WATER QUALITY AND PHYTOPLANKTON IN DAIRY FARM PONDS[1]

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Abstract: Concentrations of chlorophyll *a*, soluble orthophosphate, dissolved nitrate and nitrite, and associated water quality parameters were measured biweekly from May 1979 to May 1980 in 3 sequential ponds located on a dairy farm. Pond number 1 was located in the immediate vicinity of the barn and feedlot, and demonstrated limnological characteristics of a sewage settling pond. Chlorophyll *a* and soluble orthophosphate averaged 298 mg/m^3 and 10.1 mg/l respectively. Dissolved oxygen in pond 1 averaged 3.4 mg/l at the surface but was never present at a depth of 1 m. The presence of a settling pond as the primary recipient of wastes produced by a herd of cattle resulted in downstream impoundments having limnological characteristics highly desirable for the culture of herbivorous fishes. Chlorophyll *a* in ponds 2 and 3 averaged 103 and 77 mg/m^3 respectively. In contrast to pond 1, dissolved oxygen at the surface and 1 m in ponds 2 and 3 averaged 7.0 and 4.2, and 10.1 and 7.8 mg/l respectively. Downstream impoundments also had progressively lower concentrations of soluble orthophosphate, total alkalinity, and total hardness. Significant week to week variation in concentrations of soluble orthophosphate, dissolved nitrate and nitrite, and chlorophyll *a* occurred, but seasonal trends were not apparent. Magnitude of week to week variations was progressively less in downstream impoundments and during the winter. Week to week variations reflect activity of phytoplankton and the susceptibility of small impoundments to environmental factors.

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Domestic sewage and animal manures have been used traditionally to fertilize fish culture ponds in Asia and Europe (Hickling 1962). Increasing costs of inorganic fertilizers, proposed stringent pollution controls, and need for additional sources of animal protein are focusing attention on using nutrients in animal manures and muncipal wastewaters for production of food (EPA 1974, Toubier and Pierson 1976, D'Itri 1977).

Nationwide figures indicate that livestock wastes are 10 times that produced by humans (Pisano 1976). Annual wastes from a single herd of 100 cows, if introduced into a 1-ha impoundment, could increase nitrogen 450-fold, phosphorous 85-fold and potassium 1,200-fold in comparison to standard fertilization rates recommended for farm ponds (Boyd and Snow 1975, ASAE 1978 - 1979).

Culture of herbivorous fishes is highly desirable because of efficiency of energy transfer from primary producers to fish biomass (Weatherley and Cogger 1977). Pasture impoundments which are nutrient enriched with animal wastes may be

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ideally suited for culture of herbivorous fish species. Successful management of a fishery in pasture impoundments must be preceded by documentation of their water quality characteristics. Water chemistry and phytoplankton of pasture ponds were compared to ponds in wooded watersheds, but proximity to cattle activity was not considered (Boyd 1976). In addition, seasonal trends were not examined.

Objectives of this study were to ascertain chemical and biological characteristics of sequential dairy impoundments over the course of a year, and examine the influence of proximity to areas of intense livestock activity on water chemistry and phytoplankton.

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METHODS

The experimental area consisted of 3 sequential farm impoundments, (Fig. 1) within the Steel Creek watershed in Anderson County, South Carolina (34°35′N and 82°41′W). Morphological characteristics for each pond were determined as described by Lind (1974). Surface area was surveyed with an alidade and plane table. Depths were measured to the nearest 0.5 m by dropping a weighted line every 3 m along transects of nylon line suspended across the ponds. Approximately 150 - 200 depth measurements were recorded per pond. Area was determined by polar planimeter at 0.5-m depths. Volume was calculated as described by Welch (1948).

Chlorophyll *a*, temperature, dissolved oxygen, alkalinity, pH, hardness, calcium, magnesium, soluble orthophosphate, and dissolved nitrogen were examined at biweekly intervals for each pond from May 1979 to May 1980. Sampling was performed between 0900 and 1100 hours.

