Species Diversity

The objectives of this analysis were to determine: (1) whether the movement of cooling waters promotes a constancy of species diversity in the open-water regions of the cooling loop, and (2) whether discharge water temperatures and associated conditions during late summer reduce diversity during that period.

Diversity data from Year 1 ranged from a low of 0.46 at Station 3 in December 1978 to 3.11 at Station 4 in June 1979; the widest range of values generally occurred at those two stations throughout Year 1 (Table 6.3). The overall mean diversities in Year 1 of all stations each month ranged from 1.47 to 2.67 with an average of 2.11. Monthly means of cooling loop stations ranged from 1.65 to 2.8 with a mean of 2.15. For Stations 3 and 4 combined, the range was slightly greater at 1.10 to 2.83. An analysis of sequential trends in the cooling loop each month in Year 1 showed that, with the exceptions of November and June, populations in the warmest regions of the loop (the discharge and Station 1) had the highest diversity values. In general, however, there were no easily distinguishable month-to-month trends of either constancy or increases and declines in species diversity in the direction of water flow. A comparison of mean diversity of stations 3 and 4 and the cooling stations showed that mean diversities were generally greater at stations directly receiving thermal effluents.

In Year 2, species diversities ranged from 0.22 at Station 2 in January 1980 to 3.26 at Station 1 in June 1980. Lakewide mean diversities each month ranged from 0.50 to 2.61 in Year 2; stations 4 and 2 had the highest and lowest annual mean, respectively. A comparison of the mean diversity of stations 3 and 4 with that of the cooling loop stations in Year 2 showed that locations closest to the discharge had the highest diversity in August and September, when water temperatures were highest. Apparently, high water temperatures were less detrimental than would be expected according to the literature (Pennak 1978). Therefore, locations having water temperatures exceeding 30°C (which is a lethal level for most zooplankton according to Pennak (1978)) were able to support viable zooplankton communities in terms of richness of species. It is postulated that a large portion of the late summer community was residing below the thermal plume (Section 2), particularly in deeper regions upstream of the dam, where

Table 6.3. Diversity values of zooplankton in Coffeen Lake, July 1978 through June 1980.

Station	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Mean
YEAR 1 - 1978-1979													
Mean - Cooling Loop[1]	1.65	2.71	2.21	2.19	1.73	1.66	2.19	2.14	2.12	2.80	2.13	2.31	2.15
Mean - Stations 3 and 4	2.60	2.12	1.61	2.18	2.36	1.10	1.72	2.12	2.12	2.41	1.27	2.83	2.02
Overall Mean	1.97	2.51	2.01	2.19	1.60	1.47	2.03	2.13	2.12	2.67	2.14	2.48	2.11
YEAR 2 - 1979-1980													
Mean - Cooling Loop[1]	1.79	2.45	2.41	2.12	0.80	1.43	0.40	2.32	1.63	2.31	1.90	2.65	1.89
Mean - Stations 3 and 4	2.16	2.19	2.26	2.66	1.38	1.46	0.79	3.17	1.80	2.62	1.99	2.54	2.09
Overall Lake Mean	1.91	2.36	2.28	2.30	1.00	1.44	0.50	2.60	1.69	2.41	1.81	2.61	1.95

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[1] Includes intake, discharge, and Stations 1 and 2

stratification was evident. Since the entire water column was sampled in these areas, the high diversity may have prevailed regardless of the presence of the warmwater layer.

There were very few instances in either study year where species diversity gradually increased or decreased in the direction of water flow in the cooling loop; in most instances the data were extremely variable. Overall, the mean annual diversity of zooplankton communities in Coffeen Lake for Year 1 (2.11) and Year 2 (1.95) was within the range of variation expected and was similar to a 3-year mean for Lake Sangchris (2.13) but lower than the 2.27 computed for Lake Shelbyville (Waite 1979a).

ABUNDANCE OF MAJOR ZOOPLANKTON GROUPS

A familiar characteristic of freshwater zooplankton is the extensive variability of organism density, both seasonally and spatially. Typical curves of seasonal abundance in most temperate lakes consist of a late spring pulse; a smaller population during late summer; a second, but less pronounced pulse in autumn; followed by a reduced population in winter. In Coffeen Lake, it was questioned whether the physicochemical parameters associated with heated effluents might alter or produce atypical trends in the seasonal abundance of rotifers, cladocerans, and copepods.

Rotifera

The absolute abundance of rotifers in Year 1 was monocyclic at all stations in mid-summer. From that period, numbers gradually decreased to winter-time lows of approximately 1,000 individuals m^{-3} in the cooling loop and 20 times that number at Station 4. In February, populations quickly recovered and gradually increased from 30,000 to 50,000 organisms m^{-3} in April; in May, however, fish predation, species succession and the complete shutdown of units 1 and 2 at the Coffeen Generating Station (Fig. 1.1) probably accounted for the decrease in abundance.

There were few trends in Year 1 regarding shifts in rotifer abundance in the cooling loop each month. Rotifer numbers were variable from the discharge to intake; numbers at the cooling loop stations, however, were generally more than those at stations 3 and 4 from May through August. During Year 1, rotifer densities in Coffeen Lake were inversely proportional to the distance from the discharge canal. Station 4 favored the development of more littoral species, many of which attained relatively high densities (25,000 to 140,000 m^{-3}).

In terms of relative abundance, rotifers lakewide in Year 1 constituted 75 to 98% of total zooplankton numbers in July; in November through January, that fraction was reduced to between 1 and 80% in the cooling loop and 33 to 94% at stations 3 and 4 (Table 6.4). The annual mean percentage of rotifers for each station in Year 1 progressively increased in the direction of water flow from 41% at the discharge to 57% at the intake, with 67 and 77%, respectively, at Stations 3 and 4. While rotifer densities increased progressively with distance from the discharge, the fraction of total zooplankton that constituted this group was also larger.

It is apparent that within the community structure at various points from the discharge, rotifers had relatively less tolerance of either discharge temperatures or current velocities, both of which decrease at points downstream (see Section 2).

During Year 2, the largest lakewide pulse of rotifers occurred again in July (45,000 to 145,000 organisms m^{-3}). The total density then gradually decreased to an early winter low of 0 organisms at all stations except Station 4. As winter progressed, populations quickly recovered and densities increased at all stations through spring. A second major pulse was detected in May. This trend was similar to that of Year 1, except the spring pulse in Year 2 occurred 1 month later.

For the period September to December 1979, densities at Station 4 exceeded those of the cooling loop stations by 1.1 to 7.6 times. As suggested for Year 1, morphological differences of the lake at Station 4 were probably more favorable for the development of typical fall taxa. It is doubtful that the atypically

Table 6.4. Percentage relative abundance of major zooplankton groups in Coffeen Lake, July 1978 through June 1980.

Station	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Mean
YEAR 1 - 1978-1979													
Mean - Cooling Loop[1]													
Rotifera	86	76	42	43	5	69	12	67	82	47	5	76	49
Cladocera	7	16	23	6	5	*	8	*	*	9	7	6	8
Copepoda	*	*	3	6	15	9	44	6	3	9	17	3	10
Nauplii	5	5	24	30	61	15	27	24	10	29	55	11	25
Copepodida	1	3	8	15	14	7	10	3	4	7	16	4	8
Mean - Stations 3 and 4													
Rotifera	96	91	71	39	53	83	54	80	77	72	17	80	67
Cladocera	3	5	8	3	1	*	2	*	*	5	5	3	3
Copepoda	*	*	*	2	6	6	14	6	1	2	10	3	5
Nauplii	*	3	8	41	24	3	18	17	18	15	49	9	17
Copepodida	*	1	2	6	8	2	1	2	1	4	15	2	4
Overall Mean													
Rotifera	89	81	55	45	25	76	29	70	81	56	9	79	58
Cladocera	6	12	18	5	3	1	6	1	1	8	6	5	6
Copepoda	1	1	2	3	12	8	34	6	2	6	16	3	8
Nauplii	3	5	19	34	49	10	24	21	13	24	53	10	22
Copepodida	1	2	6	12	11	5	7	2	3	6	75	3	6
YEAR 2 - 1979-1980													
Mean - Cooling Loop[1]													
Rotifera	87	44	13	3	0	17	82	61	84	45	36	26	42
Cladocera	3	4	18	4	5	5	1	11	1	5	2	14	6
Copepoda	1	7	7	11	37	28	5	8	1	7	13	4	11
Nauplii	6	35	52	69	31	40	11	15	12	20	37	39	30
Copepodida	3	10	11	13	28	11	3	4	2	22	12	17	11
Mean - Stations 3 and 4													
Rotifera	92	33	38	5	4	24	80	47	73	62	33	45	45
Cladocera	4	8	12	4	4	1	1	17	1	2	2	4	5
Copepoda	0	5	3	8	14	32	9	13	3	4	9	2	8
Nauplii	4	44	43	72	60	33	9	21	22	28	48	46	36
Copepodida	0	10	5	11	19	10	2	3	1	4	8	3	6
Overall Mean													
Rotifera	88	40	21	4	1	19	81	56	81	51	35	3	43
Cladocera	4	6	16	4	4	4	1	13	1	4	2	11	6
Copepoda	1	6	5	10	29	29	6	9	2	6	11	4	10
Nauplii	5	38	49	70	41	37	10	19	15	23	41	41	32
Copepodida	2	10	9	12	25	11	2	3	1	16	11	12	9

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[1] Includes intake, discharge, and Stations 1 and 2

*less than 1 percent

high water temperatures in Coffeen Lake during late summer of 1979 seriously limited rotifer production, since many of the highest densities (99,000 to 145,000 organisms m^{-3}) were in the region of immediate discharge during mid- to late-summer.

In terms of the highest relative abundance in Year 2, rotifers lakewide constituted 72 to 95% of the total zooplankton community in July. The fraction of rotifers was smallest during October through December 1979 (<20%). On an annual basis, the mean percentage of rotifers for each station increased from 34% at the discharge to 50% at Station 2 and then decreased gradually to 48, 46, and 43% at the intake, Station 3, and Station 4, respectively. An unusual situation occurred in November 1979 when rotifers constituted 0% of the total community at all sampling locations except Station 4. However, a review of the lake's physicochemical parameters revealed no atypical conditions during autumn and, thus, no implication of the plant's operation.

Cladocera

The abundance of cladocerans was lowest at all stations from December through March of Year 1, with densities ranging from 17 to 1,492 organisms m^{-3}. By April, abundance had gradually increased, averaging approximately 4,000 organisms m^{-3} lakewide; by September, densities had peaked at 10,000 organisms m^{-3} at Station 4 to 55,000 organisms m^{-3} at Station 2. On a monthly basis in Year 1, there were no consistent increases or declines in the numbers of cladocerans around the cooling loop. Cladoceran densities at stations 3 and 4 were less than those of the cooling loop stations from May through December, greater in February, and virtually identical in January and March through April. Annual means of cladoceran abundance at each station in Year 1 generally decreased around the cooling loop from discharge to intake, and likewise, at stations 3 and 4.

Cladocerans constituted a relatively small percentage of total zooplankton for Year 2; the range was 0 to 27% with an overall average of 6%. On a mean lakewide basis, the largest percentages occurred in August 1979 (16%), February 1980 (13%), and June 1980 (11%); the lowest percentages were in May 1980 (2%), January 1980 (1%), and March 1980 (1%). The fraction of cladocerans at each station on an annual basis in Year 2 decreased from 8% at the discharge to 5% at Station 2 and the intake. The percentage was lower yet at Station 3, but the mean at Station 4 was equivalent to that of Station 1.

The lakewide abundance of cladocerans in Year 2 was lowest from November through March, compared to December through March in Year 1. In January, February, and March 1980, all densities were less than 500 m^{-3}. By April, abundance increased 4- to 100-fold (depending on the location), averaging approximately 1,550 organisms m^{-3}. As in Year 1, the peak in Year 2 occurred in September, with densities ranging from 6,000 to 15,000 organisms m^{-3}. On a monthly basis, densities were variable around the cooling loop. On an annual basis, the mean abundance of cladocerans generally declined from the discharge to the intake, and stations 3 and 4, exactly the same as was found in Year 1.

Copepoda

The copepod fauna in Coffeen Lake was the only major zooplankton group to exhibit two pulses in Year 1. Nauplii, copepodids, and adults were present in low concentration in February; gradually increased to a peak in May; declined in June and July; and began increasing in August to reach a second peak in November. Adults were greatly outnumbered by the immature stages; in all but three collections in Year 1, nauplii and copepodid densities surpassed the mature forms by up to 960 times. During individual months in Year 1 there were few distinguishable trends where copepods increased or decreased around the cooling loop. However, the annual mean of Year 1 for each station showed that, while the density of mature forms was variable around the cooling loop, the numbers of nauplii and copepodids were relatively equal. All forms at stations 3 and 4 were present in virtually equivalent densities, but their numbers were greatly reduced (40 to 50%) when compared to those of the cooling loop.

The relative abundance of mature copepods ranged from 72% of the total zooplankton in January 1979 at Station 1 to approximately 1% at the following: (1) all stations in July 1978, (2) five stations in August 1978, and (3) two stations in September 1978. The annual mean relative abundance decreased from the discharge to the intake (discharge, stations 1 and 2, intake), and likewise to stations 3 and 4 (13, 10, 9, 7, 6, and 3%, respectively). The percentage of nauplii was virtually the same throughout the cooling loop in Year 1 while copepodids were variable.

In Year 2, nauplii and copepodids again outnumbered their adult counterparts. All constituents were present in very low densities in February (31-63 organisms m^{-3}). Beginning in March, densities began increasing and reached their major peak in May. Populations decreased in June and July and peaked again in September. The density of nauplii, copepodids, and mature forms was variable around the cooling loop each month.

The relative abundance of mature copepods ranged from 0% at Station 2 and Station 4 in July 1979 to 62% at the discharge in November. The Year 2 annual mean relative abundance decreased progressively from 15% at the discharge to 8% at both Station 2 and the intake. On a lakewide basis in Year 2, nauplii and copepodids were variable, ranging from 0 to 47%. Annually, nauplii percentages were virtually constant throughout the lake (25-36% of total zooplankton), while copepodids decreased from the discharge to Station 4.

ZOOPLANKTON BIOMASS

Although standing crop biomass is presented in terms of dry and ash-free (total volatile organic matter) weight, the latter was preferred when the contents of some samples were suspected to contain large amounts of silt, detritus, or slag.

