OBSERVATIONS ON DISTRIBUTION, ABUNDANCE AND PRODUCTION
RELATED ASPECTS OF AQUATIC MACROINVERTEBRATES
IN NATURAL THERMAL GRADIENTS

by

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of

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ABSTRACT

The aquatic macroinvertebrate communities of the thermal gradients produced by the Ringling-Drumheller, Norris and Potosi hot springs were investigated in 1974 and 1975. The three thermal gradients differed in chemical composition, size and age. Macroinvertebrate samples were collected with Surber and Hester-Dendy samplers and an Ekman grab.

Macroinvertebrate life was excluded by temperatures in excess of 40°C. The communities typical of high thermal regimes appeared to be formed by an exclusion, rather than addition, of genera or species as temperature increased.

Macroinvertebrate numbers, taxa and biomass were found to be negatively correlated with temperature. Despite the observed depression of standing crop at elevated temperatures, higher substrate colonization rates and larger sizes of selected taxa at higher temperatures suggested that production rate may increase with temperature.

Data compiled at the genus-species level indicated that most forms were eurythermal. Cold, hot and intermediate stenothermal forms were also observed. The eurythermal group was further analyzed to yield patterns of cold preference, warm preference, preference for intermediate temperatures or a lack of preference within broader ranges of tolerance.

Abundance at the total, ordinal and genus-species levels was affected by an interaction between temperature and season. Patterns of abundance did not respond the same for all levels of temperature when taken over all seasonal levels.

Data suggest community avoidance of, rather than adaptation to, high temperatures at a relatively small thermal plume. It was speculated that longer adaptation time resulted in a higher thermal tolerance for invertebrate communities at Potosi than at Ringling although this higher tolerance may have been influenced by differences in water chemistry or stability of thermal regime. Data further suggest a higher thermal tolerance for communities of pools or slower flows than for riffle communities.

INTRODUCTION

Environmental temperature has long been considered one of the most
important factors affecting life in the aquatic ecosystem. Aquatic
communities from similar habitats within similar latitudinal, longitud-
inal and elevational regions would be expected to be subject to a
similar set of thermal regimes. In recent years, biologists have
become increasingly concerned with the upward alteration of many of
these thermal regimes due to human activities. The primary focus of
this concern has been on heated effluents produced by cooling waters
discharged from fossil fuel and nuclear-powered electrical generating
plants.

Krenkel and Parker (1969) predicted that increased needs for
electrical generation would require that approximately one-fifth of the
total surface runoff of the contiguous United States would be required
for cooling purposes by 1980. This amount could be reduced by the
increased use of cooling towers and closed cooling systems; however,
these systems could pose an additional threat through their consumptive
use of water. The thermal problem could be aggravated by an impending
shortage of fossil fuels because nuclear-powered generating plants
produce larger amounts of waste heat than fossil fuel plants (Krenkel
and Parker 1969).

Concern over possible effects of waste heat on aquatic communities
has led to many investigations of effects of increased heat on benthic
macroinvertebrates. Laboratory studies have been conducted on

metabolic effects (Newell 1973, Vernberg and Vernberg 1974), lethal
limits (Gaufin and Hern 1971, Martin and Gentry 1974, Nebeker and Lemke
1968), growth and development (Lutz 1968, Nebeker 1973, Newell 1975)
and emergence (Nebeker 1971a). However, application of laboratory
results to field situations should be done with caution (Lehmkuhl 1974,
Wurtz and Renn 1965).

Numerous field studies have been conducted on thermal effluents
produced by power plants. Thermal effects on drift, development,
emergence, distribution and abundance of macroinvertebrates have all
been investigated below power plant discharges. Much of this litera-
ture has been reviewed on an annual basis (Coutant and Talmage 1975,
Coutant and Pfuderer 1974, Coutant and Pfuderer 1973, Coutant and
Goodyear 1972). Many of these studies have been complicated, however,
by sampling difficulties due to substrate and depth differences
(Masengill 1976), variable thermal regimes due to power plant opera-
tional requirements (Wurtz and Renn 1965), the presence of other forms
of pollutants (Langford 1971, Wurtz 1969) and relatively small eleva-
tions in temperature (Wurtz 1969).

Relatively little work has been done on natural thermal effluents
produced as a result of hot spring or geyser activity. Hot springs
have been defined as those issuing at or above 38°C (Mariner et al.
1976). Some descriptive work has been done on macroinvertebrates
inhabiting hot springs (Brues 1924 and 1932, Mason 1939, Provonsha and

McCafferty 1977, Robinson and Turner 1975, Stoner 1923). Work on macroinvertebrate distribution, abundance and production has been done on two rivers, the Firehole and Gibbon in Yellowstone National Park, which receive natural thermal effluents (Armitage 1958 and 1961, Jones 1967, Vincent 1966).

Discharges of hot spring effluents into small spring streams provide unique situations for the study of thermal effects on macro-invertebrates. Advantages lie in the stability of the thermal gradient produced, the ease of sampling due to small size and the long adaptation time involved (Brock 1967). Three such heated springs in southwestern Montana provided an opportunity to compare distribution, abundance, development and production of macroinvertebrates in thermal gradients ranging in temperature from approximately 45°C down to normal ambient temperatures.

DESCRIPTION OF STUDY AREAS

Three southwest Montana hot springs were investigated during the course of the study: the Ringling-Drumheller Well, the Norris Hot Spring and the Potosi Hot Spring. All waters under study were small spring streams, 1 to 4 meters wide. Streams of this size and origin belong to the rheocrene in the classification of Illies (Hynes 1970).

The most intensive study was conducted on the Ringling-Drumheller Well and its resultant thermal plume in the south fork of the Smith River. This well is located in western Meagher County, Montana (SE 1/4, NE 1/4, Sec. 25 T7N R7E) in a semi-arid region with 47 cm of precipitation per year and an average annual temperature of 5.4°C (Groff 1965). The Ringling well had an unusual man-made origin. It was formed in September, 1929 when an attempt to drill for oil produced hot water.

The spring originates at a surface elevation of 167.4 m (5500 ft) with a discharge of approximately .05 m^3 sec^{-1} (1.8 cfs). A discharge of this magnitude places the Ringling well among the larger hot springs of Yellowstone National Park (Allen and Day 1935). Temperature of the spring at the outflow ranged from 43 to 47°C during the study period. The hot artesian water is believed to acquire its heat from deep circulation in the cave forming zone or a deep fault or fissure and originates in Devonian limestone over dolomite (Groff 1965).

The hot stream flows down a moderate gradient for approximately 500 m where it merges with the upper south fork of the Smith River producing elevated temperatures which are measurable for approximately 2 km downstream. The combined effects of the elevated temperature and the larger volume of the hot spring as compared to the receiving stream (Table 1) acts to produce this relatively large thermal plume.

Table 1. Mean discharges at low (summer and fall) flows of the hot springs and their receiving streams at Ringling and Norris.

	Hot Spring	S. Fk. Smith River
Ringling	.050 m^3/sec (1.80 cfs)	.027 m^3/sec (.98 cfs)
	Hot Spring	Hot Spring Creek
Norris	.008 m^3/sec (.31 cfs)	.200 m^3/sec (7.12 cfs)

Eight biological sampling stations were selected along this thermal gradient based on temperature differences (Fig. 1). Maximum, minimum and mean observed temperatures are listed in Table 2. Sites 5, 4 and 3 were located within the flow of the hot spring, Site 2 was located above the inflow of the hot spring and Sites 1, 6, 7 and 8 were located in the Smith River below the inflow of the hot spring. Sites 2 and 8 were the upper and lower cold water references, respectively. These two sites became cold enough in winter to be largely ice covered
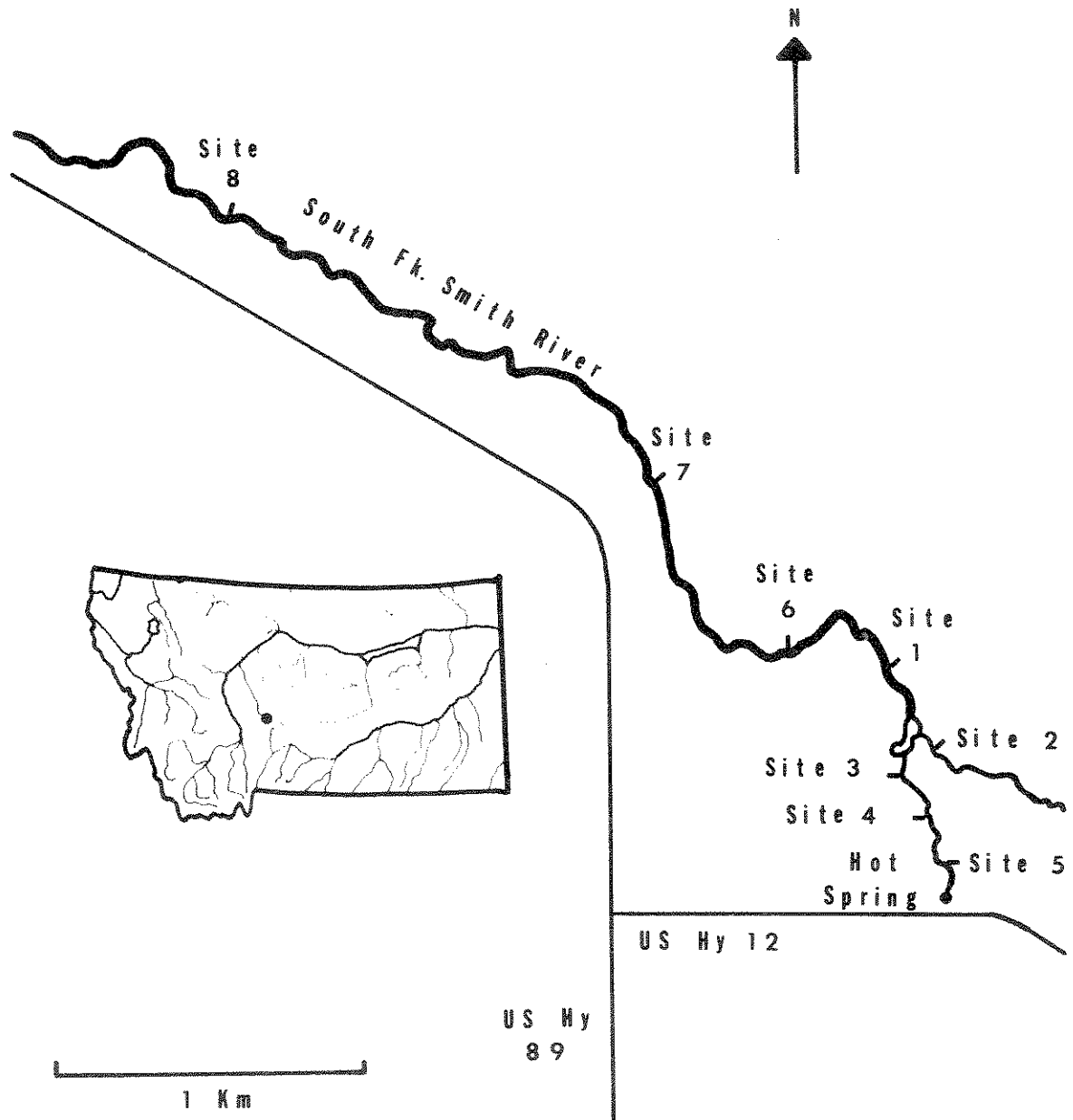
Figure 1.   Map of Ringling study area showing macroinvertebrate sample sites.

Table 2. Maximum, minimum and mean observed temperatures (°C) for sample sites at Ringling, Norris and Potosi.

RINGLING	5	4	3	1	6	7	8	2
Maximum	47.0	43.0	41.0	36.0	32.0	28.0	23.0	24.0
Mean Maximum	-----	-----	35.7	27.0	20.0	15.0	10.0	10.0
Mean Median	45.0	38.0	34.0	24.8	18.6	11.9	8.2	7.9
Mean Minimum	-----	-----	32.3	23.0	17.0	9.0	7.0	6.0
Minimum	43.0	37.0	29.0	10.0	9.0	2.0	0.0	0.0

NORRIS	5	3	2	1	4
Maximum	48.0	32.0	16.0	10.0	10.0
Mean Median	38.8	24.3	10.5	5.3	5.3
Minimum	29.0	15.0	5.0	0.0	0.0

POTOSI	2	1	3	4	5
Maximum	34.0	29.0	24.0	17.0	13.0
Mean	33.3	27.8	22.5	16.5	12.3
Minimum	32.0	26.0	21.0	15.0	10.0

and frazil or slush ice was observed during the winter of 1974-75 at Site 8. All other sites were considered hot or warmer than ambient. An annual temperature profile for some of these sites is given in Appendix Table 27.

Each sample site was divided into an erosional (riffle) and a depositional (pool) area. The riffles were characterized by fast flows (.30-1.22 m/sec), shallow depths (5-15 cm) and a rubble or cobble substrate bearing filamentous green or, in upper hot spring sites, blue green algae. The pools were characterized by slower flows, deeper water (15-50 cm) and a substrate composed of silt, sand and detritus with some larger algae (*Chara* or *Nitella*) and a few macrophytes.

Chemical data (Table 3) show that the Ringling hot spring is a calcium, magnesium, bicarbonate and sulphate spring. This corresponds to the rarest of the major types of hot spring found in Yellowstone National Park (Allen and Day 1935). The Smith River above the inflow of the hot spring is a calcium, sodium and bicarbonate water. The effect of the Ringling hot spring is to increase the importance of calcium, magnesium and sulphate and decrease the importance of sodium and chloride in the Smith River. The system is characterized by high alkalinities and conductivities throughout. Mean dissolved oxygen levels (Table 4) decrease with increasing temperatures. Chemical and physical parameters measured in the hot spring and the Smith River at Ringling compare favorably with data compiled by Groff (1965) and L.

Table 3. Selected chemical parameters at Ringling, Norris and Potosi.

	Ringling					Norris					Potosi
	5	3	1	7	2	6	5	2	1	4	4
pH	7.42	8.23	8.25	8.38	8.18	8.26	8.27	8.12	8.12	7.98	8.35
K_{s25} (μmho/cm)	1420	1421	1417	1390	1012	879	877	586	340	323	381
Tot. Alk. (me/1)	2.62	2.67	3.22	3.09	3.17	6.30	6.30	4.32	3.05	2.99	.95
Ca^{+2} (mg/1)	302	307	276	156	121	18.4	18.4	37.6	42.4	44.8	10.8
Mg^{+2} (mg/1)	63.7	60.8	45.2	34.0	24.0	3.4	3.4	6.3	8.8	11.2	0.2
Na^{+} (mg/1)	8.6	8.4	42.0	39.0	59.0	189	187	96.0	27.0	22.0	17.4
K^{+} (mg/1)	8.0	7.6	5.1	5.0	3.6	14.0	13.8	7.3	5.5	5.2	2.8
SO_4^{-2} (mg/1)	958	918	788	408	357	137	114	42.0	26.0	31.0	104
Cl^{-} (mg/1)	1.8	1.7	2.8	2.8	5.3	22.0	22.0	12.0	9.2	8.7	6.6
F^{-} (mg/1)	3.1	3.4	2.9	3.2	0.9	8.7	8.7	2.4	1.1	0.8	6.9
SiO_2 (mg/1)	28.8	28.8	28.0	26.0	28.0	94.0	94.0	50.0	44.0	40.0	49.2

Table 4. Mean dissolved oxygen levels (mg/1) at Ringling, Norris and
Potosi.

