Some Aspects of the Summer Limnology of Lake Frierson

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Abstract: Physiochemical characteristics of Lake Frierson were monitored biweekly from 15 May to 14 September 1979. Lake Frierson revealed intense thermal stratification in late May. Stratification continued until fall turnover in mid-September. The anoxic hypolimnion started at the 3.0 to 3.5 m sampling depth and continued to the bottom. During this time, evaporation accounted for the loss of 1.0 m of water. Data from the shallow stations revealed anoxia and oxygen values of 2.0 mg/1 or less on 2 dates, 10 July and 8 August 1979.

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Thermal stratification occurs in many shallow lakes in the southern United States. This condition results from rapid warmup of the upper layers of water and the inability of the wind currents to mix the water with the cooler layers below. Since density differences prevent wind induced epilimnetic currents from penetrating the hypolimnion, oxygen depletion results. The accumulation of hydrogen sulfide, ammonia, reduced iron, manganese, and orthophosphorus further accompany oxygen depletion (Garton et al. 1976).

The purpose of this study was to determine the portion of water contained in the hypolimnion of a small reservoir, the depth at which the hypolimnnion began, and the differences in physicochemical characteristics between the epilimnion and hypolimnion. Knowing the amount of habitable water lost to fish production by stratification and evaporation should enable

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reservoir management programs to maintain the correct standing crop of fish, preventing overcrowding and stunting.

Description of the Area

Lake Frierson is located in Greene County, Arkansas. This reservoir was created in 1975 by damming Big Creek and is part of the Soil Conservation Service's Big Creek Watershed Flood control program. It has a surface area of 140 ha and a maximum depth of 6 m.

The lake bed is characterized by willows along the former creek channel and various shrubby vegetation along what were fence rows prior to flooding. Along the upper end of the lake is a large shallow area. This area dries up in late summer and supports dense growths of broom sedge. An earthen dam with a spillway to maintain a flow of water in Big Creek is located at the south end of the lake. This flow has virtually no effect on the level of the lake.

Methods

Two transects were established across Lake Frierson. Transect 1 was established 1.5 km north of the dam and ran in an east-west direction. Transect 2 was located 200 m north of and ran parallel to the dam. Three stations were established along Transect 1 at 80-100 m intervals and 4 stations were established along Transect 2 at about the same intervals.

Dissolved oxygen and temperature were measured at 0.5 m intervals from surface to bottom with a YSI Model 54B Polarographic Oxygen Meter (Yellow Springs Instrument Co., Yellow Springs, Ohio) with a thermister. Specific conductance was measured in the field with a Hydrolab IIB (Hydrolab Corp., Austin, Texas).

At the laboratory, hydrogen ion concentration (pH) was measured with a Taylor Colorimeter (Taylor Chemical Co., Baltimore Md.). Ammonia-nitrogen, nitrate-nitrogen, total phosphorus, organic phosphorus, inorganic phosphorus, and turbidity were determined by use of a DR/2 Spectrophotometer (Hach Chemical Co., Ames, Iowa) using the following methods: Nesslerization for ammonia-nitrogen, cadmium reduction for nitrate-nitrogen, and persulfate oxidation-sulfuric acid hydrolysis-ascorbic acid method for phosphates (American Public Health Association 1974). Turbidity was determined by the absorptometric method (FWPCA 1968). Carbon dioxide and alkalinity were determined according to Welch (1948). Water samples for these characteristics were collected by use of a 2 liter VanDorn Bottle positioned slightly below the surface and near the bottom. These samples were wrapped in aluminum foil, refrigerated, and analyzed within 24 hours of their collection, except for carbon dioxide, which was measured in the field. All monitored characteristics, except dissolved oxygen, temperature, and specific conductance, were averaged for the month and recorded as mean monthly values.

Results and Discussion

Annual Temperature Cycle

The annual temperature cycle of Lake Frierson follows Hutchinson's (1957) definition of a warm monomictic lake. Lake Frierson was characterized by intense thermal stratification which began in late May and continued until mid-September (Figs. 1–5). During stratification, temperatures as high as 32° C were recorded at the surface, while bottom temperatures at the deepest station, on Transect 2, ranged from 15.5° to 19° C. Bottom temperatures along Transect 1, 2.0 to 2.5 m deep, remained closer to surface temperatures and stratification was milder due to periodic mixing.

