The Benthic Macroinvertebrates from the Cooling Lake of a Coal-Fired Electric Generating Station

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ABSTRACT

The benthic macroinvertebrate community of Lake Sangchris was examined to determine the effect of heated effluent from a coal-fired electric power plant on its distribution and abundance. Of the 23 taxa of macroinvertebrates collected, chaoborids and chironomids made up 98 percent of the total. The species composition in Lake Sangchris was similar to that of nearby Otter Lake although the latter had more oligochaetes. A significantly higher abundance of benthic macroinvertebrates occurred in the deep water near the dam than elsewhere in the lake because of the large numbers of *Chaoborus punctipennis* found at that station. Significantly lower levels of abundance were found in the discharge channel than at other stations because silicate slag covered the bottom. The abundance of benthic macroinvertebrates in Lake Sangchris was comparable with or significantly higher than those in Otter Lake and in the profundal zones of Lake Shelbyville, Carlyle Lake, Peoria Lake, and Lake Wawasee. The abundance of benthic macroinvertebrates in the heated area of Lake Sangchris indicated that they readily tolerated the increased water temperatures, and the seasonal biomass closely followed the pattern for the seasonal abundance. The dominant benthic macroinvertebrates in Lake Sangchris aggregated in the deeper portions of the lake where a silt substrate was present, and the greatest diversity occurred between 4 and 6 m, the transition zone from hardpan clay and sand to silt. Artificial substrate samplers indicated that increased water temperatures in the discharge channel were not a limiting factor and that macroinvertebrates would colonize that area if a suitable substrate were present.

INTRODUCTION

The benthic macroinvertebrate community of Lake Sangchris was examined from September 1973 to September 1976 to determine the effect of the heated effluent from a coal-fired electric power plant on the species diversity and temporal and spatial distribution of macroinvertebrates relative to the various thermal regimes in the lake.

Lake Sangchris is on the boundary of Sangamon and Christian counties in central Illinois. It is an artificial impoundment developed by damming three branches of Clear Creek, a tributary of the South Fork of the Sangamon River. The lake consists of three long, narrow arms (Fig. 1) generally oriented in a north-south direction. The lake covers an area of 876 ha (2,165 acres) with an average depth of 4.6 m (15.0 feet) and a maximum depth of 13.7 m (44.9 feet) at the normal elevation of 178.3 m (585 feet) above mean sea level.

Lake Sangchris lies on the Jacksonville till of the Illinoian Stage of glacial deposits (Johnson 1964). Core samples (Limnetics, Inc. 1972) showed the surface sediments to be dark gray clay and silty clay with fine-grained sand and organic fibers. The lake bottom from the shoreline to a depth of 4 m was generally hardpan clay with isolated areas of sand and fine gravel. Below 4 m the lake

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bottom consisted of fine silt with allochthonous organic detritus. The bottom sediment in the discharge channel from the power plant was covered with a layer of silicate slag.

For purposes of comparison with a lake not receiving heated effluent, the benthic community of Otter Lake was examined from April through November 1975 and from April through September 1976. Otter Lake is a water supply reservoir 9.7 km (6 miles) west of Girard, Macoupin County, Illinois, and lies on the same sediment topography as Lake Sangchris.

Benthic samples also were collected during 1974 and 1975 in the East Branch (6.1 km south of Bulpitt) and the West Branch (1.6 km north of Zenobia) of Clear Creek above the impounded waters of Lake Sangchris to gain insight into the probable composition of the stream fauna prior to the stream's impoundment.

MATERIALS AND METHODS

The average biweekly bottom temperature and oxygen concentration for the heated, or discharge arm, (stations 5, 4, and 3) and unheated or intake- and control-arm, areas (stations 2, 1, and 7) of Lake Sangchris from 1973 through 1976 have been extracted from data collected by Brigham (1977).

Monthly benthic collections in Lake Sangchris began on 19 September 1973

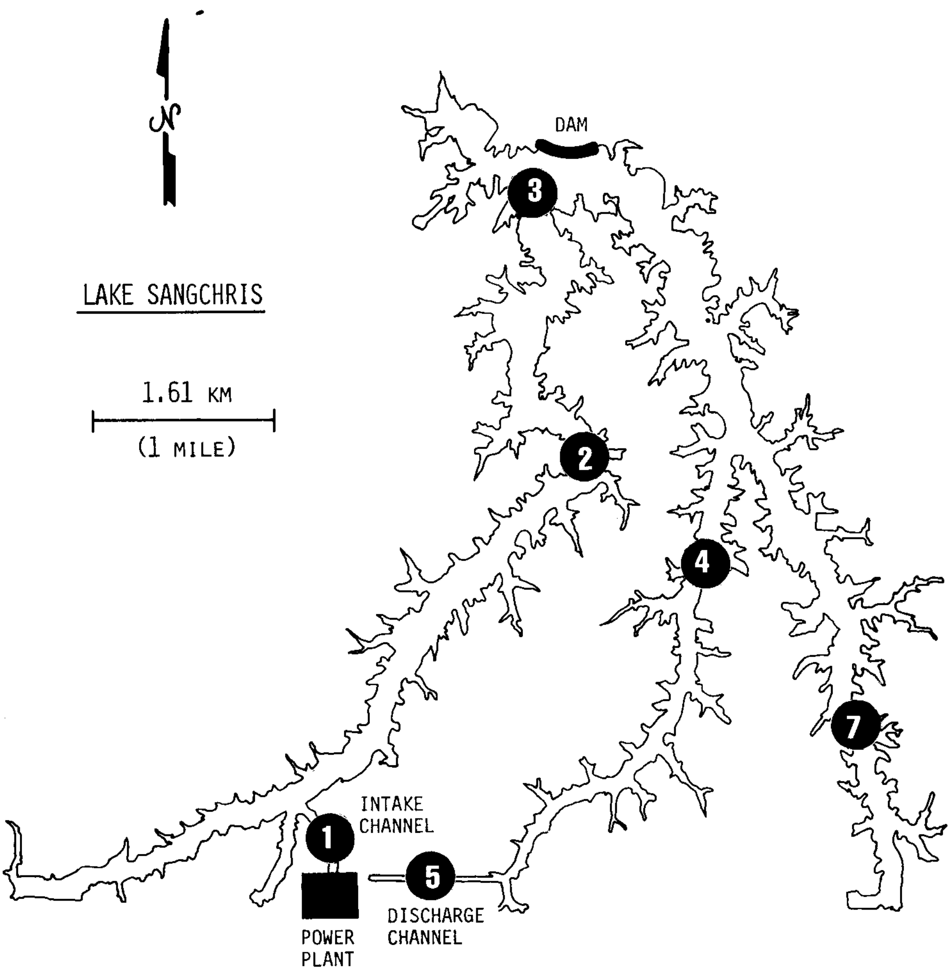


Fig. 1.—Lake Sangchris sampling stations for benthic macroinvertebrates.

and continued through 3 September 1976. Collections were made at six midchannel (profundal) sites (Fig. 1). Three 15.2- x 15.2-cm (6- x 6-inch) Ekman grab samples were taken at each station and at a depth of 2 m at both shoreline at stations 2, 3, 4, and 7. The selection of three samples at each site was based on species averaging for one standard deviation from a mean of 30 samples that had been collected for statistical analysis. Samples were washed through a brass screen (no. 30 mesh), preserved in 70-percent ethyl alcohol, and sorted in white enamel pans. At each station, species diversity (d) was determined by the equation of Margalef (1958), which expresses the relationship between the number of species (s) and the natural logarithm of the total number of individuals (N):

$$d = \frac{s-1}{\ln N}$$

To determine the spatial distribution of benthic macroinvertebrates, 12 transects were selected (Fig. 2). At each transect three Ekman grab samples were collected at the shoreline and then at every 2 m in depth across the transect to the opposite shore. A total of 288 samples was taken at 96 sites during collecting periods in May, July, and September of 1974 and May and July of 1975. Comparisons were made among different transect locations, depths, substrates, months, and water temperatures.