				Sample Site				
RINGLING	5	4	3	1	6	7	8	2
	3.9	5.4	6.6	7.7	8.6	9.5	9.8	9.0
NORRIS	6	5	3	2	1	4		
	4.9	5.1	6.5	8.6	10.0	10.0		
POTOSI	2	1	3	4	5			
	5.6	6.3	7.1	7.5	7.8			

Bahls (unpublished data, Mont. Dept. Health and Env. Sci., Helena,
Mont.).

Norris Hot Spring is located in eastern Madison County, Montana
at E 1/2 Sec. 14 T3S R1W. The spring originates at a surface eleva-
tion of approximately 1463 m (4800 ft) with a discharge of 530 1 min^{-1}
(.31 cfs) and a temperature of 49-52°C. The spring is believed to
originate in Precambrian gneiss (Mariner et al. 1976). From its out-
flow, the spring flows directly into a large plank-lined pool where
the water undergoes radiative heat loss, cooling to approximately 38°C
when it leaves the pool. The hot stream flows down a gentle gradient
for approximately 100 m undergoing little further cooling until it
merges with Hot Spring Creek producing a very small thermal plume. The

plume attains a maximum width of about 1.5 m and a length of about 5 m tapering gradually downstream as the cold water forces the warm to shore. In contrast to the situation at Ringling, a relatively small volume of hot water enters the much larger Hot Spring Creek at Norris resulting in a smaller thermal plume (Table 1).

A series of six sampling stations were selected at Norris, again, based on thermal differences (Fig. 2, Table 2). Sites 6 and 5 were located within the hot spring channel, Sites 3 and 2 were located within the thermal plume in Hot Spring Creek and Sites 4 and 1 were the upper and lower cold water references in Hot Spring Creek.

Each site was divided into a riffle and pool format similar to that at Ringling. The substrate at Norris differed from that at Ringling with the riffle areas having rubble interspersed with large amounts of gravel and the pool areas having mainly a sand bottom.

Chemically, Norris differs greatly from Ringling. The spring at Norris is a sodium, potassium, bicarbonate and chloride water (Table 3). This chemical composition corresponds to one of the two most common types of hot spring found in Yellowstone National Park (Allen and Day 1935). Again, in contrast with Ringling, the dilution effect of Hot Spring Creek is evident in that the chemistry of the stream is dominant over the chemistry of the spring. In the stream, calcium replaces sodium as the dominant cation and the sulphate and chloride concentrations are much lower in the stream than in the spring.
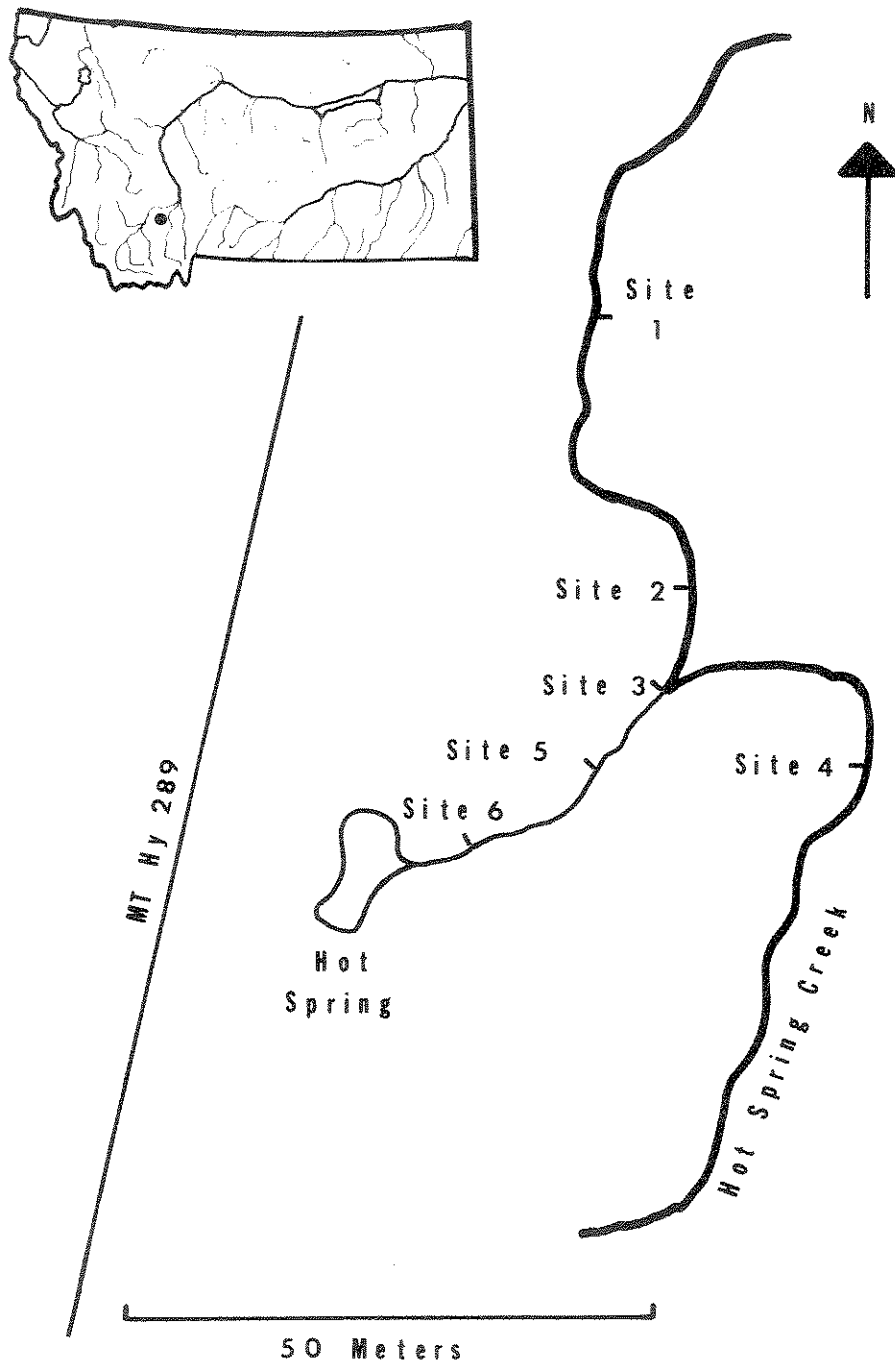
Figure 2.   Map of Norris study area showing macroinvertebrate sample
            sites.

Although thermal effects of the hot effluent are absent six meters below the entry of the hot spring, some chemical effects are evident at Site 1 approximately 50 m below the entry (Table 3). Dissolved oxygen values (Table 4) follow the same trend as those at Ringling. Chemical and physical parameters again compare favorably with those of Mariner et al. (1976) in the hot spring and L. Bahls (unpublished data, Mont. Dept. Health and Env. Sci., Helena, Mont.) in Hot Spring Creek.

Potosi Hot Spring originates on the east slope of the Tobacco Root Mountains in eastern Madison County, Montana. The site is unsurveyed with the spring located at 45°36' N, 111°54' W (Mariner et al. 1976). The spring issues from a series of vents at a surface elevation of 1890 m (6200 ft). Mariner et al. (1976) estimated the major source temperature at 50°C and the flow at several hundred liters per minute. They believed that the spring had its origin in granite bedrock and Tertiary volcanic rock.

Potosi Hot Spring is composed of several small channels less than 1 meter wide and 5 to 10 centimeters deep. The substrate is composed of sand and fine gravel. Due to the dendritic nature of the channels, a strong thermal gradient is present within the spring itself and five sampling stations were selected within the gradient (Fig. 3). Thermal data for these sites are found in Table 2. Although these temperatures represent mean values of spot readings taken on sampling dates, very little seasonal variation was observed. Thus the sites at Potosi
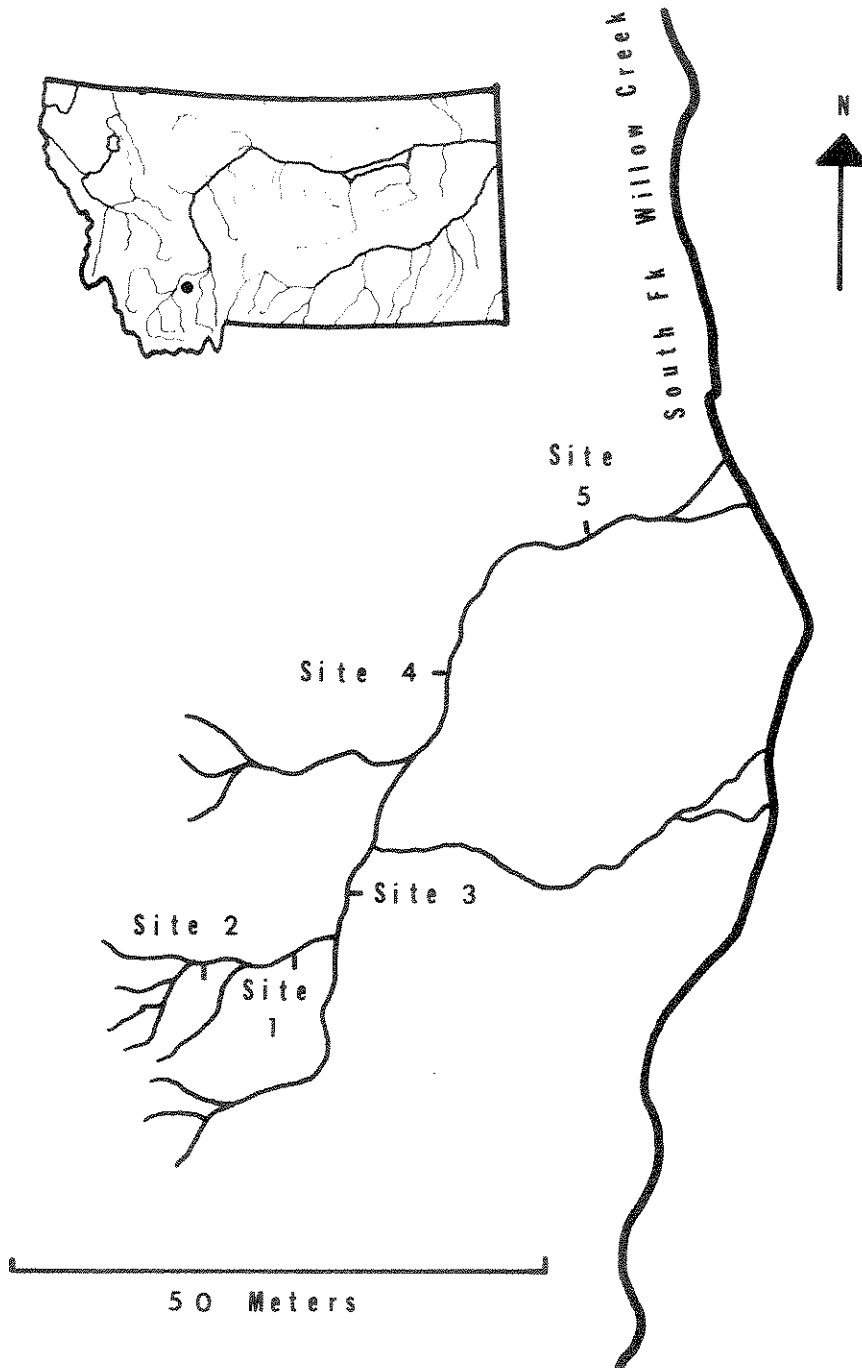
Figure 3. Map of Potosi study area showing macroinvertebrate sample sites.

demonstrated a high degree of thermal stability, probably due to their proximity to the spring source. All sample stations were within 50 m of the spring source. Although the spring produces two thermal effluents into the south fork of Willow Creek, no stations were located in the stream because no appreciable plume is produced by either effluent.

The chemistry of Potosi Hot Spring is given in Table 3. Potosi represents a third type of hot spring with a very low specific conductance and generally much lower ionic concentrations than Ringling or Norris. Dissolved oxygen concentrations decrease with increasing temperature (Table 4). Chemical data compared favorably with that presented by Mariner et al. (1976).

Although chemical and substrate differences are apparent between the study areas, the sample stations are quite comparable thermally due to the similarity of the gradients produced. Differences between the plumes exist in that the plume at Norris is very small in relation to the stream that it enters while the plume at Ringling and the gradient within the spring at Potosi dominate the thermal regimes of the areas under study. A difference between Ringling and Potosi exists in that Ringling had only been producing a thermal effluent for 45 years prior to the present study.

METHODS

A seasonal sampling program was set up at Ringling, Norris and

Potosi. Samples from all streams were taken at four-month intervals:

in early October of 1974 and mid-February, early June and early October

of 1975. An additional sample was taken at Ringling in August, 1975.

Physical

Sample sites at Ringling, Norris and Potosi were selected based

on a 5°C decrease in temperature from the hottest sample site down to

the ambient temperature of the receiving stream. The selection of

sites was made on the temperature gradient present on one day, thus the

sites were not necessarily separated by 5°C on a mean annual basis. The

5°C increment was selected as one which would probably be large enough

to yield biological differences among sites. An attempt was made to

select sites which were similar in substrate, width, depth and current

velocity in order to minimize these effects and maximize the effects of

temperature.

Flows and discharges were determined with a standard meter stick

and a Pygmy Gurley current meter. Discharge was calculated for fall

sampling periods at Ringling and Norris using Embody's formula (Welch

1948). The flows presented in Table 1 are reflective of low, stable

conditions that should prevail throughout most of the year.

Temperature was measured with a mercury thermometer and a Yellow

Springs Instruments Model 54 resistance thermometer on all sample

dates. These spot recordings are the only thermal data that were taken at Potosi. Additional thermal data were collected at Norris for the seven day period immediately following each sample date with Tempscribe seven day constant recording thermographs (Bacharach Instruments). An annual thermal cycle was recorded at Ringling from February 1975 to February 1976 with Tempscribe thermographs and Ryan Model D15 fifteen day constant recording thermographs (Ryan Instruments). Data were collected at Sites 3, 1, 6, 7, 8 and 2. Thermal data for Sites 5 and 4 consisted of spot readings because temperatures at these sites frequently exceeded the upper limits of the aforementioned instruments.

Chemical

Water samples were taken at Ringling (Sites 5, 3, 1, 7 and 2), Norris (Sites 6, 5, 2, 1 and 4) and Potosi (Site 4) for chemical analysis. These samples were analyzed for major cations and anions, silica, pH, conductivity and total alkalinity using standard methods of analyses as described by the APHA (1971). Calcium, magnesium, sodium and potassium were determined spectrophotometrically with a model 151 AA/AE Spectrophotometer (Instrumentation Laboratories). Alkalinity and chloride were determined titrametrically, sulphate was determined turbidometrically, fluoride by the SPADNS method and silica, colorometrically. Conductivity was measured with a Yellow Springs Instruments Model 31 AC Conductivity Bridge. Determination of pH and

total alkalinity titrations were made with a Beckman Expandomatic pH

Meter. Dissolved oxygen was measured at all sites on all dates, in

situ, with a Yellow Springs Instruments Model 54 oximeter. The oxi-

meter reading was compared with a Winkler dissolved oxygen determina-

tion on each sample date.