Thermal stratification occurs in many eutrophic lakes because of inability of the wind to mix epilimnetic waters with cooler, denser lower layers. Shannon and Brezonik (1972) observed that stable thermal stratification can occur in Florida lakes as shallow as 4 m, while temperature differences of 4° to 5° C can occur from the top to bottom in lakes 2 to 4 m deep. Fall turnover occurred when water temperature had dropped to 23° to 24° C (Fig. 5).

The turbidity of Lake Frierson was quite variable, with mean monthly values ranging from 7 FTUs (formazon turbidity units) in August to a high of 112 FTUs in May (Table 1). The high turbidity in May resulted from spring rains washing particles into the lake. The decrease in summer was probably caused by summer drought, sedimentation, and flocculation of the existing particles by H^+ ions released from breakdown of aquatic vegetation and other material.

Depth and Water Loss

Water depth of Lake Frierson, as in most lakes, varies seasonally with climatic conditions. On the initial sampling date, stations along Transect 1 were 2.5 m deep while stations along Transect 2 were 2.5 to 5.5 m deep. By 24 July, water loss accounted for 0.5 m change in depth at the last two stations of Transect 1 and 1.0 m at the first 3 stations of Transect 2. Some disparity can be attributed to samples not being collected in the exact same place, but as close as possible to the original collection sites. Evaporation rates for this area are 1.3 m/year (Roy Grizzel, pers. commun.).

Dissolved Oxygen and Hypolimnion Development

During this study, surface-dissolved oxygen values ranged from 9.0 mg/liter in May to 7.0 mg/liter in July (Figs. 1, 3). Percentage of dissolved oxygen saturation ranged from a low of 80% in September to a high of 103%

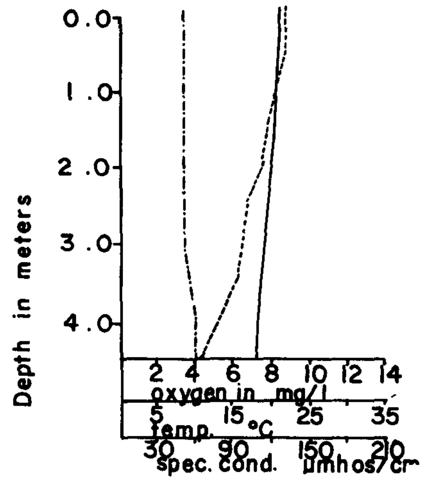

Figure 1. May 1979. Mean monthly values of dissolved oxygen (--------), temperature (———), and specific conductance (–·–·–·–) profiles from Lake Frierson.

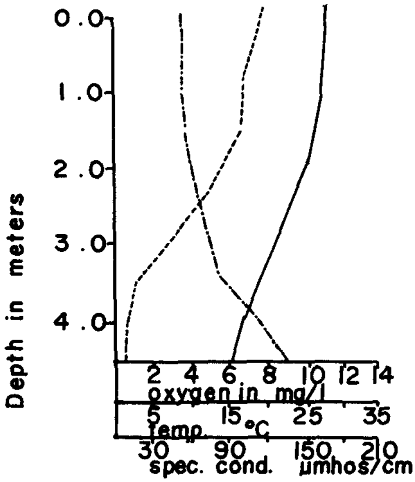

Figure 2. June 1979. Mean monthly values of dissolved oxygen (--------), temperature (———), and specific conductance (–·–·–·–) profiles from Lake Frierson.

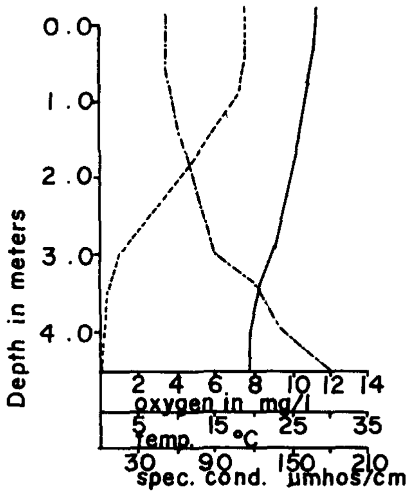

Figure 3. July 1979. Mean monthly values of dissolved oxygen (--------), temperature (———), and specific conductance (–·–·–·–) profiles from Lake Frierson.

