J. Bangladesh Agril. Univ. 6(1): 145–151, 2008 ISSN 1810-3030

Effects of Iso-nutrient fertilization on hydrological conditions and biological productivity of six earthen ponds in BAU campus

M. Begum, M.J. Alam, M.A. Wahab[1] and M.S. Haq[1]
Bangladesh Fisheries Research Institute, Brackishwater Station, Paikgacha, Khulna-9280, Bangladesh
[1]Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

Abstract

The effects of two fertilizer combinations containing a similar amount of nitrogen (N) and phosphorus (P) viz. cow manure, urea and TSP @ 5000, 125 and 100 kg/ha, respectively, (Treatment-1) and poultry-manure, urea and TSP @ of 2000, 125 and 100 kg/ha, respectively, (Treatment-2) on water and sediment quality parameters, and biological production in six earthen ponds of 100 m^2 each for a period of eight weeks use studied. The values of N nutrients (NH_3-N, NO_3-N, NO_2-N) in water were significantly lower but that of PO_4-P were significantly higher in T-2. Though not significant, total N and available P in the pond sediment were lower in T-2. Four groups of phytoplankton such as Bacillariophyceae, Chlorophycae, Cyanophyceae and Euglenophyceae and two groups of zooplankton namely, Crustacean and Rotifer were recorded from the experimental ponds. The mean abundance of both phytoplankton ($78.25 \pm 6.33 \times 10^4$ cells/l) and zooplankton ($57.63 \pm 4.59 \times 10^4$ cells/Ll), were significantly higher ($p<0.05$) in ponds treated with poultry manure (Treatment-2). The result of the present study showed that despite iso-nutrients content, poultry manure with urea and TSP is significantly superior to cow manure with urea and TSP for maintaining hydrological conditions and plankton production in earthen ponds.

Keywords: Iso-nutrients, Water quality, Sediment quality, Biological productivity

Introduction

Fertilizers are often applied to increase the productivity of the fish ponds. Inorganic fertilizers mainly increase the quantity of primary producers while the organic fertilizers (dung of cattle, pig and poultry, biomass slurry, compost, etc.) stimulate the growth of zooplankton, insect larvae and other forms of fish food organisms (Akand, 1986). Therefore, to maintain the required food chain equilibrium in fish ponds, simultaneous use of various types of fertilizers is necessary, as application of one without the other would imbalance the amount of plant and animal matter in the pond ecosystem (Moav *et al.*, 1977).

Hydrological conditions and abundance of plankton in a fish pond are of great importance in managing the successful aquaculture operations, as these vary from location to location and pond to pond within the same location even with similar ecological conditions (Boyd, 1982). Fertilization is so far the most useful technique to provide the essential nutrients to enhance the natural productivity through production of aquatic biota, which serve either directly or indirectly as the food of fishes (Knud-Hansen, 1998). Besides, determining the character and quality of biological production of a fish pond, the prevailing hydrological conditions provide important tool for successful fish cultural operations (Alam *et al.*, 1996). Improvement to fish production in ponds can best be achieved if physico-chemical changes associated with manure/fertilizer application are understood.

In Bangladesh, a monthly fertilization of cow manure, urea and triple super phosphate (TSP) @ of 5000, 125 and 100 kg/ha, respectively, is commonly practiced in fish culture along with external feeding with rice bran and mustard oil-cake (Ahmed *et al.*, 1997). The present experiment was aimed at assessing the comparative effects of fertilization on sediment and water qualities and on the production of plankton in earthen ponds without stocking of any fish species. Two different fertilizer combinations were tested in the present experiment, one is cow dung-urea-TSP and the other one is poultry manure-urea-TSP, containing a similar amount of nitrogen (N) and phosphorus (P).

Materials and Methods

The experiment was carried out for a period of eight weeks from15 March to 10 May in six earthen ponds with an area of 100 m^2 each having an average depth of about 1.5 m in the Field Laboratory Complex of the Faculty of Fisheries Bangladesh Agricultural University, Mymensingh. All the experimental ponds were dried out, bottom were ploughed and kept exposed to sunlight for three days and were treated with lime @ of 250 kg/ha and filled-up with underground water up to a depth of 1 m. Two fertilizer combinations containing approximately 102 kg N and 65 kg P were formulated for two treatments as follows: cow manure, urea and TSP @ 5000, 125 and 100 kg/ha, respectively, (Treatment-1) and poultry-manure, urea and TSP @ of 2000, 125 and 100 kg/ha, respectively, (Treatment-2). Das and Jana, (1996) was followed to determine the nutrient contents of the experimental fertilizer combinations (Table 1). The number of replication was three for each treatment. Treatment wise fertilizers were applied to the experimental ponds according to treatments from the 5^{th} day of liming and water filling and repeated at fortnight intervals up to the end of the experiment.

