CALORIC CONTENT AND IRON, MANGANESE, AND ZINC CONCENTRATIONS OF SEDIMENT, CHAOBORIDS, AND CHIRONOMIDS OF HAM'S AND ARBUCKLE LAKES

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CALORIC CONTENT AND IRON, MANGANESE, AND ZINC

CONCENTRATIONS OF SEDIMENT, CHAOBORIDS, AND

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PREFACE

The objectives of this study were to observe the effects of lake destratification on (1) concentrations of iron, manganese, and zinc in the water, sediments, chaoborids, and chironomids and (2) the caloric content of the sediments, chaoborids, and chironomids of Ham's and Arbuckle lakes.

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CHAPTER I

INTRODUCTION

Iron and manganese are important micronutrients in aquatic environments and influence the presence or absence of other substances in the water column and sediments (Mortimer 1941). Dissolved oxygen concentration and redox potential of the water and sediments in turn influence the presence and form of iron and manganese.

Iron exists as Fe^{3+} in oxidized conditions and Fe^{2+} in reduced conditions. $Fe(OH)_3$ is insoluble and precipitates with phosphates and other nutrients adsorbed on its surface. In reduced conditions soluble Fe^{2+} compounds re-enter the water. Manganese follows a similar trend, except that its reduced form enters the water at a higher redox potential than Fe^{2+}. These trends are most evident in the thermal stratification of lakes. Zinc does not change solubility in response to stratification; however, it does accumulate in the hypolimnion due to decomposition and mineralization. Little research has been done to analyze the possible effects of these metal concentration changes on the benthos.

Considerable research has been conducted on the heavy metal concentrations in organisms resulting from pollution. The concentration factor of copper, chromium, lead, and zinc was determined to be higher in chironomids than sediments (Namminga and Wilhm 1977). Heavy metal concentration in the sediment was influenced by percent loss on ignition and particle size. Mathis and Cummings (1973) however, reported highest metal concentrations in the sediment, lowest in the water, and intermediate in the biota. No studies have looked at the possible response of trace element concentrations in the biota to destratification.

Caloric content varies between 5400-6100 cal g^{-1} for many species (Slobodkin and Richman 1961). It varies with season (Comita and Schindler 1963, Wissing and Hasler 1971), environmental conditions (Spoehr and Milner 1967), nutritional condition of the organism (Slobodkin and Richman 1961) and the stage in the life history (Wiegart 1965). Golley (1961) stated that caloric constants cannot be used in intensive surveys because of the response of caloric content in fluctuating environmental factors. No studies have been undertaken to determine the effect of lake stratification and the resulting anoxia in the hypolimnion on the caloric content of the benthos.

Chironomids and chaoborids are important components of the deep water benthos in a lake and feed in the benthic area. Chaoborids are best known for their diel migrations from the bottom substrate into the epilimnion at night. Chironomids are detritivores and feed on suspended material. Little research has been done to see how these organisms reflect the changes in their environment corresponding to stratification.

The objectives of this study are to determine the effects of lake destratification on (1) concentrations of iron, manganese, and zinc in the water, sediments, chaoborids, and chironomids and (2) the caloric content of the sediment, chaoborids, and chironomids in Ham's and Arbuckle lakes. Field studies were supplemented with controlled laboratory experiments to observe the effects of low DO on iron concentration in organisms and caloric content of sediments.

CHAPTER II

LITERATURE REVIEW

Sediments greatly influence the productivity and nutritional status of a lake. The condition of the overlying waters influences the sediment. An oxidized environment affects the abundance and oxidation state of certain elements such as iron and manganese (Howeler 1972). Mixing and photosynthesis do not occur in deep water sediments and diffusion of oxygen is slow; therefore, the sediments are in a reduced state except for a few millimeters at the surface (Bouldin 1968).

One of the most electroactive elements is iron. This element's response to oxidizing conditions influences other substances present in the water column and sediments. Iron only occurs in two oxidation states in nature, Fe^{2+} and Fe^{3+} (Hem 1960). Oxidized iron, Fe^{3+}, is generally present as $Fe(OH)_3$, an insoluble colloid. Most of this ferric iron is readily removed by filtration with a 0.045μ filter (Hem 1960). When this positively charged colloid is present in the water column, particles begin to aggregate and precipitate. Numerous other substances including phosphates, nitrates, and other trace elements adsorb onto the colloid surface (Hayes et al. 1958). Ferric iron can also form insoluble phosphate and carbonate compounds which are not as frequently encountered.

Reduced ferrous iron, Fe^{2+}, forms $Fe(OH)_2$, a soluble compound. Carbonate and bicarbonate forms are also formed; however, these forms do not significantly affect Fe^{2+} solubility (Singer and Stumm 1970). Fe^{2+} can react with sulfides to form FeS, an insoluble black precipitate (Doyle 1968). Fairly large concentrations of Fe^{2+} can occasionally be found in oxidized conditions. Ferrous iron is complexed in the presence of certain organic substances such as tannic acid (Theis and Singer 1974) and yellow organic acids (Shapiro 1964). When Fe^{3+} reduces to Fe^{2+}, the sorbed compounds complexed with the $Fe(OH)_3$ colloid are released and redissolved.

Manganese follows a similar series of reactions. Mn^{4+} is the oxidized, insoluble form; Mn^{2+} is the reduced, soluble form which occurs at low E_h and pH. Mn^{3+} also occurs, but it is very unstable and quickly changes to another oxidation state. Mn^{2+} will form carbonate and sulfide compounds; however, the major one is $Mn(OH)_2$. Mn^{4+} will reduce at a higher redox potential than Fe^{3+} and therefore goes into solution sooner than iron as reducing conditions increase. Conversely, Mn^{2+} oxidizes to Mn^{4+} more slowly than Fe^{2+} oxidizes to Fe^{3+} (Wetzel 1975).

These patterns of oxidation and reduction are most clearly pronounced in nature in the stratification of eutrophic lakes. In spring oxic conditions persist throughout the water column, and a relatively high E_h exists. Iron will be present as Fe^{3+}, primarily as $Fe(OH)_3$ which will be precipitating. The surface of the sediment is the oxidized microzone and will be only a few millimeters thick. It is composed primarily of $Fe(OH)_3$ with other substances sorbed to its surface.

As summer progresses, a eutrophic lake stratifies. The upper waters are warmed and less dense than the cool lower waters. The density differences in the two layers increases. The epilimnion remains warm and oxygenated; the hypolimnion remains cool. The layers do not mix because of the density differences, so the oxygen in the hypolimnion is not replenished. Respiration and the oxygen demand of the sediments deplete hypolimnial oxygen stores (Bouldin 1968). The waters approach reducing conditions with a lower E_h. Mn^{4+} reduces to Mn^{2+} and Fe^{3+} reduces to Fe^{2+}, both becoming soluble. The oxidized microzone breaks down as Fe^{3+} reduces to Fe^{2+}, releasing the sorbed materials, and the sediment becomes reduced throughout. As anaerobic decomposition continues, CH_4, NH_4, and H_2S are released. The sulfide from this decomposition will react with Fe^{2+} to form FeS and Mn^{2+} to form MnS.

In the fall surface waters cool and become more dense. Wind action, acting with the density change causes the lake to turnover. Oxidizing conditions exist throughout the water column. Nutrients dissolved in the hypolimnion are reintroduced throughout the water column. Ferric and mangannic hydroxides reform and precipitate. The oxidized microzone reforms over the sediment surface, beginning at an E_h of 340 mV (Pearsall and Mortimer 1939).

The presence of the oxidized microzone influences the exchange of substances across the mud-water interface (Gorham 1958, Howeler 1972). Mortimer (1942) believed that the microzone was maintained by diffusion of DO into the sediment. The reducing power of the sediment is believed to influence the distance of diffusion. The distance depends on the amounts of turbulence stirring up the mud. Gorham (1958) demonstrated this by reaerating anaerobic cores of mud and water. Without mixing the sediment in reaeration, the microzone formed was thin. Hayes et al. (1958) was unable to correlate the depth of the microzone and lake productivity. In waters containing low phosphorus, the sediments are an important source of phosphorus for algal growth (Procella et al. 1970).

As mentioned before, hydrated iron oxides regulate phosphorus release and sorption (Patrick and Khalid 1974). Because the oxidized microzone is composed of hydroxides of mostly iron and manganese (Gorham and Swain 1965), it is a trap for nutrients adsorbed on the hydroxides (Mackereth 1966). Surface portions have the highest concentration of phosphorus (McKee et al. 1970), although large quantities are found in the lower portions of the sediment column (Livingstone and Boykin 1962). This phosphorus is able to move through anaerobic sediments as is ammonium (Hynes and Grieb 1970). Available organic and inorganic phosphorus associates with clay more than silt (Gill et al. 1976).

Oxygen demand of sediment is inversely correlated with particle size. Sediments with smaller particle size, like detritus, consume more oxygen than larger particle size sediments (Hargrave 1972). Mixing the sediment also affects oxygen demand thereby affecting the water (McKee et al. 1970).

In metal analyses sediments are often analyzed because they present a continuous and historical record. Water analyses often miss peak metal discharges (Oliver 1973). A higher concentration of metals is also found in the sediment, making the analyses easier (Hutchinson and Fitchko 1974).

The major inputs of iron into a lake are erosion and runoff. Iron is generally higher in concentration in particulate form than in dissolved form. The amount of particulate iron varies seasonally (Elder et al. 1976). Maximum runoff generally occurs in late spring or early summer. Soluble or dissolved iron concentrations do not vary considerably in natural waters (Williams and Chan 1966) Most of the soluble iron is either chelated or absorbed by phytoplankton.

Manganese also has several sources. The major sources are from manganiferous soils and decomposition of organic materials (Weston 1931). Because of the large amount of manganese which accumulates in reservoirs, vegetation stripping is often suggested before the water level is raised (Wolman and Stegmaier 1940, Frisk 1932). Regional differences exist in Mn concentrations. Suspended Mn concentrations are generally higher in watersheds east of the Mississippi River due to the soils in the region rich in trace elements and industrial contamination (Turekian 1967).

Concentrations of trace elements in sediments have been correlated with several factors. A high correlation was determined between metal concentrations, clay content, and loss on ignition (Fitchko and Hutchinson 1975). Chemical composition of the sediment has also been correlated to particle size, pH, E_h, geographic locations, and age of the lake. Generally in sediments there are surface enrichments of Zn, Pb, Cu, organic carbon, and phosphorus. Mn and S concentrations are related to the migrations of these elements in pore water (Kemp and Thomas 1976). Grieve and Fletcher (1976) determined a close relationship between sediment texture and the concentration of Fe and Mn, reflecting that the concentration of trace elements increased in detrital materials. A good correlation was found between Mn, Fe, P, and the depth of overlying water (Delfino et al. 1969).

Zinc concentration has been correlated with water depth (Sias and Wilhm 1975). Zinc does not respond to changes in the redox potential in the same way as Fe and Mn; however, it does accumulate in the hypolimnion. Mineralization and decomposition of detritus release zinc (Wetzel 1975). Zinc also complexes with organic compounds. Zinc concentrations increase with decreasing particle size. Most of the zinc in the detrital fraction is in sulfides. Only 14-29% of zinc is contributed by nondetrital materials (Loring 1976).

Iron, manganese, and zinc are important micronutrients (Prosser 1973). Iron is present in certain heme compounds such as cytochromes and hemoglobin. Freshwater mussels store iron and manganese in gills, mantle, and digestive glands. Mn generally occurs in organisms at levels of 5-10 mg/100 g ash weight. Oysters have high Mn content. Mn in mammals is essential and is stored in the liver. It has been shown to function as a cofactor in oxidative phosphorylation as well as a component of certain enzymes. Zinc is an important component of carbonic anhydrase and other enzymes.

As mentioned previously, organisms concentrate certain trace elements and heavy metals over concentrations found in the environment. Phelps et al. (1967) studied accumulation of Fe and Zn in shallow water infauna. Selective deposit feeders concentrated Fe, while nonselective deposit feeders and omnivores concentrated Zn. Iron was higher in fauna from silty bays than in fauna from sand and gravelly sands. Metal concentration factors in organisms depend on the metabolic behavior of the element and the species tested. In certain fish species trace elements were either concentrated, maintained at a constant level, or discriminated against (Lucas et al. 1970). Species and spatial differences were determined in sea urchins for Fe, Mn, and Ni. Mn was higher in *Echinometra* than *Tripneutus*. Iron levels varied spatially in *Tripneutus* (Stevenson and Ufret 1966).

Trace element concentrations remain fairly constant in some organisms. Mn, Fe, and Zn remained constant or decreased in bluefish muscle tissue. The fish were in steady state with their environment with respect to these elements (Cross et al. 1973). Polychaete worms kept constant concentrations of Mn, Fe, and Zn in relation to the water and sediments. The worms used active transport to maintain constant levels (Cross et al. 1970).

Trace element concentrations in organisms sometimes reflect the concentrations of trace elements in the surrounding environment. Zinc concentrations in water and fish scales of Atlantic salmon and brown trout were correlated (Abdullah et al. 1976). Frazier (1976) showed a similar correlation of zinc concentrations in sediment and oysters, but he did not indicate a direct relationship.

Physicochemical characteristics also influence trace element concentrations in organisms. Differences in salinity caused greater changes in marine mollusk shell composition than temperature changes (Pilkey and Goodell 1963). In oysters, however, Mn concentrations increased with increasing temperature (Mathis et al. 1977). In brown algae, Zn, Fe, and Mn content varied depending on species, developmental stage, and season (Black and Mitchell 1952). Fe and Mn were concentrated in certain marine mollusks. This was explained because Fe and Mn are found in high concentrations from runoff and form hydrated oxide colloids which are readily absorbed by oysters (Windom and Smith 1972). High concentrations of Fe in dead Spartina stems may elevate the iron content of organisms feeding on it (Williams and Murdoch 1969).

In 18 species of decapod crustaceans, zinc concentrations ranged from 20-35 $\mu g\ g^{-1}$. Zinc was easily absorbed from the stomach and was found bound to proteins in the blood. Because little zinc was unbound, a gradient existed (Bryan 1968). In the lobster Mn was found primarily in the exoskeleton. It was adsorbed through the stomach as well as the gills (Bryan and Ward 1965).

Zinc is also concentrated by other organisms. In tubificids concentration factors were large compared to the water for zinc as well as chromium, copper, and lead. All the elements were more concentrated in the organisms than the sediment, except for zinc (Mathis and Cummings 1971). Namminga and Wilhm (1977) found chironomids concentrated zinc 3.6 times over sediment concentration and 30,036 times over water concentrations. Trace element concentration determinations may be biased by interference of the gut contents in the analysis which may account for some of the poor correlations (Elwood et al. 1976).

Caloric content of an organism varies with environmental conditions. Because glucose has a caloric value of 3.74 cal g^{-1} and oils and fats have a caloric value of 9.4 cal g^{-1}, most organisms have a caloric value which falls between these values because they are composed of varying amounts of these compounds as well as intermediate compounds (Paine 1971). Even among organisms of the same species in the same region, caloric content may vary because of variation in the percent organic carbon (Salonen et al. 1976).

The following four methods have been used to determine caloric values: (1) determining the components of organisms such as carbon and nitrogen, (2) wet oxidation in which the organisms are oxidized with heat and strong acid, (3) thermochemistry, and (4) bomb calorimetry which is now the simplest and most frequently used (Paine 1971).

Early work in calorimetry often involved determinations of several species. Slobodkin and Richman (1961) determined the caloric content of 17 species of animal and concluded that caloric content may be an index of the nutritional status of the organism. Caloric values for several species of microcrustacea were found to vary from 4427 cal g^{-1} for immature crayfish to 5643 cal g^{-1} for female Diaptomus (Comita and Schindler 1963). Comita et al. (1966) found a spring maximum in caloric content of Calanus finmarchicus in 1 yr and a winter maximum in another. Daphnia pulicaria were sampled monthly and winter organisms had 9000 cal g^{-1} dry weight (Snow 1972). As summer progressed, caloric content decreased to 4900 cal g^{-1}. Intraseasonal changes in amphipod, cladocera, and chironomid caloric content has been determined by Wissing and Hasler (1971). Chironomid energy content increased in June and July, declining later. Wissing and Hasler (1968) determined seasonal variation of caloric content in certain small crustaceans and insects. Changes in caloric content of male mysid shrimp during their diel migrations have also been determined (Teraguchi et al. 1972). The shrimp averaged 6200 cal g^{-1} at the start of their ascent and 5400 cal g^{-1} at the morning descent.

