Effect of Intermittent Flow Regulation on Temperature and Macroinvertebrate Distribution and Abundance in a Michigan River[1]

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Abstract. During times of average and low river flow, Prickett Hydrostation ceases operation at night and on weekends. To determine the effect of this intermittent mode of operation on downstream conditions, data on benthic macroinvertebrates, temperature, current velocity, width and depth were collected for 13 months at 5 sites along 15 km of the Sturgeon River immediately downstream from the hydrostation and at an upstream control site. During station operation, current velocity increased 2.6 times 200 m downstream and 1.2 times 10 km downstream, while depth increased 75 cm and 35 cm, respectively. Depending on stream morphology, width increased 0 to 10 m during operation. Maximum temperatures observed were 22° C upstream, 24.5° C immediately downstream from the station and 23° C 10 km downstream. When the station was shut down, temperature fluctuation patterns were similar above and below the hydrostation. During operation, temperature fluctuations were reduced downstream. At the site 200 m below the hydrostation, invertebrate biomass averaged 6.9 times greater than at the upstream site and 2.5 times greater than 10 km downstream. The average number of taxa collected 200 m below the station was 12% less than at the upstream site and the site 10 km downstream, and included 6 genera of stoneflies, 9 genera of mayflies and 10 genera of caddisflies. Intermittent operation of this hydroelectric station did not have a severe adverse effect on downstream benthos and produced downstream temperature fluctuation patterns more like those upstream than would continuous operation.

The search for renewable energy sources has focused attention on low head hydroelectric stations and created a need for information about their effect on downstream conditions, particularly when they are operated intermittently (Hynes 1970; Staats 1980). Prickett Hydrostation is a surface release, low head station that has operated intermittently for the past 45 years. Because little information was available concerning its effect on downstream conditions, we conducted a 13 month study at five sites along a 15 km stretch of the Sturgeon River immediately downstream from the hydrostation and at an upstream control site. The objectives of this study were to determine the effect of hydrostation operation on river temperature, depth, width, current velocity and macroinvertebrate community composition, biomass, and trophic structure. This paper presents the major results of our study.

STUDY AREA

The Sturgeon River is located in the western portion of Michigan's Upper Peninsula. It has a forested watershed of 1890 km^2. Approximately 900 km^2 of watershed is upstream from Prickett Dam which was constructed in 1930. Prickett Reservoir has a surface area of 327 ha, a storage capacity of 8 million m^3, a mean depth of 5.6 m and a maximum depth of 19 m. During the summer, fall and winter, times of average or low flow, the station operates week days for 4 to 18 h and ceases operation at night and on weekends. Typical water release during operation is 18 m^3/s. When the station is shut down, leakage and groundwater seepage provide 0.4 m^3/s. During times of high river flow in the spring, the

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station operates continuously and water in excess of that needed for generation is released via overflow structures. Maximum flows of up to 100 m^3/s occur in April.

The locations of the six study sites are shown in Figure 1. All were in riffles. Site A was 6 km upstream from the reservoir in the Sturgeon River Gorge. The substrate was bedrock with depressions containing cobble, pebbles and gravel. No conspicuous plant growth occurred in the river at site A. Thick ice cover was present throughout the winter. Site B was 200 m below the hydrostation and had a substrate of boulders, stones and cobble larger than 10 cm in diameter. During the summer a thick growth of the moss *Fontinalis*

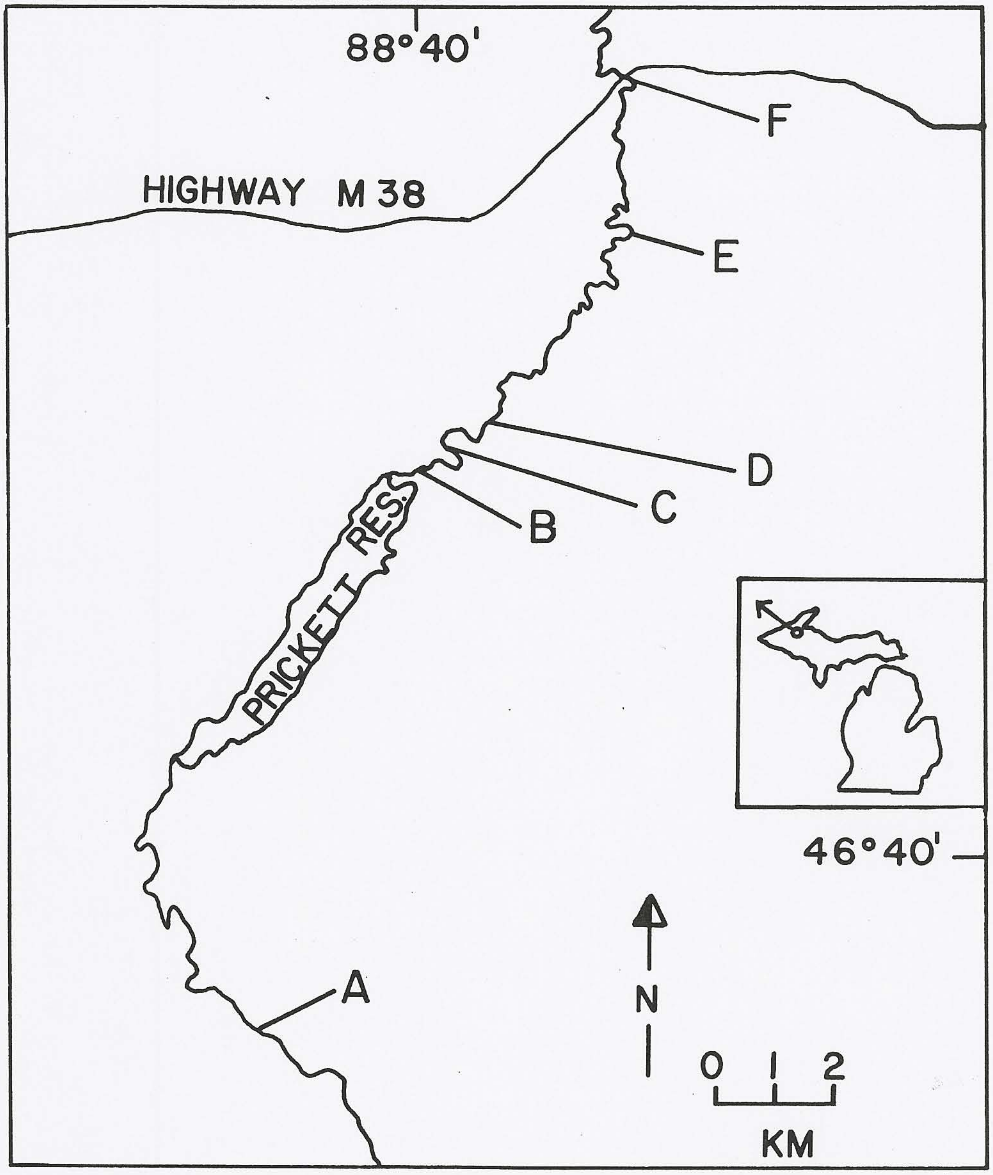

Fig. 1. Locations of the six sampling stations on the Sturgeon River.

