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Zooplankton and Ichthyoplankton in a Power Plant Cooling Reservoir

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ZOOPLANKTON AND ICHTHYOPLANKTON IN A POWER PLANT COOLING RESERVOIR

BY

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ZOOPLANKTON AND ICHTHYOPLANKTON IN A POWER PLANT

COOLING RESERVOIR

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ZOOPLANKTON AND ICHTHYOPLANKTON IN A POWER PLANT COOLING RESERVOIR

Abstract

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The species composition, abundance, seasonal cycles, distribution, and entrainment mortality of zooplankton and ichthyoplankton were studied in the Big Stone Power Plant cooling reservoir, South Dakota, from January 1979 to April 1980.

Mean annual density and biomass of zooplankton for 1979 were 15.8 organisms/liter and 384.7 ug/liter respectively. Cyclopoid copepodites made up 43.0% of the mean annual number, Daphnia pulex, 15.8% and Chydorus sphearicus, 15.2%. Zooplankton density attained a spring maximum of 203.1/liter on 16 May and a fall maximum of 18.7/liter on 15 November.

The species composition and density of zooplankton in water entrained by the power plant were similar to those in the reservoir. No differences were found between diel periods of entrainment. An estimated 48,817.4 kg or 27.1% of the annual number of zooplankton entrained suffered immediate mortality from the effects of entrainment.

Five species of ichthyoplankton were collected in the reservoir. The mean density was $.053/m^3$ with a maximum density of $.161/m^3$ in June. The intake area contained significantly higher numbers of ichthyoplankton than the other areas of the reservoir. Spawning times and larval fish growth rates were similar to those in other northern lakes.

The number of ichthyoplankton in entrainment water was similar to that estimated in the reservoir. *Lepomis* spp. made up 90.5% of the total number entrained. An estimated 100% of all entrained larval fish died from the effects of entrainment.

INTRODUCTION

Objectives of this study were to determine the species composition, abundance, seasonal cycles, distribution and entrainment mortality of zooplankton and ichthyoplankton in a power plant cooling reservoir.

Cooling reservoirs are designed to dissapate the waste heat of power plants (Metz 1977). By the year 2000, 20% of all power plants in the United States may utilize reservoirs (Meredith 1973). Through proper siting these heated waters may also serve a variety of secondary functions such as recreation, flood control, fish and wildlife use and aquaculture (Metz 1977).

Potential exists for power plant cooling reservoirs to be used as rearing and holding areas for muskellunge (*Esox masquinongy*) brood stock, providing the forage base will maintain an adequate prey fish population. Although zooplankton and ichthyoplankton are not directly utilized as a food resource by adult muskellunge, they are a main trophic link and have an effect on maintaining brood stock populations.

The variation in water temperature caused by thermal effluent may affect the population dynamics of organisms in a power plant cooling reservoir. Increased temperatures have been found to cause changes in the life cycles of aquatic organisms. Hall (1964) observed zooplankton reproductive cycles increased and life spans decreased with an increase in temperature, below critical lethal limits, and Pierce and Wissing (1974) found the metabolism and feeding rates of bluegills (*Lepomis macrochirus*) increased with temperature increases up to 25 C.

Entrainment may cause changes in the population structure of zooplankton and ichthyoplankton by direct mortality from thermal shock, mechanical and pressure damage and chemical additives (Coutant 1970). The magnitude of discharge temperatures appears to have the greatest influence on causing mortality of entrained organisms, reaching 100% at temperatures over 37 C (Crippen et al. 1977, Ginn et al. 1977). The expected increase in growth, reproduction and natural survival rates from the temperature increases may offset the cropping that results from entrainment in a once through cooling system (Lawler and Englert 1977).

Spawning periods of fishes may be altered because of the heated discharge. Ruelle et al. (1977) found several species of fish continued spawning in a cooling reservoir after a power plant began operation but observed a steady decrease in the number of larval fish caught each successive year. Ruelle et al. also noted earlier spawning times for the black crappie (*Pomoxis nigromaculatus*) and other temperature dependent behavioral changes among all fishes in the reservoir.

STUDY AREA

Big Stone Power Plant is a coal-fired 440 MW steam electric generating facility located in Grant County, South Dakota. The power plant and adjacent cooling reservoir are jointly owned by Montana-Dakota Utilities Company, Northwestern Public Service Company and Otter Tail Power Company. The cooling reservoir was completed in 1972 and the plant became operational in 1975. Water from nearby Big Stone Lake was used to fill the reservoir and is periodically used to replenish water lost through evaporation.

The cooling reservoir has a surface area of 145 ha, maximum depth of 10 m and a mean depth of 4.9 m at water level of 341.1 m above mean sea level (msl). Cooling water is withdrawn on the east side of a T-shaped dike and heated water is released on the west side; the remainder of the reservoir serves as a mixing area (Fig. 1). The water level fluctuated from 340.1 m to 342.0 m above msl during this study. The shoreline of the reservoir is composed entirely of granite rip-rap while bottom substrates are mud and sand. Dense stands of *Potamogeton pectinatus* grew in the intake area during the summer months.

Cooling water for the power plant is provided by two pumps with a total capacity of 9.71 m^3/s. Intake water passes through large vertical steel trash racks followed by two vertical traveling screens of 10 mm mesh before entering the once through cooling system.

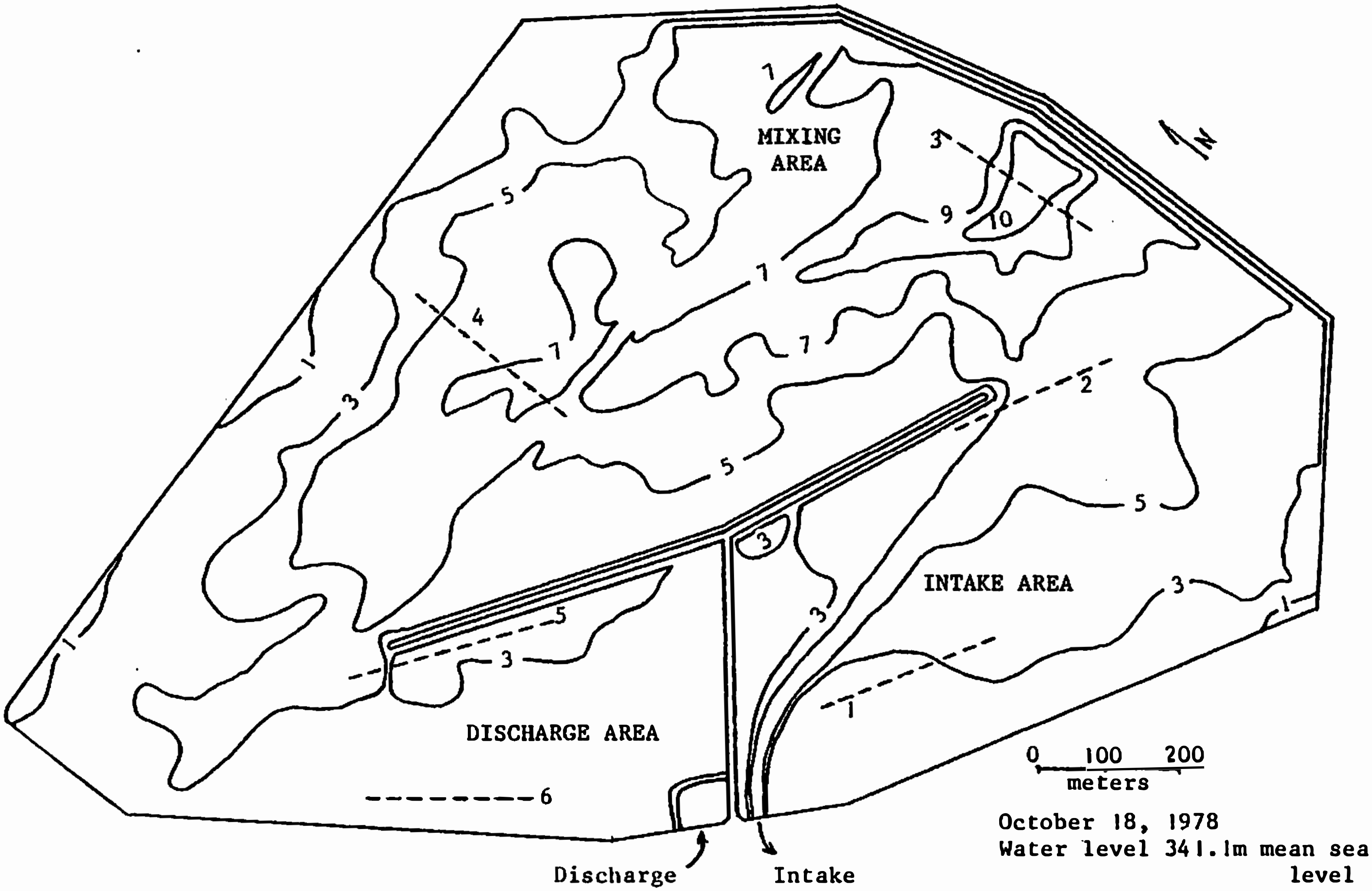

Fig. 1. Big Stone Power Plant cooling reservoir, South Dakota, with depth contours and zooplankton and ichthyoplankton sampling areas and numbered transects.

MATERIALS AND METHODS

Zooplankton

Zooplankton samples were taken on 30 dates from 18 January to 18 December, 1979, from two transects in each of three areas of the cooling reservoir during the day using a Miller Sampler (Miller 1961) equipped with a No. 10 net. Two replicate oblique tows were made at each of the six transects on all dates except 18 January and 8 February when ice cover prevented sampling from transect 2. Surface and bottom temperatures were recorded twice each month at each transect (Appendix Table 1).

Volume of zooplankton was measured by water displacement of samples collected on one day each month and dry weight was estimated by multiplying volumes by a specific gravity of 1.025 (Hall et al. 1970).

Vertical distribution of zooplankton was sampled by pumping 333.1 liters of water from surface, mid and bottom depths through a No. 10 net, at six hour intervals on 31 July-1 August 1979.

Zooplankton entrainment was sampled 25 times between 20 April 1979 and 18 April 1980. Continuous samples were taken at a flow rate of approximately 40 liter/min during a 24 hour period from the intake water line immediately after passing through the circulating pumps. Samples were filtered with a No. 10 net. Six entrainment samples were divided into three, eight hour subsamples (day, 1000 h-1800 h; night, 1800 h-200 h; morning, 200 h-1000 h) to determine peak diel periods of entrainment.

To determine entrainment mortality the number of live and dead Copepoda and Cladocera were counted in samples collected each month from intake and discharge waters. Live and dead organisms were distinguished using the motility method described by Cannon et al. (1977). All samples were examined within 3 minutes after collection. Intake and discharge water temperatures were recorded for each sample day.

All zooplankton samples were preserved in the field with lugol's solution and later in the lab with 5-10% formalin. Samples were fixed to convenient volumes and three 1 ml subsamples were identified and counted in a circular counting chamber at 30X. Zooplankton was identified using keys by Pennak (1978), Novotony (1973), Brooks (1957) and Wilson and Yeatman (1959). Immature cyclopoid copepods were classified as cyclopoid copepodites, all other cladocerans and copepods were identified to genus or species.

A nested factorial analysis of variance (ANOVA) was used to compare areas, transects, replicates, and dates for numbers of total zooplankton and major species. Two-way ANOVA was used for comparing areas and dates for zooplankton biomass, depths and times for diel vertical distribution sampling, and times and dates for diel entrainment samples. Student Newman Kuels' multiple range test was used to determine differences in depths and times for diel vertical distribution samples.

Comparisons of numbers of cladocerans, copepods, ostracods, and total zooplankton were made between concomitant reservoir and entrainment samples by use of a paired t-test. References used for assistance in statistical analysis were Mendenhall (1975), Steel and Torrie (1960), and Zar (1974).

Ichthyoplankton

Ichthyoplankton samples were collected from two transects in each of the three areas of the reservoir. Samples were collected during the day on 12 dates from 24 May to 23 August 1979, using a No. 0, bridled, 0.5 m net equipped with a flow meter mounted off center in the mouth of the net (Mahnken and Jossi 1967). Two replicate oblique tows were made at each of the six transects. From 11.2 to 51.4 m^3, with a mean of 26.2 m^3, of water was filtered for each sample.

Entrainment samples of larval fish were taken concomitantly with reservoir samples 11 times from 24 May to 8 August 1979. Continuous samples were taken during 24 periods from the intake current in front of the intake screens. Two submersible pumps placed at 1 and 3 m depths were used for sampling. When one pump malfunctioned, one mid-depth (2 meter) sample was taken. Four entrainment samples were divided into three, eight hour subsamples (day, 1000 h-1800 h; night, 1800 h-200 h; morning, 200-1000 h) to determine peak diel periods of entrainment.

All larval fish samples were preserved in 10% formalin in the field and later transferred to 70% alcohol. Ichthyoplankton up to 25 mm TL was identified to genus or species, counted, and measured. *Lepomis macrochirus* and *L. humilis* were combined as *Lepomis* spp. for all analysis. Keys used for identification were Hogue et al. (1976), Meyer (1970), and Snyder et al. (1977).