In Year 1, ash-free biomass ranged from 13 to 218 mg m^{-3} with an overall mean of 53 mg m^{-3}. For the months of July 1978 through January 1979, ash-free biomass decreased progressively around the cooling loop (from Station 1 to Station 2, etc.). In February and March 1979, the amounts were virtually the same, while during the remaining period biomass was quite variable. The annual mean ash-free biomass for each sampling station in Year 1 ranged from 86 mg m^{-3} at the discharge to 40 mg m^{-3} at the intake. For 42% of the time (months in Year 1), the lowest values were at Station 3, while the highest were recorded at the discharge (70%). A comparison of Station 4 data to those of the cooling loop stations in Year 1 showed that ash-free biomass in the former was greater than the mean biomass of cooling loop stations in both summer (May-August) and winter (December-February), but less in autumn and early spring (Table 6.5).

The organic fraction, described here as percentage organic content, was variable from station to station and month to month in Year 1. The monthly means of all stations ranged from 45 to 72%, while the annual mean of each station was 50 to 74%. For most collections, the organic fraction increased around the cooling loop with increasing distance from the discharge. That fact may reflect the settling characteristics of fly ash-slag particulates introduced into the lake within the discharge canal.

During Year 2 in Coffeen Lake, the ash-free weight of zooplankton ranged from 11 to 126 mg m^{-3} with an overall lake mean of 37 mg m^{-3}. These amounts are approximately 30% lower than those recorded for Year 1. However, a comparison to other lake values (Waite 1979a) shows that Coffeen Lake values are low on a relative scale, but within the range recorded for Lakes Sangchris and Shelbyville from 1975 through 1978.

Observation of the annual biomass means for each station in Year 2 revealed a gradual decrease of ash-free biomass from the discharge to the intake. Collectively, the mean of these cooling loop stations equalled the overall lake mean. From July through November, the biomass at Station 2 was less than that at most stations in the cooling loop. For the period December to June, the biomass at each station in the cooling loop was less than that at Station 4.

The annual mean percentage of organic biomass increased by small increments from 38% at the discharge to 54% at the intake in Year 2, suggesting that heavier inorganic particles, held in suspension by the turbulence at the discharge, progressively settled out as the current velocities decreased around the cooling loop. The mean percentage of all cooling loop stations was essentially equal to the overall lake mean.

Table 6.5. Mean standing crop biomass of Coffeen Lake zooplankton, July 1978 through June 1980.

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Mean
YEAR 1 - 1978-1979													
Dry Weight Biomass													
Mean - Cooling Loop[1]	199	143	115	129	128	42	45	33	51	69	93	75	94
Mean - Stations 3 and 4	279	271	71	71	103	172	43	47	28	85	126	102	116
Overall Mean	226	186	110	119	121	85	44	37	43	74	104	84	102
Ash-Free Biomass													
Mean - Cooling Loop[1]	112	82	66	70	68	29	30	13	25	46	68	43	54
Mean - Stations 3 and 4	88	86	46	37	38	77	33	18	18	38	64	44	49
Overall Mean	104	83	59	59	58	45	31	15	23	43	67	45	53
YEAR 2 - 1979-1980													
Dry Weight Biomass													
Mean - Cooling Loop[1]	106	105	107	68	113	33	58	61	79	65	195	44	86
Mean - Stations 3 and 4	71	135	84	71	123	100	133	94	68	99	162	36	98
Overall Mean	94	115	99	69	116	55	83	72	75	65	184	41	89
Ash-Free Biomass													
Mean - Cooling Loop[1]	45	41	56	40	69	16	21	16	15	20	71	18	36
Mean - Stations 3 and 4	25	37	39	35	46	44	59	22	24	32	99	16	40
Overall Mean	38	40	50	38	61	25	34	18	18	26	80	17	37

[1] Includes intake, discharge, and Stations 1 and 2

Implications of Zooplankton Data

In view of the overall purpose of this study, a two-year data set consisting of monthly observations of the zooplankton community structure during a period of water management improvements was not totally successful. Considering that the ideal situation would have included a minimum of 1-2 years of data documenting the lake's decline and its low, the concept of a 2-3 year study during the improvement phase would have significant merit. As it stands now, it is difficult to distinguish cause-and-effect of water treatment improvements, per se, from expected differences attributable to natural year-to-year variability. However, despite this drawback, it is judged that zooplankton in Coffeen Lake during 1979 and 1980 were productive and viable despite atypical temperature regimes, entrainment, and unusual water chemistry.

In addition to the monthly collections of zooplankton in Coffeen Lake, efforts were directed toward several specific ecological questions that relate to power plant effects on these organisms.

LEPTODORA

Recent environmental studies of electric power cooling lakes in central Illinois (Waite 1979a, 1979b, 1980) indicated a notable paucity of the cladoceran zooplankter, *Leptodora* (Fig. 6.1). Because this genus has been collected (1) in large numbers from other non-cooling lakes in Illinois (Shelbyville, Carlyle, and Rend) and (2) from lakes and reservoirs in the northern United States (new records are being reported from Kansas (Prophet 1978), Oklahoma and Texas (Holt 1979)), it was hypothesized that environmental conditions specific to cooling lakes were detrimental for leptodorid biology. That *Leptodora* is absent from a lake can be significant ecologically; they are important links in food web dynamics between primary and tertiary trophic levels. When present in large densities, they constitute an important fraction of the fisheries' food base (Costa and Cummins 1972) and, due to their predatory feeding habits, they can effect changes in community structure of prey organisms. To test the above hypothesis, an assessment of leptodorid biology consisting of two phases was undertaken.

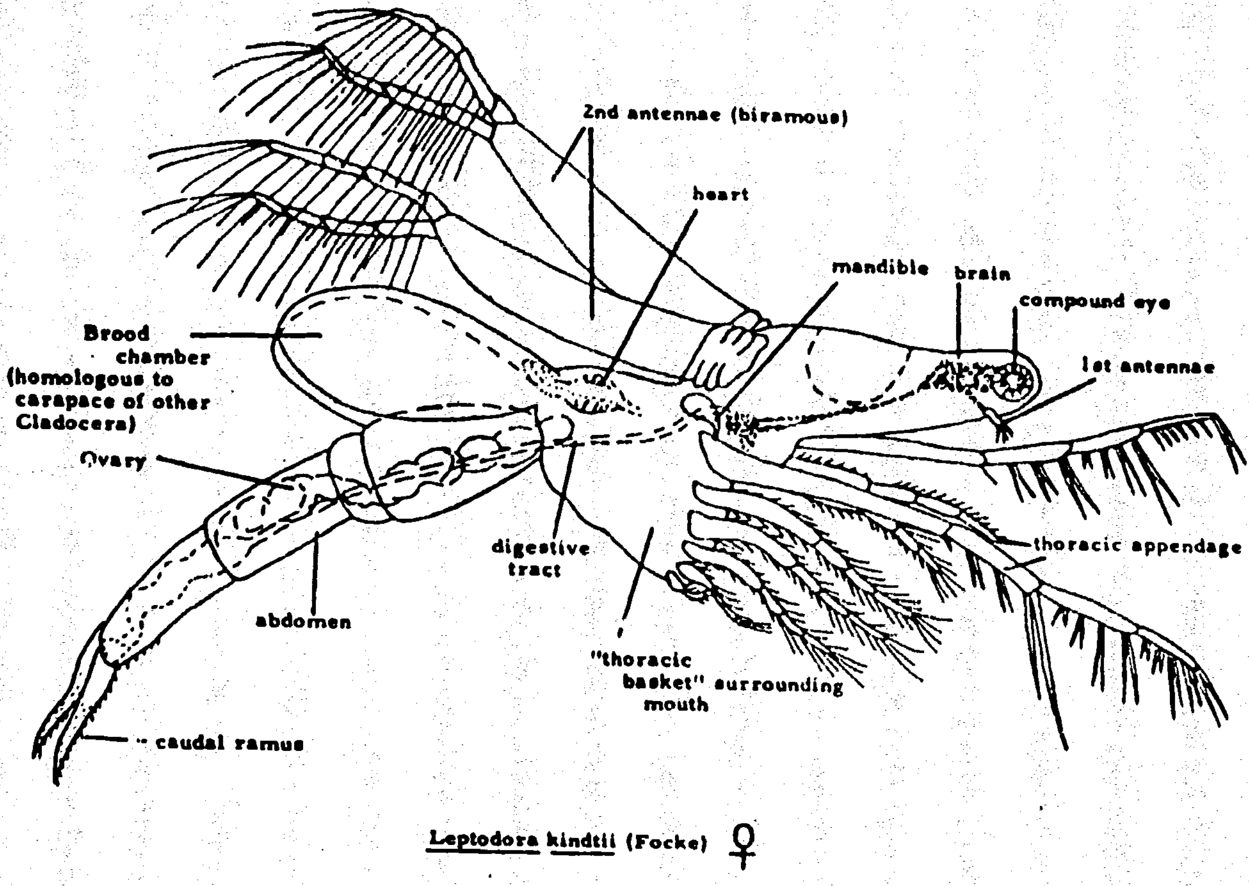

Fig. 6.1. Drawing of Leptodora kindtii (Focke) (taken from Costa 1967).

First, a preliminary sampling regime was initiated for 13 lakes, which represented the basic morphological types in Illinois: cooling lakes, flood control and water supply reservoirs, recreational lakes, etc. The intent here was to determine whether the paucity of *Leptodora* was restricted to cooling lakes. This first phase was completed within a 2-week period in September 1980 when populations typically peak. The sampling program consisted of two to three vertical replicate tows from bottom to surface with a standard 5:1 conical plankton net at two stations in each basin. Ancillary profiles of dissolved oxygen and water temperature in the water column were also taken at each station.

The results of the sampling work (Table 6.6) did not support our hypothesis; that is, *Leptodora* was found only in three of nine lakes that do not receive heated discharge waters. These data suggested that, based on the one-time sampling effort for each study lake, environmental conditions characteristic of cooling lakes per se (heat regime, physical entrainment, etc.) may not be the sole factor limiting the occurrence of *Leptodora* in these systems. The question was then changed to: what are the conditions in both cooling and non-cooling lakes that disfavor leptodorid production and/or reproduction?

Phase Two consisted of conducting an extensive literature search for information concerning environmental requirements, feeding behavior, and reproduction of *Leptodora*. Most authors agree that certain abiotic factors operating in aquatic systems combine to regulate the development and reproduction of *Leptodora* (Cummins et al. 1969). Two factors that may be most important in the biology of this organism are water temperature and photoperiodism (Costa 1967). The latter is important in controlling the synchrony of the hatching of winter eggs in the spring. The photoperiod may also work synergistically with a sudden drop in water temperature in autumn to stimulate the production of male forms and, ultimately, sexually-derived winter eggs.

In the original hypothesis of this study (that cooling lake conditions disfavor leptodorid production), it was assumed that the atypically high water temperatures, even in ambient waters, in Coffeen Lake during late summer and early autumn prevented the production of males. During this period in other lakes containing *Leptodora*, those populations reach their peak. However,

Table 6.6. List of 13 Illinois lakes samples for *Leptodora* in September 1980. * indicates where *Leptodora* was collected; † indicates cooling lakes.

Lake	Date	Maximum Mean Sampling Depth (m)	Secchi Depth (m)	Mean Surface to Bottom Dissolved Oxygen (ppm)	Water Temperature (°C)
Lake Sangchris†	09/05/80	11.0	-	6.1 - 0.0	27.9 - 20.8
Clinton Lake (A)	09/08/80	12.0	-	6.4 - 0.05	26.0 - 20.0
Lake Decatur	09/08/80	4.7	-	8.1 - 3.5	28.2 - 25.1
Lake Vermillion	09/09/80	3.1	0.38	5.5 - 2.1	24.8 - 24.4
Newton Lake†	09/09/80	12.0	0.8	8.6 - 0.04	30.0 - 14.5
Stephen Forbes Lake	09/09/80	4.5	0.8	7.2 - 0.02	27.5 - 22.9
Carlyle Lake*	09/10/80	5.0	0.48	10.0 - 5.4	27.0 - 25.2
Rend Lake*	09/11/80	4.4	0.5	6.1 - 2.5	25.6 - 25.5
Kincaid Lake	09/11/80	16.0	3.55	7.25- 0.06	27.7 - 9.6
Baldwin Lake†	09/11/80	4.5	-	9.9 - 0.05	32.2 - 30.8
Coffeen Lake†	09/15/80	10.0	-	7.9 - 0.2	27.5 - 22.0
Braidwood Lake (B)	09/19/80	-	0.8	8.6 (surf)	20.0 (surf)
Lake Shelbyville*	09/10/80	6.0	-	-	-

(A) Cooling lake prior to thermal input
(B) Prior to filling of basin

Leptodora can rarely survive water temperatures above 28°C. Cooling lake discharges of 30°C and above at Coffeen Lake during late summer could destroy the entire population before resting or winter eggs could be conceived.

The fact that *Leptodora* did not appear in over half of the non-cooling lakes sampled suggested that many factors are involved in the success or failure of these organisms within the biotic-abiotic structure of lake systems. In summary, what was originally thought to be an anomaly in the occurrence of *Leptodora* directly linked to cooling lake conditions is now considered a much more complex phenomenon which overlaps many different types of aquatic ecosystems.

BOSMINA

Results of both Year 1 and Year 2 studies of Coffeen Lake showed an unusually low occurrence of a small-bodied cladoceran, *Bosmina*; these trends were interpreted as significant in light of their occurrence in other lakes. Question: Do cooling lake characteristics, such as increased temperatures and entrainment, restrict *Bosmina* production?

One possibility is that temperature and entrainment indeed govern the dynamics of bosminid populations, but probably at a community level. However, in Lake Sangchris, *Bosmina* occurred lakewide for nearly the entire year (Waite 1979a). One other possibility is that some water chemistry parameter limited their production in Coffeen Lake. The pH range in Coffeen Lake was similar to that at Lake Sangchris and dissolved oxygen levels were well above those required for most zooplankters. Unusually high levels of total dissolved solids, chlorides, and sulfates (Section 3) may indeed have an impact on zooplankton biology, but tolerance levels are not well-documented in the literature.

A second hypothesis might be stated as follows: bosminids in Coffeen Lake are subject to heavy predatory pressure by both vertebrates (fish) and invertebrates

(*Chaoborus* and cyclopoid copepods). Stenson (1976) suggests that a paucity of vertebrate predators leads to strong invertebrate predation and dominance of larger herbivores. The relatively low numbers and biomass of zooplankters in bluegill stomachs in Coffeen Lake (Section 8) suggest that the primary factor may be increased competition for *Bosmina* by invertebrate predators.