covered the continuously submerged portion of the riverbed. In the winter the filamentous green alga *Ulothrix* grew on the boulders. No ice formed at site B. Site C was 1 km below the station and had a substrate of bedrock with depressions containing cobble and pebbles 5 to 8 cm in diameter. During the winter, a dense growth of *Fontinalis* covered the substrate. Although thin sheet ice occurred in slower water immediately upstream, no ice formed at site C. Site D was 2 km below the station and had a substrate of bedrock, large boulders and cobble and pebbles 5 to 8 cm in diameter. Conspicuous algal growth developed in the winter in areas of slower flow. No bryophytes were seen here. No surface ice formed at site D, but frazil ice was common, probably because of reduced current velocity near the substrate. Site E was 10 km below the station and had a substrate of small boulders and cobbles and pebbles 6 to 7 cm in diameter. No conspicuous plant growth occurred here. The pool upstream from site E was covered by thin sheet ice during periods of low flow, but ice did not form at site E, probably because of high current velocity at the surface and near the substrate. Site F was 15 km below the station and had a substrate of pebbles 3 to 4 cm in diameter and coarse sand. No conspicuous plant growth occurred at site F. Thick ice covered this site from early January to mid-March.

Materials and Methods

Sites A, B, and E were sampled monthly from May to October 1979. No samples were collected in November because of high water. From December 1979 to March 1980, monthly samples were collected at sites B, C, D, and E. Collections at site F were made in October, December and March. Site A, above the reservoir, was not sampled during the winter because of difficult access and heavy ice cover. Heavy ice cover prevented sampling at site F in January and February. No samples were collected in April because of high water. In May 1980, samples were again collected at sites A,B, and E.

On each sampling date, current velocity near the surface and near the substrate was measured using a pygmy current meter; both depth and width were measured and three samples of benthic macroinvertebrates were collected using a kick method (Hynes 1961).

From October 1979 to March 1980, turbidity was measured using a Helige turbidimeter. From January to March 1980, conductivity was measured using a conductivity bridge. From June to October 1979, water temperature during the 8-day periods following the sampling dates were continuously recorded using thermographs calibrated in water baths at 0 and 25° C. In December, thermographs were placed at the downstream stations and water temperatures continuously recorded until March 1980 when thermographs were removed to avoid damage during spring ice breakup.

Macroinvertebrate kick samples were taken with a D-frame aquatic net with mesh openings of 0.5 mm. Three adjacent spots were kicked for 30 seconds each to obtain one sample. Samples were preserved in 80% ethanol in the field. In the laboratory, invertebrates were hand sorted, samples measured volumetrically, identified, and counted. The principal keys used for identification were Hilsenhoff (1975) and Merritt and Cummins (1978). In order to compare our results with those of Evans (1979), we followed his method of estimating wet-weight biomass by multiplying the volume of each sample by 1.1. We estimated that each kick sample disturbed 2700 cm^2 of substrate and on that basis calculated estimates of density and biomass per m^2.

Spearman rank correlation coefficients (Siegel 1956) between sites were calculated for the May to October and the December to March invertebrate collections to measure community similarity between sites. A two-factor analysis of variance without replication (Zar 1974) was used to determine if there were significant differences in number of taxa and diversity among sites during May to October.

An examination of trophic strategies was made by determining the proportion of invertebrates in each of four feeding categories: filter-feeders, grazers, predators, and omnivores (Merritt & Cummins 1978).

RESULTS

The temperature range recorded at sites A, B, and E from June to October show maximum temperatures in late July and were 22° C at upstream site A, 24.5° C at site B, 200 m below the hydrostation, and 23° C at site E, 10 km below the station (Table 1, Fig. 2). Prickett Hydrostation operated continuously in May and an average of 23.4 h per day in June 1979. Daily temperature fluctuations were greatly reduced at site B (Fig. 3). The average daily temperature range recorded in June was 2.6° C at site A, 0.8° C at site B, and 3.0° C at site E.

During July, the station operated an average of 10.5 h per day. When the station did not operate, the pattern of temperature fluctuations were similar at sites A, B, and E (Figure 4). At site B, on days with on/off station operation, there was an abrupt rise of 2 to 3° C when generation began, little temperature change during generation, and usually, an increase of 0.9° C when generation stopped (Figure 5). At site E, 10 km below the station there was a small drop in temperature about 3 h after generation began, followed immediately by an increase of 2 to 3° C. The drop in temperature may have been caused by the head of water moving downstream displacing cooler hyporheic water into the stream. The average daily range of temperature recorded in July at site A was 1.8° C. At sites B and E on days without generation it was 5.3° C and 3.5° C, respectively, and on days with on/off generation, it was 2.1° and 4.7° C, respectively.

During August the station operated an average of 8.1 h per day. On days without generation, the temperature was 4 to 5° C higher at B than at E, but daily fluctuation patterns were similar (Fig. 6). On days with on/off generation, temperatures at B and E were more similar but fluctuation patterns were different (Fig. 7). The average daily range of temperature in August at site A was 1° C. On days without generation at sites B and E, it was 1.3° and 2.3° C, respectively, and on days with on/off generation, it was 1.6° and 2.8° C, respectively.

TABLE I

Characteristics of the six study sites. Width and depths were measured when the hydrostation was not operating. Current velocities (m/sec) were measured near the substrate when the hydrostation was not operating.

Site	Location, ice cover	Substrate	Mean width	Mean depth	Current velocity (m/sec)
A	6 km upstream, thick ice Dec. to Mar.	bedrock, boulders, pockets of cobble, pebbles	40 m	33cm	0.222-0.674
B	200 m downstream, no ice	boulders and cobble, larger than 10 cm diameter	18 m	24 cm	0.200-0.498
C	1 km downstream, no ice	bedrock, pebbles, cobble 5-8 cm diameter	34 m	24 cm	0.134-0.310
D	2 km downstream, no surface ice, much frazil ice	pebbles, cobble 5-8 cm diameter	15 m	22 cm	0.167-0.696
E	10 km downstream, no ice	cobble 6-7 cm diameter	22 m	18 cm	0.366-0.575
F	15 km downstream, ice Jan. 15 to Mar. 15	pebbles 3-4 cm diameter, course sand	30 m	16 cm	0.355-0.487

