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Since McKee and Coker's zooplankton survey in 1940, the lakes and reservoirs of piedmont North Carolina have matured ecologically with the introduction of the size-selective vertebrate predator threadfin shad, the invertebrate predator Leptodora, and two additional Diaptomus species. Now there are four common Diaptomus species, D. birgei, D. reighardi, D. pallidus, and D. mississippiensis, and several species are commonly found coexisting in the same lake.

The life cycle and feeding habits of the threadfin shad are such that they feed heavily on zooplankton in the summer and fall. During the winter and spring threadfin shad's feeding is diminished due to the cold waters which often kill it or at least strongly curtail its feeding activity.

Zooplankton collections were taken every six weeks for a year from eleven lakes of the three major river drainages in piedmont North Carolina: the Catawba, Yadkin, and Haw-Cape Fear. Samples were taken from deep (>10 m), intermediate (7 m), shallow (3.5 m), and occasionally very shallow (1 m) stations in each lake. Adult diaptomid copepods were separated by species and counted. The total numbers of Diaptomus and the percentages of the different Diaptomus species were determined from each area of the lake.

4 The lakes where threadfin shad were not present had high numbers of diaptomid copepods during the entire year. The lakes in piedmont North Carolina with shad showed definite seasonal changes in the total numbers of diaptomid copepods reflecting the threadfin shad predation pressure.

Diaptomus numbers were diminished in the summer and fall. First the shallows were depopulated of Diaptomus, then the intermediate waters were either depopulated or reduced in diaptomid copepod numbers. The deepest areas showed population minima at this time. The deep waters in all the lakes with threadfin shad maintained Diaptomus populations throughout the year, especially during the summer and fall months when threadfin shad predation pressure was greatest. With the threadfin shad remaining in the epilimnion during the summer, the dark, cool, deep waters afforded a refuge for survival of diaptomid copepods and other zooplankters. During the winter and spring, when predation pressure lessened, the diaptomid copepods increased in all areas of the lakes. Diaptomid copepods first reentered the intermediate waters and continued into the shallow waters.

In shallow, intermediate, and deep waters of most of the lakes sampled, where vertebrate predation pressure was high and the numbers of diaptomid copepods were low, the percentage of small diaptomid copepods increased. Where predation pressure was less and the numbers of diaptomid copepods were high, the percentage of large diaptomid copepods increased.

THE EFFECTS OF THREADFIN SHAD, DOROSOMA PETENENSE,
ON DIAPTOMUS IN PIEDMONT NORTH CAROLINA LAKES

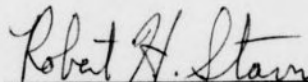
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Richard Allen Beavers

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Approved by



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INTRODUCTION

Ecological succession is the orderly process of community development caused by modification of the physical or biological environment. It is now felt that succession culminates in a stabilized ecosystem (Odum 1969). There are many trends in ecological succession, two of which are species diversity and species equitability. In a young community there tends to be fewer species at a given trophic level. As the community matures there tends to be more species at a given trophic level. Young communities often have super dominant species at a given trophic level and this may lead to instability if the superdominant species is eliminated. The mature stable community may have several different species of near equal numbers at the given trophic level. This greater species equitability is more stable because if one species is eliminated there are still others to maintain that link of the food chain.

In 1940 McKee and Coker completed a zooplankton survey in North Carolina. Many of the lakes and reservoirs sampled were ecologically young i.e. less than 10 years old (Coker 1938; McKee and Coker 1940). Diaptomus birgei and D. reighardi, the only Diaptomus species found in the piedmont North Carolina waters, never coexisted in the same lake.

Hall, Cooper and Werner (1970) and Wright (1965) have shown that vertebrate predation has an important effect on zooplankton populations. Diaptomid copepods, a major food source for planktivorous fish, can be reduced in size and numbers or completely eliminated by the introduction of vertebrate planktivores (Brooks and Dodson 1965; Wells 1970; Warshaw

1972). In small dimictic lakes (less than 110 ha and maximum depths less than 21 m) the vertebrate planktivores (when present) totally eliminate the large zooplankters leaving only the smaller species (Hrbáček, et al. 1961; Brooks and Dodson 1965). One would therefore not expect to find large diaptomid copepods where vertebrate planktivores are present in small lakes. In large deep dimictic lakes (greater than 110 ha and maximum depths greater than 21 m) the vertebrate planktivores, when present, reduce the numbers and size of the large zooplankters and therefore allow a niche for greater numbers of smaller zooplankters (Wells 1970; Warshaw 1972). Wells did not report any seasonal changes in the size, numbers, and percentage of the large zooplankter populations that were present in the large lakes with vertebrate predators. Size-selective predation is certainly a significant phenomenon in the aquatic environment.

Applegate and Mullan (1969) compared population cycles of Daphnia species of Bull Shoals Reservoir with the feeding habits of the threadfin shad, Dorosoma petenense. It was found that the number of Daphnia reached a maximum during April, May, and June and then quickly decreased to a nadir in August. The sharp decrease in Daphnia numbers was correlated with the development of the young-of-the-year shad and their feeding on zooplankton. Chapman (1970) found that about 70% of the threadfin shad's food is zooplankton. Dorosoma petenense was first introduced into the major lakes of North Carolina in 1961 (Baker 1963).

The purposes of this work are to: (1) determine the species of the diaptomid copepod populations now that the lakes of piedmont North Carolina have become more mature and have had time to approach ecological stability, (2) determine the annual or seasonal effects that Dorosoma

petenense has on diaptomid copepod populations in piedmont North Carolina lakes by comparing lakes with Dorosoma petenense to lakes without it, and (3) describe a mechanism used by Diaptomus populations that allows them to survive heavy predation pressure by threadfin shad.

MATERIAL AND METHODS

Zooplankton samples were taken from 11 lakes throughout piedmont North Carolina from 16 May 1973 through 21 June 1974. Three sampling stations representing deep, intermediate, and shallow portions of a lake were established in six of these lakes. The intermediate waters were about 7 m and the shallow waters were about 3.5 m deep while the deep portions varied from lake to lake. Lake Norman, the largest body of fresh water in North Carolina, has the Marshall Steam Station which is a Duke Power Company electrical generating station. Water from Lake Norman is used to cool the large generators and the heated effluent water is returned to the lake. Two areas of Lake Norman were sampled in the manner noted above; the sampling site at the Marshall Steam Station was called area C. The other sampling site, area B, was at the southeastern branch of Lake Norman where it was felt that the heated effluent would not directly affect the zooplankton populations. Three sampling stations representing intermediate, shallow, and very shallow (about 1 m deep) portions of a lake were established in University Lake and J.R. Taylor Lake. Lakes Sloan and Lindley, being so shallow, had two sampling stations, shallow and very shallow. The lakes were sampled every six weeks with the exceptions of Lakes Jeannette, Sloan, and Lindley which were sampled every three weeks. Lake Badin was sampled only six times due to the unavailability of a boat. A boat was used for positioning in the deep, intermediate, shallow and very shallow sites of the lakes.

Zooplankton were collected with a 24.1 cm diameter Turtox plankton net of 0.210 mm mesh size. A 30.5 cm diameter Wildco-Birge closing net

no. 27 with a single point bridle and 0.202 mm net mesh size was used on Lake Jeannette, Lake Sloan, Lake Lindley, and University Lake in May, 1974. Multiple vertical hauls from different depths at each site were taken with four hauls being made from the bottom-to-surface. When extremely low numbers of organisms were found, only two bottom-to-surface tows were made. Collected organisms were transferred from a glass vial tied in the apex of the plankton net to another glass vial where the organisms were concentrated and a 40% commercial formalin solution was added to make a final solution of 5% formalin.

In the laboratory the adult diaptomid copepods were separated from the total plankton samples of the bottom-to-surface hauls, placed in small vials, and preserved in a 5% formalin solution. After separation, the adult diaptomid copepods were counted and subsamples were withdrawn from each vial to determine the percentages of different species. Diaptomid copepodites were found in most samples but were not included in the results. The diaptomid copepods were identified according to Wilson (1959) and were counted and identified in a Sedgwick-Rafter counting cell with an A-O Cycloptic binocular microscope. When necessary some of the diaptomid copepods were dissected under a microscope and mounted on a slide with a cover slip in an aqueous mounting medium and stained for identification.

No net correction factors were applied to the total numbers of animals collected. Birge (1898) found that his net's correction coefficient varied from 1.81 to 2.04. Because of net mesh clogging, leading pressure waves, and net avoidance, etc., one would probably obtain true values by multiplying the net values by a factor of 2 to 4. By not using

a correction factor all the numbers are relative but still show the population trends.

At each sampling site additional measurements were made. The depth, Secchi disk transparency values, water temperatures at 1 m intervals, and light meter readings at 0.5 m intervals were determined. Following is a brief description of each lake examined. All of the lakes in this study are artificial.

Waters From Which Collections Were Made

Lake James, Burke and McDowell Cos., N.C.: large lake on the Catawba River covering 2,604 ha; completed in 1923; Secchi disk transparency 0.8 to 1.8 m. 6/15/73 through 5/12/74.

Lake Hickory, Alexander, Caldwell and Catawba Cos., N.C.: large lake on the Catawba River covering 1,640 ha; completed in 1928; Secchi disk transparency 0.6 to 1.25 m. 6/8/73 through 5/11/74.

Lake Norman, Catawba, Iredell, Lincoln and Mecklenburg Cos., N.C.: large lake on the Catawba River covering 13,004 ha; completed in 1962; largest lake in N.C.; Secchi disk transparency 0.4 to 1.8 m depending on the location on the lake. 6/8/73 through 5/11/74.

High Rock Lake, Davidson and Rowan Cos., N.C.: large lake on the Yadkin River covering 6,300 ha; completed in 1927; Secchi disk transparency 0.2 to 0.6 m depending on the date. 5/26/73 through 5/10/74.

Badin Lake, Montgomery and Stanley Cos., N.C.: large lake on the Yadkin River covering 2,389 ha; completed in 1928; Secchi disk transparency 0.2 to 0.6 m. 7/15/73 through 6/21/74.

Lake Tillery, Montgomery and Stanley Cos., N.C.: large lake on the Yadkin River covering 2,000 ha; completed in 1928; Secchi disk transparency 0.2 to 0.8 m. 7/15/73 through 5/10/74.

John R. Taylor Lake, Guilford Co., N.C.: small lake draining through the Haw River into the Cape Fear River, covering 7.2 ha; completed in 1951; Secchi disk transparency 0.3 to 2.5 m depending on the rainfall. 6/5/73 through 5/12/74.

Sloan Lake, Guilford Co., N.C.: small lake draining through the Haw River into the Cape Fear River, covering 2.4 ha; completed in 1933; Secchi disk transparency 0.1 to 1.0 m depending on the rainfall. 6/12/73 through 5/13/74.

Lindley Lake, Guilford Co., N.C.: small lake draining through the Haw River into the Cape Fear River, covering 2.4 ha; completed in 1933; Secchi disk transparency 0.1 to 1.0 m depending on the rainfall. 6/12/73 through 5/13/74.

Lake Jeannette, Guilford Co., N.C.: lake draining through the Haw River into the Cape Fear River, covering 115 ha; completed in 1941; Secchi disk transparency 0.5 to 2.0 m depending on the rainfall. Many dates in 1972 through 5/13/74.

University Lake, Orange Co., N.C.: lake in the Cape Fear drainage covering about 104 ha; completed in 1932; Secchi disk transparency 0.3 to 1.25 m. 5/31/73 through 5/14/74.

RESULTS

Diaptomus Distributions

Four diaptomid copepod species were commonly found in the lakes sampled, D. birgei Marsh 1894, D. reighardi Marsh 1895, D. pallidus Herrick 1879, and D. mississippiensis Marsh 1894. A fifth species D. bogalusensis Wilson and Moore 1953, occurred in one lake on one sampling date. The size range of the most common piedmont North Carolina copepods was: D. birgei 1.23-1.63 mm for males and 1.53-1.84 mm for females; D. pallidus 1.08-1.34 mm for males and 1.19-1.51 mm for females; D. reighardi 1.05-1.20 mm for males and 1.08-1.38 mm for females; D. mississippiensis 0.89-1.15 mm for males and 1.03-1.28 mm for females. These body lengths varied significantly from those reported by Wilson (1959). Coexisting populations of these species were commonly found in lakes of the three major basins that contained the threadfin shad. Table I shows the lakes sampled and the diaptomid copepod species collected in the major drainage basins of the piedmont region of North Carolina. Table II shows lakes sampled by McKee and Coker (1940) and the diaptomid copepod species in the same drainage basins of piedmont North Carolina.

The deep lakes along the Catawba River seem to be stabilized with the co-existence of several diaptomid copepod species. The large D. birgei and the smaller D. pallidus currently inhabit Lake James, while Lake Hickory and Lake Norman support D. birgei, D. pallidus, and D. mississippiensis populations. A small population of D. bogalusensis was

TABLE I Diaptomus species collected in piedmont North Carolina waters in 1973-74. D. birgei=B, D. pallidus=P, D. reighardi=R, D. mississippiensis=M, D. bogalusensis=Bo.