Biological

Bottom samples were taken at all sites at Ringling, Norris and

Potosi for the collection of macroinvertebrates. Collections were

made at Ringling on October 5, 1974 and February 15, June 11, August

11 and October 14 in 1975. Collections were made in both riffle and

pool areas. A riffle sample consisted of two collections with a

Surber square foot sampler which was modified to sample an area of .1

m^2. A pool sample consisted of two collections made with a .023 m^2

Ekman grab. Bottom samples were taken at Norris in a manner similar

to that at Ringling with two Surber and two Ekman collections made at

each sample site on each sample date. Samples were collected on

October 7, 1974 and February 12, June 10 and October 7 in 1975.

Bottom samples at Potosi consisted of two collections by Ekman grab

at each site on each date. Small channel size and low current

velocity prevented the effective use of the Surber sampler at Potosi.

Samples were collected on October 11, 1974 and February 16, June 10

and October 7 in 1975.

In addition to the bottom samples, a series of collections was made at Ringling using .2 m^2 multiple plate artificial substrate samplers (Hester and Dendy 1962). Two Hester-Dendy samplers were placed in each riffle area at Sites 3, 1, 6, 7, 8 and 2 from August 25 through December 4, 1975 and collected at approximately 14 day intervals. No Hester-Dendy samplers were used at Norris or Potosi.

Samples were concentrated in a U.S. Series No. 30 seive, transferred to glass or plastic containers and preserved in 10% formalin. Invertebrates were separated from the sample in the laboratory and placed in 70% ethanol for storage. Through the use of appropriate keys and techniques, all invertebrates were identified to the lowest practical taxon, usually genus or species, and enumerated.

With the exception of the microdrile oligochaetes which were put into Amman's lactophenol for clearing, all invertebrates from the Ringling bottom samples were weighed by genus or species. Total weight of invertebrates collected on each Hester-Dendy sampler was also recorded. Invertebrates were removed from the ethanol, blotted until no moisture appeared on the paper and weighed (Coutant 1962) on a Mettler H 16 electronic balance capable of weighing to the nearest g x 1.0^{-5}.

Linear measurements such as head length and width were made on four selected genera from Ringling. These measurements were made by

to the nearest .001 mm with an ocular micrometer disc (VWR Scientific
Instruments) fitted into a microscope.

Statistical

Macroinvertebrate genus-species distributions were analyzed, in
part, through the calculation of an index of similarity (S) developed
by Czekanowski (Clifford and Stephenson 1975). The index is described
by:

$$S = \frac{2C}{A+B} = 1.0 \text{ maximum similarity}$$

where   A = number of taxa occurring at Site A

           B = number of taxa occurring at Site B

           C = number of taxa common to both Sites A and B

The index is a nearest neighbor comparison of one sample site against
all other sample sites. Calculated S values were compiled and used to
compare sites at Ringling, Norris and Potosi.

Distributional data were further analyzed to yield patterns of
response of individual taxa to temperature. Taxa were placed in one
of four categories (i.e., eurythermal, cold stenothermal, hot steno-
thermal or intermediate stenothermal) based on distributional response
to temperature. This method yields information as to which taxa are
limited to cold or hot environments and which are adapted to a broad
range of temperatures. The method applies quite well to the steno-
thermal forms since their presence is restricted to a small number of
sites. The eurythermal forms, however, present a drawback to this

method in that presence is weighted equally over a wide range of sites without consideration as to whether this presence occurred infrequently at one site and very frequently at another or at an equal frequency throughout.

Patterns of distribution were further analyzed through the use of frequency of occurrence data. This method was used in an attempt to minimize all differences (e.g., chemical, physical, temporal etc.) among study areas and sites and maximize the effects of temperature. It also has the advantage of increasing the sample size for a single variable, temperature. This was done by pooling all samples from Ringling, Norris and Potosi that exhibited similar thermal regimes; e.g., Sites 2 and 8 at Ringling, Sites 1 and 4 at Norris and Site 5 at Potosi were pooled as the coldest group of sites from a total of 104 Surber, Ekman and Hester-Dendy samples at this thermal level. An obvious criticism of this method is that it ignores all differences among the three study areas. Frequency of occurrence was calculated as the number of samples in which an individual genus or species occurred divided by the total number of samples in which it could have occurred at a given thermal level (pooled set of sample sites). Thus, if a genus occurred at Ringling or Potosi but not at Norris, the Norris samples were not included in the frequency calculation.

Frequency of occurrence values were also used to delineate thermal distributional trends. The cold, hot and intermediate stenotherms were

partitioned out on the basis of presence or absence at a thermal level.
The eurythermal forms, however, were further subdivided on the basis
of temperature associated trends in frequency value (e.g., increased
frequency of occurrence as temperature increased).

Data were compiled on the total number of invertebrates per
sample for sample sites for the three study areas. Similar data were
compiled on numbers per sample at the ordinal and genus-species levels,
total weight of invertebrates per sample for the Ringling samples and
colonization rates for the Hester-Dendy samples.

In order to determine whether differences observed among treat-
ment (thermal site) means were significant or merely due to sampling
error, all treatment means were subjected to a multifactor analysis of
variance. This test was selected as one which would best fit the
seasonal sampling program that was used. In a one-way analysis of
variance, variation due to one treatment, e.g., temperature is compared
with variation due to error in an F test. A multifactor analysis of
variance divides treatment variation into two factors and considers the
interaction between these factors. In this study, temperature was
investigated as the primary factor in the determination of numerical
differences among sites; however, temperature is influenced by season.
The abundance of most aquatic invertebrates also fluctuates on a
seasonal basis due to factors such as changes in life stage and
mortality within the population. Because the sampling schedule

employed in this study was not continuous, the second factor partitioned out of the treatment variation was variation due to sample date or season. The multifactor analysis of variance also tests the variation due to the interaction between temperature (sample site) and season (sample date). A significant interaction is interpreted to mean that patterns of numerical response to levels of one factor (temperature) is not the same when taken over all levels of the other factor (season). In the calculation of F values, a fixed model was assumed thus implying experimental repeatability and denying randomness of sample.

A Neuman-Keuls Test was also employed to determine which sample sites were significantly different from all other sample sites. This test uses Q values to compare one sample site to all others.

Quantitative data were analyzed for a linearity of response to temperature by means of linear regression and correlation. Numbers and weights from each sample site were regressed against and correlated with temperature. Temperature values assigned to sample sites for each sample date were mean values compiled from mean daily temperatures 8 days prior to and 8 days following a sample date at Ringling and 7 days following a sample date at Norris. Thermal data for Potosi consisted of spot temperature readings taken on the sample date. In the Ringling analysis, Sites 5 and 4 were eliminated due to the virtual lack of a macroinvertebrate community. Site 2 was eliminated because of extreme

deviations from linear numerical thermal patterns. All sites from

Norris and Potosi were included in regression-correlation analysis.

All regression equations ($y = ax + b$) were tested with an F test

and all correlation coefficients (r) were tested with a T test for

statistical significance. Calculation of the coefficient of determina-

tion (r^2) provided a means of assessing the percent of variation in the

dependent variable (e.g., number of invertebrates per sample) that can

be attributed to variation in the independent variable (e.g., tempera-

ture).

Table 5. Checklist and distributions of taxa collected at Ringling.

			Sample Site			
4	3	1	6	7	8	2

	4	3	1	6	7	8	2
Ephemeroptera							
Baetidae							
Baetis sp. A			*	X	X	X	X
Baetis sp. B				X	X	*	
Callibaetis sp.						X	X
Leptophlebiidae							
Choroterpes albiannulata McDunnough			X	X	X	X	X
Ephemerellidae							
Ephemerella infrequens McD.					X		X
Tricorythidae							
Tricorythodes minutus Traver			X	X	X	X	X
Caenidae							
Caenis simulans McD.			X	X	X	X	X
Odonata							
Gomphidae							
Ophiogomphus sp.			X	X	X	X	X
Aeschnidae							
Aeschna umbrosa Walker					X		X
Coenagrionidae							
Ischnura sp.			X	X	X	X	X
Hemiptera							
Corixidae							
Hesperocorixa laevigata (Uhler)							*
Trichoptera							
Helicopsychidae							
Helicopsyche borealis (Hagen)			X		X	X	X
Polycentropidae							
Polycentropus sp.			*	*	X	X	X
Hydropsychidae							
Cheumatopsyche spp.			X	X	X	X	X
Hydropsyche sp. A				X	X	X	X
Hydropsyche sp. B			*	X	X	X	
Hydropsyche sp. C				X			
Hydroptilidae							
Hydroptila sp.			X	X	X	X	X

Table 5 (continued).

	Sample Site						
	4	3	1	6	7	8	2
Leptoceridae							
Oecetis sp.						X	
Limnephilidae							
Hesperophylax sp.							X
Coleoptera							
Dytiscidae							
Agabus sp.			X				
Deronectes sp.						X	X
Hydroporus sp.							X
Hydrophilidae							
Helophorus sp.					X		X
Elmidae							
Dubiraphia minima Hilsenhoff			X	X	X	X	X
Microcylloepus pusillus (LeConte)			X	X	X	X	
Optioservus quadrimaculatus (Horn)			X	X	X	X	X
Zaetzevia parvula (Horn)					*		*
Haliplidae							
Haliplus sp.			X		X	X	X
Diptera							
Tipulidae							
Dicranota sp.						X	X
Tipula sp. A						X	
Tipula sp. B							X
Culicidae							
Aedes sp.				X			
Simuliidae							
Simulium spp.			X	X	X	X	X
Chironomidae							
Conchapelopia sp.		X	X	X	X	X	X
Procladius sp.			X	X	X		X
Diamesa spp.					X	X	X
Chironomus sp.							X
Cladopelma sp.					X		
Cladotanytarsus spp.			X	X		X	
Cryptochironomus spp.			X	X	X	X	X
Dicrotendipes sp.			X	X	X	X	X
Endochironomus sp.						X	X

Table 5 (continued).

	Sample Site						
	4	3	1	6	7	8	2
Micropsectra spp.			X	X	X	X	X
Paratendipes sp.			X	X	X	X	X
Phaenopsectra sp.							*
Polypedilum spp.				X	X		
Rheotanytarsus spp.			X	X	X	X	X
Stictochironomus sp.						X	
Tanytarsus spp.			*				
Acricotopus sp.			X	X			
Cricotopus spp.			X	X	X	X	X
Eukiefferiella spp.		X	X	X	X	X	X
Paraphaenocladius sp.	*						
Pseudosmittia sp.		X					
Orthocladius spp.			X	X	X	X	X
Ceratopogonidae							
Tr. Stilobezziini			X	X	X	X	X
Stratiomyiidae							
Alluaudomyia sp.					*		
Stratiomyia sp.		X					
Tabanidae							
Chrysops spp.			X	X	X	X	X
Tabanus sp.					*		
Dolichopodidae							
Hydrophorus sp.							*
Empididae					X		
Muscidae		X					
Anthomyiidae							
Limnophora aequifrons Stein						X	
Limnophora torreyae Johannsen				*			
Ephydridae							
Notiphila sp.					*		
Hydracarina							
Sperchonidae							
Sperchon sp.						X	
Haplotaxida							
Lumbricidae							
Eiseniella tetraedra (Savigny)				*	X	X	

Table 5 (continued).

	4	3	1	6	7	8	2
			Sample Site				
Tubificidae							
Limnodrilus claparedianus Ratzel						X	X
Limnodrilus hoffmeisteri Claparede		X	X	X	X	X	X
Limnodrilus udekemianus Claparede			*				
Peloscolex ferox (Eisen)		X	X	X	X	X	X
Naididae							
Ophidonais serpentina (Muller)			*	*	X		X
Hirudinea							
Glossiphonidae							
Helobdella stagnalis (Linnaeus)					X		
Erpobdellidae							
Dina anoculata Moore			X				*
Pulmonata							
Physidae							
Physa spp.		X	X	X	X	X	X
Lymnaeidae							
Lymnaea spp.		X	X		X		X
Planorbidae							
Gyraulus sp.					X		
Heterodonta							
Sphaeriidae							
Pisidium sp.					X		X
Ostracoda							
Cypris sp.		X					
Amphipoda							
Talitridae							
Hyalella azteca (Saussure)			X	X	X	X	X
Gammaridae							
Gammarus lacustris Sars						X	

X denotes presence
* denotes very rare presence

Table 6. Checklist and distributions of taxa collected at Norris.

	Sample Site					
	6	5	3	2	1	4
Collembola						
Isotomurus sp.	*					
Ephemeroptera						
Siphlonuridae						
Ameletus cooki McDunnough						X
Baetidae						
Baetis sp. A			*	X	X	X
Leptophlebiidae						
Paraleptophlebia heteronea McD.			*	X	X	X
Ephemerellidae						
Ephemerella grandis Eaton					X	
Ephemerella inermis Eaton			X	X	X	X
Tricorythidae						
Tricorythodes minutus Traver					X	X
Odonata						
Gomphidae						
Ophiogomphus sp.					X	X
Plecoptera						
Pteronarcidae						
Pteronarcella badia (Hagen)			*	X	X	X
Perlodidae						
Arcynopteryx sp.			*		X	X
Diura knowltoni Frison				X	X	X
Isoperla fulva Claassen				X	X	X
Trichoptera						
Helicopsychidae						
Helicopsyche borealis (Hagen)					X	X
Hydropsychidae						
Hydropsyche sp. D			X	X	X	X
Brachycentridae						
Brachycentrus sp.			X	X	X	X
Micrasema sp.			*	X	X	X

Table 6 (continued).

| | Sample Site | | | | | |
	6	5	3	2	1	4
Coleoptera						
Curculionidae	X		X			
Elmidae						
Optioservus quadrimaculatus (Horn)				X	X	X
Diptera						
Tipulidae						
Dicranota sp.			X	X		
Hexatoma sp.			X	X	X	X
Tipula spp.			*	X	X	X
Simuliidae						
Simulium spp.				X	X	X
Chironomidae						
Conchapelopia sp.	X		X			X
Procladius sp.						X
Diamesa spp.			X	X	X	X
Odontomesa sp.			X	X	X	X
Chironomus spp.				*		
Cladotanytarsus spp.				X		
Cryptochironomus spp.			X			
Endochironomus sp.						X
Micropsectra spp.					X	X
Microtendipes sp.			X	X	X	X
Phaenopsectra sp.				X		X
Polypedilum spp.			X	X		
Rheotanytarsus spp.			X			
Acricotopus sp.		X	X			X
Cricotopus spp.			*	X		
Eukiefferiella spp.			X	X		
Lymnophyes sp.		*				
Orthocladius spp.			X	X	X	X
Pseudosmittia sp.	X	X				
Ceratopogonidae						
Tr. Stilobezziini						X
Stratiomyiidae						
Eulalia sp.			X			
Tabanidae						
Chrysops spp.						X

Table 6 (continued).