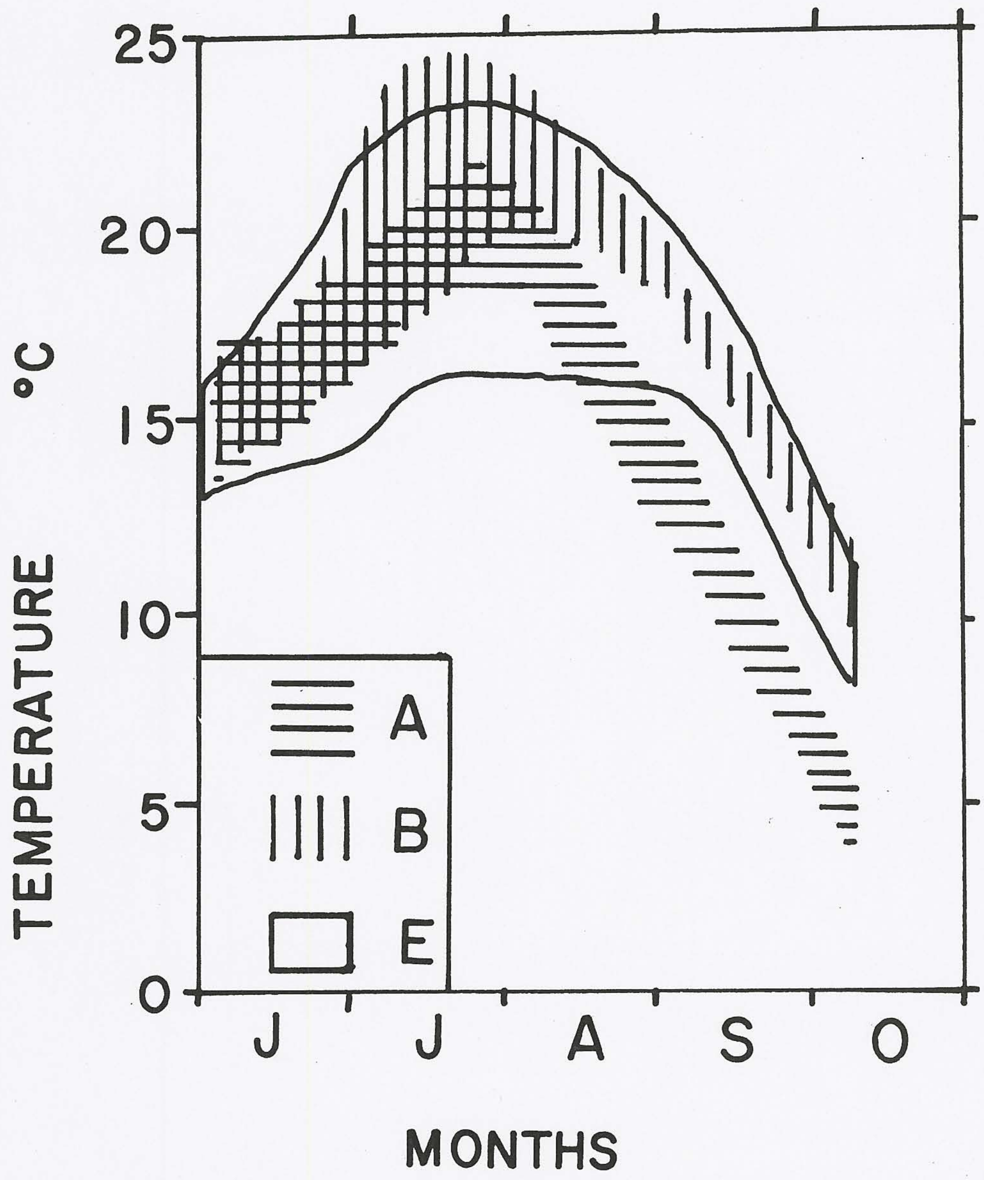

Fig. 2. Water temperature ranges recorded at sites A, B, and E from June to October 1979.

Station operation averaged 10.5 h per day in September, 13.6 h in October, 18.1 h in November. At site B in September and October, there was virtually no change in temperature on days without generation and an average daily range of 0.7° C on days with on/off generation. At site E during this period, there was an average daily range of 1° C on days without generation and 2.2° C on days with generation.

The station operated an average of 10.4 h per day in December, 8.5 h in January, 8.3 h in February, and 10.0 h in March. During this period, water temperatures were nearly identical at the five downstream sites. Temperatures dropped from 3° C in late December to −1° C in early January. The daily temperature range was only 0.25 to 0.5° C at these sites with the daily increase at sites B and C clearly correlated with times of hydrostation operation.

The range of current velocities measured near the substrate when the hydrostation was not operating is shown in Table 1. At site B, current velocity during hydrostation operation increased 2.2 times near the substrate and 2.6 times near the surface. At site E during station operation, there was little change near the substrate and an increase of only 1.2 times near the surface.

Depth at site B increased 75 cm within 5 min after generation began. At site E, depth increased 40 cm during a 40 min period approximately 3 h after generation began. At sites B and E, width increase due to generation was 8 to 10 m. Change in depth due to generation decreased progressively downstream, while increase in width was determined by channel morphology.

Turbidity values during October to March were low at all stations, ranging from 7.5 to 12.0. Conductivity values during January to March ranged from 120 to 150 μmhos/cm.

Insects made up 99% of the 74,000 invertebrates collected. Most invertebrates were identified to genus, but the 16,000 chironomids were identified only to family. During

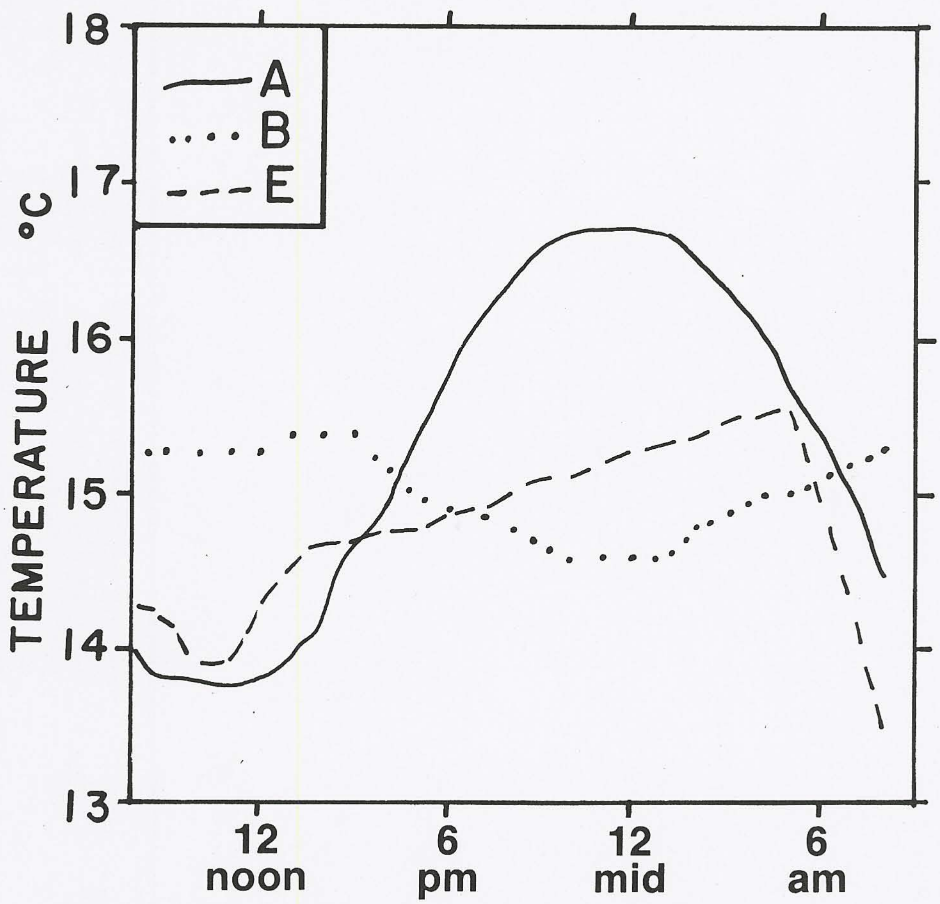

Fig. 3. Water temperatures at sites A, B, and E from 8 AM June 5 to 8 AM June 6, 1979. The hydrostation operated continuously during this period.