Caloric content varies with life stage. Wiegart (1965) found the range of caloric values of instars of the meadow spittlebug was as large as the range of 60 different animal species. Higher caloric values were found for eggs and resting stages than for other instars of Diaptomus siciloides (Comita 1962). Paine (1964) noted that low values imply either the presence of high concentrations of low caloric value carbohydrates in adults or systematic error.

The effect of different factors on caloric content has also been determined. In third instar chironomids, the interaction of pH and NaCℓ affected the caloric content. Caloric content of fourth instar was affected by the interaction of phenol and NaCℓ (Thornton and Wilhm 1974). Alterations in food can change the caloric content. Changes in the concentration of the algae fed to benthic crustaceans Asellus and Gammarus changed the caloric composition (Swiss and Johnson 1976).

In the profundal benthos chironomids are an integral part. These bloodworms live in U-shaped tubes in the sediment, with a sheet of saliva stretched over the tube's opening. Suspended material is trapped and eaten along with the salivary sheet (Walshe 1947). Female chironomids lay eggs on the lake surface which absorb water, swell, and sink to the bottom where they hatch in 3-14 days. Larval females weigh about 60 mg when they pupate; males often weigh less. At the end of the second instar the larvae develop a faint pink color which gradually darkens throughout the other instars (Hilsenhoff 1966). The pink color is hemoglobin; however, the purpose of this is uncertain. It may maintain the organism in times of low oxygen concentration, providing the oxygen for active processes such as filter feeding (Walshe 1950).

Chironomid distribution is influenced by the sediment more than the overlying water (Hilsenhoff 1967). Chironomid distribution is also correlated with the amount of available food and pH, although correlations exist with particle size, presence of other chironomids, concentrations of K^+, Mg^{2+}, $C\ell^-$, $SO_4^=$, and dissolved oxygen (Topping 1971).

Chaoborids, or phantom midges, are also important components of the profundal benthos, showing peak abundance in late spring and early fall (Hitchcock 1965). Chaoborids can survive in anoxic environments, although not indefinitely. The daily migration provides some relief from this condition (Hunt 1958). The migrations consist of nightly ascents into the epilimnion, at which time they feed on cladocerans and copepods (Goldspink and Scott 1971, Fedorenko 1975b), and daily descents into the benthos (Roth 1968, Woodmansee and Grantham 1961) where they also feed. These migrations occur in the third and fourth instars. The first and second instars are planktonic at all times and are positively phototactic (Wood 1965).

It is not certain what causes the daily migrations. Light may trigger the migratory response; however, in most lakes light does not penetrate deep enough (Lewis 1975). Chaoborids showed no preference between dark and light. Light may be an important stimulus, but it is not the basis for the migrations (Cook and Conners 1964). Subsurface illumination may cause seasonal and diel changes in the timing of ascent and descent (Teraguchi and Northcote 1966) suggesting an exogenous rhythm controlled by light. Chaoborus larvae kept in constant darkness maintained their diel rhythms for up to 10 days (LaRow 1968). When light and dark cycles were reversed, chaoborids varied in their time of movement into and out of the sediments. LaRow (1976) concluded the rhythm is a population rhythm with the organismal interaction aiding in rhythm synchronization.

Vertical migrations may have adaptive significance because migrants gain an energetic advantage over nonmigrants by partitioning energy more effectively into growth. Swift (1976), however, stated that it would be more energetically sound if the organisms remained at the surface.

Chaoborids overwinter in the fourth instar. Both food abundance and temperature (Fedorenko 1975a) as well as photoperiod (Bradshaw 1969) may act to terminate the diapause.

CHAPTER III

DESCRIPTION OF LAKES

Ham's Lake, located 8 km west of Stillwater, Payne County, Oklahoma, was built in 1965 as a flood retention reservoir by the Soil Conservation Service. The volume of the lake is 115 ha-m with a surface area of 40 ha. The lake averages 2.9 m in depth, with a maximum depth of 9.5 m. The drainage basin is about 14.7 km^2 (Steichen 1974) (Figure 1).

Arbuckle Lake is located 9.6 km southwest of Sulphur, Murray County, Oklahoma. It was built in 1967 by the Bureau of Reclamation to provide water, flood control, recreation, and for wildlife (Gomez and Grindstead 1973). Arbuckle Lake has a volume of 8930 ha-m with a surface area of 951 ha. Mean and maximum depths are 9.4 and 27.4 m, respectively. The drainage basin is about 326 km^2 (Garton 1976) (Figure 2).

During spring and summer, Ham's Lake stratifies producing an anoxic hypolimnion with a thermocline at about 4 m. During summers of 1974-1976 and 1978, Ham's Lake was destratified by pumping oxygenated surface water to the bottom (Punnett 1978). The lake stratified normally in 1977. Pumping was irregular in 1979.

Arbuckle Lake also stratifies during spring and summer, producing a thermocline at about 7 m. In summers 1974, 1975, and 1978, attempts to destratify the lake were unsuccessful (Punnett 1978). In 1979 pumping did not occur on the lake.

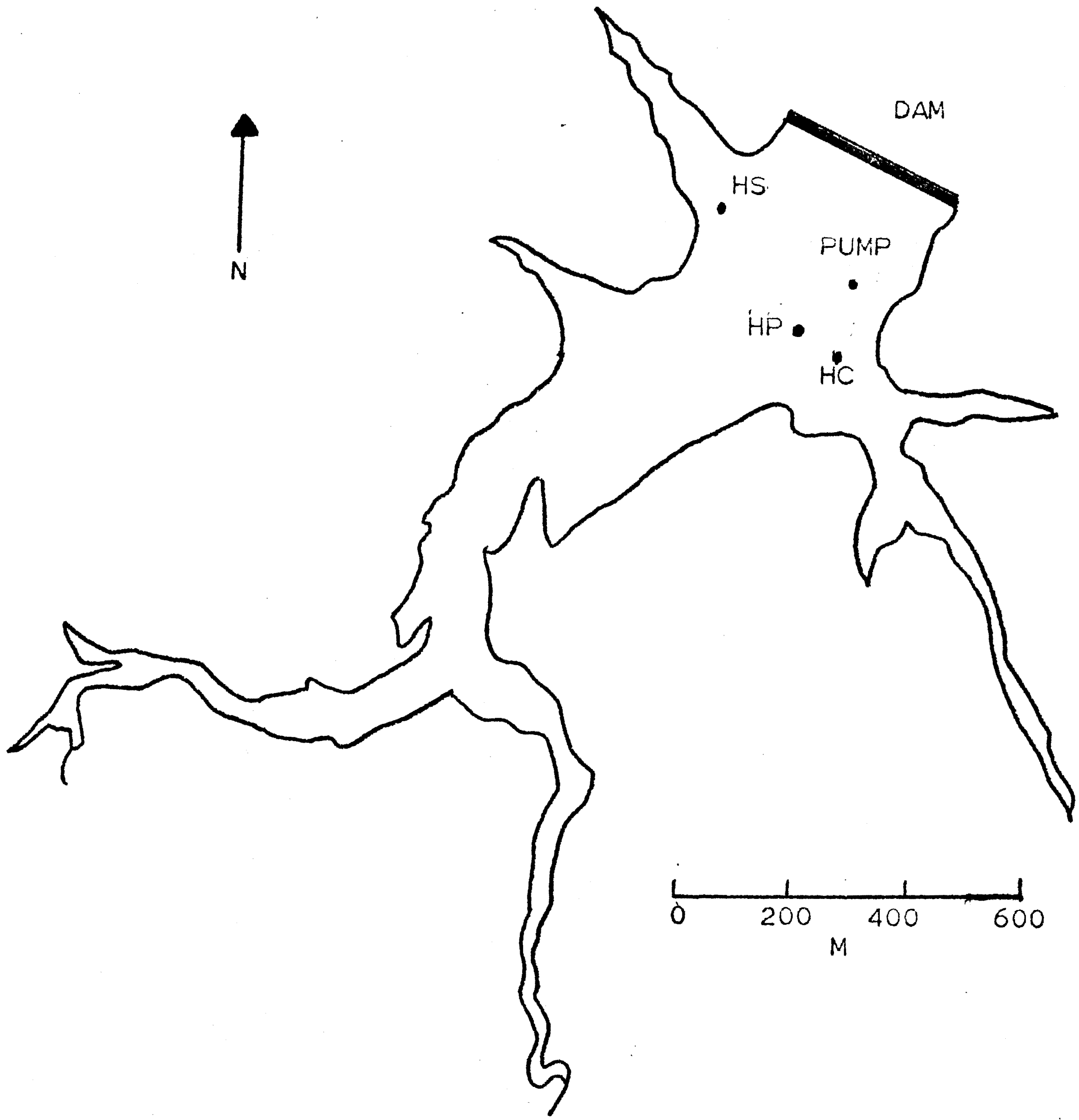

Figure 1. Ham's Lake Showing Sampling Stations

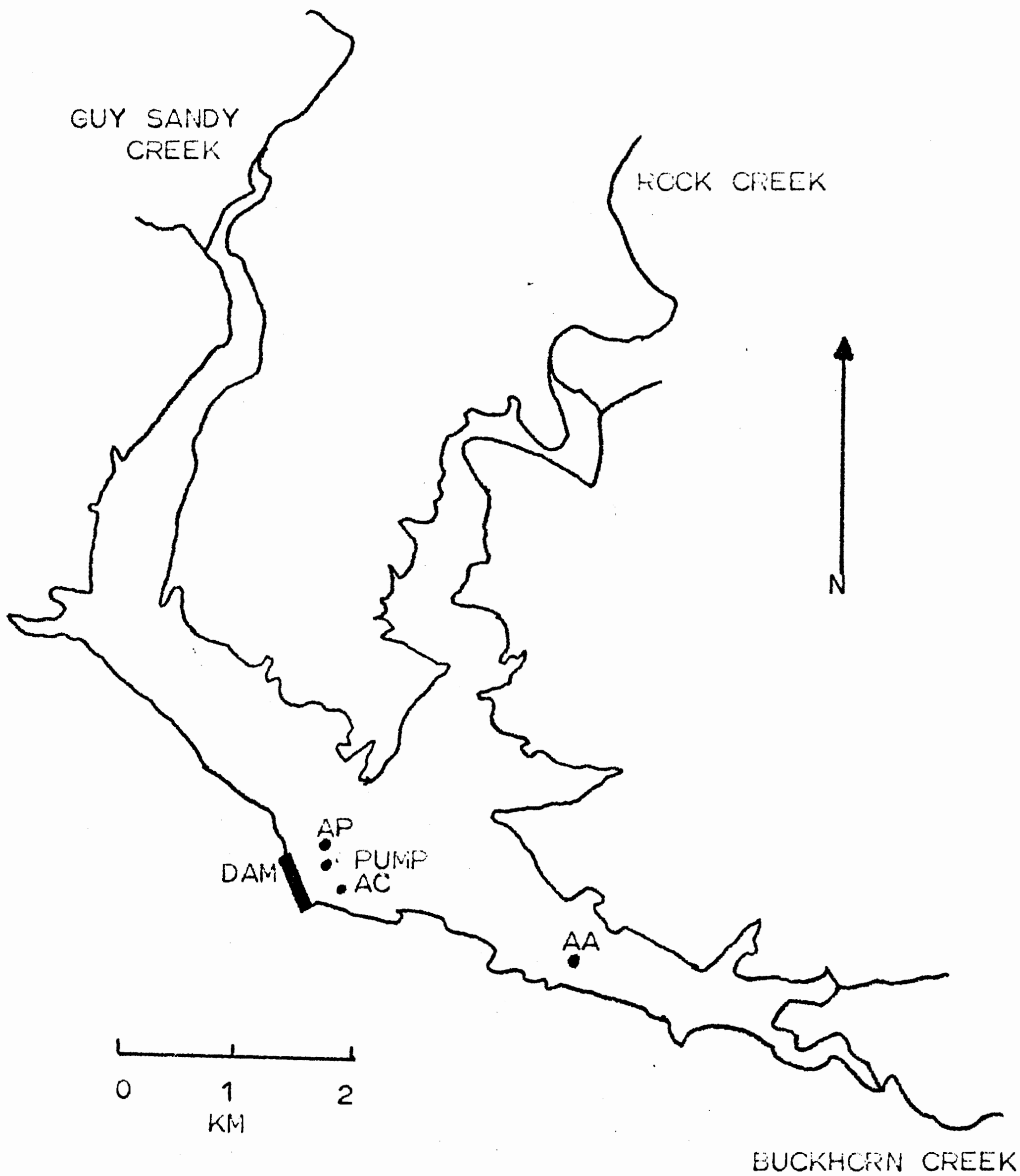

Figure 2. Arbuckle Lake Showing Sampling Stations

Three stations each were established in Ham's and Arbuckle lakes to collect water, sediment, and organisms. In Ham's Lake stations HS, HP, and HC were established. The depth of the station by the pump was 8 m while the other two stations were 5 m deep. Station HS is in an arm of the lake which is separated from the rest of the lake by an underwater ridge. Stations HC and HP are in the central pool with Station HP nearest the pump.

In Arbuckle Lake stations AC, AP, and AA were established. Station AA is in the Buckhorn Creek arm of the lake and is 15 m deep. Stations AC and AP are in the central pool with Station AP nearest the pump and 24 m deep. Station AC is 26 m deep.

CHAPTER IV

METHODS

Field

Samples were taken at three stations each in Ham's and Arbuckle lakes monthly in 1978 and bimonthly in 1979. Dissolved oxygen and temperature were measured with a YSI Model 54A DO meter and conductivity with a YSI S-C-T Model 33 conductivity meter at meter intervals from the surface to the bottom. The pH of the surface and bottom water was determined using a Corning Model 610A portable pH meter, while alkalinity was determined at these depths by titration with 0.02N sulfuric acid to a methyl purple endpoint (APHA 1977). A Secchi disk reading was taken at each station.

Water samples from the surface, metalimnion as determined by temperature readings, and from about 1 m above the sediment were taken with a 2.2 ℓ Van Dorn water bottle. Three 250 mℓ acid-rinsed plastic bottles were filled and acidified with 3 mℓ of concentrated HNO_3. Three other acid-rinsed 250 mℓ bottles were filled, returned to the laboratory, and a small portion used to determine turbidity using the Spectronic 20. The remainder of the sample was filtered through a 0.45 μ millipore filter apparatus, acidified with 3 mℓ of concentrated HNO_3, and used for determination of the dissolved concentration of iron, manganese, and zinc.

Samples of sediment were obtained by inserting 2.5 cm polyethylene tubes into a filled 15 × 15 cm Ekman grab sampler. After sealing with corks, the tubes were stored on ice until they were frozen in the laboratory. One grab sample was used to determine sediment pH. Six cores were used for determination of sorbed metals, three were used for loss on ignition and percent organic matter, and four were used for phosphate.

Three 15 × 15 cm Ekman grab samples were taken at each station, preserved in 10% formalin, and returned to the laboratory for identifying organisms to the lowest taxon possible.

Several grab samples were taken in the field and washed in a #30 wash bucket until about 1 g wet weight of organisms was obtained. Chaoborus punctipennis was sampled in both lakes, while Chironomus riparius was taken from Ham's Lake and C. tentans from Arbuckle Lake. The organisms were put on ice in the field. In the laboratory, organisms were separated from the debris and placed in clean water for 12 h to allow evacuation of gut contents. After drying at 60°C for 12 h, the sample was divided into two subsamples if sufficient organisms were collected; one subsample was used for measuring trace metals and one was used for caloric content.

Laboratory

Two hundred mℓ of the filtered water samples were placed in acid-rinsed beakers, evaporated on a 100°C hot plate, and the volume increased to 25 mℓ with 0.2N HNO_3. The samples were analyzed on the Varian Techtron Atomic Absorption Spectrophotometer (AAS) for iron, manganese, and zinc dissolved in the water.

Two hundred mℓ of the other water samples were placed in acid-rinsed beakers, 3 mℓ of concentrated HNO_3 added, and the samples evaporated on a 100°C hot plate. The residue was digested with 3 mℓ of concentrated HNO_3 until light colored, 3 mℓ of a 1:1 HCℓ to water solution was added to dissolve most of the residue, and the volume increased to 25 mℓ with 0.2N HNO_3. The samples were analyzed for total iron, manganese, and zinc in the water on the AAS.