Therefore, it is suspected that the infrequent occurrence of *Bosmina* in Coffeen Lake was not directly related to power plant effects, but is probably the result of heavy pressure by invertebrate predators (Fig. 6.2).

ENTRAINMENT METHODOLOGIES

Aside from the potential physiological effects of waste heat on aquatic biota in the receiving systems downstream of power plants, one of the most important perturbations to these systems is the combined effects of heat with the physical forces resulting from entrainment through the plant proper. Because the most obvious effects were initially associated with fish production, much of the entrainment work has been directed toward perfecting fish sampling methodologies. It is also assumed, however, that planktonic and benthic invertebrates are affected by entrainment, but methodologies have in some cases precluded an accurate determination of mortality rates. One of the objectives of this subproject was to assess two techniques in terms of their simplicity and reliability for measuring zooplankton entrainment.

Method One

The first method tested was ATP (adenosine triphosphate) assay. The determination of live biomass in aquatic ecosystems has been frustrated by the presence of non-living, particulate detritus. Gravimetric techniques (which were utilized in the biomass determinations discussed earlier) are often suitable when total organic content is required, but are unreliable for determinations of live biomass since total mass contains non-living organic constituents (Weber 1973). ATP assay can be an ideal method for live biomass estimates because it is found only in living cells and is detectable even in very small amounts. ATP is extracted in a boiling Tris solution and injected into a luciferin-luciferase

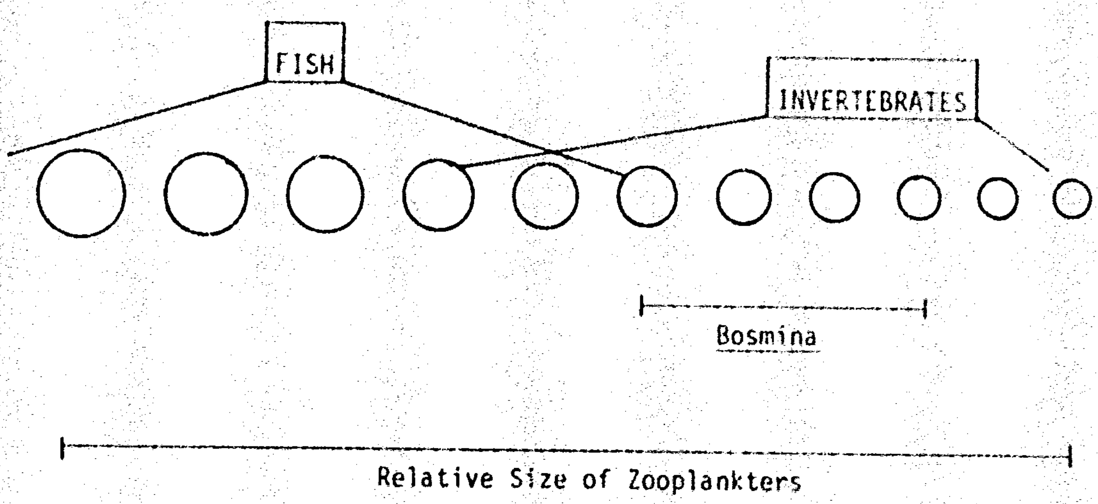

Figure 6.2 Influence of vertebrate (fish) and invertebrate predators on zooplankton prey populations. Lack of vertebrate predators leads to strong invertebrate predation and dominance of larger herbivores. The reverse leads to dominance of smaller herbivores. The former situation supports the proposed hypothesis regarding Bosmina in Coffeen Lake (derived from Stenson 1976).

(firefly) preparation, where, for each molecule of ATP hydrolyzed, one photon of light is emitted. The concentration of ATP in a sample can then be calculated by measuring the intensity of light with an ATP photometer. Detailed methods are described by Patterson et al. (1970), Holm-Hansen (1972), Weber (1973), APHA et al. (1975) and others.

The proposed use of the firefly assay ideally would be two-fold: (1) to develop a method that closely estimates the degree of entrainment mortality in the discharge or other regions of the receiving systems, and (2) to determine overall viable biomass fractions of the standing crop anywhere in the system.

The scope of work for this methodology, which was tested during August 1979, included the following points. Replicate samples of plankton were collected from both the intake and discharge canals with a Waite-O'Grady filter pump (which yields low sampler-induced mortalities). Sample times were varied so that measurements could be made during periods of pumped discharge under both heated and non- heated conditions. In this way, measurements could be made during different phases of the plant's operation to assess component stress parameters (i.e., temperature, mechanical abrasion and shearing forces). The final data could be interpreted by developing an index in which the percent survivorship would be expressed as the ratio of ATP-discharge to ATP-intake times 100.

After three daylight collections were taken, the data were found to be extremely variable and non-repetitive, so sampling was discontinued. The data were invalid to the extent that they will not be reported here. ATP extracted from paired intake and non-heated discharge samples was, however, more consistent than those pairings involving heated discharges. In the latter case, both ATP per unit volume of water and ATP per unit biomass were greater in the discharge. These results led us to consider some other conditions and assumptions.

One important assumption of the ATP assay is that concentrations of ATP/cell remain constant from one individual to another, as well as among species.

Theoretically, however, a relationship between ATP and biomass can be considered valid only if physical parameters affecting metabolic rates (i.e., temperature, salinity, etc.) are considered.

A second assumption is that the assay measured ATP derived only from live cells. This condition is easily justifiable, since lysosomal action following death causes cell rupture and the released ATP undergoes rapid hydrolysis.

Two conditions must be resolved for the use of ATP assay in entrainment studies. (1) Water sampled in the discharge must be the same water that was sampled in the intake. Knowledge of travel time through the plant and appropriate scheduling of sampling satisfies this condition. (2) The most critical condition, however, is the effect of temperature on the steady-state levels of ATP. An increase of environmental temperature will generate increased metabolic activity, which significantly affects steady state levels. This becomes a critical point in closed cooling lake systems where the difference in temperature between intake and discharge is usually greater than 5°C. Thus, during periods of heated discharge, higher ATP levels recorded for the discharge would probably not be indicative of greater live biomass, but, rather, of increased metabolic activity. One way to resolve this problem would be to increase or decrease the temperature of the sampled water so that the temperature of both intake and discharge organisms would be the same when they were killed. Problems of choosing an appropriate acclimation time and of minimizing sampler and handling-related mortality are unresolved. This methodology, originally thought to be simple and applicable to field conditions, was not suitable and is not recommended for entrainment studies.

Method Two

Vital and mortal staining techniques are gaining popularity for determining live from dead individuals in freshwater plankton. A mortal stain proposed by Seepersad and Crippen (1978) was found to be an effective tool for such distinctions in power plant-entrained zooplankton. The method had added usefulness in reducing prolonged handling stress and in enabling the researcher to analyze them at a later date. This method was assessed on Coffeen Lake zooplankton in spring 1980.

Zooplankters were collected from both the intake and discharge regions (representing ambient and heated waters) with a filter-pump apparatus (Waite and O'Grady 1980), which is known to reduce sampling-induced mortality. The organisms were rinsed (with lake water) into a small sieve, which was immersed in an aniline blue dye solution (5 g aniline blue·100 ml^{-1} distilled water). At the end of a 15-minute immersion period, the sieves with organisms were removed from the dye, rinsed, and submerged into hot water. The "heat-killed" specimens were then transferred to bottles containing 10% formalin. Optimum temperature for "heat killing" was 50°C. Temperatures above this level yielded partially stained individuals and 75 to 90°C temperatures resulted in a total denaturization of protein; thus no distinction between live and dead organisms would be possible.

Virtually all samples collected adjacent to the intake screens contained entirely unstained individuals; these results, in addition to laboratory testing, indicate no immediate effects in consuming the dye. Often the organisms had the dye particles in part or all of their guts. Although some organisms sampled from the discharge regions were partially stained (indicating a possible moribund condition), most were either wholly stained or unstained. As expected, large-bodied cladocerans, copepods and even rotifers were stained, indicating their greater susceptibility to entrainment mortality. Preliminary calculating of entrainment, plus sampler mortality, indicated that fewer than 1.0% of the returning organisms were dead. The fact that these organisms have short reproductive cycles facilitates the recovery of their population numbers in downstream waters. These data are similar to the estimate obtained for Lake Sangchris (Waite 1979a).

Of the two methods examined here, the dye technique was far superior in terms of simplicity of both field and laboratory procedures. Since several larval fish collected with the zooplankton were also dyed, this method, with modificaitons, may be also effective for mortality studies of larval fish.

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SECTION 7

BENTHIC INVESTIGATIONS AT COFFEEN LAKE

by

Gary L. Warren and James H. Buckler

ABSTRACT

Eighteen benthic collections were made at Coffeen Lake during the study period in order to ascertain the effects of new wastewater treatment facilities and the heated discharge upon the macroinvertebrate community. Mean total density, biomass and dominant major taxonomic groups were similar to those of Lakes Sangchris and Shelbyville, Illinois, however, all three lakes are relatively unproductive when compared to many other lakes in North America and throughout the world. One hundred eleven macroinvertebrate taxa were collected from Coffeen Lake; three major taxonomic groups, Oligochaeta, Chironomidae, and Chaoboridae, dominated the lake in total abundance. These same groups, along with Ephemeroptera, dominated total biomass. Dominant oligochaetes included unidentified immatures, Naididae, *Dero digitata*, *Aulodrilus pigueti*, and *Paranais frici*; dominant chironomids were: *Tanypus*, *Coelotanypus*, *Polypedilum*, *Cryptochironomus*, and *Procladius*. The lone dominant chaoborid was *Chaoborus punctipennis*.

Station 1 was the sampling location nearest the heated discharge, and was overwhelmingly predominated by the oligochaete taxa listed above; predatory midges were also dominant at this location. High temperatures and low dissolved oxygen concentrations during the summer months excluded many taxa from the discharge area. The Station 2 community was dominated by *C. punctipennis* and consistently had the lowest biomasses, densities, and numbers of taxa of all stations throughout the study. The extensive profundal zone and summer thermal stratification prevented diversity at Station 2 from being greater. The communities at Stations 3 and 4 were dominated by Chironomidae and were typical of shallow midwestern lakes. Diversity index values indicated little stress on the communities at both locations. A general slight increase in density, biomass, and diversity as the study progressed was noted at all stations except Station 2, indicating a slight improvement in benthic habitat quality during the two-year study period.

INTRODUCTION

Benthic macroinvertebrate communities, due to their trophic position, are an important component of freshwater ecosystems. The densities, biomasses, and taxonomic compositions of such communities are determined by abiotic and biotic factors imposed within the ecosystem; therefore, these complexes of organisms are indicative of the conditions that have prevailed during their development and aid in the assessment of the water quality and biological condition of lakes and streams.

The benthic investigation at Coffeen Lake has been conducted as a part of the program to evaluate the operational effects of CIP's Coffeen Power Station. The specific objectives of the benthos program were: (1) to determine if the quality of the benthic community improved as a result of refinements in wastewater treatment methods, (2) to evaluate the effect of waste heat discharge upon the benthic community, and (3) to compare the benthos of Coffeen Lake to that of two other central Illinois impoundments, Lakes Sangchris and Shelbyville.

METHODS AND MATERIALS

Eighteen benthos collections were obtained from Coffeen Lake during the study period (September and November, 1978; January, March, May, June, July, August, September, and November, 1979; January, March, May, June, July, August, September, and November, 1980). Each collection consisted of 40 samples; two replicate grabs were taken at each of five sampling sites along transects at Stations 1, 2, 3, and 4 (Fig. 1.2). Samples were obtained with a petite ponar dredge (surface area sampled = 0.024 m^2), washed in a U.S. Standard No. 30 sieve bucket, and preserved with 10% formalin. In the laboratory each sample was examined separately under a stereodissecting microscope with magnification to 40X. Organisms were hand-picked from detritus and inorganic material, identified to the lowest positive taxonomic level utilizing the literature in Appendix A7.1, counted, and wet-weighed. Raw data were converted to number or milligrams of organisms per square meter.

Organisms that required slide-mounting for identification, such as Chironomidae and Oligochaeta, were cleared in 10% KOH solution or Amman's lactophenol and mounted in Polyvinyl Lactophenol or Hydramount. Identifications were then made using a compound microscope with magnification to 1000X.

Ancillary measurements taken concurrently with benthic collections included bottom depth and temperature and dissolved oxygen just above bottom. Measurements taken during collections from July 1980 through November 1980 are included in Appendix A7.2.

RESULTS AND DISCUSSION

In order to examine the benthos of Coffeen Lake in perspective, data describing the benthic communities of two other central Illinois impoundments, Lakes Sangchris and Shelbyville, are presented for comparative purposes. Both Lake Sangchris and Lake Shelbyville are newer and larger than Coffeen Lake, but are similar in many key morphometric characteristics (Table 7.1). Lake Sangchris was created between 1964 and 1966 as a source of cooling water for Commonwealth Edison Company's coal-fired Kincaid Station. The lake is supplied by a low-order stream (Clear Creek) and has extensive littoral areas. Lake Shelbyville was completed in 1970 by damming the Kaskaskia River. The primary purpose of the lake is flood control, hence, the water level is subject to fluctuation throughout the year (McNurney and Larimore 1980). Swadener and Buckler (1979) found the two lakes to be similar in mean biomass, mean density, and major taxonomic group composition.

Table 7.1 Comparison of major morphometric characteristics of Lakes Coffeen, Sangchris, and Shelbyville.

Parameter	Coffeen Lake	Lake Sangchris	Lake Shelbyville
Surface area	446 ha	876 ha	4,490 ha
Mean depth	5.7 m	4.6 m	4.9 m
Maximum depth	17.7 m	13.7 m	19.8 m
Volume	$27.2 \times 10^6 m^3$	$37.4 \times 10^6 m^3$	$267.0 \times 10^6 m^3$
Surface/volume ratio	$0.16\ m^{-1}$	$0.22 m^{-1}$	$0.17 m^{-1}$
Volume development	0.97	1.08	0.75
Shoreline development	10.6	14.2	11.7

One hundred eleven macroinvertebrate taxa were collected from Coffeen Lake over the course of the two-year study; the number of taxa collected during a single sampling period ranged from 26 in January 1979 to 56 in May 1980. During the two-year (1976-1977) study of Lakes Sangchris and Shelbyville, 88 and 78 taxa, respectively, were collected with ranges of 29 to 48 taxa found at Lake Sangchris and 24 to 44 taxa at Lake Shelbyville (Swadener and Buckler 1979). The total number of taxa present at Coffeen Lake appears much larger than the total taxa at Lakes Sangchris and Shelbyville; however, oligochaetes collected from the latter two lakes were not identified past the Class level, while 32 separate oligochaete taxa were identified from Coffeen Lake. Without these additional taxa the total at Coffeen Lake falls within the range between Lakes Sangchris and Shelbyville.