Catawba Drainage	Species
Lake James	B, P
Lake Hickory	B, P, M
Lake Norman	B, P, M, Bo
Yadkin Drainage	Species
High Rock Lake	P, R, M, B
Lake Badin	P, R, M, B
Lake Tillery	P, R, M
Haw-Cape Fear Drainage	Species
*Lake Sloan	R
*Lake Lindley	R
Lake Jeannette	B, R
*J.R. Taylor Lake	P
University Lake	P, R

*No threadfin shad present

TABLE II Diaptomus species collected in piedmont North Carolina waters in 1938 by McKee and Coker (1940). D. birgei=B, D. reighardi=R.

Catawba Drainage	Species
Lake James	B
Oxford Lake (Hickory)	B
Lookout Shoals Lake (just north of Hickory)	B
Mt. Island Lake (just north of Norman)	B
Yadkin Drainage	Species
High Rock Lake	R
Talassee Lake (Badin)	R
Norwood Lake (Tillery)	R
Blewett Falls Lake (just north of Tillery)	R
Haw-Cape Fear Drainage	Species
University Lake	None
Lake Brandt (near Jeannette)	B

in Lake Norman in June, 1973. In 1940 D. birgei was reported as the only diaptomid copepod existing in the separate lakes along the Catawba River. D. pallidus and D. mississippiensis have now emerged as small diaptomid copepod species coexisting with D. birgei.

All the Yadkin River drainage lakes studies had two major coexisting Diaptomus species, D. pallidus and D. mississippiensis. However, late August samples first showed an increase in species in the Yadkin lakes. D. birgei and D. reighardi were coexisting with the forenamed species. Subsequent samples in the Yadkin lakes indicated that D. birgei and D. reighardi were present occasionally in small numbers. D. reighardi has been largely replaced by D. pallidus and D. mississippiensis populations.

The Haw-Cape Fear River drainage contained three different diaptomid copepod species, the large D. birgei and the smaller D. reighardi and D. pallidus. Previous reports (McKee and Coker 1940) show that D. birgei was the only diaptomid copepod found in this drainage. The small lakes Lindley and Sloan which feed into Lake Jeannette had abundant populations of D. reighardi throughout the entire year. The small J.R. Taylor lake maintained an abundant yearlong population of D. pallidus. Populations of D. reighardi and D. pallidus were found coexisting in University Lake which did not support Diaptomus during earlier surveys (McKee and Coker 1940).

Leptodora Distributions

The invertebrate predator Leptodora was commonly found in two of the three piedmont drainages that were sampled. Leptodora was collected

in Lakes Hickory and Norman of the Catawba drainage. High Rock Lake and Lake Tillery of the Yadkin drainage also had Leptodora.

Physical Data

The Secchi disk transparency values were relatively high through the summer until November, 1973. After the November sampling the Secchi disk transparency values were lowest with low readings continuing throughout the winter period (see lake description for Secchi disk transparency values ranges). Most of the lakes of North Carolina had low water levels until heavy rains came to the state in December and restored the water levels to normal. The Secchi disk transparency values showed increases during the May, 1974 sampling. The overall trend was for low Secchi disk transparency values correlating with the increased rainfall in the winter and spring. The rain probably washed mineral and organic matter from the surrounding watershed into the lakes. The Catawba drainage lakes were more transparent than the lakes of the Yadkin drainage. The Secchi disk transparency value range for the sampled lakes in the Catawba drainage was 0.4-1.8 m, while the values from the sampled lakes of the Yadkin drainage was 0.2-0.8 m.

All the lakes studied were warm monomictic lakes. Thermal profiles of all the lakes are in Appendices N-R. Lake James and Lake Hickory of the Catawba drainage were isothermal during the winter with lowest temperatures in January of about 5.5°C. Lake Norman area C, near the Marshall Steam Station, was stratified year round, with the lowest temperature of about 7.5°C at the bottom and 15°C at the surface of the deep site in January. Area B of Lake Norman, about 12 kilometers south of the

Marshall Steam Station, reached a winter low with an isothermal temperature of 7.9°C in January. The two Lake Norman stations had the highest winter temperatures of all the lakes studied.

The Yadkin drainage lakes (High Rock, Badin, and Tillery) were partially stratified in July, August and on up to September. The rest of the year these waters were isothermal with low temperatures of about 6.8°C in January. The water temperatures were warmer as one went south (downstream) from High Rock Lake to Badin and finally to Lake Tillery.

The lakes of the Haw-Cape Fear drainage demonstrated late spring and summer stratification and late fall, winter, and early spring isothermal profiles. The four lakes in Guilford County had January and February low temperatures of between 5°C and 6°C and University Lake in Orange County to the east had a February low of about 6.7°C .

Seasonal Changes in Diaptomus Populations

The following is a drainage by drainage and lake by lake presentation of the seasonal cycle of the Diaptomus populations with graphs showing the total numbers contained in bottom-to-top hauls from all the stations of each lake. There are also graphs showing the percentage of each Diaptomus species from each location of each lake. If less than 20 animals were collected from a location on a given date, then no percentage points were plotted.

Catawba River Drainage

Diaptomus populations were absent in the shallow waters from July through mid October except in Lake Norman areas B and C where small

numbers of Diaptomus were collected in mid October (Fig. 1); area C of Lake Norman continued with an early Diaptomus increase. The intermediate waters of Lake James and Lake Norman C were void of Diaptomus in early September while Lake Norman area B and C had early September minima and Lake Hickory had an October minimum. The deep waters of all the lakes in this drainage had an early September or October minimum. The Diaptomus populations were at their highest from January through May with general increases in numbers through this period in all depths of each lake with the exception of Lake Hickory. Lake Hickory had a January high in the shallow and intermediate waters followed by declines in the Diaptomus populations during the spring. The percentage occurrences and dominance relations of the different Diaptomus species were as follows:

Lake James

Shallow: Diaptomus numbers were too low for reliable percentages from July until early January (Fig. 5). D. pallidus emerged as the dominant species in early January and March. D. birgei dominated for a short time in February and then in May.

Intermediate: Diaptomus numbers were too low for reliable percentages from mid July until mid November. D. pallidus was the dominant species in early July and from mid November until February at which time D. birgei became dominant and remained as such until May.

Deep: D. birgei was dominant from July until mid November when it was about equal with D. pallidus. D. pallidus was the dominant Diaptomus species from December until April and D. birgei was dominant in May.

Lake Hickory

Shallow: Diaptomus numbers were too low for reliable percentages from July through early January and again from late January through May (Fig. 5). D. pallidus was the dominant species during January.

Intermediate: Diaptomus numbers were too low for reliable percentages from early September until early January and from mid January until April. In July D. pallidus dominated followed by D. mississippiensis in August and September and D. pallidus became the dominant Diaptomus in early January. In May D. pallidus and D. birgei were about equal in numbers.

Deep: D. pallidus was dominant in July and August; D. mississippiensis became dominant in September. In October D. pallidus became dominant until mid February when D. birgei became dominant until May.

Lake Norman B

Shallow: Diaptomus numbers were too low for reliable percentages from July until early January (Fig. 5). D. mississippiensis dominated in January followed by D. pallidus which dominated from February through mid March. In late March D. mississippiensis was again dominant with D. birgei making a strong showing in May.

Intermediate: Diaptomus numbers were too low for reliable percentages from August until mid October. In July D. mississippiensis was dominant. D. pallidus composed 100% of the Diaptomus population in October and from January through May

D. mississippiensis was once again the dominant species.

Deep: D. mississippiensis was the dominant Diaptomus species during the entire year.

Lake Norman C

Shallow: The numbers of Diaptomus between July and mid November were too low for reliable species percentages (Fig. 5). In mid November D. mississippiensis became the dominant Diaptomus species until January when it became about equal with D. pallidus. D. birgei dominated in February. In March through April D. mississippiensis was the dominant species and by May D. mississippiensis and D. birgei were equal in number.

Intermediate: D. birgei was the dominant Diaptomus species in July and D. mississippiensis became dominant in late August through mid December. D. pallidus became dominant from mid December through February. From March through May D. mississippiensis was dominant.

Deep: D. birgei was dominant in July. D. mississippiensis became dominant in late August and remained such until mid December at which time D. pallidus became dominant. D. pallidus remained dominant until D. birgei became dominant in mid February and remained such until mid April. D. mississippiensis was dominant from mid April until May.

Yadkin River Drainage

The shallow waters of the lakes in this drainage were void of Diaptomus from July through October and the shallows of High Rock Lake

remained depopulated until November (Fig. 2). The intermediate waters were depopulated of Diaptomus during the same periods from July through August in Lake Tillery, through October in Lake Badin, and through November in High Rock Lake. The deep waters of these lakes had a late August minimum except for High Rock Lake where there was a November minimum. The percentage occurrences and dominance relations of the different Diaptomus species were as follows:

High Rock Lake

Shallow and intermediate: The numbers of Diaptomus were too low for reliable percentages during the entire year (Fig. 6).

Deep: D. pallidus was dominant all year.

Badin Lake

Shallow: The only time of the year that sufficient numbers of Diaptomus were detected for estimating reliable percentages was in early January when D. mississippiensis was the dominant species (Fig. 6).

Intermediate: Diaptomus numbers were too low for reliable percentages all year.

Deep: D. reighardi was the dominant species for July and August, D. mississippiensis was the dominant species in October and January. D. mississippiensis was slightly greater than D. pallidus in February and June.

Lake Tillery

Shallow: Diaptomus numbers were too low for reliable percentages all year (Fig. 6).

Intermediate: The only times of the year that the Diaptomus numbers were high enough for reliable percentages were in November when D. mississippiensis dominated and from April until May when D. pallidus dominated.

Deep: D. mississippiensis dominated in July and from October to November. From February through April D. pallidus was dominant and in May D. mississippiensis was dominant.

Haw-Cape Fear Drainage

Two lakes (Jeannette and University) had threadfin shad while three lakes (Lindley, Sloan, and Taylor) did not. The lakes without shad had high numbers of Diaptomus at every sample site year round (Fig. 4). Only a few diaptomid copepods were collected from the intermediate waters of J.R. Taylor Lake in February due to heavy rains that probably washed out animals near the drain. Of the two lakes with threadfin shad, Lake Jeannette's Diaptomus populations fluctuated in a manner similar to Diaptomus populations of other shad lakes of piedmont North Carolina (Fig. 3). The shallow waters of Lake Jeannette were depopulated of Diaptomus from July through November. The intermediate waters were depopulated from July through mid September while the deep waters were never depopulated but had a September minimum. The Diaptomus populations of the shallow waters peaked in March while the populations in the intermediate and deep waters peaked in May. The Diaptomus populations in University Lake, which had threadfin shad, unexpectedly showed a resemblance to the fluctuations of populations in shad-free lakes (Fig. 3). All sample sites had high numbers of Diaptomus year round except the very

shallow site in July when there were only $18.5/m^3$. The very shallow and shallow waters showed high concentrations of the colonial gelatin-coated rotifer Conochilus in September, the time of low Diaptomus numbers in all the lakes with shad. In September, the very shallow waters had extremely high numbers of Diaptomus. The intermediate waters in September had no Conchilus and the numbers of Diaptomus were at their lowest concentration. The percentage occurrences and dominance relations of the different Diaptomus species were as follows:

Lake Jeannette

Shallow: Diaptomus numbers were too low for reliable percentages from July through early April and from late April until June (Fig. 7). D. reighardi was the dominant species in early April.

Intermediate: When Diaptomus numbers were high enough for reliable percentages from January through May, D. reighardi dominated. D. birgei was present in small numbers during January and February.

Deep: Diaptomus numbers were too low for reliable percentages from July through early January. D. reighardi dominated from January through May. D. birgei was present in low numbers during February.

University Lake

Very Shallow and Shallow: Diaptomus numbers were too low for reliable percentages from July through early September (Fig. 7). D. pallidus was dominant from early September to June. The shallow station was not sampled in July.

Intermediate: D. reighardi was dominant in July and D. pallidus dominated from August until May.



Fig. 1. Seasonal variation in Diaptomus numbers at the three sample sites of the Catawba drainage lakes. Points below the graph represent Diaptomus depopulation. Shallow = S; Intermediate = I; Deep = D.