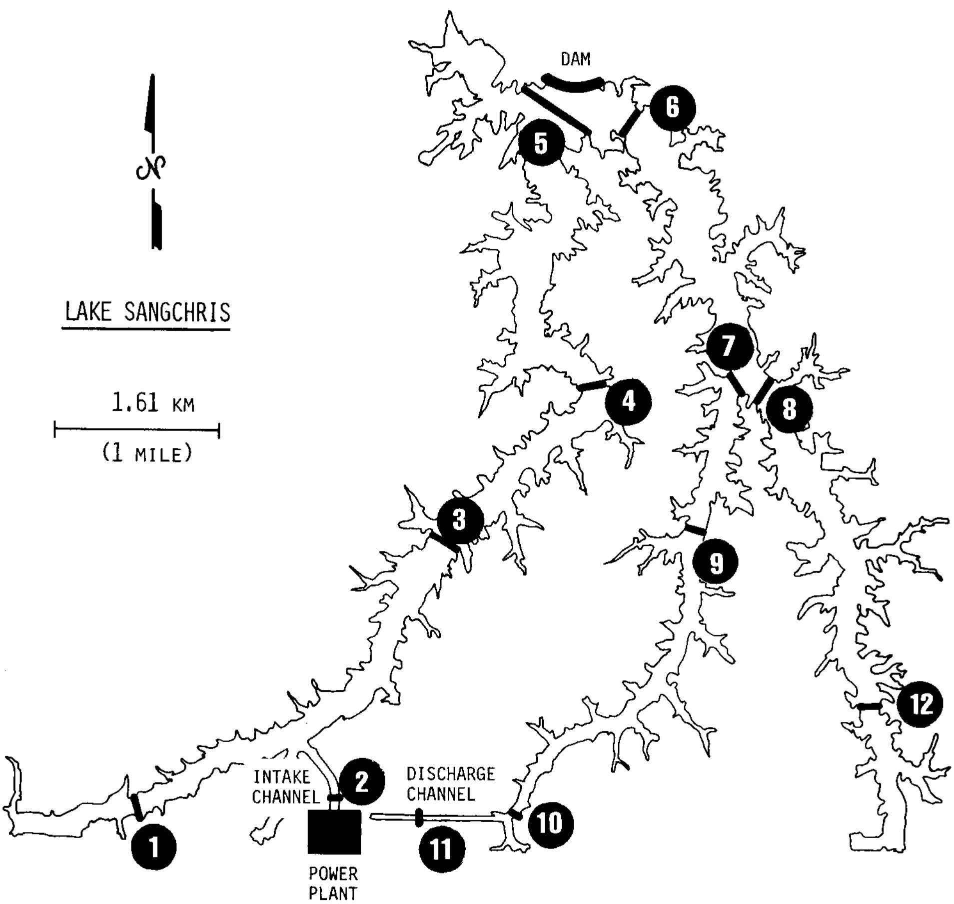


Fig. 2.—Lake Sangchris sampling transects for spatial distribution of benthic macroinvertebrates.

In viewing the distribution pattern of benthic macroinvertebrates within Lake Sangchris, the sampling efficiency of the Ekman grab on hardpan clay and sand must be taken into consideration. For samples taken along the shoreline the jaws of the grab were closed by hand to ensure that the surface area enclosed by the grab was scraped clean. In taking samples from depths of 2–4 m, only those samples in which the jaws of the grab were completely closed were retained for sorting and counting.

The effect of heated effluent and bottom substrate on benthic macroinvertebrates in the discharge channel (Station 5) was compared to that in the intake channel (Station 1) by taking three artificial substrate samples at each station, beginning in April 1975, and collecting the colonizing organisms in June, August, and October. The artificial substrate samplers were constructed from half of a minnow trap with an aluminum pan sealing each end. Each sampler contained four 7.6- x 7.6- x 7.6-cm (3- x 3- x 3-inch) cement blocks, with a surface area of 1,386 cm^{-2}, placed on edge. Only specimens from the bottom pan and six sides of the four cement blocks, having a total area of 1,796.7 cm^{-2}, were collected.

In Otter Lake, benthic collections were taken monthly from 16 April through 18 November 1975 and from 19 April through 3 September 1976. Three Ekman grab samples were collected at each of six sites (Fig. 3) in the northern half of Otter Lake. The depth at these sites ranged from 1 to 8 m, with stations 1 to 5 in the littoral-sublittoral zone and Station 6 in the profundal zone.

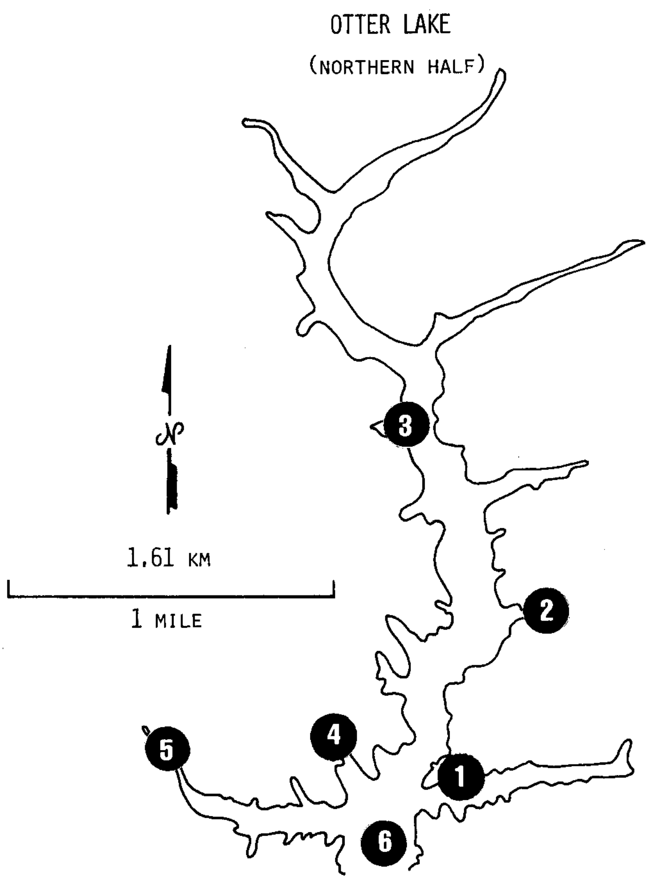
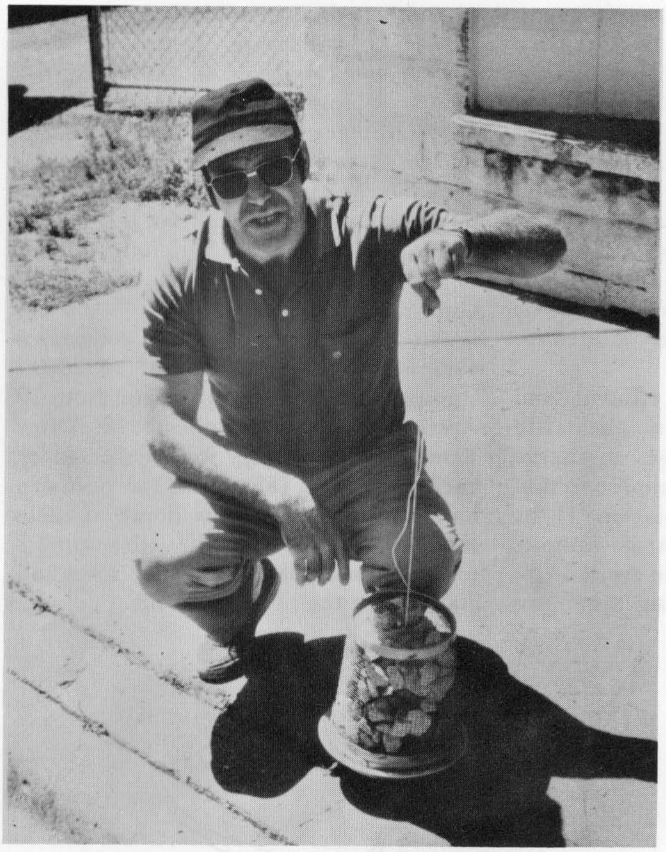


Fig. 3.—Otter Lake sampling stations for benthic macroinvertebrates.