Table 1. Constituents (on oven dry basis) of cow and poultry manure used in the experiment

Chemical component (%)	Cow manure	Poultry manure
Moisture	75.30	58.20
Organic matter	24.20	18.65
Total nitrogen (N)	0.90	2.25
Total phosphorus (P_2O_5)	0.40	0.95
Available potassium (K)	0.35	0.80
Available calcium (Ca)	0.70	1.10

Water samples were collected between 9:00 to 10:00 am from a depth of 20 cm from the surface at ten-day intervals from some fixed sampling stations of each pond. Water temperature (^{0}C), dissolved oxygen (mg/L), pH, total alkalinity (mg/L) and Chlorophyll-*a* (μg/L) were determined titrimetrically in the laboratory according to the standard procedure (APHA, 1992). The concentrations of ammonia-nitrogen (mg/L), nitrate-nitrogen (mg/L), nitrite-nitrogen (mg/L) and phosphate-phosphorus (mg/L) in water were determined by using DR-2010 HACH Kit. Triplicate sediment samples of bottom sediment were collected fortnightly from each pond with the help of an Ekman dredge (covering an area of 225 cm^2. Sediment pH, total nitrogen, available phosphorus and exchangeable calcium (Ca), magnesium (Mg) and potassium (K) was analyzed according to the standard procedure. For plankton enumeration, ten liters of water samples were collected weekly from different areas and depths of ponds and passed through a 25 μ mesh plankton net. The collected plankton samples were preserved in 5% buffered formalin and the number was estimated, using a Sedgewick-Rafter counting cell, after Stirling (1985) as follows:

$$N = (Ax1000xC)/(VxFxL)$$

where, 'N' is the number of plankton cells or units per liter of original water; 'A' is the total number of plankton counted, 'C' is the volume of final concentrate of the samples in ml; 'V' is the volume of a field in cubic mm; 'F' is the number of fields counted; and 'L' is the volume of original water in liter. Plankters were identified following APHA (1992) and Bellinger (1992). One-way ANOVA was done to analyze the data and significance test was done by using the statistical package the Statgraphics *Version 7.*