Water temperatures at 10 cm and 1 m below the surface were recorded to the nearest 0.1 C with a temperature probe. One-liter water samples were retrieved at 10 cm below surface by hand and at 1 m with a van Dorn bottle. All samples were stored in polyethylene bottles and kept on ice until analysis. Two samples from each liter of water collected were used for alkalinity, total hardness, calcium, pH, nitrogen and phosphorus. Alkalinity and total hardness were measured as mg CaC0 per l (APHA 1976). Calcium was measured as mg Ca per l (APHA 1976). An electrode was used to determine pH. Two hundred mililiters of water were passed through 0.45 μm Millipore® filters. Filtrate was stored at 0 C until analysis of orthophosphate by ascorbic acid method (APHA 1976) and dissolved nitrogen (NO_3 & NO_2) (Lind 1974, Hach 1979). Filtrable orthophosphate was expressed as mg PO_4 per l and dissolved nitrogen as mg N per l. Duplicate samples from each depth were analyzed for dissolved oxygen. Samples from 10-cm depth were collected in 300-ml BOD bottles, whereas samples from 1-m depths were collected in a van Dorn bottle and transferred to 300-ml BOD bottles. Dissolved oxygen was determined by the Winkler method and recorded to the nearest 0.1 mg per l.

Phytoplankton biomass was determined from acetone extraction of chlorophyll *a* (Lind 1974). A volume of pond water was passed through the 0.45 μm filter to obtain a green sediment on the filter pad for chlorophyll *a* extraction. After overnight extraction, samples were measured at 665 nm on a Spectronic 21.