Artificial substrate sampler used in benthic studies at Lake Sangchris.

Data were analyzed by one-way analysis of variance and the Kramer (1956) extension of Duncan's multiple range test. Comparisons were made at the 0.05 level of significance.

RESULTS AND DISCUSSION

WATER TEMPERATURE AND OXYGEN CONTENT

Because both water temperature and oxygen concentration can limit the growth, distribution, and abundance of benthic macroinvertebrates, the seasonal variation of those parameters in Lake Sangchris are presented (Fig. 4 and 5) for reference to the distribution and abundance of benthic organisms.

Bottom temperatures in Lake Sangchris were highest in the discharge channel (Station 5), ranging from 25° to 40° C during the summer and 10°–15° C during the winter. The next highest temperatures were at Station 4 and Station 3, considered a transition zone between the heated and unheated areas and included in the heated area because it was affected by the thermal effluent. Differences in the average bottom temperatures between the heated and unheated areas generally ranged from 4° to 8° C through the spring, summer, and autumn and between 8° and 12° C during the winter months. Bottom temperatures in Otter Lake followed the general pattern observed for Lake Sangchris.

Oxygen concentrations generally ranged higher in the unheated area of Lake Sangchris from 1973 through 1976 than in the heated area (Fig. 5), but the discharge channel consistently had the highest levels of oxygen (except for the winter of 1973–1974). The higher oxygen concentrations in the discharge channel were due to enhanced atmospheric reaeration resulting from

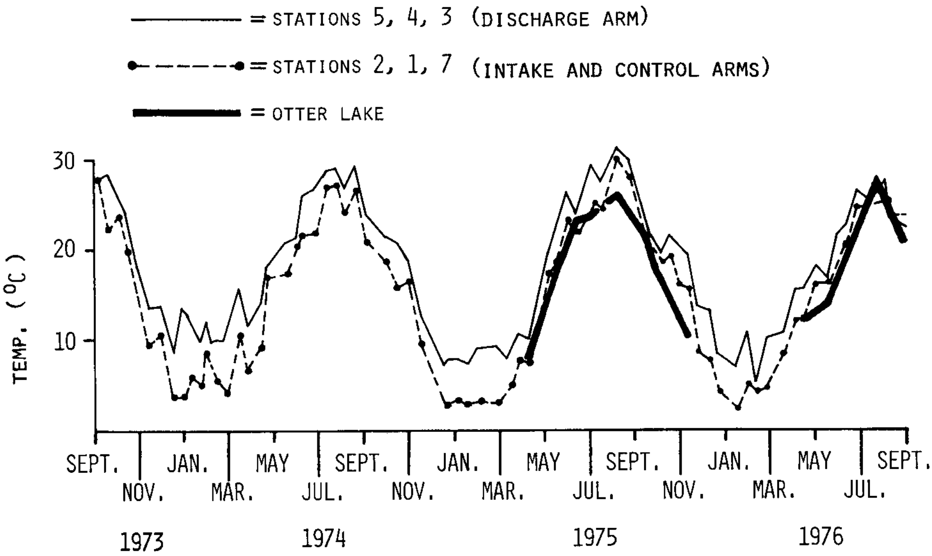


Fig. 4.—Average bottom temperatures in the discharge and the intake and control arms of Lake Sangchris from 1973 through 1976 and in Otter Lake during 1975 and 1976.

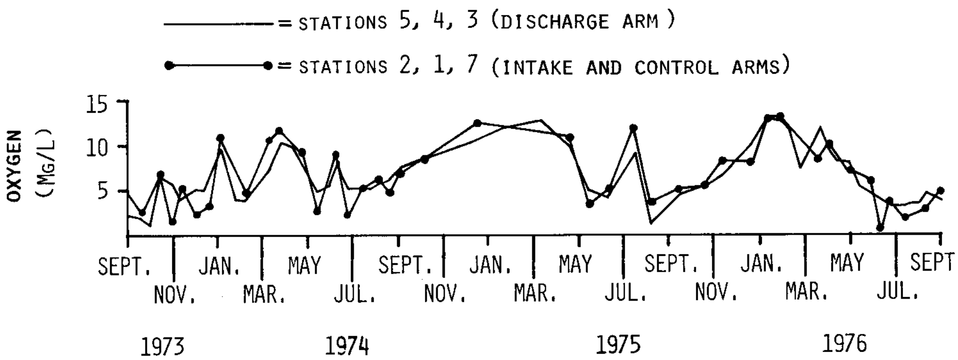


Fig. 5.—Average oxygen concentrations in the discharge and the intake and control arms of Lake Sangchris from 1973 through 1976.

the high turbulence as the heated effluent was expelled from the power plant. Oxygen concentrations in Otter Lake for 1975 (April through November) and 1976 (April through September) ranged from 3.4 to 9.6 mg/1 at a depth of 8 m, which was comparable to those at Station 2 in the unheated area of Lake Sangchris.

TAXA COLLECTED

Twenty-three taxa of oligochaetes, decapods, mollusks, and insects were collected in Lake Sangchris (Table 1). The phantom midge (*Chaoborus punctipennis*) represented 59 percent of all organisms collected, and the nonbiting midges (Chironomidae) 39 percent. Within the Chironomidae, six species (*Chironomus attenuatus, Cryptochironomus fulvus, Coelotanypus concinnus, Glyptotendipes lobiferus, Procladius bellus, Xenochironomus festivus)* of the 15 collected represented 94 percent of the chironomids collected. Other benthic macroinvertebrates, such as mayflies, caddisflies, and oligochaetes, represented only 2 percent of the organisms collected.

Benthic macroinvertebrates (Table 1) in the headwaters of the East and West branches of Clear Creek above the impounded waters of Lake Sangchris exhibited greater diversity than did those in the impounded habitat. Forty-one taxa were collected, including the major taxa occurring in Lake Sanghcris. The greater

Table 1.—Species of benthic organisms collected in dredge samples from Lake Sangchris, Lake Sangchris tributaries, and Otter Lake.

Species	Lake Sangchris Stations						Clear Creek		Otter Lake Stations					
	1	2	3	4	5	7	East Branch	West Branch	1	2	3	4	5	6
Annelida														
Oligochaeta														
Limnodrilus hoffmeisteri	X	X	X	X		X	X	X	X	X	X	X	X	X
Branchiura sowerbyi			X	X		X	X							
Hirudinea														
Helobdella sp.					X									
Insecta														
Ephemeroptera														
Hexagenia limbata	X	X	X	X			X	X		X			X	
Caenis sp.		X	X	X		X	X		X	X		X	X	
Baetis sp.							X	X						
Heptagenia sp.								X						
Trichoptera														
Cyrnellus marginalis		X	X	X		X	X							
Hydropsyche sp.							X							
Cheumatopsyche sp.							X	X						
Odonata														
Argia sp.							X							
Somatochlora sp.							X							
Ischnuria sp.							X							
Hemiptera														
Mesovelia mulsanti							X	X						
Corixidae								X						
Coleoptera														
Dubiraphia quadrinotata							X			X			X	
Macronychys glabratus							X							
Stenelmis sp.							X	X						
Diptera														
Chaoborus punctipennis	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chironomus attenuatus	X	X	X	X		X	X	X	X	X	X	X	X	X
Cryptochironomus fulvus	X	X	X	X		X	X	X	X	X	X	X	X	X
Procladius bellus	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Coelotanypus concinnus	X	X	X	X		X		X	X	X	X	X	X	X
Palpomyia complex	X	X	X	X		X	X	X	X	X	X	X	X	X

diversity was due primarily to the greater diversification of habitat.

Eighteen taxa of oligochaetes and insects (Table 1) were collected from Otter Lake, all of which were collected in Lake Sangchris. The oligochaete,

Table 1.—Continued.