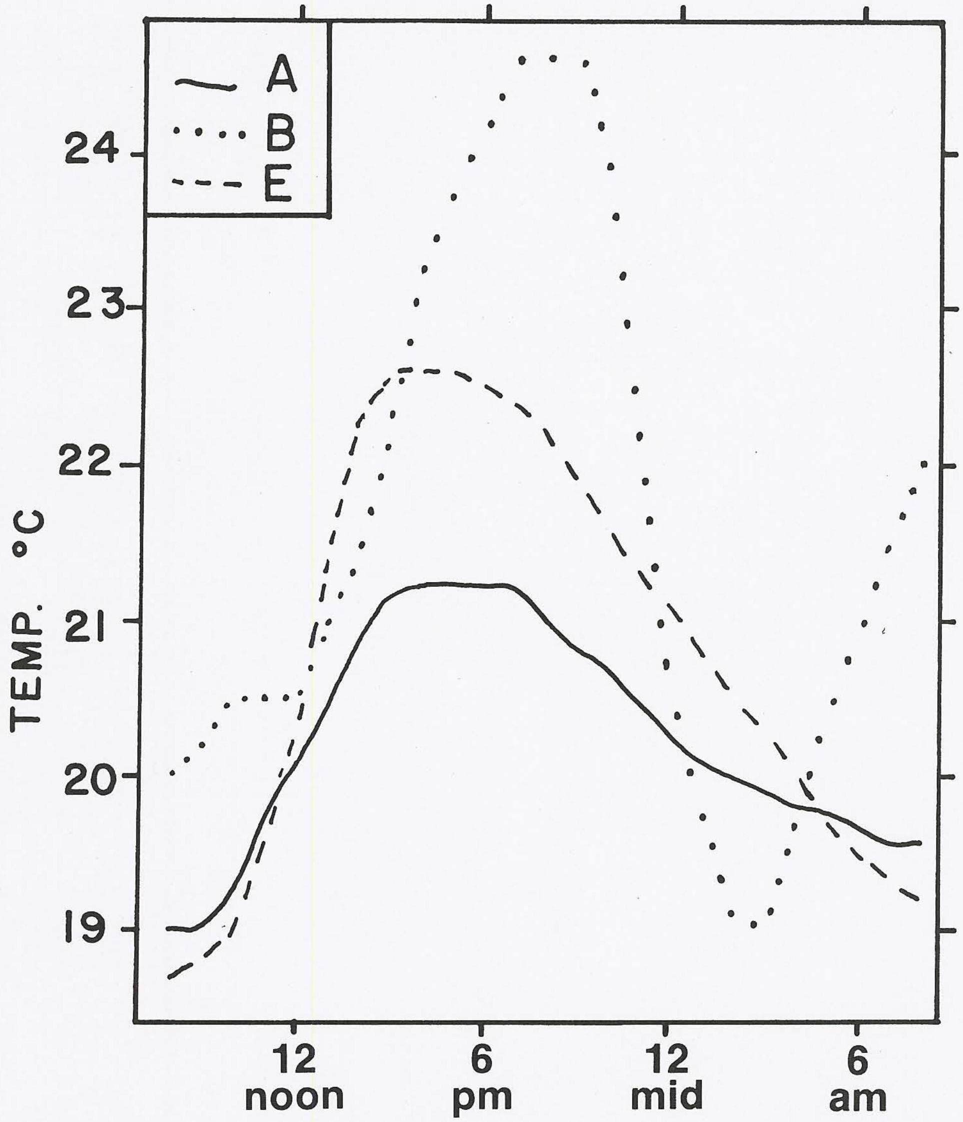

Fig. 4. Water temperatures at sites A, B, and E from 8 AM July 14 to 8 AM July 15, 1979. The hydrostation did not operate during this period.

May to October, a total of 56 taxa were collected at site A, 50 at site b, and 61 at site E. Two-factor analysis of variance showed that the number of taxa collected was significantly different ($p<0.001$) among sites. The average number of taxa collected per month during May to October was 33 at sites A and E and 29 at site B. The fewest taxa were found in May 1979, when samples from sites A, B, and E contained 14, 12, and 24 taxa, respectively, and the most were found in September when the sites had 39, 40 and 40 taxa, respectively. There was an increase in density from spring to fall for many taxa, as illustrated by *Cheumatopsyche* (Fig. 8). During December to March, nine additional taxa were collected at site B and three at site E. The mean number of individuals of total combined taxa collected from May to October 1979 at sites A, B, and E are listed in Table 2. There were significant positive Spearman rank correlation coefficients between these

TABLE II

Mean density (number/m^2 ± 1 SD) of total combined taxa collected, total taxa collected and total number of samples from stations A, B, and E, collected from May to October 1979.

	Sites		
	A	B	E
$\bar{x}$ No. of individuals/m^2	1042± 542	5022±3834	2108±1340
Total taxa collected	56	50	61
Total No. samples	18	18	18