Table 7.2 compares the mean total density and biomass at Lakes Coffeen, Sangchris, and Shelbyville. As was the case with total taxa, values from Coffeen Lake appear similar to those of the other central Illinois lakes (an improved method of enumerating oligochaetes accounted for the mean density at Coffeen Lake being substantially higher than the other lakes); however, the values listed for all three lakes are quite low when compared to those of Hayes' (1957) worldwide study of 251 lakes ranging from high to low productivity. The lowest mean biomass reported by Hayes was 2,360 mg/m^2 for lakes of the Finnish region. Data from a wide variety of lakes summarized by Wetzel (1975) also support the conclusion that the benthic community of Coffeen Lake appears to be not highly productive.

Table 7.2. Mean total biomass and density of the benthic communities of Lakes Coffeen, Sangchris, and Shelbyville.

Lake	Biomass* (mg/m^2)	Density (no./m^2)
Coffeen	1339	1465
Sangchris	1381	1015
Shelbyville	1415	1081

*excludes weight of Mollusca

The seasonal fluctuations in mean total biomass and mean total density at Lakes Coffeen, Sangchris, and Shelbyville are presented in Figure 7.1. At Coffeen Lake, mean density ranged from 504 organisms/m^2 in January 1979 to 3,460 organisms/m^2 in June 1980. Mean biomass ranged from 557 mg/m^2 in September 1978 to 2,776 mg/m^2 in June 1980 (biomass of Mollusca excluded). Mean densities and biomasses were generally lower during the winter months and highest in the summer, a pattern of seasonal fluctuation which is unlike that

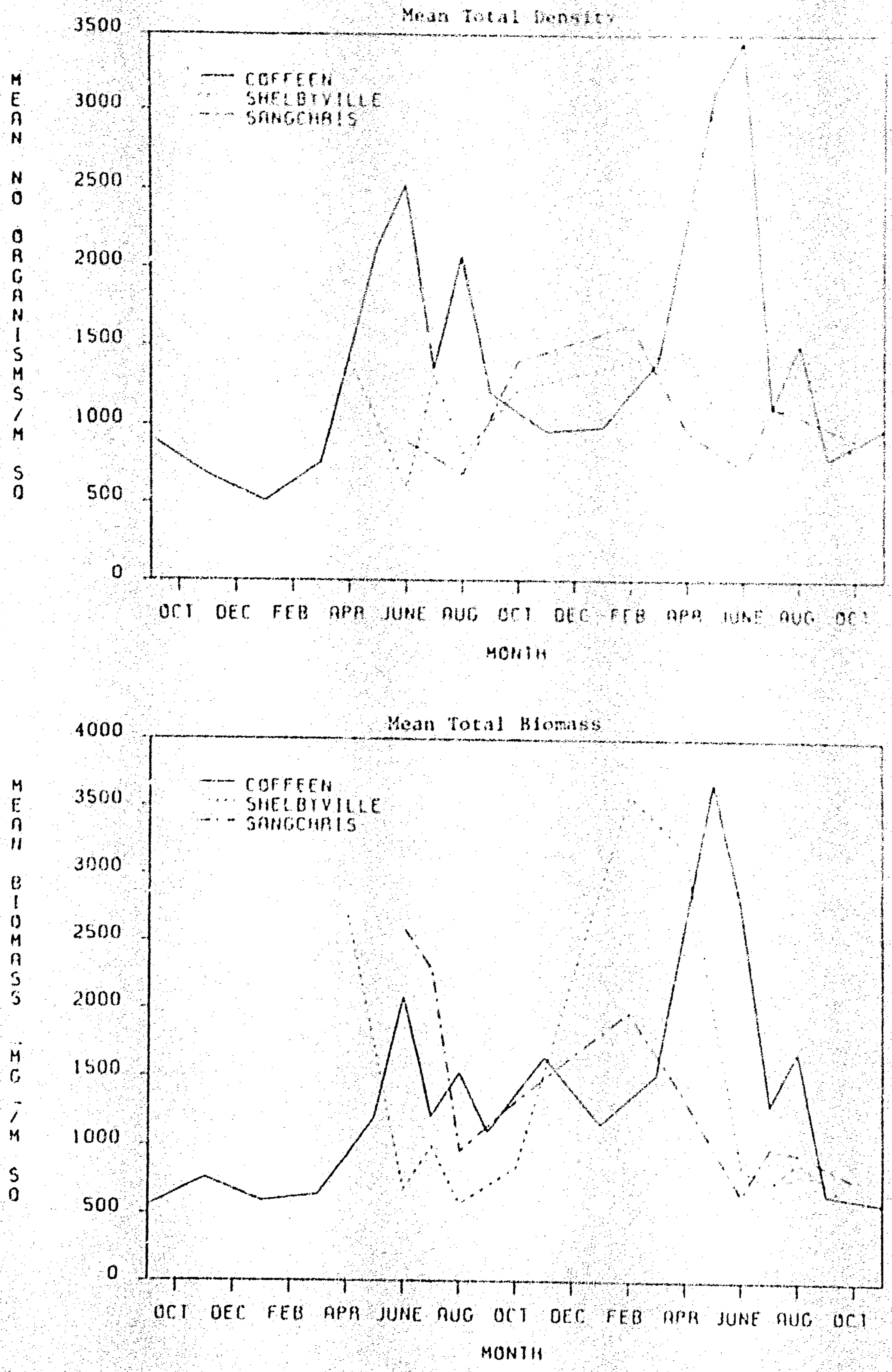


Figure 7.1. Seasonal fluctuations in mean total densities and biomass of benthic organisms collected from Lakes Coffeen, Sangchris, and Shelbyville.

typically found in lakes. Density and biomass of lentic benthic communities are generally at their lowest point in early summer due to emergence, mortality, and predation. Reproduction then causes the numbers and biomass to increase throughout the summer. The rate of increase is slow, however, due to continued emergence, mortality, and predation. Populations are at their highest levels in late fall and early winter when emergence has, for the most part, ceased. Biomass continues to increase during the winter, while densities may decrease slightly (Wetzel 1975). In a normal situation, density and biomass during winter would expectedly be much greater than in summer. This pattern was not evident in the data collected from Coffeen Lake due, probably, to the sieve size employed during sample processing. The 600 um sieve used undoubtedly allowed many early instar insects and immature oligochaetes to escape during the processing procedure. The real seasonal pattern of fluctuation at Coffeen Lake was probably similar to that of a typical lake.

Mean monthly biomass and density values from Lakes Sangchris and Shelbyville (Fig. 7.1) are not directly comparable to those from Coffeen Lake because the studies occurred in different years. It is evident from Figure 7.1 that seasonal fluctuations in biomass at the three lakes were at times very similar, while fluctuations in density at Coffeen Lake occurred in a manner exactly opposite to that at Lakes Sangchris and Shelbyville.

Three major groups of organisms, Oligochaeta (aquatic worms), Chironomidae (true midges), and the phantom midge, <u>Chaoborus</u> <u>puntipennis</u>, dominated the benthic community of Coffeen Lake. These groups accounted for 38.1, 34.6, and 16.1%, respectively, of the total organisms collected, and 22.8, 30.8 and 11.8%, respectively, of the total biomass (Fig. 7.2). The insect order Ephemeroptera (mayflies), although not a dominant group in total numbers, accounted for 26.9% of the total biomass (Fig. 7.2). Previous studies have shown these same major groups to be dominant (accounting for nearly 90% of the total numbers and biomass) in several other Illinois lakes (Dufford et al. 1977a and b, 1978a and b, Swadener and Buckler 1979). Figures 7.2 and 7.3 compare the percent compositions, mean total densities and mean total biomass of the major groups dominating the benthic communities at Lakes Coffeen, Sangchris, and Shelbyville. Mean densities of Oligochaeta at Coffeen Lake are not comparable to those at

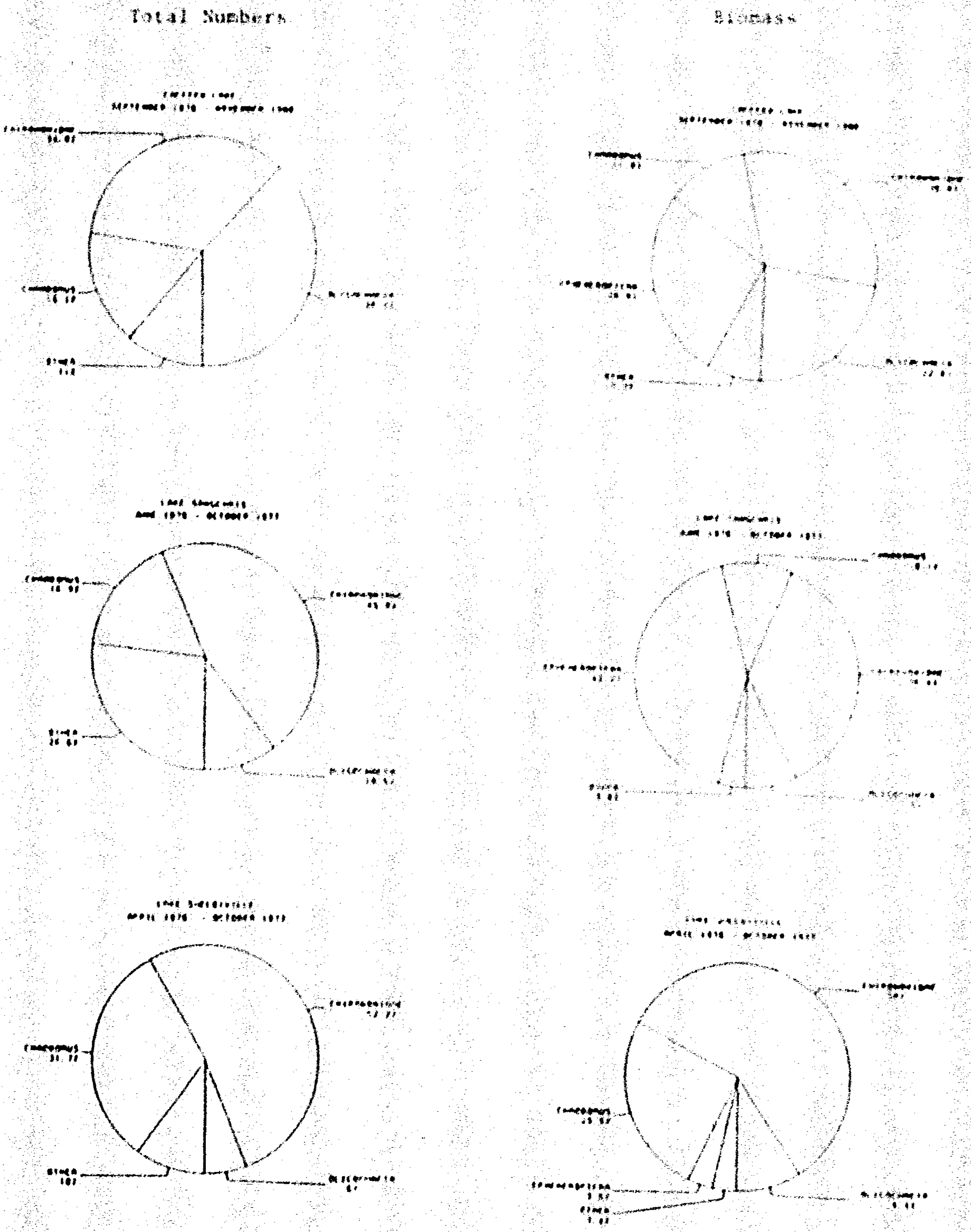


Figure 7.2. Per cent composition of total numbers and biomass of the major taxonomic groups collected from Lakes Coffeen, Sangchris, and Shelbyville.

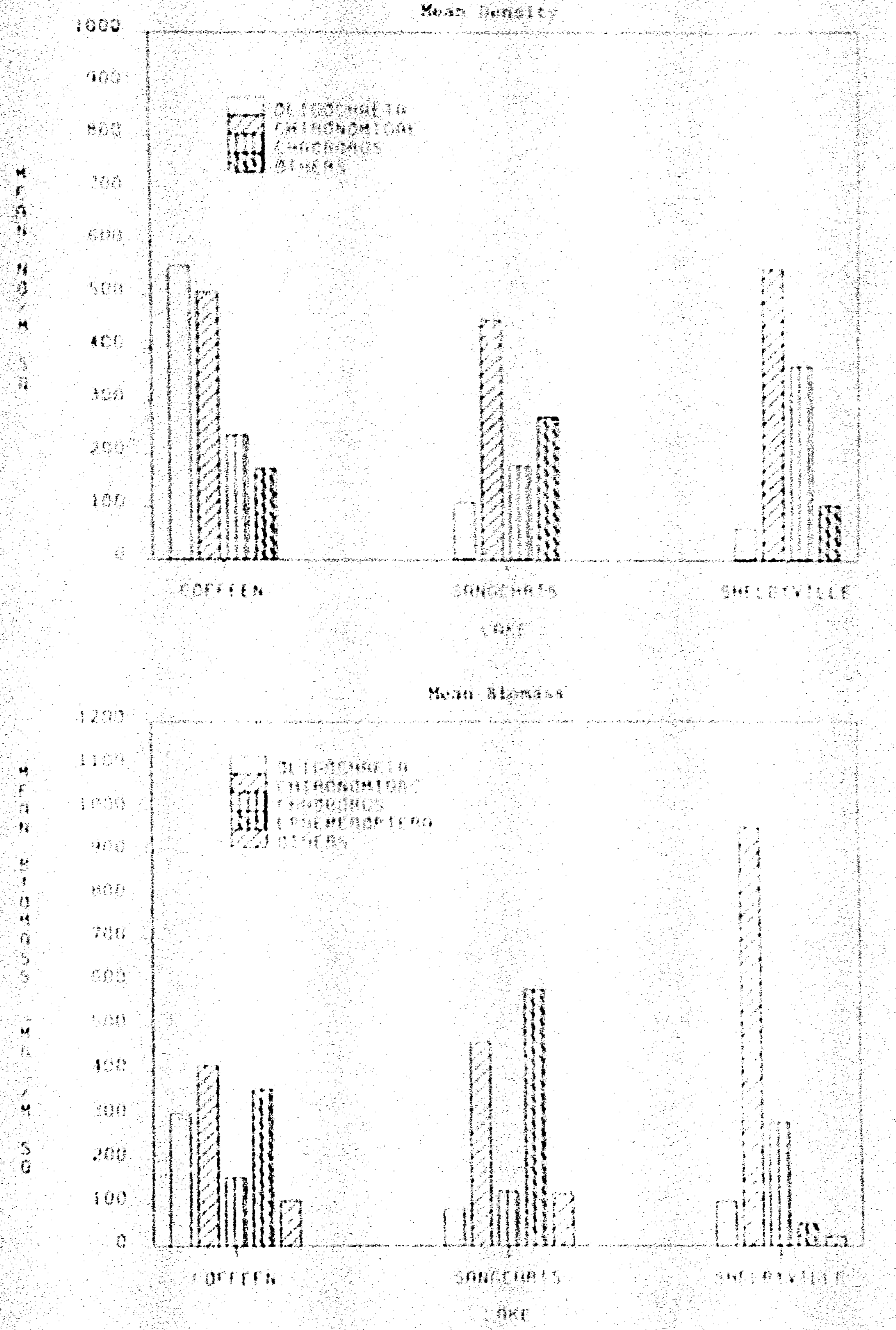


Figure 7.3. Mean density and biomass of the major taxonomic groups collected from Lakes Coffeen, Sangchris, and Shelbyville.