Species	Lake Sangchris Stations						Clear Creek		Otter Lake Stations					
	1	2	3	4	5	7	East Branch	West Branch	1	2	3	4	5	6
Glyptotendipes lobiferus	X	X	X	X			X	X	X	X	X	X	X	X
Xenochironomus festivus		X	X	X	X	X	X	X	X	X		X	X	
Cricotopus bicinctus		X	X	X		X	X	X		X	X	X		X
Dicrotendipes modestus	X	X	X	X	X	X		X		X				
Dicrotendipes neomodestus							X	X						
Tanypus stellatus		X		X		X								
Polypedilum sp.		X	X	X		X	X	X	X	X	X	X	X	
Ablabesmyia sp.	X			X				X			X		X	
Harnischia sp.	X	X			X			X			X	X	X	
Paracladopelma sp.								X						
Paralauterborniella nigrohalteralis							X	X						
Thienemannimyia complex							X	X						
Tanytarsus sp.		X		X			X	X	X	X	X	X	X	
Micropsectra sp.						X		X						
Phaenopsectra jucundus							X	X						
Tabanus sp.							X	X						
Psychoda sp.							X	X						
Tipula sp.							X	X						
Hexatoma sp.							X	X						
Mollusca														
Pelecypoda														
Corbicula fluminea	X	X	X	X	X	X								

Limnodrilus hoffmeisteri (18 percent), the phantom midge, *Chaoborus punctipennis* (40 percent), and the nonbiting midges (Chironomidae) (39 percent) made up 97 percent of the total organisms collected from Otter Lake. Oligochaetes were distinctly more abundant in Otter Lake than in Lake Sangchris.

Initially, Limnetics, Inc., (1972) reported a paucity of benthos in Lake Sangchris, but in a supplemental study (Limnetics, Inc. 1973) collected 24 taxa. Paloumpis & Starrett (1960) studied three floodplain lakes of the Illinois River near Havana. The species composition consisted of Diptera larvae (*Pelopia = Tanypus, Procladius, Coelotanypus, Chaoborus*), oligochaetes, mayflies (*Hexagenia limbata*), sphaeriid clams, and leeches. The benthic communities varied markedly from lake to lake although oligochaetes constituted over 60 percent of the fauna in each of the lakes. Studies on Illinois River lakes (Richardson 1921*a*, 1921*b*, 1924, 1925, and 1928) indicated that oligochaetes and clams were the dominant macroinvertebrates although a variety of leeches, chironomids, snails, amphipods, isopods, caddisflies, mayflies, odonates, and sialids were present. Most of these organisms were distributed in the wide portions of the lakes, away from the main river channel. A study of Clearwater Lake, Missouri, (O'Connell & Campbell 1953) showed that a wide variety of taxa inhabits newly formed reservoirs. Oligochaetes, Culicidae (probably Chaoboridae), and Chironomidae constituted 90 percent of the fauna, and at no time were fewer than 13 taxa collected in the littoral zone during any sampling period.

Annual reports to the Army Corps of Engineers for Lake Shelbyville (Brigham 1973, 1974, 1975, and 1976) and Carlyle Lake (Dufford, Swadener, & Waite 1976 and 1977) indicated that the diversity of benthic organisms was greatest at lotic stations. The lentic stations in these central Illinois reservoirs were dominated by chaoborids, oligochaetes, and chironomids, which accounted for more than 80 percent of the benthic macroinvertebrates.

The wide variety of macroinvertebrates in northern Indiana lakes was similar to that collected in Illinois River lakes. In Wabee Lake (Wohlschlag 1950) benthic macroinvertebrates were restricted to a narrow littoral zone because a marl substrate covered much of the lake bottom. In Lake Wawasee (Scott, Hile, & Spieth 1928) 22 taxa were collected, with the diversity of macroinvertebrates extending well into the profundal zone (9–15 m).

The diversity of macroinvertebrates in Lake Sangchris appears normal when compared with those of other central Illinois lakes (Otter Lake, Lake Shelbyville, Carlyle Lake) although it lacks the variety of clams, isopods, amphipods, and leeches prevalent in Illinois River and northern Indiana lakes. The littoral zone of Lake Sangchris, outside of the coves, consists primarily of hardpan clay and sand with scattered areas of macrophytes, a habitat which may account for the absence of certain macroinvertebrates there.

SEASONAL ABUNDANCE

The seasonal abundances of benthic macroinvertebrates at midchannel (profundal) sites in Lake Sangchris from 1973 through 1976 are shown in Fig. 6. In the discharge channel (Station 5) benthic macroinvertebrates ranged in abundance from 0 to 244 organisms m^{-2}. Although the highest bottom temperatures and oxygen concentrations were in the discharge channel, the silicate slag covering the bottom provided an unsuitable habitat for the animals. Artificial substrate samples at that station (Table 4) indicated that benthic macroinvertebrates would colonize a suitable substrate in areas of high water temperature. With the exception of those taken from the discharge channel, benthic macroinvertebrates collected from the cooling loop of the lake (stations 4, 3, 2, and 1) 57 to 5,028 organisms m^{-2}, equal to or greater than the levels of

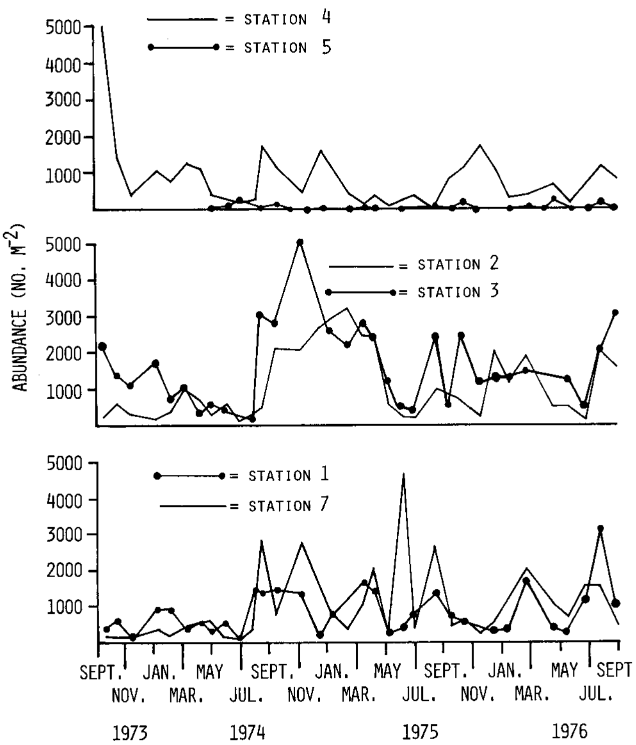


Fig. 6.—Seasonal abundances of benthic microinvertebrates in Lake Sangchris from 1973 through 1976.

abundance (86–4,735 organisms m^{-2}) found in the control arm (Station 7). The seasonal abundance of benthic macroinvertebrates in Lake Sangchris was in phase with those of Illinois lakes that receive no heated effluent.

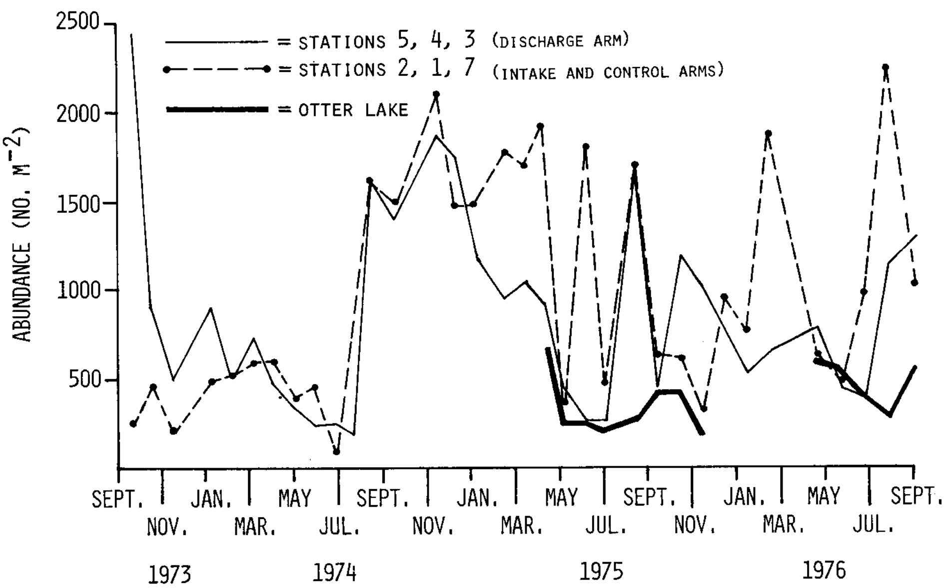


Fig. 7.—Average seasonal abundances of benthic macroinvertebrates in the discharge arm (heated) and intake and control arms (unheated) of Lake Sangchris from 1973 through 1976 and in Otter Lake during 1975 and 1976.