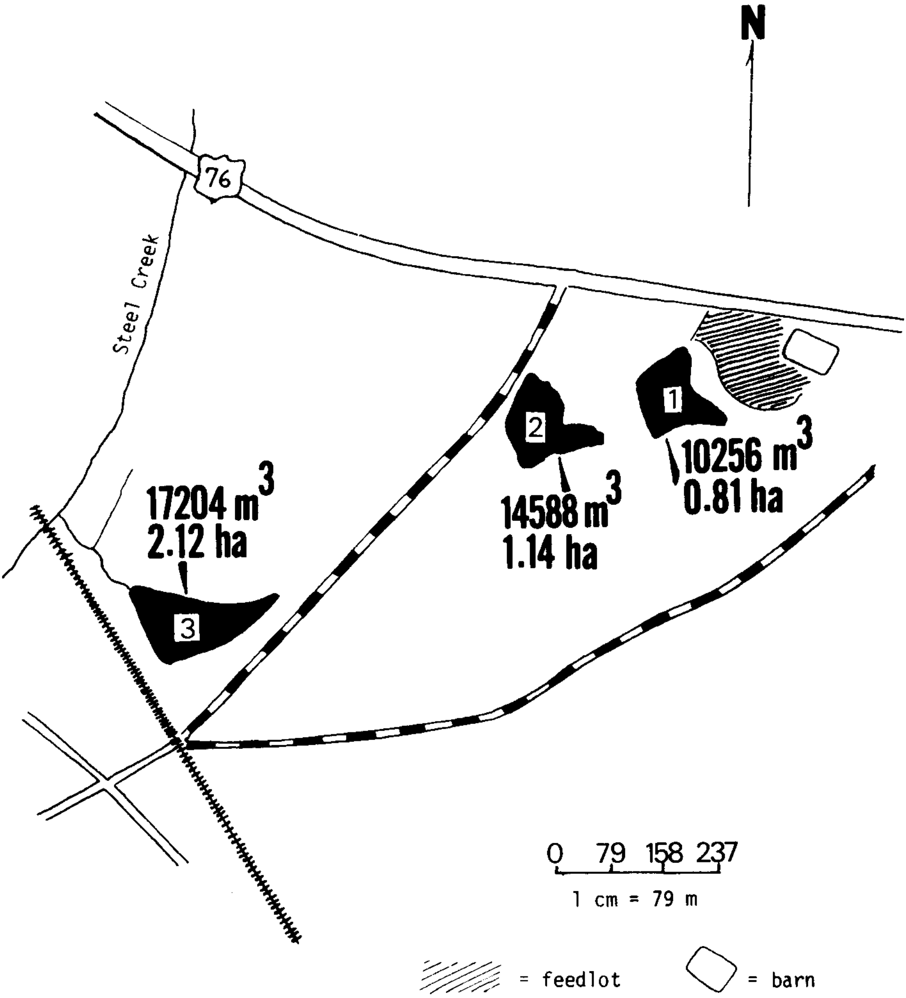

Fig. 1. Location of the 3 sequential impoundments in relation to the dairy barn and feedlot.

Phytoplankton biomass was expressed as mg chlorophyll *a* per m^3 from equations in Lind (1974).

Multiple analysis of variance was used to determine the significance of pond and collection date on chemical and algal parameters. Paired comparisons were used to determine significant differences between ponds. Significance testing was done at the 0.05 error level.

RESULTS

Pond Position

Pond 1 was located directly behind the barn/feedlot area (Fig. 1). Effluent deposited in pond 1 resulted from washing and sanitizing the milking equipment and washing down of the barn twice daily, in addition to runoff from the feedlot. Utilization of the area draining into pond 1 averaged 4500 cattle hours daily (i. e., 225 head of cattle 20 hours/day). Pond 2 was located approximately 200 m from the barn/feedlot area and was separated from this area by pond 1. Pond 2 received no direct drainage from the barn/feedlot area, but did receive effluent from pond 1. Daily utilization of this area averaged 900 cattle hours. Pond 3 was located 700 m from the barn/feedlot area. Inflow to pond 3 was the sequence of effluents of ponds 1 and 2. Although pond 3 was surrounded by pasture, utilization of its immediate drainage area was limited to 15 bulls located here.

Differences Between Ponds

Average soluble orthophosphate ranged from 0.42 - 10.07 mg PO_4/l (Table 1). Highest concentrations of orthophosphate (10.07 mg PO_4/l) occurred in pond 1, the area of intense livestock activity and principal recipient of drainage from the barn and feedlot area. Average orthophosphate decreased progressively to 1.90 mg PO_4/l in pond 2 and 0.42 mg PO_4/l in pond 3. In contrast, average dissolved nitrogen concentrations were lowest in pond 1 (0.001 mg N/l) and increased progressively in ponds 2 (0.22 mg N/l and 3 (0.44 mg N/l).

Chlorophyll *a* concentrations were significantly higher in pond 1, averaging 298 mg/m^3 over the 1-year period. In contrast, ponds 2 and 3 averaged only 103 and 77 mg/m^3 chlorophyll *a*, respectively (Table 1). No significant differences existed in yearly mean chlorophyll *a* concentrations between ponds 2 and 3 (Table 1).

Average dissolved oxygen (DO) concentration was lowest in pond 1 (1.7 mg/l) and increased with respect to distance from the barn and feedlot area (Table 1). Pond 2 averaged 5.6 mg/l DO and pond 3 averaged 8.9 mg/l DO. Dissolved oxygen concentration of surface water and at 1 m depth differed significantly for all 3 ponds. Magnitude of this difference was greatest in pond 1 and decreased progressively in ponds 2 and 3.

Yearly average concentrations for hardness, calcium, magnesium and alkalinity decreased with increasing distance of a pond from the barn/feedlot area (Table 2). For example, total hardness was highest in pond 1 (147.2 mg $CaCO_3$), decreasing to 65.4 and 49.8 mg $CaCO_3$ in ponds 2 and 3 respectively. Of these 4 parameters, the greatest porportional decrease occurred with alkalinity which decreased from 273.2 in pond 1 to 46.8 mg $CaCO_3$/l in pond 3. Slight but significant differences occurred in hydrogen ion concentrations, with pH values ranging from 6.8 to 7.2.