Lakes Sangchris and Shelbyville due to the aforementioned differences in counting methods; mean biomasses of Oligochaeta are comparable. Differences among the lakes can generally be attributed to morphometric variations intrinsic to the individual basins, rather than to trophic (age), chemical, or thermal factors. The mean biomasses, mean densities, and percent compositions of the major groups dominating Coffeen Lake are very similar to those of Lake Sangchris, with the exception of Ephemeroptera and Oligochaeta biomass (Fig. 7.2 and 7.3). Over 95% of the Ephemeroptera biomass at both lakes is constituted by the large mayfly <u>Hexagenia</u>, a burrowing detritivore that prefers soft sediments (silt) in shallow areas (Hunt 1953, Beatty and Hooper 1958, Cowell and Hudson 1967, Swanson 1967, and Hall 1972). The expansive littoral areas of Lake Sangchris and the relative lack of such areas at Coffeen Lake may account for the mean Ephemeroptera biomass at the former lake exceeding that of the latter by more than 200 mg/m^2. Mean total Oligochaete biomass at Coffeen Lake exceeded that of Lakes Sangchris and Shelbyville by over 100% (Fig. 7.3). The highest densities of Oligochaetes at Coffeen Lake occurred at Station 1 (nearest the discharge). Worm populations typically thrive in heated areas (provided the temperature does not exceed tolerance levels) and this may account for the higher oligochaete biomass at Coffeen Lake. Although Lake Sangchris also receives a heated discharge, estimated biomass of oligochaete populations may have been lower than at Coffeen Lake because the discharge station collected by Swadener and Buckler (1979) was 1.5 kilometers farther from the discharge canal than was Station 1 at Coffeen Lake; therefore, Coffeen Lake Station 1 received more thermal loading which resulted in larger populations and biomass of Oligochaeta.

The mean total densities of Chironomidae at Lakes Coffeen, Sangchris, and Shelbyville were all between 450 and 550/m^2; however, biomass of Chironomidae at Lakes Coffeen and Sangchris was much lower than that at Lake Shelbyville (Fig. 7.3). This difference was accounted for by the presence of the midge genus <u>Chironomus</u> in large numbers (20% of total density and 56% of total biomass) at Lake Shelbyville. The same genus was a very small constituent of the total density and total biomass at Lakes Coffeen and Sangchris; its occurrence at Coffeen Lake was quite rare (less than 1% of total density and biomass). <u>Chironomus</u> are tube-building herbivore-detritivores that are considered primary components of the profundal bottom fauna of very productive, eutrophic lakes (Jonasson 1977). The profundal areas that *Chironomus* seems to prefer are abundant at Coffeen Lake, and the genus is common in other central Illinois lakes. The relative absence of *Chironomus* at Coffeen Lake (as compared to Lake Shelbyville) may be due to lack of food availability or predation; the absence is not due to thermal factors, since the genus was most abundant at Station 1. During a study of Baldwin Lake, another Illinois cooling lake, Parkin and Stahl (1981) also found the highest density of *Chironomus* to occur in the discharge canal.

Rankings of the ten most dominant taxa in abundance and biomass at Lakes Coffeen, Sangchris, and Shelbyville are presented in Tables 7.3 and 7.4. Unidentified immature oligochaetes (probably of the family Tubificidae), *C. punctipennis*, and three genera of Chironomidae (*Tanypus*, *Coelotanypus*, and *Polypedilum*) were the most commonly collected invertebrates at Coffeen Lake. These taxa are all vital links in the food web of the lake. The Oligochaeta live on or in the substrate and obtain their nutrition from bacteria ingested along with sediments, detritus, and fecal materials (Brinkhurst 1974). *C. punctipennis*, *Tanypus*, and *Coelotanypus* are carnivorous; oligochaetes, midges and zooplankton are their principal prey (Wetzel 1975, Baker and McLachlan 1979, Pastorok 1980). *Polypedilum* are omnivorous, although many species may be strictly herbivore-detritivores (Merritt and Cummins 1978). Biomass was dominated by the mayfly *Hexagenia*, which accounted for nearly 47% of the total, but was present in relatively small numbers (1% of the total density). Other taxa dominant in biomass were the same as those dominant in relative abundance, with the exception of Bryozoa. This trophic (predator-prey) arrangement is typical for a lake of Coffeen's morphometric characteristics and latitude, and is similar to that of Lakes Sangchris and Shelbyville (Tables 7.3 and 7.4). The major difference in taxonomic ranking among the three lakes is the presence of two genera of Chironomidae (*Chironomus* and *Procladius*) in the top five at Lake Shelbyville that occurred in much smaller numbers at Lakes Coffeen and Sangchris. The reasons for the differences in abundance of *Chironomus* have been discussed previously. *Procladius* is a carnivorous member of the same subfamily (Tanypodinae) as *Tanypus* and *Coelotanypus*, which were among the top taxa in abundance and biomass at Lakes Coffeen and Sangchris. *Procladius* replaces the latter two genera at Lake Shelbyville due to its preference for a profundal habitat (Merritt and Cummins 1978, Swadener and Buckler 1979).

Table 7.3. Ranking of the ten most abundant (mean no./m^2) taxa collected at Lakes Coffeen, Sangchris, and Shelbyville.*

	Lake								
	Coffeen			Sangchris			Shelbyville		
Rank	Taxon	$\bar{x}$ no./m^2	% total	Taxon	$\bar{x}$ no./m^2	% total	Taxon	$\bar{x}$ no./m^2	% total
1.	Unidentified immature Oligochaetes	283	19.3	*Chaoborus punctipennis*	180	17.7	*Chaoborus punctipennis*	352	32.6
2.	*Chaoborus punctipennis*	238	16.2	*Tanypus*	114	11.2	*Chironomus*	215	19.9
3.	*Tanypus*	115	7.9	*Coelotanypus*	104	10.2	*Procladius*	118	10.9
4.	*Coelotanypus*	113	7.7	Oligochaeta	102	10.0	Oligochaeta	58	5.4
5.	*Polypedilum*	73	5.0	*Palpomyia* complex	78	7.7	*Polypedilum*	48	4.4
6.	Naididae	70	4.8	*Chironomus*	55	5.4	*Cryptochironomus*	34	3.1
7.	*Dero digitata*	63	4.3	*Corbicula manilensis*	46	4.5	*Tanypus*	28	2.6
8.	*Cryptochironomus*	48	3.3	*Caenis*	45	4.4	*Mesocyclops* edax	25	2.3
9.	*Palpomyia* complex	48	3.3	*Procladius*	39	3.8	*Harnischia*	24	2.2
10.	*Procladius*	39	2.6	*Polypedilum*	33	3.3	Hydracarina	15	1.4

*Data from Lakes Sangchris and Shelbyville modified from Swadener and Buckler 1980.

Table 7.4. Ranking of the ten taxa most abundant in biomass[a] ($\overline{x}$ mg/m^2) at Lakes Coffeen, Sangchris, and Shelbyville.*

	Lake								
	Coffeen			Sangchris			Shelbyville		
Rank	Taxon	$\overline{x}$ no./m^2	% total	Taxon	$\overline{x}$ no./m^2	% total	Taxon	$\overline{x}$ no./m^2	% total
1.	*Hexagenia*	358	46.8	*Hexagenia*	641	46.4	*Chironomus*	798	56.4
2.	*Coelotanypus*	221	16.5	*Chironomus*	224	16.2	Oligochaeta	280	19.8
3.	Unidentified Immature Oligochaetes	193	14.4	*Chaoborus punctipennis*	127	9.2	*Chaoborus punctipennis*	99	7.0
4.	*Chaoborus punctipennis*	158	11.8	Oligochaeta	77	5.6	*Hexagenia*	44	3.1
5.	Bryozoa	85	6.3	*Tanypus*	76	5.5	*Procladius*	40	2.8
6.	*Tanypus*	79	5.9	*Coelotanypus*	66	4.8	*Cryptochironomus*	21	1.5
7.	*Cryptochironomus*	26	1.9	*Cryptochironomus*	22	1.6	*Tanypus*	20	1.4
8.	Naididae	25	1.9	*Palpomyia complex*	21	1.5	*Pseudo chironomus*	16	1.1
9.	*Procladius*	18	1.2	*Procladius*	17	1.2	*Glyptotendipes*	14	1.0
10.	*Dero digitata*	18	1.2	*Corbicula maniliensis*	17	1.2	*Coelotanypus*	7	0.5

[a] Biomass of Mollusca excluded.

*Data from Lakes Sangchris and Shelbyville modified from Swadener and Buckler 1980.

Station 1

Station 1 was the sampling location nearest the discharge canal, hence, it was the area most thermally influenced. Mid-channel bottom temperatures ranged from between 10 and 15°C during the winter months to a maximum of 35°C during the summer (Fig. 7.4). Temperatures in more shallow areas of coves reached 40°C during the summer (Appendix A7.2). Mid-channel dissolved oxygen concentrations on the bottom ranged from near 1 ppm in late August and September to 9 and 10 ppm in the winter months (Fig. 7.4). The bottom in the area of Station 1 was covered with deposits of silicate slag that originated from the power plant; the physical properties of these depositions combined with the high temperatures and low levels of dissolved oxygen to make the Station 1 habitat intolerable to many benthic taxa during the summer months.

Oligochaetes overwhelmingly predominated the benthic community at Station 1 (Fig. 7.5 and 7.6), accounting for 69% of the total organisms collected. Densities and biomasses of worm populations were highest during spring, dropped in June and July and peaked secondarily in late summer (Fig. 7.6). The high temperatures and low concentrations of dissolved oxygen present during the summer apparently did not exceed oligochaete tolerance levels, and may have benefitted them by increasing their bacterial food source (Wetzel 1975) and excluding their predators, such as *Coelotanypus* and *Tanypus*. Twenty-seven oligochaete taxa were collected from Station 1, eight more than at any other station. The most abundant oligochaete taxa were: unidentified immatures (686/m^2), unidentified Naididae (225/m^2), *Dero digitata* (206/m^2), *Paranais fricci* (139/m^2), and *Aulodrilus pigueti* (72/m^2). *D. digitata* and *P. frici* were the species most abundant during the population peaks of spring; *P. frici* was absent from all stations but the discharge, while *D. digitata* averaged less than 18/m^2 at all other stations. Unidentified immatures were the most abundant oligochaetes during the smaller population peaks of late summer.

Other important taxa at Station 1 were *C. punctipennis* (160/m^2) and the chironomid *Polypedilum* (125/m^2). Mature *C. punctipennis* larvae are inhabitants of the profundal sediments during the day and are planktonic predators at night. This ability to migrate through the water column may have

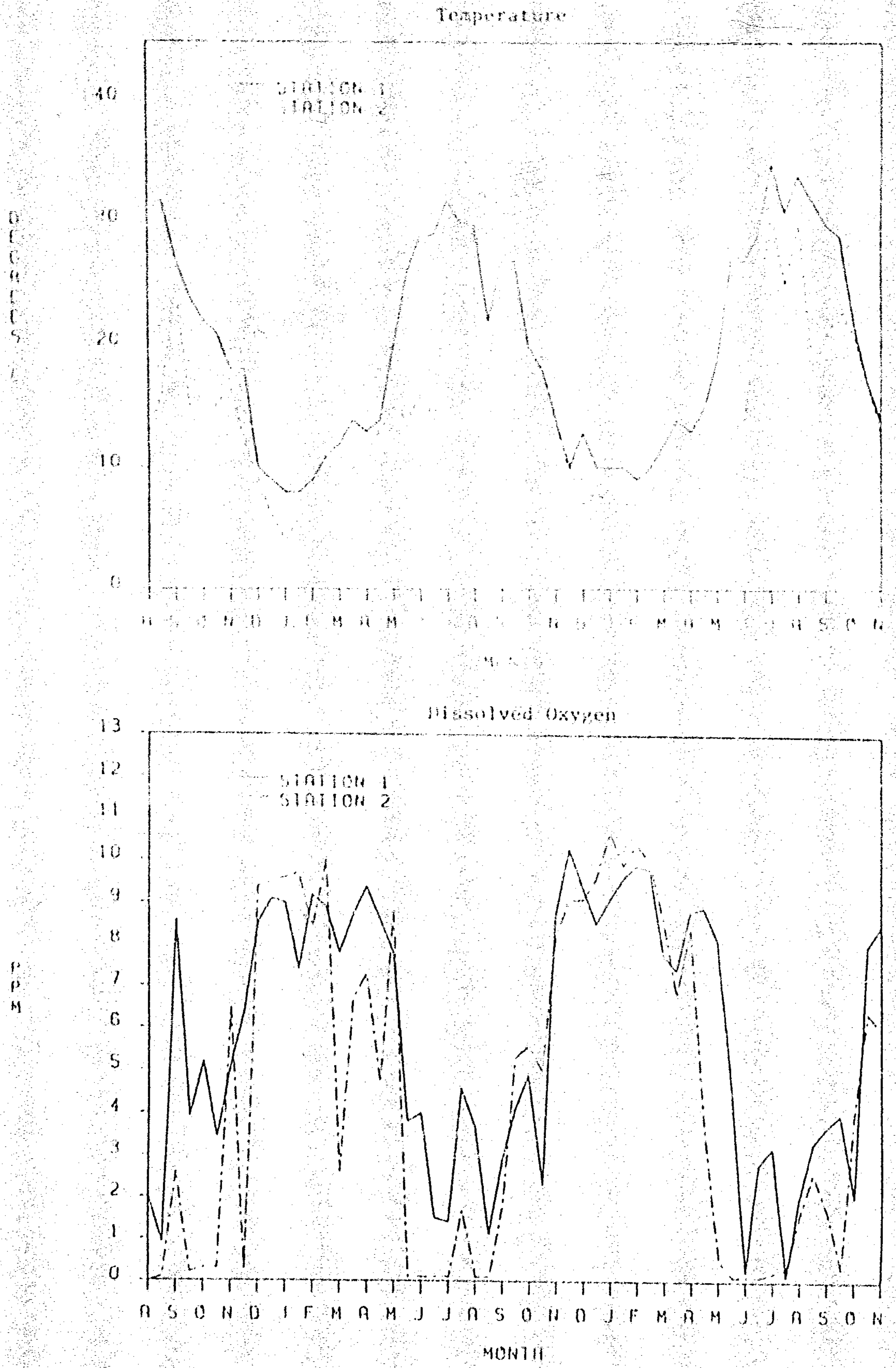


Figure 7.4. Semi-monthly mid-channel temperature and dissolved oxygen measured near bottom at Coffeen Lake Stations 1 and 2 from August 1978 through November 1980.