	Sample Site					
	6	5	3	2	1	4
Empididae				*	X	X
Anthomyiidae						
Limnophora aequifrons Stein				*	X	
Haplotaxida						
Lumbricidae						
Eiseniella tetraedra (Savigny)			*	*		X
Tubificidae						
Limnodrilus hoffmeisteri Claparede			X	X	X	X
Limnodrilus udekemianus Claparede					X	*
Peloscolex ferox (Eisen)			X	X	X	X
Naididae						
Ophidonais serpentina (Muller)						X
Hirudinea						
Glossiphonidae						
Helobdella stagnalis (Linnaeus)						X
Pulmonata						
Physidae						
Physa spp.			X	X	X	X
Heterodonta						
Sphaeriidae						
Pisidium sp.			*	X	X	X
Amphipoda						
Talitridae						
Hyalella azteca (Saussure)					X	X

X denotes presence
* denotes very rare presence

Table 7. Checklist and distributions of taxa collected at Potosi.

	Sample Site				
	2	1	3	4	5
Ephemeroptera					
Baetidae					
Baetis sp. A		X		X	
Tricorythidae					
Tricorythodes minutus Traver		*			
Odonata					
Gomphidae					
Ophiogomphus sp.		X	X	X	X
Libellulidae					
Erythemis sp.		X		X	
Coenagrionidae					
Argia sp.		*		X	
Plecoptera					
Nemouridae					
Nemoura sp.					*
Hemiptera					
Naucoridae					
Ambrysus heidemanni Montandon	X	X		X	
Corixidae					
Sigara omani (Hungerford)				*	
Trichoptera					
Helicopsychidae					
Helicopsyche borealis (Hagen)			X	X	
Hydropsychidae					
Cheumatopsyche sp.		*			
Hydroptilidae					
Oxyethira sp.		*		*	
Philopotamidae					
Chimarra sp.				*	
Coleoptera					
Hydrophilidae					
Tropisternus sp.		*			
Elmidae					
Microcylloepus pusillus (LeConte)	X	X	X	X	X

Table 22. Mean biomass (g) and numbers of organisms collected in
          Ringling Surber samples on each sample date.

	Fall '74	Winter	Spring	Summer	Fall '75
Biomass	2.4920	.9289	.6532	1.1850	3.4890
Number	1167.0	476.7	258.3	562.3	741.9

individual organism was calculated on a seasonal and thermal site basis

for the Ringling Surber samples (Table 23). This was accomplished by

Table 23. Mean weight (mg) per individual organism, by sample site and
          season, from the Ringling Surber samples.

Sample Site	3	1	6	7	8	2
Weight by Site	5.43	3.60	2.51	2.26	2.71	3.29
Sample Season	Fall '74	Winter	Spring	Summer	Fall '75	
Weight by Season	2.13	1.94	2.53	2.11	4.70	

dividing the mean weight of invertebrates per sample by the mean number

per sample for thermal sites and sampling dates. Data contained in

Table 23 reflect a general decrease in the size of the individual

organism with decreasing temperatures. Site 2 was found to deviate from

the general trend in that it appears to most closely resemble Site 1 in

value. Seasonal comparisons show similarities in mean weight of

individuals between the fall 1974 and winter samples with an increase

in weight in the spring samples.

Differences in mean biomass per sample were tested with a Newman-Keuls test. No significant difference was found among Sites 3, 1, 6 and 2 in any combination. Sites 7 and 8 differed significantly from each other and all other sites.

Mean biomass per sample was correlated with temperature for sites at Ringling. Correlation coefficients and coefficients of determination were calculated on an annual and seasonal basis and are found in Table 24. On an annual basis, biomass was weakly correlated with

Table 24. Correlation coefficients and coefficients of determination[a] for mean biomass per sample[b]; Ringling Surber samples.

Annual	Fall '74	Winter	Spring	Summer	Fall '75
-.336*	-.890**	-.949**	+.753*	-.619*	-.747*
(.11)	(.79)	(.90)	(.57)	(.38)	(.56)

[a] in parentheses   * significant (P$\leq$.05)
[b] .1 m^2 **highly significant (P$\leq$.01)

temperature with 11% of the variation in biomass attributed to variation in temperature. Seasonal r values generally showed a strongly negative correlation between biomass and temperature (-.619 to -.949) with 38 to 90% of the variation due to thermal variation. The spring sample provided an exception to this trend with biomass strongly correlated with temperature in a positive manner (+.753). All correlations for mean biomass with temperature were significant or highly significant.

The linear regression for mean sample biomass as dependent on temperature is described by $y = .1x + 3.8$. The regression was found to be significant and is graphed in Figure 6. The rate of change of .1 g per °C applied to the annual, winter, spring and summer samples but the fall samples displayed a higher rate.

Colonization rates of Hester-Dendy artificial substrate samplers were computed for sample sites at Ringling. The samplers were harvested at approximately 14 day intervals with a maximum sample period of 21 days. This is less than the four to eight weeks recommended to achieve colony equilibreum by many authors (Anderson and Mason 1968, Fullner 1971, Hilsenhoff 1969, Nilsen and Larimore 1973). On each sample date, samplers were scraped bare thus presenting a denuded substrate for each sample period. Mean colonization rates were calculated in number of organisms per square meter per day and milligrams per square meter per day for Sites 3, 1, 6, 7 and 8 at Ringling (Table 25). Site 2 was eliminated due to the presence of extremely large populations of *Simulium* which occurred irregularly in some of the samples. Numerical colonization rate was lowest at Site 3. Site 1 exhibited a dramatic increase in rate over Site 3 and Site 6 had the maximum rate with a mean value of 201.3 organisms per square meter per day. The rate was lowest at the lower cool sites, Sites 7 and 8. A similar pattern can be observed in the weight related rates with a marked increase between Site 3 and Sites 1 and 6, the maximum being achieved

$y = -.1x + 3.8$
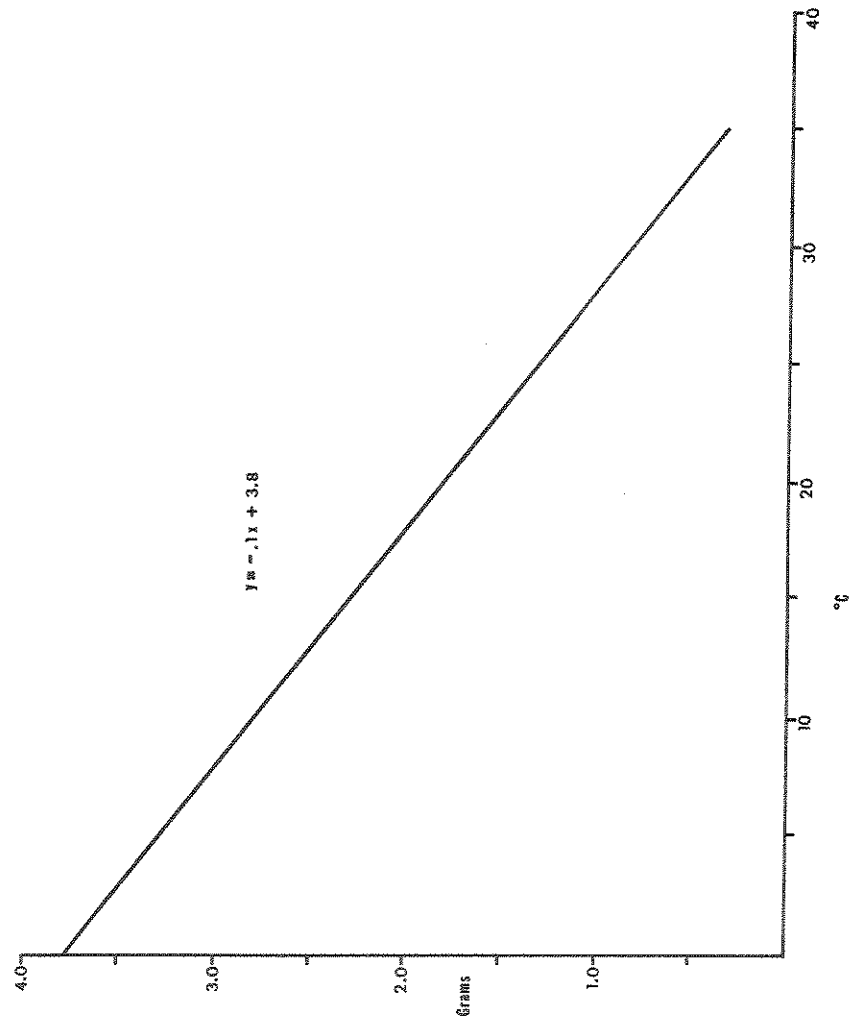
Figure 6. Linear regression of macroinvertebrate biomass and temperature from Surber samples collected at Ringling.

Table 25. Colonization rates of macroinvertebrates on Hester-Dendy samplers with multifactor analysis of variance, Ringling.

| | Sample Site | | | | | Analysis of Variance | | |
	3	1	6	7	8	Date	Site	Date x Site
No./m^2/day	1.0	102.4	201.3	59.0	73.4	HS	HS	S
mg/m^2/day	69.1	238.8	205.3	95.0	76.1	HS	HS	NS

HS = highly significant difference (P$\leq$.01)
 S = significant difference (P$\leq$.05)
NS = differences non-significant

at Site 1, and a marked drop in rate between Sites 1 and 6 and Sites 7 and 8 as temperatures cooled further. Analysis of variance showed that variation in mean rates of colonization was highly significant.

A Newman-Keuls Test was performed on the colonization rates. The only significant difference that could be detected for the numerical rates was found between the extremes, Sites 3 and 6. The weight related rates showed a significant difference between Sites 1 and 6 and Sites 3, 7 and 8. No difference was found between Sites 1 and 6 or among Sites 3, 7 and 8.

Regression-correlation analysis was performed on the numerical and weight related colonization rates. Both numerical (+.064) and weight related (+.156) colonization rates were very weakly correlated with temperature. The numerical rate of colonization as dependent on temperature was described by the linear regression $y = 1.2x + 62.6$ while

colonization rate by weight was described by $y = 2.1x + 92.1$. Neither the correlations nor the regressions were found to be significant.

Another production related parameter, genus-species mean weight, was compared among the Ringling sample sites. Mean weight was calculated as the total wet weight of each genus or species divided by the total number of individuals weighed. Data from the fall and winter samples were selected for comparison to minimize complications due to emergence, egg stage, spates etc. Mean weights for 25 taxa are presented in Appendix Table 32. All of the taxa exhibited different mean weights at different sample sites with the most marked differences found between the warmer sites, Sites 1 and/or 6, and the cooler sites, Sites 7 and/or 8. Thirteen of the 25 taxa exhibited increased mean weight with increased temperature and an additional four taxa had higher mean weights at higher temperatures without linearity of response. Eight taxa showed a reverse of this trend with increased mean weights as temperature decreased.

Ten taxa common to both Sites 6 and 7 exhibited an increase in weight between the fall 1974 and the winter samples. The difference in mean weight between these samples for each taxon was calculated as the growth increment for that period and divided by 10 to yield a mean increment of growth for Site 6 and Site 7. The mean growth increment for the 10 taxa was 3.09 mg per organism at Site 6 and .28 mg per organism at Site 7.

Comparison of intersite growth rates was further investigated through the use of length frequency analysis. Four taxa; the mayflies *T. minutus* and *C. albiannulata*, the caddisfly *Cheumatopsyche* and the amphipod *H. azteca* were selected because of their common occurrence at a range of thermal sites and an external morphology that lent itself to linear measurement. Head capsule length or width were selected for measurement because of their acceptability for the differentiation of instars by frequency analysis (McCauley 1974, Newell 1976, Terch 1972). No attempt was made to define individual instars due to a lack of sufficient accompanying data (Newell 1976).