Results and Discussion

The mean values of water quality parameters as obtained in the present experiment are presented in Table 2. Water temperature of the experimental ponds belonging to T-1 and T-2 ranged from 29.00 - 32.40 and 29.20 - 32.50 ^{0}C respectively, treatment to treatment variation was not significant. The present findings agree with the findings of Hossain *et al.* (1997) who reported that the water temperature in shallow and small fish ponds in Bangladesh conditions has been found to range from 26 -35°C, with the maximum in May to August. The mean values of transparency were 32.88 ± 2.03 and 26.54 ± 1.80 cm for T-1 and T-2, respectively, and treatment to treatment variation was significant ($p<0.05$). Boyd (1982) suggested that a transparency between 15 - 40 cm is suitable for fish culture, so all the experimental ponds were suitable for aquaculture although poultry manure-urea-TSP application (T2) resulted in significantly lower transparency with the higher chlorophyll-*a* content. Dewan *et al.* (1991) observed an inverse relationship between Chlorophyll-*a* and secchi-depth values in pond water. The value of dissolved oxygen was found to vary widely (3.50 - 7.50 mg/L) although treatment mean values were similar (5.43 ± 0.22 and 5.74 ± 0.24 mg/L for T-1 and T-2, respectively). A similar trend in fluctuation (3.2 to 8.5 mg/L) of dissolved oxygen has been reported in fertilized fish ponds by Grag and Bhatnagar (2000). In spite of 2.5 times higher loading rate of cow manure in T-1 than that of poultry manure in T-2, no significant difference in the dissolved oxygen was noticed in T-1 ponds. The pH of water of all the experimental ponds was alkaline almost throughout the experimental period, though it varied from 6.48 - 8.90, two treatments did not extent any significant effect on pH. Kohinoor *et al.* (1998), reported pH to vary from 7.18 to 7.24 in fertilized fish ponds. During the study period, the highest (166.30 ppm) total alkalinity as found in T-1 in the 4th sampling week and the lowest (100.80 ppm) in T-2 in the 7th sampling week. Very low (< 20 ppm) and very high (> 220ppm) total alkalinity with a pH more than 9.0 are not favorable for primary production of phytoplankton (Rahman, 1992). The total alkalinity level as obtained in the present study more or less similar to those of Grag and Bhatnagar, (2000). The availability of phosphate phosphorus has been considered to be the most critical single nutrient in maintenance of aquatic productivity. The average phosphate phosphorus values as obtained in the present study are 0.55 -1.38 and 0.84-1.75 mg/L in T-1 and T-2, respectively, close to the average ranges of 0.03 - 3.2 mg/L obtained by Milstein *et al.*, (1995). Not only the average phosphate concentration in water but also its fluctuations throughout the experimental period were significantly higher, though the nutrient input was similar in both the treatments. Banerjee *et al.*, (1979) reported that poultry manure has the higher nutrient mineralization capacity than cow manure. Lower values of phosphate, as observed onwards from the 6th week might be due to utilization of this nutrient by the increased autotrophic biomass. The highest values of phosphate as observed in the 5th week could be attributed to the decomposition of plankton population. The concentrations of nitrite-nitrogen were found to be relatively low with significant treatment to treatment difference ($P<0.05$) but were within the safe range for fish culture as reported by Grag and Bhatnagar, (2000). Significant treatment to treatment variation was found in the average ammonia-nitrogen content in water of the experimental ponds but the results are more or less similar to those Kohinoor *et al.* (1998). The nitrate-nitrogen content in water of the experimental ponds as recorded in the present study is close to that observed by Wahab *et al.* (1995). However, there was significant difference ($P<0.05$) in nitrate-nitrogen values between T-1 and T-2. Significantly lower availability of all forms of nitrogenous nutrients throughout the experimental period in T-2 ponds indicates greater mineralization and uptake of these nutrients by the phytoplankton community in poultry manure-urea-TSP treated ponds.

Table 2. Range and (mean ± SD) values of different water quality parameters of ponds under two treatments

Water quality parameter	Treatment 1 (T-1)	Treatment 2 (T-2)	F – value	Level of significance
Temperature (°C)	30.13 ± 0.20	30.16 ± 0.20	0.013	ns
Transparency (cm)	32.88 ± 2.30	26.54 ± 1.80	5.44	*
Dissolved oxygen (mg/L)	5.43 ± 0.22	5.74 ± 0.24	0.911	ns
pH	7.76	7.72	0.043	ns
Total alkalinity (mg/L)	131.63 ± 3.38	126.83 ± 3.12	1.084	ns
Nitrate-nitrogen (mg/L)	1.91 ± 0.11	1.35 ± 0.10	13.10	*
Nitrite-nitrogen (mg/L)	0.018 ± 0.002	0.011 ± 0.004	57.42	*
Ammonia-nitrogen (mg/L)	0.85 ± 0.05	0.41± 0.03	54.80	*
Phosphate-phosphorus (mg/L)	0.97 ± 0.048	1.22 ± 0.052	12.87	*
Chlorophyll-*a* (μg/L)	275.18 ± 43.86	389.28 ± 55.15	2.62	*

'ns' represents non-significance (P > 0.05)
'*' represents significance (P < 0.05)

The average chlorophyll-*a* content in ponds under T-2 (389.28 ± 55.15 μg/L) was significantly higher (P<0.05) than that of T-1 (275.18 ± 43.86 μg/L). However, the chlorophyll-*a* contents in both treatments increased, possibly in relation to increased growth rate of phytoplankton, as the study period progressed. Fertilization in fish pond has profound effects on chlorophyll-*a*, which is the primary pigment used by phytoplankton to capture the light energy for photosynthesis and often used to estimate phytoplankton biomass (Wetzel and Likens, 1979). The results obtained are close to these (32.5 to 812.80 mg/L) recorded by Wahab *et al.* (1999) from organic and inorganic fertilized ponds. However, obtaining of significantly higher concentration of chlorophyll-*a* in T-2 indicates that nutrients in poultry manure had a better effect on maintaining primary production.