To determine organic matter of the sediment cores were cut at the 0-1 cm and 4.5-5.5 cm depths and the sediment was dried at 60°C. The sample was ground to a fine powder and 0.25 g was placed in a 20 mℓ beaker. After adding 10 mℓ of potassium dichromate and 15 mℓ of concentrated sulfuric acid, the sample was heated to 165°C. Then 50 mℓ of tapwater and 2 drops of 0-phenanthroline were added, and the sample was titrated to a faint pink color with standardized ferrous ammonium sulfate. The percent organic matter was calculated as follows:

$$\%\ \text{organic matter} = \text{Amount of titrant} \times \text{N of } Fe(NH_4)SO_4 \times 2.5$$

Samples to be used for loss on ignition were taken from the same sample as percent organic matter. Tared crucibles were filled almost full with sediment and oven dried at 90-100°C for 1 h. After cooling, the sample and crucible were weighed, muffled for 1 h at 550°C, rewet with distilled water, dried at 100°C, and weighed again. Percent loss on ignition was calculated using the following formula:

$$\%\ \text{LOI} = \frac{\text{ash free weight}}{\text{dry weight}} \times 100$$

Phosphorus of the sediment was determined from separate sediment cores which were cut at 1 and 5 cm depth and dried at 100°C for 12 h. About 0.01-0.015 g of dried sample was placed in a crucible, weighed, muffled at 550°C for 1 h, and added to a 50 mℓ jar with a lid. Two mℓ of 1.0 N HCℓ and 10 mℓ of distilled water were added to the samples. The lids were replaced and the jars were heated for 2 h at 100°C. The lids were then loosened and the sample was allowed to cool. Then 2.5 mℓ of acid molybdate were added and 30 min allowed for color development. The samples were read on a standardized Spectronic 20.

For determination of sediment sorbed metals, the surface 2.5 cm of sediment was removed, placed in acid-rinsed 200 mℓ plastic bottles, and dried at 60°C. About 1 g of sediment was removed from later caloric content analysis and the dried weight of the remaining sample was determined. Half of a 1:10 ratio of ammonium acetate to sediment weight was added. The flasks were left for 12 h after initial shaking and the samples were filtered in a Buchner funnel. The remaining ammonium acetate was added to leach out the remaining sorbed metals (Jackson 1953). The filtrate was analyzed for sorbed Fe, Mn, and Zn on the AAS. In 1979 another sample from the 6-8 cm depth was also analyzed for sorbed metals. The formula for calculation of the concentration of sorbed metals is as follows:

$$\text{mg } \ell^{-1}, X = \frac{\text{volume in m}\ell}{\text{sample weight in g}} = \mu\text{g g}^{-1} \text{ sediment}$$

Caloric content of the sediment was determined for three subsamples per station. For each sample an equal amount of sediment and benzoic acid was mixed in a mortar and pestle. Three subsamples from each sample, weighing from 7-16 mg were measured for caloric content. Calories due to the benzoic acid were subtracted from the total amount of calories liberated to arrive at the number of calories released by the sediment. This value was divided by sediment weight to give cal g^{-1} dry weight sediment.

Tared duplicate samples, weighing about 0.1 g dry weight of C. punctipennis and C. riparius and C. tentans were fired at 550°C for 12 h. After cooling in a desiccator, the muffled chaoborid samples were washed into 25 mℓ acid-rinsed flasks using 10 mℓ of 0.1N HCℓ. The muffled chironomid samples were washed into 25 mℓ flasks using 25 mℓ of 0.1N HCℓ. These solutions were analyzed using the AAS for Fe, Mn, and Zn of the organisms. The final concentrations were calculated using the following formula:

$$\text{mg } \ell^{-1} \times \frac{\text{volume in m}\ell}{\text{sample wt in g}} = \mu\text{g g}^{-1} \text{ organism}$$

Separate samples of the chaoborid and chironomid samples were pressed into pellet form with a pellet press, tared, placed in the microbomb calorimeter, charged with oxygen, and allowed to equilibrate. After firing the resultant curve was recorded on a Honeywell Electronik Recorder. Calories liberated were analyzed and calculated as cal g^{-1} dry weight.

Laboratory Experiments

A series of laboratory experiments were established to supplement information gained in the field on the effects of low dissolved oxygen on iron content of Chironomus riparius and on calorie content of the sediment.

Sediment and water from Ham's Lake was placed into four wide-mouth jars and allowed to equilibrate overnight. Two jars represented an oxygenated situation. A thin layer of mineral oil was placed over the water surface of the other two jars. Since respiration by sediments depleted the oxygen in the water, these jars represented the anoxic condition. After 4 days, the sediment was removed and analyzed for calorie content.

Two experiments were established for determinating iron concentrations in C. riparius in response to various levels of iron and oxygen content of the water. In the first experiment, iron concentration by C. riparius in response to variation in iron content of the water was studied. Six jars, containing aged tap water and 200 g of sand, were established and allowed to equilibrate. About 0.1 g of Hershey's Dog Kisses was added for food. To a set of two jars each were added 1000, 3000, and 5000 μg ℓ^{-1} of iron chloride. Ten organisms were added. After 4 days, duplicate samples of water and sediment were collected and analyzed for iron content.

In the second experiment a series of six pairs of jars were established with 200 g of sand, 500 mℓ of aged tap water, and 0.1 g of Hershey's Dog Kisses. Then, 5000 μg ℓ^{-1} of iron chloride was added to each jar and allowed to equilibrate overnight. Ten C. riparius were added to each jar. One jar of each pair represented the oxygenated condition. In the other jars mineral oil was layered over the water surface and 2 mℓ of 10% sodium sulfite added to leach out the dissolved oxygen. At 12 h intervals one jar of each type was removed at random. Water, sediment, and organisms were analyzed for iron content.

CHAPTER V

RESULTS

Physicochemical Conditions of the Water

Water temperature, dissolved oxygen concentration, alkalinity, specific conductance, turbidity, transparency, and pH were measured in Ham's Lake. Mean water temperature ranged from 7-28°C (Table I). Temperature was similar throughout the lake on 22 April 1978. Station HS, in the arm protected from the effects of pumping by an underwater ridge, stratified by 25 May; however, temperature in the central pool mixed by pumping was isothermal during summer. Temperature of the bottom water was 27°C in the central pool on 21 July and 19°C at the stratified station. Bottom water of Station HS increased to 25°C on 22 August. The lake remained nearly isothermal until 31 May 1979 when the central pool and arm station stratified. Pumping began in June and the central pool destratified by 14 July, but Station HS remained stratified. Station HS turned over by 22 September.

Dissolved oxygen (DO) of the water in Ham's Lake ranged from 0.2-16.4 mg ℓ^{-1} (Table I). The concentration exceeded 8.4 mg ℓ^{-1} at all stations on 13 March and 22 April 1978. DO decreased to 0.2 mg ℓ^{-1} in the hypolimnion of the stratified station in summer; however, the minimum DO in the central pool was 2.9 mg ℓ^{-1}. Station HS turned over by 29 October and DO reached 5.5 mg ℓ^{-1}. DO was relatively uniform at all stations during spring and fall. The lake stratified by 31 May 1979 in

TABLE I

TEMPERATURE, DISSOLVED OXYGEN, AND ALKALINITY OF THE WATER IN HAM'S LAKE IN 1978-79

Date	Temp. (°C)			DO (mg ℓ^{-1})			ALK (mg ℓ^{-1})		
	Surf.	Bottom		Surf.	Bottom		Surf.	Bottom	
		HP + HC	HS		HP + HC	HS		HP + HC	HS
14 Mar	8	7	7	9.6	8.4	9.0	145	143	141
23 Apr	17	16	16	9.2	8.7	8.5	148	150	154
25 May	26	23	19	6.8	5.3	4.5	134	142	139
23 Jun	26	25	18	5.6	3.6	0.2	119	121	163
21 Jul	27	27	19	5.3	3.2	0.3	117	124	176
22 Aug	27	26	25	5.8	4.4	2.5	-	-	-
29 Sep	24	23	22	5.5	4.6	0.2	139	142	143
29 Oct	16	16	15	6.6	6.3	5.5	150	145	144
2 Dec	10	9	10	8.4	8.1	8.4	137	143	140
14 Mar	10	9	9	8.1	8.3	8.3	136	138	136
31 May	23	18	17	8.8	1.9	1.5	138	145	146
18 Jul	28	28	20	5.5	5.5	0.7	117	116	145
22 Sep	24	24	22	10.3	9.5	8.5	116	117	116
18 Nov	11	10	10	16.4	15.3	15.5	127	124	128

both the central pool and stratified station. Pumping destratified the central pool before 18 July and DO reached 5.5 mg ℓ^{-1}; however, DO in the hypolimnion of the stratified stations was less than 0.7 mg ℓ^{-1}. Maximum DO occurred on 18 November 1979 at all stations.

Alkalinity of the water ranged from 116-176 mg ℓ^{-1} (Table I). Surface and bottom water of the central pool were similar throughout the study. Values decreased in the bottom water of the central pool from spring to 23 June 1978; however, alkalinity of the stratified station increased to 176 mg ℓ^{-1}. Values were again similar by 22 September. Similar trends occurred in 1979; however, the values were generally lower.

Specific conductance of the water ranged from 220-482 μmho cm^{-1}. Little spatial variation existed. Conductivity values were similar through the lake in March. Generally, conductivity increased in both years from spring to a maximum in July and decreased in fall. Conductivity was similar at all stations in November.

Turbidity ranged from 1-45 JTU. No consistent trends were observed. Higher values occurred in the bottom water than at the surface of the central pool in both years except in March when values were similar. Turbidity exhibited considerable fluctuation in the central pool during summer 1978 during pumping and then decreased through fall. Turbidity exhibited less fluctuation in 1979 when pumping was irregular. Turbidity was maximum on 14 May 1979 at all stations.

Secchi disk depth ranged from 43-150 cm. Maximum depth occurred on 25 May at all stations. The value decreased in the central pool and remained low through summer during mixing. Secchi disk transparency was greater at Station HS during this time. Values were lower in 1979 when pumping was irregular.

pH of the water in Ham's Lake ranged from 7.2-8.8 and averaged 8.1. Little spatial difference existed, except in May 1978 when pH was significantly lower at Station HS than the central pool. Values of pH were lower in 1979.

Physicochemical variables were also measured in Arbuckle Lake. Mean temperature of the bottom water ranged from 5-27°C (Table II). Temperature was similar at all stations on 15 March 1978. The stations in the central pool, AC and AP, stratified by 29 April 1978 and the 15 m station in the arm by 11 July. Temperature of the bottom water among stations was similar from 22 October until stratification existed in the central pool on 14 May 1979. Station AA had stratified by 11 July 1979. Isothermal conditions existed on 11 November. Maximum surface temperatures of 30°C were measured in July of both years. The thermocline occurred at a depth of 19-20 m in the central pool by 29 April 1978. The thermocline remained low throughout the summer; however, the chemocline occurred at shallower depths, 5-6 m, by 11 July 1978.

In Arbuckle Lake, DO of the bottom water varied from nondetectable to 12.0 mg ℓ^{-1} (Table II). DO exceeded 8.0 mg ℓ^{-1} at all stations on 15 March 1978. The hypolimnion of all stations had less than 1.0 mg ℓ^{-1} in summer 1978. Values increased to 2.0 mg ℓ^{-1} on 22 September in the arm station and 3.4 mg ℓ^{-1} on 22 October in the central pool. DO exceeded 8 mg ℓ^{-1} at all stations on 24 November. Values in the hypolimnion of all stations had decreased to less than 0.4 mg ℓ^{-1} by 14 July and increased to concentrations exceeding 11.5 mg ℓ^{-1} by 11 November. DO at the surface exceeded 5.0 mg ℓ^{-1} throughout both years.

Alkalinity of the bottom water ranged from 127-165 mg ℓ^{-1}

TABLE II

TEMPERATURE, DISSOLVED OXYGEN, AND ALKALINITY OF THE WATER IN ARBUCKLE LAKE IN 1978-79

Date	Temp. (°C)			DO (mg ℓ^{-1})			ALK (mg ℓ^{-1})		
	Surf.	Bottom		Surf.	Bottom		Surf.	Bottom	
		AC + AP	AA		AC + AP	AA		AC + AP	AA
15 Mar	6	5	5	10.0	8.7	8.0	150	151	150
29 Apr	18	11	16	7.7	4.8	5.0	155	151	152
9 Jun	24	14	21	7.7	0.3	1.0	131	138	127
11 Jul	32	16	25	7.0	0.1	0.0	129	142	140
15 Aug	29	18	26	-	-	0.1	135	165	131
16 Sep	28	17	27	5.6	0.2	2.0	135	161	128
22 Oct	21	19	20	6.1	3.4	2.8	137	138	137
24 Nov	15	14	14	8.3	-	-	128	133	145
10 Mar	7	5	7	9.5	10.0	9.8	143	140	131
14 May	20	12	17	7.8	1.5	4.1	152	149	155
14 Jul	30	14	22	9.9	0.2	0.4	123	155	140
15 Sep	26	18	24	10.6	0.8	1.5	128	162	150
11 Nov	14	14	13	11.6	12.0	12.0	135	137	135

(Table II). Surface concentrations were similar at all stations throughout the study. Values tended to decrease in the bottom water of Station AA from spring through summer; however, alkalinity in the central pool increased to the maximum concentrations of 165 mg ℓ^{-1} measured on 15 August. Values were similar at all stations by 22 October. In 1979 alkalinity at Stations AC and AP again increased from spring through summer.

Specific conductance of the bottom water ranged from 290-465 μmho cm^{-1}. Surface values of conductivity were generally slightly larger than values in the bottom water. Conductivity tended to increase from 15 March 1978 through summer and decreased through 14 March 1979. In 1979 values again tended to increase through summer and decrease through fall.

Turbidity was generally low and averaged 13 JTU. Lowest values were generally determined in spring and largest values in summer. Variation among stations was generally slight.

Secchi disk readings ranged from 120-252 cm and little spatial variation occurred. Secchi disk transparancies were largest at all stations in March. Mean depth in March was 205 cm in 1978 and 252 cm in 1979.

In Arbuckle Lake pH values averaged 8.1 for both the water and sediments. Values fluctuated through the study with no apparent spatial or temporal trends.

pH, LOI, POM, and Phosphate of the Sediment

In Ham's Lake pH of the sediments ranged from 7.8-9.2 during the study and averaged 8.3. pH values fluctuated throughout the study and little spatial variation existed. Values were lower in 1979.

Percent loss on ignition (LOI) of the sediments in Ham's Lake ranged from 7.0-11.2% (Figure 3). Although values were consistently greater at the 8 m station in the central pool, HP, than at the 5 m station, HC, variation was generally slight and the means of the two stations are presented in Figure 3. The only significant variation occurred on 18 July 1979 when LOI reached 10.8% at Station HP. Values were consistently greater at the arm station which remained stratified in summer (HS) than at the stations in the central pool. This difference was especially large during summer 1978 when the lake was destratified at Stations HC and HP. Values exceeded 9.3% in the stratified arm and decreased to 7.0% on 21 July in the destratified area. Loss on ignition decreased in both areas in November and increased slightly by 14 March 1979. Although values again increased at Station HS during summer 1979, values were lower and erratic in the central pool when the pumping regime was erratic.

Spatial and temporal trends of percent organic matter (POM) as determined by the oxidation method were similar to those observed for loss on ignition (Appendix, Table XV). However, values measured by the oxidation procedure were consistently lower, ranging from 2.4-6.1%. Measurements at the two stations in the central pool were similar except for a significantly greater value at Station HP on 18 July 1979. Percent organic matter at Station HS in summer 1979 was generally over twice as great as values in the central pool. Little variation occurred during the remainder of the study.