In the case of the mayflies, the observation was made that many sizes of individuals were present, ranging from very small early instars to very large individuals whose well developed wing pads, adult eyes and color indicated that they were near emergence. Because of this, a master histogram was constructed for both *T. minutus* and *C. albiannulata* with the result that eight arbitrary instar groups were selected for the former and 10 instar groups were selected for the latter (Figure 7). Head widths for *T. minutus* and head lengths for *C. albiannulata* from the fall sample 1974 were categorized and their frequencies plotted for Sites 6, 7 and 8 for *T. minutus* (Figure 8) and Sites 1, 6, 7 and 8 for *C. albiannulata* (Figure 9). *T. minutus* occurred in all eight instar groups at Site 6 while only the first five groups occurred at Sites 7 and 8. The highest mode was achieved at instar
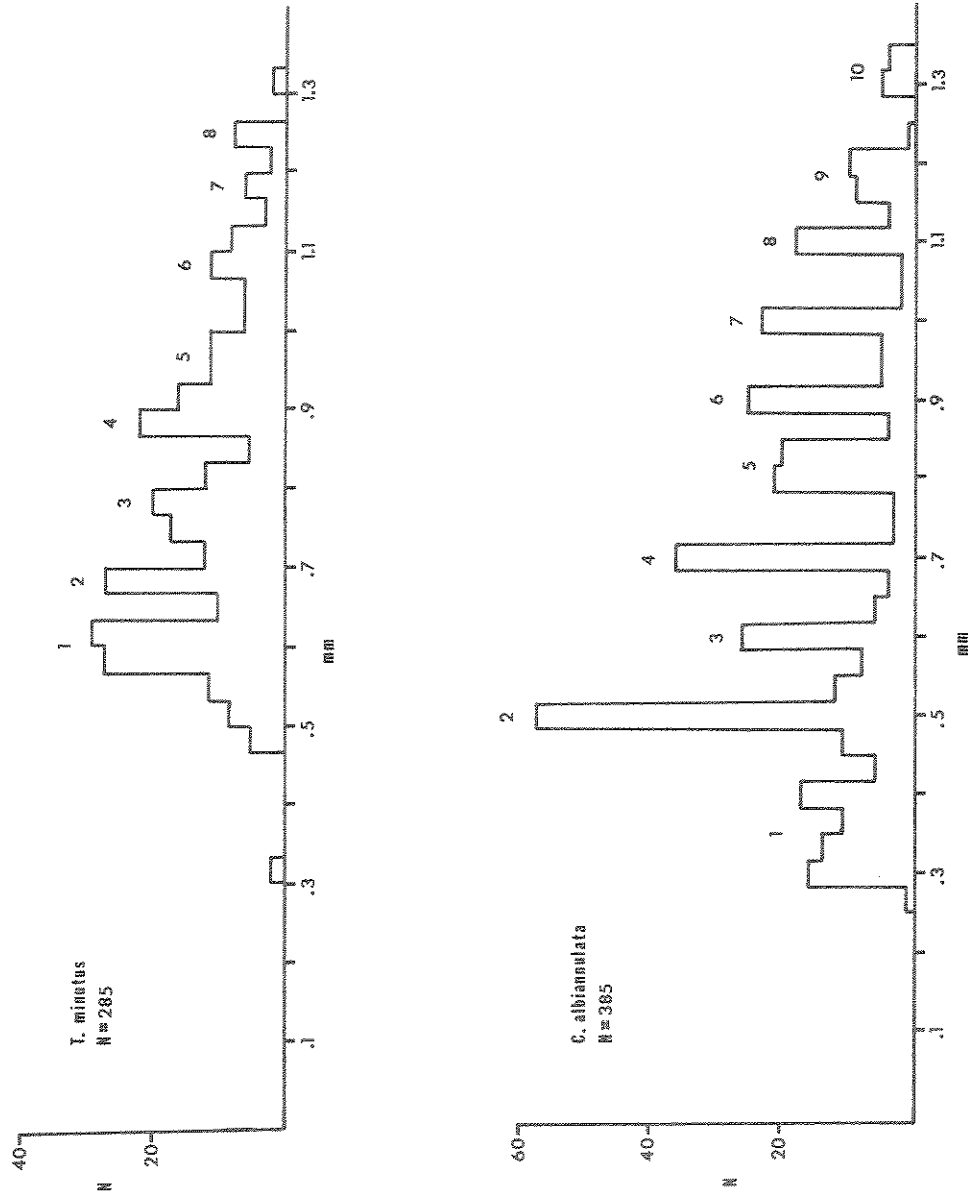
Figure 7. Head width (*Trichorythodes minutus*) and head length (*Choroterpes albiannulata*) frequency histograms used to estimate instar groups (numbers above modes) from samples collected Oct. 5, 1974 at Ringling.
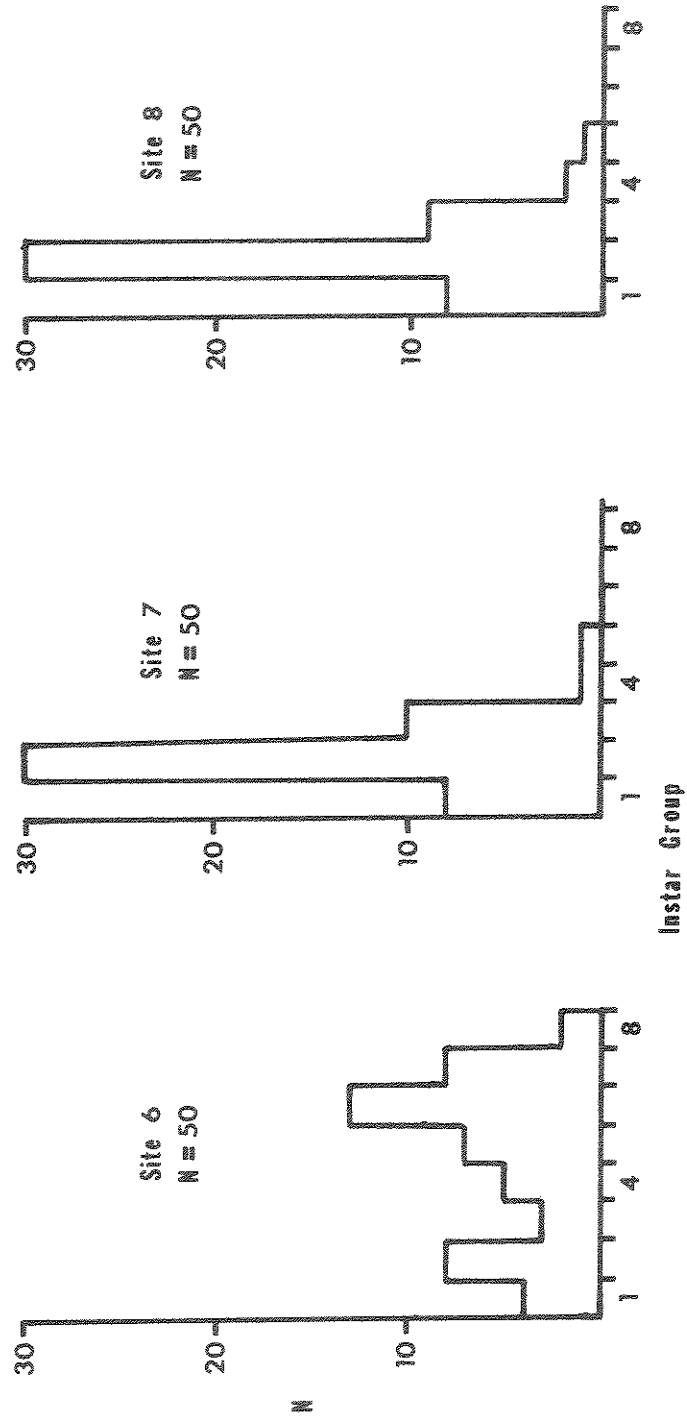
Figure 8. Instar group frequency based on head width measurements of *Trichorythodes minutus* collected Oct. 5, 1974 at Ringling.
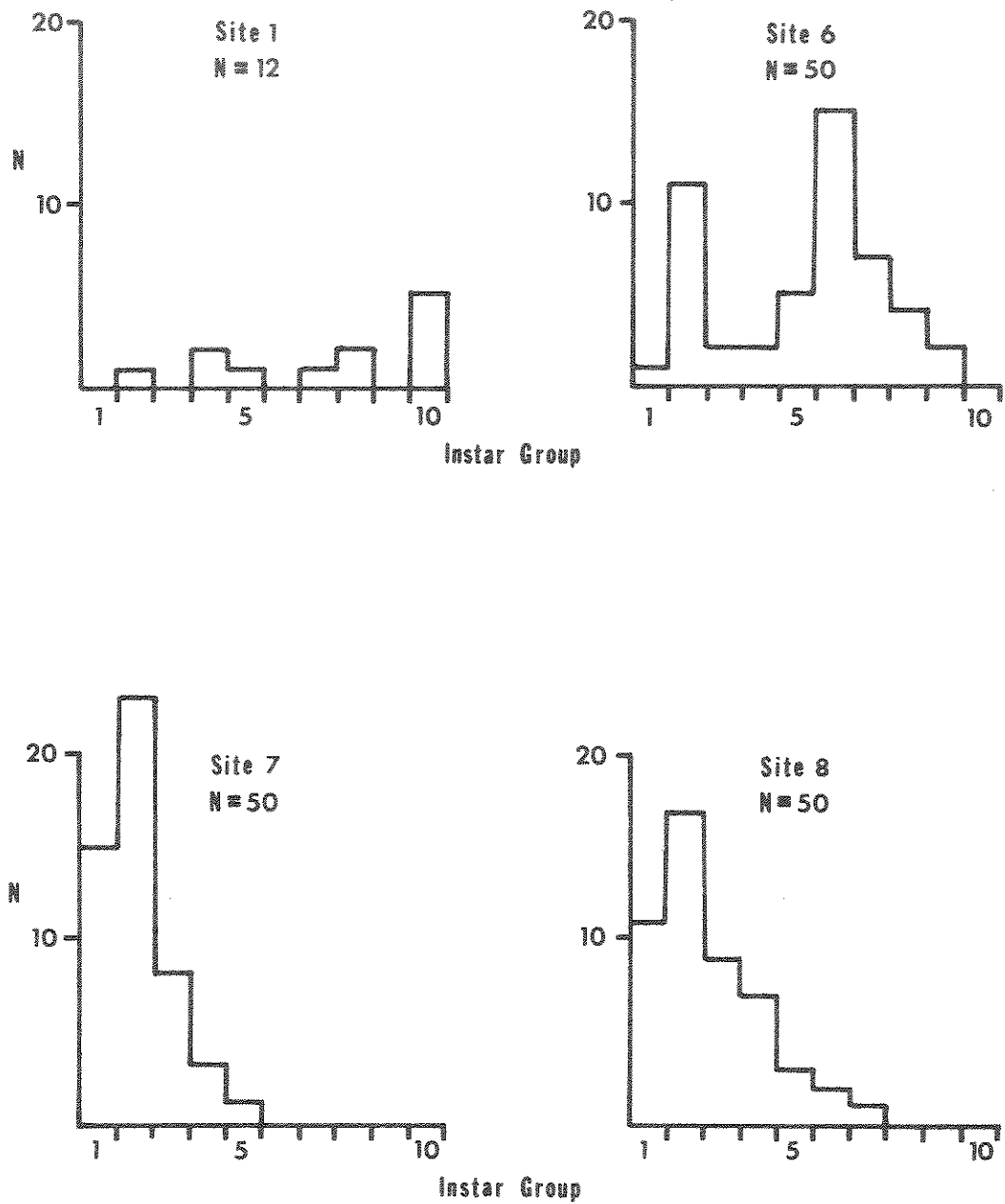
Figure 9. Instar group frequency, based on head length measurements, of *Choroterpes albiannulata* collected Oct. 5, 1974 at Ringling.

group six for Site 6 while the maximum frequency was observed at instar group two at Sites 7 and 8. A similar situation was observed for *C. albiannulata* with nearly a full range of instar groups occurring at Sites 1 and 6 and a lower range of groups represented at Sites 7 and 8. Maximum frequencies of occurrence for *C. albiannulata* occurred at instar group six for Site 6 and instar group two for Sites 7 and 8.

The large range in developmental stage within a single sample was not observed in *H. azteca* or *Cheumatopsyche* thus no instar groups were calculated and only length frequency data were plotted (Figures 10 and 11). *H. azteca* did not show the marked shift toward larger instars at high temperatures that the mayflies did; however, a lack of the smaller instars was noticed at the warmer sites, Sites 1 and 6. The larger instars were found at both warmer and cooler sites. Length frequency data for *Cheumatopsyche* exhibited three modes at each site which did shift appreciably with temperature.
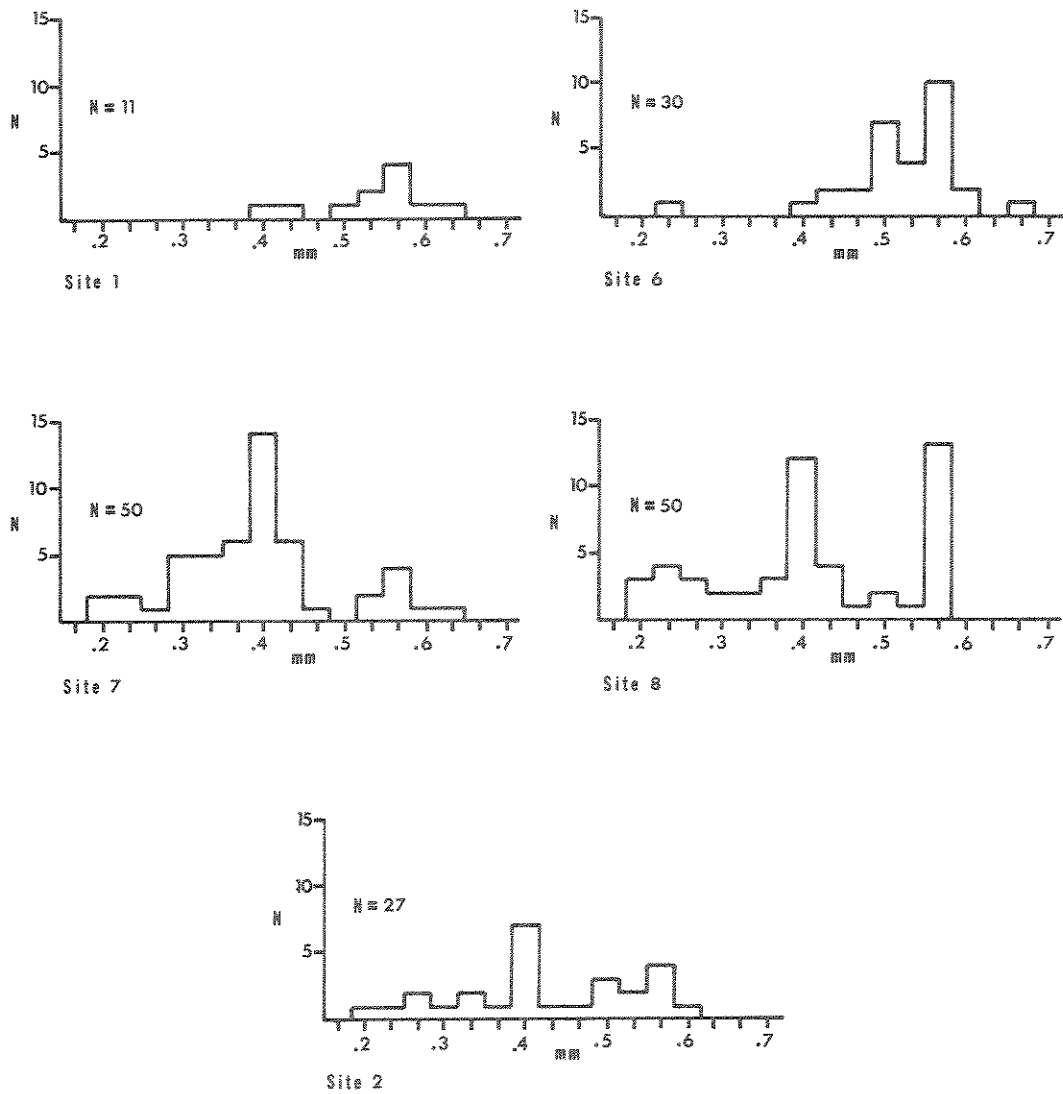
Figure 10. Head length frequency of *Hyalella azteca* collected Oct. 5, 1974 at Ringling.
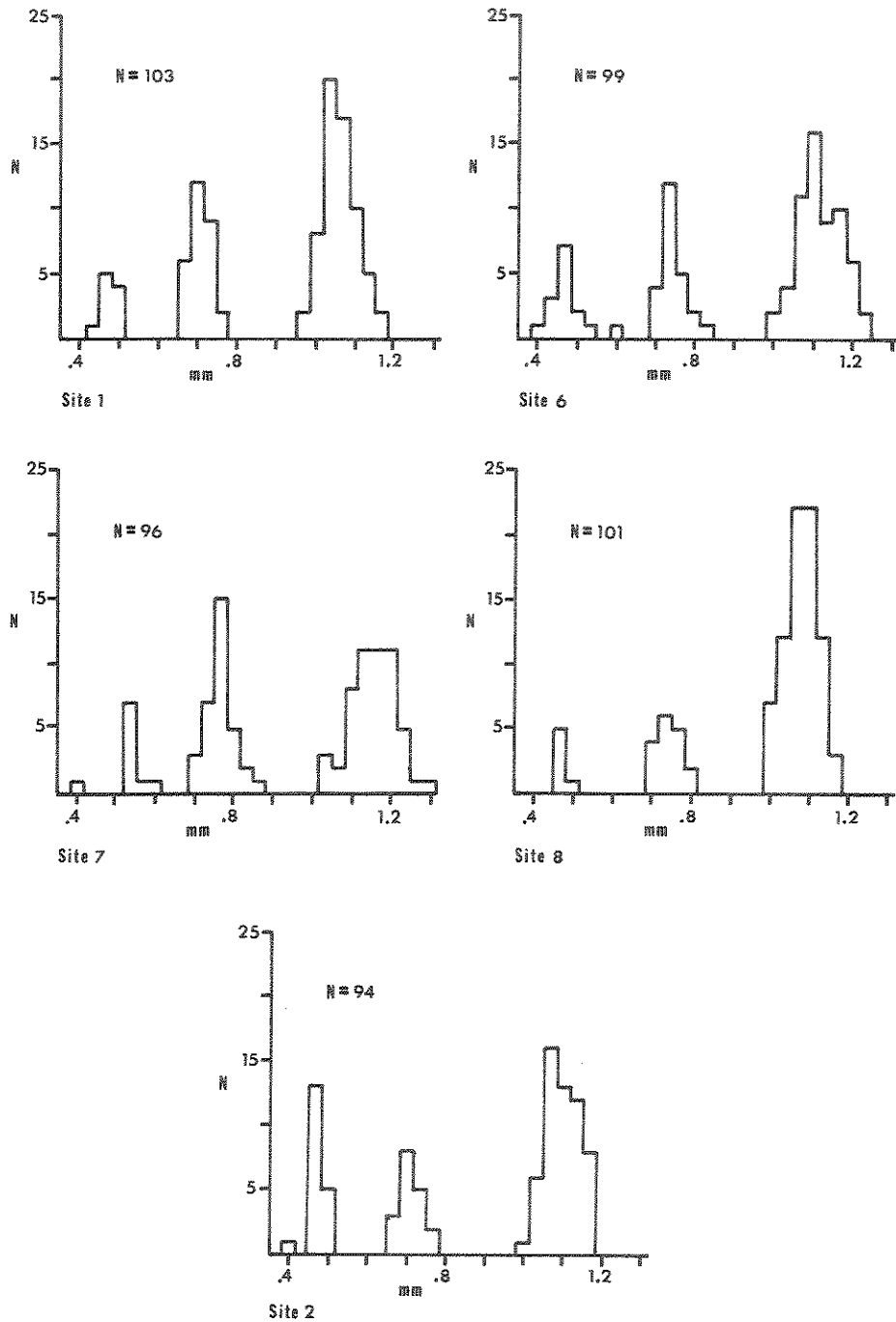
Figure 11. Head length frequency of *Cheumatopsyche* spp. collected Oct. 5, 1974 at Ringling.