The average abundance of benthic macroinvertebrates (Fig. 7) was higher in the discharge (heated) arm (stations 5, 4, and 3) of Lake Sangchris from September 1973 through March 1974 and then closely paralleled the abundance in the intake and control arms (stations 2, 1, and 7) through the rest of the year. Through 1975 and 1976, the average abundance fluctuated considerably, particularly in the intake and control arms, with the average abundance generally higher there than in the discharge arm. The average abundance for the entire lake during this study ranged from 250 to 2,000 organisms m^{-2} and was, with one exception, always above the levels of abundance observed for Otter Lake.

Analyses of variance of the mean numbers of benthic macroinvertebrates at each profundal station in Lake Sangchris demonstrated that they were significantly more abundant (0.05 level) at Station 3 than at any other station (Table 2). Stations 2, 7, 4, and 1 (in rank order of decreasing means) formed a subset having an intermediate level of abundance. The mean abundance of macroinvertebrates was significantly (0.05 level) lower at Station 5 in the discharge channel than at any other station.

In Otter Lake during both 1975 and 1976, Station 6 in the profundal zone was significantly higher in the abundance of macroinvertebrates (0.05 level) than were stations 1 through 5 in the littoral-sublittoral zone (Table 2).

From April through November 1975, the abundances of macroinvertebrates at stations 3, 4, and 7 in Lake Sangchris were comparable to that at Station 6 in Otter Lake (Table 2). During April through September 1976, the abundances of macroinvertebrates at stations 3, 1, 7, and 2 in Lake Sangchris were comparable to that at Station 6 in Otter Lake (Table 2). During both periods the numbers in the discharge channel (Station 5) of Lake Sangchris were comparable to those of the littoral-sublittoral stations of Otter Lake.

A comparison of the profundal stations of Lake Sangchris, Lake Shelbyville (Brigham 1973, 1974, 1975,

Table 2.—Comparison of the analyses of variance of the means of abundance of benthic macroinvertebrates at each profundal station in Lake Sangchris (Sa); in Otter Lake (Ot); and in the profundal zones of Lake Shelbyville (Sh), Carlyle Lake (Ca), and Lake Wawasee (Wa), Indiana (0.05 level of confidence). Each underlined value is comparable to values with the same underline and is significantly higher than the other values to its right.

Lake Sangchris Profundal Stations

Station	3	2	7	4	1	5
Mean	1,688	1,117	985	920	818	40

Otter Lake 1975 (April to November)

Station	6	2	4	5	3	1
Mean	61	23	15	12	12	10

Otter Lake 1976 (April to September)

Station	6	1	5	3	4	2
Mean	84	27	21	21	13	13

Lake Sangchris (Sa) Otter Lake (Ot) 1975 (April to November)

Station	3(Sa)	4(Sa)	7(Sa)	6(Ot)	2(Sa)	1(Sa)	2(Ot)	4(Ot)	5(Ot)	3(Ot)	1(Ot)	5(Sa)
Mean	101	66	62	61	55	51	23	15	12	12	10	.3

Lake Sangchris (Sa) Otter Lake (Ot) 1976 (April to September)

Station	3(Sa)	6(Ot)	1(Sa)	7(Sa)	2(Sa)	4(Sa)	1(Ot)	5(Ot)	3(Ot)	4(Ot)	2(Ot)	5(Sa)
Mean	118	84	83	74	68	47	27	21	21	13	13	2

Lake Sangchris (Sa) Lake Shelbyville (Sh) Carlyle Lake (Ca) Lake Wawasee (Wa)

Station	3(Sa)	(Sh)	2(Sa)	(Ca)	7(Sa)	4(Sa)	(Wa)	1(Sa)	5(Sa)
Mean	1,688	1,209	1,117	1,114	985	920	890	818	40

and 1976), Carlyle Lake (Dufford, Swadener, & Waite 1976 and 1977), and Lake Wawasee, Indiana (Scott, Hile, & Spieth 1928) (Table 2) showed that the abundance of macroinvertebrates at Station 3 in Lake Sangchris and in the profundal zone of Lake Shelbyville were comparable and significantly higher (0.05 level) than those at stations 2, 7, 4, 1, and 5 of Lake Sangchris and of Carlyle Lake and Lake Wawasee. Macroinvertebrate abundances in Lake Shelbyville, Carlyle Lake, and Lake Wawasee were comparable to those of stations 2, 7, 4, and 1 of Lake Sangchris. The discharge channel (Station 5) of Lake Sangchris had a significantly lower abundance (0.05 level) than the other stations in Lake Sangchris and Lake Shelbyville, Carlyle Lake, and Lake Wawasee.

The range of abundance of benthic macroinvertebrates in Lake Sangchris is also comparable to those in Upper, Middle, and Lower Peoria Lake (Richardson 1928) in the Illinois River. During 1924 the abundance of macroinvertebrates in Peoria Lake varied from 192 to 5,634 organisms m^{-2} (mean 2,252), and in 1925 from 844 to 1,684 organisms m^{-2} (mean 1,530). In contrast, Paloumpis & Starrett (1960) found benthic macroinvertebrates in Lake Matanzas, middle Quiver Lake, and Lake Chautauqua to vary from 1,959 to 16,792 (mean 5,326), 2,680 to 43,981 (mean 11,922), and 3,767 to 17,976 (mean 9,533) organisms m^{-2}, respectively. Those lakes are broad expansions of floodplain lakes of the Illinois River and received considerable enrichment from waterfowl.

From these data it is evident that the benthic macroinvertebrates of Lake Sangchris form three distinct subsets in terms of abundance, the deepest profundal zone (Station 3) being significantly higher in macroinvertebrate abundance; the cooling loop and control arm being intermediate and, within this subset, having comparable populations; and the discharge channel having a significantly lower abundance of macroinvertebrates than the other stations. With the exception of the discharge channel, where the presence of slag covering the bottom apparently limits the colonization by benthic macroinvertebrates, the abundance of such organisms in the cooling loop of Lake Sangchris is comparable to or significantly higher than the abundance at Station 7 in the control arm and the abundance in Lake Shelbyville, Carlyle Lake, Lake Wawasee, and Peoria Lake. Apparently no reduction in the abundance of benthic macroinvertebrates has resulted from the increase in water temperature.

ABUNDANCE OF DOMINANT SPECIES

Analyses of variance of the means of abundance of the dominant macroinvertebrates of Lake Sangchris showed that *Chaoborus punctipennis* was significantly more abundant (0.05 level) in the deepest area of the lake (Station 3) than at any other station. Its lowest abundance occurred in the control arm (Station 7) and the discharge channel (Station 5) (Table 3).

Table 3.—Comparison of the analyses of variance of the means of abundance of the dominant benthic macroinvertebrates from the profundal zone of Lake Sangchris (0.05 level of confidence). Each underlined value is comparable to values with the same underline and is significantly higher than the other values to its right.