Two-way ANOVA and Student Newman Keuls' multiple range test were used to compare numbers of total ichthyoplankton and *Lepomis* spp. between the three areas and transects within areas. The same tests were used to compare ichthyoplankton numbers for times and datea of entrainment.

A paired t-test was used to compare numbers of larval fish between the 1 and 3 m entrainment pumps and numbers collected in entrainment to numbers in the reservoir samples.

All statistical tests for both zooplankton and ichthyoplankton data were made at 0.05 or 0.01 level of probability.

RESULTS AND DISCUSSION

Zooplankton

A total of 11 species of Cladocera, ten species of Copepoda, and four miscellaneous invertebrates were identified in the plankton of the cooling reservoir (Table 1). The four major species of cladocerans were; Chydorus sphearicus, Daphnia pulex, Ceriodaphnia quadrangula and Alona rectangula. The most abundant copepods were; cyclopoid copepodites, Cyclops vernalis, C. bicuspidatus thomasi, Mesocyclops edax, Diaptomus spp. and Onychocamptus spp. Ostracoda was also abundant. The composition of the zooplankton was similar to that reported in other regional lakes. Applegate et al. (1973) noted eight species of zooplankton abundant in Lake Poinsett, South Dakota, and Repsys (1972) reported seven in the same lake. Of the 24 Species found in Lewis and Clark Lake, South Dakota, 11 were considered abundant (Cowell 1967).

The mean density and biomass of zooplankton in the cooling reservoir for 1979 were 15.8/liter and 384.7 ug/liter respectively (Tables 2, 3). The highest number of zooplankton collected in one sample was 399.5/liter at transect 1 on 16 May and the lowest number was 0.1/liter at transect 6 on 7 August. The biomass in the cooling reservoir was less than that reported by Applegate et al. (1973) of 660 ug/liter from nearby Lake Poinsett, South Dakota, and the mean density of zooplankton was also lower.

Copepods were the most abundant zooplankters with a mean density of 8.9/liter; cladocerans and ostracods had means of 6.6 and 0.3/liter respectively. Cyclopoid copepodites had a mean density of 6.8/liter,

Table 1. Zooplankton collected from Big Stone Power Plant cooling reservoir, South Dakota, 18 January to 18 December 1979.
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Zooplankton
Cladocera:
Diaphanosoma brachyurum
Daphnia pulex
Ceriodaphnia quadrangula
Ceriodaphnia reticulata[a]
Simocephalus serrulatus
Moina brachiata
Chydorus sphearicus
Alona rectangula
Camptocercus spp.[b]
Bosmina longirostris
Ilyocryptus spinifer[a]
Copepoda:
Diaptomus spp.[c]
Mesocyclops edax
Cyclops vernalis
Cyclops bicuspidatus thomasi
Eucyclops agillis
Macrocyclops albidus[b]
Onychocamptus spp.

Table 1 (cont).

Zooplankton
Ostracoda
Ephemeroptera[a]
Hydracarina[a]
Chironomidae[a]

[a]Organisms not found in zooplankton entrainment samples.

[b]Species not collected in zooplankton samples but found in fish stomach analysis (Krska 1980).

[c]Species composing _Diaptomus_ spp.; _D. ashlandi_, _D. clavipes_, and _D. siciloides_.

Table 2. Mean monthly abundance (number/liter) of zooplankton, Big Stone Power Plant cooling reservoir, South Dakota, 18 January to 18 December 1979.

Species	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year[a]
	Month											
Chydorus sphearicus	1.9	1.3	8.5	14.2	T[c]	T	T	T	.3	.4	.2	2.4
Daphnia pulex	T			16.7	9.9	1.1					T	2.5
Ceriodaphnia quadrangula				T		T	.1	1.7	4.7	8.2	.8	1.4
Alona rectangula	.6	.2	.1	T		T	T	T	.4	.2	T	.1
Bosmina longirostris	.4	T	T			T			T		T	T
Cyclopoid copepodite	3.2	1.3	12.8	42.1	1.5	.8	.6	.7	1.6	6.6	4.1	6.8
Cyclops vernalis	.5	.1	1.8	7.4	.2	T	T	T	.1	.6	.3	1.0
Cyclops bicuspidatus	.1	.1	1.8	1.0	.1	T		T	T	.2	T	.3
Mesocyclops edax			.2	1.2	.2	.1	T	T	T	T		.2
Diaptomus spp.	T	T		.1	1.5	.4	T		T	.1	T	.2
Onychocamptus spp.	T	T	2.7	1.0	T	T		T	T	.1	T	.3
Ostracoda			1.6	1.0	.3	.2	T			T		.3
Miscellaneous[b]	T	T	T		T	T	T	T		T	T	T
Cladocera	2.9	1.5	8.7	30.9	9.9	1.1	.2	1.9	5.5	8.9	1.0	6.6
Copepoda	3.8	1.5	19.4	52.9	3.4	1.4	.6	.8	1.8	7.7	4.4	8.9
Total	6.7	3.0	29.7	84.8	13.7	2.7	.8	2.7	7.2	16.6	5.4	15.8

[a]Annual mean calculated by averaging the eleven monthly means.

[b]Miscellaneous includes; *Diaphanosoma brachyurum*, *Moina brachiata*, *Ceriodaphnia reticulata*, *Ilyocryptus spinifer*, *Eucyclops agilis*, Ephemeroptera, Hydracarina, *Simocephalus serrulatus*, and Chironomidae.

[c]Trace organism $\leq$0.05/liter.

Table 3. Mean monthly abundance (number/liter) and biomass (ug/liter in parenthesis) of zooplankton collected in the three areas in Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Month	Intake area		Mixing area		Discharge area		Reservoir	
January	4.8	(131.4)	8.9	(113.9)	5.4	(85.9)	6.7	(110.4)
February	2.3	(18.4)	5.0	(32.8)	1.6	(15.5)	3.0	(22.2)
April	18.5	(43.2)	31.2	(89.4)	39.5	(53.1)	29.7	(61.9)
May	89.3	(3086.7)	78.4	(2029.5)	86.7	(3906.3)	84.8	(3007.5)
June	15.2	(1046.2)	12.6	(390.2)	13.3	(55.7)	13.7	(497.4)
July	2.7		4.6		.6		2.7	
August	.5	(3.9)	1.1	(5.4)	.8	(5.6)	.8	(5.0)
September	2.8	(4.7)	4.0	(3.3)	1.2	(6.0)	2.7	(4.7)
October	6.9	(37.2)	9.1	(38.0)	5.7	(22.9)	7.2	(32.7)
November	17.6	(95.1)	21.3	(82.3)	10.9	(39.8)	16.6	(72.4)
December	6.1	(34.5)	7.2	(45.2)	2.9	(17.6)	5.4	(32.4)
Year	15.2	(450.1)	16.7	(283.0)	15.3	(420.8)	15.8	(384.7)

Daphnia pulex 2.5/liter, and Chydorus sphearicus 2.4/liter.

Pennak (1957) found that only one or two species of cladocerans and a similar number of copepods are usually abundant at any one time in a lake. This was typical in the cooling reservoir. Chydorus sphearicus was found on 28 of the 30 sampling dates but was only abundant with another cladoceran on 16 May when Daphnia pulex was increasing in density (Fig. 2). Ceriodaphnia quadrangula was the only abundant cladoceran present during the fall peak.

Chydorus sphearicus made up from 12.4-50.0% of the total number of zooplankton from 18 January to 16 May (Fig. 3). It was less abundant during the fall peak attaining a maximum of 4.6% on 4 October. On 11 May Daphnia pulex made up only 5.8% of the total number but it increased to 81.3% by 22 June and then decreased until it was not present after 24 July. On 24 July Ceriodaphnia quadrangula made up 1.0% of the population density but it steadily increased to 69.4% by 18 October and then decreased to 8.0% on 18 December. Alona rectangula was present on 21 of the 30 sampling dates attaining a maximum of 8.6% of the total number of zooplankton on 8 February.

Cyclopoid copepods are typically one of the most abundant zooplankters (Reid and Wood 1976). Cyclops sp. was the most abundant organism sampled in two seperate studies on Lake Poinsett, South Dakota (Repsys 1972, Applegate et al. 1973). Cyclopoid copepods made up the largest percentage of the total number of zooplankton with cyclopoid copepodites the most common and abundant organisms collected in the present study. Cyclopoid copepodites occurred on all sampling dates consisting of from 31.1-63.4% of the number of zooplankton from 18

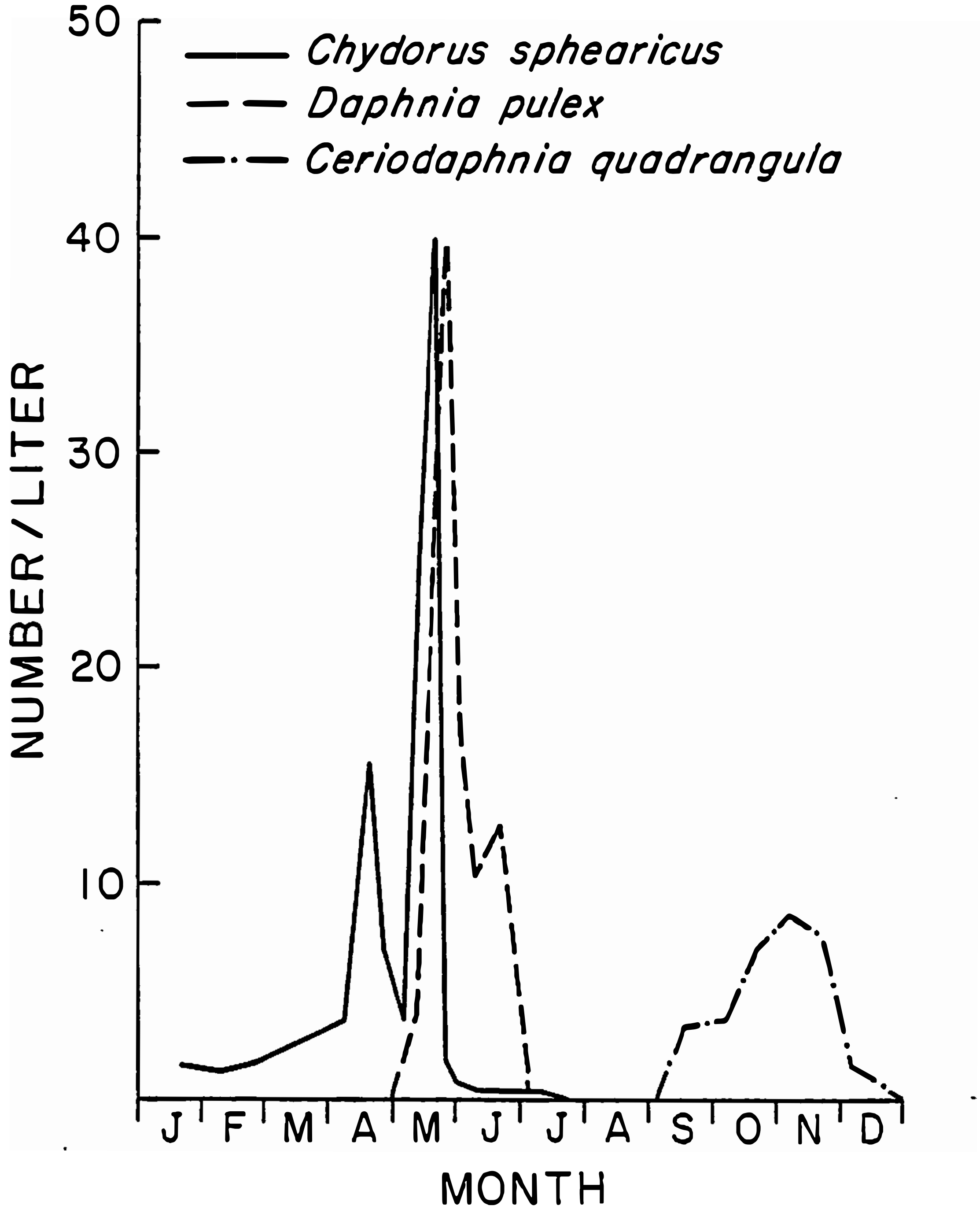

Fig. 2. Abundance of the three major species of Cladocera, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