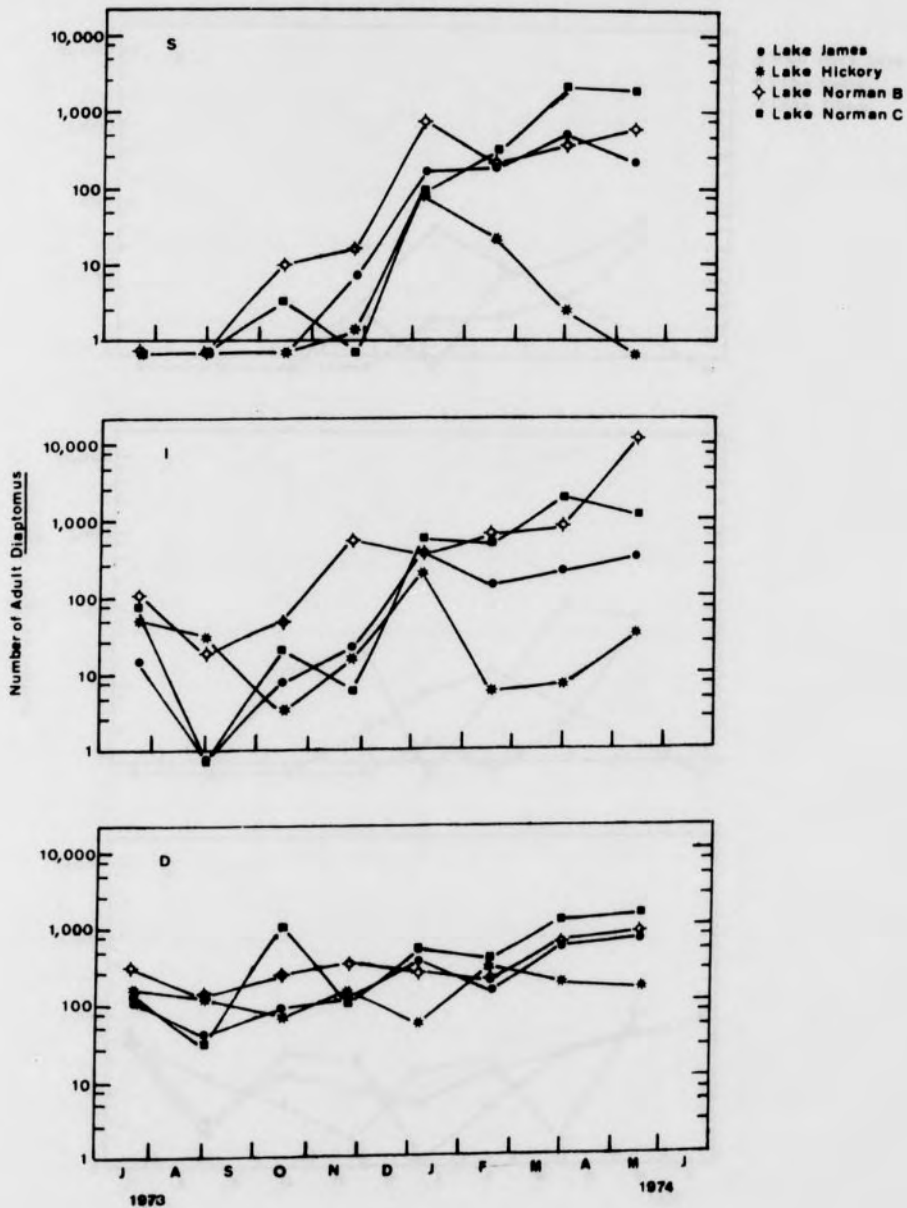


Fig. 3. Seasonal variation in *Diaptomus* numbers at the sample sites of the Haw-Cape Fear drainage lakes with shad. Points below the graph represent *Diaptomus* depopulation. Very Shallow = VS, Shallow = S, Intermediate = I, Deep = D.

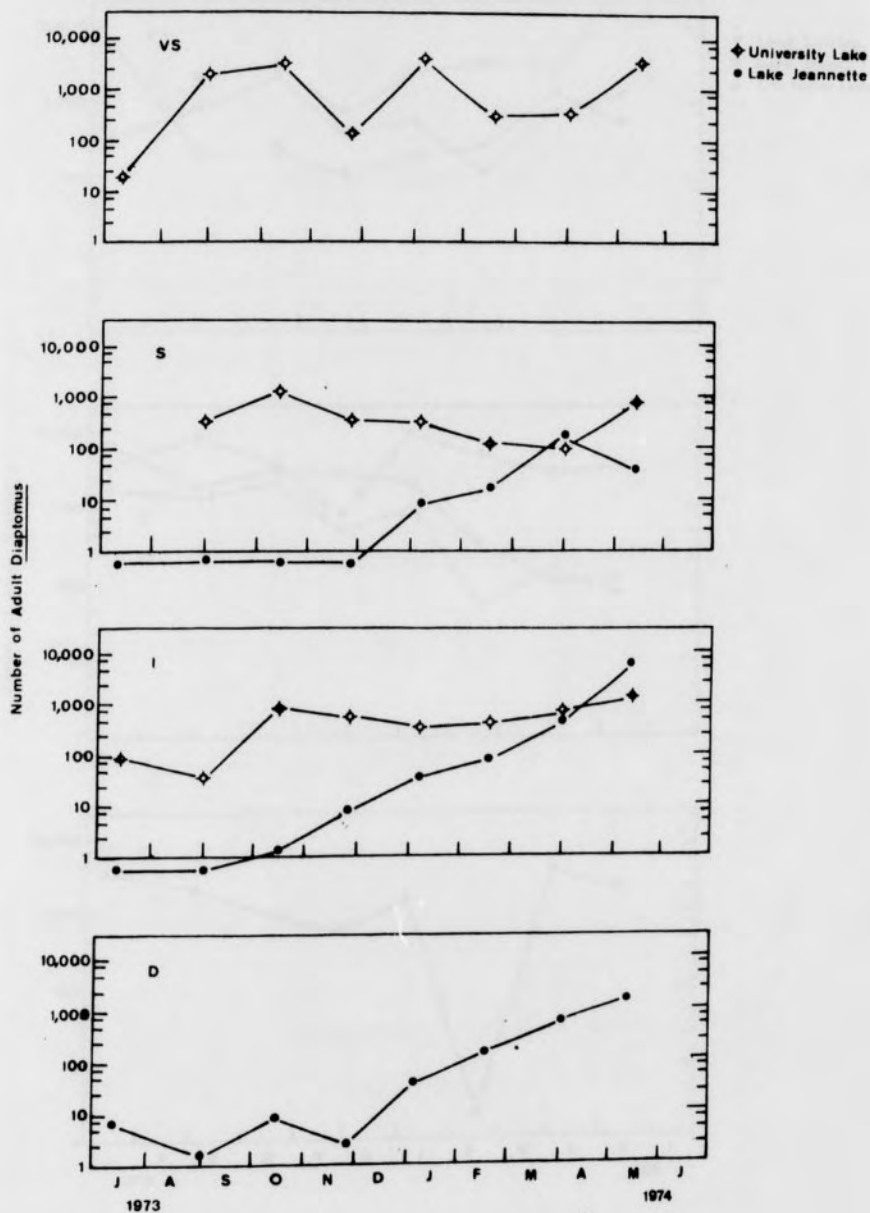
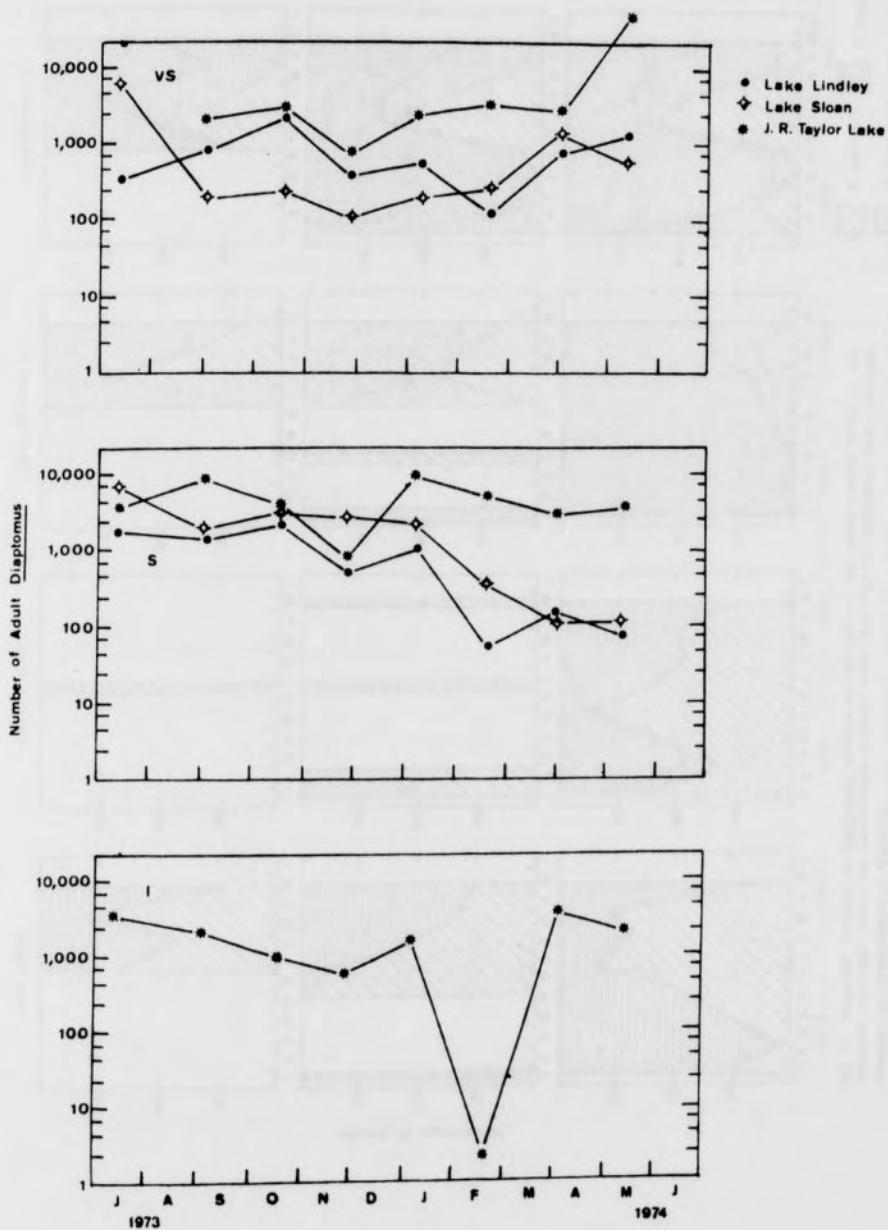


Fig. 4. Seasonal variation in *Diaptomus* numbers at the sample sites of the shad-free lakes of the Haw-Cape Fear drainage. Very Shallow=VS, Shallow=S, Intermediate=I.



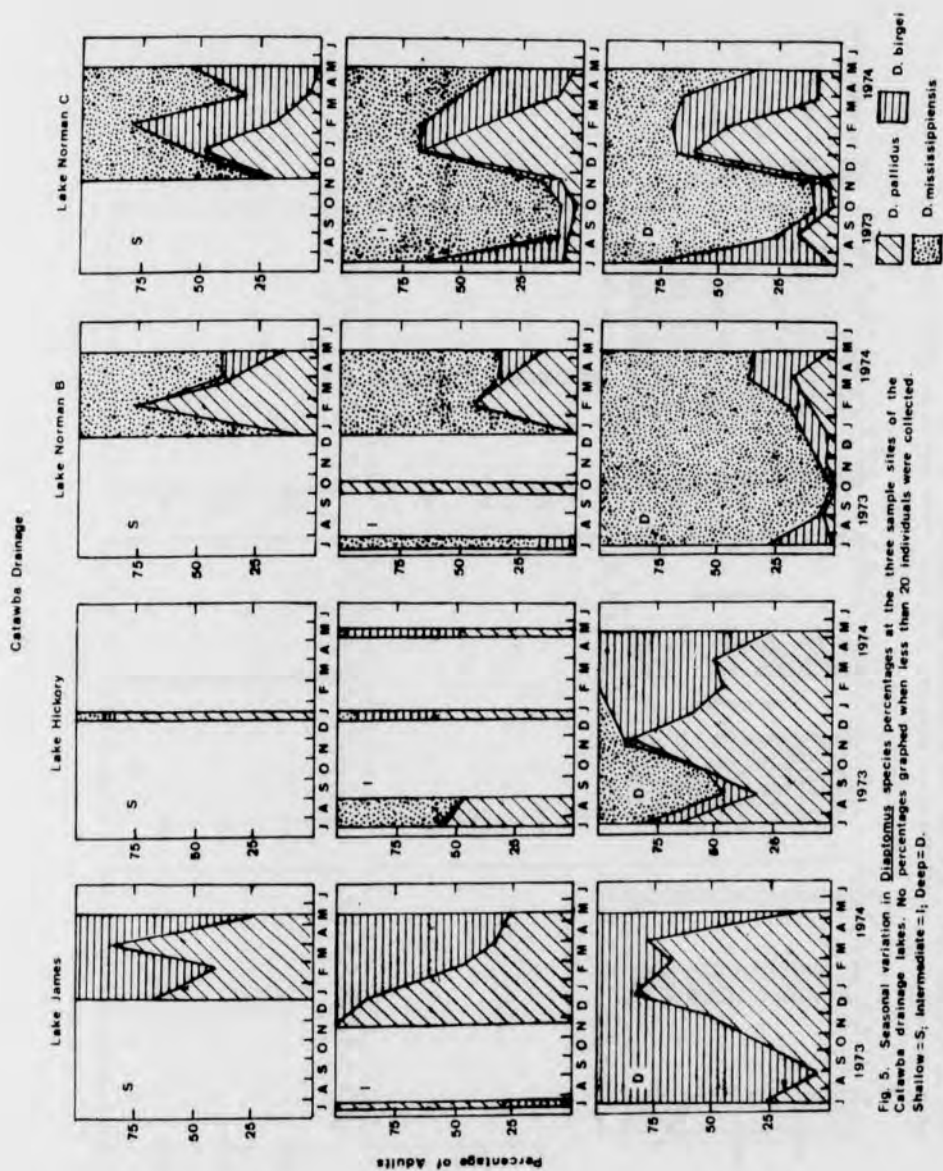


Fig. 5. Seasonal variation in *Diablogmus* species percentages at the three sample sites of the Catawba drainage lakes. No percentages graphed when less than 20 individuals were collected.