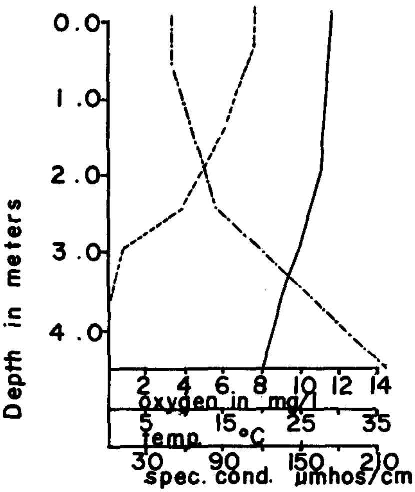

Figure 4. August 1979. Mean monthly values of dissolved oxygen (--------), temperature (———), and specific conductance (–·–·–·–) profiles from Lake Frierson.

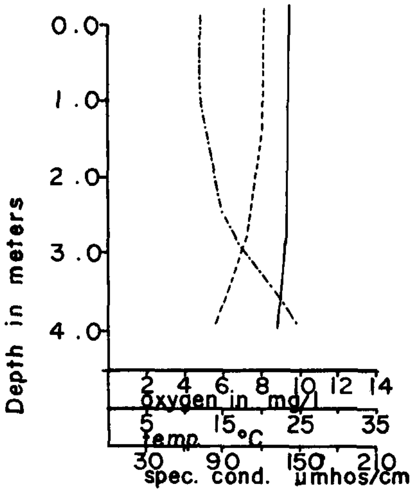

Figure 5. September 1979. Mean monthly values of dissolved oxygen (--------), temperature (———), and specific conductance (–·–·–·–) profiles from Lake Frierson.

in July. The lowest saturation occurred during fall turnover and the highest occurred as a result of photosynthesis. Similar findings were reported by Begg (1970) who noted an oxygen decrease at turnover. In eutrophic lakes, Varga and Falls (1972) reported that during the summer growing season, oxygen values will be near or above the saturation point in the epilimnion.

Clinograde curves were recorded during stratification periods while orthograde curves were recorded at fall turnover (Figs. 1–5). Surface dissolved oxygen values along each transect were similar. During stratification, along Transect 1, anoxia was recorded only once, on 8 August. Dissolved oxygen values of 2.0 mg/liter or less were recorded on 2 dates, 10 July and 8 August, therefore it seemed evident that oxygen depletion occurred only briefly and then broke up. Oxygen depletion occurred along Transect 2 from 24 May until fall turnover.

The hypolimnion at Transect 2 on May 24 started at a depth of 4.5 m and continued to a depth of 5.0 m. These findings are similar to those of Cowell et al. (1975), who reported dissolved oxygen values of 0.5 mg/liter at the 3.0 m depth in a Florida lake, indicating a hypolimnion. A small hypolimnion occurred from 3.0 to 3.5 m at Transect 2, on 12 June.

The thermocline on 12 June began at 1.5 m and continuetd to a depth of 3.5 m. Similar findings were reported by Eckstein (1970) in a meromictic lake. He reported a thermocline from the 1 to 3 m depths.

Maximum hypolimnion size was reached on 24 July at Transect 2, station 2. Here, the hypolimnion occupied the zone from 3.0 to 4.5 m. Anoxic hypolimnions were recorded at stations 1 and 3 along Transect 2. The thermocline at Transect 2, station 2, was very sharp, starting at 2.0 m and continuing to 3.0 m in depth. For the remainder of the summer, the hypolimnion

Table 1. Mean monthly values of physicochemical characters from Lake Frierson. May–September 1979.