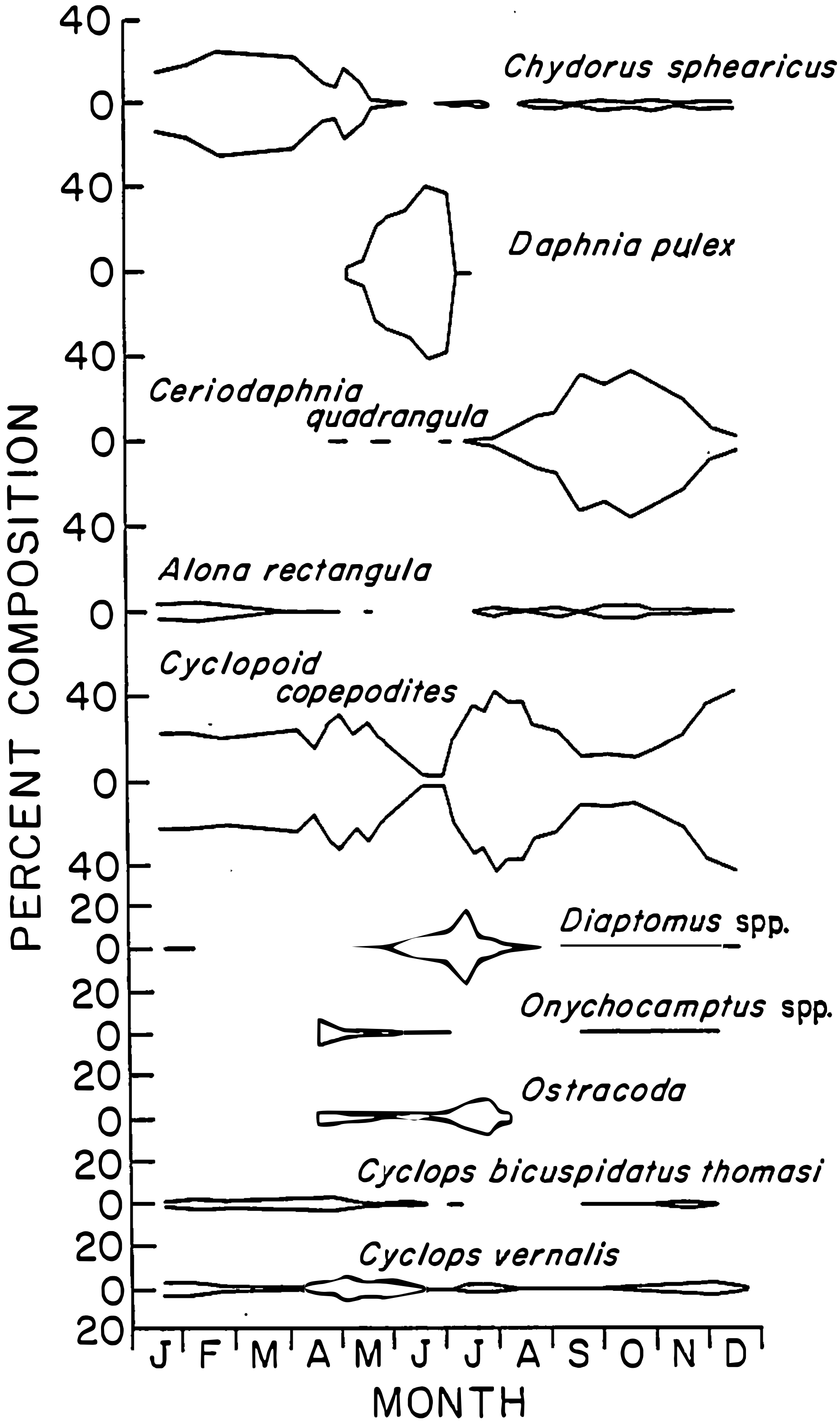

Fig. 3. Percent composition of the major species of zooplankton, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

January to 29 May (Fig. 3). Copepodites made up the smallest percentage in June but reached a maximum of 85.0% on 1 August. *Cyclops vernalis* was the most abundant adult cyclopoid copepod. It occurred on each of the 30 sampling dates attaining a high of 12.0% of the total number on 3 May. *Cyclops bicuspidatus thomasi* made up from 1.0-6.2% of the population between 18 January and 16 May but otherwise occurred in low numbers or was not present. *Diaptomus* spp. was abundant from 13 June to 24 July when it made up from 9.1-36.0% of the population. *Onychocamptus* spp. was only briefly abundant on 19 April (11.8%) but it declined to 1.2% by 16 May. Ostracods were a major part of the zooplankton in late April (6.8%) and mid July (17.4%).

The seasonal cycle of zooplankton in the cooling reservoir had the typical population succession described by Wetzel (1975) and Hall (1964) consisting of spring and fall peaks (Fig. 4). A winter minimum of 2.8/liter was found on 27 February. The spring peak density was 203.1/liter reached on 16 May and was followed by a mean low of 0.8/liter from 24 July through 6 September. Total zooplankton increased to 18.7/liter on 15 November and decreased to 2.2/liter by 18 December.

The seasonal cycle of total zooplankton biomass (Fig. 5) was similar to the cycle for zooplankton abundance reaching a spring peak of 3,007.5 ug/liter in May and a fall peak of 72.4 ug/liter during November. Biomass of zooplankton in the cooling reservoir had a higher spring maximum than reported by Applegate et al. (1973) for Lake Poinsett, South Dakota, but it decreased to a lower summer minimum than found in Lake Poinsett. The fall peak in biomass in Lake Poinsett occurred in early September. Zooplankton biomass in the cooling

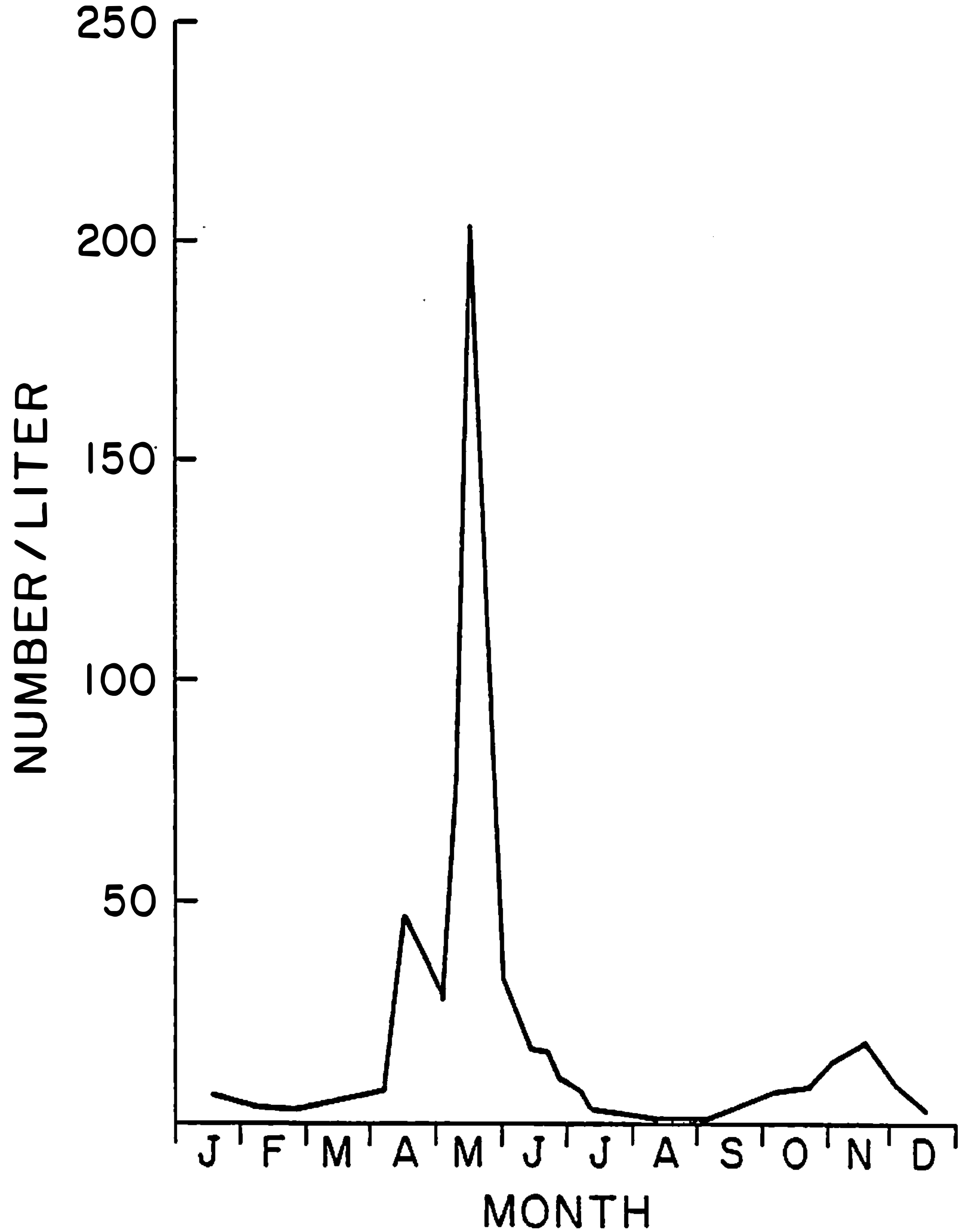

Fig. 4. Abundance of zooplankton, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

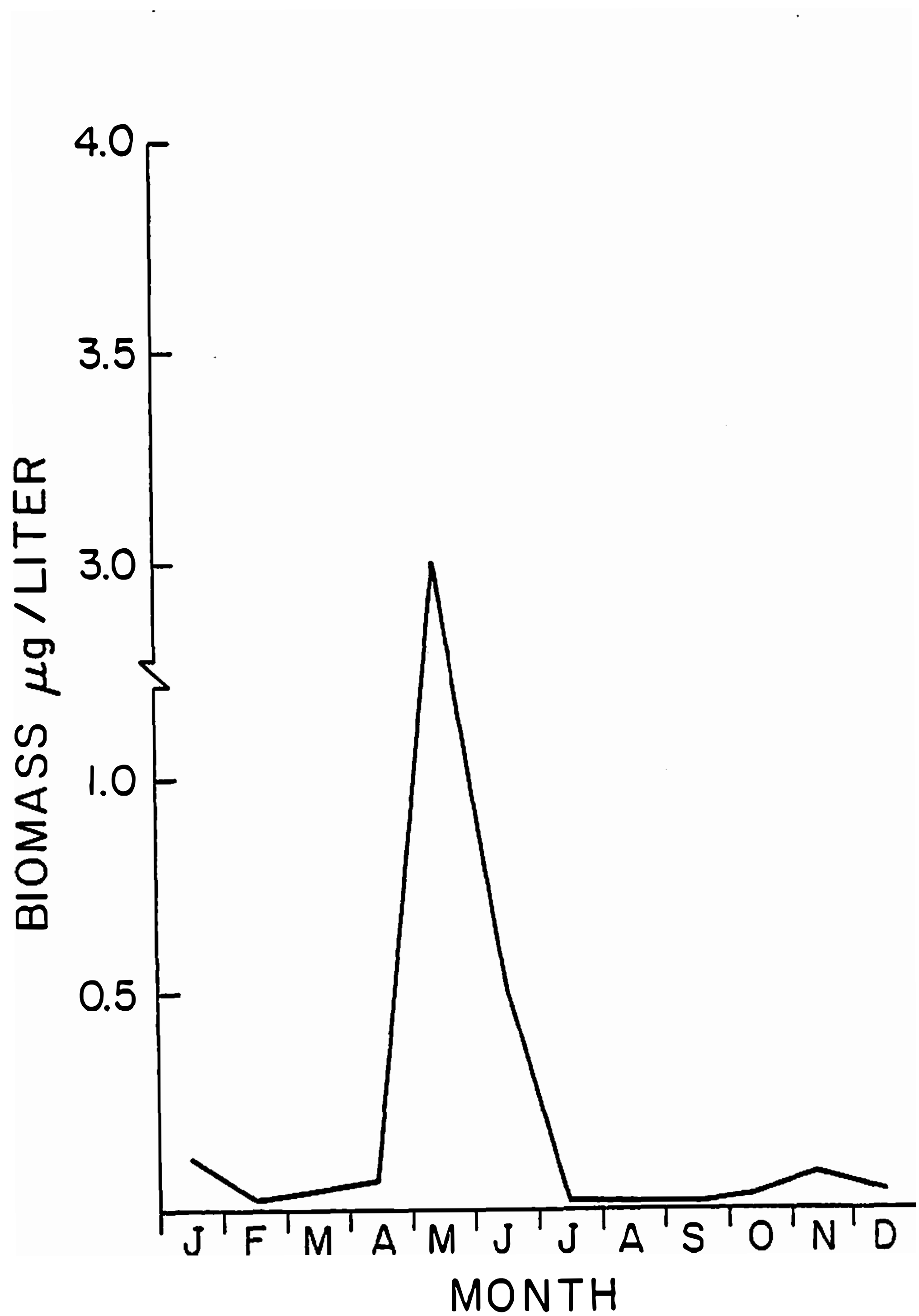

Fig. 5. Biomass of zooplankton, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

reservoir was at an annual low in early September and did not reach a fall peak until mid November. This delay may have been caused by the sustained high water temperatures from the thermal effluent.

Zooplankton density and biomass in the three areas of the reservoir were compared over all dates and were not significantly different (Tables 4,5). The intake area had the highest mean number of organisms in May (89.3/liter) while the discharge area had the highest mean biomass of 3,906.3 ug/liter in May. The lowest mean number (0.5/liter) was found in the intake area during August. The mixing area contained the lowest mean biomass (3.3 ug/liter) in September.