DISCUSSION

The thermal regime of a body of water is a function of latitude,
altitude and season and fluctuates on a daily and seasonal basis.
Dodds and Hisaw (1925) considered average annual temperature, winter
minimum, summer maximum, summer average, duration of summer season and
duration of ice cover to be the most critical components of water
temperature for the aquatic invertebrate community. When the normal
thermal regime is disrupted due to the addition of heated water, either
from geothermal or man-caused sources, the result is a quantitative and
qualitative shift in the macroinvertebrate fauna. These shifts may
occur as a result of direct lethality from high temperatures and/or
indirect effects on some stage of the life cycle of a species which may
result in a reduction in population number or in its ultimate removal
from the community (Tarzwell 1970). Although it may be theorized that
addition of new species may accompany a thermal shift, this was not
observed in the present study.

Direct lethality due to high temperature may not act on the organ-
ism as an individual or as a species. The effects of direct lethality
on community composition are difficult to distinguish from indirect
effects in a field situation and may play a minor role when compared to
the latter. Wurtz (1969) questioned the use of maximum temperature on
an annual, mean daily or mean annual basis in the determination of
thermal effects on invertebrate communities because most north

temperate species are eurythermal. He emphasized the importance of the rate of temperate change.

Attempts have been made to measure upper lethal limits in the laboratory. Gaufin and Hern (1971) measured 96 hr TLm values from a low of 14.5°C for *Gammarus limnaeus* to highs of 30.5°C for *Hydropsyche* and 32.4°C for *Atherix variegata*. Mean values were 18.8°C for Ephemeroptera, 26.5°C for Trichoptera and 28.7°C for Diptera. Nebecker and Lemke (1968) tested 12 species that were acclimated at 10°C for one week and found a range of 21 to 33°C for 96 hr TLm values.

Indirect effects of high temperature pertain to phenomena that occur at temperatures below the lethal level. An organism may be able to survive at such temperatures but be unable to successfully reproduce, thus eliminating such a species from the aquatic community at that thermal regime (Nebecker 1971a). In many aquatic insects, a timed sequence of thermal stimuli is often necessary for egg hatching, nymphal development and emergence (Lehmkuhl 1974). If these criteria are met, a species can often tolerate a wide range of temperatures. If the proper temperature is missing for one stage of development, however, the species may be eliminated from the community or its numbers drastically reduced. Low summer temperatures, for example, have been found to remove species from the macroinvertebrate community due to the disruption of this thermal synchrony (Elgmork and Saether 1970, Lehmkuhl 1972, Pearson et al. 1968).

The structure of a macroinvertebrate community may also be influenced by the interactions between temperature and various other factors that determine macroinvertebrate distribution and abundance (Vernberg and Vernberg 1974). One such factor is the amount of dissolved oxygen that is present in the water. The interaction between temperature and dissolved oxygen was demonstrated by Krenkal and Parker (1969) who showed that at 25°C the deoxygenation curve crosses the reaeration curve and sweeps rapidly upward causing oxygen depletion.

Whichever of the aforementioned processes or combination of processes is involved, temperature does exert a strong influence on the determination of the macroinvertebrate communities of a body of water. At high temperatures, this effect seems to be manifested as a process of elimination, rather than addition, of species as temperature increases to the point at which macroinvertebrate life is excluded.

Macroinvertebrate Thermal Maxima

Perhaps the most obvious effect of direct lethality due to high temperature is the exclusion of macroinvertebrate life from the aquatic ecosystem. The data suggest that macroinvertebrates were unable to inhabit sites where temperatures often exceeded 40°C at Ringling and Norris. Similar results were obtained by Durrett and Pearson (1975) who found no invertebrates inhabiting a power plant effluent channel when temperatures exceeded 41°C. Jones (1967) determined that macroinvertebrate life was excluded by temperatures in excess of 43.5°C in

the Firehole River. Brock (1967) found macroinvertebrates inhabiting temperatures up to 43°C in hot springs in Yellowstone National Park.

It is difficult to determine whether invertebrate life is excluded by temperatures in excess of 40°C or by temperatures acting in combination with other factors. Langford (1971) and Wurtz (1969) mentioned the problem of separating thermal effects from the effects of other pollutants in power plant effluents. Brues (1924, 1932) considered low dissolved oxygen levels, high salinities and variable pH values as compounding the problem of high temperatures in hot springs. Gaufin (1962) found that for most stonefly larvae oxygen demands increased very rapidly above 16.5°C. It has been postulated that temperature can interact with other factors, biotic or abiotic, to exert a more profound effect on living organisms than any one factor by itself (Vernberg and Vernberg 1974). This interaction may be additive or synergistic.

The Hot Spring Fauna

The majority of the taxa collected within the flows of the hot springs were not restricted to these heated environments and were also collected at cooler stations. This appears to be consistent with the findings of Robinson and Turner (1975) in some Virginia hot springs and Mason (1939) in an Algerian hot spring. The ability of certain species to inhabit a broad thermal range may be due to an ability to synthesize multiple forms (isozymes) of regulary enzymes (Newell 1973). The elimination of most species from the temperature regime of the hot

spring and the restriction of some others to this environment may be due to their inability to synthesize the appropriate isozymes.

Of the taxa that were restricted to the hot springs, some doubt exists as to whether *Isotomurus*, the Curculionidae, the muscid pupae and the midges *Paraphaenocladius* and *Limnophyes* are truly members of the aquatic community. The remaining taxa; *Pseudosmittia, Atrichopogon* and *Cypris* may be restricted to elevated temperatures.

Although there does not appear to be a unique thermal fauna created through the addition of species, one has evolved via the elimination of most forms found at the cooler sites. Most genera that are capable of inhabiting hot springs demonstrate a common North American and even a world-wide distribution in these springs (Robinson and Turner 1975). Hynes (1970) stated that a very select fauna is found as temperatures approach 40°C consisting mainly of dytiscid and hydrophilid beetles, stratiomyids, chironomids, oligochaetes and ostracods. Results of the present study indicate that Pulmonata, represented by *Physa* and *Lymnaea*, should be added to this group.

Members of the dipteran family Ephydridae and the dragonfly *Libellula* have been previously reported as common inhabitants of hot springs (Brues 1924 and 1932, Mason 1939, Provonsha and McCafferty 1977); however, no representatives of these taxa were collected in the present study. Their absence may be due to some thermal-chemical

interaction or other habitat requirements that are limiting in the
hot springs under study.

Fauna Of The Thermal Gradients

Faunal distributions within the thermal gradients revealed that
many of the taxa were limited to the colder sites. All of the Plecop-
tera collected during the study were rigidly restricted to the cooler
sites. Gaufin (1962) stated that thermal optima for most Plecoptera
occur in the range of 10 to 15°C. Armitage (1961) observed that no
Plecoptera showed a preference for warmer sites in the Firehole River.
Several of the mayfly species were limited to the cooler sites. One of
these, *E. grandis,* also showed thermal avoidance in the Firehole River
(Armitage 1961). Few chironomids exhibited a thermal avoidance although
Diamesa, a common inhabitant of cold mountain brooks (Elgmork and
Saether 1970), *Endochironomus, Phaenopsectra, Stictochironomus* and
Chironomus appeared to be limited to the colder sites. Although
Chironomus and *Endochironomus* were only collected at cool sites, species
of these genera have been found to be tolerant of high temperatures.
This cold stenothermal fauna was limited to sites representing observed
thermal extremes of 0 to 26°C at Ringling, 0 to 16°C at Norris and 10
to 17°C at Potosi. A further subdivision of this group revealed that
the majority of the cold stenotherms were restricted to the coldest
sites at each study area. This further restricts the temperature
ranges inhabited by most of the cold stenotherms to observed extremes

of 0 to 22.5°C at Ringling, 0 to 10°C at Norris and 10 to 13°C at Potosi.

Another group of taxa appeared to be restricted to intermediate thermal sites. At Ringling and Potosi, the majority of these taxa were found at the first level of temperature increase over the coldest sites present. This slight elevation in temperature may provide a niche for a unique thermal community. Two species of caddis, *Hydropsyche* sp. C and *Heliopsyche borealis*, were limited to intermediate temperatures. *Hydropsyche* has been known to thrive at elevated temperatures (Roback 1962) while *H. borealis* has been collected in hot spring effluents (Brues 1924) and at temperatures as high as 35°C (Roback 1962). The chironomid *Polypedilum* occurred only at Sites 6 and 7 at Ringling, Sites 3 and 2 at Norris and Sites 3, 4 and 5 at Potosi. This genus has been known to be intolerant of temperatures below 4.4°C (Curry 1962) and may require the elevated temperatures of these sites.

No taxa were found to be unique to Site 1 at Ringling or Potosi or Site 3 at Norris. These sites represent the first mixing and cooling points of the three hot springs but do no appear to provide a unique ecological niche for the benthic fauna.

Most of the taxa collected during the study were considered to be eurythermal. Some of these taxa exhibited an ability to inhabit thermal extremes of 0 to 40°C. These extremely tolerant forms included the chironomids *Conchapelopia* and *Eukiefferiella*; the tubificids *L.*

hoffmeisteri and *P. ferox;* and the snails *Physa* and *Lymnaea.* All of
these forms have been known to tolerate a wide range of temperatures
as well as other environmental conditions. The majority of the eury-
thermal forms were more restricted to thermal extremes of 0 to a
30-36°C range. Although most north temperate mayflies are considered
to be cool or cold water forms; *T. minutus, C. albiannulata, C.
simulans* and *E. inermis* were included in this broadly tolerant group.
Brues (1932) collected two other mayfly genera, *Baetis* and *Lepto-
phlebia,* at temperatures of 32.8 and 33.0°C. Several caddis genera
(e.g., *Hydropsyche, Cheumatopsyche* and *Brachycentrus*) were included
in this tolerant grouping. Roback (1962) found most species of
Hydropsyche and *Cheumatopsyche* to be tolerant of temperatures to 35°C
while *Brachycentrus* was not found above 28°C. The majority of the
chironomid genera exhibited a broad range of thermal tolerance.
Most chironomids have been found to exhibit a range of tolerance of 0
to 32°C while some of the genera collected in the present study (e.g.,
Procladius, Cryptochironomus, Paratendipes and *Cricotopus*) have been
known to tolerate temperatures as high as 34 to 40°C (Curry 1962).

The selection of sites at approximately 5°C increments within the
thermal gradients did not reveal communities unique to each sample
site. The data suggest, however, that at least four major communities
were found in the thermal gradients. The two largest communities, the
eurythermal and cold stenothermal faunas, could probably be further

subdivided on the basis of temperature range. The hot and intermediate

stenothermal groups may be true examples of uniquely thermal communi-

ties. Armitage (1961) investigated the thermal responses of 32 taxa

from the Firehole River and concluded that three basic communities

were present. The taxa were categorized as exhibiting a cold prefer-

ence, a warm preference or no preference within the thermal gradient.

In a comparison of a heated and cold riffle in the Gibbon River,

Vincent (1966) found 41 of 54 taxa common to both riffles while nine

were found only in the cold riffle and four were unique to the heated

riffle.

Analysis of frequency of occurrence data was most useful in

determining patterns of thermal preference for eurythermal taxa.

Results revealed four patterns of response within the eurythermal

forms. A method of faunal classification that used relative average

weights, rather than frequencies of occurrence, was employed by

Armitage (1961) on the Firehole River. This method revealed similar

groupings with the exception that the largest group in the present

study, forms that occurred with the highest frequency at intermediate

temperatures, was not observed by Armitage.

Comparison Of Sites Within The Thermal Gradients

A comparison of thermal sites utilizing an index of similarity

indicated that strong faunal zonation did not occur at the approximate

5°C increment. This was reflective of the dominance of eurythermal

forms at Ringling and Potosi. A subtle zonation was evidenced through the various alliances of sites closest in temperature, e.g., Sites 1 and 6 at Ringling. The strongest points of differentiation occurred between the hottest sites capable of supporting macroinvertebrate communities and all other sites. Jones (1967) used a coefficient of similarity (C) to compare stations in the Firehole River and found that all stations except those above 43°C exhibited a high degree of similarity. Langford and Aston (1972) found no change in diversity up to 28°C in a series of stations within a power plant effluent. Other researchers have determined that normal invertebrate communities can exist at temperatures up to 32°C in north temperate streams (Bush et al. 1974, Coutant 1962).

Another point of differentiation occurred at Norris between Site 3 and all other sites. The lack of similarity between this site and the cooler sites is attributable to the dominance of cold stenothermal forms at Norris.

Potosi resembled Ringling in that most of the sites were found to bear a close similarity to each other; however, in contrast with Ringling, it was the coolest, rather than the hottest, site that was differentiated from the others. This may be due to the near constant temperatures present at Potosi or the adaptation of a more thermally acclimated fauna.

Both Sites 2 and 8 at Ringling were more similar to Site 1 than

Sites 6 and 7. This apparent contradiction may be due to drift into

Site 1 from cooler areas upstream. Invertebrate drift has been shown

to interact with or be influenced by temperature. Some studies have

shown a positive correlation between temperature and drift (Bisson

and Davis 1976, Waters 1968) while others have found a negative corre-

lation (Pearson and Franklin 1968). Durrett and Pearson (1975) indi-

cated that drift may have a method of thermal avoidance in a power

plant effluent channel. In contrast with the above information,

several studies have found that temperature had little or no effect on

invertebrate drift (Bishop and Hynes 1969, Cloud and Stewart 1974,

Reisen and Prins 1972, Wojtalik and Waters 1970).