	Alk. mg/1	CO_2 mg/1	pH	Tur.[a] FTU's	NH_3–N mg/1	NO_3–N mg/1	Phos.[b] mg/1 Tot.	T.I.	Org.
				May					
Surface	26.71	1.78	7.20	100.21	0.38	0.78	No phosphorus taken		
Bottom	25.42	4.28	7.11	—	0.53	0.78	this month.		
				June					
Surface	20.85	1.89	7.20	50.92	0.37	0.60	0.27	0.18	0.09
Bottom	31.92	10.57	6.85	—	1.10	0.49	0.36	0.21	0.15
				July					
Surface	23.70	1.57	7.20	17.28	0.26	0.52	0.31	0.23	0.08
Bottom	36.57	9.21	6.85	—	0.85	0.37	0.34	0.25	0.09
				August					
Surface	24.28	1.75	7.01	9.71	0.23	0.67	0.49	0.26	0.23
Bottom	36.85	12.42	6.61	—	0.71	0.46	0.62	0.40	0.22
				September					
Surface	32.14	2.00	7.00	11.00	0.16	0.76	0.32	0.24	0.08
Bottom	35.42	4.57	6.94	—	0.37	0.83	0.40	0.25	0.15

[a] Tur. = Turbidity.
[b] Tot. = Total, T.I. = Total Inorganic, Org. = Organic.

occupied depths from 3.0 to 4.5 m. The hypolimnion at the other stations never occupied more than 0.5 m of the water column.

Hydrogen Ion Concentration

Mean monthly pH values of the surface waters ranged from 6.9 to 7.3 (Table 1). Highest values were recorded in June. Lower values were a result of diminished photosynthetic activity. During stratification periods, slight differences occurred between surface and bottom samples along Transect 1. Along Transect 2, a larger difference between surface and bottom pH values occurred during stratification. Mean values of 6.3 were recorded for August at 3 stations. The decrease in pH was probably due to the presence of carbon dioxide and hydrogen sulfide produced during the breakdown of organic material (Larsen and Malueg 1976). At turnover, only slight differences occurred between surface and bottom values on either transect (Table 1).

Alkalinity

Based on categories by Reid and Wood (1976), Lake Frierson was classified as a medium hard-water lake in that the pH is circumneutral and free carbon dioxide concentrations varied widely. Only methyl-orange, or bicarbonate alkalinity, occurred in Lake Frierson. Mean surface values were low, ranging from 21 mg/liter in June to 45 mg/liter during fall turnover (Table

1). Little difference was recorded between the surface and bottom samples at the shallow stations. An increase in alkalinity occurred with increased depth during stratification. This increase was due to the release of carbon dioxide and subsequent conversion of carbon dioxide to the bicarbonate form. Weimer and Lee (1973) and Larsen and Malueg (1976) reported an alkalinity increase as a result of carbon dioxide released from anaerobic decomposition in the lower mixolimnion or lake bottom. By definition, alkalinity of water does not change with addition of carbon dioxide; however, when the addition of carbon dioxide is accompanied by the addition of an agent that may remove free H^+ ions from the water then it does increase the alkalinity of the water. Begg (1970) reported that an increase in alkalinity with depth may be due to the presence of hydrogen sulfide laden water or nearness of the bottom. At the fall turnover, little difference was recorded between surface and bottom values at any station (Table 1).

Carbon Dioxide

Accumulation of carbon dioxide occurs in the hypolimnion of eutrophic lakes during stratification. Mean monthly values of carbon dioxide in surface waters ranged from 0.8 mg/liter in June to a high of 3 mg/liter at fall turnover (Table 1). A slight difference was recorded between surface and bottom samples along Transect 1 during the summer months, but the shallow depth allowed enough mixing to prevent the accumulation of larger concentrations. A larger difference occurred between surface and bottom samples along Transect 2 during stratification, with highest mean monthly values of 23.0 and 16.5 mg/liter being recorded at stations 2 and 3 during August. The accumulation was due to this layer not being mixed for a 3-month period and because the biota present could not utilize carbon dioxide. The presence of larger amounts in the surface waters at turnover time was due to mixing.