Diel vertical distribution samples contained significantly less zooplankton ($P < 0.01$) during the day (Tables 6-8). The number of organisms in the surface samples were significantly less ($P < 0.01$) than the mid-depth and bottom samples.

An apparent day time decrease in zooplankton numbers similar to the one observed in the cooling reservoir was discussed by Woodmansee and Grantham (1961). They determined that the difference was due to either greater avoidance capabilities during the day or a daytime movement of some plankters onto or very near the bottom. Evidence was cited to indicate that avoidance was not an important factor and that vertical movement to the bottom was the probable cause for the daytime reduction in population size. Zooplankton in the diel distribution sampling exhibited a daytime reduction in numbers. Because differences in visual avoidance between day and night sampling would not be a major factor when using a stationary pump, the primary reason for the change in abundance is considered to be

Table 4. Analysis of variance of the number of zooplankton collected on six transects in Big Stone Power Plant cooling reservoir, South Dakota, 27 February to 18 December 1979.

Source of variation	Degrees of freedom	Mean square	F
Date	28	20,049.715	406.26**
Area	2	2.315	0.03
D X A	56	576.821	11.69**
Transect(A)	3	696.451	9.80**
D X T(A)	84	1,024.502	20.76**
Replicate(A X T)	6	71.060	1.44

**Significant at 0.01 level of probability.

Table 5. Analysis of variance of zooplankton biomass in the three areas in Big Stone Power Plant cooling reservoir, South Dakota, 18 January to 18 December 1979.

Source of variation	Degrees of freedom	Mean square	F
Area	2	.0888	.1560
Date	10	2.4058	4.2271**
Error	20	.5691	

**Significant at 0.01 level of probability.

Table 6. Mean abundance (number/liter) of zooplankton collected from three depths during each of four sample times from the diel vertical distribution sampling, Big Stone Power Plant cooling reservoir, South Dakota, 31 July to 1 August 1979.

	Time (hour)			
Species	Day (1300)	Evening (2000)	Night (100)	Morning (700)
Copepodites	1.5	4.4	4.2	0.8
Mesocyclops edax	0.0	2.0	2.7	T[b]
Ostracoda	0.0	1.3	2.6	0.1
Miscellaneous[a]	0.1	0.1	0.2	0.1
Total	1.6	7.8	9.7	1.0

[a]Miscellaneous organisms consists of seventeen groups of zooplankton.

[b]Trace organism $\leq$0.05/liter.

Table 7. Analysis of variance of the number of zooplankton collected in diel distribution samples taken at three depths over four time periods, Big Stone Power Plant cooling reservoir, South Dakota, 31 July to 1 August 1979.

Source of variation	Degrees of freedom	Mean square	F
Time	3	338.2010	19.9876**
Depth	2	150.8606	8.9158**
Time X Depth	6	26.9251	1.5913
Error	60	16.9205	

**Significant at 0.01 level of probability.

Table 8. Student Newman Keuls' analysis of the mean number/liter of zooplankton in vertical diel distribution samples, Big Stone Power Plant cooling reservoir, South Dakota, 31 July to 1 August 1979.

	Morning	Day	Evening	Night
All depths	1.04	1.62	7.76	9.65
Surface	0.43	0.72	3.28	4.59
Mid-depth	1.11	3.02	8.87	10.73
Bottom	1.58	2.26	11.13	13.63
	Surface	**Mid**	**Bottom**	
All times	2.26	5.93	7.15	

Means not underscored by the same line are significantly different.

Significant at 0.05 level of probability.

a daytime migration onto or near the bottom out of sampling range. Mean surface temperatures at the four sample times ranged from 28.8 C at transect 1 to 35.8 C at transect 5. Mean bottom temperatures ranged from 25.0-29.0 C (Table 9).

Zooplankton Entrainment

Chydorus sphearicus, Daphnia pulex, Ceriodaphnia quadrangula, cyclopoid copepodites, *Diaptomus* spp., *Cyclops vernalis* and Ostracoda were the most abundant organisms entrained.

The estimated mean annual density of zooplankton in the reservoir as determined by entrainment samples was 21.4/liter (Table 10). This estimate was higher than that calculated from the reservoir samples, however, when comparisons were made between concomitant reservoir and entrainment samples from 19 April to 19 December (Table 11) no differences were found for cladocerans, copepods or total zooplankton. When seasonal comparisons were made there were significantly more ($P < 0.05$) cladocerans entrained than were collected from the reservoir from 19 April to 3 July. There were also significantly higher ($P < 0.05$) numbers of total zooplankton entrained from 11 July to 7 September. When numbers of ostracods were compared from 19 April to 8 August entrainment samples contained significantly higher ($P < 0.01$) numbers than concomitant reservoir samples. Ostracods are described as benthic organisms (Wetzel 1975, Pennak 1978) that are generally not collected in zooplankton samples. Diel distribution samples indicated significantly higher numbers of ostracods in the pelagic region during the night indicating they were more available for collection at that time.

Table 9. Surface and bottom (in parenthesis) temperatures (C) at each transect during zooplankton diel vertical distribution sampling, Big Stone Power Plant cooling reservoir, South Dakota, 31 July to 1 August 1979.

	Time (hour)			
Transect	Day (1300)	Evening (2000)	Night (100)	Morning (700)
1	28.4 (28.2)	29.5 (29.0)	29.5 (28.0)	28.2 (28.2)
2	29.1 (28.1)	30.0 (28.2)	30.0 (28.0)	29.0 (28.0)
3	31.1 (28.1)	30.0 (27.0)	29.5 (25.0)	29.5 (27.8)
4	32.8 (28.5)	32.2 (28.1)	33.0 (28.0)	30.0 (28.3)
5	37.5 (28.5)	37.5 (28.0)	34.5 (28.0)	33.5 (28.8)
6	36.0 (29.0)	35.0 (28.0)	34.0 (29.0)	32.5 (29.0)

Table 10. Mean monthly abundance (number/liter) of zooplankton in entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 20 April 1979 to 31 March 1980.

	Month											
Species	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Mar	Year[a]
Chydorus sphearicus	1.1	34.5	.1	T[c]	T	T	.8	.9	.3	.2	.1	3.4
Daphnia pulex		35.9	27.0	2.0								5.9
Ceriodaphnia quadrangula				T	.1	T	3.7	7.7	.4	.1	T	1.1
Alona rectangula	.5	T			.1	.1	.6	.2	.2	.1	.2	.2
Cyclopoid copepodite	1.5	77.4	3.4	1.0	.6	.2	1.6	5.6	2.6	2.0	.7	8.8
Cyclops vernalis	.6	2.8	.1	.1			.1	.9	.3	T	.1	.5
Cyclops bicuspidatus	.1						T		T	.1	.3	T
Mesocyclops edax	T	.7	.2	T	.3	T	.2	T				.1
Eucyclops agillis	T	.5			T	T	.1	.2	.1		.2	.1
Diaptomus spp.	T	.2	1.5	.2	T			T	T			.2
Onychocamptus spp.	1.8	.8			T		.1	T	T		.1	.3
Ostracoda	.7	3.4	1.7	3.0	.3	.1	T					.8
Miscellaneous[b]				T	T	.1	T					T
Cladocera	1.6	70.4	27.1	2.0	.2	.2	5.2	8.8	.9	.4	.3	10.6
Copepoda	4.1	82.4	5.2	1.3	.9	.2	2.1	6.8	3.0	2.2	1.4	10.0
Total	6.4	156.2	34.0	6.3	1.4	.5	7.3	15.6	3.9	2.6	1.7	21.4

[a]Annual mean calculated by averaging the eleven monthly means.

[b]Miscellaneous includes; *Simocephalus serrulatus*, *Moina brachiata*, and *Diaphanosoma brachyurum*.

[c]Trace organism ≤0.05/liter.

Table 11. Abundance (number/liter) of zooplankton in concomitant reservoir and entrainment (in parenthesis) samples, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Date	Cladocera	Copepoda	Ostracoda	Total
4-19 (20)	15.8 (1.2)	26.1 (5.6)	3.1 (1.4)	45.0 (8.2)
5-16 (17)	62.4 (120.5)	138.7 (189.7)	1.9 (9.3)	203.1 (319.5)
5-23 (24)	41.1 (62.2)	41.9 (38.8)	0.2 (0.4)	83.3 (101.4)
5-29 (30)	17.8 (28.6)	14.5 (18.0)	0.4 (0.6)	32.7 (47.2)
6-13 (13)	10.1 (28.6)	5.8 (5.3)	0.7 (1.1)	16.7 (35.0)
6-22 (20)	12.4 (50.4)	2.7 (9.1)	0.2 (3.6)	15.3 (63.1)
6-26 (30)	7.1 (2.3)	1.7 (1.2)	0.1 (0.5)	9.0 (4.0)
7-3 (3)	5.5 (6.0)	1.7 (1.7)	0.2 (2.7)	7.4 (10.4)
t value	1.9266*	0.6285		1.3855
7-11 (12)	T[a] (T)	1.5 (1.8)	0.2 (1.8)	1.8 (3.6)
7-18 (19)	T (T)	2.0 (0.6)	0.4 (4.5)	2.5 (5.2)
7-31(8-1)	T (0.1)	0.6 (1.2)	T (0.5)	0.7 (1.8)
8-7 (8)	T (0.2)	0.5 (1.0)	T (0.4)	0.6 (1.6)
8-15 (16)	0.3 (0.2)	0.8 (0.5)		1.1 (0.8)
8-24 (23)	0.3 (0.3)	0.4 (0.5)		0.8 (1.0)
9-6 (7)	0.3 (0.2)	0.3 (0.2)		0.6 (0.6)
t value		0.1674		2.3026*
10-4 (5)	4.5 (5.4)	1.7 (2.0)		6.2 (7.4)
10-18 (19)	6.3 (4.9)	1.9 (2.3)		8.3 (7.2)
11-1 (2)	9.3 (8.4)	5.2 (4.7)		14.6 (13.1)
11-15 (16)	8.4 (9.3)	10.3 (8.8)		18.7 (18.1)

Table 11 (cont).

Date	Cladocera	Copepoda	Ostracoda	Total
12-4 (7)	1.7 (0.9)	6.8 (2.7)		8.6 (3.6)
12-18 (19)	0.3 (0.7)	1.9 (3.4)		2.2 (4.1)
t value	0.3654	0.8109		0.8567
Annual t value	1.720	0.599	24.220**	1.360

[a]Trace organism <0.05/liter.

*Significant at 0.05 level of probability.

**Significant at 0.01 level of probability.

Samples from the power plant intake current were taken at both day and night and therefore included a higher mean density of ostracods than the daytime reservoir samples.

The lack of significance in total numbers of zooplankton collected in entrainment and reservoir population samples indicated that daytime reservoir collections were adequate for measuring zooplankton density and that 24 hour entrainment samples were also adequate for monitoring reservoir zooplankton abundance. The seasonal cycle of zooplankton in entrainment samples (Fig. 6) paralleled the cycle of the reservoir samples. Maximum number of total zooplankton in entrainment occurred on 17 May at 319.5/liter. The annual low number of 0.5/liter occurred on 7 September followed by the fall peak of 18.1/liter on 16 November.

Cladocerans and copepods made up nearly equal numbers of the organisms entrained (Table 10). Cyclopoid copepodites were the most abundant organisms entrained, making up 41.1% of the mean annual number of zooplankton while Daphnia pulex and Chydorus sphearicus made up 27.6% and 15.9% respectively. There was no significant difference in the number of organisms entrained during the three time periods of diel entrainment (Tables 12, 13).

Total mortality of entrained zooplankton in discharge water samples ranged from 91.1-100% from 29 May to 24 August (Table 14) when discharge temperatures were greater than 37 C (Table 15). The mortality of cladocerans and copepods sampled from the discharge water and the ambient and discharge temperatures are presented in Fig. 7.