Seasonal Changes

Temperatures for all ponds were similar and seasonal trends characteristic of small farm impoundments in the southeastern United States were observed. Highest temperatures (22 - 28 C) were observed from June through August whereas lowest temperatures (6 - 7 C) occurred during February. Dissolved oxygen, alkalinity

Table 1. Yearly mean values for soluble orthophosphate, dissolved nitrogen, chlorophyll *a* and dissolved oxygen (standard errors in parentheses) for water samples taken biweekly between May 1979 and May 1980. Means preceded by asterisks are not significantly different ($P > 0.05$) from one another.

Pond	Soluble[a] orthophosphate ($mg\ PO_4/l$)	Dissolved[b] nitrogen (mg N/l)	Chlorophyll *a*[c] (mg/m^3)	Dissolved oxygen (mg/l)[d]		
				surface	1 m	average
1	10.07 (0.90)	0.001 (0.001)	298 (64)	3.4 (0.5)	0.0 (0.0)	1.7
2	1.90 (0.11)	0.22 (0.04)	*103 (17)	7.0 (0.5)	4.2 (0.4)	5.6
3	0.42 (0.06)	0.44 (0.08)	* 77 (9)	10.1 (0.5)	7.8 (0.4)	8.9

[a] $F_{pond} = 94.28$, $P \leq 0.0001$.
[b] $F_{pond} = 17.93$, $P \leq 0.001$.
[c] $F_{pond} = 10.86$, $P \leq 0.0001$.
[d] $F_{pond} = 110.21$, $P \leq 0.0001$; $F_{depth} = 65.96$, $P \leq 0.0001$.

Table 2. Yearly mean values for total hardness, calcium, magnesium, alkalinity and pH (standard errors in parentheses) for water sampled biweekly between May 1979 and May 1980. Mean values differed significantly ($P \leq 0.05$) between ponds for all parameters.

Pond	Total[a] hardness ($mg\ CaCO_3/l$)	Calcium[b] (mg/l)	Magnesium[c] (mg/l)	Total alkalinity[d] ($mg\ CaCO_3/l$)	pH[e]
1	147.2 (3.3)	19.1 (0.5)	24.1 (0.8)	273.2 (6.9)	7.2 (0.04)
2	65.4 (1.4)	10.1 (0.2)	9.8 (0.2)	78.9 (1.5)	6.8 (0.1)
3	49.8 (1.1)	7.0 (0.1)	7.9 (0.3)	46.8 (1.0)	7.0 (0.1)

[a] $F_{pond} = 607.46$, $P \leq 0.0001$.
[b] $F_{pond} = 401.73$, $P \leq 0.0001$.
[c] $F_{pond} = 323.13$, $P \leq 0.0001$.
[d] $F_{pond} = 888.47$, $P \leq 0.0001$.
[e] $F_{pond} = 10.80$, $P \leq 0.0001$.