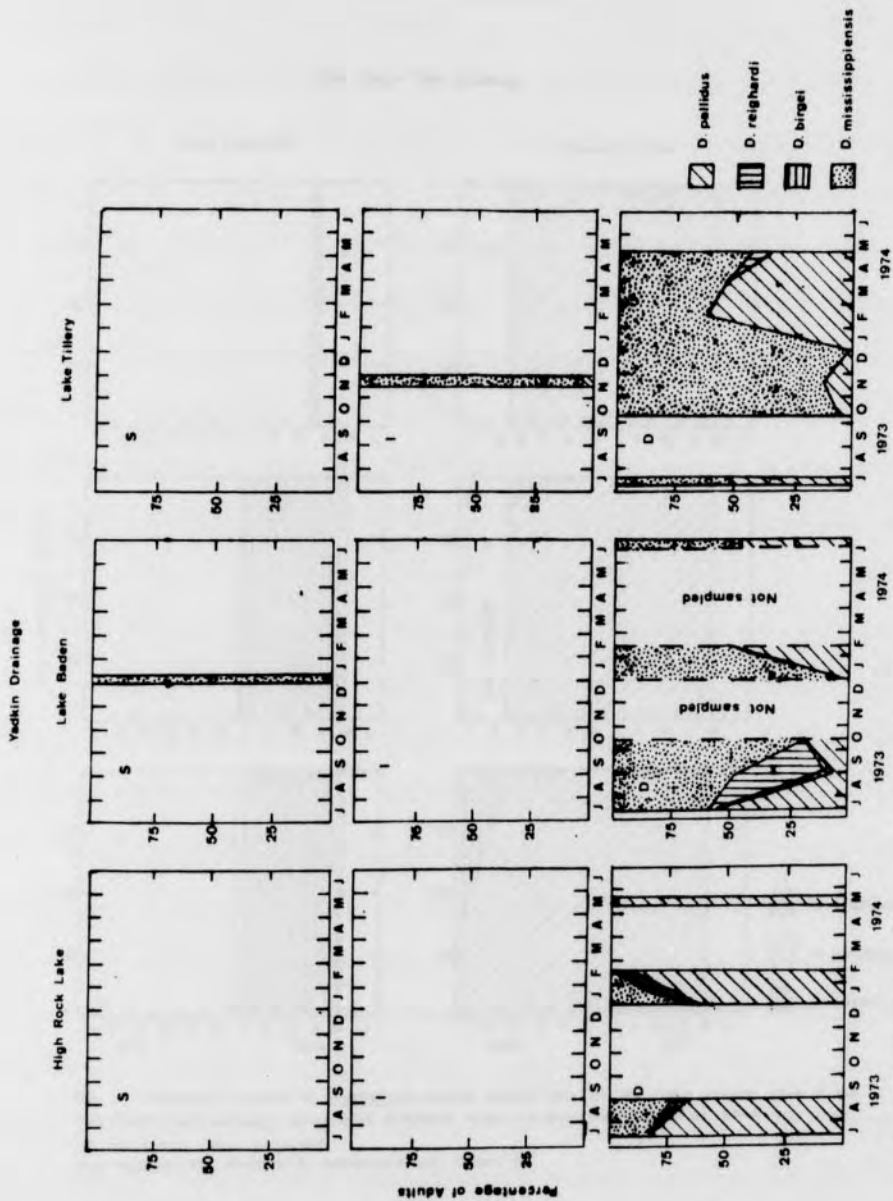


Fig. 6. Seasonal variation in *Diptomus* species percentages at the three sample sites of the Yadkin drainage lakes. No percentages graphed when less than 20 individuals were collected. Shallow = S; Intermediate = I; Deep = D.

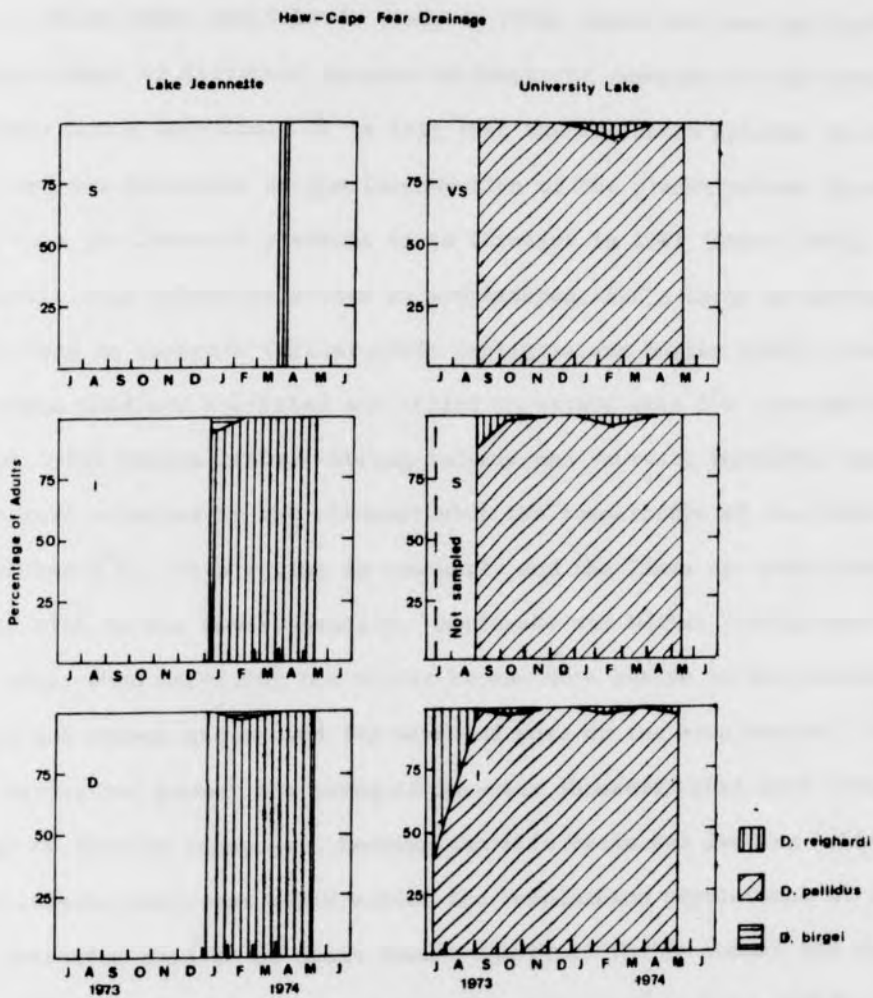


Fig. 7. Seasonal variation in *Diaptomus* species percentages at the three sample sites of the Haw-Cape Fear drainage lakes with threadfin shad. No percentages graphed when less than 20 individuals were collected.
 Very shallow = VS, Shallow = S, Intermediate = I, Deep = D.

DISCUSSION

Since McKee and Coker's study in 1938, there has been an increase in the number of different species of diaptomid copepods in the lakes of piedmont North Carolina. It is felt that the increased species diversity has been due primarily to the introduction of the planktivorous threadfin shad into the lakes of piedmont North Carolina in 1961 (Baker 1963). Threadfin shad selectively feed on zooplankton, and a large proportion of their food is copepods (Miller 1967; Applegate and Mullan 1969). Also, threadfin shad are inhibited and killed in waters near 5°C (Parsons and Kimsey 1954; Strawn 1965). During January and February threadfin shad kills were observed in the piedmont when the temperature of the water approached 5°C. This region is southerly and the lakes are warm monomictic with no ice cover, usually. Applegate and Mullan (1965) reported that adult shad surviving the winter became more active in the warming spring and summer waters and fed more and more on the zooplankton. In late spring and summer the young-of-the-year threadfin shad were large enough to feed on copepods. Knowing the life cycle and feeding habits of the threadfin shad, one would expect the zooplankton populations of lakes with threadfin shad to be their lowest densities in the summer and fall and at their highest densities during the winter and spring. Lakes without threadfin shad should not show as dramatic a change in total numbers of Diaptomus as those lakes with threadfin shad. Recognizing the size-selective nature of the predation by threadfin shad, one would expect that in the spring and summer the largest diaptomid copepods would be

reduced or eliminated by heavy predation pressure and the smaller diaptomid copepods would become dominant. In the late fall and winter this trend should reverse itself as predation pressure slackens. When vertebrate predation is reduced, the more efficient large Diaptomus species should outcompete the smaller less efficient Diaptomus species (Brooks and Dodson 1965).

Catawba Drainage

The lakes of this drainage had no diaptomid copepods in the shallows and declining numbers in the intermediate waters during the summer and early fall (Fig. 1). During this period the smaller species were dominant in the intermediate waters, while the shallow waters had either very few or no Diaptomus (Fig. 5). Also at this time the deep waters had a depression in the total numbers of Diaptomus; however, there was always a viable Diaptomus population. The smaller diaptomid copepods were also dominant in the deep waters. These observations can be explained as a consequence of heavy vertebrate predation pressure. Throughout late fall and winter when the waters became cooler and cooler and the predation pressure lessened, the numbers of Diaptomus increased in all areas of every lake. This increase continued generally into the spring season. When the numbers of Diaptomus increased in the intermediate waters and the populations were then reestablished in the shallow waters in late fall, the percentages of the smaller species increased or remained high. By late spring the larger species became dominant or were approaching this condition. Through late fall, winter, and spring the deep waters had a general population increase which was accompanied by a trend of increasing

percentages of larger species which were usually dominant by spring. This appears to be a consequence of lessened predation pressure and the greater competitive ability of the larger zooplankton species. Lake James and Lake Hickory showed decreased numbers of Diaptomus in the shallow waters in late spring, indicating the beginning of increased vertebrate predation pressure.

The deep waters of Lake James and Lake Norman B provided the only exceptions to the above observations. D. mississippiensis, the smallest Diaptomus species in piedmont North Carolina, was the dominant species year round in the deep waters of Lake Norman B (Fig. 5). During the summer and fall when vertebrate predation pressure presumably was highest, the diaptomid copepods in Lake Norman B were fewer than in Lake Norman C. During the winter when predation pressure was lessened, the number of diaptomid copepods was larger in area B than in area C. Adair and DeMont (1971) reported that during the cold months of winter, the populations of threadfin shad were greatest in the Marshall Steam Station area (Lake Norman C) where the waters were warm enough for survival. The Marshall Steam Station effluent probably stimulated larger populations of threadfin shad in Lake Norman than there are in the Catawba drainage lakes without heated effluents. During the warm summer and fall months, the threadfin shad migrated out of the Marshall Steam Station effluent area. Thus in the areas of Lake Norman where the numbers of Diaptomus were relatively low there were greater numbers of threadfin shad. The thermal load from the Marshall Steam Station caused Lake

Norman B to have the highest deep water temperature of any lake studied -also contributing to high shad survivorship and relatively higher winter predation of these shad populations. Apparently, sustained heavy predation in Lake Norman B, due to high survivorship of shad at the Marshall Steam Station in winter and the high deep water temperatures at area B, kept the larger Diaptomus species suppressed so that D. mississippiensis was the dominant species in the deep waters all year round.