Thermal, mechanical, chemical and pressure changes all occur while entrained organisms pass through a power plant cooling system, however

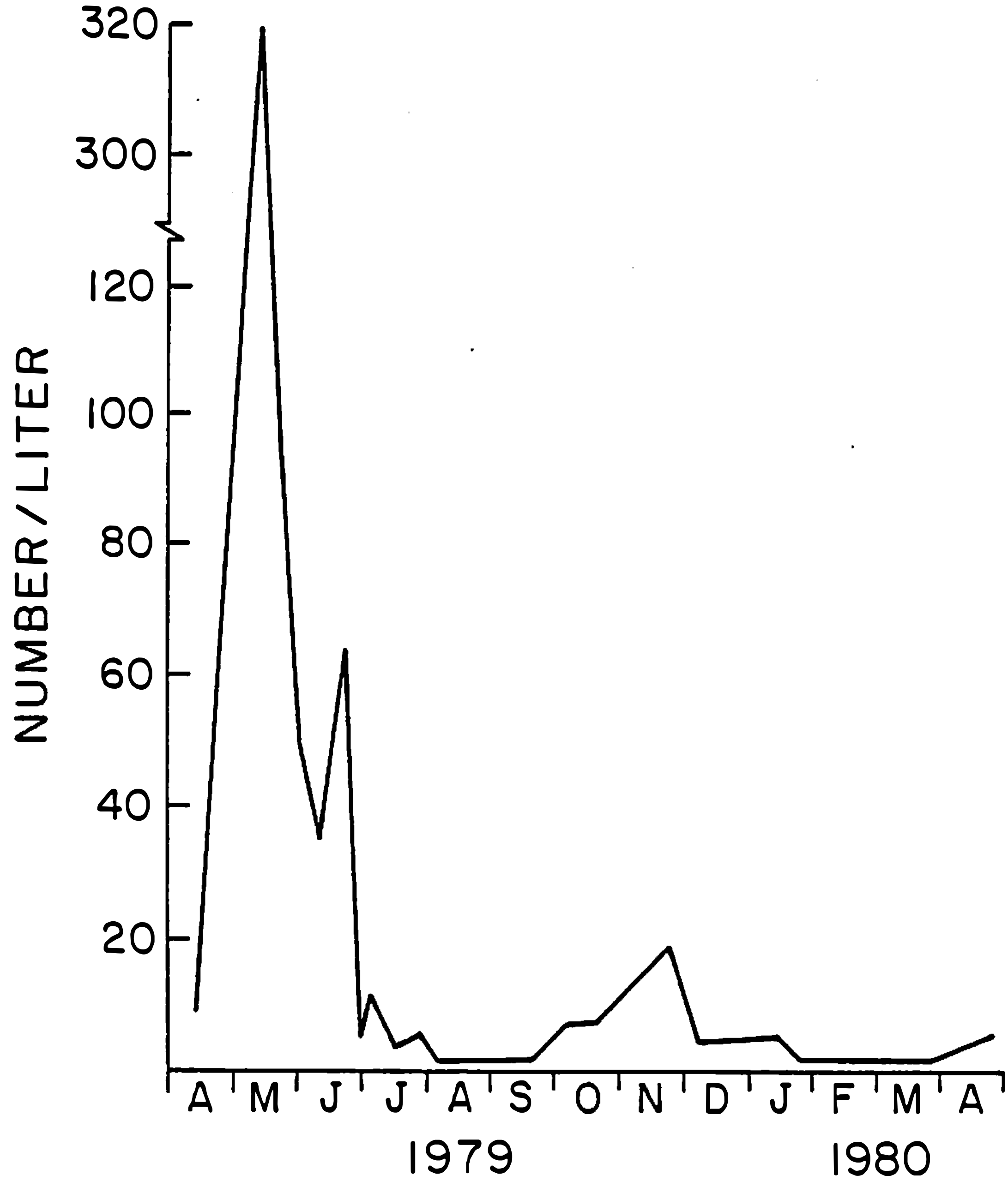

Fig. 6. Abundance of zooplankton in entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 20 April 1979 to 17 April 1980.

Table 12. Analysis of variance of the number of zooplankton collected in day, night, and morning entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 30 May to 5 October 1979.

Source of variation	Degrees of freedom	Mean square	F
Time	2	61.4926	3.3093
Date	4	2430.5573	130.8031**
Error	8	18.5818	

**Significant at 0.01 level of probability.

Table 13. Abundance (number/liter) of zooplankton in three time periods of entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

	Cladocera			Copepoda			Ostracoda			Total Zooplankton		
Date	D[a]	N	M	D	N	M	D	N	M	D	N	M
5-30	27.9	30.4	27.3	14.3	25.0	15.6	0.5	1.1	0.3	42.7	55.6	43.2
6-20	42.7	52.1	56.3	10.9	9.6	6.7	0.5	7.6	2.6	54.1	69.3	65.6
7-12	T[b]	T	0.1	0.7	1.8	2.8	0.1	3.7	1.7	0.8	5.6	4.6
8-8	0.5	0.2	0.1	0.2	1.7	1.2	0.3	0.6	0.4	1.0	2.5	1.7
10-5	4.2	3.7	8.4	1.1	1.7	3.1		T		5.3	5.4	11.5

[a]D-Day 1000 h - 1800 h, N-Night 1800 h - 200 h, M-Morning 200 h - 1000 h.

[b]Trace organism $\leq$0.05/liter.

Table 14. Percent mortality estimates of zooplankton in entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 11 May 1979 to 17 April 1980.

	Cladocera			Copepoda			Total Zooplankton		
Date	I[a]	D	D-I	I	D	D-I	I	D	D-I
5-11	70.6	90.3	19.7	47.3	81.7	34.4	53.1	83.3	30.2
5-16	32.8	71.2	38.4	19.2	78.2	59.0	24.6	76.2	51.6
5-29	19.0	96.1	77.1	22.5	91.5	69.0	20.7	93.6	72.9
6-12	19.6	100.0	80.4	50.7	84.1	33.4	38.7	91.7	53.0
6-30	27.0	100.0	73.0	28.1	100.0	71.9	27.5	100.0	72.5
7-19				42.3	100.0	57.7	42.3	100.0	57.7
7-31				40.3	100.0	59.7	40.3	100.0	59.7
8-24	30.0	90.0	60.0	54.3	92.3	38.0	44.7	91.1	46.4
10-5	17.5	53.3	35.8	45.8	53.8	8.0	28.1	53.7	25.6
11-15				44.9	58.9	14.0	36.7	61.8	25.1
2-28				25.5	64.4	38.9	25.5	64.4	38.9
3-13				14.3	71.2	56.9	14.7	71.2	56.5
4-17				37.5	69.4	31.9	37.5	69.4	31.9

[a]I-Intake, D-Discharge, D-I Discharge minus Intake.

Table 15. Temperature of intake and discharge water during entrainment sampling, Big stone Power Plant cooling reservoir, South Dakota, 20 April 1979 to 18 April 1980.

	Temperature (C)		
Date	Intake	Discharge	delta-T
4-20	12.5	33.1	20.6
5-3	16.7	32.1	15.4
5-11	13.6	28.3	14.7
5-17	17.2	29.9	12.7
5-24	21.1	35.3	14.2
5-30	24.0	37.2	13.2
6-13	23.6	38.8	15.2
6-30	26.1	40.7	14.6
7-19	28.9	42.8	13.9
8-1	27.5	42.3	14.8
9-7	26.1	40.4	14.3
9-20	17.0	17.0	0.0
10-5	17.1	30.7	13.6
11-16	13.3	28.2	14.9
12-19	3.6	28.2	24.8
12-27	9.4	33.9	24.5
2-8	6.8	32.9	26.1
2-29	3.9	28.9	25.0
3-13	5.6	5.6	0.0
4-18	16.9	32.3	15.4

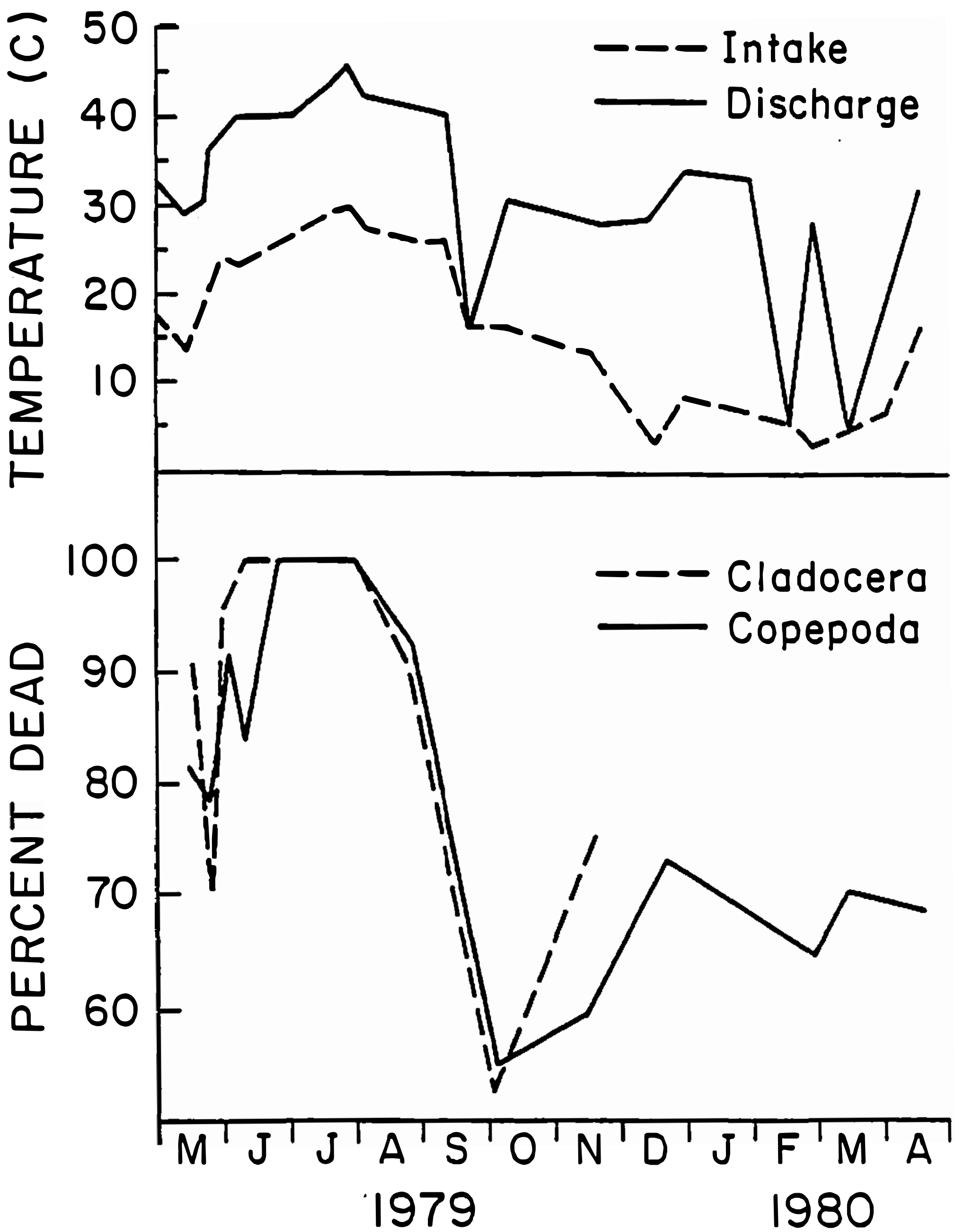

Fig. 7. Percent of zooplankton found dead in discharge water samples and temperature of intake and discharge water, Big Stone Power Plant cooling reservoir, South Dakota, 11 May 1979 to 17 April 1980.

temperature elevations are considered to be the most detrimental (Coutant 1970, Rogers 1977, Ginn et al. 1977). Ambient and discharge temperatures as well as the change in temperature (delta-T) are all important in influencing entrainment mortality (Crippen et al. 1977). Evans et al. (1977) found that mortality of zooplankton from entrainment ranged from 0% to 12% with a mean of 1.9% at discharge temperatures below 35 C and a delta-T not more than 10 C. Rogers (1977) noted a similar zooplankton mortality range of from 0% to 16% with a mean of 3.7% attributing the majority of the entrainment loss to thermal stress. Rogers also reported mortality of entrained zooplankton ranged from 5.5% to 21.6% when discharge temperatures were 35.0-37.1 C. Crippen et al. (1977) determined that a critical temperature (ambient-T + delta-T) exists that when exceeded significant zooplankton entrainment mortality occurs. When discharge temperature exceeded 32 C and ambient temperature was 4.8 C mortality increased dramatically until 100% mortality occured above 37 C. When the ambient temperature was 18 C increased mortality became apparent above 36 C.

An annual estimate of 179,834.4 kg of zooplankton was entrained from 20 April 1979 to 19 April 1980. Entrainment mortality was determined by using the mean mortality estimate by Rogers (1977) of 3.7% at temperatures below 37 C and a lethal temperature of 37 C where 95% of all zooplankton entrained were killed. A total estimate of 48,817.4 kg or 27.1% of the annual number of zooplankton entrained suffered immediate mortality from the direct effects of entrainment.

Ichthyoplankton

Five species of larval fish were collected in the reservoir (Table 16). The mean density of ichthyoplankton collected from 24 May to 24 July 1979 was .053/m^3 (Table 17). Ichthyoplankton abundance of .079/m^3 was found on 24 May increasing to the peak density of .161/m^3 found on 12 June and then decreasing to .002/m^3 on 24 July (Fig. 8). The highest number of ichthyoplankton collected in one sample was .429/m^3 at transect 2 on 12 June. *Lepomis* spp. was collected on all dates except 24 May and was the only genus collected after 29 June (Fig. 9). Carp (*Cyprinus carpio*) was found from 24 May to 29 June reaching the greatest abundance of any species (.087/m^3) on 12 June making up 54.0% of the total number collected on that date. Johnny darters (*Etheostoma nigrum*) fathead minnows (*Pimephales promelas*) were found only on 24 May and 29 May respectively.

