175	06-Aug-89	76	422	346	27.25	0.098	0.01	0.025	4.78	0.17
176	08-Aug-89	58	397	339	27.91	0.045	<.01	0.017	4.26	0.14
177	Field Blk	0	14	14	0	<.010	<.01	0.001	0.09	0.03
178	Field Blk	0	16	16	0	0.020	<.01	0.007	0.15	0.03
179	10-Aug-89	56	358	302	32.51	0.060	0.01	0.015	4.74	0.21
180	12-Aug-89	66	358	292	31.77	0.062	0.01	0.009	4.02	0.14
181	14-Aug-89	74	374	300	30.87	0.027	<.01	0.002	4.02	0.18
182	16-Aug-89	60	328	268	29.88	0.123	0.01	0.043	6.49	0.14
183	18-Aug-89	60	320	276	30.26	0.066	0.01	0.013	4.55	0.11
184	20-Aug-89	82	377	295	30.71	0.079	<.01	0.026	6.13	0.12
185	22-Aug-89	52	342	290	27.48	0.179	0.01	0.020	6.40	0.12
186	24-Aug-89	66	415	349	32.01	0.087	0.01	0.028	6.50	0.11
187	26-Aug-89	62	372	310	29.17	<.010	<.01	0.003	7.16	0.13
188	28-Aug-89	64	363	299	26.92	0.146	0.01	0.018	6.13	0.11
189	30-Aug-89	66	293	227	27.02	<.010	<.01	0.006	5.74	0.14
190	01-Sep-89	64	290	226	25.91	0.201	0.02	0.061	4.25	0.19
191	03-Sep-89	80	359	279	33.24	0.222	0.01	0.039	5.29	0.23
192	05-Sep-89	66	336	270	30.14	0.165	0.02	0.031	4.75	0.21
193	07-Sep-89	60	340	280	28.77	0.063	0.01	0.017	9.05	0.21

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Sample	Date	TSS	TS	TDS	TOC	NH4-N	NO3-N	SRP	TKN	TP
#		mg/L	mg/L	mg/L	mg/L			mg/L		
194	09-Sep-89	62	293	231	27.38	0.168	0.03	0.038	4.49	0.22
195	11-Sep-89	64	326	262	28.94	0.090	0.01	0.023	4.62	0.20
196	13-Sep-89	72	362	290	29.59	0.041	0.01	0.010	4.86	0.22
197	15-Sep-89	72	349	277	34.35	<.010	<.01	0.052	4.37	0.20
198	17-Sep-89	78	389	311	30.46	0.170	<.01	0.026	4.71	0.20
199	19-Sep-89	82	362	280	33.28	0.185	<.01	0.094	5.08	0.22
200	21-Sep-89	96	444	348	32.15	0.114	<.01	0.052	7.42	0.37
201	23-Sep-89	64	351	287	30.39	0.092	0.01	0.017	4.47	0.25
202	25-Sep-89	80	341	261	31.37	0.056	<.01	0.029	4.86	0.21
203	27-Sep-89	66	339	273	29.71	0.075	<.01	0.031	4.62	0.20
204	29-Sep-89	75	344	270	34.95	0.029	0.03	0.014	6.44	0.21
205	01-Oct-89	71	333	263	32.11	<.010	0.02	0.006	6.30	0.20
206	03-Oct-89	89	365	275	36.41	0.103	0.01	0.037	6.13	0.20
207	05-Oct-89	61	361	300	33.84	<.010	0.02	0.003	6.59	0.19
208	07-Oct-89	59	351	292	37.44	0.078	0.01	0.027	5.16	0.16
209	09-Oct-89	71	297	227	34.76	0.018	<.01	0.014	10.20	0.32
210	11-Oct-89	68	371	303	35.03	<.010	<.01	0.010	8.40	0.25
211	13-Oct-89	67	376	310	36.27	<.010	<.01	0.003	9.86	0.32