Phosphate concentration of the sediment in Ham's Lake collected from the surface and a depth of 4.5-5.5 cm ranged from 8.2-25.9 $\mu g\ g^{-1}$

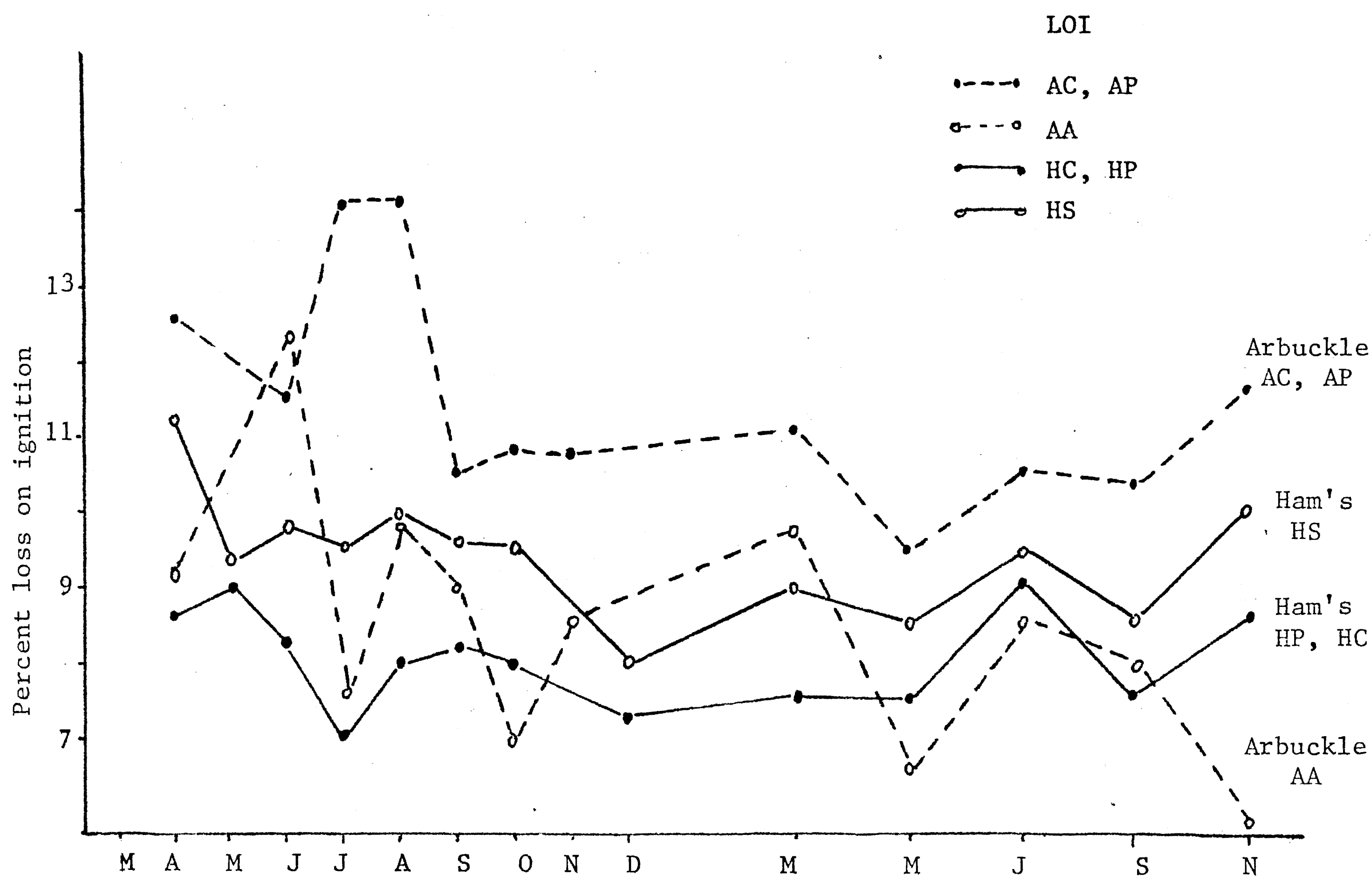

Figure 3. Loss on Ignition of the Surface Sediments of Arbuckle and Ham's Lakes in 1978-79

(Appendix, Table XV). Phosphate concentrations were larger at the surface than at the 4.5-5.5 cm depth. Values were generally larger at Station HP than HC; however, the values were not significantly different. The concentration was usually greater at Station HS than in the central pool. All stations reached maximum concentrations on 23 June 1978. Values fluctuated little from July through March 1979 and decreased at all stations until July 1979. Values doubled on 22 September and remained similar in November.

In Arbuckle Lake LOI of the sediments ranged from 5.7-14.5% (Figure 3). Values were consistently less in the sediment from 4.5-5.5 cm depth than the surface. Stations AC and AP in the central pool had similar concentrations and means are on Figure 3. Values were larger in the central pool stations than at the arm station AA except on 9 June 1978. No trend was observed at Station AA. Loss on ignition in the central pool increased to a mean of 14.2% on 15 August and then decreased to 10.6% on 16 September. Loss on ignition exhibited less fluctuation during 1979. Values decreased at all stations from 10 March to 14 May while subsequent variation was slight.

POM was consistently less in Arbuckle Lake than loss on ignition and ranged from 3.0-7.6% (Appendix, Table XVI). Values were lower in the sediment from 4.5-5.5 cm depth than the surface. Values at Stations AC and AP were similar except on 15 March 1978 when the value at Station AP was significantly larger. Station AA generally had the lowest POM than the stations in the central pool. POM was similar at Station AC throughout spring 1978; however, Stations AA and AP decreased from a mean of 7.2% on 15 March to less than 4.5% on 29 April. Stations AC and

AP had similar values the remainder of the year. Values were similar in 1979.

Phosphate concentrations of the sediments from the surface and 4.5-5.5 cm depth ranged from 10.4-38.6 μg g^{-1} (Appendix, Table XVI). Concentrations were generally larger in the sediment from the surface than the deeper area. Values at Stations AC and AP were generally similar. Concentrations were lower in the arm station than in the central pool throughout the study. Values in the central pool exceeded 33 μg g^{-1} in March and April 1978 and decreased by 9 June to less than 27 μg g^{-1}. Little fluctuation occurred during the remainder of 1978. Concentrations in the central pool decreased to a mean of 22.3 μg g^{-1} on 14 May 1979 and increased to a mean of 31.1 μg g^{-1} on 14 July. Values generally decreased the remainder of the year.

Benthic Macroinvertebrates

Eighteen taxa were identified from the two central pool stations and the one station in the stratified arm during spring and summer in Ham's Lake (Table III). More species were collected during 1978 than 1979, primarily because the 22 April sample had 12 taxa. Variety tended to decrease during both years and decreased to five on 22 September 1978. Seventeen species were taken from the destratified stations in the central pool, while only 12 were taken from the stratified station. In June 1978 during pumping, nine species were collected from stations HP and HC, while only four were taken from Station HS.

Density was also considerably greater in 1978 than 1978 in Ham's Lake. During 1978 at the two stations in the central pool, the individuals m^{-2} decreased from the maximum of 7560 on 22 April to 2820 on

TABLE III

DENSITY (INDIVIDUALS m^{-2}), TOTAL TAXA, AND SPECIES DIVERSITY OF BENTHIC MACRO-INVERTEBRATES COLLECTED FROM HAM'S LAKE IN 1978-1979

Species	Station*	22 Apr	23 Jun	29 Sep	14 Mar	31 May	18 Jul	22 Sep
Chaoborus punctipennis	HS	216	677	576	274	-	-	245
	HP-HC	5047	72	2477	209	36	7	382
Chironomus riparius	HS	821	58	504	1757	-	86	
	HP-HC	1066	770	259	7	7	29	58
Dero digitata	HS	1037	14	-		-	-	-
	HP-HC	655	677			7	29	101
Procladius sp.	HS	432	-	-	29	-	-	-
	HP-HC	482	166	72		187	-	-
Probezzia	HS	230	14	115	58	-	-	-
	HP-HC	58	50	29		7	-	-
Total Density**	HS	2981	763	1195	2117	0	86	245
	HP-HC	7560	1786	2880	259	245	65	547
Total Taxa	HS	12	4	3	4	0	1	1
	HP-HC	12	9	5	6	5	3	4
Diversity	HS	2.5	0.6	1.4	-	-	-	-
	HP-HC	1.6	1.9	0.8	-	-	-	-

* HS - stratified station
HP-HC - Total of two stations in the central pool

** Includes density of *Cladotanytarsus* sp., *Cryptochironomus* sp., *Polypedilum* sp., *Harnischia* sp., Nematodes, *Hexagenia* sp., *Tanytarsus* sp., *Dicrotendipes* sp., *Ablabesmyia* sp., *Sialis* sp., *Limnodrilus* sp. including *claparendus* and *Tubifex* sp.

\- Not calculated, insufficient sample size

22 September. At the stratified station density decreased from 2981 to 763 between the spring and summer sample. The concentration of individuals was also low during summer 1979.

Species diversity decreased abruptly at Station HS with the onset of stratification, from 2.50 on 22 April to 0.65 on 23 June. Diversity increased on 22 September. In contrast at the destratified stations in the central pool, the value increased in summer to 2.03 and then decreased in September. Values were not calculated in 1979 because of the small numbers of organisms collected.

Chaoborus punctipennis and *Chironomus riparius* were the most abundant organisms collected during the study comprising 51 and 23%, respectively, of the total numbers of organisms collected. The maximum density of *C. punctipennis* was 5047 individuals m^{-2} on 22 April in the central pool. Density decreased abruptly between 22 April and 23 June at Stations HC and HP, while the concentrations increased at the stratified station. The sample contained a number of early instar larvae on 22 September. In 1979, density of *C. punctipennis* was low at all stations, especially during May and June.

Chironomus riparius was the most abundant chironomid in the benthic samples. Individuals m^{-2} decreased in 1978 from a mean of 944 on 22 April to less than 385 on 22 September. An abrupt decrease was observed at Station HS with the onset of stratification. On 22 September values decreased at the destratified stations but increased at the stratified station. In 1979 density of *C. riparius* was extremely low at all stations except in March when 1757 individuals m^{-2} were taken at Station HS.

Three other species were relatively common in Ham's Lake. *Dero digitata* was common in the central pool in April 1978 at all stations and in June at the mixed stations. Procladius sp. generally was present in the central pool but was collected from the stratified stations only in spring. Probezzia sp. was generally present in the samples but at a low density. None of the other species present in the samples exceeded 14 individuals/m^2 and most were collected only on 22 April 1978.

In Arbuckle Lake 18 taxa were identified from the two central pool and the one arm stations (Table IV). More species were collected during 1978 than 1979 primarily because 17 taxa were taken on 29 April 1978. Variety decreased over time during both years, decreasing to three on 16 September in 1978. Seventeen taxa were taken from the central pool stations, while only 11 taxa were collected from the arm station AA. During summer 1978, four taxa were collected from the central pool and six from the arm station.

Density of organisms in Arbuckle Lake was greater in 1978 than 1979. During 1978 at the two central pool stations, the individuals m^{-2} decreased from a maximum of 5796 on 29 April to 43 on 16 September. At Station AA density decreased from 2362 to 166. During 1979, density never exceeded 706.

Species diversity decreased abruptly at Station AA from 2.2 on 29 April to 0.71 on 11 July. However, diversity only decreased from 1.8 to 1.5 in the central pool. Values were not calculated for 1979 because of the low density.

Generally, Chaoborus punctipennis was the most abundant organism collected during the study, comprising 56% of the total numbers of individuals. Maximum density of C. punctipennis was 3442 individuals m^{-2} on 29 April in the central pool. Density decreased abruptly in the central pool during summer 1978. Less than 50 chaoborids m^{-2} were

TABLE IV

DENSITY (INDIVIDUALS m^{-2}), TOTAL TAXA, AND SPECIES DIVERSITY OF BENTHIC MACRO-INVERTEBRATES COLLECTED FROM ARBUCKLE LAKE IN 1978-1979

Species	Station*	29 Apr	11 Jul	16 Sep	10 Mar	14 May	14 Jul	15 Sep
Chaoborus punctipennis	AC-AP	3442	50	7	43	43	36	50
	AA	619	1915	216	317	-	-	518
Chironomus tentans	AC-AP	108	-	-	36	36	-	-
	AA	288	-	115	115	-	-	115
Limnodrilus sp.	AC-AP	1008	720	36	130	130	65	-
	AA	-	14	-	-	-	-	-
Tubifex sp.	AC-AP	302	144	-	8	21	-	2
	AA	216	101	-	-	-	-	-
Procladius	AC-AP	144	-	-	7	7	-	-
	AA		-	-	115	-	-	-
Aulodrilus piqueti	AC-AP	713	432	-	-	-	-	-
	AA	1080	-	-	-	-	-	-
Total Density**	AC-AP	5796	1346	43	237	245	101	65
	AA	2362	2189	166	576	706	0	634
Total Taxa	AC-AP	11	4	2	6	6	2	2
	AA	11	6	2	5	6	0	2
Diversity	AC-AP	1.8	1.5	-	-	-	-	-
	AA	2.2	0.7	-	-	-	-	-

* AC-AP - stations in the central pool
AA - station in the arm

** Total density includes density of Dero digitata, Coelotanypus sp., Caenis sp., Tribelos, Nematodes, Tanytarsus sp., Probiezzia sp., Cryptochironomus sp., Sphaerium sp., Branchiura sowerbyi, Glyptotendipes sp., Musculium sp.

collected from the central pool per sampling date during 1979. At the arm station the numbers exceeded 200 at all times except on 14 May and 14 July 1979 when they were not collected.

Chironomus tentans and *Procladius* sp. were the most abundant chironomids identified in the benthic samples, comprising 5 and 6%, respectively, of the total numbers of organisms collected. *C. tentans* was more abundant at the arm station than in the central pool. Density at the central pool decreased from 108 individuals m^{-2} on 29 April to zero on 11 July and 16 September. At the arm station, *C. tentans* was not found on 11 July. In 1979 organisms were only collected on 10 March and 16 September at the arm station.

Three taxa of oligochaetes were relatively common in Arbuckle Lake. *Limnodrilus* sp. was common in the central pool stations through the study. The individuals m^{-2} decreased from 1008 on 29 April 1978 to less than 40 on 16 September. *Tubifex* sp. also was abundant in spring and summer 1978, but values were low in 1979 in both areas. *Aulodrilus pigueti* represented 9% of the total number of organisms collected; however, most of these annelids were collected on 29 April 1979.

Caloric Content of the Sediments and Macroinvertebrates

Caloric content of the sediment of Ham's Lake ranged from non-detectable to 3230 cal g^{-1}. Values were similar in the central pool and arm station and are averaged on Table V. Maximum values occurred at Station HP on 23 June 1978 and 31 May 1979. Caloric content decreased from 13 March to 25 May 1978 in both areas. Although Station HS had low values during the remainder of the summer and fall, caloric content

TABLE V

CALORIES g^{-1} OF THE SEDIMENTS, CHAOBORUS PUNCTIPENNIS, AND CHIRONOMUS RIPARIUS IN HAM'S LAKE IN 1978-79

	Station* (Depth in m)	14 Mar	23 Apr	25 May	23 Jun	21 Jul	22 Aug	29 Sep	29 Oct	2 Dec	14 Mar	31 May	18 Jul	22 Sep	18 Nov
Sediment	HP-HS	2943	2094	343	1540	28	79	49	Not Detected	157	893	400	397	1537	1671
Chaoborus punctipennis	HS(5)	6579	6300	-	6351	6850	-	6103	-	6532	6692	-	-	6582	-
	HP(8)	6409	6163	-	6125	6532	-	6237	-	6348	6392	-	-	5832	-
	HC(5)	6129	6320	-	-	-	-	6328	-	-	6330	-	-	6713	-
Chironomus riparius	HS(5)	5271	5115	-	4777	-	-	4240	-	-	5359	-	3474	4708	-
	HP(8)	5101	5098	-	3423	4838	-	4931	-	-	-	-	4481	4609	-
	HC(5)	5200	5027	-	3460	-	-	3878	-	4350	-	-	3975	-	-

* HP and HC - stations in central pool
HS - stations in the arm

at Station HP peaked on 23 June at 2300 cal g^{-1}. Calories were nondetectable in the sediments on 23 October 1978. Values increased to 1400 cal g^{-1} on 22 March 1979 at Station HP and were considerably lower at the arm station. Values increased between 23 July and 22 September 1979 at both stations. Little change occurred in November.

Information on the calorie content of Chaoborus punctipennis and Chironomus riparius in Ham's Lake is limited because of the low numbers collected during some months. The calorie content of C. punctipennis ranged from 5832-6850 cal g^{-1} (Table V). In spring 1978 variation among stations was not significant and the mean of all stations was 6317 cal g^{-1}. During summer, values increased at Station HP and HS, but a considerably greater increase occurred at the stratified station. The summer means were 6305 and 6605 cal g^{-1}, respectively. The caloric content of C. punctipennis decreased abruptly between 11 July and 16 September 1978. The mean of all stations for September and November was around 6300 cal g^{-1}. In 1979 sufficient organisms were collected only in March and September to permit measurements. The mean content for 1979 was 6400 cal g^{-1}.