The intake area contained significantly greater ($P < 0.05$) numbers of *Lepomis* spp. and total ichthyoplankton than the other areas of the reservoir (Tables 18-21). Total mean numbers per area were .091/m^3 for the intake area, .032/m^3 for the mixing area and .036/m^3 for the discharge area (Table 22). Mean number of *Lepomis* spp. collected from the intake area was .045/m^3 while mean numbers of the mixing and discharge areas were .013/m^3 and .016/m^3 respectively.

The presence of 4.0-5.9 mm TL *Lepomis* spp. on each date from 29 May througn 24 July (Table 23) indicates an extended spawning period from approximately mid May to late July. Carlander (1977) reported the nesting times of *L. humilis* and *L. macrochirus* from May to July or August in Iowa. Gerking (1962) noted a month long spawning period

Table 16. Species of ichthyoplankton in Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Common name	Scientific name
Carp	*Cyprinus carpio*
Fathead minnow	*Pimephales promelas*
Bluegill	*Lepomis macrochirus*
Orangespotted sunfish	*Lepomis humilis*
Johnny darter	*Etheostoma nigrum*

Table 17. Mean abundance (number/m^3) of ichthyoplankton, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Date	*Lepomis* spp.	*Cyprinus carpio*	*Etheostoma nigrum*	*Pimephales promelas*	Total
5-24		.008	.071		.079
5-29	.026	.065		.004	.095
6-12	.074	.087			.161
6-19	.024	.013			.037
6-29	.059	.005			.064
7-3	.017				.017
7-12	.017				.017
7-18	.005				.005
7-24	.002				.002
Mean	.025	.020	.008	T[a]	.053

[a]Trace organism ≤0.0005/m^3

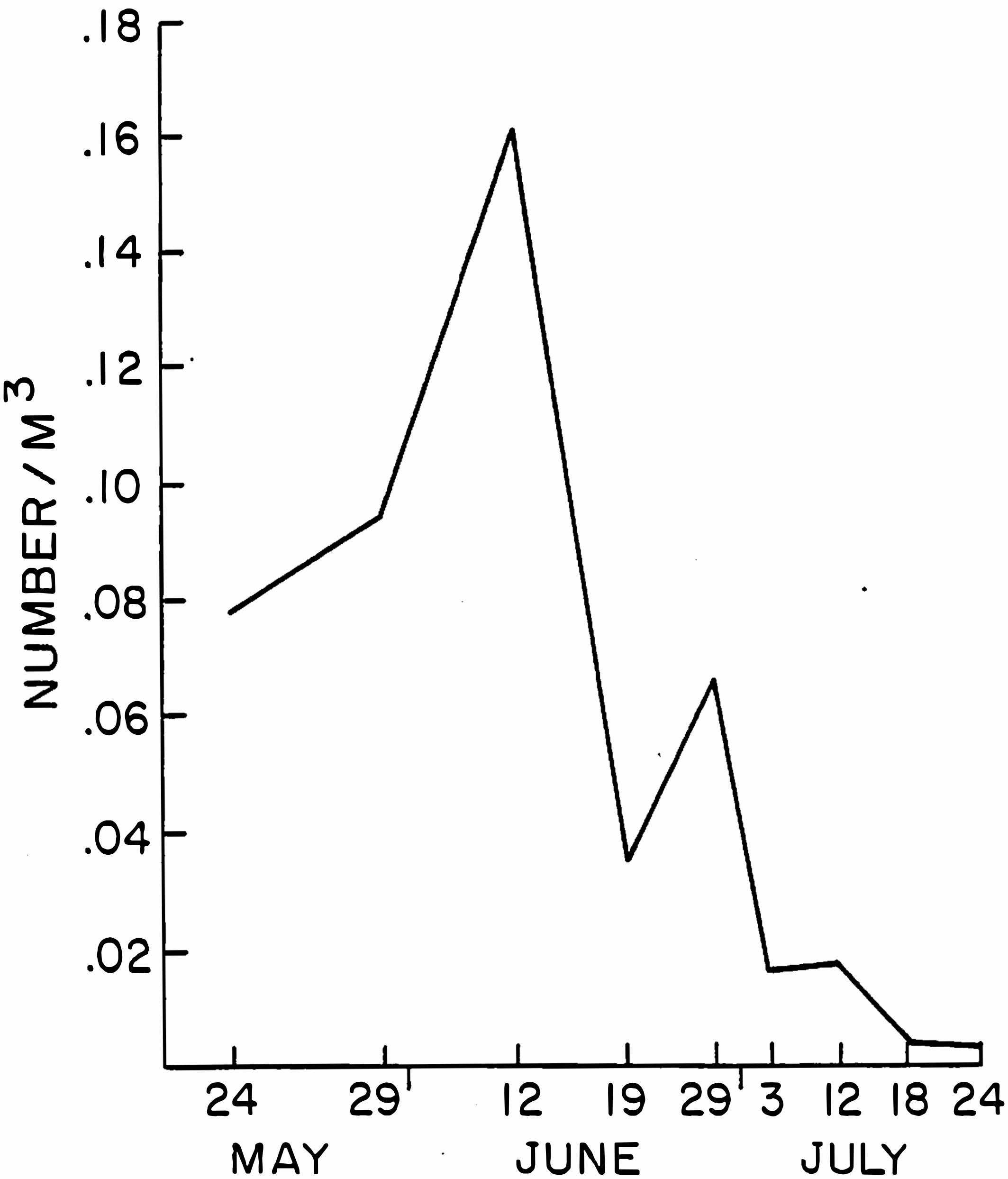

Fig. 8. Abundance of ichthyoplankton, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

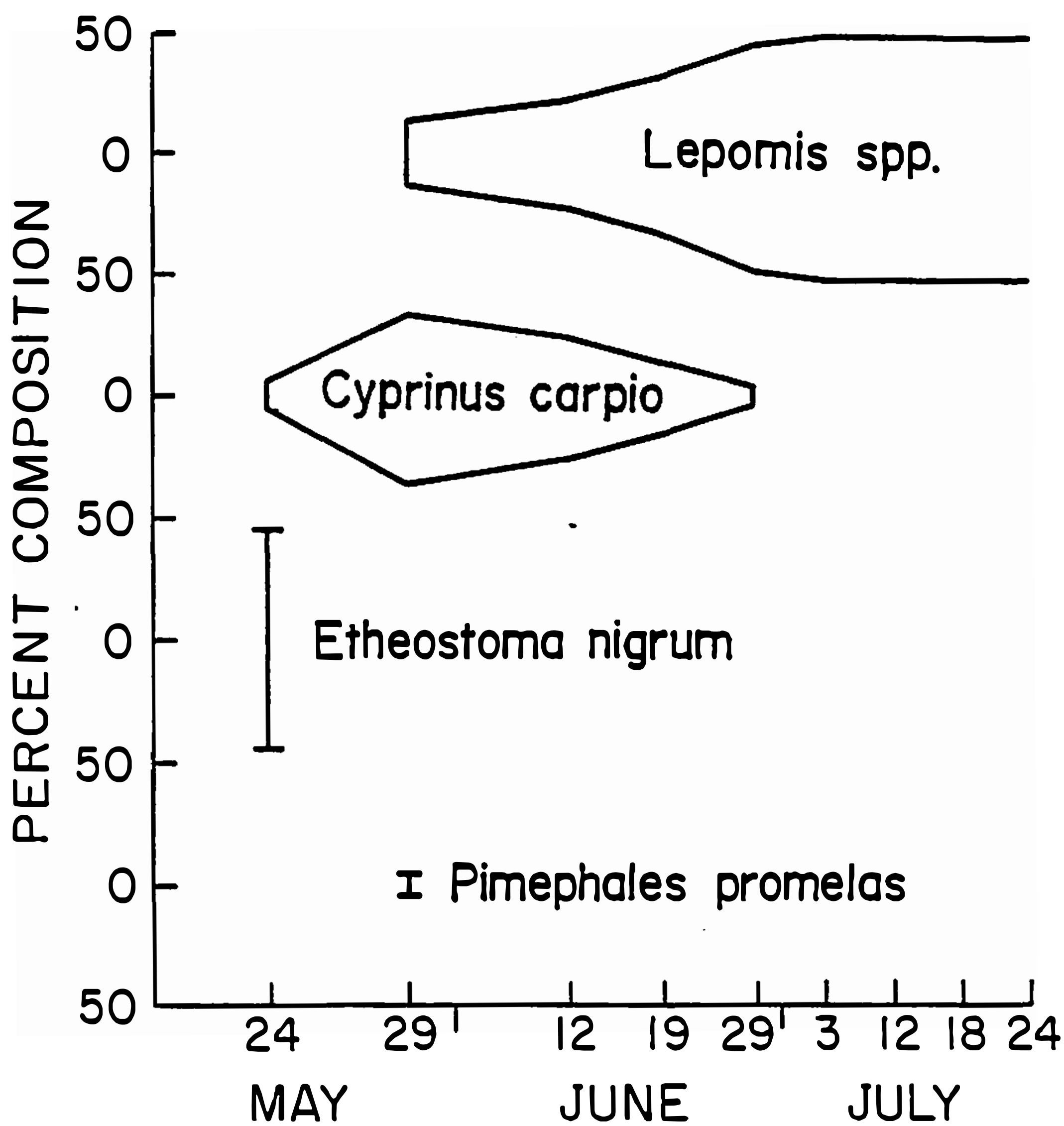

Fig. 9. Percent composition of ichthyoplankton, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Table 18. Analysis of variance of the number of ichthyoplankton collected in three areas in Big Stone Power Plant cooling reservoir, South Dakota, 24 May to 1 August 1979.

Source of variation	Degrees of freedom	Mean square	F
Area	2	35.5989	6.5716*
Transect	1	7.2120	1.3313
Transect X Area	2	10.7848	1.9909
Error	6	5.4171	

*Significant at 0.05 level of probability.

Table 19. Student Newman Keuls' analysis of the mean number/m^3 of ichthyoplankton collected in three areas in Big Stone Power Plant cooling reservoir, South Dakota, 24 May to 1 August 1979.

Mixing area	Discharge area	Intake area
0.32	0.36	0.91

Means not underscored by the same line are significantly different.

Significant at 0.05 level of probability.

Table 20. Analysis of variance of the number of *Lepomis* spp. collected in three areas in Big Stone Power Plant cooling reservoir, South Dakota, 30 May to 1 August 1979.

Source of variation	Degrees of freedom	Mean square	F
Area	2	10.0274	6.1307*
Transect	1	2.0937	1.2801
Transect X Area	2	0.9272	0.5669
Error	6	1.6356	

*Significant at 0.05 level of probability.

Table 21. Student Newman Keuls' analysis of the mean number/m^3 of *Lepomis* spp. collected in three areas in Big Stone Power Plant cooling reservoir, South Dakota, 30 May to 1 August 1979.

Mixing area	Discharge area	Intake area
4.80	5.80	16.24

Means not underscored by the same line are significantly different.

Significant at 0.05 level of probability.

Table 22. Mean abundance (number/m^3) of ichthyoplankton in three areas in Big Stone Power Plant cooling reservoir, South Dakota, 24 May to 24 July 1979.

Species	Intake area	Mixing area	Discharge area
Lepomis spp.	.045	.013	.016
Cyprinus carpio	.026	.019	.015
Etheostoma nigrum	.019		.005
Pimephales promelas	.001		
Total	.091	.032	.036

Table 23. Length range (mm) and number collected (in parenthesis) of ichthyoplankton ≤25 mm, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Date	*Lepomis* spp.	*Cyprinus carpio*	*Etheostoma nigrum*	*Pimephales promelas*
5-24		6.0-7.2 (2)	5.0-6.1 (13)	
5-29	4.1-6.2 (6)	4.9-6.5 (15)		5.7 (1)
6-12	4.1-14.5 (20)	5.1-11.6 (23)		
6-19	4.7-15.1 (5)	5.3-6.0 (4)		
6-29	4.1-21.0 (14)	5.9-6.0 (2)		
7-3	4.7-25.0 (7)			
7-12	4.0-17.0 (8)			
7-18	4.0-4.1 (2)			
7-24	4.6 (1)			

beginning in late May or June depending on temperature. Bluegills have a spawning temperature range from 17-26 C (Kitchell et al. 1974) but may spawn in temperatures from 17-32 C (Carlander 1977). Temperatures at one meter in the cooling reservoir were from 16.0-26.5 C on 9 May and by 25 June had reached 24.5-33.0 C. The presence of fry 6.1 mm long on 8 August indicates that spawning continued at least until the end of July when temperatures at a depth of 1 m ranged from 31.0-37.0 C on 25 July.

Carp ranging from 4.0-5.9 mm long found from 24 May to 29 June indicating a spawning season from mid May to late June. Carlander (1969) noted most spawning of carp in South Dakota in early June when water temperatures are about 18.5 C, however, spawning was also recorded from May to August in other northern U.S. lakes.