Comparison Of The Thermal Gradients

Some physical and temporal differences existed between the three

study areas that may help to explain some of the faunal differences

that were observed. The spring at Norris produced a small easily

avoided plume into Hot Spring Creek whereas the heated gradients pro-

duced at Ringling and Potosi were quite large relative to the study

areas. Another point of difference concerns the observed stability of

temperatures at Potosi while sites at Ringling and Norris were subject

to a seasonal range in thermal regime that increased with the distance

of the site from the hot spring source. Finally, the man-made spring

at Ringling had been producing a thermal gradient for 45 years whereas

the Norris and Potosi gradients had been produced for long periods of time.

Ringling and Potosi were dominated by eurythermal forms while Norris was dominated by the cold stenothermal fauna. This was supported by the high degree of similarity found between most stations at Ringling and Potosi while the cold stations at Norris bore little similarity to Site 3 at the head of the thermal plume. This suggests a strategy of thermal avoidance, rather than adaptation, on a community level. This suggestion is supported, in part, by the responses of several taxa common to two or all three study areas. Nine of the taxa that were classified as cold stenotherms at Norris were found to be eurythermal at Ringling or Potosi. Some of these different responses could be due to species differences when the generic level was treated in the comparison.

A major difference between Ringling and Potosi was observed in the similarity of Site 2 at Potosi to most other sites and the lack of similarity of Site 3 at Ringling to all other sites. These two sites had similar mean temperatures. Conversely, the coolest site at Potosi was sharply differentiated from others within the plume while the upper and lower cold sites at Ringling were quite similar to other sites in the plume. This may be a function of the time required for a community to fully adapt to high temperatures. It is possible that 45 years is not enough time for the adaptation of a large community at Site 3 at

Ringling. It is also possible, however, that these differences are due to the thermal stability or the different water chemistry of the sites at Potosi.

Several taxa common to Ringling and Potosi showed different thermal responses that support these assumptions. *Microcylloepus pusillus*, *Rheotanytarsus*, *Hyalella azteca* and *Limnodrilus udekemianus* were all capable of inhabiting Site 2 at Potosi but were absent from Site 3 at Ringling. Nebecker and Lemke (1968) suggested that longer adaptation time at high temperatures would raise the 96 hr TLm values for many species. Martin and Gentry (1974) found that *Libellula* nymphs collected from a thermal effluent exhibited a significantly higher Critical Thermal Maximum (CTM) and Lethal Temperature (LT) than nymphs of the same genus from a control stream.

Total Numbers Of Invertebrates

Numbers of invertebrates in the Ringling and Norris riffle samples were strongly depressed as temperature increased. Similar numerical depressions at high temperatures were observed by Coutant (1962) and Masengill (1976) in power plant effluents. Contrasting data was presented by Benda and Proffitt (1974), Dahlberg and Conyers (1974), Howell and Gentry (1974) and Vincent (1966) who found numerical increases at higher temperatures.

Samples from pools at Ringling and Norris and the samples from Potosi did not reveal as strong a numerical reduction with temperature

increase as was revealed in the riffle samples. This may be reflective of the apparent higher thermal tolerance of inhabitants of slower flowing waters (Wurtz 1969).

Despite faunal similarities between the upper and lower cold sites at Ringling, large numerical differences existed between the two. The mean number of organisms per sample from Site 2 places it mid-way between Sites 1 and 6 rather than equal to Site 8 as might be expected. This is possibly due to chemical enrichment from the hot spring and/or physical differences such as stream size and flow.

Population estimates of the invertebrate communities of Ringling, Norris and Potosi were made by putting the mean number of invertebrates per sample on a per square meter basis (Table 26). Riffle populations

Table 26. Mean numbers* of invertebrates per m^2 at Ringling, Norris and Potosi.

Sample Site	3	1	6	7	8	2
Ringling Surber	1032	2221	4867	11570	15110	3674
Ringling Ekman	972	1883	2361	3474	2872	2997
Sample Site	6	5	3	2	1	4
Norris Surber	4	10	263	348	3675	4371
Norris Ekman	13	4	2765	1849	1905	1647
Sample Site	2	1	3	4	5	
Potosi Edman	1699	959	882	1570	1324	

* rounded to the nearest whole number

of 11,570 and 15,110 invertebrates per square meter at Sites 7 and 8

at Ringling can be compared with Baril's (1977) estimate of 6,007 per

m^2 on Rosebud Creek which was believed to be rich in invertebrate

numbers when compared with other Montana streams.

Numbers Of Taxa Present

The mean numbers of taxa per sample were generally depressed as

temperature increased. A similar negative correlation between numbers

of taxa and temperature was observed by Coutant (1962) in a series of

samples taken at 5°F (2.8°C) increments in the Delaware River. Howell

and Gentry (1974) observed an increase in species diversity as tempera-

ture decreased. Hopwood (1974), however, found no difference in

numbers of taxa between cold stations and stations within a thermal

plume in the Mississippi Rover.

Abundance At The Ordinal Level

Most of the major orders demonstrated a negative numerical

response to temperature. Exceptions were shown by the Coleoptera,

Pulmonata and Haplotaxida which increased in number with temperature.

Howell and Gentry (1974) found that numbers of Ephemeroptera,

Plecoptera and Trichoptera decreased while numbers of Diptera

increased with temperature in a thermal plume. Hopwood (1974) found

that Ephemeroptera and Diptera responded negatively to temperature

while Trichoptera numbers increased as temperature increased. Vincent

(1966) found numbers of Ephemeroptera and Coleoptera to be highest in

a cold riffle while numbers of Diptera increased in a heated riffle
and Plecoptera numbers remained about the same in both riffles in the
Gibbon River. Masengill (1976) found that oligochaetes increased in
number as temperature increased in a thermal plume in the Connecticut
River. This variability of response at the ordinal level may be indica-
tive of the varying thermal regimes of the various areas that were
studied or may indicate that the ordinal level is not fine enough to
detect thermal effects because of the variable thermal tolerances of
the genera and species within an order.

Abundance At The Genus-Species Level

Most of the taxa that showed significantly different mean numbers
at Ringling and Potosi reached maximum abundance at intermediate or
high temperatures while the majority at Norris were most abundant at
low temperatures. This would suggest a better thermal adaptation at
Ringling and Potosi and thermal avoidance at Norris.

With few exceptions, patterns of abundance followed patterns
previously established by frequency of occurrence analysis.
Cheumatopsyche, *Baetis* sp. B, *Dicrotendipes* and *Peloscolex ferox*
deviated from this trend and achieved their maximum abundance at inter-
mediate temperatures. This is probably indicative of a range of
thermal optimum within a broader range of thermal tolerance.

Correlation coefficients confirmed patterns of abundance estab-
lished by the site means for those taxa that achieved maximum

abundance at low or high temperatures. All of the taxa that achieved their maximum numbers at intermediate temperatures were found to be correlated in a weakly negative manner with temperature. This is indicative of a greater abundance at the lower rather than the higher extremes and can probably be viewed as a more rapid numerical decline at supra-optimal rather than sub-optimal temperatures.

Several taxa reached maximum abundance at high temperatures suggesting a high thermal optimum. *Procladius* and *Cladotanytarsus* have been known to exhibit a high thermal tolerance (Curry 1962). *Limnodrilus hoffmeisteri* has been observed to be the most numerous organism in the hottest sites in power plant effluents (Langford and Aston 1972, Masengill 1976). *Physa* was observed to increase with temperature in the Firehole River (Jones 1976) and was found to be one of the most important trout foods in a heated section of the same stream by Kaeding (1976).

Three species of *Hydropsyche* reached maximum numbers at lower temperatures. This genus has been known to be tolerant of high temperatures (Roback 1962) and was one of the numerically dominant organisms collected in a thermal plume in the Mississippi River (Hopwood 1974). This apparent contradiction is probably due to species differences within the genus.

Maximum abundance at intermediate temperatures was observed for several species of mayflies. Baril (1977) found three of these species;

Choroterpes albiannulata, Tricorythodes minutus and *Caenis simulans,*
to be capable of withstanding extreme conditions of slow flows, high
turbidity and high summer temperatures in Rosebud Creek. *Cheumatopsyche*
also reached maximum abundance at intermediate temperatures. This
genus has been found to be tolerant of high temperatures as well as
a wide range of other physical and chemical conditions (Roback 1962).

Seasonal Variations

Both water temperature and macroinvertebrate abundance fluctuate
on a seasonal basis. The multifactor analysis of variance that was
utilized partitioned variation due to season, temperature and the inter-
action between the two. The effect of the interaction on macroinverte-
brate abundance is difficult to interpret since no interaction means
can be calculated. An example of an interaction is presented (Figure
12) and shows that mean numbers of taxa do not respond the same to
levels of one factor (temperature) when taken over all levels of the
other factor (season). The mean number of taxa increased between the
fall and winter samples for Sites 6 and 7 at Ringling while the number
of taxa at Site 8 underwent a drastic reduction in the same period. A
significant interaction in the present study could be interpreted as
a disruption in the normal patterns of seasonal abundance by tempera-
ture. The interaction between temperature and season was found to
significantly effect total numbers of invertebrates, numbers of taxa
present, and abundance at the ordinal and genus-species levels.
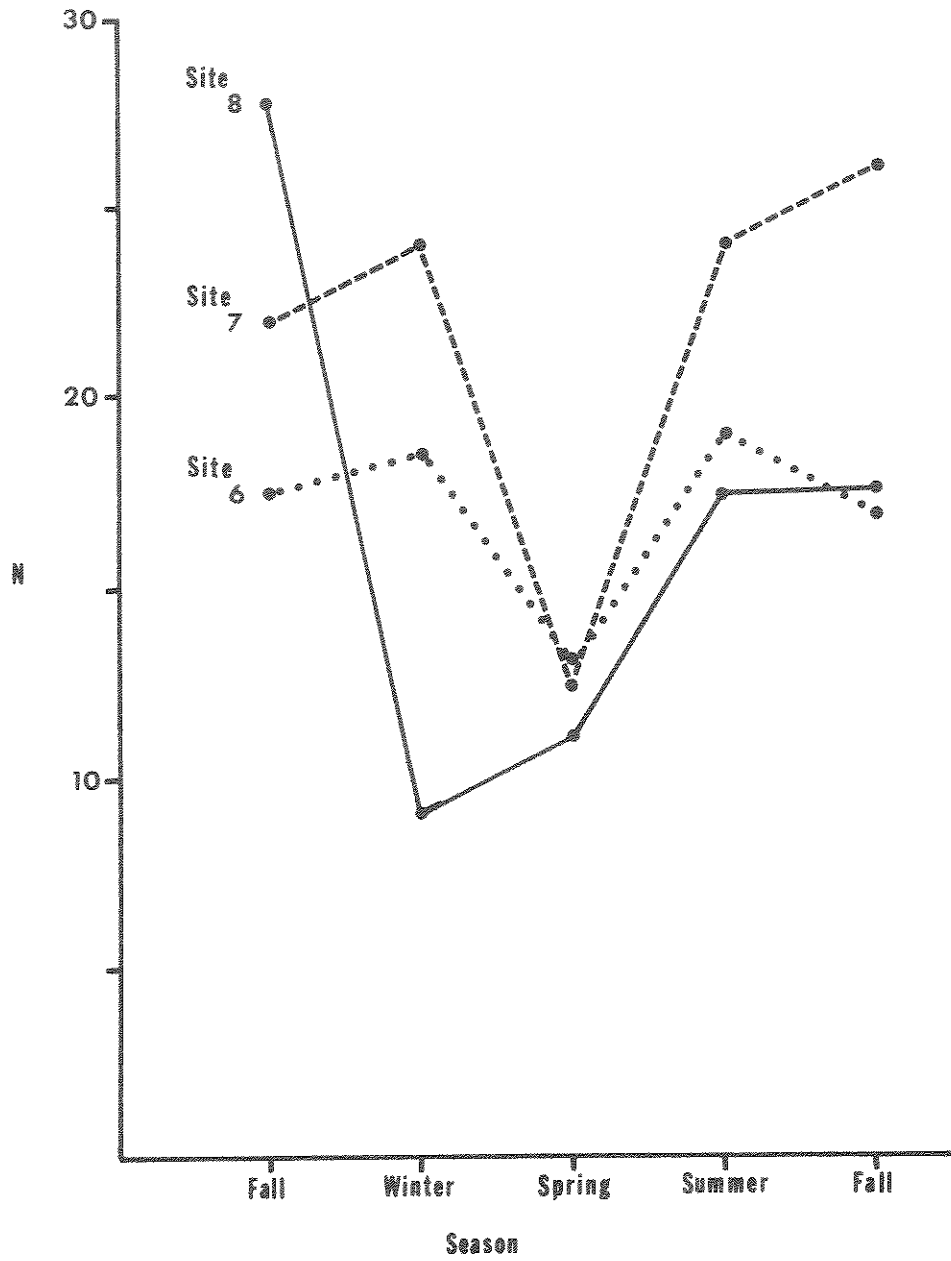
Figure 12. Interaction between temperature and season as it affects number of taxa per sample (N) collected from selected sites at Ringling.

Seasonal variation has been observed in the qualitative and quantitative recovery of invertebrate populations during the winter in thermal plumes. Coutant (1962), Masengill (1976) and Trembley (1962) noted such recoveries in power plant effluents. Winter correlation coefficients, with the exception of the Norris Ekman samples, do not indicate such recovery for the total number of invertebrates or the number of taxa present. This may be a function of the distance between cold and heated sites at Ringling, extreme thermal differences between cold stations upstream and stations in the plumes at Ringling and Norris or the thermal stability of the Potosi sites.

The previously mentioned winter reduction in taxa at Site 8 at Ringling was accompanied by a reduction in total number of invertebrates. These reductions were observed only in the riffle samples and not in those from the pool. These changes were believed to be the result of frazil or slush ice which was observed moving through the riffle on several occasions during the winter of 1974-1975. A similar reduction of a riffle population by frazil and anchor ice was observed by Reimers (1957) and Vincent (1966). Benson (1955) observed entrapment and movement of invertebrates in anchor ice but did not think that numbers were large enough to significantly alter a riffle population.

Standing Crop (Biomass)

The relative productive capacities of stations within the thermal gradient at Ringling were estimated, in part, through the calculation of standing crop as mean biomass per sample. Biomass was found to be substantially increased as temperature decreased. The spring samples provided an exception to this trend with a positive correlation. This was due to an abnormally high biomass present at Site 3 as a result of a large population of gastropods. Similar negative correlations of biomass with temperature were observed by Bisson and Davis (1976) and Coutant (1962). Contrasting data was presented, however, by Armitage (1958) and Vincent (1966) who found that biomass increased with temperature. Although Armitage did find a positive correlation between biomass and temperature (+.386), the correlation was not significant. He did, however, find a highly significant correlation (+.839) between biomass and alkalinity.