The deep waters of Lake James had the large Diaptomus species dominant during the summer and early fall, a time of heavy shad predation, and the smaller Diaptomus dominant during the late fall and winter, a time of light shad predation (Fig. 5). This occurrence was the only one of its kind in all the lakes sampled. During the summer and early fall the thermocline, at a depth of about 8 m, was more shallow and the hypolimnion was colder than all other large lakes sampled. Threadfin shad do not go below the thermocline in the summer (Houser and Dunn 1967). The species of the Diaptomus population found in the September sampling from the deep site of Lake James varied as to the depth of the sample. In the 8 m-to-surface hauls D. pallidus was found exclusively. In the bottom-to-surface hauls 95% of the Diaptomus population was D. birgei. One may assume that the D. pallidus population was largely above the thermocline and the D. birgei population was below it. The Diaptomus population below the thermocline was relatively free of threadfin shad predation compared to the Diaptomus population above the thermocline. D. birgei was dominant during the summer in the deep water of Lake James because of the unusually shallow thermocline which afforded it a refuge from shad predation. The other large lakes of piedmont North Carolina

had deeper thermoclines during the summer and early fall and had less accessible refuges from shad predation. The shallow and intermediate waters of Lake James without the thermal barrier during the summer and early fall had the smaller D. pallidus as the dominant Diaptomus species. During the winter Lake James' temperature was colder early in November, while other lakes of piedmont North Carolina were still mild. The January temperature of Lake James was colder and remained colder into early spring than waters of all the other lakes of piedmont North Carolina. These severe and sustained cold temperatures during the winter may have inhibited the D. birgei population (such as slowing its rate of egg production) in the deep waters of Lake James, for it was not until middle to late spring, when waters warmed, that D. birgei once again became the dominant Diaptomus species.

Yadkin Drainage

The lakes of this drainage showed not only summer to early or late fall depopulated shallow waters, but also depopulated intermediate waters for comparable periods (Fig. 2). The duration of depopulated shallow and intermediate waters was generally longer in the Yadkin drainage lakes than in the lakes of the other two drainages. In addition, there were not enough Diaptomus in the shallow and intermediate waters to reliably determine dominance relations at this time (Fig. 6). The deep waters maintained a diaptomid copepod contingent throughout the summer and fall, a period of population minima generally. Even in the deep areas of two Yadkin drainage lakes, the total numbers of Diaptomus were too low to reliably determine dominance relations in the late summer and early fall. The general trend

for this period is for the largest piedmont Diaptomus to be absent or at very low numbers with the smaller species being dominant. These phenomena are also explicable as a consequence of increased predation pressure. The Diaptomus number increased in the intermediate and then in the shallow waters as the winter months passed. The spring months showed a general increase in Diaptomus in all areas of the two lakes sampled. Most of the samples collected in the shallow and intermediate waters had too few diaptomid copepods to graph the species percentages with reliability. Where the numbers were high enough to graph, the smallest Diaptomus species was dominant during the late fall and winter while the larger Diaptomus species increased in the spring until it was dominant in May. In the deep waters the Diaptomus numbers showed a general increase from winter to spring. This is also explicable as a result of lessened predation pressure and greater competitive ability of larger Diaptomus species.

Haw-Cape Fear Drainage

Lake Jeannette had depopulated shallow and intermediate waters during the summer and early fall while the Diaptomus numbers in the deep waters were very low (Fig. 3). This is interpreted as indicating heavy vertebrate predation pressure of young shad and adult shad. During the late fall, diaptomid copepods reentered the intermediate waters and in January they were reestablished in the shallow waters. D. birgei, the largest Diaptomus, never reestablished in significant numbers in the spring (Fig. 7). Low numbers of D. birgei were collected in the intermediate and deep waters during the winter and spring while D. reighardi maintained its dominance from the summer of 1973 until May of 1974. The

winter was relatively mild and the shad predation was probably heavier than normal during the winter and spring of this year.

During July, the month of heaviest predation in University Lake, there was a population minimum at the very shallow station, and a minimum at the intermediate depth which continued through the summer (Fig. 3). The shallow depths were not sampled in July. The numbers at the very shallow depths were too low to graph species percentages reliably while D. reighardi and D. pallidus were at nearly equal numbers in the intermediate waters (Fig. 7). During the late summer and fall months of low Diaptomus numbers in other lakes with threadfin shad in the piedmont, University Lake had high numbers of diaptomid copepods in the very shallow and shallow waters with the typical fall depression in the intermediate waters. The colonial gelatin-coated rotifer Conochilus was dense in the very shallow and shallow waters and was not present in the intermediate waters at this time. Since the plankton nets were readily clogged with Conochilus, it appears that this colonial rotifer inhibited the feeding process of threadfin shad and, therefore, the area it inhabited served as a refuge in which Diaptomus could thrive without being preyed upon. This was the only lake studied that had such large populations of Conochilus. The predation pressure was thus heaviest in the intermediate waters where the slightly smaller D. reighardi could maintain populations with D. pallidus. During the winter and spring, University Lake maintained high numbers of Diaptomus throughout the lake with D. pallidus clearly dominant. These phenomena can be seen as a result of lessened predation pressure.

The lakes in the Haw-Cape Fear drainage without shad, Lake Lindley, Lake Sloan, and J.R. Taylor Lake, had comparatively high numbers of Diaptomus

through the year in all areas of the lakes (Fig. 4). One exception was noted in the intermediate area of J.R. Taylor's Lake in February due to heavy rains that probably washed out animals near the drain. In general, these lakes were shallower than lakes with shad but had thermal and optical properties that were comparable with deeper lakes (Lake list, Appendices N, O, and P). It certainly appears that the only significant variable is the presence of absence of shad.

General Conclusions

Most of the lakes with and without shad in piedmont North Carolina had high numbers of Diaptomus in late winter and spring, a time of lessened vertebrate predation. The summer and fall was a time of increased vertebrate predation. Generally speaking, with the exception of University Lake with its Conochilus, the lakes with threadfin shad had either no adult diaptomid copepods or reduced numbers of them at all sample sites throughout the summer and fall, while lakes without shad maintained large numbers of copepods. At the height of threadfin shad predation in September there were 11,722 diaptomid copepods per m^2 at the intermediate site of J.R. Taylor Lake (Appendix K). On the comparable date and sample site in Lake Norman B, Lake Tillery, and Lake Jeannette, the lakes with the lowest numbers of Diaptomus in each drainage (Appendices B, G, and J), there were no diaptomid copepods. To make the comparison more striking, on the comparable date in Lake Hickory, the shad lake with the greatest number of Diaptomus (Appendix B), there were only 224 diaptomid copepods per m^2 at the intermediate site and 3,954 diaptomid copepods per m^2 at the deep site of 31 meters depth.

Vertebrate predation pressure seems to vary from lake to lake and from drainage to drainage, due most likely to individual differences in the size of the shad population in each lake. Predation pressure was apparently most intense in the lakes of the Yadkin drainage. This can be seen by the fact that the deep waters of the Yadkin drainage lakes had lower numbers of Diaptomus year round than did the shad lakes of the Catawba drainage and quite often lower numbers than the comparable lakes of the Haw-Cape Fear drainage (Figs. 1, 2, and 3). In addition the shallow and intermediate waters of the Yadkin drainage lakes were depopulated of Diaptomus during the summer until early or late fall while shallow waters of the Catawba drainage lakes were depopulated of Diaptomus during summer or early fall. The intermediate waters of only two Catawba drainage lakes were depopulated on one date in the summer. Only one lake in the Haw-Cape Fear drainage, Lake Jeannette, had depopulated shallow and intermediate waters during the summer. By the fall diaptomid copepods had returned to the shallow and intermediate waters of Lake Jeannette. Although the lakes of the Yadkin drainage generally had lower numbers of diaptomid copepods than comparable samples of the Catawba drainage lakes in all areas of these lakes, the Secchi disk transparency values of the Yadkin drainage lakes were less than those of the Catawba drainage lakes. The lessened Secchi disk transparency values might be helpful in escaping a visually directed vertebrate predator. This anomaly might be explained by the fact that the Yadkin drainage is polluted and might inhibit the existence of diaptomid copepods. Winston-Salem and the regional Schlitz Brewery empty their processed and unprocessed sewage into the Yadkin River. No town or industry of comparable size empties its sewage into the portion of the

Catawba River that I have studied. If pollution were the inhibiting factor of diaptomid copepods one would expect High Rock Lake to be the most polluted by Winston-Salem. Lakes Badin and Tillery, further down the Yadkin River, would be less polluted and diaptomid copepod populations would be less affected. In truth, the Diaptomus population trends in all three lakes of the Yadkin drainage were identical in the deep areas and similar in the shallows (Fig. 2). Another possible explanation was that there were more threadfin shad in the Yadkin drainage than there were in the Catawba drainage. From the Lake Norman findings we know that where there were more shad, there were fewer diaptomid copepods. I speculate that there were more threadfin shad per hectare in the Yadkin drainage lakes than in the Catawba and Haw-Cape Fear drainage lakes. It was also possible that the Yadkin drainage had an indigenous predator that was not found in the Catawba and Haw-Cape Fear drainages because McKee and Coker did not find D. birgei in the Yadkin drainage in 1938 when threadfin shad were not present in North Carolina.

Knowing that the feeding activity of vertebrate planktivores first lowers the density of the largest zooplankters in the aquatic community (Brooks and Dodson 1965), it is possible to propose the relative occurrence of large zooplankters as an index of vertebrate predation pressure. D. birgei, the largest Diaptomus species of piedmont North Carolina, was primarily found in the Catawba drainage where it was often the dominant species; however it was found in some Yadkin and Haw-Cape Fear drainage lakes in low numbers during certain times of the year. D. birgei was found only in the deep lakes (>10 m deep) of piedmont North Carolina. In the Catawba drainage D. birgei never became dominant in Lake Norman B

because of the heavy and sustained vertebrate predator pressure. In all other Catawba drainage lakes D. birgei tended to be dominant in the spring after a winter increase in numbers; late summer and fall were times in which D. birgei declined and would nearly disappear. These phenomena reflect the periods of lessened and increased vertebrate predation pressure respectively. In the Yadkin drainage D. birgei was found occasionally in very low numbers in only the deep waters of High Rock Lake and Badin Lake. This relative lack of the large Diaptomus of North Carolina was another indicator of greater predation pressure in the Yadkin drainage than occurred in the Catawba drainage lakes. Of the Haw-Cape Fear drainage lakes studied, Lake Jeannette was the only one deep enough to have D. birgei which was found in small numbers in the intermediate and deep waters in January and February. Since Lake Jeannette was the shallowest lake to harbor D. birgei populations, it is probable that a winter with severe temperatures is needed to significantly reduce the threadfin shad population and encourage growth of D. birgei. In addition, this shallow lake is probably not D. birgei's preferred habitat.

D. mississippiensis, the smallest Diaptomus species in piedmont North Carolina, would be another indicator of predation pressure because it would be dominant only when heavy vertebrate predation had eliminated larger more efficient competitors. D. mississippiensis occurred in most of the lakes of the Catawba and Yadkin drainages. Of the two Lake Norman sample areas, area B was subject to more threadfin shad predation during the summer and fall due to the shad migration from the Marshall Steam Station effluent area to cooler areas. The high winter temperatures at area B probably stimulated some shad predatory activity also.

D. mississippiensis was dominant year round in the deep waters of Lake Norman B. In Lakes Badin and Tillery of the Yadkin drainage, D. mississippiensis was the dominant Diaptomus species not only in the summer and fall but also during most of the remainder of the year. The frequent dominance of D. mississippiensis in the Yadkin drainage lakes also helps establish that these lakes are subject to greater vertebrate predation pressure than were the Catawba and Haw-Cape Fear drainage lakes.

In piedmont North Carolina D. pallidus appears to be a superior competitor over D. reighardi. In 1938, before the introduction of thread-fin shad into the lakes of North Carolina, D. reighardi was the only smaller Diaptomus species observed in the piedmont. D. pallidus and D. mississippiensis have replaced D. reighardi as the dominant Diaptomus species in the Yadkin drainage lakes. D. reighardi was found in small numbers in the Yadkin drainage lakes primarily during the periods of heavy predation and when predation pressure slackened D. reighardi was out-competed and no longer present (Fig. 6; Appendix F; 31 Aug. 73). In University Lake of the Haw-Cape Fear drainage, D. pallidus and D. reighardi were found in near equal numbers during the months of heavy predation. When predation pressure subsided and the number of diaptomid copepods increased, the D. pallidus percentage was much greater than D. reighardi which was often at undetectable levels (Fig. 7). Lakes Sloan and Lindley contained only D. reighardi while Lake Jeannette was dominated by D. reighardi. It is felt that the colonization of Diaptomus species is a largely random phenomenon and that a viable population of D. pallidus has not been introduced into these lakes. In summary, where D. pallidus has been introduced it has outcompeted D. reighardi. The only time D. reighardi

was present when they were sympatric was during periods of heavy predation when dominant D. pallidus was being grazed back and therefore leaving a niche for the less efficient D. reighardi.