In Arbuckle Lake mean caloric content of the sediments collected from 0-2 and 6-8 cm depths ranged from nondetectable to 2930 cal g^{-1}. Values are averaged on Table VI. Station AC in the central pool generally had the lowest caloric content of any station measured. Caloric content at all stations exceeded 2100 cal g^{-1} on 15 March 1978 and decreased to less than 900 cal g^{-1} on 29 April. Values at all stations were low throughout the summer 1978 and averaged less than 100 cal g^{-1} and increased in the fall. In 1979 values at all stations generally remained low until a sharp increase in September at Station AP. All

TABLE VI

CALORIES g^{-1} OF THE SEDIMENTS, CHAOBORUS PUNCTIPENNIS, AND CHIRONOMUS TENTANS IN ARBUCKLE LAKE IN 1978-79

	Station* (Depth in m)	15 Mar	29 Apr	9 Jun	11 Jul	15 Aug	16 Sep	22 Oct	24 Nov	10 Mar	14 May	14 Jul	15 Sep	11 Nov
Sediment $\overline{X}$		2455	672	888	32	55	314	49	204	61	855	766	1486	1330
Chaoborus punctipennis	AC(26)	4532	4489	4362	-	-	-	-	-	-	-	-	-	-
	AP(24)	4417	4780	-	-	-	-	4738	4696	4499	-	-	-	-
	AA(15)	4826	4076	4305	4271	-	-	4876	4813	4783	-	-	-	-
Chironomus tentans	AC(26)	3598	4028	-	-	-	-	-	-	4767	-	-	-	-
	AP(24)	3780	3945	-	-	-	-	-	-	4625	-	-	-	-
	AA(15)	3201	3481	-	-	-	3170	3288	-	4825	4529	-	4432	-

* AC and AP - stations in the central pool
AA - station in the arm

stations increased in November to a mean exceeding 1800 cal g^{-1}.

Information on the caloric content of *Chaoborus punctipennis* and *Chironomus tentans* is limited in Arbuckle Lake because of the low numbers of organisms collected during some months. The caloric content of *C. punctipennis* ranged from 4076-4876 cal g^{-1} (Table VI). Spatial variation in spring 1978 generally was not significant and the mean of all stations was 4520 cal g^{-1}. During summer 1978 few chaoborids were collected in the central pool. Mean caloric content of the organisms at Station AA was 4288 cal g^{-1}. Values increased in fall 1978. In 1979 chaoborids were sparce and values averaged 4641 cal g^{-1}.

Caloric content of *Chironomus tentans* ranged from 3170-4825 cal g^{-1} (Table VI). Little spatial variation existed in spring 1978 and the mean of all stations was 3672 cal g^{-1}. Few *C. tentans* were collected in summer 1978. During fall content at Station AA was lower. Values during 1979 were significantly larger and the mean of all stations was 4636 cal g^{-1}.

Iron

Sorbed iron of the sediments in Ham's Lake ranged from nondetectable to 11.2 μg g^{-1} (Figure 4). Since iron concentrations were similar at Stations HC and HP in the central pool, means are given. Values were similar at all stations in the sediment collected from the surface and 6-8 cm depth and only surface values are presented. Little spatial variation existed except in spring 1978 when values were greater at the stratified station than in the central pool. Sorbed iron at all stations decreased to about 0.8 μg g^{-1} from 25 May to 23 June and remained low until an abrupt increase was measured on 29 October 1978. In 1979

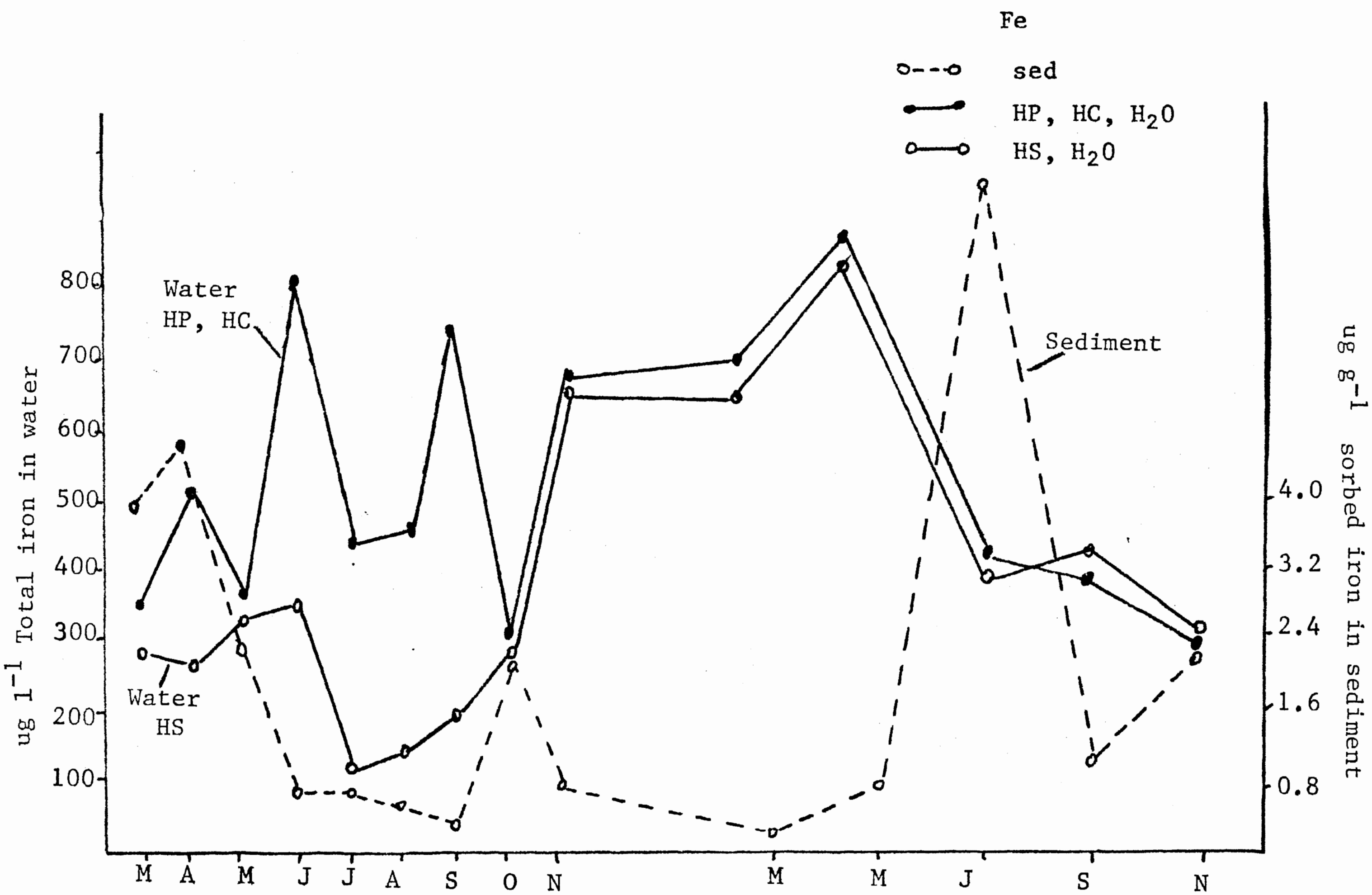

Figure 4. Total Iron in the Water and Sorbed Iron in the Sediments of Ham's Lake in 1978-79

values increased in spring and reached an average of over 7.3 μg g^{-1} at all stations by 18 July. Values returned to low levels by 22 September and increased slightly in November.

Total iron of the water in Ham's Lake ranged from 70-1571 μg ℓ^{-1} (Appendix, Table XVII). Since soluble iron averaged 16% of the total iron present in the water and since little spatial or seasonal variation existed, only total iron trends are presented. Total iron at the surface and in the metalimnion had similar ranges and trends as in the hypolimnion except values in the bottom water generally were greater and exhibited greater fluctuation. Values of total iron in the hypolimnion of the stations in the central pool were similar during the study and are averaged on Figure 4. In spring 1978 total iron of the hypolimnion of all stations was similar; however, in summer during pumping the values of total iron were larger in the central pool reaching values over 880 μg ℓ^{-1}. At the stratified station total iron had decreased on 21 July and increased gradually through 24 November. Little variation existed among stations in 1979. Concentrations increased from 10 March 1979 to maximum values on 14 May, exceeding 800 μg ℓ^{-1} at all stations and generally decreased the remainder of 1979.

Iron concentrations in Chaoborus punctipennis found in Ham's Lake ranged from 487-1411 μg g^{-1} (Table VII). Values were generally lower in organisms at Station HS than in the central pool. Iron in organisms decreased from 13 March to 23 June 1978 and increased through 22 August. Less variation existed among stations on 2 December than in summer. In 1979 few chaoborids were collected; however, the maximum concentration measured during the study occurred at Station HP.

Iron concentration in Chironomus riparius collected from Ham's Lake

TABLE VII

IRON CONCENTRATIONS (IN $\mu g\ g^{-1}$) IN CHAOBORUS PUNCTIPENNIS AND CHIRONOMUS RIPARIUS IN HAM'S LAKE IN 1978-1979

	Station*	13 Mar	22 Apr	25 May	23 Jun	21 Jul	22 Aug	2 Dec	14 Mar	31 May	18 Jul
Chaoborus	HS	557	531	-	487	649	687	718	729	-	-
punctipennis	HP	911	893	-	891	979	1198	979	1411	-	-
	HC	936	840	-	-	-	-	773	-	-	-
Chironomus	HS	1209	1262	1730	1607		2075	3100	2934	2984	1060
riparius	HP	1523	1913	3933	4622	4029	4553	3105	2256		2715
	HC	2029	3063	3947	6168	5812	6697		2974		2733

* HS - station in stratified arm
HP and HC - stations in central pool

ranged from 1060-6697 μg g^{-1} (Table VII). As was observed for C. punctipennis, values were generally lower in chironomids at the stratified station than in the central pool. Concentrations generally increased from 13 March to 23 June 1978. During summer values were low at Station HS but averaged 5313 μg g^{-1} in the central pool. Between 22 August and 2 December, concentrations in the central pool decreased. Few organisms were collected during 1979. Values at all stations were similar on 14 March and averaged 2721 μg g^{-1}. Iron concentrations in C. riparius from the central pool were similar in the central pool on 18 July.

Sorbed iron of the sediments in Arbuckle Lake collected from 0-2 and 6-8 cm depths ranged from nondetectable to 17.9 μg g^{-1} (Table VIII). Values were similar at both depths and only several surface values are presented in Table VIII. Little variation existed among stations except on 29 April 1978 when Station AP had over five times the iron content as the other stations. Mean maximum concentration was 12.6 μg g^{-1} on 15 March 1978. Values decreased at all stations by 29 April to 1.2 μg g^{-1} and remained low the remainder of the year. In 1979 concentrations increased from 15 March to a mean of 4.8 μg g^{-1} on 14 July and decreased the rest of the study.

Total iron in the water of Arbuckle Lake ranged from 50-1571 μg ℓ^{-1} (Appendix, Table XVIII). Since soluble iron represented 28% of the total iron in the water and since it followed no spatial or seasonal trends, only total iron is presented. The hypolimnetic water generally contained slightly larger amounts of iron than the surface and metalimnion. Stations AC and AP had similar values of total iron in the hypolimnion throughout the study except on 15 August 1978 when iron values

TABLE VIII

IRON CONCENTRATION ($\mu g\ g^{-1}$) IN SEDIMENTS, *CHAOBORUS PUNCTIPENNIS*, AND *CHIRONOMUS TENTANS* IN ARBUCKLE LAKE IN 1978-79

	Station*	15 Mar	29 Apr	9 Jun	11 Jul	15 Aug	16 Sep	22 Oct	24 Nov	10 Mar	14 May	14 Jul	15 Sep	11 Nov
Sediments	AC, AP, AA	12.9	3.5	1.1	1.0	0.4	0.4	1.2	1.1	0.2	0.8	4.7	2.6	1.0
Chaoborus punctipennis	AC	286	693	-	-	2140	1932	2173	-	217	-	-	-	-
	AP	129	243	-	-	3421	-	-	-	804	-	-	-	-
	AA	446	-	-	636	1222	809	-	-	858	1218	1272	-	-
Chironomus tentans	AC	349	-	-	-	-	-	-	-	950	1324	-	-	-
	AP	402	1106	-	-	-	-	-	-	2290	1071	-	-	-
	AA	572	707	-	-	-	-	-	-	1092	732	1598	-	-

* AC and AP - stations in central pool
AA - station in arm

at Station AC were over three times that at Station AP and on 15 September 1979 when Station AP had over twice the values at Station AC. Generally, all stations were similar in iron content from 15 March through 11 July 1978 and increased abruptly on 15 August to a mean exceeding 900 μg ℓ^{-1}. Values decreased by 16 September and remained low until the concentrations began to increase in May 1979 and reached a maximum in September. Content decreased by November 1979.

Iron concentrations in Chaoborus punctipennis from Arbuckle Lake ranged from 129-3421 μg g^{-1} (Table VIII). On 15 March values were larger in chaoborids from Station AA in the arm than in the central pool. Concentrations increased at all stations through 15 August, averaging 2261 μg g^{-1} and decreased by 16 September. In 1979 few chaoborids were collected; however, concentrations of iron increased from 15 March to 14 July.

Iron concentrations in Chironomus tentans ranged from 349-2290 μg g^{-1} (Table VIII). During spring 1978, chironomids at all stations had similar iron values with a mean of 442 μg g^{-1}. Little information is present for the remainder of the year. During 1979, considerable variation existed. On 10 March the mean of all stations was 1440 μg g^{-1}. Values decreased slightly by 14 May at Stations AP and AA and increased at Station AC. Few organisms were collected during summer and fall.

Manganese

Sorbed manganese of the sediments collected from 0-2 and 6-8 cm depths in Ham's Lake ranged from 141-2076 μg g^{-1} (Table IX). Values were generally similar in both depths measured and only surface values are presented on Table IX. Sorbed manganese at Stations HC and HP in

TABLE IX

MANGANESE CONCENTRATIONS ($\mu g\ g^{-1}$) IN SEDIMENTS, <u>CHAOBORUS PUNCTIPENNIS</u>, AND <u>CHIRONOMUS RIPARIUS</u> IN HAM'S LAKE IN 1978-79

	Station*	14 Mar	23 Apr	25 May	23 Jun	21 Jul	22 Aug	29 Sep	29 Oct	2 Dec	14 Mar	31 May	18 Jul	22 Sep	18 Nov
Sediment	HS, HP, HC	303	470	440	993	809	753	723	531	396	294	1311	1529	1362	1382
Chaoborus punctipennis	HS	47	45	-	146	174	283	-	-	39	83	-	-	-	-
	HP	97	62	-	50	69	77	-	-	64	174	-	-	-	-
	HC	107	86	-	-	-	-	-	-	53	-	-	-	-	-
Chironomus riparius	HS	245	151	-	280	174	283	-	-	372	378	-	293	-	-
	HP	108	185	536	571	488	552	-	-	181	216	-	401	-	-
	HC	610		624	1074	1133	1072	-	-	-	251	244	387	-	-

* HP and HC - stations in central pool
HS - station in stratified arm

the central pool were similar throughout the study and are averaged on Table IX. During 1978, the arm station HS and the central pool stations had similar values except in November. Values increased from a mean exceeding 300 μg g^{-1} on 13 March to an average of 993 μg g^{-1} on 23 June and decreased the remainder of 1978. During 1979 the sediment at Station HP in the central pool consistently had larger concentrations than the arm station; however, both areas had similar seasonal trends. Values increased from 14 March through 18 July and exhibited little fluctuation the remainder of 1979.

Total manganese of the bottom water ranged from 40-11,733 μg ℓ^{-1} (Appendix, Table XIX). Soluble manganese represented about 21% of the total manganese of the water; however, seasonal trends were similar in both soluble and total values. Concentrations of total manganese were lower at the surface than the other depths throughout the study. Metalimnetic and hypolimnetic concentrations were similar and bottom water values are presented on Table IX. During March and April 1978 all stations had low concentrations of manganese and values averaged less than 70 μg ℓ^{-1}. Values had increased abruptly by 23 June in the stratified arm station to 4320 μg ℓ^{-1}; however, the bottom water in the central pool contained about 200 μg ℓ^{-1}. Peak concentrations of 11,733 μg ℓ^{-1} occurred in the bottom water of Station HS on 11 July 1978, and values decreased on 15 August. Values remained low the remainder of the year at all stations until 14 March 1979. On 14 May values in the bottom water of the central pool increased abruptly to a mean of 1100 μg ℓ^{-1} and to 235 μg ℓ^{-1} in the stratified station. Concentrations decreased the remainder of 1979 in the central pool, but the stratified station reached the peak content on 14 July at 8672 μg ℓ^{-1} and decreased the rest of 1979, averaging less than 45 μg ℓ^{-1}.

Manganese concentrations in Chaoborus punctipennis found in Ham's Lake ranged from 39-283 μg g^{-1} (Table IX). Values were consistently lower in the chaoborids from the arm station, HS, than the central pool during spring 1978. Manganese in C. punctipennis in the central pool decreased from 13 March to 22 April. During summer, the concentrations in chaoborids from Station HS were about three times larger than the values in the central pool. Values decreased abruptly between 22 September and 2 December in organisms at Station HS. Few C. punctipennis were found in 1979 in Ham's Lake except on 14 March when the chaoborids from Station HS had less than half the concentrations of those in the central pool.