	Chaoborus punctipennis					
Station	3	4	2	1	7	5
Mean	96	64	35	35	25	1
	Procladius bellus					
Station	7	3	1	2	4	5
Mean	13	6	4	4	4	0.03
	Coelotanypus concinnus					
Station	7	2	1	3	4	5
Mean	4	2	2	1	1	0.15
	Chironomus attenuatus					
Station	2	3	1	7	4	5
Mean	34	19	11	10	1	0.03
	Cryptochironomus fulvus					
Station	1	7	2	3	4	5
Mean	3	3	2	2	1	0.31

This is the typical distribution for *C. punctipennis* in large lakes, where they tend to be restricted to the deeper zones (Eggleton 1931, Juday 1921, Stahl 1966). The mature larvae live in the mud during the day and become nektonic and limnetic during the night (Berg 1937, Eggleton 1931, Juday 1921), feeding on copepods, oligochaetes, chironomid larvae, rotifers, mosquito larvae, and other chaoborid larvae (Berg 1937, Deonier 1943, Main 1953, Stahl 1966). Chaoborid larvae are especially abundant in the deeper portions of lakes where the hypolimnion becomes depleted of oxygen (Thienemann 1922, Findenegg 1955). Although showing a preference for the deeper, colder zone of a lake, chaoborid larvae are extremely eurythermal, capable of migrating from 4° C to 20° C and back to 4° C within a day (Welch 1952).

Procladius bellus and *Coelotanypus concinnus* were significantly more abundant (0.05 level) in the control arm (Station 7) (Table 3) than at other stations in the lake. Both species are considered predators or scavengers and eurythermal (Beck 1977). Roback (1969) reported both species feeding heavily on diatoms, as well as on oligochaetes, cladocerans, and other chironomid larvae. The level of phytoplankton photosynthesis in the control arm (Station 7) was higher than it was at other stations (R.L. Moran, Illinois Natural History Survey, personal communication) although the abundance of benthic macroinvertebrates there was comparable to that of the cooling loop in general except at Station 3 and significantly below the abundance of macroinvertebrates in the intake arm. There was no evidence that fish predation on benthic macroinvertebrates was concentrated in the control arm as compared with such predation at other stations in the lake. These data suggest that *Procladius bellus* and *Coelotanypus concinnus* may have been seeking the area of greatest growth or abundance of phytoplankton.

Chironomus attenuatus was significantly more abundant (0.05 level) (Table 3) at Station 2 in the intake arm than at any other station, and its lowest abundance was at stations 4 and 5 in the discharge arm. This species is embenthic (Beck 1977) and considered primarily a scavenger, feeding on nonliving plant and animal material. It is also eurythermal to mesothermal (Beck 1977) although Iovino & Miner (1970) found it to be oligothermal in Beaver Reservoir, Arkansas. In Beaver Reservoir, Iovino & Miner (1970) found that *C. attenuatus* concentrated in the deepest areas of the lake. In Lake Sangchris, the aggregation of *C. attenuatus* at Station 2 rather than in the deepest area of the lake (Station 3) could be the result of competition for space with *Chaoborus punctipennis* or of heavy predation from *Chaoborus punctipennis* feeding on the earlier and smaller instars of *Chironomus attenuatus*. Both possibilities are conceivable, as *Chaoborus punctipennis* was nearly three times more abundant at Station 3 than *Chironomus attenuatus*. The abundance of *Cryptochironomus fulvus* was not significantly different among the sampling sites. Thus, each of the dominant species of macroinvertebrates in Lake Sangchris tends to exhibit a distinctiveness in its abundance with respect to its interrelationships which other species and with the physical conditions of the lake.

SEASONAL VARIATIONS IN BIOMASS

The seasonal variations in the average biomass (wet weight) of benthic macroinvertebrates for the heated and unheated arms of Lake Sangchris from 1973 through 1976 and in Otter Lake for 1975 (April through November) and 1976 (April through September) are shown in Fig. 8. The variations in biomass generally followed the pattern for the seasonal level of abundance (Fig. 7). The biomass in the discharge (heated) arm ranged from 0.11 to 2.30 g m^{-2} and was quite similar to that of the intake and control arms (0.04–1.47 g m^{-2})(Fig.8), indicating that increased water temperatures did not limit the growth of

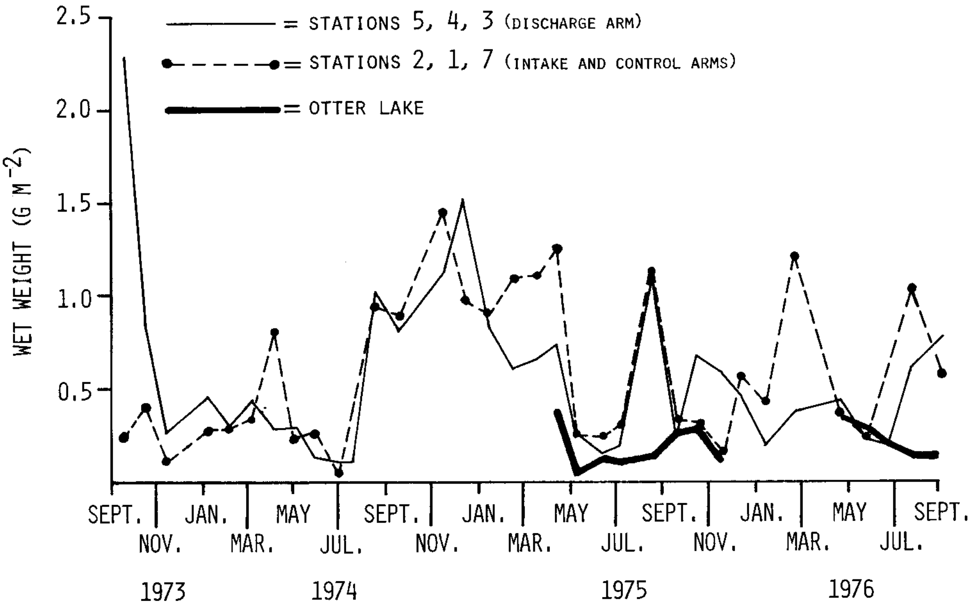


Fig. 8.—Average seasonal distribution of the standing crop of benthic macroinvertebrates in the discharge arm (heated) and the intake and control arms (unheated) of Lake Sangchris from 1973 through 1976 and in Otter Lake during 1975 and 1976.

benthic macroinvertebrates in the heated arm of the lake. The small numbers of benthic macroinvertebrates in the discharge channel reduced the average values for biomass in the heated portion of the lake. With two exceptions, the biomass values in the heated and unheated parts of Lake Sangchris were higher than the levels for Otter Lake, which ranged from 0.06 to 0.38 g^{-2} during the summer of 1975 and 0.15 to 0.37 g m^{-2} during the summer of 1976. In Carlyle Lake (Dufford, Swadener, & Waite 1977) the lentic biomass ranged from 0.15 to 5.64 g m^{-2}, and for the floodplain lakes of the Illinois River (Paloumpis & Starrett 1960) the average biomass in Lake Matanzas, middle Quiver Lake, and Lake Chautauqua was 9.69, 47.79, and 16.15 g m^{-2}, respectively. The high average biomass of benthic macroinvertebrates in the floodplain lakes compared to that of Lake Sangchris is due to the larger biomass of fingernail clams collected. The biomass in Lake Sangchris falls within the range of those found in other central Illinois lakes (Otter Lake, Carlyle Lake).

BATHYMETRIC DISTRIBUTION

The bathymetric distribution of benthic macroinvertebrates in Lake Sangchris during 1974 and 1975 indicated that their greatest abundance (Fig. 9) occurred at depths of 4 m or more where the bottom sediments were composed primarily of silt. The bottom sediments from the shoreline to a depth of 4 m contained large areas of hardpan clay and sand, in addition to the layer of slag which covered the bottom of the discharge channel, all of which are unsuitable as habitats for most benthic organisms. *Xenochironomus festivus, Glyptotendipes lobiferus,* and *Cricotopus bicinctus,* which is epiphytic (Beck 1977), were collected only in the littoral and sublittoral zones from 0 to 4 m. Both *Procladius bellus* and *Coelotanypus concinnus,* which are eurythermal and predaceous or scavengers (Beck 1977), were distributed throughout all depths of the lake. *Chaoborus punctipennis* and *Chironomus attenuatus,* which is embenthic (Beck 1977), were generally collected only in the profundal zone.