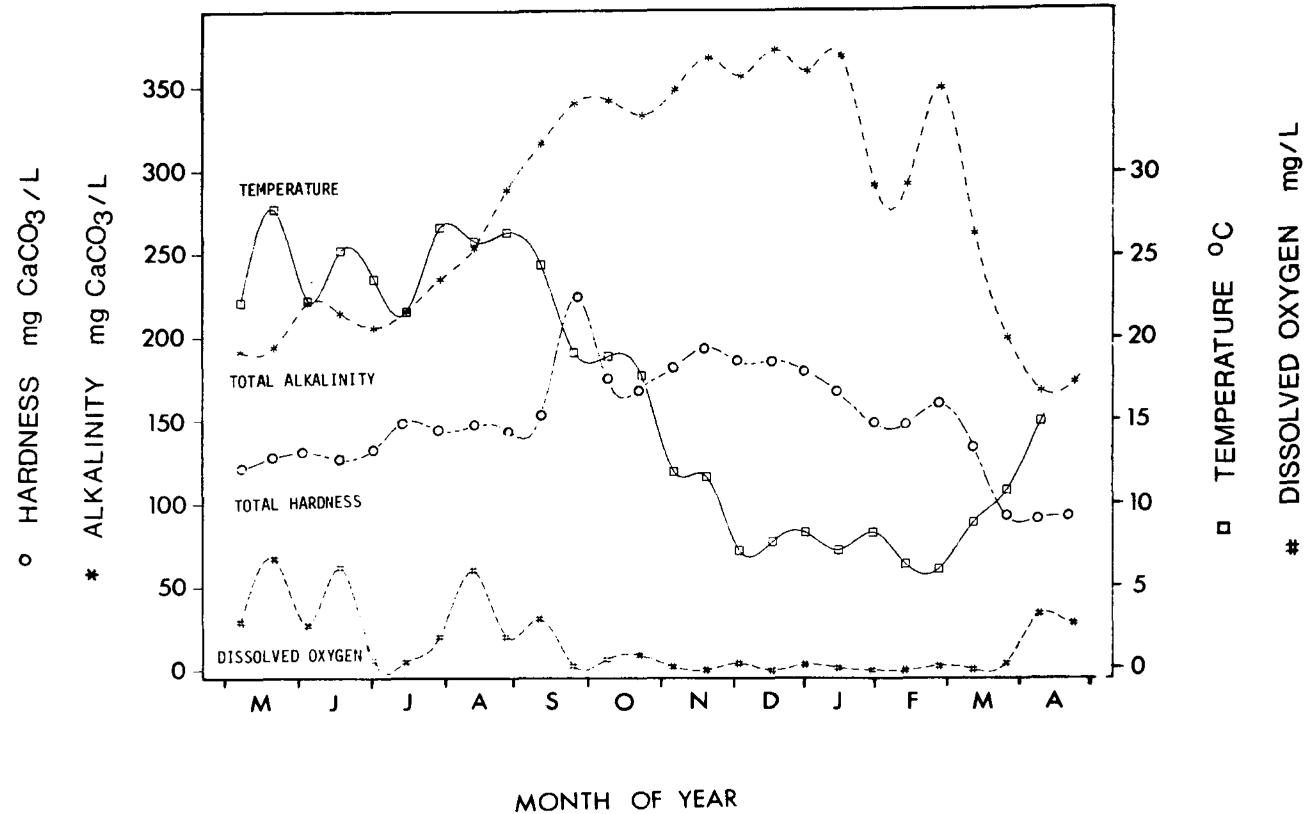

Fig. 2. Relationship between dissolved oxygen, total alkalinity and total hardness in pond number 1 located in the immediate vicinity of the barn and feedlot. Each point represents the average of 4 determinations.

and hardness concentrations fluctuated from week to week in ponds 2 and 3, but no seasonal trends were observed. However, the 1st pond in the sequence demonstrated a prolonged period of extremely low dissolved oxygen (i.e. 0.1 mg/l from 26 September to 26 March). In contrast, alkalinity and hardness concentrations in this pond showed a trend opposite that of dissolved oxygen, with highest values occurring during the period corresponding to low dissolved oxygen (Fig. 2).

Soluble orthophosphate concentrations in all ponds demonstrated week to week fluctuations with no seasonal trends (Fig. 3). Soluble orthophosphate levels in pond 1 achieved highest and lowest concentrations in an interval of only 6 weeks duration during July and August. Magnitude of week to week variations decreased progressively with distance from feedlot. Chlorophyll *a* concentrations in all 3 ponds changed from week to week, with occasional peaks representing massive algal blooms. Concentrations of chlorophyll *a* were most stable during the months of December through February. Dissolved nitrate and nitrite correlated positively with dissolved oxygen ($r = 0.16$, $P \leq 0.05$). Dissolved nitrogen was detectable on only 1 sampling date in pond 1, which consistently maintained lower dissolved oxygen concentrations than ponds 2 and 3. Large fluctuations in concentrations of dissolved nitrogen occurred between sampling dates in ponds 2 and 3. However, changes in concentrations of dissolved nitrate and nitrite did not bear any relationship to changes in chlorophyll *a* or soluble orthophosphate. For example, nitrate and nitrite in ponds 2 and 3 ranged from a high of approximately 1.8 mg/l to a low of 0.1 mg/l between 10 October and 9 November. In comparison, soluble orthophosphate remained relatively constant, averaging about 0.4 mg/l.