Manganese concentrations in Chironomus riparius collected from Ham's Lake ranged from 108-1133 μg g^{-1} (Table IX). Values fluctuated considerably at all stations during spring 1978. During summer manganese was lower in C. riparius from the stratified station HS than in the central pool, while the reverse was true on 2 December and 14 March. On 18 July 1979 values were again lower at Station HS than in the central pool.

In Arbuckle Lake, sorbed manganese of the sediments collected from 0-2 and 6-8 cm depths ranged from 61-851 μg g^{-1} (Table X). Values were generally lower in the deeper sediment than the surface; however, values were generally similar and the surface content is presented on Table X. Values at Stations AC and AP were similar except in summer 1978 when Station AP had larger concentrations. Manganese at Station AA in the arm generally was lower than the central pool. Concentrations in the central pool increased from 15 March 1978 through summer; however,

TABLE X

MANGANESE CONCENTRATIONS (μg g^{-1}) IN THE SEDIMENT, *CHAOBORUS PUNCTIPENNIS*, AND *CHIRONOMUS TENTANS* IN ARBUCKLE LAKE IN 1978-79

	Station*	15 Mar	29 Apr	9 Jun	11 Jul	15 Aug	16 Sep	22 Oct	24 Nov	10 Mar	14 May	14 Jul	15 Sep	11 Nov
Sediments	AC, AP, AA	316	327	361	360	348	348	339	288	209	492	642	152	522
Chaoborus punctipennis	AC	36	39	-	-	624	492	248	-	29	31			
	AP	8	30	-	-	431	-	-	-	169	79			
	AA	46	-	-	106	319	380		-	58	88	488		
Chironomus tentans	AC	-	-							170				
	AP	32	40							199				
	AA	57	-							191				

* AC and AP - stations in central pool
AA - station in arm

Station AA increased to 269 $\mu g\ g^{-1}$ on 9 June and decreased abruptly in August. Values at all stations decreased through 10 March 1979 and increased through 15 July 1979. After a decrease in September, concentrations increased again in November.

Manganese of the bottom water in Arbuckle Lake ranged from 15-2744 $\mu g\ \ell^{-1}$ (Appendix, Table XX). Soluble manganese accounted for 51% of the total manganese in the water and generally followed the same seasonal trends, thus only total manganese is presented. Surface values were low throughout the study. Hypolimnetic and metalimnetic values were similar; however, the values in the bottom water were generally larger and only bottom water trends are discussed. Concentrations of manganese in the bottom water of the central pool stations were generally similar and are averaged in Table X. Values were lower in the arm than in the central pool. Total manganese at all stations averaged 48 $\mu g\ \ell^{-1}$ in March and April 1978. After an increase on 9 June at all stations, values at Station AA tended to decrease the remainder of the year. Manganese in bottom water of the central pool increased to a mean of 1736 $\mu g\ \ell^{-1}$ and remained high until a sharp decrease in October. During 1979, the concentration in the central pool increased abruptly in May and reached maximum values of 2544 $\mu g\ \ell^{-1}$ on 14 July 1979. Content at all stations decreased by 11 November to an average of 37 $\mu g\ \ell^{-1}$.

Manganese concentrations in Chaoborus punctipennis from Arbuckle Lake were generally the lowest of any metal measured and ranged from 8-624 $\mu g\ g^{-1}$ (Table X). Values of manganese were low in chaoborids during spring 1978 at all stations and averaged 32 $\mu g\ g^{-1}$. During summer, chaoborids at Station AA in the arm had the lowest manganese concentrations of all stations. Values in summer were larger than in spring. Concentrations fluctuated little in fall 1978. By 15 March 1979 the average of all stations was 84 $\mu g\ g^{-1}$. Values increased in the chaoborids of Station AA in July.

Manganese content in Chironomus tentans found in Arbuckle Lake ranged from 32-199 $\mu g\ g^{-1}$ (Table X). Few C. tentans were collected during the study. Concentrations averaged 43 $\mu g\ g^{-1}$ in spring 1978, while few organisms were collected in summer and fall. During 1979 values averaged 180 $\mu g\ g^{-1}$ in March.

Zinc

Sorbed zinc of the sediments in Ham's Lake collected from 0-2 and 6-8 cm depths ranged from 0.3-2.8 $\mu g\ g^{-1}$ (Table XI). Zinc values were similar at both depths measured and surface values are shown on Table XI. Sediment at all stations generally had similar concentrations and are averaged on Table XI. In 1978 when pumping was constant fluctuation in zinc values at all stations was considerable. During 1979 when pumping was inconsistent, values at all stations fluctuated less and no seasonal trends were observed. The mean zinc value at all stations during 1979 was 0.95 $\mu g\ g^{-1}$.

Total zinc in the bottom water of Ham's Lake ranged from 1.4-32.9 $\mu g\ \ell^{-1}$ (Appendix, Table XXI). Soluble zinc represented 74% of the total zinc in the water. Surface, mid-depth, and bottom water concentrations were similar throughout the study and only bottom water is presented. Fluctuation was considerable in 1978 when pumping was constant. On 23 June the maximum occurred at all stations and values averaged 28 $\mu g\ \ell^{-1}$. Concentrations tended to decrease through the remainder of 1978. In 1979 little fluctuation existed and no seasonal trends were observed.

TABLE XI

ZINC CONCENTRATIONS ($\mu g\ g^{-1}$) IN THE SEDIMENT, *CHAOBORUS PUNCTIPENNIS*, AND *CHIRONOMUS RIPARIUS* IN HAM'S LAKE IN 1978-79

	Station*	14 Mar	23 Apr	25 May	23 Jun	21 Jul	22 Aug	29 Sep	29 Oct	2 Dec	14 Mar	31 May	18 Jul	22 Sep	18 Nov
Sediment	HS, HP, HC	0.6	1.5	0.7	0.9	0.8	1.5	0.9	0.5	1.1	0.5	0.8	0.8	0.5	0.8
Chaoborus punctipennis	HS	730	549	-	146	386	239	-	-	347	-	-	-	-	-
	HP	934	700	-	-	103	252	-	-	267	366	-	-	-	-
	HC	503	-	-	-	-	-	-	-	82	-	-	-	-	-
Chironomus riparius	HS	745	505	-	1280	891	-	-	-	1296	130	257	1024	-	-
	HP	235	635	984	589	368	171	-	-	-	-	-	1100	-	-
	HC	680		1020	836	538	134	-	-	-	252	1209	536	-	-

* HP and HC in the central pool
HS in the stratified arm

Maximum values occured in May and the mean of all stations was 15 μg ℓ^{-1}.

Zinc concentrations in Chaoborus punctipennis from Ham's Lake ranged from 82-934 μg g^{-1} (Table XI). In spring 1978 zinc of chaoborids averaged 673 μg g^{-1}. Concentrations decreased between 22 April and summer. C. punctipennis averaged 257 and 178 μg g^{-1} in summer at the stratified stations and Station HP in the central pool, respectively. On 2 December zinc concentrations averaged 347 μg g^{-1} at Station HS and 175 μg g^{-1} in the central pool. During 1979, density of chaoborids was low.

Zinc concentrations in Chironomus riparius found in Ham's Lake ranged from 130-1280 μg g^{-1} (Table XI). Values exhibited considerable variation during spring 1978 and averaged 569 μg g^{-1}. Zinc in C. riparius found in the central pool increased to a mean of 1000 μg g^{-1} on 25 May. On 23 June and 21 July, values were considerably larger at the stratified station than in the central pool. Concentrations decreased during summer. During 1979, zinc increased at all stations from 15 March to 15 May; however, by 14 July values increased at the stratified station and decreased in the central pool. Density of chironomids was low the remainder of 1979.

Sorbed zinc in the sediment collected from 0-2 and 6-8 cm depths in Arbuckle Lake ranged from 0.5-1.9 μg g^{-1} (Table XII). Surface values are presented on Table XII. Generally, sediment at all stations had similar zinc values. Fluctuation was more pronounced at all stations in 1978 than 1979. Sorbed zinc generally decreased from 1.1 μg g^{-1} on 15 March to less than 0.8 μg g^{-1} on 29 April. Although values at Station AC reached peak concentrations on 9 June, concentrations at

TABLE XII

ZINC CONCENTRATIONS ($\mu g\ g^{-1}$) IN THE SEDIMENT, CHAOBORUS PUNCTIPENNIS, AND CHIRONOMUS TENTANS IN ARBUCKLE LAKE IN 1978-79

	Station*	15 Mar	29 Apr	9 Jun	11 Jul	15 Aug	16 Sep	22 Oct	24 Nov	10 Mar	14 May	14 Jul	15 Sep	11 Nov
Sediment	AC, AP, AA	1.1	0.7	1.2	0.9	1.2	0.6	0.5	1.3	1.0	1.0	0.8	0.6	0.4
Chaoborus punctipennis	AC	180	135		-	163	145			150				
	AP	664	116		-	190	-			160				
	AA	330	-		95	130	326			123		217		
Chironomus tentans	AC	-	-							53	179			
	AP	60	189							137	443			
	AA	316	-							159	557	593		

* AC and AP - stations in the central pool
AA - stations in the arm

Stations AP and AA fluctuated around 0.8 μg g^{-1}. Zinc at all stations increased in November to a mean exceeding 1.1 μg g^{-1}. In 1979 sorbed zinc tended to decrease at all stations from March through November.

Total zinc in the bottom water in Arbuckle Lake ranged from non-detectable to 30.3 μg ℓ^{-1} (Appendix, Table XXII). Soluble zinc represented 83% of total zinc in the water; however, both had similar seasonal trends and total is shown on Table XXII in the Appendix. Values were similar at surface, mid-depth, and bottom depths. Total zinc at Station AA generally decreased from 15 March through 24 November; however, greater fluctuation was seen at Station AC and AP in the central pool during the same period. Concentrations at all stations decreased from a mean of 25 μg ℓ^{-1} on 15 March 1978 to less than 14 μg ℓ^{-1} on 9 June. Values in the central pool fluctuated little from 14 μg ℓ^{-1} until an abrupt decrease in September to less than 4 μg ℓ^{-1}. Zinc increased abruptly in October in the central pool. During 1979 values were generally lower than in 1978 and averaged less than 6 μg ℓ^{-1} at all stations.

Zinc concentrations in Chaoborus punctipennis in Arbuckle Lake ranged from 95-664 μg g^{-1} (Table XII). Values averaged over 390 μg g^{-1} at all stations on 15 March 1978. Concentrations decreased at the central pool stations by 29 April and were similar through August. Station AA had lower zinc values than the central pool during summer. Zinc increased at Station AA on 16 September. Few organisms were collected in fall. During 1979 values averaged 140 μg g^{-1}.

Zinc values in C. tentans from Arbuckle Lake ranged from 53-593 μg g^{-1} (Table XII). Concentrations averaged 188 μg g^{-1} during spring 1978 while few organisms were collected the remainder of the year. During

1979 zinc values increased from 10 March to 14 May. In spring 1979 chaoborids at Station AC had a lower content than either Stations AP or AA.

Concentration Factors

Concentration factors of iron comparing organisms and sediment were considerably less than factors comparing invertebrates and water (Table XIII). The maximum concentration factor for iron was 7000 for concentration by *Chironomus riparius* from the water. This factor was almost four times greater than that for *Chaoborus punctipennis* in Ham's Lake. In Arbuckle Lake the concentration of iron from the water was similar in *Chironomus tentans* and *Chaoborus punctipennis*. The concentration factors for sediment were also similar in the two species.

The concentration factor for manganese ranged from 100-700. The sediments were sinks for manganese. Organisms in both lakes concentrated manganese less than either iron or zinc.

Concentration factors comparing zinc in organisms and water were extremely high reaching 54,000 for *Chironomus riparius* in Ham's Lake. The factors were lower in *Chaoborus punctipennis* than in *C. riparius*. The factor for *C. riparius* and sediments in Ham's Lake was 806 which was twice the factor for *C. punctipennis*. Values were more similar for the two species in Arbuckle Lake.

Laboratory Experiments

Caloric content of the sediments in the controlled experiments after 4 days ranged from nondetectable to 1652 cal g^{-1}. Values in the oxygenated jars were generally low and averaged 46 cal g^{-1}. The

TABLE XIII

MEAN CONCENTRATION FACTORS OF IRON, MANGANESE, AND ZINC IN HAM'S AND ARBUCKLE LAKES IN 1978-79

Lake	Metal	S/W*	CP/W	CP/S	C/W	C/S
Ham's	Fe	4	1,800	443	7,000	1649
	Mn	1080	100	0.1	700	0.6
	Zn	70	29,000	434	54,000	806
Arbuckle	Fe	5	2,600	498	2,700	472
	Mn	640	400	0.6	200	0.2
	Zn	13	17,000	217	26,000	326

* S = sediment, W = water, CP = _Chaoborus punctipennis_, C = _Chironomus riparius_ (Ham's) or _Chironomus tentans_ (Arbuckle)

sediment in the anoxic jars had a significantly larger caloric content than the oxic jars, averaging 1528 $\pm$ 131 cal g^{-1}.

Iron content in the water of the experiment containing different levels of iron ranged from 1004-2731 μg ℓ^{-1}. At the 1000 μg ℓ^{-1} level, iron increased to 2731 μg ℓ^{-1} after 4 days, while values decreased significantly in the water at 3000 and 5000 μg ℓ^{-1}.

Sorbed iron in the sediments ranged from 0.037-0.112 μg g^{-1}. Values were consistently low in the sediment of all jars with the largest values measured in the jars with 3000 μg ℓ^{-1}.

Iron concentrations in *Chironomus riparius* in the laboratory systems ranged from 1073-1219 μg g^{-1}. Minimum values were measured in the jar containing 1000 μg g^{-1} of iron; however, the difference was not significant because of the large amount of variability.

In the laboratory experiments in which iron concentration was measured over time from 12-60 h, values ranged from 17-1459 μg ℓ^{-1} in the water (Table XIV). Values were lower in the oxygenated than in the anoxic jars except for the sample at 12 h. Iron concentrations in the oxic jars decreased abruptly between 12 and 24 h, while subsequent changes were considerably less. In the anoxic jars, iron increased fourfold in the water between 12 and 24 h and then decreased between 36 and 60 h.

Sorbed iron of the sediments in the experiments over time ranged from nondetectable to 0.162 μg g^{-1}. Values were lower in the sediments from the oxic than from the anoxic jars except in the 12 h sample. Maximum difference between oxic and anoxic samples occurred at 24 h when the extreme values were measured. Temporal changes were similar to the trends observed in the water samples.

TABLE XIV

CONCENTRATIONS OF IRON IN THE WATER, SEDIMENT, AND *CHIRONOMUS RIPARIUS* OVER TIME IN OXIC AND ANOXIC LABORATORY SYSTEMS

Time (in h)	Water ($\mu g\ \ell^{-1}$)		Sediment ($\mu g\ g^{-1}$)		*C. riparius* ($\mu g\ g^{-1}$)	
	Oxic	Anoxic	Oxic	Anoxic	Oxic	Anoxic
12	1459	109	0.065	0.053	1153	1353
24	132	446	ND	0.162	1284	2736
36	17	324	0.009	0.132	977	3799
48	53	191	0.041	0.066	923	4697
60	46	37	0.015	0.108	1061	3296

The iron content of Chironomus riparius ranged from 923-4697 μg g^{-1}. Iron values were consistently lower in the organisms from the oxygenated jars than the anoxic jars. Values of iron in the oxygenated jars were similar in all samples and averaged 1079 μg g^{-1}. Values in the anoxic samples increased from the 12 h samples to the 48 h samples and then decreased.

CHAPTER VI

DISCUSSION

Organic Matter, Phosphorus, and Macroinvertebrates

Values of loss on ignition (LOI) were generally similar in Arbuckle and Ham's lakes and ranged from 5.7-14.7%. Values were similar to those summarized in a review article by Dean and Gorham (1976) and to those reported in a previous study of the two lakes (Clay and Wilhm 1979). LOI in Arbuckle and Ham's lakes were generally higher than that reported in an area stream possibly because of the large particle size in the stream (Namminga and Wilhm 1977).

Larger values of LOI of the sediments existed in the central pool than in the arm in Arbuckle Lake. A smaller grain size occurred in the central pool sediments than at the arm station since larger particles are deposited in the arms and smaller sized particles are carried into the central pool (Clay and Wilhm 1979). Studies have shown an inverse relationship between grain size and LOI (Hargrave 1972, Namminga and Wilhm 1977).