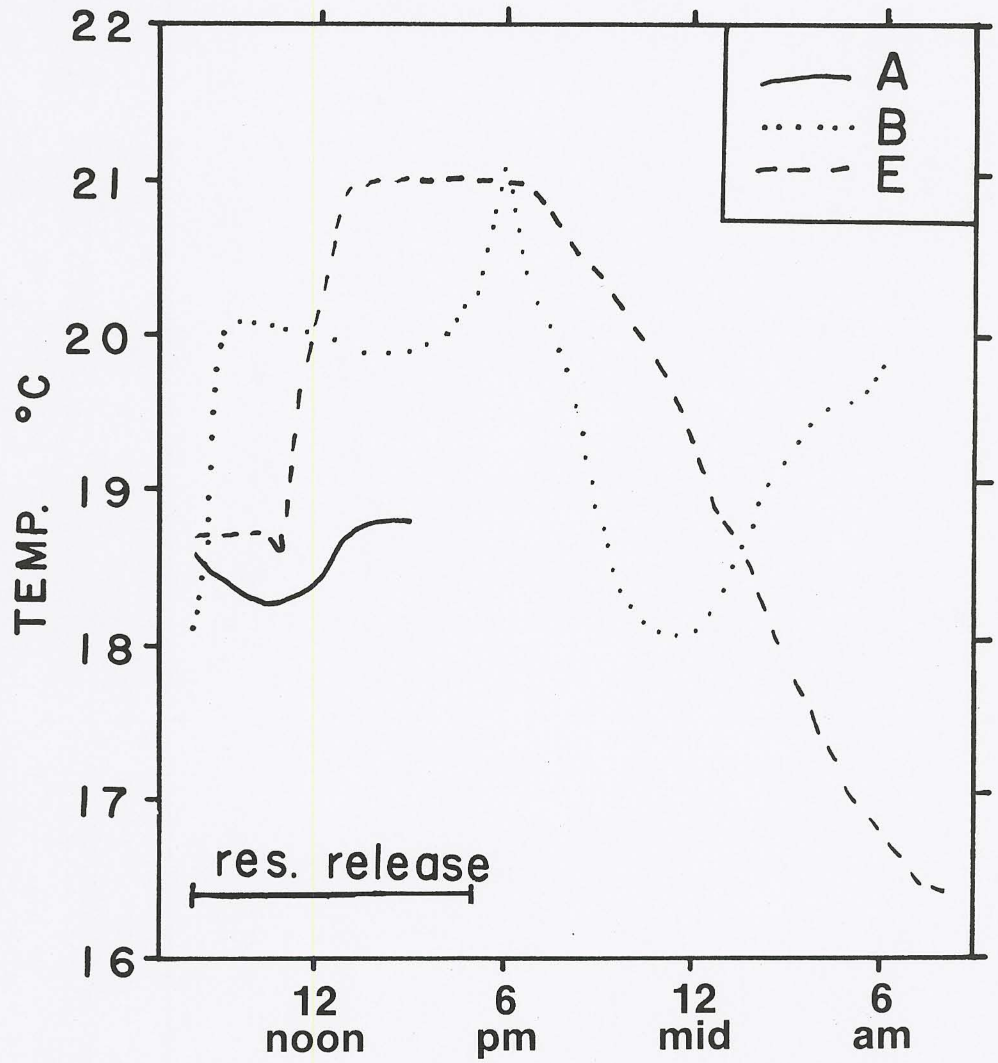

Fig. 5. Water temperatures at sites A, B, and E from 8 AM July 16 to 8 AM July 17, 1979. The hydrostation operated from 8 AM to 5 PM on July 16.

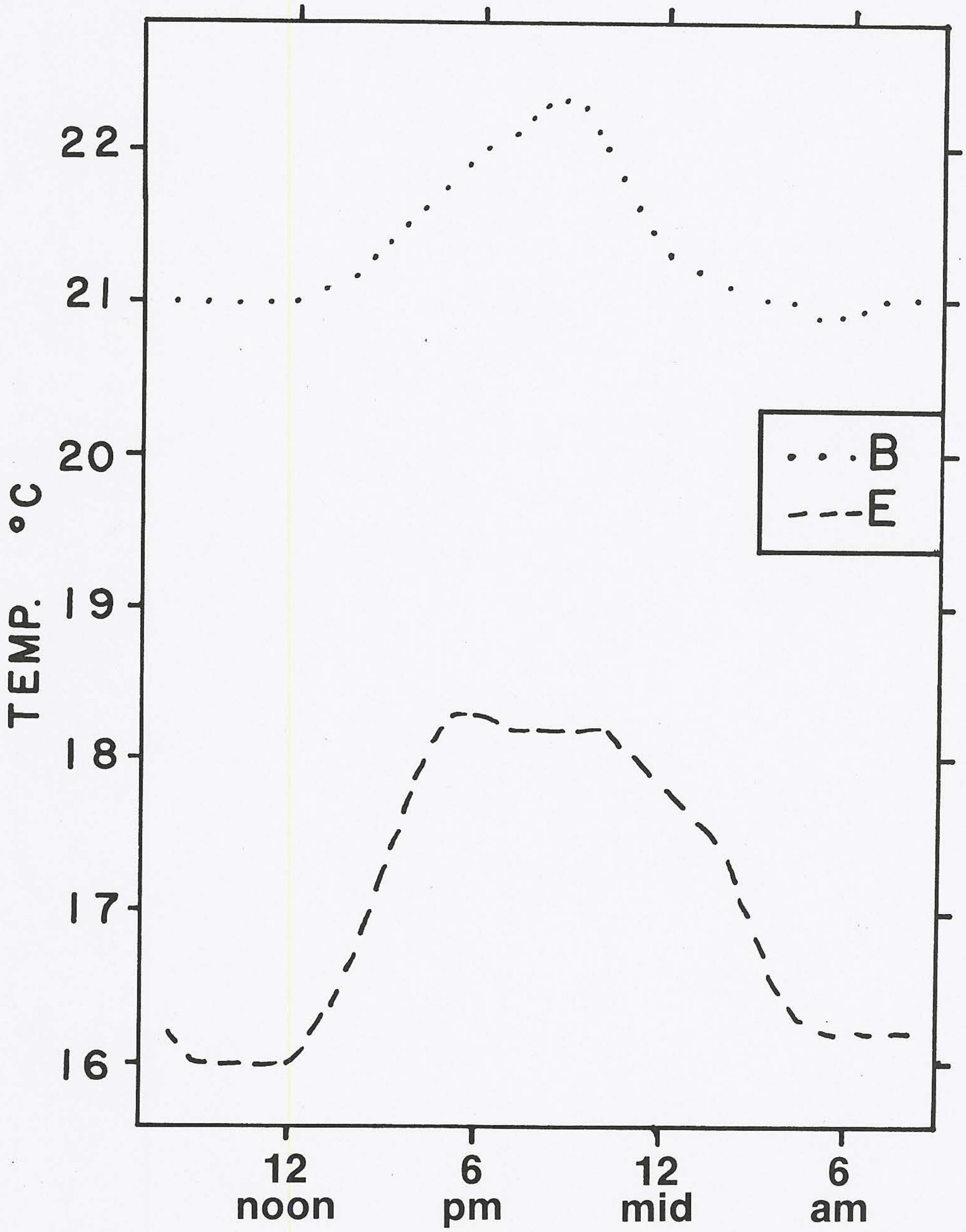

Fig. 6. Water temperatures at sites B and E from 8 AM August 11 to 8 AM August 12, 1979. The hydrostation did not operate during this period.

sites. For May to October data, the coefficient between sites A and B was 0.427 ($p<0.01$), between sites A and E 0.663 ($p<0.001$), and between sites B and E 0.636 ($p<0.001$). The mean number of individuals of combined taxa collected from December 1979 to March 1980 at sites B, C, D, E, and F are listed in Table 3. For these December to March data, the Spearman rank correlation coefficient between sites B and C was 0.542 ($p<0.001$), between sites B and D 0.534 ($p<0.001$), and between sites B and E 0.335 ($p<0.05$). Site F comparisons are omitted because no samples were collected there in January or February. The low density of invertebrates at site F may have been due to the sand substrate which was not present at the other sites.

During May to October 1979, macroinvertebrate density was lowest in May and highest in September or October (Fig. 9). During May to October, average density at site B was 5.6 times higher than at site A, and 2.3 times higher than at site E. During December to March, average density at site B was 4970/m^2 which was 4.5 times higher than at C, 5.6 times higher than at D, and 3.2 times higher than at E.