The spawning times of johnny darters and fathead minnows were difficult to estimate in the reservoir because of the low numbers collected. Lord (1927) and Markus (1962) found fathead minnows spawn from May through August, and Scott and Crossman (1973) reported johnny darters spawn in May or June in Canada.

The spawning seasons of fishes in the reservoir appeared to be typical for natural lakes in the Midwest U.S. The increased water temperature did not have any obvious effect on the time or length of the spawning seasons of the fishes sampled.

The estimated growth of Lepomis spp. calculated from the increase in size of the largest fish collected each entrainment sampling period was 0.5 mm/day. This is similar to other northern lakes where the growth of bluegills from 12-25 mm was 0.1-0.6 mm/day (Krumholz 1946) and 0.4

mm/day (Werner 1969) in Indiana, 0.2-0.5 mm/day in Minnesota (Lux 1960) and 0.5 mm/day in Wisconsin (Neill and Magnuson 1974). Growth of larger young-of-the-year *Lepomis* spp. in the cooling reservoir was not noticeably different from other northern lakes (Wahl 1980).

Ichthyoplankton Entrainment

Ichthyoplankton entrainment samples collected the same five species of fish that were found in the reservoir samples (Table 16). The mean number of larval fish entrained during the collection period was $.865/m^3$ (Table 24). Peak entrainment of $3.877/m^3$ occurred on 20 June. *Lepomis* spp. made up 90.5% of the total number of fish collected throughout the sample period and 99.4% from 13 June to the end of the period. Carp, johnny darters, and fathead minnows all reached their peak abundance on 30 May (Fig. 10).

No significant difference was found in the number of ichthyoplankton collected from the pumps placed at 1 and 3 m depths in the intake current (Table 25). No significant difference was indicated in the number of ichthyoplankton collected in day, night and morning entrainment periods (Tables 26,27). The interaction between times and dates could have prevented significance from being observed between entrainment periods but interaction could not be determined by the sampling scheme used. Ichthyoplankton collected during the day time period made up only 7.3% of the total number collected in the four entrainment samples while the night and morning periods made up 51.4 and 41.3% respectively (Fig. 11).

Comparisons were made between the numbers of ichthyoplankton collected in concomitant reservoir and entrainment samples and no

Table 24. Mean abundance (number/m^3) of entrained ichthyoplankton ≤25 mm, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Date	*Lepomis* spp.	*Cyprinus carpio*	*Etheostoma nigrum*	*Pimephales promelas*	Total
5-24		.003	.002	.010	.015
5-30	.320	.326	.438	.056	1.140
6-13	3.105	.014	.006		3.125
6-20	3.847	.030			3.877
6-30	.395				.395
7-3	.364				.364
7-12	.502				.502
7-19	.070				.070
7-25	.012				.012
8-1	.006				.006
8-8	.008				.008
Mean	.783	.034	.042	.006	.865

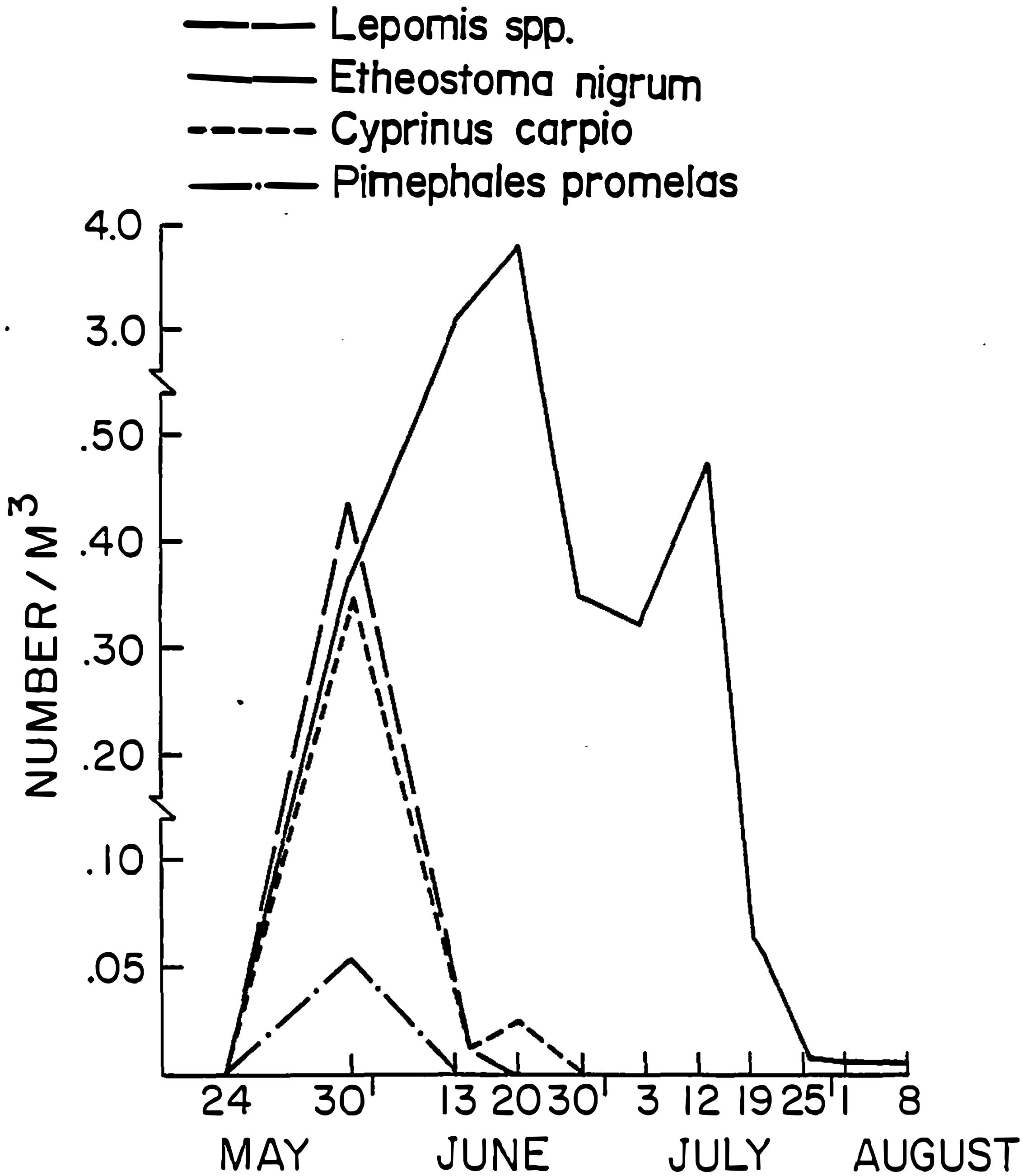

Fig. 10. Mean abundance of entrained ichthyoplankton ≤25 mm, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Table 25. Abundance (number/m^3) of ichthyoplankton ≤25 mm collected in two pumps during entrainment sampling, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Date	1 m	3 m
5-24	.418	0.0
6-30	3.435	7.885
7-3	2.917	7.501
7-12	2.160	12.261
7-19	1.135	.866
7-25	.120	.269
t value	1.836	

Table 26. Abundance (number/m^3) of ichthyoplankton ≤ 25 mm in three periods of diel entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

	Time		
Date	Day 1000 h-1800 h	Night 1800 h-200 h	Morning 200 h-1000 h
5-30	.050	.626	.464
6-20	.350	1.970	1.557
7-12	.003	.237	.262
8-8	0.0	.006	.002
Mean	.101	.710	.571

Table 27. Analysis of variance of the number of ichthyoplankton collected during day, night, and morning periods of entrainment, Big Stone Power Plant cooling reservoir, South Dakota, 30 May to 8 August 1979.

Source of variation	Degrees of freedom	Mean square	F
Time	2	0.4076	2.9861
Date	3	0.9940	7.2821*
Error	6	0.1365	

*Significant at 0.05 level of probability.

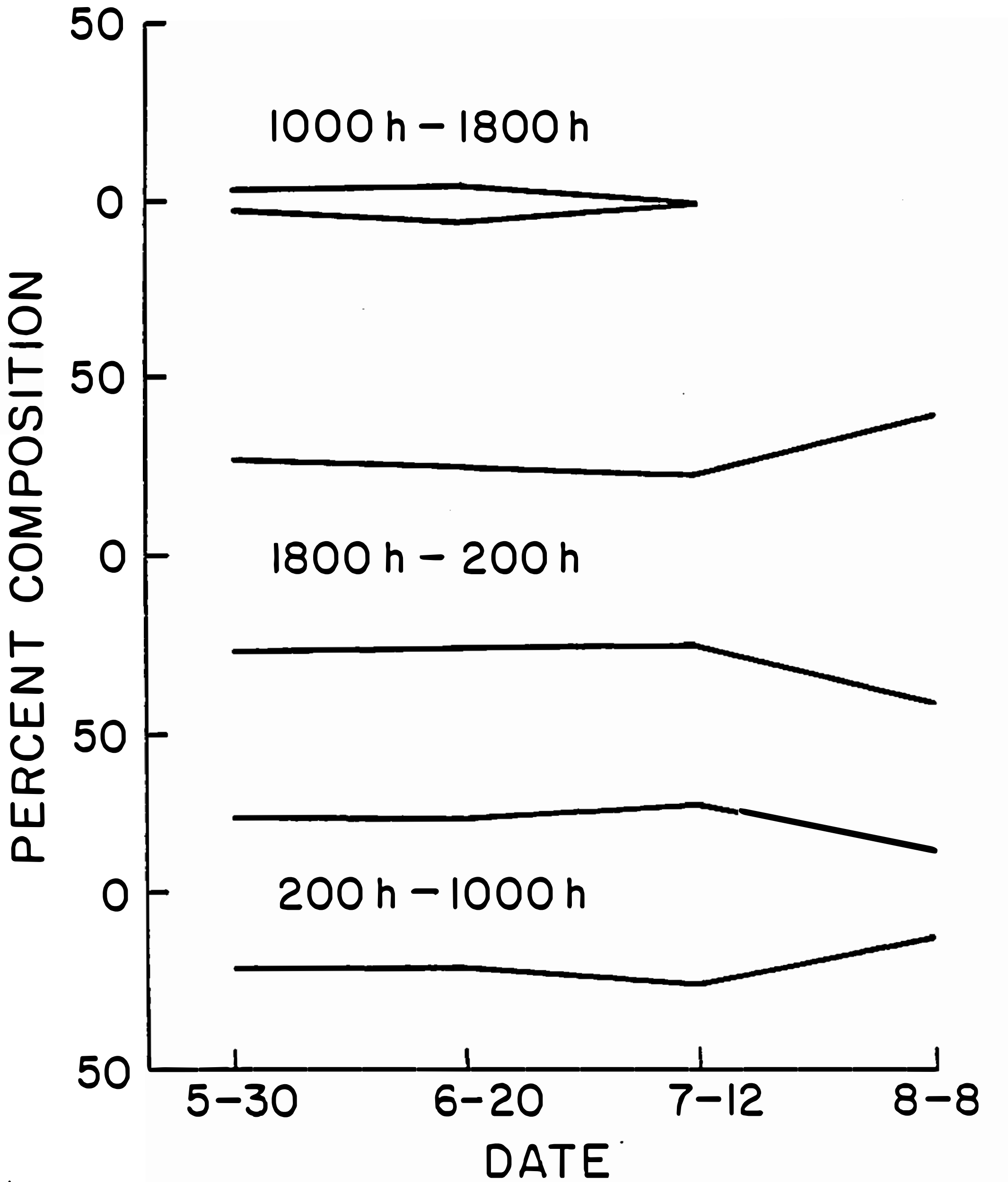

Fig. 11. Percent composition of ichthyoplankton ≤25 mm in three time periods of diel entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

significant differences were found for Lepomis spp., carp, or total numbers (Table 28). Although no significance was found, the number collected from entrainment samples exceeded the concomitant reservoir sample on ten of the eleven dates for total numbers and on all ten dates for Lepomis spp. The length ranges for entrained larval fishes (Table 29) were similar to the length ranges from reservoir samples.

No mortality studies were done to determine entrainment mortality of ichthyoplankton from the cooling reservoir because of the difficulty in collecting enough larval fish for testing. Ginn et al. (1977) determined that the magnitude of temperature elevation was the main factor governing the survival of entrained carp and striped bass. Ginn et al. also reported virtually no immediate mortality of larval carp when passed through a simulated condensor tube until discharge temperatures reached 35.0 C with a delta-T of 16.7 C. Mortalities quickly rose to 100% at temperatures above 37.5 C. Cannon et al. (1977) noted similar mortalities when temperatures increased above 33.0 C for striped bass and Clupeidae larvae. Discharge temperatures during the present study ranged from 35.3-45.4 C during the time when larval fish were being entrained (Table 15), therefore 100% mortality was assumed for determining entrainment mortality .

An estimated total of 56 million larval fish ≤25 mm TL were entrained and consequently killed between 24 May and 8 August 1979. Wahl (1980) found the mean length of impinged young-of-the-year Lepomis spp. in the cooling reservoir to be 38 mm during the last week in June. The estimated entrainment mortality for ichthyoplankton is therefore a minimum as fish between 25 and 38 mm were not included.