212	15-Oct-89	61	376	315	34.18	0.017	<.01	0.012	3.62	0.22
213	17-Oct-89	59	297	239	34.85	<.010	<.01	0.006	6.76	0.18
214	19-Oct-89	67	344	278	33.10	<.010	<.01	0.005	7.35	0.29
215	21-Oct-89	81	359	278	33.81	0.029	<.01	0.010	6.39	0.24
216	23-Oct-89	61	363	302	36.49	<.010	0.01	0.005	4.61	0.14
217	25-Oct-89	69	303	234	33.73	0.119	<.01	0.034	6.78	0.28
218	27-Oct-89	79	345	267	37.64	<.010	<.01	0.006	5.04	0.17
219	29-Oct-89	101	369	268	44.02	0.059	<.01	0.028	5.90	0.23
220	31-Oct-89	73	388	315	36.24	0.122	0.01	0.012	5.39	0.21
221	02-Nov-89	69	341	273	32.50	0.135	0.01	0.014	4.23	0.20
222	04-Nov-89	86	451	365	35.14	0.135	0.01	0.017	4.53	0.22
223	06-Nov-89	78	442	364	47.76	0.318	0.01	0.013	4.96	0.23
224	08-Nov-89	86	364	278	34.14	0.133	0.01	0.120	5.01	0.25
225	10-Nov-89	63	394	330	37.55	0.133	0.01	0.018	5.77	0.25
226	12-Nov-89	71	406	335	41.13	0.084	0.01	0.014	8.56	0.25
227	14-Nov-89	86	388	302	34.49	0.135	0.01	0.016	4.35	0.19
228	16-Nov-89	75	378	303	33.47	0.079	0.01	0.018	5.07	0.33
229	18-Nov-89	82	407	325	37.71	0.130	0.01	0.042	4.92	0.23
230	20-Nov-89	69	348	279	39.21	0.160	0.01	0.020	4.38	0.31
231	22-Nov-89	53	441	388	34.72	0.122	0.01	0.016	3.87	0.15
232	24-Nov-89	78	360	282	34.16	0.163	0.01	0.044	4.59	0.22
233	26-Nov-89	45	366	321	31.97	0.112	0.01	0.010	3.73	0.16
234	28-Nov-89	27	351	323	31.84	0.130	0.01	0.073	3.86	0.11
235	30-Nov-89	87	370	282	34.68	0.082	<.01	0.025	4.95	0.21
236	02-Dec-89	54	358	304	31.34	0.196	<.01	0.087	3.74	0.13
237	04-Dec-89	85	380	295	37.52	0.116	0.01	0.063	5.77	0.23
238	06-Dec-89	55	356	301	39.30	0.170	0.01	0.050	3.07	0.19
239	08-Dec-89	49	357	308	33.09	0.151	0.01	0.042	4.01	0.16
240	10-Dec-89	85	357	272	34.65	0.176	0.02	0.071	4.76	0.20
241	12-Dec-89	35	368	332	34.20	0.131	0.01	0.020	4.24	0.17
242	14-Dec-89	70	358	288	33.54	0.227	0.01	0.064	5.02	0.30
243	16-Dec-89	42	352	310	35.28	0.147	0.01	0.056	3.90	0.17
244	20-Dec-89	58	318	260	32.86	0.128	0.01	0.048	4.00	0.19
245	22-Dec-89	58	369	311	33.72	0.075	0.01	0.098	4.63	0.18
246	26-Dec-89	57	352	295	38.98	0.084	0.01	0.091	4.34	0.18
247	28-Dec-89	45	275	231	33.79	0.038	<.01	0.054	3.87	0.16
248	30-Dec-89	47	398	351	31.48	0.092	0.01	0.025	3.24	0.24
249	01-Jan-90	51	357	305	34.49	0.216	0.04	0.117	4.10	0.25