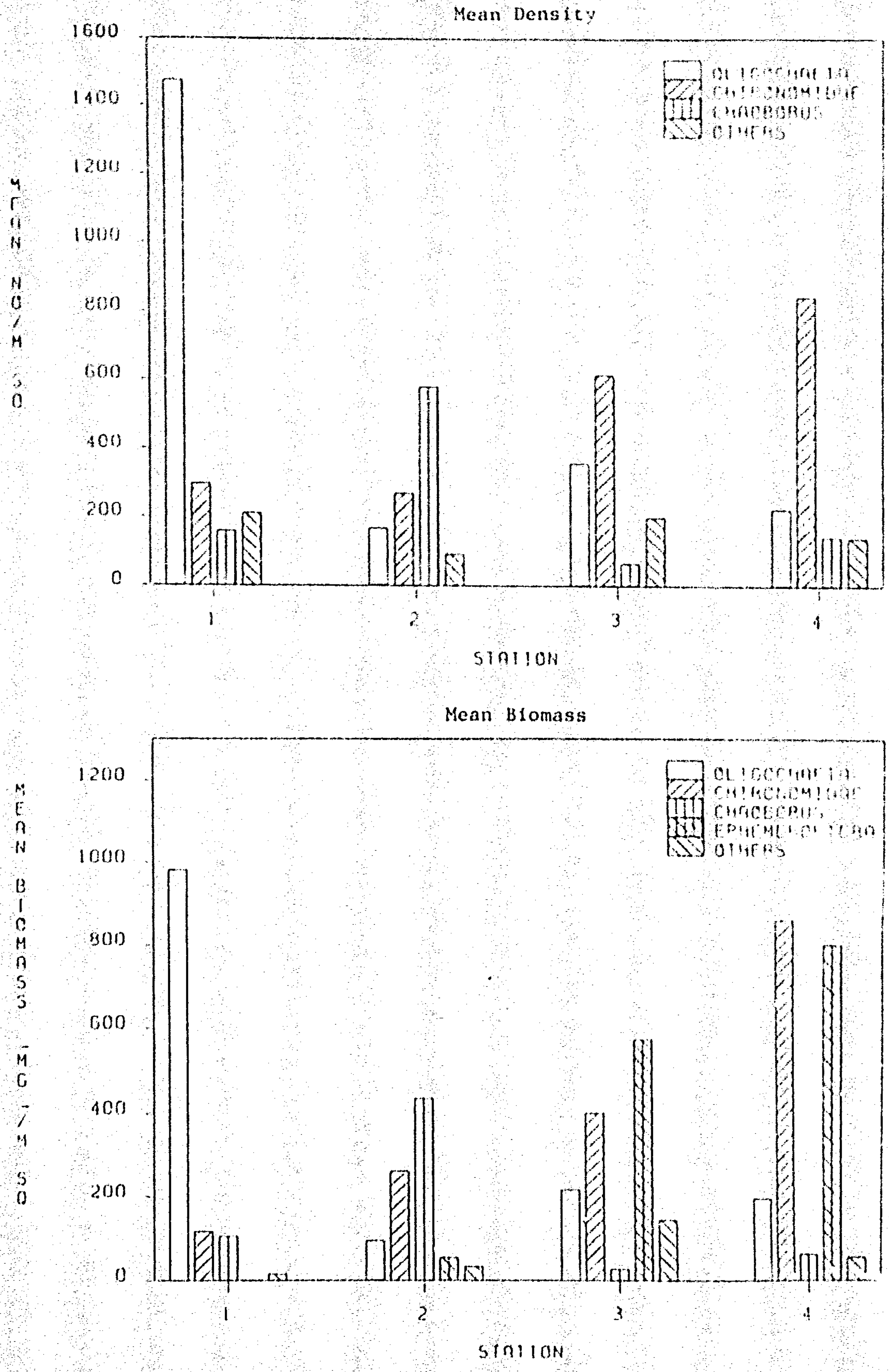
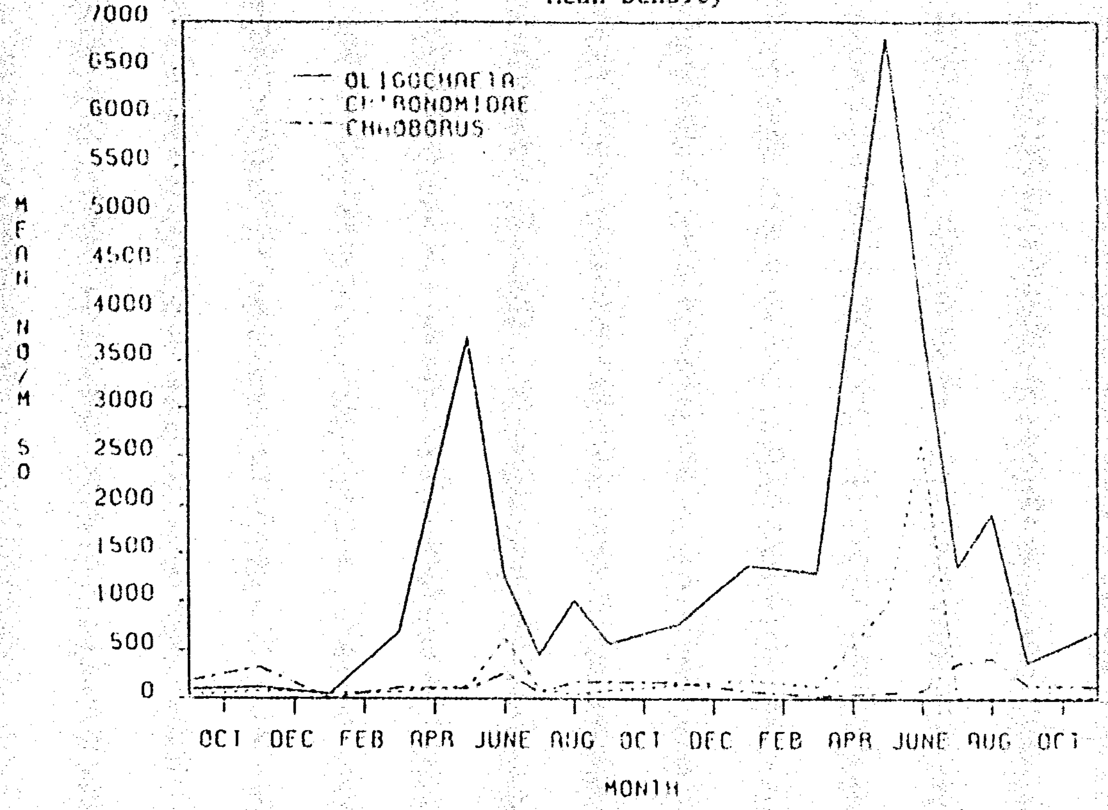


Figure 7.5. Mean density and biomass of major taxonomic groups collected at Coffeen Lake from September 1978 through November 1980.

Mean Density



Mean Biomass

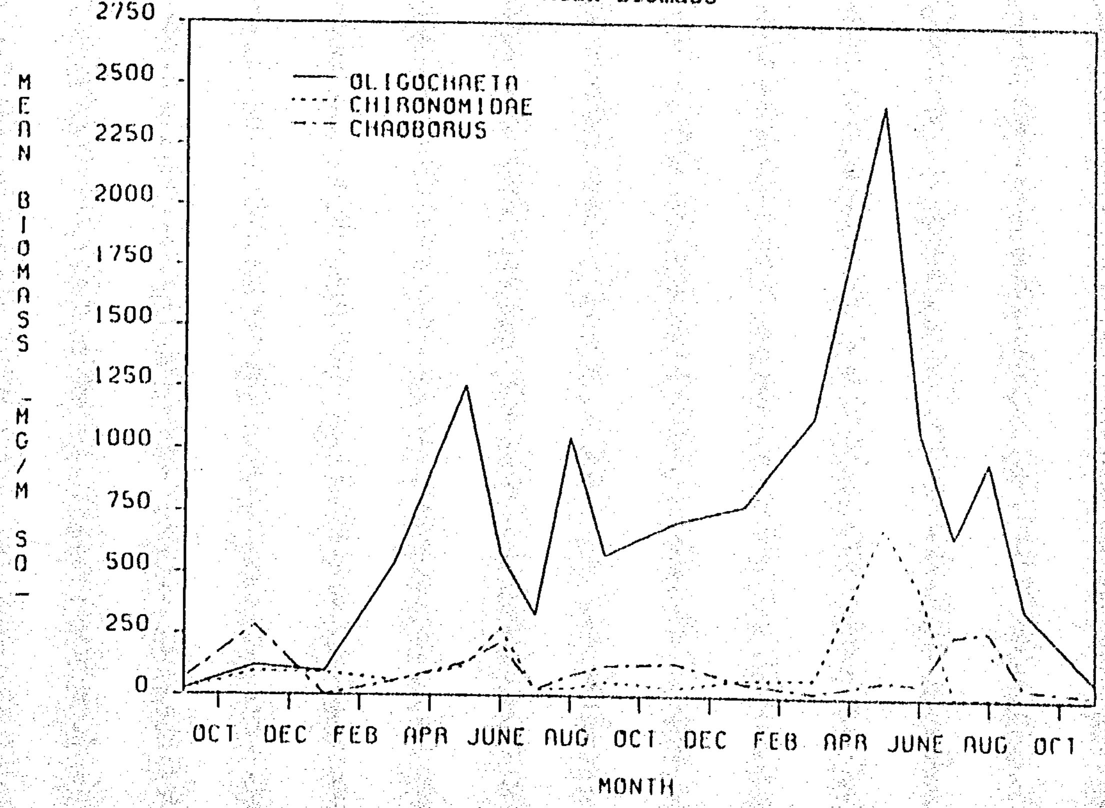


Figure 7.6. Seasonal fluctuations in mean density and biomass of major taxonomic groups collected at Coffeen Lake Station 1 from September 1978 through November 1980.

allowed these larvae to tolerate the high temperatures and low oxygen concentrations that characterized the bottom at Station 1 at times during the warmer months. *Chaoborus* feed largely on zooplankton but have exhibited a preference for Oligochaeta (Wetzel 1975), a food source in great abundance at Station 1. Peaks in *C. punctipennis* density and biomass usually occurred one month after peaks in oligochaete abundance (Fig. 7.6).

The largest densities of *Polypedilum* occurred at Station 1, making it one of the few taxa most abundant at this location. However, in only one collection (June 1980) were individuals of this genus present in large numbers (1921/m^2). Many *Polypedilum* species are associated with aquatic macrophytes (Berg 1950), while others are tube builders in soft sediments (Thut 1969). The genus includes herbivorous and predaceous species (Merritt and Cummins 1978). Since *Polypedilum* were not speciated in this study, the trophic role of the genus at Station 1 is difficult to ascertain.

The high temperatures measured in coves at Station 1 may have precluded many insect taxa. Gaufin and Hern (1971) reported a TL_m of 26.6°C for *Hexagenia limbata*. Hubbard and Peters (1978) reported that *Caenis* did not occur at temperatures above 30°C. An upper tolerance limit of 33°C has been indicated for many Chironomidae (Curry 1965). Densities of the predaceous midges *Tanypus* and *Coelotanypus* were low at Station 1 (3 and 7 individuals/m^2, respectively), and increased with distance from the discharge. *Tanypus* and *Coelotanypus* depend upon oligochaetes as a major food source and would be expected to be much more abundant in a similar habitat free of thermal influence. In addition to excluding taxa or causing depressed densities, high temperatures may cause community respiration to exceed biomass production, resulting in smaller, weaker individuals. Reduced fecundity is another serious sublethal effect of high discharge temperatures. Lowered egg production can cause recruitment to fall below the level needed for population maintenance, resulting in the local extinction of a species. Despite any of these influences of elevated temperatures at Station 1, total density and biomass and the densities and biomasses of the major taxonomic groups present increased from summer 1979 to summer 1980 (Fig. 7.6).

Station 2

Heat originating from the power plant was dissipated prior to or at the dam area (Liehr 1979), so bottom temperatures at Station 2 were unaffected by the thermal discharge. The major factors influencing benthic community development at this location were depth and low concentrations of dissolved oxygen. Depths of collection sites ranged from three to 15m (Appendix A7.2). Mid-channel dissolved oxygen levels ranged from 9.0 to 10.0 ppm in late fall and winter to as low as 0.1 ppm during the period of thermal stratification in June, July, August, and September (Fig. 7.4) Dissolved oxygen never fell below 4.0 ppm in littoral areas of the coves sampled.