Higher LOI values were measured at the stratified station than in the central pool in Ham's Lake. Particle sizes in the two areas were similar (Clay and Wilhm 1979). LOI at the destratified region were probably lower because oxygen permitted more efficient breakdown of organic matter.

Percent organic matter (POM) of the sediments of Arbuckle and Ham's lakes were generally similar and ranged from 2.4-7.6%. These values were similar to those measured in an earlier study (Clay and Wilhm 1979). As with LOI, POM was lower at arm station than in the central pool in Arbuckle Lake, probably due to variation in particle size among areas. Although LOI and POM are closely related, POM was always lower than LOI. In Ham's Lake no significant difference ($p = 0.05$) existed in POM between the central pool and the stratified station. Clay and Wilhm (1979) found no significant difference in POM values among stations in Ham's Lake in an earlier study. Seasonal variation was also found to be slight in POM values in their study.

Phosphate concentrations of the sediment of Arbuckle and Ham's lakes were similar and ranged from 8.2-38.6 $\mu g\ g^{-1}$. Concentrations were generally similar to values in the literature (Oschwald 1972, Wetzel 1975). As with LOI and POM, concentrations were lower in the arm station than the central pool in Arbuckle Lake, probably because of variation in particle size of the sediments. In Ham's Lake the stratified station had larger concentrations of phosphate than the central pool. It was expected that higher phosphate values would be associated with the sediments of the central pool than the stratified station. Mortimer (1941) found a phosphorus release from the sediments associated with summer stratification and the concomittant breakdown of the oxidized microzone. Gorham and Swaine (1965), in a study analyzing element distribution in response to oxic and anoxic conditions, found phosphorus to enrich about 20% more in oxic than anoxic sediments;

however, enrichment was highly variable in the samples. This variability might have obscured the difference between areas in Ham's Lake.

Similar taxa were found in Arbuckle and Ham's lakes during the study and were comparable to those found in earlier studies (Parrish and Wilhm 1978, Ferraris and Wilhm 1977). These studies indicated *Chaoborus punctipennis* and *Procladius* sp. were the most prevalent taxa in the two lakes. In the present study two species of *Chironomus* were identified: *C. tentans* in Arbuckle Lake and *C. riparius* in Ham's Lake.

Variation existed between the lakes in the species of oligochaetes collected. *Dero digitata* was the prevalent species in Ham's Lake in the present study and in a previous study (Ferraris and Wilhm 1977). In Arbuckle Lake *Limnodrilus* sp. was prevalent while *Tubifex* sp. and *Aulodrilus pigueti* were also common. Parrish and Wilhm (1978) found that *D. digitata* was especially abundant at shallower depths, but also was dense at the deep water stations in late spring.

Species diversity values were lower in the two lakes than values found in the literature (Ferraris and Wilhm 1977, Parrish and Wilhm 1978). This was undoubtedly influenced by the water depth of the stations sampled. Station depths were 5 and 8 m in Ham's Lake and 15, 24, and 26 m in Arbuckle Lake. Ferraris and Wilhm (1977) found that species composition and diversity varied with depth. Shallow water sediments contained a higher diversity of benthic macroinvertebrates than deeper water stations. The benthic assemblage of the profundal zone was dominated by one or two abundant species and few rare taxa causing a low diversity. A similar result was found in a study of Arbuckle Lake by Parrish and Wilhm (1978), and the relationship between depth and species diversity was fitted to models. Ransom and Dorris (1972) also observed a decrease in diversity with increasing water depth in Keystone Reservoir, Oklahoma.

Calories

Sediment caloric content ranged from nondetectable to 3230 cal g^{-1} and were similar in both lakes. Values were generally similar to that in a survey of sediment types (Gorham and Sanger 1967).

Values were similar at all stations in Arbuckle Lake; however, in Ham's Lake a difference existed between stations in the stratified arm and in the central pool in summer 1978. It was expected that values would be lower in the aerated central pool than at the stratified station; however, the reverse was observed. Several precipitation periods occurred prior to sampling in 1978 and the central pool receives an inflow from several large streams, while the stratified station receives only one small stream. It is possible that the increase in the central pool resulted from allochthonous sources. Station HS had low values during summer and fall 1978 and a peak calorie content occurred in the central pool on 23 June 1978. A heavy rainfall occurred 2 days before the sampling period and might have influenced the calorie content of the sediment by increased organic matter in the runoff.

The caloric content of *Chaoborus punctipennis* ranged from 4076-6850 cal g^{-1}, while the range for the two species of *Chironomus* was 3170-5358 cal g^{-1}. No values were found in the literature for *C. punctipennis*; however, the range for chironomids is similar to the range reported for these organisms by Wissing and Hasler (1966). Thornton and Wilhm (1974) observed caloric content of *Chironomus attenuatus* subjected to varying levels of phenol and sodium chloride and found slightly higher content and a smaller range; however, measurements were made under controlled laboratory conditions.

The calorie content was less in organisms collected from Arbuckle than Ham's Lake. This might be related to differences in the daily vertical migrations of Chaoborus punctipennis. Teraguichi et al. (1974) found a significant difference in the calorie content of mysid shrimp during different stages in their daily migration. Calorie content was lower during ascent than descent. The migrations that occur at Arbuckle Lake are longer than those occurring in Ham's Lake due to the difference in water depths. The difference in distance migrated could affect the calorie content of the chaoborids.

Calorie content was lower in the chironomids collected from Arbuckle Lake than those from Ham's Lake. In addition to variation in species collected in the two lakes, variation may have also been influenced by differences in environmental conditions in the lakes. Wissing and Hasler (1968) have found calorie content to vary with differences in the environment or nutrition of organisms. Paine (1971) found that an organism's caloric content is related to the relative abundance of different components like lipids or carbohydrates.

Heavy Metals

Total iron in the water was similar in Ham's and Arbuckle lakes and ranged from 50-1571 $\mu g\ \ell^{-1}$. This exceeds most ranges reported in the literature (Cross et al. 1970, Elder et al. 1976, and Benes et al. 1976). Wetzel (1975) stated that the range in most alkaline lakes is 50-200 $\mu g\ \ell^{-1}$ and is constituted largely of Fe (OH_3), organically complexed iron, and adsorbed iron of seston in particulate form. Turbidity is relatively high in the two lakes, especially in the bottom water. Less than 16% and 28% of total iron was in soluble forms in Ham's and Arbuckle lakes, respectively, suggesting the large concentrations of iron existing as adsorbed iron onto inorganic particles. Soluble iron in Ham's and Arbuckle lakes is within the range reported in most studies.

Several additional trends suggest that turbidity is related to the values of the iron concentration in the water. In both lakes, values of total iron in the bottom water exceeded values in the surface water. Turbidity averaged 17 JTU in the bottom water and 10 JTU in the surface water ($p > 0.05$). Although little variation existed between the 15 m and the deeper stations in Arbuckle Lake, considerable variation existed between the stratified and destratified stations in Ham's Lake during pumping in summer 1978. Mean total iron was 444 $\mu g\ \ell^{-1}$ at the mixed stations and 254 $\mu g\ \ell^{-1}$ at the stratified station ($p > 0.05$). It was expected that values would be greater at the stratified station because of mobilization of iron into the water as the oxygen content decreases (Mortimer 1971). However, higher values in the mixed areas were probably caused by high turbidity resulting from resuspension due to pumping. Burns and Nriagu (1977) estimated that about 95% of the iron in the water in Lake Erie is bound to inorganic particles and is present because of sediment resuspension. A similar situation probably existed in Ham's Lake. Little variation existed between the two areas in 1979 because of the erratic pumping regime.

Considerable variation exists among values of sorbed iron in sediments because of variation in extraction techniques as well as variation in physicochemical conditions. Values were about equal in the two lakes ranging from nondetectable to 17.9 μg g^{-1}, which is lower than ranges given in many studies. However, an ammonium acetate extraction method was used in the present study in order to estimate the iron available to the organisms. This extraction method typically produces lower values than acid extraction methods.

Total iron values in Chaoborus punctipennis ranged from 129-141 μg g^{-1}. Values of iron concentrations have been reported in a wide variety of aquatic organisms including phytoplankton (Wetzel 1975), vertebrates (Bohn and McElroy 1976, Cross et al. 1973) and invertebrates (Stevenson and Ufret 1966, Windom and Smith 1972). Values in this study are within the range of those in the literature (Cross et al. 1970).

The concentrations of iron were lower in Chaoborus punctipennis than in Chironomus riparius or Chironomus tentans. This is probably related to the presence of iron-containing hemoglobin in the chironomids. The iron content was lower in C. tentans in Arbuckle Lake than in C. riparius in Ham's Lake which might be related to the greater concentration of available iron in Ham's Lake. Filipek and Owens (1970) characterized metals into three levels of availability to organisms: (1) available, those metals soluble in mild acid; (2) moderately available, those complexed with sulfides, organics, or coprecipitated with iron and manganese colloids; and (3) not available, those metals present in crystalline matrix. Observations reveal a fairly high sulfide content in the sediments of Arbuckle Lake in summer.

Concentrations of total manganese in the water ranged from 15-11,733 μg ℓ^{-1}. Both lakes had higher concentrations than generally reported in the literature (Mathis et al. 1979, Brezonik et al. 1969, Delfino and Lee 1968, and Gerloff and Skoog 1958). Wetzel (1975) stated that the range of manganese is generally from 10-850 $\mu g\ \ell^{-1}$ and is highly variable. Ranges in the present study may be high because they were taken in a reservoir in which the vegetation had not been removed prior to filling. Wolman and Stegmaier (1940) indicated that vegetative stripping should be done because of the resultant buildup of manganese in the sediment and bottom water of the reservoir after completion.

The movement of manganese from the sediment during summer stratification and resultant oxygen depletion in the hypolimnion of eutrophic lakes has been reported (Mortimer 1940, 1941, 1971). In Arbuckle Lake total manganese was higher during summer in the hypolimnion than at the surface. This form of manganese is reduced and soluble. Soluble manganese in the hypolimnion of Arbuckle Lake averaged 51%. A similar situation was observed in the hypolimnion at the stratified station in Ham's Lake, but not at the stations in the central pool.

The central pool of Ham's Lake was successfully destratified and oxygen was present throughout the lake in summer 1978. Manganese values remained low and were similar at the surface and bottom. Most of the manganese present was the insoluble oxidized form. In 1979 the concentrations was large in May and decreased the rest of the year. This large increase probably resulted from the erratic pumping schedule.

Generally the sorbed manganese of the sediment of Arbuckle and Ham's lakes was the largest of any metal measured. Values of manganese were generally larger than those reported in the literature (Cross et al. 1970).

The concentrations of manganese of the sediment were related to particle size in Arbuckle Lake. Hargrave (1972) found an inverse relationship between grain size and heavy metal content of the sediments.

Station AA in the arm had a larger grain size (Clay and Wilhm 1979) and a lower manganese content than the central pool.

It was expected that the concentrations of manganese would increase more during summer pumping in the sediments in the central pool stations than in the stratified arm. However, in 1978 this was observed only on 23 June and may have been influenced by runoff as described for calorie content.

Manganese concentrations in *Chaoborus punctipennis* ranged from 8-624 µg g^{-1} and were generally similar in Ham's and Arbuckle lakes. Values are similar to those reported in the literature (Bohn and McElroy 1976, Cross et al. 1970). Manganese values in the present study were the lowest of any metal measured. Harvey (1971) indicated that midges do not concentrate manganese.

Concentrations of manganese were lower in *Chironomus tentans* than in *Chironomus riparius*. This might be related to the larger amount of sulfide in Arbuckle Lake described previously. Although Wetzel (1975) indicated that manganous sulfide is more soluble than most of the other metal sulfides, it would still be less available to organisms than other forms (Filipek and Owens 1970).

Although little difference existed in manganese concentration in *C. tentans* among stations in Arbuckle Lake, variation was significant for *C. riparius* from Ham's Lake. During summer of both years, *C. riparius* had lower manganese values at the stratified station than in the central pool. This probably resulted from changes in manganese solubility resulting from destratification. The manganese content in the surface sediment in summer was lower at the stratified station than in the central pool.

Concentrations of total zinc in the water of Arbuckle and Ham's lakes were similar. Values ranged from nondetectable to 32.9 μg ℓ^{-1} and are similar to concentrations reported by Namminga and Wilhm (1977), Sias and Wilhm (1975), Wilber and Hunter (1977, and Cross et al. (1970). Wetzel (1975) stated that zinc concentrations were generally low in aerated surface water. He also indicated that some hypolimnetic accumulation occurs because of sorption phenomenon on ferric hydroxide colloids. Sias and Wilhm (1975) indicated that hypolimnetic accumulation occurred in Lake Carl Blackwell; however, no significant difference existed between surface and bottom water concentrations in either lake in the present study. Considerable variation existed among replicates in the zinc values in the present study and might have obscured differences.

In Arbuckle Lake variation among stations in zinc concentrations in the water was not significant. The zinc consisted mostly of the soluble form. In Ham's Lake large fluctuations occurred at Station HP in the central pool which might be related to its proximity to the pump. Pumping may have increased sediment resuspension.

Values of sorbed zinc of the sediment of Arbuckle and Ham's lakes ranged from 0.34-2.81 μg g^{-1} and were generally similar to values measured in Lake Carl Blackwell, Oklahoma (Sias and Wilhm 1975). Namminga and Wilhm (1977) and Mathis and Cummings (1973) reported larger values in streams.

Heavy metal concentrations have been correlated with grain size (Hargrave 1972) and with percent loss on ignition (Namminga and Wilhm 1977). It was expected that zinc concentrations would be lower in the arm of Arbuckle Lake than in the central pool since grain size is larger in the arm (Clay and Wilhm 1979). In this study, concentrations were not significantly different indicating the influence of other factors.

Concentrations of zinc in Chaoborus punctipennis were similar in both lakes and ranged from 82-934 $\mu g\ g^{-1}$. No concentrations of zinc were found in the literature for C. punctipennis. Values have been reported for a wide variety of aquatic organisms (Bohn and McElroy 1976, Abdullah and Brown 1977) including crane fly larvae (Elwood et al. 1976).

Although the concentration of zinc was lower in Chironomus tentans from Arbuckle Lake than Chironomus riparius from Ham's Lake, the values were similar to that seen in a study of Chironomus attenuatus (Namminga and Wilhm 1977). In their study of a stream receiving oil field pollution, the average value of zinc found in C. attenuatus was 57 $\mu g\ g^{-1}$. The difference in zinc values between the two species of chironomids analyzed in the present study might be related to different amounts of sulfide found in the two lakes as mentioned previously (Filipek and Owens 1970).

Concentration Factors

Concentration factors compare the amount of a given metal that an organism accumulates over ambient values in the sediment or water. Cushing and Rancitelli (1972) measured a maximum concentration factor of 76,000 for iron in phytoplankton and water in the Columbia River which is significantly larger than the maximum measured for Chaoborus punctipennis and Chironomus sp. in the present study. However, the average concentration of iron in the water was generally less than 62 $\mu g\ \ell^{-1}$ in the study on the Columbia River which was considerably less than the concentration in Ham's and Arbuckle lakes. Concentration factors may decrease as the concentration in the water increases.

Manganese was concentrated significantly less than either iron or zinc by the benthic macroinvertebrates in the present study. Manganese concentration factors were low in a study comparing tipulids to detritus (Cushing 1979) and tubificids to sediment (Dean 1974). Harvey (1972) also found that midges were poor accumulators of manganese from ambient levels.

Zinc is generally concentrated to large amounts from the water by aquatic organisms (Cushing and Watson 1968, Cushing and Rose 1970, Cushing and Rancitelli 1972, Cushing 1979, and Dean 1974). In the present study the concentration factors for zinc from the water by the macroinvertebrates exceeded the factors for iron or manganese. *Chaoborus punctipennis* concentrated zinc to greater amounts from the water in Ham's Lake than in Arbuckle Lake. Larger levels of zinc were concentrated by *Chironomus riparius* in Ham's Lake than by *Chironomus tentans* in Arbuckle Lake. This difference might be related to the relative availability of the metals from the water (Filipek and Owen 1970).

Laboratory Experiments

Caloric content of the sediments in the controlled experiments ranged from nondetectable to 1652 cal g^{-1}. These values were similar to that found in the field studies of the sediment from Arbuckle and Ham's lakes. In a study of different soil and sediment types, Gorham and Sanger (1967) found a higher range of values in lake and pond muds, with the highest values exceeding 5000 cal g^{-1}.

Caloric content was significantly lower in the sediment from the oxygenated jars than the anoxic jars. This difference was probably related to a higher rate of decomposition with dissolved oxygen. In aerobic sediments, both biological and chemical oxidation occur (Hargrave 1972). Chemical oxidation occurs in anaerobic situations, but anaerobic biological reactions are much less efficient.