Brooks and Dodson (1965) showed that in small (maximum <110 ha and max. depth <21 m) dimictic lakes with obligatory vertebrate planktivores the composition of the zooplankton populations changes to one of smaller species less than 1 mm in length. Large zooplankters are reduced in number by predation during the spring and summer and they are unable to recover in the ice covered winter waters due to their greatly reduced feeding and reproductive rates at winter temperatures of 1^o-2^oC (Birge 1898) even though predation pressure has fallen off. In Lake Jeannette and University Lake (max. area <110 ha and max. depth <21 m) there occur the large D. birgei, D. pallidus, and D. reighardi (>1 mm in length) together with threadfin shad. Thus in small warm monomictic lakes large zooplankton species can survive in the presence of obligatory planktivores. I found that warm monomictic lakes with threadfin shad had diaptomid copepod population maxima in the winter and spring and population minima in the summer and fall, indicating that their numbers can increase during winter in warm monomictic lakes which seldom dip below 5^oC in the winter. The accepted seasonal trend for Diaptomus population numbers in dimictic lakes is one of population maxima in late spring and summer and population minima in fall, winter, and early spring (Appendix M), an indication of the inability of large Diaptomus species in dimictic lakes to recover during the winter months from heavy summer predation. In warm monomictic lakes without vertebrate planktivores, diaptomid copepod populations were high year round.

In addition to the thermal survival mechanism postulated above, a survival mechanism based on the vertical migration habit and the maximum depth of a lake can explain the persistence of large diaptomid copepod species during the summer. Houser and Dunn (1967) reported that threadfin shad were only in the epilimnion of the lake they studied during the summer and were not found below the thermocline. The general observed pattern of vertebrate predation in the North Carolina piedmont was that diaptomid copepods were first eliminated in the first 3.5 m (shallow waters) of a lake and then they were eliminated in the next 3.5 m (intermediate waters). The waters below 7 m of a lake showed a decline in the numbers of diaptomid copepods, but there still remained a viable population in the deep portions of the lakes (Fig. 8). My study had shown that viable populations of Diaptomus found refuge in the summer and fall in the deep dark cool portions of lakes where the threadfin shad do not go. Lake James, which had a shallow thermocline and correspondingly shallow epilimnion, supports large populations of D. birgei in the summer while the other deep lakes with thick epilimnia exhibited sharp declines in their D. birgei populations during the summer. As the vertebrate predation pressure eased in the fall the smaller diaptomid copepods in the deep waters reentered the intermediate and then the shallow waters as the upper water layers again became habitable. The large Diaptomus species filed back into the intermediate and shallow waters after the small species, presumably as a function of the easing of predation pressure. Thus, a large Diaptomus species can survive vertebrate predation pressure in the summer if it undergoes a vertical migration cycle that keeps it deep enough during the day so that it is out of the range of a visually directed

Predation Consequences and Diaptomus Survival Mechanism

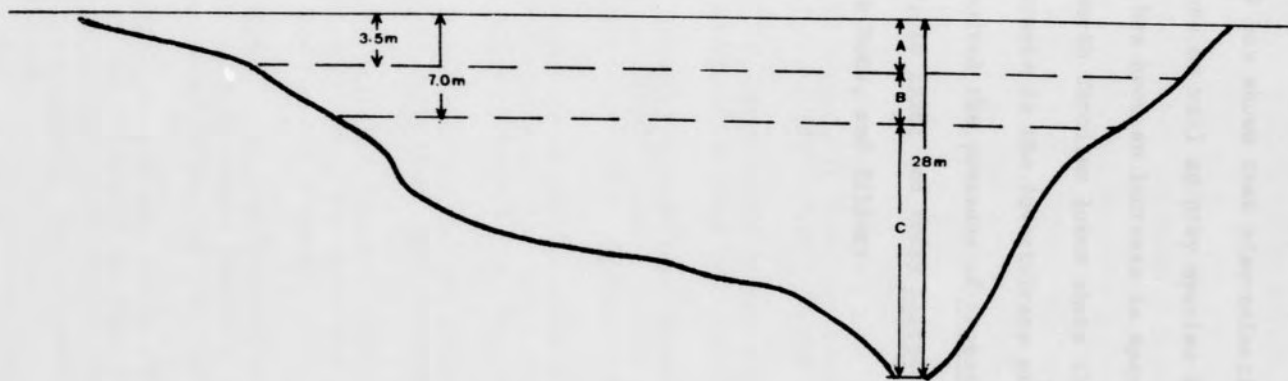


Fig. 8. As spring progresses into summer, various zones of a lake are depopulated of Diaptomus starting from the surface downward. Zone A (at a depth of 3.5m) is depopulated first, then zone B (the next 3.5m) is depopulated. Zone C maintains viable populations of Diaptomus the entire year and may start at a depth of 7m, being greater or lesser depending on the intensity of vertebrate predation pressure. The process reverses in the fall.

predator. It then migrates up to the surface in late afternoon and evening to feed in the food-rich upper layers of a lake.

Dodson (1970) has shown that size-selective predation affects the diversity of predators as well as prey species in freshwater planktonic communities. There has been an increase in species diversity of diaptomid copepod species in North Carolina lakes where threadfin shad exist. There has also been an increase in the invertebrate predator Leptodora. McKee and Coker (1940) reported the presence of Leptodora, only in Phelps Lake in Washington County, in 1938; and today Leptodora is found in Lakes Norman, Hickory, High Rock, and Tillery.

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Appendix A

Lake James Table of Diaptomus numbers and percentages. D. birgei=B,
D. pallidus=P.

DATE	STA.	DEPTH	%B	%P	# CTED	HAULS		#/m ³	#/m ²
						CTED			
21	S	3 m	0	0	0	2	0	0	0
Jul	I	10 m	28	72	25	4	14	140	
73	D	22 m	75	25	436	4	110	2,442	
1	S	3 m	0	0	0	2	0	0	0
Sep	I	7 m	0	0	0	4	0	0	0
73	D	27 m	95	5	213	4	44	1,193	
14	S	3 m	0	0	0	2	0	0	0
Oct	I	7 m	60	40	10	4	8	56	
73	D	27 m	74	26	454	4	96	2,598	
25	S	3 m	0	100	4	4	7	22	
Nov	I	7 m	0	100	26	4	21	146	
73	D	27 m	50	50	597	4	123	3,343	
6	S	4 m	33	67	133	4	185	745	
Jan	I	6.5 m	14	86	537	4	459	3,007	
74	D	28 m	17	83	2,023	4	401	11,329	
17	S	4 m	59	41	128	4	178	717	
Feb	I	7 m	53	47	189	4	150	1,058	
74	D	20 m	32	68	477	4	133	2,671	
31	S	4 m	15	85	92	1	511	2,042	
Mar	I	7 m	68	32	79	1	247	1,754	
74	D	20 m	22	78	625	1	694	13,875	
12	S	3.5 m	74	26	33	1	206	733	
May	I	7 m	73	27	97	1	303	2,153	
74	D	27.5 m	86	14	896	1	723	19,891	

Appendix B

Lake Hickory Table of Diaptomus numbers and percentages. D. birgei=B,
D. pallidus=P, D. mississippiensis=M.

DATE	STA.	DEPTH	%B	%P	%M	# CTED	HAULS CTED	#/m ³	#/m ²
21	S	4 m	0	0	0	0	2	0	0
Jul	I	8 m	2	56	42	82	4	57	459
73	D	22 m	13	66	21	545	4	138	3,052
1	S	4 m	0	0	0	0	2	0	0
Sep	I	6 m	0	47.5	52.5	40	4	37	224
73	D	31 m	13	31	56	706	4	127	3,954
13	S	4 m	0	0	0	0	2	0	0
Oct	I	6 m	0	25	75	4	4	4	22
73	D	26 m	0	55	45	348	4	74	1,949
24	S	4 m	0	100	0	1	4	1	6
Nov	I	6 m	0	67	33	15	4	14	84
73	D	26 m	2	87	11	586	4	125	3,282
5	S	4 m	2	85	13	57	4	79	319
Jan	I	8 m	33	61	6	165	2	229	1,832
74	D	27 m	34	60	6	302	4	62	1,691
17	S	4.5 m	50	50	0	18	4	22	101
Feb	I	7 m	0	100	0	9	4	7	50
74	D	27 m	54	46	0	1,735	4	357	9,716
30	S	4.5 m	0	100	0	2	4	3	11
Mar	I	6.5 m	11	89	0	9	4	7	50
74	D	29 m	50	50	0	219	1	167	4,862
11	S	4.5 m	0	0	0	0	4	0	0
May	I	7.5 m	47	50	3	46	4	34	258
74	D	27 m	76	24	0	172	1	141	3,818

Appendix C

Lake Norman C Table of *Diaptomus* numbers and percentages. *D. birgei*=B,
D. pallidus=P, *D. mississippiensis*=M.

DATE	STA.	DEPTH	%B	%P	%M	# CTED	HAULS CTED	#/m ³	#/m ²
21	S	3 m	0	0	0	0	4	0	0
Jul	I	10 m	59	7	34	259	4	144	1,450
73	D	22 m	78	3	19	1,256	4	317	7,034
1	S	3 m	0	0	0	0	4	0	0
Sep	I	6.5 m	4.5	4.5	91	22	4	19	123
73	D	20 m	8	17	75	456	4	127	2,554
13	S	3 m	0	0	100	3	2	11	33
Oct	I	6.5 m	6	2	92	65	4	56	364
73	D	20 m	9	1	90	1,049	4	291	5,874
24	S	3 m	2	20	78	86	4	159	482
Nov	I	7 m	10	8	82	756	4	600	4,234
73	D	22 m	8	4	88	1,601	4	404	8,966
5	S	3 m	8	48	44	215	2	796	2,387
Jan	I	6.5 m	1	68	31	524	4	448	2,934
74	D	20 m	6	63	31	1,017	4	283	5,695
16	S	3.5 m	59	20.5	20.5	149	4	237	834
Feb	I	7.5 m	27	41	32	885	4	656	4,956
74	D	22 m	24	47	29	737	4	186	4,127
30	S	3.5 m	26	5	69	72	1	450	1,598
Mar	I	7 m	41	10	49	264	1	825	5,861
74	D	22 m	58.3	8.3	33.4	724	1	731	16,073
11	S	3.5 m	52	1	47	206	2	644	2,287
May	I	7 m	32	3	65	447	1	1,397	9,923
74	D	18.5 m	27	8	65	675	1	813	14,985

Appendix D

Lake Norman B Table of Diaptomus numbers and percentages. D. birgei=B,
D. pallidus=P, D. mississippiensis=M.

DATE	STA.	DEPTH	%B	%P	%M	# CTED	HAULS		
							CTED	#/m ³	#/m ²
22	S	4 m	0	0	0	0	2	0	0
Jul	I	10 m	14	3	83	69	2	77	766
73	D	22 m	25	1	74	507	4	128	2,839
1	S	3.5 m	0	0	0	0	2	0	0
Sep	I	6.5 m	0	0	0	0	2	0	0
73	D	22 m	2	5	93	148	4	37	829
13	S	2.5 m	0	0	100	1	2	4	11
Oct	I	6.5 m	0	100	0	27	4	23	151
73	D	22 m	1	0	99	4,139	4	1,045	23,178
24	S	3.5 m	0	0	0	0	2	0	0
Nov	I	7 m	0	12.5	87.5	8	4	6	45
73	D	22 m	3	4	93	440	4	111	2,464
5	S	3.5 m	0	11	89	54	4	86	302
Jan	I	7 m	1	2	97	729	4	579	4,082
74	D	22 m	10	3.5	86.5	2,049	4	517	11,474
16	S	3.5 m	0	78	22	208	4	330	1,165
Feb	I	7 m	0	44	56	729	4	579	4,082
74	D	22 m	7	22	71	1,719	4	434	9,626
30	S	3 m	4	36	60	332	1	2,371	7,370
Mar	I	7 m	3	30	67	625	1	1,953	13,875
74	D	25 m	18	19	63	1,330	1	1,177	29,526
11	S	3 m	25	15	60	312	1	2,229	6,926
May	I	7 m	18	15	67	402	1	1,256	8,924
74	D	25 m	32	3	65	1,668	1	1,463	37,030

Appendix E

High Rock Lake Table of Diaptomus numbers and percentages. D. birgei=B,
D. pallidus=P, D. reighardi=R, D. mississippiensis=M.