Specific Conductance

Specific conductance is a measure of electrolytes in a solution and indicates the concentration of inorganic dissolved solids in most waters (Bacon 1978). During the study, specific conductance of surface water of Lake Frierson was low, measuring 50 μmho/cm most of the time. Stratification resulted in an increase in specific conductance with increased depth (Figs. 1–4). An example of this was a reading of 220 μmho/cm on 29 August at Transect 2. Begg (1970) found the increase of specific conductance with increased depth to be due to the presence of hydrogen sulfide, while Young et al. (1972) found the increase closely correlated with high alkalinity.

Throughout stratification, an increase in specific conductance always marked the start of the thermocline and increased greatly in the hypolimnion. Highest surface values occurred at fall turnover with values as high as 90 μmho/cm. This increase was due to mixing.

Ammonia-Nitrogen

Ammonia is released as an excretory product by many aquatic animals and by action of heterotrophic bacteria in decomposition of organic material (Bacon 1978). Ammonia accumulates in the hypolimnion of eutrophic lakes often-times in concentrations lethal to fish. Flagg (1978) and Flagg and Hinck (1978) reported fish survived at 0.04 mg/liter of ammonia for 17 days; however, *Aeromonas* bacteria increased per gram of liver tissue.

Mean monthly values of ammonia in surface waters ranged from 0.65 mg/liter in May to 0.10 mg/liter in September (Table 1). Ammonia values increased slightly with increased depth during stratification periods along Transect 1, while increasing drastically along Transect 2. Mean monthly values of 2.0 mg/liter or more were recorded throughout the summer months. The slight increase at the shallow stations was due to partial oxidation of the produced ammonia, thus preventing a buildup. Anoxia at the deeper stations prevented the ammonia from being oxidized and the accumulation resulted. Schindler and Comita (1971) reported an increase in ammonia during stratification due to release by sediments and lower water column.

Nitrate-Nitrogen

Mean monthly nitrate values of Lake Frierson ranged from 0.20 to 1.08 mg/liter. Reid and Wood (1976) reported a world average of 0.30 mg/liter of nitrate-nitrogen in waters. Putnam and Olson (1959) reported values from 0.93 to 1.15 mg/liter in western Lake Superior, while Bacon (1978) reported values of 2.82 mg/liter in Lake Chicot, Arkansas.

Maximum values at Lake Frierson were recorded in May, during the rainy season, because of leaching and also because highly oxygenated waters benefit nitrification. Minimum values occurred in late summer when maximum photosynthetic activity reduced the supply of nitrates available. Schindler and Comita (1971) reported a near absence of nitrate-nitrogen in the euphotic zone in mid-summer because of use by phytoplankton.

Higher values were generally recorded at the surface with a decrease with increased depth during stratification. This was due to oxygen reduction in the hypolimnion.

Phosphorus

Of all the elements present in living organisms, phosphorus is likely to be ecologically the most important. The ratio of phosphorus to other elements tends to be greater than the ratio in the primary source of the biological element (Hutchinson 1957).

Mean monthly values of total phosphorus in Lake Frierson ranged from 0.18 mg/liter in June to 1.01 mg/liter in August (Table 1). Hutchinson (1957) reported the world average for most river water is 0.07 mg/liter, while Reid and Wood (1976) reported that the mean concentration in most lakes ranges from 0.02 to 0.03 mg/liter.

During stratification, an increase in total phosphorus was recorded with increased depth. This was a result of decomposition. Little difference in total phosphorus was recorded between transects with regard to surface values.

Conclusion

Lake Frierson is a shallow reservoir in which a definite thermal stratification occurred during the summer. Stratification involved formation of an anoxic hypolimnion beginning at 3.0 m depth and continuing to the bottom (4.5 to 5.0 m). A sharp thermocline occurred at the 2.0 to 3.0 m depth and was indicated by an increase in specific conductance values. Evaporation involved a loss of approximately 1.0 m of water. The combination of 1.5 to 2.0 m in the hypolimnion plus the loss due to evaporation accounted for a significant percentage of the lake's volume of water. In Lake Frierson, this leaves 2.5 to 3.0 m for most aquatic organisms to carry on their activities.

It is suggested that the effect of large water losses on the aquatic environment should be studied. Crowding of fishes may result in stress, stunted growth, predation by predators, and increased incidences of pathogens and parasites. Determining the effects on other aquatic communities would be of interest.

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