Iron concentration of the water, sediment, and in Chironomus riparius after 4 days were not significantly different among jars receiving different initial inputs of iron. Thus, it was not possible to account for the additional iron added in the jars receiving higher input. It is likely that the excess iron was sorbed onto the surface sediment and was not recovered because of sampling problems.

In experiments comparing iron concentrations in oxic and anoxic jars, the concentration was lower in the water and in C. riparius in the oxic jars than in the anoxic jars. No significant difference existed among sediment in the two treatments. This is probably related to precipitation of iron as ferric hydroxide in the oxic jars (Mortimer 1940). Sampling problems associated with collecting iron at the interface may have resulted in no significant difference among sediments in the oxic and anoxic jars. Variation among replicate sediment samples was also large and may have obscured differences. In chironomids iron is associated with hemoglobin (Walshe 1950). Although the function of hemoglobin in chironomids is controversial, some studies have indicated its importance in response to oxygen stress. Fox (1960) has studied hemoglobin formation in chironomids and indicated that more hemoglobin is produced in organisms from oxygen-poor water than aerated water. Therefore, the organisms in the anoxic jars might begin concentrating iron for hemoglobin production.

Total iron of the water ranged from 17-2731 μg ℓ^{-1} in the controlled experiments and 50-1571 μg ℓ^{-1} in the field. Sorbed iron of the sediments in the field and controlled experiments ranged from nondetectable to 17.9 μg g^{-1} and nondetectable to 0.16 μg g^{-1}, respectively. Iron content in _C. riparius_ ranged from 923-4697 μg g^{-1} in the controlled experiments and 1060-6697 μg g^{-1} in Ham's Lake.

Conclusions

The organic matter of the sediment was expected to decrease in destratified areas because oxygenation of the water would provide more efficient breakdown. Loss on ignition (LOI) and percent organic matter (POM) were used to determine approximate organic content of the sediment. In Ham's Lake the sediment in the central pool had lower LOI values than that from the stratified station. POM values showed no spatial differences and were consistently lower than LOI. The large amount of clay in the sediment samples might have biased the POM values downward.

In Arbuckle Lake LOI values were larger in the sediments from the central pool than the arm station, probably because of the difference in grain size of the sediments. No spatial difference was apparent in POM values because of the high amounts of clay.

Phosphorus of the sediment was expected to increase in the anoxic samples in summer because of mobilization from the sediment. In Ham's Lake larger phosphorus values were determined in the sediment from the stratified station than the central pool. In Arbuckle Lake particle size of the sediment influenced the phosphorus content of the samples from the arm stations and central pool. Larger concentrations of phosphorus were determined from the central pool than the arm station sediments.

Species diversity of the benthic assemblage was predicted to be larger in the destratified areas than in the stratified station because of the stress caused by low oxygen concentrations. In Ham's Lake diversity was larger in the central pool than in the stratified station in 1978 as expected; however, in 1979 too few organisms were collected to compute diversity values. At all stations diversity values were lower than predicted which is probably related to the water depth of the stations.

In Arbuckle Lake little spatial variation in species diversity existed probably because of the anoxic conditions at all stations. All values were lower than predicted which might be related to the water depth of all stations.

Caloric content of the sediment was expected to decrease in the destratified areas in summer; however, in Ham's Lake the central pool sediments had a larger caloric content than that from the stratified station. This might be related to the small sample sizes analyzed. Pellets of 7-16 mg were used for determinating sediment caloric content. Further, the heterogeneous composition of the sediment also may have obscured the results.

In Arbuckle Lake little spatial variation existed in caloric content of the sediment. All stations had anoxic water conditions in summer and similar caloric contents were expected.

Caloric content of *Chaoborus punctipennis* was expected to be similar in both lakes; however, values were lower in the organisms collected from Arbuckle Lake than Ham's Lake. This difference might be related to the greater vertical migration distance that C. punctipennis migrates in Arbuckle Lake which would reduce the calories of the organisms in the deeper lake.

Caloric content was expected to be similar in the two species of Chironomus studied; however, C. tentans from Arbuckle Lake had significantly lower caloric value than C. riparius from Ham's Lake. The two species may have different levels of carbohydrates and lipids which would affect the caloric value.

In Ham's Lake a difference in caloric content was expected between the C. punctipennis and C. riparius obtained from the stratified and destratified areas probably because of the stress of low oxygen levels. This result did not exist; however, the paucity of organisms collected may have obscured the expected differences.

Total iron content of the water should increase in the hypolimnetic water of the stratified station more than in the bottom water of the destratified area and sorbed iron of the sediments show the reverse conditions. In Ham's Lake, however, values were larger in the bottom water of the destratified stations than in the stratified stations. Resuspension of particulate iron caused by pumping in the central pool might have obscured the results. Sorbed iron of the sediments was similar at all stations which is probably related to the extraction technique.

In Arbuckle Lake all stations had anoxic water conditions in summer and no spatial differences existed in either total iron or sorbed iron.

The iron content of certain benthic macroinvertebrates was predicted to change in response to the changes in total iron of the water and sorbed iron of the sediments. This may possibly be due to stresses caused by the changing availability of the essential element. No spatial difference was evident in *C. punctipennis* or *C. riparius* from the destratified stations or the stratified area in Ham's Lake. The expected difference was probably obscured by the small number of organisms collected during the study. No differences existed in the iron content of organisms from different stations in Arbuckle Lake.

An increase in soluble manganese similar to that for iron was expected in the hypolimnion of the stratified station during summer and a decrease in sorbed manganese was predicted. Soluble manganese increased in the bottom water of the stratified station of Ham's Lake in summer. No spatial differences existed in sorbed manganese probably due to the extraction technique. In Arbuckle Lake all stations had anoxic conditions in the hypolimnion in summer, and little difference existed in the total manganese of the water and the sorbed manganese of the sediment.

The changes of manganese content in the water and sediment were expected to influence the concentrations measured in the benthic organisms. No difference in manganese content of the organisms from different stations was measured in either lake, probably because of the paucity of organisms collected during the study.

Zinc does not respond to oxygen changes in the water as does iron and manganese. Thus, total zinc concentrations of the water and sorbed zinc of the sediments were not predicted to vary between the stratified and destratified areas which was observed during the study.

Zinc concentrations in *C. punctipennis*, *C. riparius*, and *C. tentans* from different stations were expected to be similar. No significant difference existed in zinc concentrations in organisms of the same species from different stations in either of the lakes.

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APPENDIX

TABLE XV

LOSS ON IGNITION, PERCENT ORGANIC MATTER, AND PHOSPHATE OF THE SURFACE SEDIMENT OF HAM'S LAKE IN 1978-79

	Loss on Ignition (%)			Percent Organic Matter			Phosphate, $\mu g\ g^{-1}$		
	HS	HP	HC	HS	HP	HC	HS	HP	HC
Mar				4.8	3.6	2.4			
Apr	11.2	8.7	8.6	5.7	3.2	3.9	16.5	14.7	14.2
May	9.3	9.7	8.4	5.0	4.0	3.8	18.5	17.8	14.8
Jun	9.8	8.6	8.1	5.6	4.0	3.8	25.9	20.4	21.0
Jul	9.5	7.1	7.0	5.6	3.7	4.0	17.0	16.4	12.4
Aug	9.9	8.5	7.1	6.1	4.6	4.0	18.4	17.2	15.6
Sep	9.1	8.6	7.8	5.5	4.3	3.4	19.9	17.3	14.9
Oct	9.5	8.3	7.7	5.6	4.0	3.7	16.31	13.1	13.4
Nov	7.9	7.6	7.0	4.9	4.1	3.8	16.8	18.2	16.0
Mar	8.9	7.9	7.3	5.1	4.0	3.4	15.9	16.3	14.3
May	8.5	7.5	7.4	4.8	3.3	3.4	14.7	12.6	13.5
Jul	9.5	10.8	7.5	4.8	4.9	3.5	11.1	10.7	8.4
Sep	8.5	8.2	6.8	4.7	4.2	3.1	22.5	23.6	15.1
Nov	10.0	9.4	7.7	5.5	4.5	3.8	23.0	21.1	18.8

TABLE XVI

LOSS ON IGNITION, PERCENT ORGANIC MATTER, AND PHOSPHATE OF THE SURFACE SEDIMENT IN ARBUCKLE LAKE IN 1978-79

	Loss on Ignition			Percent Organic Matter			Phosphate		
	AC	AP	AA	AC	AP	AA	AC	AP	AA
Mar				6.0	7.6	6.7	37.5	34.0	
Apr	12.3	12.9	9.2	5.8	5.9	3.0	36.0	38.6	20.2
Jun	12.3	10.7	12.3	6.0	5.9	5.5	24.1	28.4	16.6
Jul	14.1	14.1	7.5	6.3	6.4	4.0	22.8	24.1	20.0
Aug	14.7	13.7	9.8	6.9	6.7	4.0	26.9	26.6	20.6
Sep	11.0	10.2	9.0	6.9	6.7	4.8	27.6	25.4	21.2
Oct	11.1	10.6	6.9	7.0	6.4	4.5	26.2	22.5	18.6
Nov	9.7	10.5	8.5	6.0	6.6	6.0	24.3	25.8	21.2
Mar	11.0	11.3	9.8	6.3	5.8	5.3	27.4	25.8	23.6
May	9.4	9.5	6.7	5.8	5.8	4.2	22.7	21.9	18.1
Jul	10.6	10.6	8.5	5.9	6.4	6.0	31.0	31.3	27.7
Sep	9.9	10.9	8.5	5.7	6.6	5.0	27.7	26.3	22.9
Nov	11.7	11.6	5.8	6.5	5.9	3.3	27.0	26.4	13.8

TABLE XVII

TOTAL IRON IN SURFACE AND BOTTOM WATER AND SORBED IRON IN THE SEDIMENT OF THREE STATIONS IN HAM'S LAKE IN 1978-1979

Date	Surface ($\mu g\ \ell^{-1}$)	Bottom Water ($\mu g\ \ell^{-1}$)			Sediments ($\mu g\ g^{-1}$)		
		HS	HP	HC	HS	HP	HC
Mar	360	319	306	381	7	2	2
Apr	289	303	582	442	12	2	0
May	159	344	439	348	2	3	2
Jun	448	338	883	740	1.6	0.6	0.7
Jul	241	129	505	388	0.6	0.8	0.6
Aug	206	135	558	432	0.0	0.8	0.5
Sep	465	176	788	764	0.5	0.3	0.3
Oct	226	233	308	250	2.9	2.1	2.3
Nov	599	600	617	675	1.1	0.8	0.4
Mar	616	596	655	666	0.4	0.6	0.1
May	435	835	1072	805	1.0	0.5	0.8
Jul	339	377	543	353	7.8	8.8	4.8
Sep	306	423	294	401	1.2	1.1	0.5
Nov	200	284	200	217	1.5	3.0	1.5

TABLE XVIII

TOTAL IRON IN THE SURFACE AND BOTTOM WATER AND SORBED IN SEDIMENTS IN ARBUCKLE LAKE IN 1978-1979

Date	Surface ($\mu g\ \ell^{-1}$) Av.	Bottom Water ($\mu g\ \ell^{-1}$)			Sediment ($\mu g\ g^{-1}$)		
		AC	HP	AA	AC	AP	AA
Mar	442	315	265	653	17.9	11.0	10.1
Apr	132	339	268	340	1.3	8.3	1.0
Jun	144	331	330	630	1.3	0.9	1.1
Jul	81	203	196	408	1.2	1.1	0.7
Aug	99	1563	466	679	0.5	0.5	0.4
Sep	61	294	219	238	0.7	0.3	0.2
Oct	150	308	274	197	1.3	1.2	1.0
Nov	188	276	416	514	2.3	0.5	0.4
Mar	50	70	74	191	0.1	0.3	0.0
May	152	349	754	468	0.7	0.9	0.9
Jul	67	598	439	355	7.5	4.5	2.3
Sep	111	925	586	1571	5.8	1.1	1.1
Nov	149	170	170	161	1.0	1.3	0.7

TABLE XIX

TOTAL MANGANESE IN THE SURFACE AND BOTTOM WATER AND SORBED IN THE SEDIMENTS OF THREE STATIONS IN HAM'S LAKE IN 1978-1979

Date	Surface ($\mu g\ \ell^{-1}$)	Bottom Water ($\mu g\ \ell^{-1}$)			Sediments ($\mu g\ g^{-1}$)		
		HS	HP	HC	HS	HP	HC
Mar	69	67	70	71	339	294	277
Apr	49	52	72	66	525	361	524
May	50	231	82	97	382	600	339
Jun	33	4319	173	204	750	975	1254
Jul	119	11732	229	202	833	987	614
Aug	63	103	165	115	689	930	642
Sep	97	245	146	125	851	711	607
Oct	68	89	70	58	457	597	539
Nov	36	43	35	36	174	329	635
Mar	37	42	41	39	140	454	289
May	109	234	1659	647	1086	1541	1306
Jul	201	8671	411	213	1180	2075	1323
Sep	62	195	100	86	1045	2025	1017
Nov	41	43	43	47	1236	1917	997

TABLE XX

TOTAL MANGANESE IN THE SURFACE AND BOTTOM WATER AND SEDIMENTS OF THREE STATIONS IN ARBUCKLE LAKE IN 1978-79

Date	Surface ($\mu g\ \ell^{-1}$)	Bottom Water ($\mu g\ \ell^{-1}$)			Sediments ($\mu g\ g^{-1}$)		
		AC	AP	AA	AC	AP	AA
Mar	32	22	15	35	407	343	199
Apr	11	142	42	31	344	424	213
Jun	20	1475	49	855	352	462	269
Jul	14	323	456	138	379	535	166
Aug	33	2359	1113	251	420	516	108
Sep	14	1869	1878	77	382	431	232
Oct	43	236	160	49	374	513	132
Nov	34	70	78	47	314	392	158
Mar	22	29	25	26	261	229	138
May	23	461	1050	114	587	653	237
Jul	23	2743	2344	426	851	802	275
Sep	50	1128	700	1113	198	198	60
Nov	22	45	40	26	601	712	253

TABLE XXI

TOTAL ZINC IN THE SURFACE AND BOTTOM WATER AND SORBED IN THE SEDIMENTS OF THREE STATIONS IN HAM'S LAKE IN 1978-1979

Date	Surface ($\mu g\ \ell^{-1}$)	Bottom Water ($\mu g\ \ell^{-1}$)			Sediments ($\mu g\ g^{-1}$)		
		HS	HP	HC	HS	HP	HC
Mar	14	15	35	18	0.7	0.6	0.5
Apr	14	21	9	28	1.1	2.8	0.5
May	19	17	20	10	0.7	0.7	0.5
Jun	25	26	25	32	0.9	1.0	0.7
Jul	5	20	7	8	0.8	0.8	0.7
Aug	27	18	25	18	0.8	2.4	1.2
Sep	9	9	3	1	1.0	0.7	0.8
Oct	5	6	4	6	0.5	0.8	0.3
Nov	10	11	9	9	0.7	1.2	0.8
Mar	7	10	8	9	0.5	0.6	0.5
May	11	15	20	10	1.1	0.7	0.5
Jul	7	14	8	8	0.9	0.9	0.5
Sep	9	10	11	7	0.6	0.6	0.4
Nov	10	13	8	9	1.0	0.3	0.7

TABLE XXII

TOTAL ZINC IN THE SURFACE AND BOTTOM WATERS AND SORBED IN THE SEDIMENTS OF THREE STATIONS IN ARBUCKLE LAKE IN 1978-1979

Date	Surface ($\mu g\ \ell^{-1}$)	Bottom Water ($\mu g\ \ell^{-1}$)			Sediments ($\mu g\ g^{-1}$)		
		AC	AP	AA	AC	AP	AA
Mar	24	22	30	24	1.05	1.12	1.07
Apr	29	25	15	18	0.78	0.69	0.69
Jun	10	12	11	19	1.94	0.72	1.02
Jul	11	13	11	11	0.86	0.86	0.88
Aug	12	13	18	16	1.65	0.81	1.02
Sep	4	3	1	8	0.73	0.59	0.61
Oct	12	18	20	8	0.50	0.51	0.53
Nov	13	2	3	6	1.10	1.27	1.58
Mar	9	7	9	5	1.36	0.82	0.89
May	4	0	0	0	0.81	1.17	1.03
Jul	8	0	9	0	0.71	0.89	0.83
Sep	33	6	3	7	0.71	0.47	0.62
Nov	28	28	17	22	0.75	0.75	0.81

VITA 2

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