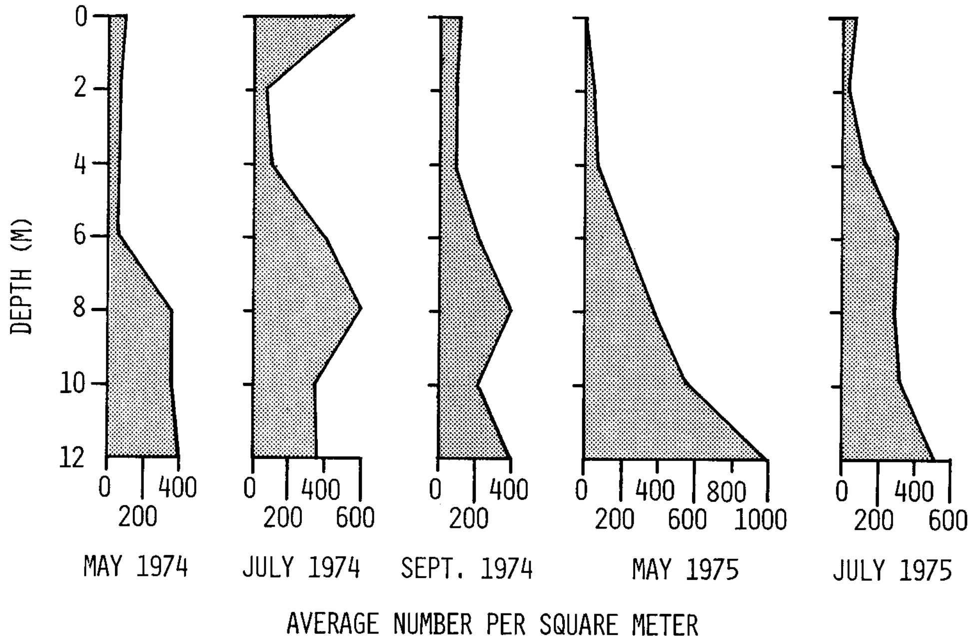


Fig. 9.—Bathymetric distribution of benthic macroinvertebrates in Lake Sangchris during 1974 and 1975.

SPATIAL DISTRIBUTION

The spatial distribution of benthic macroinvertebrates in Lake Sangchris during 1974 is shown in Fig. 10. The flow of heated effluent moves from transect 11 in the discharge channel (Fig. 2) to transect 1 in the intake arm, with transect 12 in the control arm of the lake unaffected by the thermal discharge. In May, July, and September, the general abundance of benthic macroinvertebrates increased in numbers from transect 11 in the discharge channel to transect 3 in the intake arm and then decreased moderately toward the intake area. Across each transect the abundance of macroinvertebrates increased with depth, the greatest abundance occurring generally in the deepest portions of each transect. On some occasions high concentrations of benthic macroinvertebrates (reaching 2,500-3,000 organisms m^{-2}) were collected immediately along the shoreline (Fig. 10) although generally the abundance of macroinvertebrates in the littoral zone averaged below 200 organism m^{-2} (Fig. 9). When large numbers of chironomid larvae *(Cricotopus bicinctus)* were collected along the shoreline, they were associated with a layer of algae covering the hardpan clay. The low abundance of macroinvertebrates collected during May can be attributed to the emergence of aquatic insects at that period of the year. Larvae hatching from deposited eggs would account for the increase in abundance during July and September.

Depth distributions of benthic macroinvertebrates have not been reported for other Illinois lakes although in Lake Wawasee, Indiana (Scott, Hile, & Spieth 1928) benthic macroinvertebrates were collected abundantly to the deepest portions of the lake, reaching over 1,000 organisms m^{-2} at depths of 3, 11, 13, 15, and 17 m. The bottom sediments in Lake Wawasee consisted of fine silt at depths of 3–23 m, indicating that silt provides a suitable substrate for the growth and development of benthic macroinvertebrates.

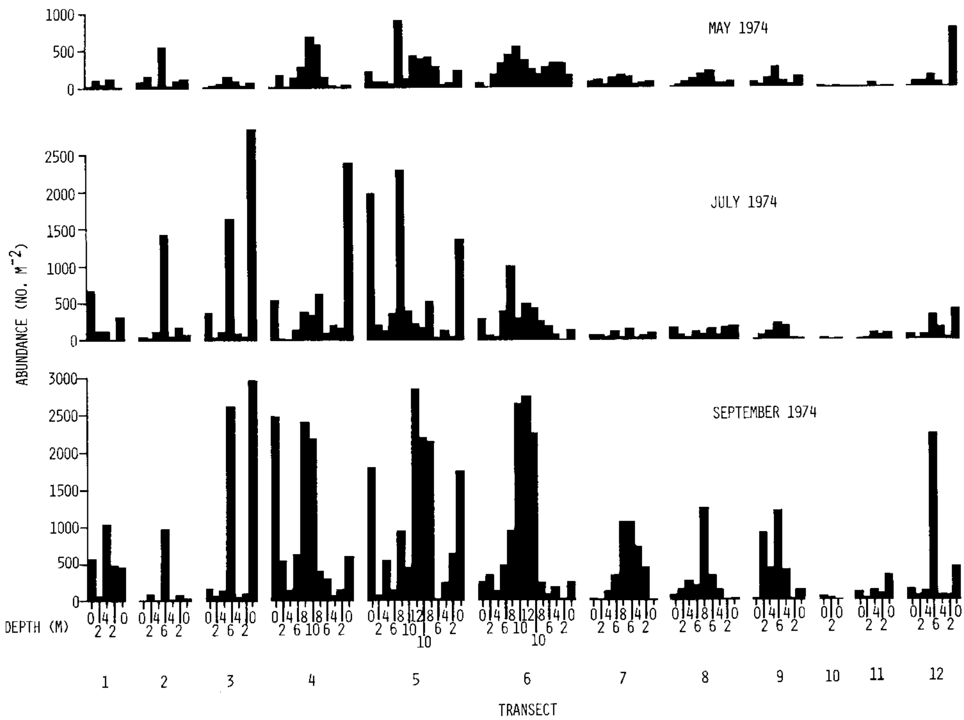


Fig. 10.—Spatial distribution of benthic macroinvertebrates in Lake Sangchris during May, July, and September 1974.

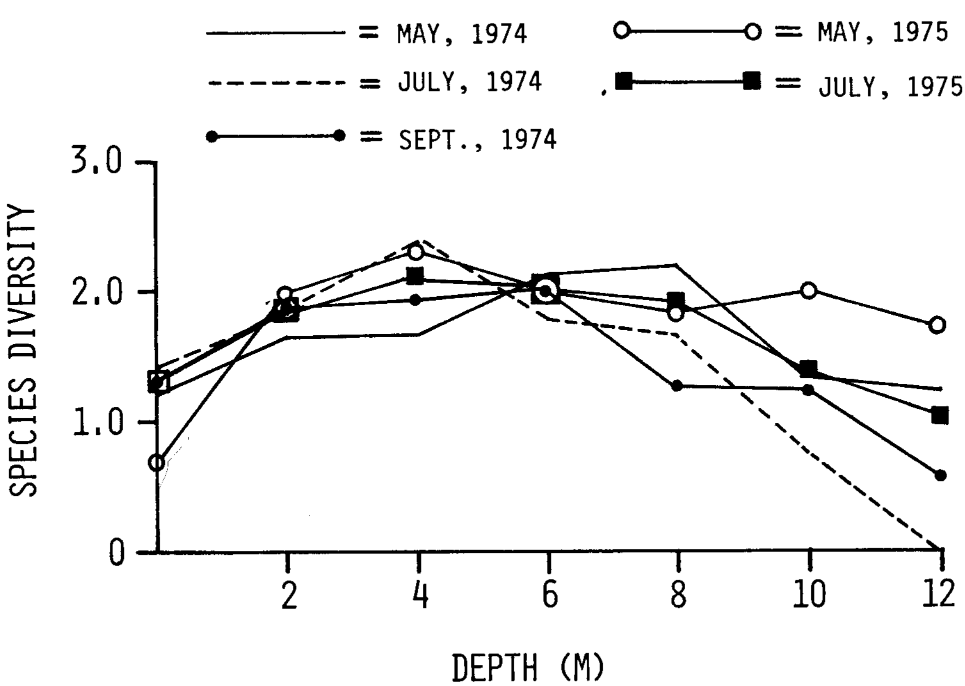


Fig. 11.—Average species diversity at various depths of benthic macroinvertebrates in Lake Sangchris during 1974 and 1975.