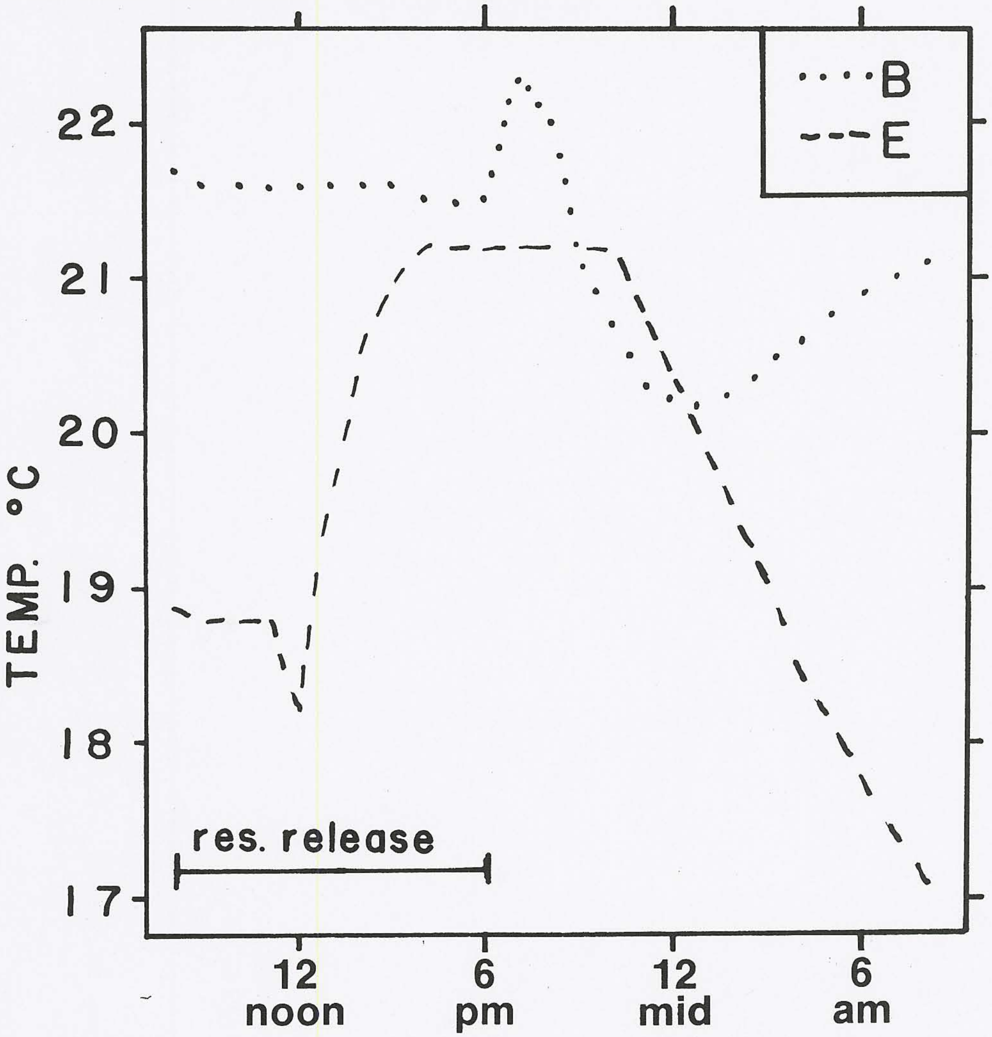

Fig. 7. Water temperatures at sites B and E from 8 AM August 8 to 8 AM August 9, 1979. The hydrostation operated from 8 AM to 6 PM on August 8.

TABLE III

Mean density (number/m^2 ± 1 SD) of total combined taxa collected, total taxa collected and total number of samples from stations B, C, D, E, and F from December 1979 to March 1980.

	Sites				
	B	C	D	E	F
$\bar{x}$ No. of individuals/m^2	4967±1336	1103± 188	895±770	1570±1308	194±100
Total taxa collected	44	43	48	48	25
Total No. of samples	12	12	12	12	6

Wet weight standing crop biomass showed a pattern similar to density (Figure 10). The May value for site E was anomalous due to the collection of two large crayfish. During May to October, average biomass at site B was 6.9 times higher than at site A and 2.5 times higher than at site E. During December to March, biomass at site B averaged 39.6 g/m^2 which was 4.7 times higher than at site C, 7.8 times higher than at site D, and 9.9 times higher than at site E.

During May to October, Shannon diversity index values at site A ranged from 3.47 to 4.12; at site B from 2.19 to 2.81; and at site E from 2.67 to 3.59. During December to March, diversity index values at site B ranged from 2.40 to 2.67; at site C from 3.01 to 3.56; at D from 3.18 to 3.89; and at E from 2.99 to 3.27. Two-factor analysis of variance showed significant differences in diversity among sites ($p<0.001$), but not among dates ($p>0.05$) for the two periods.

During May to October, at site A, grazers comprised 58% and filter-feeders 15% of the macroinvertebrates collected; at site B grazers made up 12% and filter-feeders 60%; and at site E grazers accounted for 39% and filter-feeders 40%. During December to March, at site B grazers made up 8% and filter-feeders 50%; at site C grazers made up 35% and filterfeeders 26%; at site D grazers made up 44% and filter-feeders 25%; and at site E grazers made up 40% and filter-feeders 40%.

Discussion

Prickett Hydrostation's release of reservoir surface water increased the summer and fall water temperatures and reduced the daily temperature fluctuations at downstream sites. When the hydrostation was shut down, the pattern of daily temperature fluctuations at the downstream sites resembled those at the upstream site, although the absolute values were higher downstream. Some of the differences in temperature between sites A and B may have been due to differences in local topography. Site A was in a deep, narrow, north-south trending valley subject to intense shading and cold air drainage while site B was in a relatively level, exposed area. Generation was nearly continuous in April, May, and June. During the remainder of the year, the hydrostation operated each weekday for a period of from 4 to 18 h and shut down at night and on weekends. Evans (1979) mistakenly reported that power generation occurs twice daily. The on/off operation of the hydrostation allowed a more normal downstream temperature regime than would occur if water release had been continuous.