Range and mean values of pond bottom sediment characteristics (pH, total nitrogen, organic carbon, available phosphorus, exchangeable K, Ca, and Mg) as recorded from different experimental ponds are shown in Table 3. Values of all the sediment parameters were similar (P>0.05) for both the treatments. The average values of different sediment parameters as obtained for ponds belonging to T-1 and T-2 are: pH (6.13 and 6.01 respectively), total nitrogen (0.55 ± 0.17 % and 0.45 ±0.17 % respectively), organic carbon (1.87±0.28% and 1.52±0.23%, respectively), available phosphorus (11.63 ± 1.29 mg/L and 9.30 ± 0.27 mg/L respectively), exchangeable potassium (0.71 ± 0.17 and 0.56 ±0.15 meq/100g respectively), exchangeable calcium (1.35 ± 0.16 and 1.19 ±0.11 meq/100g respectively) and exchangeable magnesium (7.54 ± 1.74 and 8.18 ± 1.95 meq/100g respectively).

Table 3. Range and (mean ± SD) values of different sediment parameters in ponds under two treatments

Sediment quality parameter	Treatment 1 (T-1)	Treatment 2 (T-2)	F -value	Level of significance[1]
pH	6.13	6.01	0.032	ns
Total N (%)	0.55±0.17	0.45±0.77	0.174	ns
Organic C (%)	1.87±0.28	1.52±0.23	0.927	ns
Available P (mg/L)	11.63±1.29	9.30±0.27	3.13	ns
Exchangeable K (meq/100g)	0.71±0.17	0.56±0.15	0.41	ns
Exchangeable Ca (meq/100g)	1.35 ± 0.16	1.19 ± 0.01	0.71	ns
Exchangeable Mg (meq/100g)	7.54±1.74	8.18±1.95	2.96	ns

[1]'ns' represents non-significant difference (p> 0.05)

The concentrations of total nitrogen, organic carbo and available phosphorus were found to increase as the study progressed in ponds belonging to both the treatments. Application of two different combinations of fertilizers increased the concentrations of those sediment quality parameters in all the experimental ponds. Generally, liming and organic fertilization at standard doses are considered essential for improving the sediment qualities of fishponds (Bhowmik and Tripathi, 1985). Sediment data obtained in the present study are slightly higher than those obtained by Wahab *et al.* (1983) in fertilized ponds under fish culture.

Group wise abundance of the planktonic organisms as obtained for the experimental ponds belonging to T-1 and T-2 are shown in Table 4. The phytoplankton population comprised four major groups, viz., Bacillariophyceae (62%), Chlorophycae (58%), Cyanophyceae (55%) and Euglenophyceae (68%). Statistical analysis showed a significant difference ($P<0.05$) in average abundance of total phytoplankton obtained for the two treatments, the abundance of phytoplankton was higher in T-2.

Table 4. Range and (mean ± SD) abundance of various group of plankton ($\times10^4$ cells/L) in pond waters under two treatments

Plankton group	Treatment 1 (T-1)	Treatment 2 (T-2)	F- value	Level of significance
Bacillariophyceae	(6.90 - 7.68) 7.50±0.97	(11.20 - 13.20) 12.13±0.85	12.91	*
Chlorophyceae	(25.35 - 27.25) 26.33±3.58	(36.88 - 39.85) 36.75±4.21	3.55	ns
Cyanophyceae	(14.30 -16.50) 15.17±1.64	(18.50 -19.26) 18.88 ±1.53	2.72	ns
Euglenophyceae	(4.50 -6.15) 5.25±0.40	(10.75 -11.65) 11.08±0.92	33.52	*
Total phytoplankton	(52.70 -55.90) 54.54 ±5.60	(78.62 - 82.13) 78.25±6.33	7.86	*
Crustacea	(21.40 - 23.46) 22.67±2.61	(30.20 - 34.18) 32.29±2.60	6.78	*
Rotifera	(12.30 -15.10) 13.50±1.22	(20.35 - 24.40) 22.50±1.62	19.71	*
Total zooplankton	(33.70 - 38.30) 37.08±3.54	(51.55 -56.98) 57.63±4.59	12.54	*
Total plankton	(86.40 - 94.20) 95.08±10.14	(129.03 -139.03) 135.88±10.62	7.72	*