Station 2 had the lowest densities, biomasses, and taxa numbers throughout the study (Fig. 7.5). Organisms were collected from the littoral zone (3.0m or less) on only five occasions (September and November 1978, June, August, and November 1979). *C. punctipennis* predominated the Station 2 community (Fig. 7.5), accounting for 52% of the total abundance (579/m^2) and 50% of the total biomass (439 mg/m^2). As discussed previously, *C. punctipennis* are inhabitants of the profundal sediments during the day and migrate to feed in the limnetic zone at night; early instar larvae may be entirely limnetic (Wetzel 1975). The Station 2 habitat would seem to be the most conducive of all Coffeen Lake stations for the development of a large *C. punctipennis* population. The habit of diel migration through the water column allowed these larvae to survive during the summer by rising from the hypolimnion to levels of higher oxygen concentration. During the period of summer stratification at Lake Shelbyville, *C. punctipennis* was found to be the only organism present in the hypolimnion (Swadener and Buckler 1979).

Other dominant taxa at Station 2 were: unidentified immature oligochaetes (94/m^2), the chironomids *Coelotanypus* (80/m^2), *Cryptochironomus* (44/m^2), *Procladius* (44/m^2), and biting midges (Ceratopogonidae) of the *Palpomyia* complex (51/m^2). These taxa, except for the oligochaetes, are predators with no special ability to withstand long periods of low oxygen concentration. The abundance of carnivorous taxa at Station 2 may have caused the densities of prey organisms (oligochaetes, zooplankton, and early instar chironomids) to be depressed, accounting for the overall low density and biomass at this station. Figure 7.7 illustrates a general trend toward an increase in numbers of Oligochaeta and Chironomidae during periods when the *C. punctipennis* population was at a low point and a corresponding decrease in numbers of oligochaetes and chironomids when the *C. punctipennis* population peaked. This trend was especially evident in June 1980 when densities and biomasses of Chironomidae and Oligochaeta peaked sharply while *C. punctipennis* density and biomass fell to the lowest point of the summer. Predation pressure by *C. punctipennis* may have been responsible for this cycle.

As at Station 1, total mean density and biomass of the benthic community, as well as the mean densities and biomasses of the major taxonomic groups, increased slightly from summer 1979 to summer 1980.

Stations 3 and 4

The benthic communities of Stations 3 and 4 are discussed together because of their similarity. Both are typical of what would be expected at a shallow lake of Coffeen's age and latitude. Temperatures were measured as high as 34°C during the summer months in coves at both locations, but temperature was not a critical factor at either area because it was not elevated for extended periods of time. Station 4 was usually slightly cooler and slightly more shallow than Station 3. Thermal stratification occurred during May, June, and July at Station 3 in both 1979 and 1980. Dissolved oxygen during this period was consistently below 4.0 ppm. The deep area of Station 4 stratified only during May of 1980 (Fig. 7.8).

The communities at Stations 3 and 4 were the most diverse at Coffeen Lake. Over 20 taxa were present in each collection. Only at Station 1 did the number of taxa per collection approach 20; however, most of these were oligochaete taxa. Chironomidae predominated both Stations 3 and 4 in density and Station 4 in biomass (Fig. 7.5). *Hexagenia* accounted for the largest percentage biomass at Station 3. The most abundant chironomids at both stations were tanypodines. *Coelotanypus* was the most dominant midge at Station 3 (161/m^2) while *Tanypus*

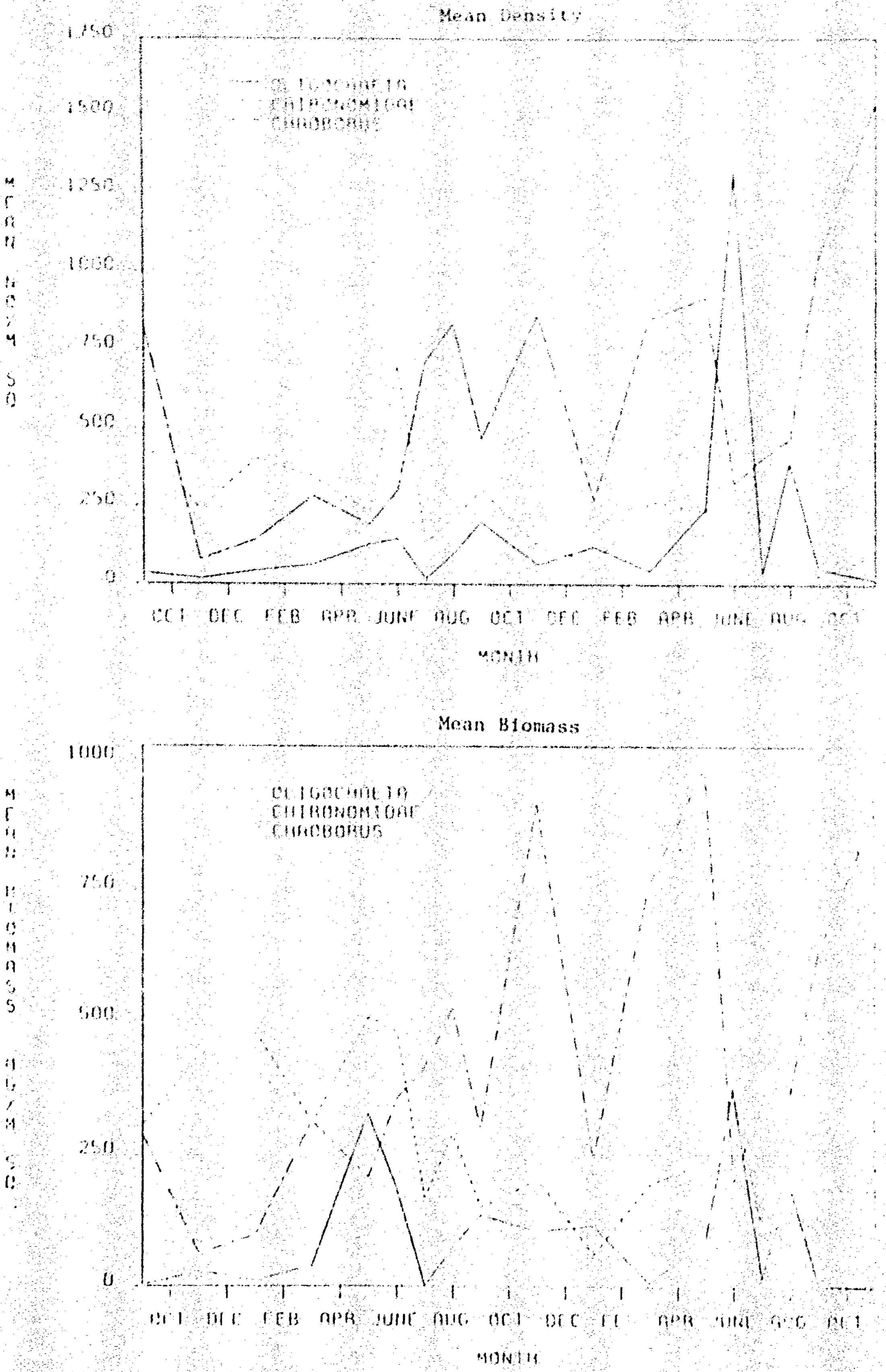


Figure 7.7. Seasonal fluctuations in mean density and biomass of major taxonomic groups collected at Coffeen Lake Station 2 from September 1978 through November 1980.

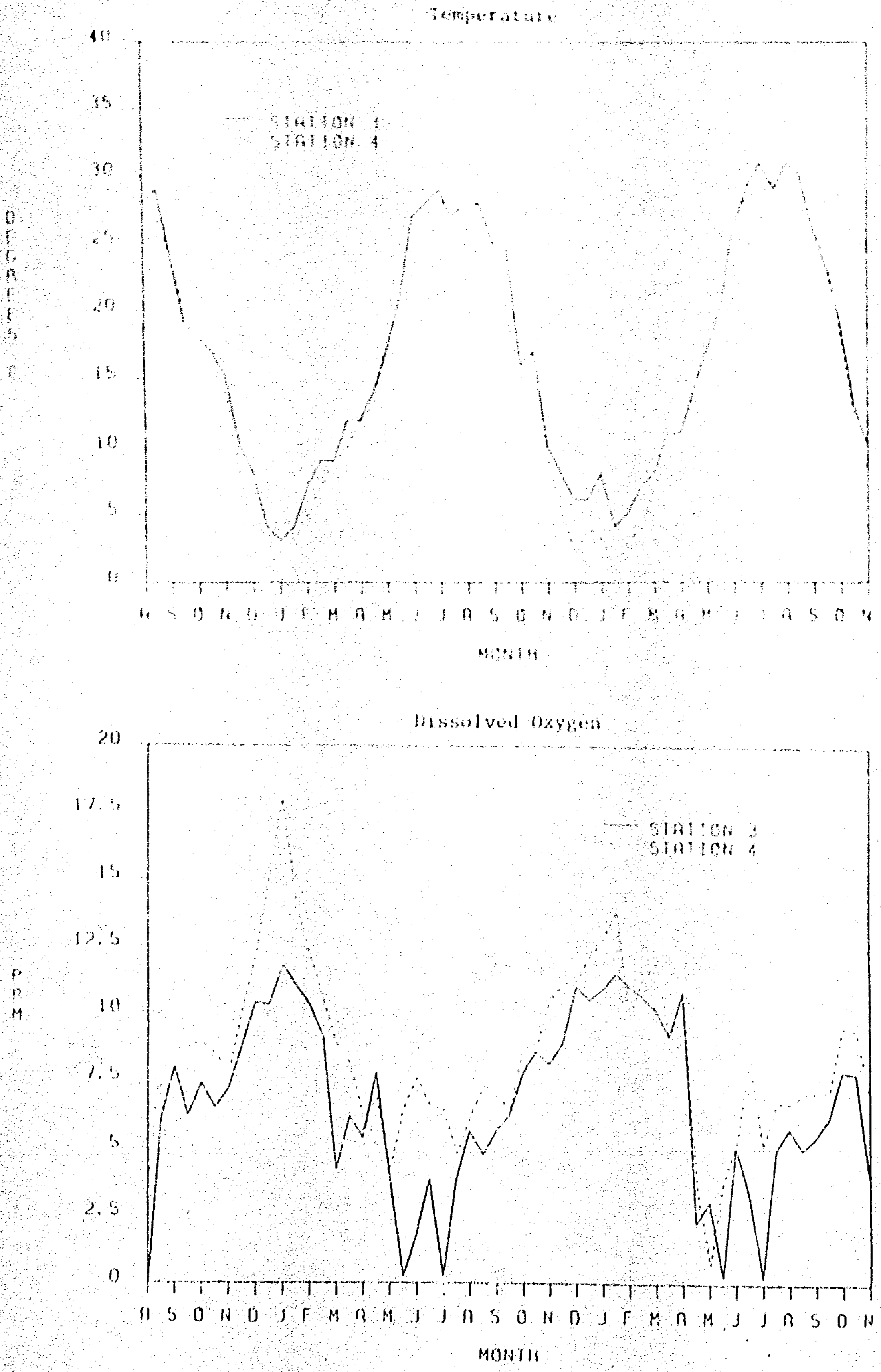


Figure 7.8. Semi-monthly mid-channel temperature and dissolved oxygen measured near bottom at Coffeen Lake Stations 3 and 4 from August 1978 through November 1980.

was predominant at Station 4 ($433/m^2$). Other midge taxa important to the Station 3 and 4 communities included Procladius (33 and $41/m^2$, respectively), Cryptochironomus (66 and $46/m^2$, respectively), Polypedilum (116 and $6/m^2$, respectively), and the Palpomyia complex (81 and $56/m^2$, respectively). Here, as at the stations previously discussed, many of the abundant midge taxa were predators. Several genera of Chironomidae were commonly collected at Stations 3 and 4, but were rare or absent in collections from the other two stations. Among these genera were: Ablabesmyia, Cladotanytarsus, Tanytarsus, Glyptotendipes, Pseudochironomus, Stictochironomus, and Microchironomus. This list includes taxa from a variety of trophic habits.

Unidentified immatures were the most abundant oligochaetes at Stations 3 and 4. Mean densities of these worms were $206/m^2$ at Station 3 and $158/m^2$ at Station 4. Other worm taxa that occurred were not nearly as abundant. Although a good forage base seemed to be present for C. punctipennis at Stations 3 and 4, mean density and biomass for the species were lower at these locations than at Stations 1 and 2. Lack of an extensive profundal zone or the inability to compete with the predaceous chironomidae may be reasons for the relatively low densities of C. punctipennis at Stations 3 and 4.

The burrowing mayfly Hexagenia was absent from Station 1 due to high discharge temperatures and an unstable bottom (silicate slag). Lack of littoral areas excluded the genus from Station 2. However, the habitat at Stations 3 and 4 was adequate for the establishment of a small population ($30/m^2$ at both stations). Hexagenia were major contributors to the biomass at both locations, accounting for 40% at Station 3 and 65% at Station 4. Hexagenia are burrowing detritivores that are able to exclude other taxa in competition for space by virtue of their size; in areas where large populations occur, it is possible for densities of other taxa to be depressed. This was not the case at Coffeen Lake. The most important role of Hexagenia in the lake may be that of a forage base for fish.