The only previous study of this portion of the Sturgeon River known to us is that of Evans (1979). On June 20, 1977, Evans (1979) sampled invertebrates at four sites including our sites A, B, and F. He found no significant difference between sites in number of taxa per sample or in mean diversity. He found significantly higher density at site B, immediately below the reservoir, than at the other sites and significantly greater

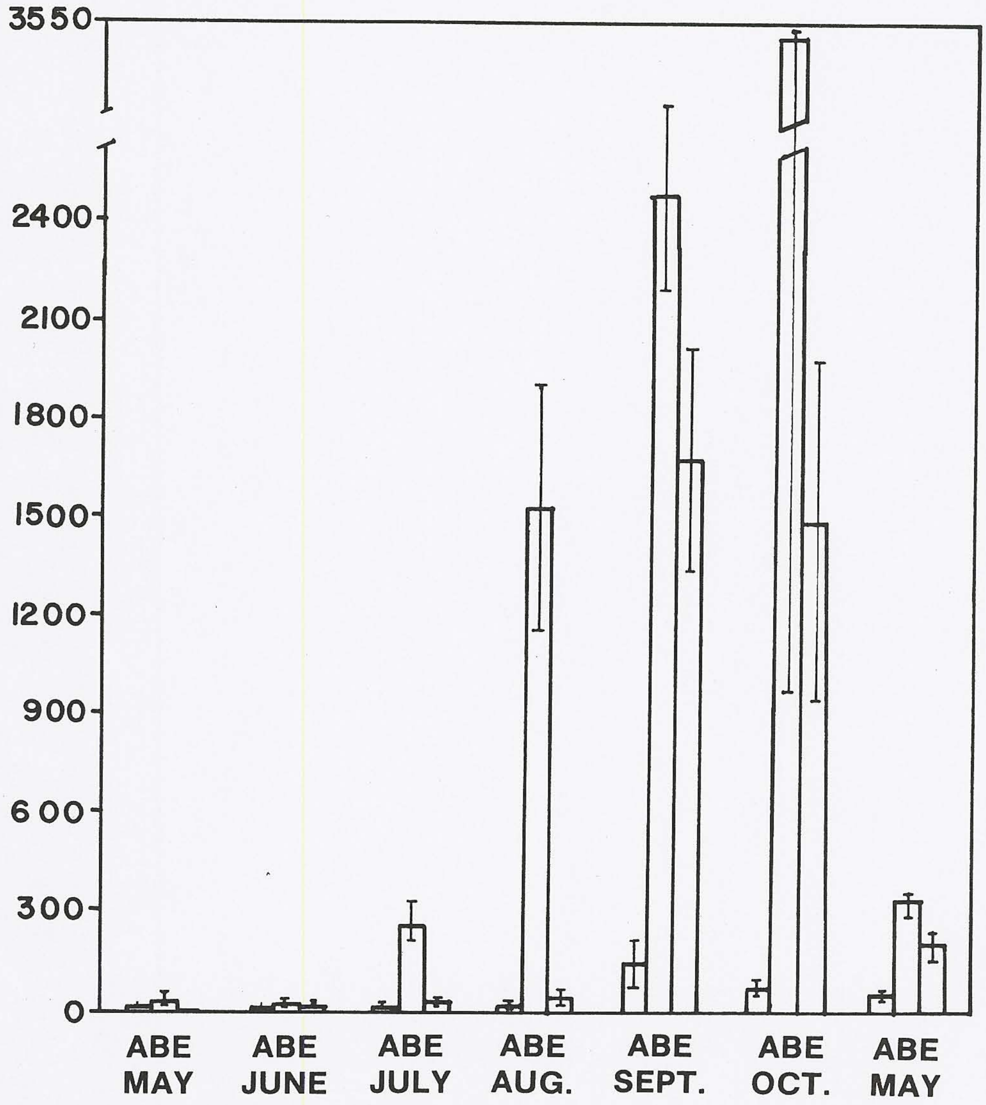

Fig. 8. Density of *Cheumatopsyche* at sites A, B, and E, May to October 1979 and May 1980. The thin line represents one standard deviation.

biomass at upstream site A than at the other sites. Evans (1979) concluded that Prickett Hydrostation caused a reduction in biomass, in average size of invertebrates, and in the number of taxa. Our data contradict Evans' (1979) first two conclusions and do not fully support the third.

We sampled sites A, B, and E in May, June, July, August, September, October 1979 and May 1980. Biomass at site B, immediately below the reservoir, was much higher than at upstream site A in 6 of those 7 months. Average biomass at site B was 580% greater than at site A. Average biomass at site E, 10 km below the reservoir, was 215% greater than at site A. Only in May 1979, when the lowest biomass values were observed, was biomass greater at site A than at site B. The overall average wet weight per individual invertebrate for these seven months was 3.6 mg at site A, 4.4 mg at site B, and 3.9 mg at site E. The

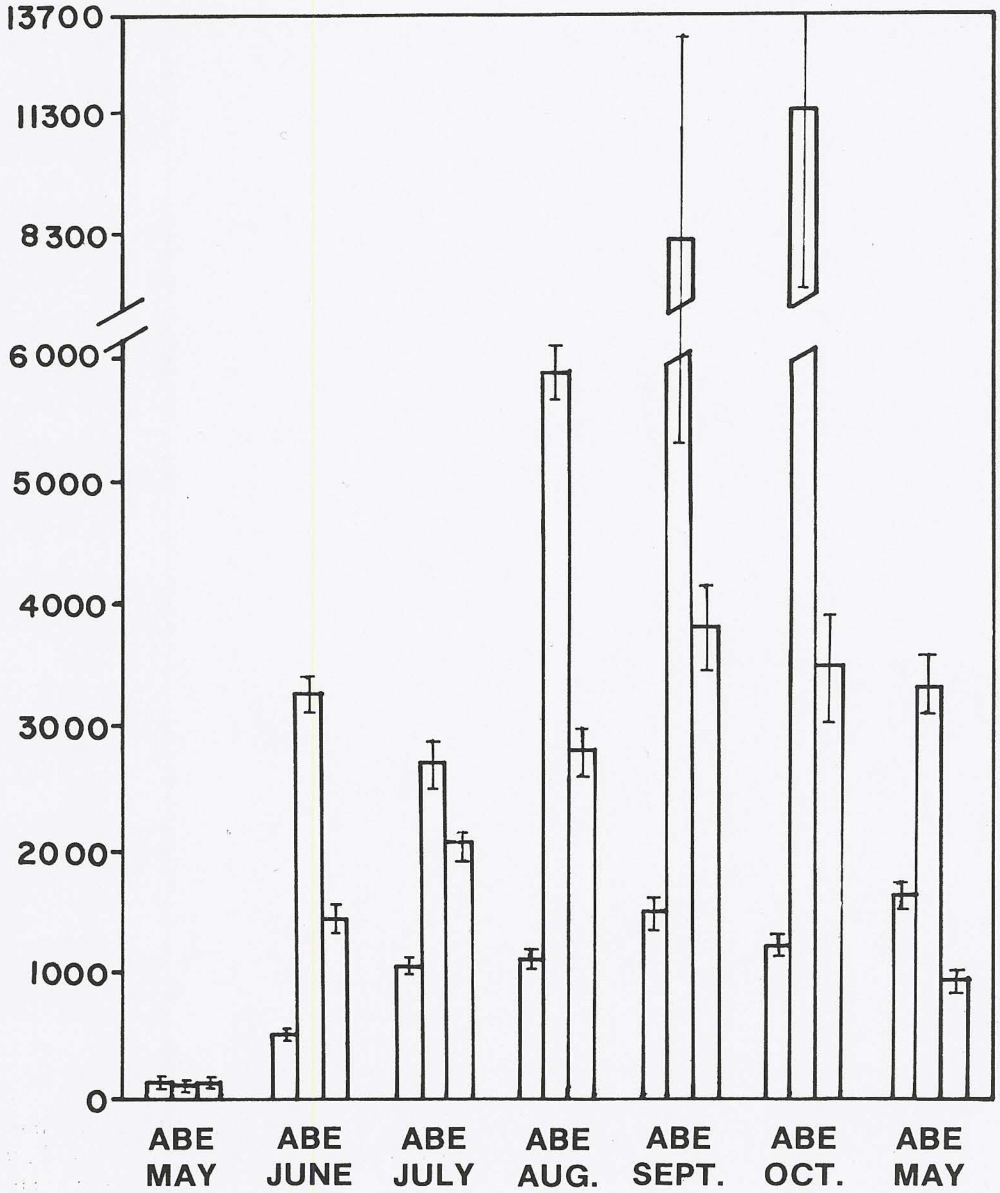

Fig. 9. Density (number/m^2) of benthic macroinvertebrates at sites A, B, and E, May to October 1979 and May 1980. The thin line represents one standard deviation.