'ns' represents non-significance ($p>0.05$)
'*' represents significance ($p< 0.05$)
Values in the parentheses are the range

Almost similar order of dominance in different groups of phytoplankton has been reported in both organic and inorganic fertilized fish ponds in the vicinity of BAU (Wahab *et al.*, 1994). Though the phytoplankton groups were more or less common in order to their abundance in the vicinity of study area, the generic representation differs either in quality and quantity (Azim *et al.*, 2001). Higher abundance of phytoplankton in ponds under T-2 throughout the experimental period, suggests that the fertilization effects of poultry manure in supplying nutrients in water column is better than that of cow manure. Total phytoplankton abundance in the ponds treated with poultry manure alone has been higher due to sufficient PO_4-P and NO_3-N release from the manure in water (Sood 1984)

The zooplankton population comprised of two major groups: Crustacea and Rotifers, Crustacea was the most dominant zooplankton group in both treatments. Total zooplankton abundance (57.63 ± 4.59 $\times10^4$ cells/L) in T-2 was significantly ($P<0.05$) higher than that of T-1 (37.08 ± 3.54 $\times10^4$ cells/L).

The poultry manure with inorganic fertilizer (T-2) resulted in significantly higher qualitative and quantitative production of zooplankton. Crustacea was found to be the most dominant zooplankton group in both the treatments in the present study. The results obtained in the present study more or less agree with the findings of Hasan (1990) but differ from those of Shandhu *et al.* (1985) who reported Rotifer to be the common and dominant group in the manure rich waters.

The plankton production in the experimental ponds belonging to both the treatments increased rapidly from around the 3rd week of fertilization and stabilized, though apparently in an increasing rate. Quick dissolution of organic manure might have given rise to high phytoplankton abundance 21-28 days after fertilization. Despite loading of almost a similar amount of nitrogen and phosphorus in ponds under two treatments (poultry manure-urea-TSP and cow manure-urea-TSP), poultry manure treated ponds resulted in high production of plankton. This might be due to released of plankton growth promoting soluble salts in water column at a higher rate by poultry manure than cow manure, as has been observed by Banerjee *et al.* (1979).

Conclusions

On the basis of the results obtained in the present experiment, it can be concluded that poultry manure is more efficient than the cow manure in maintaining favorable hydrological conditions for plankton production.

Acknowledgement

The research funding from the World bank financed ARMP (Agricultural Research Management Project-BFRI Part) is gratefully acknowledged.

References

APHA (American Public Health Association). 1992 . Standard Methods for the Examination of water and wastewater, Washington, D.C. 20036. 874 pp.

Ahmed G.U., Hossain, M.A.R., Wahab, M.A. and Rahman, K.M.A. 1997. Effect of fertilizers on soil and water quality parameters and growth of a crap (*Labeo rohita*, Hamilton) fry. *Progress. Agric.*, 8(172): 111-114.

Akand, M.A. 1986. Effect of inorganic fertilizers on water quality and fish production in carp ponds. *Bangladesh J. Fish.*, 9 (1-2) : 47-53.

Alam, M.S., Amin, M.R., Hasan, M.R, Rahmatullah, S.M. and Miah, M.I. 1996. Effects of fertilizers and supplementary feeds on physico-chemical parameters of ponds. *Bangladesh J. Fish.*, 19(1-2): 9-16

Azim, M. E., Wahab, M.A., Van Dam,A.A., Beveridge, M.C.M., Milstein, A. and Verdegem, M.C.J. 2001. Optimization of fertilization rates for maximizing periphyton growth on artificial substrates and implications for periphyton- based aquaculture. *Aquac. Res.* 32, 749-760.

Banerjee, R.K, Roy, P., Singit, G.S. and. Dutta, B.R. 1979. Poultry droppings its manurial potentiality in aquaculture. *J. Inland Fish. Soc.* India., 11 (1): 94-108.

Bellinger, E.G., 1992. A Key to Common Algae. The Institute of Water and Environmental Management, London, 138 pp.

Bhowmik, M.I. and Tripathi, S.D. 1985. The plankton and fish growth of ponds under semi- intensive fish culture in acid soils of Jalpaiguri, West Bengal. *J. Inland Fish. Soc.*, India, 17 (1&2): 39-47.