Figures 7.9 and 7.10 present the seasonal fluctuations in density and biomass of the major taxonomic groups at Stations 3 and 4. The pattern of peak values during the summer months at Stations 1 and 2 was not nearly as evident at Stations 3 and 4, but it did occur. Peaks in chironomid densities during June

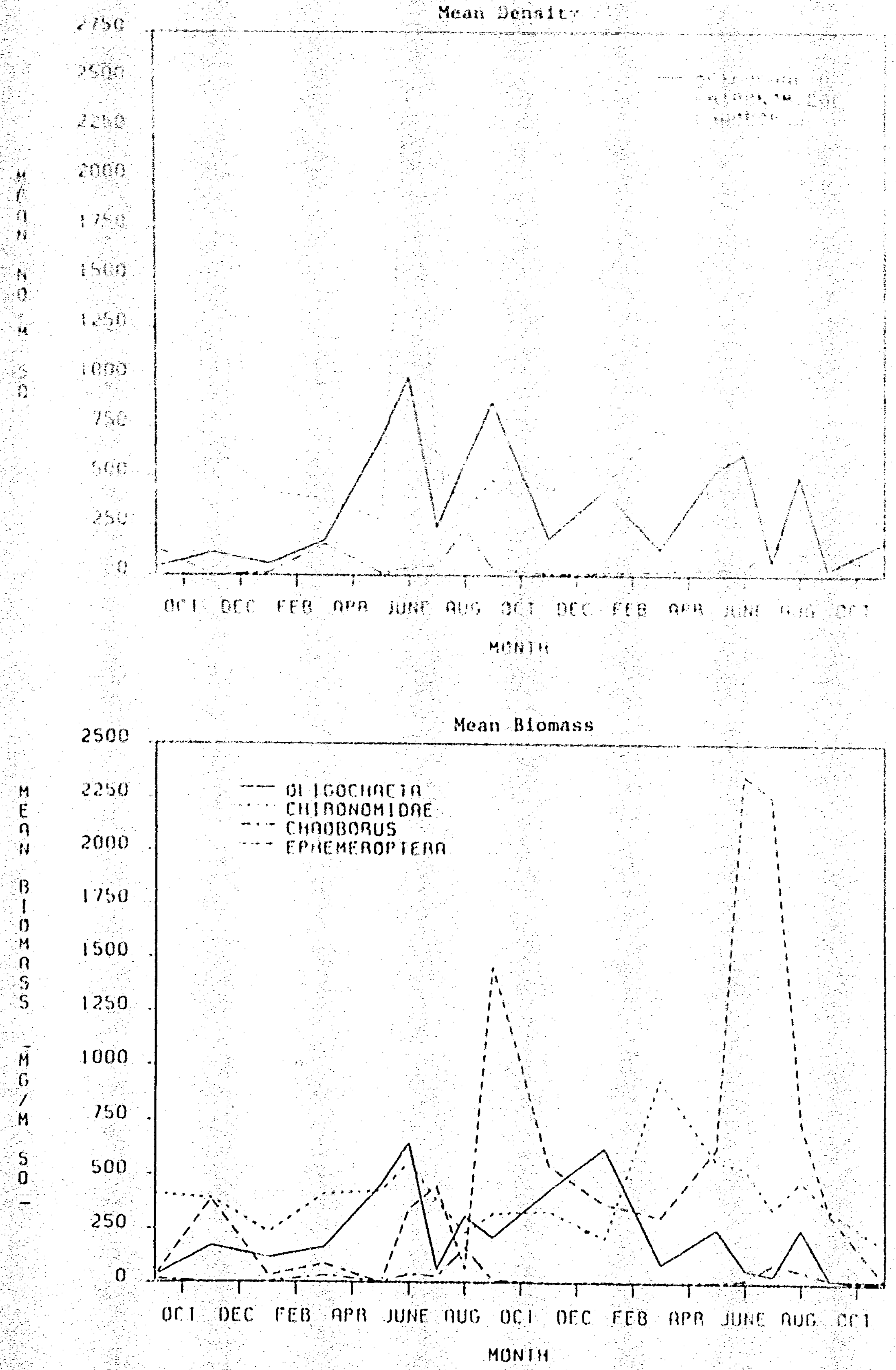


Figure 7.9. Seasonal fluctuations in mean density and biomass of major taxonomic groups collected at Coffeen Lake Station 3 from September 1978 through November 1980.

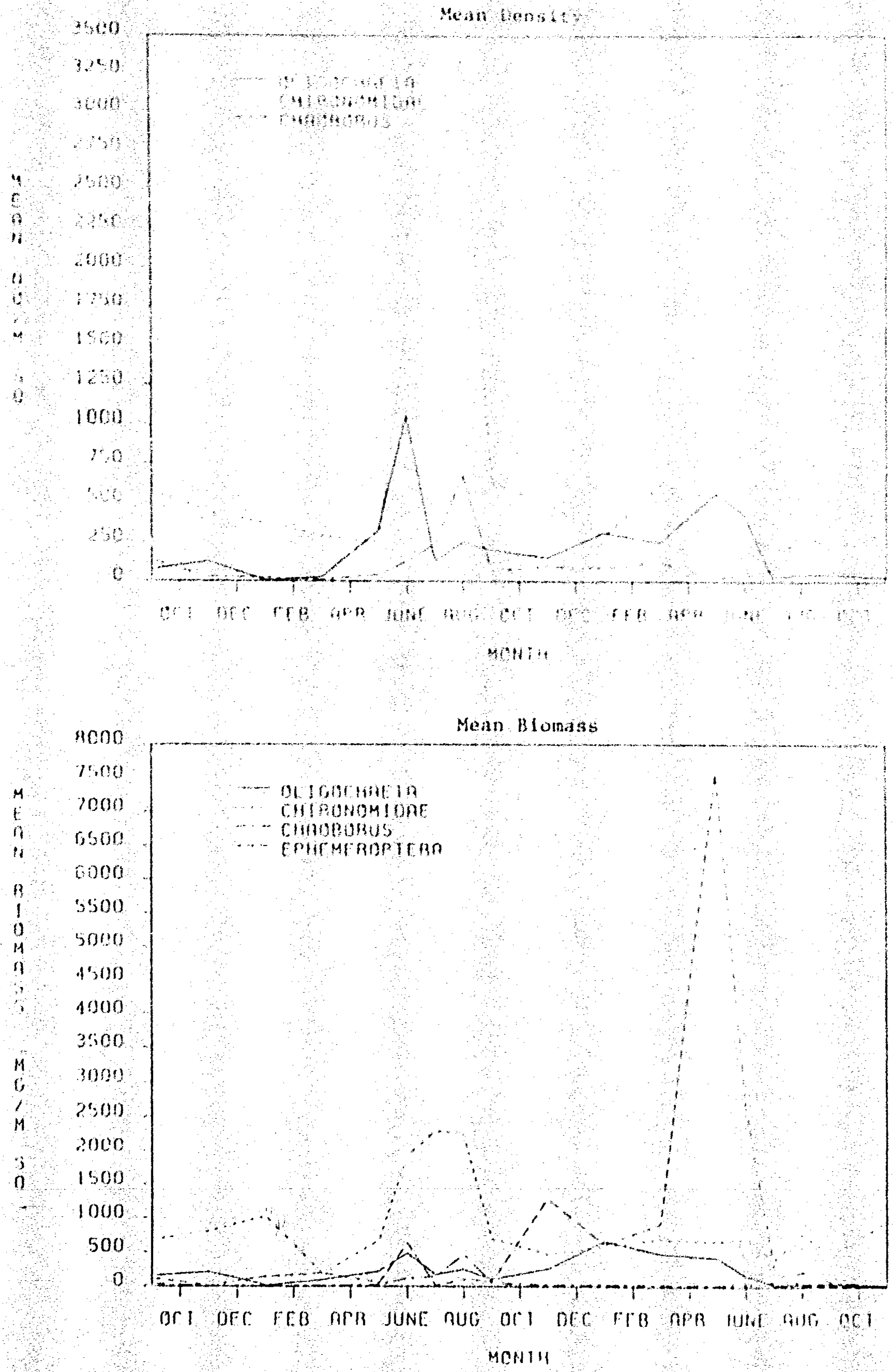


Figure 7.10. Seasonal fluctuations in mean density and biomass of major taxonomic groups collected at Coffeen Lake Station 4 from September 1978 through November 1980.

and July 1979 were due to rapid increases in *Polypedilum* abundance at Station 3 ($1537/m^2$) and *Tanypus* abundance at Station 4. No substantial increase in total density and biomass or densities and biomasses of the major taxonomic groups was noted over the course of the study at either Station 3 or 4.

Diversity and Redundancy

Diversity and redundancy indices are mathematical expressions that attempt to summarize community structure in order to provide a basis for comparison of sampling locations and habitat (water) qualities. The diversity index of Shannon (1948) takes into account the number of taxa from a given community and the numerical distribution of individuals among these taxa. Communities with few numbers of individuals distributed evenly among a large number of taxa have a high index value. Diversity values of less than 1 have been obtained in areas of heavy pollution, values between 1 and 3 in areas of moderate pollution, and values above 3 in clean water areas. Diversity indices are most accurate when all taxa tested are identified to the species level; however, due to the poor taxonomic state of many aquatic groups (i.e., the Chironomidae), identifications to this level are often impossible. In such situations diversity indices lose some of their accuracy and meaning.

Diversity values over the course of the Coffeen Lake study ranged from 0.51 at Station 2 in November 1980 to 4.00 at Station 3 in September 1979 and June 1980 (Table 7.5). Values at Station 3 never fell below 3.00, indicating a relatively stress-free habitat, and were consistently higher than at all other stations; the mean value at Station 3 was 3.53. Station 4 was the next most diverse station with a mean of 2.81, values above 3.00 were not uncommon at this location. Station 2 had the lowest mean diversity value (2.14), probably as a result of the occurrence of large numbers of a single taxon (*C. punctipennis*) and the extensive profundal zone which excluded many taxa during periods of thermal stratification. The highest value recorded at Station 2 was 3.66 in June 1980 when 37 taxa were collected, the most taxa that occurred in any collection at this station. All other values at Station 2 were below 3.0. Index values of 0.54 and 0.51 occurred during September and November 1980 at Station 2. These values were the lowest of the entire study and were the result

Table 7.5. Diversity ($\overline{d}$) and redundancy (r) values of the benthic community of each station and collection at Coffeen Lake from September 1978 through November 1980.

Station		1978		1979								1980							
		Sep	Nov	Jan	Mar	May	Jun	Jul	Aug	Sep	Nov	Jan	Mar	May	Jun	Jul	Aug	Sep	Nov
1	$\overline{d}$	1.72	2.24	2.63	2.50	2.83	3.10	2.09	2.56	3.38	2.37	2.45	2.59	3.26	3.20	1.49	2.61	2.05	1.19
	r	0.49	0.47	0.15	0.47	0.40	0.32	0.48	0.40	0.29	0.45	0.47	0.45	0.38	0.36	0.59	0.37	0.44	0.58
2	$\overline{d}$	2.31	2.58	1.87	2.96	2.94	2.87	1.20	1.78	2.52	1.39	2.16	2.08	2.53	3.66	1.94	2.74	2.54	0.51
	r	0.44	0.24	0.39	0.31	0.24	0.32	0.70	0.55	0.39	0.55	0.39	0.55	0.45	0.28	0.36	0.34	0.85	0.84
3	$\overline{d}$	3.41	3.48	3.00	3.29	3.21	3.05	3.86	3.25	4.00	3.22	3.41	3.88	3.87	4.[illegible]	3.14	3.[illegible]	3.28	3.39
	r	0.27	0.23	0.28	0.22	0.33	0.42	0.24	0.36	0.21	0.27	0.32	0.24	0.22	[illegible]	0.23	[illegible]	0.26	0.27
4	$\overline{d}$	1.98	2.69	2.41	2.63	3.06	2.76	1.78	2.06	3.47	3.32	3.31	3.82	3.47	3.09	2.[illegible]	2.24	2.59	2.50
	r	0.47	0.35	0.37	0.26	0.36	0.44	0.59	0.58	0.29	0.26	0.28	0.22	0.31	0.32	0.41	0.34	0.37	0.36

of the extreme dominance by *C. punctipennis* (93% of the total organisms at both stations) and low numbers of taxa (9 in September, 8 in October) (Fig. 7.[illegible]).

Diversity values at Station 1 were intermediate between the values of the most and least diverse stations (mean = 2.45). The large number of oligochaete taxa at this location was responsible for keeping the values consistently between 2.0 and 3.0. Values during the late summer months, when discharge temperatures were highest, were not substantially lower than during the remainder of the year. The highest value (3.38) was recorded in September 1979 when dissolved oxygen was near 3 ppm and temperature was measured as high as 28.0°C across the transect (Fig. 7.4).

An overall slight increase in diversity values as the study progessed was noted at all sampling locations except Station 2. This increase, coupled with the increases in biomass and density, seems to indicate a small improvement in habitat quality during the study period.

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SECTION 8

FOOD HABITS OF BLUEGILLS FROM HEATED AND AMBIENT AREAS OF COFFEEN LAKE

by

Dennis L. Newman

ABSTRACT

Food habits of bluegills collected from heated and ambient areas of Coffeen Lake were examined. Data analysis followed the frequency of occurrence and gravimetric methods; the geometric mean of those values yielded an index of significance for each food item. Principal food items of bluegills from the heated station, in order of decreasing index of significance values, were: plant material, terrestrial arthropods, gastropods, algae, and chironomids. A similar list of principal food items from the ambient station included: terrestrial arthropods, plant material, chironomids, other aquatic insects, and bryozoans. Diversity values, calculated to provide a qualitative assessment of feeding at heated and ambient locations, demonstrated that the diet of bluegills from the ambient station was consistently more diverse. Seasonal variations in diet reflected the bluegills' opportunistic feeding behavior as seasonally abundant food resources (such as fish eggs, bryozoans, and terrestrial arthropods) were utilized as major food items. Other investigations have suggested that bluegills from heated locations feed more frequently than those from ambient waters. However, fullness indices calculated for this study indicated that feeding rates were significantly higher at the heated station for only two of eight collection dates.

INTRODUCTION

A fundamental problem for all animals in an aquatic ecosystem is obtaining sufficient nutrition. For fishes inhabiting thermally altered environments the problem may be compounded due to accelerated rates of digestion and maintenance metabolism (Bennett and Gibbons 1972, Graham 1974). These fishes may exhibit several responses to mitigate these problems: migration to areas of cooler temperatures (Tranquilli et al. 1979), transitory forays into unpreferred temperatures to forage (Bennett and Gibbons 1972), or consumption of a larger daily ration. Alternatively, these fishes may not be capable of mitigating those metabolic problems and poor growth and population inbalance may ensue.

This investigation of bluegill feeding dynamics was initiated for the purpose of increasing our understanding of the ecological role of bluegill inhabiting cooling lakes. Specifically, this study was designed to ascertain and compare the diet of bluegill (Lepomis macrochirus) from heated and ambient locations of Coffeen Lake.

MATERIALS AND METHODS

Bluegill were collected from heated (Station 1) and ambient (Station 4) areas of Coffeen Lake using a 230-volt AC electrofishing unit. All collections were made during daylight hours. The fish were placed immediately on ice and transported to the laboratory. Weight (grams) and total lengths (mm) were measured before the stomachs were removed and stored in 10 percent formalin. In order to obviate size- specific or age-related variations in the diet (Sarker 1975, Sule et al. 1981) only fish larger than 89 mm were included in the analyses.

Stomach contents were removed, identified and weighed while moist on a Mettler (H 80) balance (precision 0.1 mg). The composition of the diet was quantified using percent frequency of occurrence, the gravimetric method, and the index of significance as described by Windell (1971). The index of significance value, which represented the geometric mean of the frequency of occurrence and percent weight (gravimetric) values, allowed each food item to be ranked according to