DISCUSSION

Watersheds in the Piedmont of South Carolina are characterized by very low alkalinities and water hardness (e.g., 5-15 mg/l). Excreta produced by the herd of cows elevated concentrations of water hardness and alkalinity by a factor of 10 or more. Pond 2, which was characterized by concentrations intermediate of those in ponds 1 and 3, averaged 65 and 79 mg/l total hardness and total alkalinity respectively. In comparison, total hardness and alkalinity values between 20 and 30 mg/l were reported for fertilized ponds and pasture impoundments (Boyd 1976). Concentrations of chlorophyll *a* were likewise high. In this study, chlorophyll *a* averaged 298, 103, and 77 mg/m^3 in ponds 1, 2 and 3 respectively. Fertilized watershed ponds examined in a previous study averaged between only 19 and 31 mg/m^3 (Boyd and Sowles 1978). Reduced concentrations of soluble orthophosphate, hardness, calcium, magnesium and chlorophyll *a* with increasing distance from the feedlot area could be accomplished by utilization of nutrients within the aquatic system, incorporation of nutrients into detritus on pond bottoms or by entering ground water while travelling in creeks connecting ponds (Prowse 1969).

A concentration of 5.0 mg/l is recognized as the minimum dissolved oxygen concentration required for warmwater fish culture (Boyd 1979). In this study, pond 1, located most proximal to intensive livestock concentration and activity achieved this value on only 3 sampling dates. Low dissolved oxygen levels observed in pond 1 coincided with increased carbon dioxide levels which consequently resulted in increased alkalinity and hardness concentrations. Input into pond 1 of large quantities of allochthonous organic matter originating in the feedlot area produced