DATE	STA.	DEPTH	%B	%P	%R	%M	# CTED	HAULS		#/m ³	#/m ²
								CTED			
15	S	3 m	0	0	0	0	0	2		0	0
Jul	I	7 m	0	0	0	0	0	2		0	0
73	D	11 m	0	81	0	19	103	4		52	579
31	S	3 m	0	0	0	0	0	2		0	0
Aug	I	5.5 m	0	0	0	0	0	2		0	0
73	D	12 m	3	67	3	25	32	4		15	179
12	S	3 m	0	0	0	0	0	2		0	0
Oct	I	5.5 m	0	0	0	0	0	2		0	0
73	D	12 m	0	60	27	13	15	4		7	84
23	S	3 m	0	0	0	0	0	2		0	0
Nov	I	6.5 m	0	0	0	0	0	2		0	0
73	D	9 m	0	75	0	25	4	4		3	22
4	S	4 m	0	0	0	100	1	2		3	11
Jan	I	5.5 m	0	100	0	0	1	4		1	6
74	D	13.5 m	0	64	2	34	50	4		21	280
15	S	3.5 m	0	100	0	0	2	4		3	11
Feb	I	5 m	0	0	0	0	0	2		0	0
74	D	9 m	7	90	3	0	41	4		25	230
29	S	4 m	0	60	20	20	5	4		7	28
Mar	I	7.5 m	0	75	25	0	4	4		3	22
74	D	13 m	0	20	60	20	5	4		2	28
10	S	4.25 m	0	57	14	29	7	1		37	155
May	I	7 m	0	74	16	10	19	1		59	422
74	D	13.5 m	0	98	2	0	51	1		84	1,132

Appendix F

Lake Badin Table of Diaptomus numbers and percentages. D. birgei=B,
D. pallidus=P, D. reighardi=R, D. mississippiensis=M.

DATE	STA.	DEPTH	%B	%P	%R	%M	# CTED	HAULS CTED	#/m ³	#/m ²	
15	S	-----	NOT SAMPLED				-----				
Jul	I	-----	NOT SAMPLED				-----				
73	D	20 m	0	59	0	41	111	2	62	1,232	
31	S	3 m	0	0	0	0	0	2	0	0	
Aug	I	7 m	0	0	0	0	0	2	0	0	
73	D	36 m	3	7	37	53	30	4	5	168	
12	S	3 m	0	0	0	0	0	2	0	0	
Oct	I	7 m	0	0	0	0	0	2	0	0	
73	D	36 m	0	19	0	81	120	4	19	672	
4	S	3.5 m	0	3	0	97	33	4	52	185	
Jan	I	7 m	0	10	0	90	10	4	8	56	
74	D	36 m	0	2	0	98	46	4	7	258	
15	S	4 m	0	40	0	60	10	4	14	56	
Feb	I	7 m	0	41	0	59	17	4	14	95	
74	D	30.5 m	0	49	0	51	86	4	16	482	
21	S	3 m	0	0	0	0	0	2	0	0	
Jun	I	6 m	0	0	0	0	0	2	0	0	
74	D	35 m	0	47	2	51	145	1	91	3,219	

Appendix G

Lake Tillery Table of Diaptomus numbers and percentages. D. pallidus=P,
D. reighardi=R, D. mississippiensis=M.

DATE	STA.	DEPTH	%P	%R	%M	# CTED	HAULS CTED	#/m ³	#/m ²
15	S		NOT SAMPLED						
Jul	I	7 m	0	0	0	0	2	0	0
73	D	19 m	52	0	48	171	4	50	958
31	S	3.5 m	0	0	0	0	2	0	0
Aug	I	6.5 m	0	0	0	0	2	0	0
73	D	18 m	10	20	70	10	4	3	56
12	S	3.5 m	0	0	0	0	2	0	0
Oct	I	6.5 m	12.5	6.5	81	16	4	14	90
73	D	18 m	6	0	94	99	4	31	554
23	S	3 m	0	0	100	1	2	4	11
Nov	I	7 m	5	2	93	56	4	44	314
73	D	20 m	12	0	88	100	4	28	560
4	S	3.5 m	0	0	0	0	4	0	0
Jan	I	7 m	0	0	0	0	4	0	0
74	D	20 m	0	0	100	2	4	1	11
15	S	4 m	50	0	50	8	4	11	45
Feb	I	7 m	30	0	70	10	4	8	56
74	D	20 m	62	0	38	23	4	6	129
29	S	3.5 m	55	0	45	11	4	18	62
Mar	I	7 m	46	0	54	35	1	109	777
74	D	20 m	54	0	46	26	1	29	577
10	S	3.5 m	90	0	10	10	1	63	222
May	I	7 m	82	0	18	28	1	88	622
74	D	20 m	33	10	57	51	1	57	1,132

Appendix H

Lake Lindley Table of Diaptomus numbers and percentages. D. reighardi=R.

DATE	STA.	DEPTH	%R	# CTED	HAULS CTED	#/m ³	#/m ²
13	VS	3 m	100	51	1	364	1,132
Jul 73	S	3.5 m	100	246	1	1,538	5,461
4	VS	1 m	100	36	1	800	799
Sep 73	S	3 m	100	155	1	1,107	3,441
17	VS	1 m	100	236	1	4,720	5,239
Oct 73	S	3 m	100	313	1	2,236	6,949
27	VS	1 m	100	77	4	428	431
Nov 73	S	3 m	100	81	1	579	1,798
8	VS	1 m	100	116	4	644	650
Jan 74	S	3.5 m	100	174	1	1,088	3,863
19	VS	1.5 m	100	8	1	114	178
Feb 74	S	3.5 m	100	9	1	56	200
2	VS	1.5 m	100	209	4	774	1,170
Apr 74	S	3.5 m	100	85	4	135	476
13	VS	1 m	100	72	1	1,143	1,145
May 74	S	3.5 m	100	17	1	77	270

Appendix I

Lake Sloan Table of Diaptomus numbers and percentages. D. reighardi=R.

DATE	STA.	DEPTH	%R	# CTED	HAULS		#/m ³	#/m ²
					CTED			
13	VS	2.5 m	100	732	1	6,655	16,250	
Jul 73	S	3 m	100	988	1	7,057	21,934	
4	VS	1 m	100	8	1	160	178	
Sep 73	S	2.5 m	100	195	1	1,773	4,329	
17	VS	1 m	100	42	4	233	235	
Oct 73	S	2.5 m	100	392	1	3,564	8,702	
27	VS	1 m	100	17	4	106	95	
Nov 73	S	2.5 m	100	302	1	2,746	6,704	
8	VS	1 m	100	40	4	222	224	
Jan 74	S	2.75 m	100	282	1	2,350	6,260	
19	VS	1 m	100	14	1	280	311	
Feb 74	S	3 m	100	52	1	371	1,154	
2	VS	1 m	100	234	4	1,300	1,310	
Apr 74	S	3 m	100	62	4	115	347	
13	VS	1.3 m	100	48	1	600	763	
May 74	S	3 m	100	22	1	116	350	

Appendix J

Lake Jeannette Table of Diaptomus numbers and percentages. D. birgei=B,
D. reighardi=R.

DATE	STA.	DEPTH	%B	%R	# CTED	HAULS		#/m ³	#/m ²
						CTED			
13	S	4 m	0	0	0	2		0	0
Jul	I	7 m	0	0	0	2		0	0
73	D	8.5 m	0	100	11	4		7	62
2	S	3.5 m	0	0	0	2		0	0
Sep	I	7 m	0	0	0	2		0	0
73	D	9 m	0	100	2	4		1	11
15	S	3 m	0	0	0	2		0	0
Oct	I	6 m	0	100	1	4		1	6
73	D	9 m	0	100	13	4		8	73
26	S	3 m	0	0	0	4		0	0
Nov	I	5.5 m	0	100	6	4		9	34
73	D	8.5 m	0	100	4	4		3	22
6	S	4 m	0	100	3	2		8	33
Jan	I	6 m	6	94	35	4		32	196
74	D	9 m	0	100	57	4		35	319
18	S	4 m	0	100	10	4		14	56
Feb	I	6 m	0	100	96	4		89	538
74	D	10 m	2	98	233	4		129	1,305
1	S	4 m	0	100	27	1		150	599
Apr	I	6 m	0	100	234	1		867	5,195
74	D	9 m	0	100	230	1		561	5,106
13	S	3.5 m	0	100	10	1		46	159
May	I	6.5 m	0	100	2,710	1		6,610	43,089
74	D	9 m	0	100	660	1		1,158	10,494

Appendix K

John R. Taylor Lake Table of Diaptomus numbers and percentages. D.
pallidus=P.

DATE	STA.	DEPTH	%P	# CTED	HAULS CTED	#/m ³	#/m ²
13	VS	----- NOT SAMPLED -----					
Jul	S	3 m	100	584	1	4,171	12,965
73	I	5 m	100	769	1	3,344	17,072
4	VS	1.5 m	100	152	1	2,171	3,374
Sep	S	3 m	100	1,291	1	9,221	28,660
73	I	5 m	100	1,056	2	2,347	11,722
16	VS	1.5 m	100	195	1	2,786	4,329
Oct	S	3 m	100	641	1	4,579	14,230
73	I	5 m	100	928	4	1,031	5,197
26	VS	1.5 m	100	54	1	771	1,199
Nov	S	3 m	100	115	1	821	2,553
73	I	5 m	100	142	1	617	3,152
7	VS	1.5 m	100	162	1	2,314	3,596
Jan	S	3 m	100	1,407	1	10,050	31,235
74	I	5.5 m	100	348	1	1,392	7,726
19	VS	1 m	100	196	1	3,920	4,351
Feb	S	3 m	100	755	1	5,393	16,761
74	I	5.5 m	100	2	4	2	11
31	VS	1 m	100	151	1	3,020	3,352
Mar	S	3.5 m	100	458	1	2,863	10,168
74	I	5 m	100	1,004	1	4,365	22,289
12	VS	1.5 m	100	1,481	1	21,157	32,878
May	S	3 m	100	597	1	4,264	13,253
74	I	5 m	100	465	1	2,022	10,323

Appendix L

University Lake Table of Diaptomus numbers and percentages. D. pallidus=P,
D. reighardi=R.

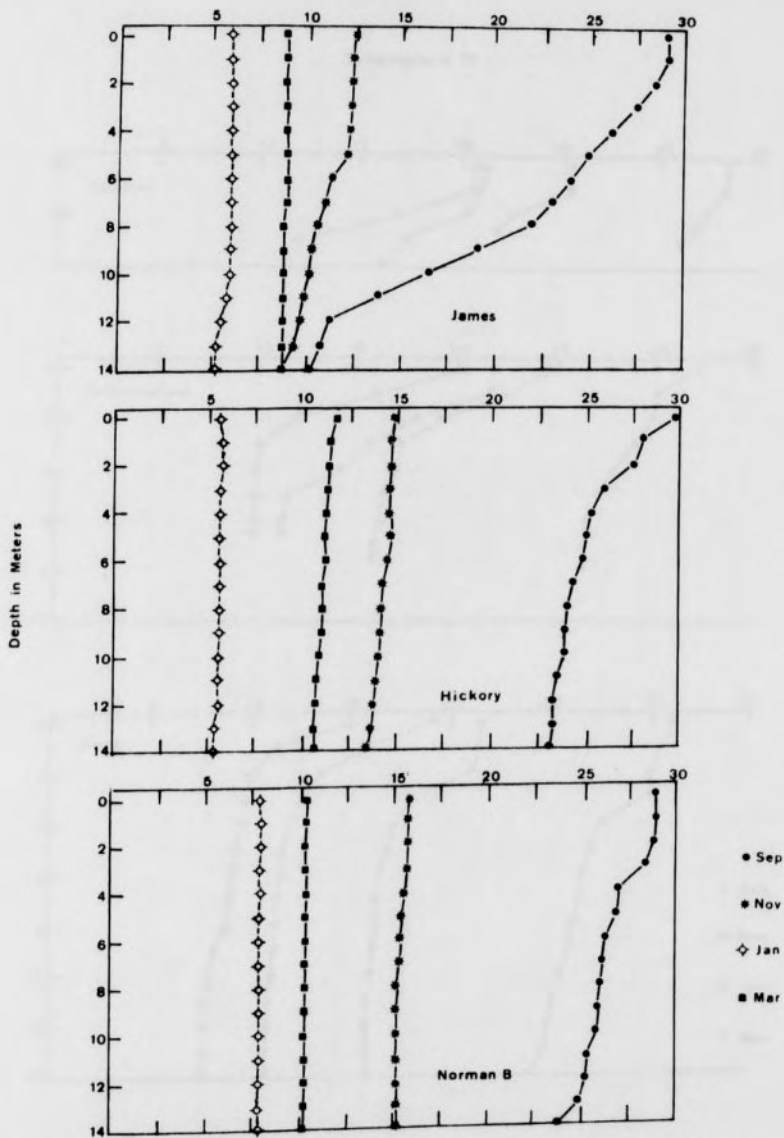
DATE	STA.	DEPTH	%P	%R	# CTED	HAULS CTED	#/m ³	#/m ²
13	VS	1.5 m	40	60	5	4	19	28
Jul	S	NOT SAMPLED						
73	I	6.5 m	41	59	114	4	97	638
2	VS	1.5 m	100	0	438	4	1,622	2,453
Sep	S	3.5 m	87	13	190	4	302	1,064
73	I	6.5 m	100	0	57	4	49	319
14	VS	1.5 m	100	0	760	4	2,815	4,256
Oct	S	3 m	99	1	704	4	1,304	3,942
73	I	5 m	98	2	797	4	886	4,463
25	VS	1.5 m	100	0	37	4	137	207
Nov	S	3 m	100	0	217	4	402	1,215
73	I	4.5 m	100	0	433	4	535	2,425
7	VS	1 m	99	1	849	4	4,717	4,754
Jan	S	3.5 m	100	0	194	4	308	1,086
74	I	6.5 m	100	0	454	4	388	2,542
18	VS	1 m	94	6	55	4	306	308
Feb	S	4 m	97	3	89	4	124	498
74	I	7 m	99	1	642	4	510	3,595
2	VS	1 m	100	0	59	4	328	330
Apr	S	4 m	100	0	55	1	306	1,221
74	I	7 m	100	0	252	1	788	5,594
14	VS	1 m	100	0	273	1	4,333	4,341
May	S	4 m	100	0	214	1	856	3,403
74	I	7 m	99	1	593	1	1,348	9,429