SPECIES DIVERSITY BY DEPTH

All values for species diversity across the 12 transects were averaged for each depth for collections taken in May, July, and September 1974 and May and July 1975. Fig. 11 shows the greatest diversity occuring at 4–6 m, the transition zone from hardpan clay and sand to silt.

EFFECTS OF WATER TEMPERATURE AND BOTTOM TYPE

To determine if increased water temperatures or the presence of silicate slag caused the severe paucity of benthos in the discharge channel (Station 5), three artificial substrate samplers were placed in both the discharge channel (Station 5) and the intake channel (Station 1) during 1975. The abundance and diversity of organisms collected from the samplers during June, August, and October are shown in Table 4. Macroinvertebrates were most abundant in the intake channel (Station 1) during August and October. The lower numbers observed in June could be attributed to the emergence of adult insects from the lake during this period. A high degree of species diversity was observed during each period. At the discharge channel (Station 5) the abundance of organisms collected was relatively low, ranging from 180 to 407 organisms m^{-2}, compared with 244–800 organisms m^{-2} for Station 1. During June and August the species

Table 4.—Benthic organisms collected from artificial substrate samplers in the intake channel and discharge channel of Lake Sangchris during 1975. The numbers shown were taken from three substrate samplers unless otherwise noted.

Species	Intake Channel (Station 1)			Discharge Channel (Station 5)		
	June	August	October	June	August	October
Oligochaeta						
Limnodrilus hoffmeisteri	4	1	...	...	...	2
Ephemeroptera						
Hexagenia limbata	3	5	11	...	...	...
Caenis sp.	...	3	...	...	...	...
Trichoptera						
Cyrnellus marginalis	...	85	62	...	...	10
Odonata						
Argia sp.	15	5	4	...	2	2
Diptera						
Chaoborus punctipennis	4	...	...	...	...	...
Procladius bellus	11	2	...	...	...	...
Coelotanypus concinnus	4	8	191	...	2	...
Chironomus attenuatus	2	...	5	...	...	...
Glyptotendipes lobiferus	42	178	...	111	93	48
Polypedilum sp.	1	...	...	...	...	2
Cricotopus bicinctus	3	...	...	...	...	8
Dicrotendipes modestus	...	7	...	...	...	...
Ablabesmyia sp.	14	5	...	...	...	...
Cryptochironomus fulvus	...	3	...	...	...	1
Xenochironomus festivus	...	1	64	...	...	...
Decapoda						
Orconectes virilis	7	3	...	...	...	...
Mollusca						
Corbicula fluminea	21	124	26	6	...	...
Total	*131*	*430*	*363*	*117*	*97*	*73*
Number of taxa	*13*	*14*	*7*	*2*	*3*	*7*
Number per square meter	*244*	*800*	*675*[a]	*218*	*180*	*407*[b]

[a] Numbers based on specimens collected from two substrate samplers.

[b] Numbers based on specimens collected from one substrate sampler.

diversity was low but showed an increase during October. When the abundance of macroinvertebrates at Station 5 was compared with the numbers collected during standard Ekman grab sampling (Fig. 6), it was evident that the increased water temperature in the discharge channel was not the principal factor limiting the presence of benthic macroinvertebrates, but rather the presence of an unstable silicate slag covering the bottom sediments. Organisms colonized in this channel when a suitable substrate was provided.

Massengill (1976) found that benthic macroinvertebrates in the discharge channel from a nuclear power plant on the Connecticut River ranged from 0 to 900 organisms m^{-2}, and generally fewer than 200 organisms m^{-2} were collected during most of the year. With water temperatures of 37° C, *Limnodrilus hoffmeisteri* was the only species of macroinvertebrate present during July, reaching 900 organisms m^{-2}. Four days later at temperatures of about 40° C, the abundance of *L. hoffmeisteri* dropped to 30 organisms m^{-2}. The maximum temperature this organism could tolerate appeared to be slightly above 37° C.

The bottom sediment in the discharge channel was predominately silt, and the average velocity in the channel varied from 0.3 to 0.6 m/sec, diminishing to 6 cm/sec at the mouth. During February, April, and June, when average temperatures were 11°, 14°, and 22° C, respectively, the abundance of benthic macroinvertebrates was less than 200 organisms m^{-2}. The highest abundance of macroinvertebrates occurred at temperatures of 37° C during July.

Massengill presented no reasons for the paucity of macroinvertebrates in the discharge channel except at temperatures over 37° C during the summer. During the remainder of the year, bottom temperatures were not excessive and considerable silt habitat was present. At no time was the channel velocity high enough to remove the silt from the channel. From this study it is evident that only prolonged periods of high water temperatures would restrict the diversity of benthic macroinvertebrates.

SUMMARY

1.—Twenty-three taxa of benthic macroinvertebrates were collected in Lake Sangchris, with chaoborids (59 percent) and chironomids (39 percent) representing 98 percent of the total numbers. The diversity of benthic macroinvertebrates in Lake Sangchris is consistent with those of other central Illinois lakes (Otter Lake, Lake Shelbyville, Carlyle Lake) although it lacks the variety of clams, isopods, amphipods, and leeches prevalent in Illinois River and northern Indiana lakes.

2.—Eighteen taxa of benthic macroinvertebrates were collected in Otter Lake, with chaoborids (40 percent), chironomids (39 percent), and oligochaetes (18 percent) representing 97 percent of the total numbers, the major species being the same as those in Lake Sangchris.

3.—The abundance of benthic macroinvertebrates in Lake Sangchris shows three distinct subsets: it was significantly higher in the deepest areas; intermediate in the cooling loop and control arm, where there were comparable populations; and significantly lower in the discharge channel than elsewhere in the lake.

4.—The abundance of *Chaoborus punctipennis* (59 percent of the total numbers of macroinvertebrates) was greatest in the deepest areas of the lake. The significantly low abundance of macroinvertebrates in the discharge channel was due to the silicate slag covering the bottom and providing an unsuitable substrate for colonization.

5.—With the exception of the discharge channel, the abundance of benthic macroinvertebrates in the cooling loop of Lake Sangchris was comparable with or significantly higher than those in the control arm (Station 7) and in the Lake Shelbyville, Carlyle Lake, Lake

Wawasee, and Peoria Lake, and showed no detrimental effects from the increase in water temperature.

6.—*Chaoborus punctipennis* was significantly more abundant in the deepest water, *Procladius bellus* and *Coelotanypus concinnus* were significantly more abundant in the control arm, and *Chironomus attenuatus* was significantly more abundant in the intake arm than at the other stations in Lake Sangchris. *Cryptochironomus fulvus* was ubiquitous in its distribution. Each dominant species exhibits a distinctiveness in its abundance with respect to its interrelationship with other species and the physical conditions of the lake.

7.—The seasonal variation in biomass (wet weight) of benthic macroinvertebrates in the discharge (heated) arm of Lake Sangchris was quite similar to that of the intake and control arms. Average biomass values were generally higher than those of Otter Lake and comparable to those determined for Carlyle Lake, indicating that increased water temperatures in the heated arm did not limit the growth of benthic macroinvertebrates in Lake Sangchris.

8.—The greatest abundance of benthic macroinvertebrates in Lake Sangchris occurred at depths of 4 m or more where the bottom sediment was silt. The presence of hardpan clay to a depth of 2–4 m and the absence of layers of organic detritus within the littoral-sublittoral zone, outside the peripheral coves, appear to limit the habitat and food availability for benthic macroinvertebrates in this zone.

9.—The greatest species diversity of benthic macroinvertebrates in Lake Sangchris occurred between 4 and 6 m, the transition zone from hardpan clay and sand to silt.

10.—The abundance and diversity of benthic macroinvertebrates collected from substrate samplers in the discharge channel indicated that increased water temperature was not a limiting factor but that the bottom provided an unsuitable substrate for benthic colonization.

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