250	03-Jan-90	38	344	306	32.16	0.107	0.02	0.221	3.87	0.26
251	05-Jan-90	45	427	382	33.40	0.194	0.04	0.114	3.33	0.19
252	07-Jan-90	17	365	349	30.44	0.048	0.01	0.19	3.29	0.19
253	09-Jan-90	47	377	330	39.15	0.062	0.01	0.033	3.99	0.14
254	11-Jan-90	42	351	309	38.77	0.025	<.01	0.054	3.37	0.11
255	13-Jan-90	106	418	312	44.71	0.029	0.01	0.008	6.05	0.26
256	15-Jan-90	37	350	313	32.89	0.026	<.01	0.013	3.63	0.13
257	17-Jan-90	49	367	318	42.88	0.131	0.01	0.054	4.57	0.20
258	19-Jan-90	41	350	309	36.86	0.039	<.01	0.016	3.55	0.12

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Sample # 	Date	TSS mg/L	TS mg/L	TDS mg/L	TOC mg/L	NH4-N	NO3-N	SRP mg/L	TKN	TP
259	21-Jan-90	36	368	332	36.86	0.084	0.01	0.045	3.73	0.21
260	23-Jan-90	51	368	317	37.04	0.085	0.01	0.061	3.98	0.15
261	25-Jan-90	64	400	336	35.66	0.017	<.01	0.013	2.96	0.10
262	27-Jan-90	87	407	320	49.65	0.148	0.02	0.101	4.66	0.19
263	29-Jan-90	55	384	329	44.62	0.079		0.039	4.11	0.16
264	31-Jan-90	60	404	344	39.03	0.248		0.074	4.08	0.15
265	02-Feb-90	75	404	329	46.03	0.214		0.14	3.96	0.15
266	04-Feb-90	75	396	320	38.81				4.90	0.20
267	06-Feb-90	69	458	388	37.21	0.355	0.07	0.161	5.54	0.18
268	08-Feb-90	56	431	375	36.68	0.137	0.06	0.080	4.78	0.11
269	10-Feb-90	96	408	312	35.62	0.080	0.04	0.101	5.60	0.15
270	12-Feb-90	118	408	290	34.96	0.124	0.05	0.073	7.25	0.20
271	14-Feb-90	88	440	352	46.7	0.090	0.03	0.084	6.89	0.17
272	16-Feb-90	78	455	377	50.13	0.390	0.13	0.276	7.02	0.28
273	18-Feb-90	86	435	349	33.77	0.137	0.04	0.068	5.80	0.16
274	20-Feb-90	84	450	366	33.76	0.163	0.04	0.138	6.66	0.17
275	22-Feb-90	120	460	340	39.18	0.048	0.02	0.034	8.53	0.27
276	24-Feb-90	154	534	380	34.43	0.099	0.02	0.018	9.55	0.37
277	26-Feb-90	78	386	308	34.24	0.150	0.04	0.037	7.09	0.23
278	28-Feb-90	72	442	370	38.02	0.201	0.05	0.037	7.44	0.24
279	02-Mar-90	64	515	451	45.43	0.255	0.06	0.075	7.37	0.17
280	04-Mar-90	76	406	330	32.98	0.139	0.03	0.015	6.19	0.18
281	06-Mar-90	84	361	277	41.02	0.096	0.05	0.037	6.78	0.23
282	08-Mar-90	138	457	319	37.52	0.160	0.07	0.040	9.78	0.45
283	10-Mar-90	82	449	367	37.26	0.048	0.03	0.015	6.07	0.18
284	12-Mar-90	64	404	340	32.86	0.032	0.03	0.009	6.18	0.17
285	14-Mar-90	74	381	307	35.27	0.234	0.04	0.092	7.84	0.27
286	16-Mar-90	98	363	265	53.61	0.265	0.07	0.060	9.08	0.31