Appendix M

Average numbers of Diaptomus expressed in thousands per square meter of surface in Lake Mendota in 1896 reported by Birge

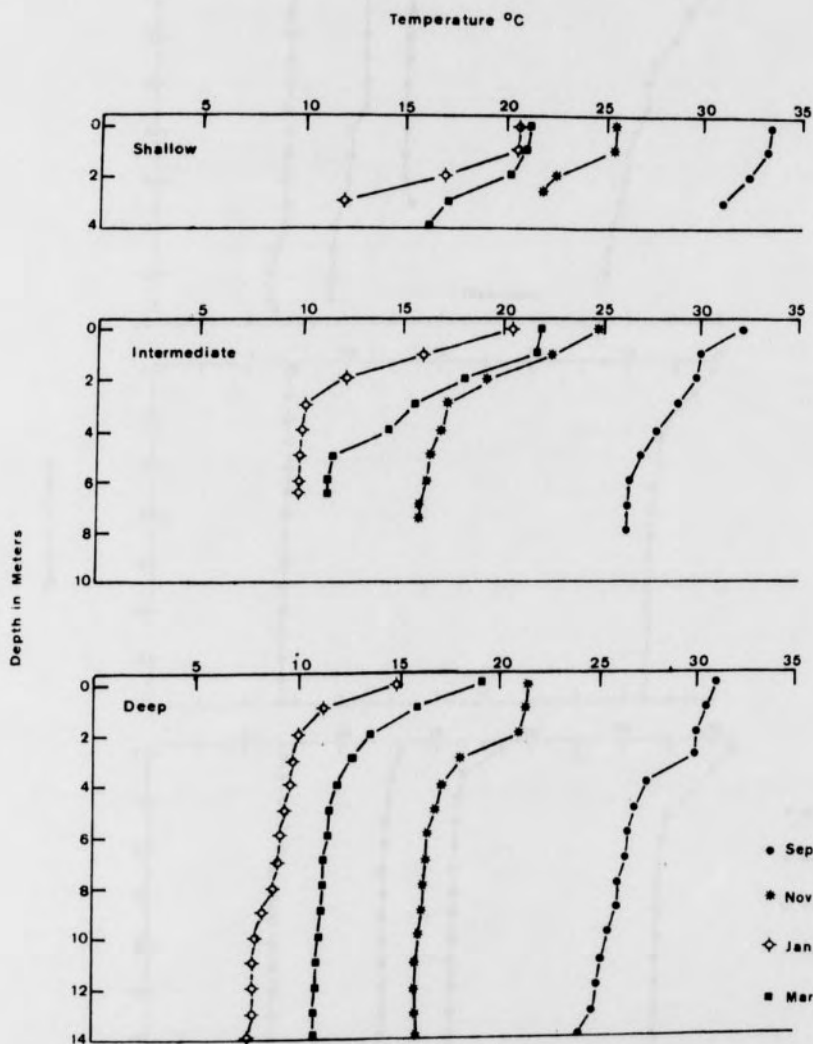
DATE	AVERAGE NUMBERS ($\times 10^3/m^2$)
1896	
Jan 1-15	48.6
Jan 16-31	23.3
Feb 1-14	38.9
Feb 15-29	34.9
Mar 16-30	33.3
Apr 1-15	35.2
Apr 16-30	29.9
May 1-15	102.3
May 16-31	360.2
Jun 1-15	343.5
Jun 16-30	386.2
Jul 1-15	202.9
Jul 16-31	152.1
Aug 1-15	91.9
Aug 16-31	167.0
Sept 1-15	125.9
Sep 16-30	163.4
Oct 1-15	52.8
Oct 16-31	48.8
Nov 1-15	29.8
Nov 16-30	28.5
Dec 1-15	29.3
Dec 16-31	24.7

Appendix N
Temperature °C

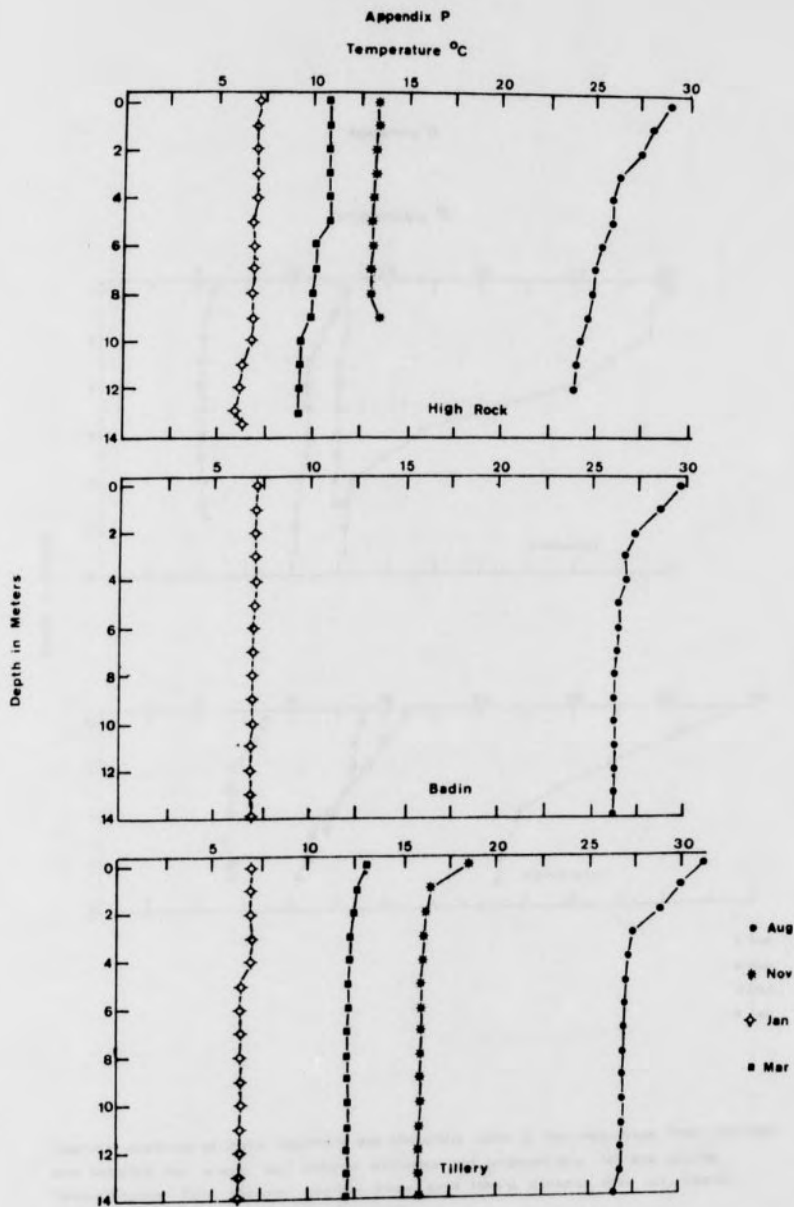


Thermal profiles of three Catawba drainage lakes are showing the winter and summer extremes and the intermediary fall and spring temperatures. Only thermal profiles from deep sites are shown because the shallow and intermediate water profiles were same.

Appendix O

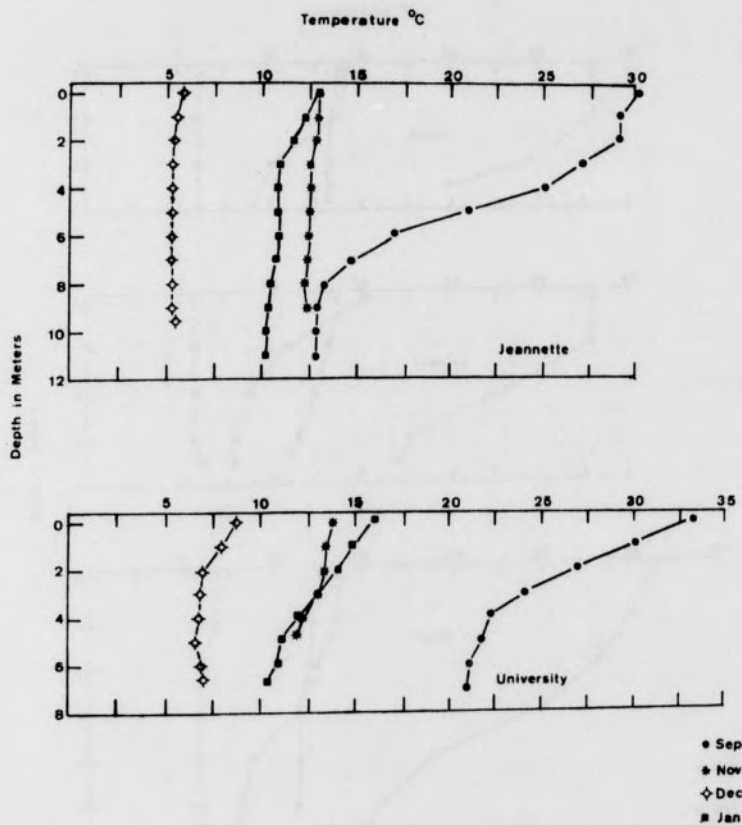


Thermal profiles of the shallow, intermediate, and deep sites of Lake Norman C are showing the winter and summer extremes and intermediary fall and spring temperatures. Thermal profiles from the shallow, intermediate, and deep sites are shown due to the great variance.



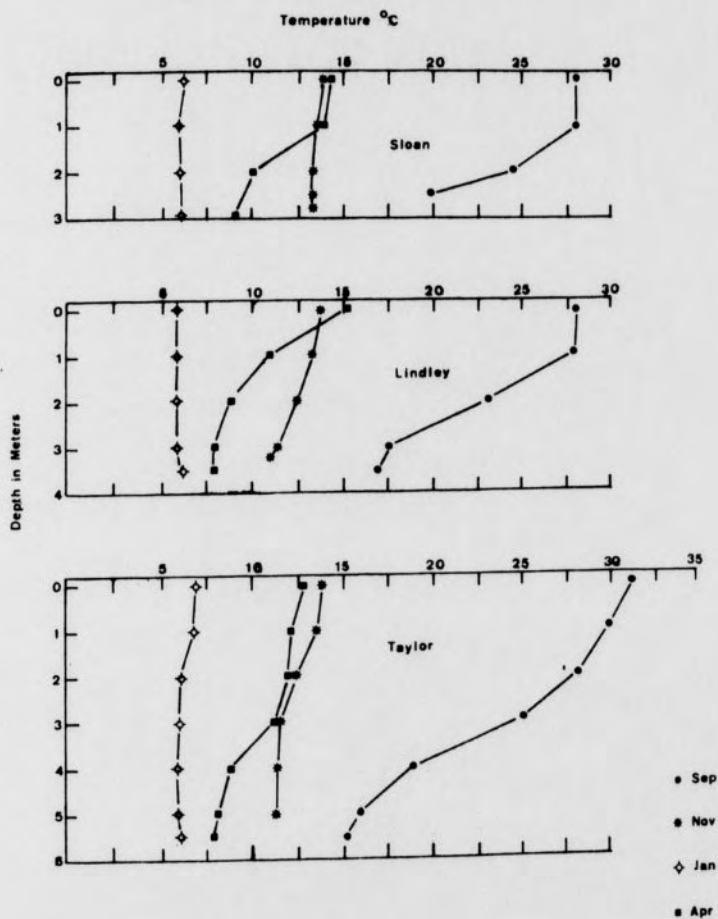
Thermal profiles of the Yadkin drainage lakes are showing the winter and summer extremes and intermediary fall and spring temperatures. Only thermal profiles from deep sites are shown because the shallow and intermediate water profiles were the same. No spring and fall profiles were taken in Lake Badin.

Appendix Q



Thermal profiles of Lake Jeannette and University Lake of the Haw-Cape Fear drainage are showing the winter and summer extremes and intermediary fall and spring temperatures. Only thermal profiles from each lake's deepest sites are shown because the lesser depths were the same.

Appendix R



Thermal profiles of shad-free lakes of the Haw-Cape Fear drainage are showing the winter and summer extremes and the intermediary fall and spring temperatures. Only thermal profiles from the deepest site of each lake are shown because the shallower sites were the same.