Table 28. Mean abundance (number/m^3) of ichthyoplankton ≤25 mm in concomitant reservoir and entrainment (in parenthesis) samples, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Date	*Lepomis* spp.	*Cyprinus carpio*	Total
5-24 (24)		.008 (.003)	.079 (.014)
5-29 (30)	.026 (.320)	.065 (.326)	.095 (1.140)
6-12 (13)	.074 (3.105)	.087 (.014)	.161 (3.125)
6-19 (20)	.024 (3.847)	.013 (.030)	.037 (3.877)
6-29 (30)	.059 (.395)	.005 (0.0)	.064 (.395)
7-3 (3)	.017 (.364)		.017 (.364)
7-12 (12)	.017 (.502)		.017 (.502)
7-18 (19)	.005 (.070)		.005 (.070)
7-24 (25)	.002 (.014)		.002 (.014)
8-1 (1)	0.0 (.006)		0.0 (.006)
8-8 (8)	0.0 (.008)		0.0 (.008)
t value	1.917	.935	2.045

Table 29. Length range (mm) and number (in parenthesis) of ichthyoplankton ≤25 mm collected in entrainment samples, Big Stone Power Plant cooling reservoir, South Dakota, 1979.

Date	*Lepomis* spp.	*Cyprinus carpio*	*Etheostoma nigrum*	*Pimephales promelas*
5-24		8.5-10.5 (3)	4.9-6.2 (11)	
5-30	4.0-10.5 (60)	4.2-14.2 (59)	4.0-7.0 (70)	5.0-10.2 (10)
6-13	5.5-17.8 (162)	5.0-9.2 (6)	10.0-11.5 (3)	
6-20	6.0-21.0 (209)	5.2-10.0 (5)		
6-30	3.8-25.0 (120)			
7-3	4.3-21.8 (161)			
7-12	6.0-25.0 (160)			
7-19	5.5-25.0 (65)			
7-25	6.0-19.5 (8)			
8-1	6.8-19.5 (8)			
8-8	6.1-9.0 (4)			

Zooplankton and ichthyoplankton populations in Big Stone Power Plant cooling reservoir appear to be similar to those observed in other midwestern lakes. Although the major physical features of the reservoir (heated effluent, entrainment, etc.) do have some effects on population structure and behavior, the overall impact on the forage base would probably not be a limiting factor in establishing a muskellunge brood stock. I conclude that the cooling reservoir may provide an adequate means for rearing and holding a brood stock of muskellunge.

LITERATURE CITED

Applegate, R. L., A. J. Repsys, and S. B. Smith. 1973. Dissolved organic matter, seston, and zooplankton cycles in Lake Poinsett, South Dakota. Proc. South Dakota Acad. Sci. 52: 28-46.

Brooks, J. L. 1957. The systematics of North American *Daphnia.* Mem. Conn. Acad. Arts and Sci. 13: 180 p.

Cannon, T. C., S. M. Jinks, L. R. King, and G. J. Lauer. 1977. Survival of entrained ichthyoplankton and macroinvertebrates at Hudson River power plants, p. 71-90. *In* L. D. Jensen (ed.) Fourth national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Carlander, K. D. 1969. Handbook of freshwater fishery biology. Vol. I. Iowa State University Press, Ames, Iowa. 752 p.

———. 1977. Handbook of freshwater fishery biology. Vol. II. Iowa State University Press, Ames, Iowa. 431 p.

Coutant, C. C. 1970. Biological aspects of thermal pollution. Entrainment and discharge canal effects, p. 341-381. *In* A. J. Brook (ed.) CRC Critical Rev. Env. Contr. Union Carbide Corp., Oak Ridge, Tennessee.

Cowell, B. C. 1967. The Copepoda and Cladocera of a Missouri River reservoir: a comparison of sampling in the reservoir and the discharge. Limnol. Oceanog. 12: 125-136.

Crippen, R. W., F. K. Fahmy, B. Seepersad, and A. M. Hayton. 1977. Impacts of three types of power generating discharge systems on entrained plankton, p. 191-202. In L. D. Jensen (ed.) Fourth national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Evans, M. S., B. E. Hawkins, and T. E. Wurster. 1977. Effects of Donald C. Cook Nuclear Power Plant on zooplankton of Southeastern Lake Michigan, p. 125-140. In L. D. Jensen (ed.) Fourth national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Gerking, S. D. 1962. Production and food utilization in a population of bluegill sunfish. Ecol. Monogr. 32: 31-78.

Ginn, T. C., G. V. Poje, and J. M. O'Connor. 1977. Survival of planktonic organisms following passage through a simulated power plant condenser tube, p. 91-102. In L. D. Jensen (ed.) Fourth national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Hall, D. J. 1964. An experimental approach to the dynamics of a natural population of Daphnia galeata mendotae. Ecology 45: 94-112.

———, W. E. Cooper, and E. E. Werner. 1970. An experimental approach to the production, dynamics and structure of freshwater animal communities. Limnol. Oceanog. 15: 839-928.

Hogue, J. J. Jr., R. Wallus, and L. K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. T. V. A. Technical Note B 19.

Kitchell, J. F., J. F. Koonce, R. V. O'Neill, H. H. Shugart Jr., J. J. Magnuson, and R. S. Booth. 1974. Model of fish biomass dynamics. Trans. Am. Fish. Soc. 103: 786-798.

Krska, R. J. 1980. The feeding ecology of fishes in a South Dakota power plant cooling reservoir. M. S. Thesis, South Dakota State University, Brookings, S. D. 62 p.

Krumholz, L. A. 1946. Rates of survival and growth of bluegill yolk fry stocked at different intensities in hatchery ponds. Trans. Am. Fish. Soc. 76: 190-203.

Lawler, J. P., and T. L. Englert. 1977. Models useful for the estimation of equilibrium population reduction due to power plant cropping, p. 102-114. In L. D. Jensen (ed.) Fourth national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Lord, R. F. Jr. 1927. Notes on the use of the blackhead minnow Pimephales promelas as a forage fish. Trans. Am. Fish Soc. 57: 92-99.

Lux, F. E. 1960. Notes on first year growth of several species of Minnesota fish. Prog. Fish-Cult. 22: 81-82.

Mahnken, C. V. W., and J. W. Jossi. 1967. Flume experiments of the hydrodynamics of plankton nets. J. Cons. pern. int. Explo. Mer. 31: 38-45.

Markus, H. C. 1934. Life history of the blackhead minnow (Pimphales promelas). Copeai. 1934: 116-122.

Mendenhall, W. 1975. Introduction to probability and statistics. Duxbury Press, North Scltuate, Mass. 460 p.

Meredith, D. L. 1973. Nuclear power plant siting: a handbook for the layman. Mar. Bull. 6: 95 p.

Metz, W. C. 1977. Cooling ponds, lakes and reservoir - a positive factor in power plant siting. Aware 4: 5-9.

Meyer, F. A. 1970. Development of some larval centrarchids. Prog. Fish-Cult. 32: 130-136.

Miller, D. 1961. A modification of the small Hardy plankton sampler for simultaneous high speed plankton hauls. Bull. Mar. Ecol. 5: 165-172.

Neill, W. H. and J. J. Magnuson. 1974. Distributional ecology and behavoiral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. Trans. Am. Fish Soc. 103: 663-710.

Novotony, J. F. 1973. Guide to the identification of common crustacean zooplankton in Missouri River reservoirs. North Central Reservoir Investigations. U. S. Fish and Wildl. Serv. Yankton, South Dakota. 64 p.

Pennak, R. W. 1957. Species composition of limnetic zooplankton communities. Limnol. Oceanog. 2: 222-232.

———, 1978. Freshwater invertebrates of the United States. 2nd Ed. John Wiley and Sons Inc., New York, New York.

Pierce, R. J. and T. E. Wissing. 1974. Energy cost of food utilization in the bluegill (Lepomis macrochirus). Trans. Am. Fish. Soc. 103: 38-45.

Reid, G. K. and R. D. Wood. 1976. Ecology of inland waters and estuaries. D. Van Nostrand Co., New York, New York. 485 p.

Repsys, A. J. 1972. Food selectivity of the black bullhead (Ictalurus melas, Rafinesque) in Lake Poinsett, South Dakota. M. S. Thesis, South Dakota State University, Brookings, S. D. 39 p.

Rogers, G. D. 1977. Entrainment of crustacean zooplankton through Fort Calhoun Station, p. 141-154. In L. D. Jensen (ed.) Fourth national workshop on entrainment and impingement. Ecological Analysts, Inc., Melville, New York.

Ruelle, R., W. Lorenzen, and J. Oliver. 1977. Population dynamics of young-of-the-year fish in a reservoir receiving heated effluent. Southeastern Reservoir Investigations. U. S. Fish and Wildl. Serv., Clemson, South Carolina. p. 46-67.

Scott, W. B., and Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bul. 184. 966 p.

Snyder, D. E., M. B. M. Snyder, and S. C. Douglas. 1977. Identification of golden shiner, Notemogonis crysoleucas, spotfin shiner, Notropis spilopterus, and fathead minnow, Pimephales promelas, larvae. J. Fish Res. Board. Can. 34: 1397-1409.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and proceedures of statistics. McGraw - Hill Book Co., Inc., New York, New York. 481 p.

Wahl, J. R. 1980. Forage fish populations and growth of muskellunge in a South Dakota power plant cooling reservoir. M. S. Thesis, South Dakota State University, Brookings S. D. 71 p.

Werner, R. G. 1969. Ecology of limnetic bluegill (Lepomis macrochirus) fry in Crane Lake, Indiana. Am. Mid Nat. 81: 164-181.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia, Penn. 743 p.

Wilson, M. S., and H. C. Yeatman. 1959. Free-living Copepoda. p. 738-861. In W. T. Edmondson (ed.) Freshwater biology 2nd ed. John Wiley and Sons Inc., New York, New York.

Woodmansee, R. A., and B. J. Grantham. 1961. Diel vertical migrations of two zooplankters (*Mesocyclops* and *Chaoborus*) in a Missippi Lake. Ecology. 42: 619-628.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 620 p.

APPENDIX

Appendix Table 1. Surface and bottom (in parenthesis) temperatures (C) at the six transects in Big Stone Power Plant cooling reservoir, South Dakota, 1979.

	Transect					
Date	1	2	3	4	5	6
1-30	1.0(2.3)	2.5(3.0)	2.0(3.5)	1.0(3.8)	16.5(6.0)	21.0(6.5)
2-8	0.5(2.5)	3.0(4.0)	1.0(3.5)	5.5(4.5)	12.0(4.5)	17.0(5.8)
2-27	(4.5)	(4.5)	(5.0)	(6.0)	(6.5)	(4.8)
4-16	10.5(10.5)	12.0(11.0)	10.0(8.0)	14.0(7.0)	25.2(10.5)	20.0(10.0)
4-27	17.0(18.5)	17.8(17.0)	19.0(18.0)			
5-9	16.0(17.0)	16.0(16.0)	16.0(16.0)	18.5(18.0)	21.3(18.5)	23.5(18.0)
5-23	22.0(22.0)	22.0(21.5)	22.0(20.8)	24.0(22.0)	31.5(22.0)	34.0(21.5)
6-10	24.5(24.5)	25.0(26.5)	27.0(26.5)	28.5(27.0)	34.0(26.0)	34.0(25.5)
6-25	25.0(25.0)	25.0(25.0)	26.0(23.5)	27.0(26.0)	32.0(26.0)	33.0(25.0)
7-10	32.0(30.0)	32.0(27.0)	31.0(25.0)	33.0(28.0)	39.0(29.0)	40.0(27.5)
7-25	31.0(30.0)	32.0(29.0)	34.0(24.5)	36.5(31.0)	41.0(31.0)	42.0(29.0)
8-10	28.5(29.0)	29.0(29.0)	29.0(28.0)	30.0(29.0)	31.0(28.5)	38.0(28.0)
8-22	27.3(27.0)	28.6(25.9)	29.0(25.0)	31.2(27.0)	37.2(27.0)	38.5(27.0)
9-6	27.6(27.4)	28.0(28.0)	28.1(27.4)	29.0(28.5)	34.0(28.1)	38.0(28.0)
9-20	17.9(18.1)	18.5(18.5)	18.6(18.6)	18.6(18.6)	18.1(18.1)	18.3(18.1)
10-11	18.2(18.1)	19.9(18.1)	20.1(17.3)	21.4(17.8)	28.0(18.0)	28.2(17.9)
10-27	17.0(17.0)	17.5(17.5)	17.5(16.0)	19.0(19.0)	23.0(17.5)	27.0(17.0)
11-9	9.5(10.0)	12.0(10.5)	13.0(11.0)	12.0(13.0)	18.0(13.0)	20.0(13.0)
11-23	13.2(13.2)	13.0(13.0)	13.5(13.0)	15.0(13.5)	23.0(13.5)	24.0(14.0)