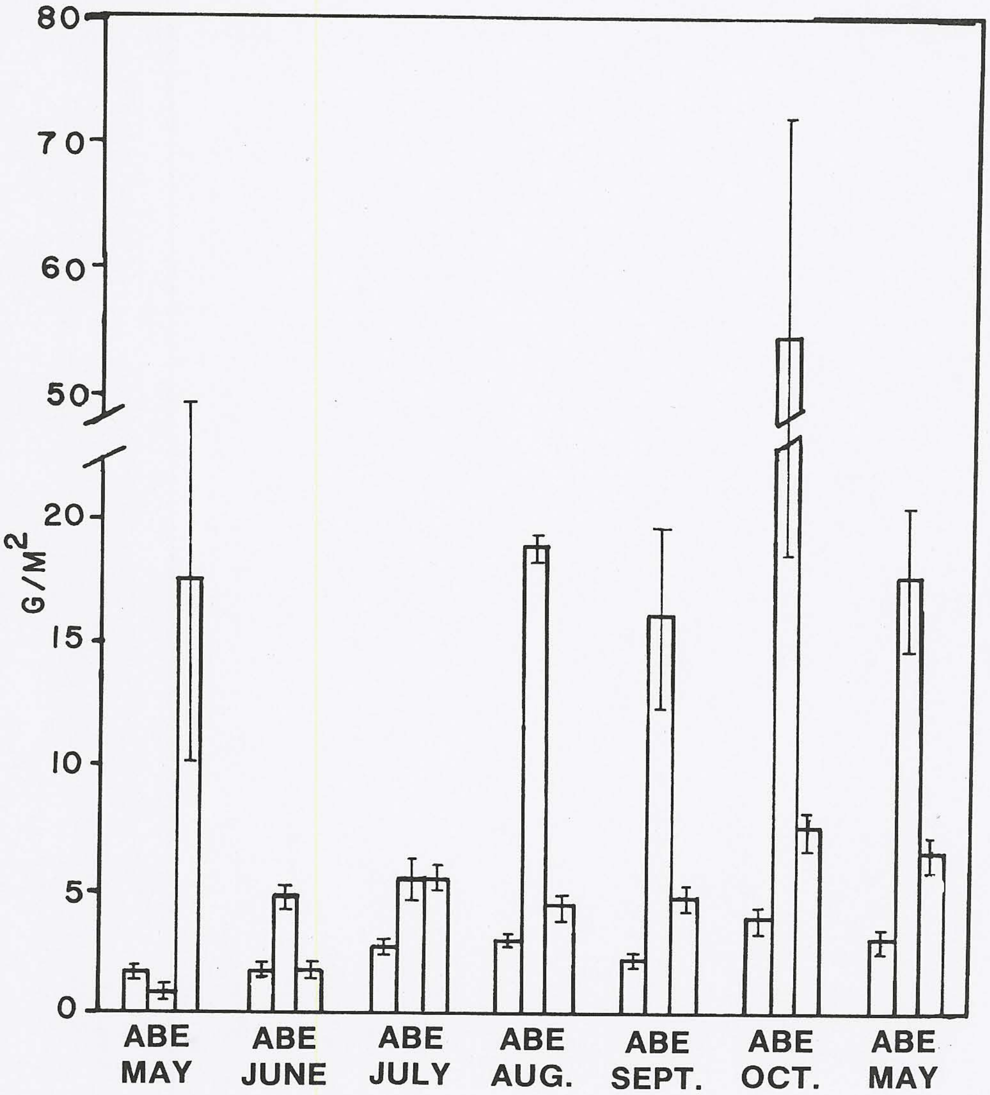

Fig. 10. Wet weight standing crop biomass (g/m^2) of benthic macroinvertebrates at sites A, B, and E, May to October 1979 and May 1980. The thin line represents one standard deviation.

monthly average wet weight per individual was greater at site A than site B in May, June and July 1979, but the reverse was true in August, September, October 1979 and May 1980. The average number of taxa collected at each station for the seven months was 32.9 at site A, 28.9 at site B, and 32.7 at site E. This was a 12% reduction at site B compared to site A, but virtually no difference between sites A and E. The total number of taxa collected from May through October 1979, 56 at site A, 50 at site B, and 61 at site E, showed a 11% reduction at site B compared to site A and a 9% increase at site E compared to site A. The number of taxa collected at sites A and B ranged from 14 and 12, respectively, in May 1979, to 40 in October and September, respectively. During May to October 1979, average biomass/m^2 at sites A and B ranged from 1.6 and 0.8 g, respectively, in May to 3.9 and 57.3 g, respectively, in October. Because of this great seasonal variation, information gathered on one sampling date cannot provide a comprehensive picture of conditions. The large differences in biomass and density between our samples collected in May 1979 and May 1980 indicates that several years of data are needed to draw sound conclusions.

During the summer and fall of 1979, five genera of caddisflies, two genera of mayflies, and two genera of stoneflies each represented by 10 or more individuals in samples from upstream site A were not collected at site B, immediately below the reservoir. Three of these genera were also absent at site E, 10 km below the reservoir. Their absence may have been due to higher water temperatures, but other factors such as the heavy periphyton growth at site B may have been involved. Spence and Hynes (1971) reported the absence of several stonefly genera from a reservoir outlet which they attributed to nighttime reductions in oxygen due to the respiration of a dense growth of macrophytes. In spite of the absence of some taxa, the benthic macroinvertebrate community at site B was quite diverse. There were six caddisfly genera and two stonefly genera represented at site B that were not found at site A. Site B collections contained representatives of six genera of stoneflies, nine genera of mayflies, and ten genera of caddisflies. Site B had the highest biomass and greatest density of macroinvertebrates of the six study sites. Our data indicate that the on/off operation of Prickett Hydrostation did not have a severe adverse effect on the downstream benthic macroinvertebrate community. This suggests that in situations where great reductions in diversity are found below reservoirs, the reduction is due to alteration of the temperature regime rather than to changes in stream flow (Ward & Stanford 1982). Small hydroelectric stations which operate intermittently and thus allow more normal diel and seasonal temperature regimes may have less harmful impact on the downstream biota than stations which operate continuously.

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