287	18-Mar-90	102	355	253	49.05	0.140	0.02	0.064	4.79	0.29
288	20-Mar-90	102	410	308	40.56	0.084	0.01	0.040	9.22	0.31
289	22-Mar-90	84	370	286	38.43	0.089	0.01	0.034	7.72	0.26
290	24-Mar-90	80	350	270	42.27	0.160	0.02	0.133	9.73	0.22
291	26-Mar-90	50	339	289	41.97	0.204	0.04	0.137	9.97	0.14
292	28-Mar-90	84	369	285	40.95	0.036	0.02	0.035	7.12	0.23
293	30-Mar-90	90	336	246	38.08	0.313	0.04	0.033	8.67	0.26
294	01-Apr-90	68	390	322	36.98	0.135	0.01	0.039	6.78	0.21
295	03-Apr-90	116	439	323	39.56	0.801	0.04	0.044	9.26	0.32
296	05-Apr-90	70	403	333	43.47	0.072	0.01	0.022	9.29	0.25
297	07-Apr-90	80	328	248	37.78	0.110	0.01	0.081	6.74	0.23
298	09-Apr-90	106	399	293	37.88	0.062		0.001	7.84	0.28
299	11-Apr-90	136	310	174	47.73	0.054		0.032	9.61	0.37
300	13-Apr-90	96	257	161	53.05	0.156		0.195	9.18	1.14
301	15-Apr-90	84	332	248	36.68	0.163	0.01	0.058	6.59	0.22
302	17-Apr-90	58	341	283	39.28	0.098	0.01	0.045	5.25	0.12
303	19-Apr-90	66	404	338	49.20	0.271		0.155	7.30	0.22
304	21-Apr-90	72	416	344	36.78	0.314		0.188	6.37	0.19
305	23-Apr-90	78	423	345	38.38	0.277		0.200	7.37	0.20
306	25-Apr-90	70	411	341	37.64	0.145		0.127	6.59	0.19
307	27-Apr-90	88	456	368	26.77	0.167		0.091	2.38	<.01
308	29-Apr-90	64	406	342	46.79	0.060		0.018	5.37	0.13
309	01-May-90	54	387	333	36.04	0.111		0.037	5.60	0.13
310	03-May-90	72	394	322	38.02	0.074	0.01	0.004	6.26	0.17
311	05-May-90	80	407	327	48.12	0.060		0.046	6.24	0.18
312	07-May-90	70	446	376	46.33	0.028		0.002	7.09	0.22
313	09-May-90	84	428	344	45.45	0.030		0.012	7.86	0.24
314	11-May-90	90	336	246	45.82	0.014		0.002	8.76	0.24
315	13-May-90	76	434	358	40.31	0.111		0.094	6.88	0.20
316	15-May-90	60	401	341	46.47	0.073		0.002	6.62	0.16
317	17-May-90	98	430	332	43.68	0.033		0.016	7.30	0.22
318	19-May-90	80	424	344	40.24	0.060	0.01	0.058	7.80	0.22
319	21-May-90	80	421	341	53.05	0.103		0.097	7.66	0.21
320	23-May-90	78	421	343	44.29	0.025		0.002	6.49	0.17
321	25-May-90	92	378	286	38.25	0.176	0.01	0.080	3.02	0.19
322	27-May-90	82	416	334	52.56	0.145	0.01	0.100	2.94	0.19
323	29-May-90	116	406	290	30.97	0.122	0.01	0.077	3.78	0.26
324	31-May-90	130	401	271	34.53	0.105	0.01	0.063	3.70	0.24

Appendix 7.2.2. Selected chemical properties of the porewater of the sediment cores obtained from Station F-6 of Lake Apopka.