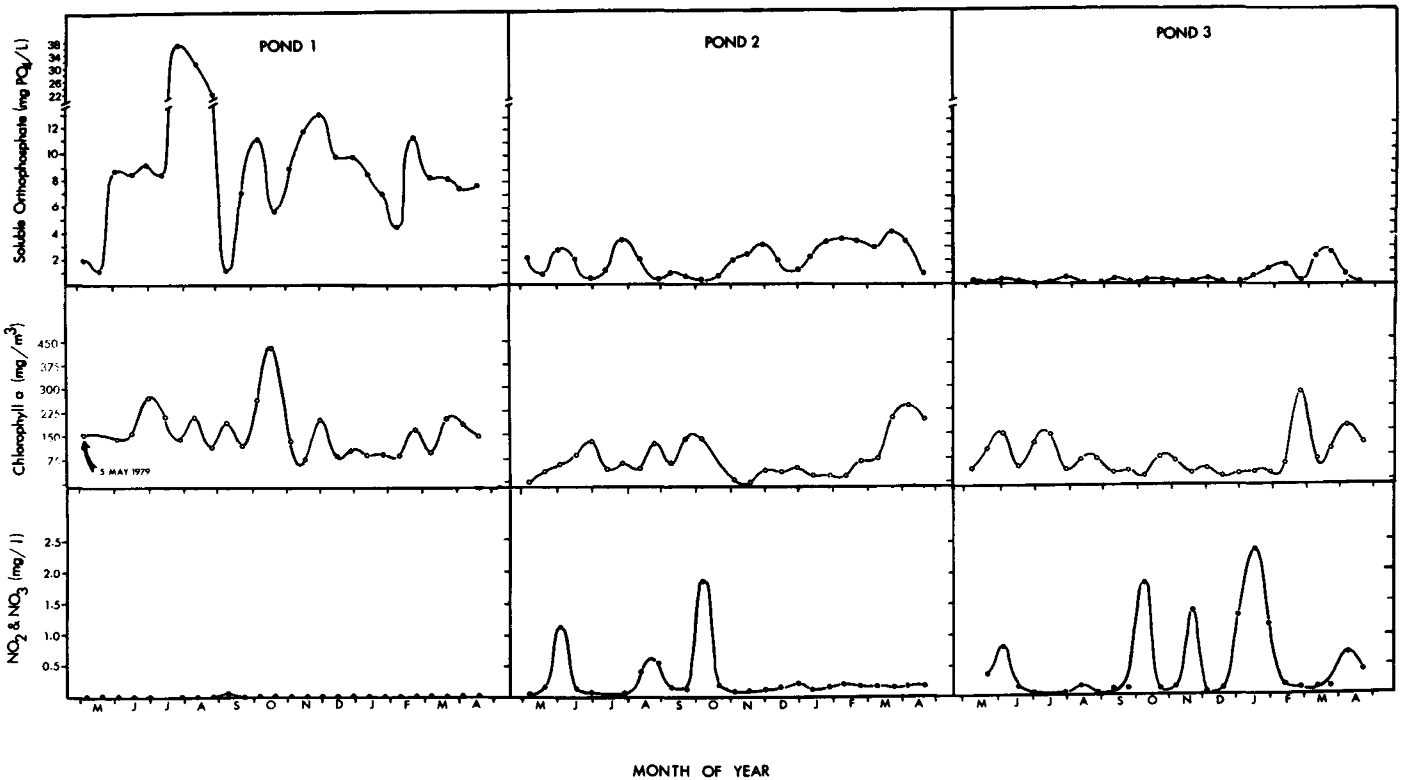

Fig. 3. Biweekly variation in concentrations of soluble orthophosphate, chlorophyll *a*, and dissolved nitrate and nitrite. Each point represents the average of 4 replicate determinations.

water quality characteristics similar to sewage settling ponds (Carpenter et al. 1976, Sopper 1976).

In contrast, ponds 2 and 3 would be highly desirable for the culture of herbivorous fishes, particularly a phytoplanktivore such as the silver carp (*Hypophthalmichthys molitrix*). The combination of suitable dissolved oxygen, high alkalinity and dense phytoplankton should result in successful fish production.

Small impoundments (i.e. <5 ha) are unstable aquatic systems because of their small size and resulting vulnerability to environmental factors. For this reason, trophic state indices which utilize parameters such as phosphorus and chlorophyll *a* concentrations (Carlson 1977) should be applied with caution to small impoundments and ponds. The importance of frequent long-term measurements can not be understated. Significant week to week fluctuations, with no trends, were observed for dissolved nitrogen, soluble orthophosphate, dissolved oxygen, calcium, magnesium, and chlorophyll *a* in all ponds. Algal uptake of dissolved nitrogen and soluble orthophosphate for rapid growth (Wetzel 1975, Reid and Wood 1976) would result in decreases of these nutrients causing weekly fluctuations observed in this study. Potential errors exist with a single measurement, making long term studies with frequent measurements more comprehensive in describing the trophic status or water quality characteristics of farm ponds. In addition, levels of NO_2 & NO_3 are not necessarily suitable measurements of trophic status, since low dissolved nitrogen levels were found with low dissolved oxygen levels in pond 1 which, incidentally, had the highest chlorophyll *a* concentrations. The range of dissolved nitrogen levels for a single pond was related to range of dissolved oxygen. Dissolved nitrogen concentrations curves have been found to follow dissolved oxygen curves (Wetzel 1975).

Observations made on these farm ponds revealed that water quality parameters appear to fluctuate with no seasonal trend; therefore, concrete assessments should not be made on few randomly chosen samples. Intense livestock activity and drainage (runoff) increased concentrations of total hardness, soluble orthophosphate and chlorophyll *a*. Presence of a settling pond close to the area of intense livestock activity resulted in downstream impoundments having limnological characteristics suitable for fish culture.

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