Boyd, C.E. 1982. Water quality management for pond fish culture. Developments in Aquaculture and Fisheries Science, Vol. 9. 1st Edition. Elsevier Scientific Publishing Company, Amsterdam. Oxford, New York, 318 pp.

Das, S.K. and Jana, B.B. 1996. Pond fertilization through inorganic sources: an overview. *Indian J. Fish.,* 43 (2): 137-155.

Dewan S., Wahab, M.A., Beveridge, M.C.M., Rahman, M.H. and Sarkar, B.K. 1991. Food selection, electivity and dietary overlap among planktivorous Chinese and Indian major carp fry and fingerlings grown in extensively managed rain-fed ponds in Bangladesh. *Aquacult. Fish. Managt.* 22: 277-294.

Grag S.K. and Bhatnagar, A. 2000. Effect of fertilization frequency on pond productivity and fish biomass in still water ponds stocked with *Cirrhinus mrigala* (Ham.). *Aquacult. Res.,* 31: 409-414.

Hasan M.S. 1990. Development of fertilization strategy for culture with nitrogen and phosphorus supplementation of cattle manure. Ph. D. Dissertation, AIT, Bangkok, Thailand, 183 pp.

Hossain M.A., Rahmatullah S.M., Islam M.S., Kabir A.K.M.A., Islam M.S. and Dewan, S. 1997. Impact of Chapila (*Gudusia chapra* Ham.) on growth of Carps in polyculture. *Bangladesh J. Fish. Res.,* 1 (2): 19-23.

Knud-Hansen C.F. 1998. *Pond Fertilization: Ecological Approach and Practical Application.* Pond Dynamics/Aquaculture Collaborative Research Support Programme, Oregon State University, Corvallis, Oregon. 125 pp.

Kohinoor, A.H.M., Islam, M.L., Wahab, M.A. and. Thilsted, S.H. 1998. Effect of mola (*Amblypharyngodon mola* Ham.) on the growth and production of carps in polyculture. *Bangladesh J. Fish. Res.,* 2(2): 119-126.

Milstein A., Alkon, A., Karplus, I., Kochba, M. and Avnimelech, Y. 1995. Combined effects of fertilization rate, manuring and feed pellet application on fish performance and water quality in polyculture ponds. *Aquacult. Res.,* 26: 55-65.

Moav, R., Wohlfarth, G., Schroeder, G.L. Hulata, G. and Barash, H. 1977. Intensive polyculture of fish in freshwater ponds. I. Substitution of expensive feeds by liquid cow manure. *Aquaculture.,* 10: 25-43.

Sood, V. 1984. Studies on fecundity of exotic fish (*Cyprinus carpio*) in relation to feeding and ecological niches. M.Sc. Thesis, PAU, Ludhiana, India.

Stirling H.P 1985. Chemical and biological methods of water analysis for aquaculturists. Institute of Aquaculture, University of Stirling, Scotland, 119 pp.

Shandhu J.S., Toor, H.S. and Sehgal, H.S. 1985. Zooplankton community in manured fish tanks. *Ann. Biol.,* 1: 94-97.

Wahab M. A., Haque, A.K.M.A.,.Bhuiya, Z.H and Islam, M.A. 1983. Nutrient status of bottom soils of two ponds in BAU campus. *Bangladesh J. Fish.,* 6(1-2): 1-9.

Wahab M.A., Ahmed, Z.F., Haq, M.S and Begum, M. 1994. Compatibility of silver carp in the polyculture of cyprinid fishes. *Progress. Agric.,* 5(2): 221-227.

Wahab M.A. Ahmed, Z.F., Aminul Islam, M. and Rahmatullah, S.M. 1995. Effect of introduction of common carp, *Cyprinus carpio* (L), on the pond ecology and growth of fish in polyculture. *Aquacult. Res.,* 26, 619-628.

Wahab M.A. Huda, M.A., Mannan, M.A., Beveridge, M.C.M. and Tollervey, A.G. 1999. Effects of periphyton grown on bamboo substrates on growth and production of Indian major carps rohu (*Labeo rohita* Ham). *Bangladesh J. Fish. Res.,* 3(1): 1-10.

Wetzel R.G. and. Likens, G.E. 1979. *Limnological Analyses.* W.B. Saunders Co., *Philadelphia, Pennsylvania,* 357 pp.