	Depth	Dry weight	Dry bulk density	pH	EC	Alkalinity	NH_4-N	SRP
	cm	—%—	g cm^{-3}		μS cm^{-1}	mg $CaCO_3$ L^{-1}	——mg L^{-1}——	
Sampling date 10/7/88 (Fall):								
Core I	0-2	1.17	0.013	8.15	370	141	0.316	0.010
	2-4	1.37	0.016	7.55	510	151	4.757	0.010
	4-8	1.54	0.015	7.39	600	322	10.307	0.021
	8-12	1.96	0.022	7.29	680	363	16.967	0.922
	12-16	2.46	0.026	7.20	700	413	21.556	2.010
	16-20	2.92	0.034	7.10	760	429	23.258	1.943
	20-25	4.13	0.046	6.95	800	458	26.218	2.219
	25-30	7.15	0.088	7.20	830	491	26.588	2.100
	30-40	8.16	0.093	7.10	800	475	25.700	1.772
	50-60	7.21	0.082	7.10	800	482	24.146	1.130
Core II	0-2	1.09	0.011	7.95	385	181	0.316	0.008
	2-4	1.50	0.018	7.70	430	205	1.427	0.007
	4-8	1.65	0.017	7.43	520	293	7.125	0.012
	8-12	2.23	0.026	7.00	660	345	16.597	1.190
	12-16	2.62	0.025	7.20	700	352	21.408	2.107
	16-20	3.19	0.036	7.10	770	372	23.776	2.405
	20-25	4.04	0.046	7.10	800	479	26.292	2.532
	25-30	7.14	0.083	7.10	800	497	27.846	2.301
	30-40	6.84	0.076	7.10	800	506	25.848	1.921
	50-60	6.71	0.065	7.10	810	496	24.738	1.287
Core III	0-2	1.09	0.011	8.00	380	158	0.316	0.005
	2-4	1.30	0.014	7.70	435	115	1.797	0.007
	4-8	1.63	0.018	7.30	560	327	9.345	0.010
	8-12	2.14	0.023	7.35	650	371	16.893	1.160
	12-16	2.95	0.032	7.20	710	423	23.850	2.219
	16-20	3.75	0.042	7.15	750	482	26.440	2.517
	20-25	5.92	0.065	7.15	800	468	27.254	2.405
	25-30	9.02	0.107	7.15	790	483	27.180	2.187
	30-40	6.35	0.069	7.10	790	489	26.292	1.794
	50-53	6.63	0.048	NA	NA	NA	23.258	1.101

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Sample	Date	TSS	TS	TDS	TOC	NH4-N	NO3-N	SRP	TKN	TP
#		mg/L	mg/L	mg/L	mg/L			mg/L		
325	02-Jun-90	104	404	300	33.10	0.110	0.01	0.039	3.48	0.21
326	04-Jun-90	116	389	273	42.45	0.069	0.01	0.034	2.83	0.14
327	06-Jun-90	78	375	297	35.44	0.092	0.01	0.017	2.94	0.16
328	08-Jun-90	78	382	304	29.89	0.111	0.01	0.022	3.21	0.16
329	10-Jun-90	80	395	315	46.74	0.058	0.01	0.018	3.40	0.18
330	12-Jun-90	100	335	235	29.47	0.151	0.01	0.100	3.97	0.28
331	14-Jun-90	68	340	272	39.18	0.094	0.01	0.034	2.79	0.14
332	16-Jun-90	104	360	256	41.22	0.079	0.01	0.017	3.70	0.23
333	18-Jun-90	108	415	307	44.04	0.036	0.01	0.003	3.48	0.22
334	20-Jun-90	112	401	289	38.80	0.035	0.01	0.006	3.86	0.25
335	22-Jun-90	108	415	307	49.02	0.110	0.01	0.051	3.55	0.23
336	24-Jun-90	89	343	254	43.58	0.110	0.01	0.019	3.17	0.20
337	26-Jun-90	81	373	292	40.81	0.059	0.03	0.021	3.67	0.23
338	28-Jun-90	67	346	279	17.28	0.149	0.03	0.021	2.26	0.10
339	30-Jun-90	121	340	219	24.11	0.107	0.02	0.024	3.36	0.17

*not collected : 12/18 and 12/24/90 NS = no sample received
**Sample #307 was clear, Filtered?, Take sample from TS, redigest

Appendix 7.2.2 (cont'd.)

	Depth	Dry weight	Dry bulk density	pH	EC	Alkalinity	NH_4-N	SRP
	cm	—%—	g cm^{-3}		$\mu S\ cm^{-1}$	mg $CaCO_3$ L^{-1}	——mg L^{-1}——	
<u>Sampling date 1/10/89 (Winter)</u>:								
Core I	0–2	0.98	0.010	7.65	385	194	0.410	0.005
	2–4	1.32	0.014	7.35	440	245	0.410	0.004
	4–8	2.06	0.022	7.35	580	330	6.394	0.004
	8–12	2.26	0.026	7.15	670	375	11.883	0.091
	12–16	3.02	0.032	7.40	700	391	15.295	1.177
	16–20	3.51	0.040	7.23	750	444	17.372	1.770
	20–25	5.48	0.064	7.10	800	463	23.009	2.262
	25–30	8.88	0.100	7.05	810	464	22.317	1.998
	30–40	6.59	0.075	7.10	815	516	25.135	2.084
	50–60	7.29	0.079	6.90	850	519	24.740	1.405
Core II	0–2	0.74	0.007	7.60	360	161	0.509	0.005
	2–4	1.46	0.018	7.45	470	235	2.092	0.005
	4–8	2.06	0.022	7.10	580	319	8.124	0.005
	8–12	2.28	0.024	7.40	660	374	11.883	0.128
	12–16	3.03	0.036	7.20	720	418	16.284	1.063
	16–20	3.62	0.039	7.15	760	447	19.795	1.961
	20–25	5.53	0.063	7.15	800	484	22.811	2.449
	25–30	11.82	0.141	6.85	770	520	23.751	2.258
	30–40	9.14	0.104	6.80	860	490	26.025	2.089
	50–60	6.91	0.074	6.90	830	499	25.729	1.291
Core III	0–2	1.37	0.015	7.60	440	212	1.993	0.003
	2–4	1.90	0.023	7.40	540	281	5.454	0.004
	4–8	2.31	0.025	7.30	630	400	10.399	0.007
	8–12	2.61	0.027	7.05	680	387	15.196	0.629
	12–16	3.18	0.037	7.10	700	422	23.256	2.363
	16–20	3.93	0.045	7.15	800	456	18.806	1.660
	20–25	5.62	0.063	7.00	800	477	25.234	2.545
	25–30	7.28	0.080	6.90	810	493	26.718	2.440
	30–40	7.49	0.087	7.05	860	518	28.547	2.144
	50–60	6.91	0.074	6.90	850	500	26.174	1.131
<u>Sampling date 4/10/89 (Spring)</u>:								
Core I	0–2	0.97	0.010	8.00	335	163	0.178	0.006
	2–4	1.41	0.013	7.55	430	220	0.940	0.011
	4–8	2.03	0.023	7.35	545	307	5.319	0.006
	8–12	2.54	0.030	7.20	600	385	11.837	0.165
	12–20	3.04	0.029	7.00	620	413	15.361	1.051
	25–30	6.05	0.070	7.20	710	484	18.619	1.987
	30–40	7.17	0.077	6.80	690	468	20.855	1.933
	50–60	6.75	0.074	6.95	640	473	22.447	1.593

Appendix 7.2.2 (cont'd.)

	Depth	Dry weight	Dry bulk density	pH	EC	Alkalinity	NH_4-N	SRP
	cm	—%—	g cm^{-3}		$\mu S\ cm^{-1}$	mg $CaCO_3$ L^{-1}	——mg L^{-1}——	
Core II	0-2	1.38	0.015	7.95	340	221	0.267	0.013
	2-4	1.70	0.016	7.75	460	218	0.571	0.010
	4-8	2.21	0.024	7.30	570	308	5.585	0.007
	8-12	2.53	0.028	7.20	620	386	12.974	0.007
	12-16	2.98	0.034	7.20	570	404	17.900	0.928
	16-20	3.15	0.032	7.15	625	412	19.794	1.495
	20-25	3.36	0.038	7.10	660	455	21.765	2.179
	25-30	5.78	0.064	7.20	690	495	22.825	2.342
	30-40	6.85	0.078	6.90	710	485	25.023	2.283
	50-60	6.50	0.067	7.05	710	496	25.099	1.672
Core III	0-2	1.13	0.011	8.05	390	172	0.305	0.006
	2-4	1.57	0.017	7.85	440	223	0.886	0.005
	4-8	2.04	0.023	7.25	500	311	6.911	0.005
	8-12	2.56	0.029	7.30	680	394	15.247	0.189
	12-16	2.95	0.031	7.25	720	424	19.036	0.854
	16-20	3.43	0.039	7.20	720	433	21.689	1.519
	20-25	3.99	0.046	6.95	750	454	23.583	1.879
	25-30	6.98	0.080	7.10	700	470	23.204	1.938
	30-40	6.73	0.075	6.85	710	474	25.478	1.913
	50-60	7.23	0.073	6.95	720	503	26.804	1.495
Sampling date 7/20/89 (Summer):								
Core I	0-2	1.05	0.032	8.05	400	188	0.126	0.000
	2-4	1.45	0.048	8.00	500	247	3.484	0.000
	4-8	1.89	0.099	7.45	620	332	11.821	0.000
	8-12	2.35	0.136	7.40	750	408	22.822	1.073
	12-16	2.58	0.151	7.10	800	458	29.190	2.054
	16-20	2.91	0.153	7.10	860	484	32.201	2.510
	20-25	4.34	0.215	7.30	925	555	34.169	2.658
	25-30	5.68	0.341	7.25	910	536	32.375	2.366
	30-40	6.06	0.712	7.05	900	529	30.059	2.173
	50-60	7.25	0.749	7.00	900	515	28.959	1.763
Core II	0-2	1.40	0.032	8.00	400	162	0.068	0.000
	2-4	1.65	0.060	7.90	490	238	2.847	0.000
	4-8	1.97	0.122	7.70	620	335	10.374	0.000
	8-12	2.41	0.147	7.15	730	404	21.374	0.769
	12-16	2.79	0.150	7.40	840	530	30.059	2.017
	16-20	2.85	0.161	7.33	920	505	34.343	2.777
	20-25	3.64	0.237	7.20	950	535	35.964	2.879
	25-30	5.45	0.293	7.30	920	535	34.054	2.551
	30-40	5.98	0.584	7.05	900	501	30.638	2.223
	50-60	6.61	0.820	7.00	900	520	28.901	1.611

Appendix 7.2.2 (cont'd.)

	Depth	Dry weight	Dry bulk density	pH	EC	Alkalinity	NH_4-N	SRP
	cm	—%—	g cm^{-3}		μS cm^{-1}	mg $CaCO_3$ L^{-1}	——mg L^{-1}——	
Core III	0-2	1.09	0.044	8.00	450	202	2.037	0.000
	2-4	1.57	0.055	7.85	550	284	8.058	0.000
	4-8	2.10	0.111	7.35	800	400	19.869	0.564
	8-12	2.50	0.157	7.10	880	479	32.375	2.375
	12-16	2.78	0.173	6.95	900	504	36.312	2.551
	16-20	3.55	0.158	7.20	920	543	38.628	2.740
	20-25	4.39	0.218	7.00	950	555	38.164	2.715
	25-30	5.66	0.324	7.20	910	525	33.996	2.182
	30-40	5.45	0.706	7.05	900	530	31.043	1.976
	50-60	6.79	0.708	7.20	900	515	29.306	1.410