Differences in standing crops over an interval of time have been used as indices of animal production (Cummins 1972). Armitage (1958) believed that the difference between minimum and maximum standing crop was indicative of the minimum production over that period of time. It is believed, however, that animal standing crop is relatively constant over a long period of time and that rates of assimilation and exchange between trophic levels and turnover times of various components are the critical factors in stream production (Cummins 1972). Thus, the

smaller standing crops at higher temperatures are not necessarily an indication that production is higher at the cooler sites.

Colonization Rates

Macroinvertebrate numbers and biomass were related to the rate of deposition or colonization on denuded Hester-Dendy artificial sub-strates. Investigations have related the colonization of artificial substrates with time, thus putting standing crop on a rate related basis. Sheldon (1977) found rate of colonization to fit a power function and found it to be correlated more often with time than with other factors. Nilsen and Larimore (1973) found that colonization rates for both number and weight followed a sigmoidal curve which began with a lag phase of about two weeks, a rapid exponential growth period of about two weeks and a leveling off at about four to six weeks after the carrying capacity or an equilibrium condition was reached. If the assumption is made that the mechanisms of colonization such as direct transport or drift (Waters 1968) are in operation at an equal level throughout the colonization period, then the lag and subsequent rapid growth phases should be related to the acceptability of the sampler as a colonizable substrate. A further assumption could be made that the criteria for the acceptability of a bare substrate for macroinverte-brate colonization would be related to the growth of bacteria, peri-phyton and filamentous algae and the subsequent entrapment of micro-organisms and detritus as a source of shelter and food. Williams

et al. (1977) found that recolonization of a substrate was accomplished, first, by detritivores, followed by periphyton grazers and predators and concluded that colonization was related to the accumulation of various types and sizes of food particles. In this manner, the colonization of bare artificial substrates was related to the productive capacity of a station at which it was placed provided it was harvested prior to equilibrium.

Despite negative correlations existing between standing crop and temperature, colonization rates of the plates were found to increase, up to a point, with temperature. Low colonization rates at Site 3 probably do not reflect the acceptability of the plates for colonization due to the low numbers of invertebrates present and the absence of taxa that showed a preference for the multiplate samplers. The high colonization rates at Sites 1 and 6 are probably indicative of a shorter time period required for the establishment of a suitable food supply for the invertebrates, and hence, a greater productive potential at the higher temperatures. Hopwood (1974) found that colonization rates of artificial substrates were changed enough by temperature to shift generic composition but statistical analysis showed no differences in the numerical rate of colonization between cold and heated sites.

Growth

Increased temperatures have been found to increase the growth rate of many larval insects. This relationship is based on a temperature summation theory in which a certain number of degree days above a temperature of zero growth are required for a larval insect to complete its development (Newell 1975). The temperature-growth relationship may be limited on the upper end by a temperature that is supra-optimal for growth due to the high caloric cost of maintenance (Nebecker 1971c, 1973). Increased larval growth rates may result in early emergence (Nebecker 1971a, Newell 1975) although some species have been found to have other methods for the sychronization of emergence (Lutz 1968, Nebecker 1971b). When early emergence accompanies increased larval growth rates, the result may be a bivoltine or multivoltine population of a species that is univoltine under normal conditions (Newell 1976). This shortened generation time can increase the productivity of a body of water (Nebecker 1971a).

Differences in growth were observed through an estimate of the mean weights of selected genera from the Ringling samples. This comparative method was based on the assumption that different mean weights between sites were indicative of a different timing in the sequence of generations or of different growth rates and thus related to different rates of secondary production. All of the investigated taxa exhibited different mean weights at different thermal sites with

most attaining maximum mean weights at the hotter sites; this suggests
that differences in production rate existed at the various tempera-
tures. The growth increment for the 10 taxa common to Sites 6 and 7
was found to be 11 times greater at Site 6 than at Site 7 between the
fall 1974 and winter samples. This indiates a higher rate of assimila-
tion, and hence, a higher rate of production at the warmer winter
temperatures of Site 6. Hopwood (1974) found higher mean weights in
a heated effluent than at cold stations, for selected invertebrate
groups in three of seven 35 day periods.

Thermal effects on growth were further investigated through
length frequency analysis. The presence of a full range of sizes,
including individuals that appeared near to emergence, of *Tricorythodes*
minutus and *Choroterpes albiannulata* at the warmer sites indicated
that rapid development was accompanied by a shortened generation time.
Newell (1976) found that *T. minutus* was bivoltine at colder study sites
while a population in a constant temperature spring was multivoltine.
Hyalella azteca exhibited a shift toward larger instars at higher
temperatures while *Cheumatopsyche* showed no shift in size at any
thermal site. This may indicate a strong thermal tolerance that was
previously demonstrated by its frequency of occurrence and percent
contribution responses. The three modes may be indicative of three
cohorts of a single species or three different species of the genus.

Results suggest that secondary production rates may be increased at higher temperatures at Ringling. Brock (1967) investigated primary production in a hot spring gradient that ranged from 30 to 70°C. He found that while standing crop was greatest at intermediate temperatures in the range under study, photosynthetic efficiency continued to increase as the temperature increased to 70°C. An increase in primary and secondary production at elevated temperatures may result in increased production at higher trophic levels. Kaeding (1976) theorized that large populations of molluscs, emerging insects and a general good food availability may have been responsible for better trout growth in a heated section than in cold water in the Firehole River.

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APPENDIX

Table 27. Mean daily maximum, minimum and median temperatures (°C)
per month and monthly maxima and minima measured from
February 1975 through January 1976 at Ringling.

SITE 3	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Maximum	35.0	36.0	34.0	37.0	37.0	41.0	40.0	43.0	35.0	34.0	34.0	35.0
Mean Maximum	34.0	34.1	33.7	33.0	34.7	38.7	40.2	39.2	34.4	33.5	33.5	34.1
Mean Median	32.4	32.5	32.0	32.1	33.4	37.2	37.1	37.6	33.4	32.0	32.0	32.2
Mean Minimum	30.7	30.9	30.3	31.2	32.0	35.7	35.0	36.0	32.4	30.4	30.4	30.2
Minimum	29.0	29.0	30.0	30.0	31.0	33.0	33.0	35.0	32.0	30.0	30.0	29.0
SITE 1												
Maximum	29.0	29.0	30.0	29.0	27.0	36.0	36.0	36.0	34.0	26.0	23.0	28.0
Mean Maximum	26.6	28.4	27.0	20.6	21.4	33.5	33.6	33.4	28.1	23.4	21.3	23.0
Mean Median	24.8	25.1	24.8	19.4	19.5	31.0	31.5	31.6	27.2	22.4	20.2	20.9
Mean Minimum	23.0	21.7	22.6	18.2	17.5	28.4	29.3	29.8	26.2	21.4	19.1	18.8
Minimum	21.0	19.0	20.0	17.0	10.0	26.0	26.0	27.0	23.0	15.0	17.0	14.0
SITE 6												
Maximum	19.0	22.0	23.0	24.0	23.0	32.0	32.0	32.0	26.0	20.0	18.0	21.0
Mean Maximum	16.4	19.3	20.4	15.7	16.5	28.3	29.4	27.7	22.1	18.2	15.5	15.8
Mean Median	13.9	17.0	18.0	13.9	14.4	26.2	27.2	24.7	21.0	16.9	14.2	13.8
Mean Minimum	11.3	14.7	15.6	12.0	12.2	24.1	25.0	21.7	19.8	15.6	12.9	11.7
Minimum	9.0	12.0	14.0	10.0	6.0	20.0	22.0	20.0	16.0	11.0	10.0	9.0
SITE 7												
Maximum	14.0	15.0	17.0	20.0	21.0	27.0	28.0	28.0	19.0	14.0	14.0	12.0
Mean Maximum	11.3	12.6	14.0	12.8	13.0	23.9	23.7	20.1	13.8	10.0	8.4	8.7
Mean Median	8.6	9.7	12.2	10.6	12.0	21.3	21.0	17.0	12.7	8.6	6.9	6.7
Mean Minimum	5.9	6.8	10.4	8.4	11.0	18.7	18.3	13.8	11.5	7.1	5.4	4.7
Minimum	4.0	5.0	9.0	7.0	5.0	15.0	17.0	14.0	8.0	5.0	2.0	3.0
SITE 8												
Maximum	7.0	10.0	12.0	17.0	18.0	21.0	22.0	23.0	14.0	10.0	9.0	7.0
Mean Maximum	4.3	7.0	9.0	11.4	11.1	18.6	18.0	16.2	8.9	4.3	4.0	3.9
Mean Median	3.2	5.3	7.3	9.5	9.6	16.4	16.6	14.7	7.7	3.4	3.2	2.8
Mean Minimum	2.1	3.6	5.5	7.6	8.0	14.2	15.2	13.1	6.4	2.5	2.4	1.6
Minimum	0.0	2.0	4.0	6.0	5.0	12.0	14.0	7.0	3.0	0.0	0.0	0.0
SITE 2												
Maximum	7.0	9.0	11.0	16.0	18.0	20.0	24.0	24.0	13.0	12.0	8.0	7.0
Mean Maximum	4.7	6.7	8.8	11.0	11.7	18.5	19.0	15.9	8.7	4.8	4.1	3.6
Mean Median	3.6	4.9	7.0	9.3	10.0	16.4	17.4	14.0	7.4	3.9	3.5	2.7
Mean Minimum	2.4	3.1	5.2	7.6	8.3	14.3	15.8	12.0	6.1	2.9	2.8	1.7
Minimum	1.0	2.0	4.0	6.0	6.0	12.0	12.0	7.0	3.0	1.0	0.0	1.0

Table 28. Taxa collected within the undiluted flows of the hot springs at temperatures above 30°C at Ringling, Norris and Potosi.

Collembola
  Isotomurus sp.*

Hemiptera
  Naucoridae
    Ambrysus heidemanni Montandon*a

Coleoptera
  Dytiscidae
    Agabus sp.*a
  Curculionidae*
  Elmidae
    Microcylloepus pusillus (LeConte)a

Diptera
  Chironomidae
    Conchapelopia
    Rheotanytarsus
    Acricotopus
    Eukiefferiella
    Lymnophyes
    Paraphaenocladius
    *Pseudosmittia**
  Ceratopogonidae
    *Atrichopogon**
    Tr. Stilobezziini

Stratiomyiidae
  Eulalia sp.a
  Stratiomyia sp.a
  Muscidae*

Haplotaxida
  Tubificidae
    Limnodrilus hoffmeisteri Claparede
    L. udekemianus Claparede
    Peloscolex ferox (Eisen)

Pulmonata
  Physidae
    *Physa*a
  Lymnaeidae
    *Lymnaea*a

Ostracoda
  Cypris sp.*a

Amphipoda
  Talitridae
    Hyalella azteca (Saussure)a

* collected only at temperatures above 30°C
a also collected in hot springs by other researchers

Table 29. Genus-species frequency of occurrence (X 100) in pooled samples collected by all sampling methods at thermal levels composed of sample sites at Ringling, Norris and Potosi with similar temperature regimes.

	Thermal Levels*					
	1	2	3	4	5	6
Collembola						
Isotomurus sp.	0.0	0.0	–	0.0	1.4	0.0
Ephemeroptera						
Ameletus cooki	3.1	0.0	–	0.0	0.0	–
Baetis sp. A	28.1	41.1	35.0	7.1	0.0	0.0
Baetis sp. B	1.6	31.3	25.0	0.0	0.0	0.0
Callibaetis sp.	1.6	3.1	0.0	0.0	0.0	0.0
Choroterpes albiannulata	29.7	32.8	34.4	18.8	0.0	0.0
Paraleptophlebia heteronea	25.0	25.0	–	12.5	0.0	–
Ephemerella grandis	3.1	0.0	–	0.0	0.0	–
E. inermis	56.3	37.5	–	31.3	0.0	–
E. infrequens	1.6	9.4	0.0	0.0	0.0	0.0
Tricorythodes minutus	19.2	26.8	27.5	5.3	0.0	0.0
Caenis simulans	31.3	40.6	40.6	25.0	0.0	0.0
Odonata						
Erythemis sp.	0.0	37.5	0.0	12.5	0.0	–
Ophiogomphus spp.	17.3	14.3	27.5	17.5	0.0	0.0
Aeschna umbrosa	3.1	6.3	0.0	0.0	0.0	0.0
Argia sp.	0.0	25.0	0.0	12.5	0.0	–
Ischnura spp.	12.5	21.9	6.3	18.8	0.0	0.0
Plecoptera						
Nemoura sp.	12.5	0.0	0.0	0.0	0.0	–
Pteronarcella badia	62.5	0.0	–	6.3	0.0	–
Arcynopteryx sp.	25.0	0.0	–	0.0	0.0	–
Diura knowltoni	37.5	12.5	–	0.0	0.0	–
Isoperla fulva	81.3	31.3	–	0.0	0.0	–
Hemiptera						
Hesperocorixa laevigata	1.0	0.0	0.0	0.0	0.0	0.0
Sigara omani	0.0	6.3	–	0.0	0.0	–
Ambrysus heidemanni	0.0	12.5	0.0	12.5	12.5	0.0

Table 29 (continued).

	Thermal Levels*					
	1	2	3	4	5	6
Trichoptera						
Helicopsyche borealis	7.7	17.9	2.5	5.4	0.0	0.0
Polycentropus sp.	12.5	15.6	9.4	6.3	0.0	0.0
Cheumatopsyche spp.	58.3	60.0	50.0	55.0	0.0	0.0
Hydropsyche sp. A	32.5	40.0	35.0	0.0	0.0	0.0
Hydropsyche sp. B	17.5	10.0	20.0	5.0	0.0	0.0
Hydropsyche sp. C	2.5	0.0	25.0	0.0	0.0	0.0
Hydropsyche sp. D	21.9	12.5	–	12.5	0.0	–
Hydroptila spp.	10.9	6.3	9.4	6.3	0.0	0.0
Oxyethira sp.	0.0	12.5	0.0	12.5	0.0	0.0
Chimarra sp.	3.1	0.0	0.0	0.0	0.0	–
Oecetis sp.	3.1	0.0	0.0	0.0	0.0	0.0
Brachycentrus sp.	53.1	25.0	–	12.5	0.0	–
Micrasema sp.	15.6	12.5	–	6.3	0.0	–
Hesperophylax sp.	4.7	0.0	0.0	0.0	0.0	0.0
Coleoptera						
Agabus sp.	0.0	0.0	0.0	0.0	3.1	0.0
Deronectes sp.	6.3	0.0	0.0	0.0	0.0	0.0
Hydroporus sp.	1.6	0.0	0.0	0.0	0.0	0.0
Helophorus sp.	1.6	3.1	0.0	0.0	0.0	0.0
Tropisternus sp.	0.0	0.0	0.0	12.5	0.0	0.0
Curculionidae	0.0	0.0	0.0	6.3	3.1	0.0
Dubiraphia minima	43.8	50.0	46.9	59.4	0.0	0.0
Microcylloepus pusillus	13.9	65.0	52.5	17.5	15.0	0.0
Optioservus quadrimaculata	35.4	14.6	21.9	16.7	0.0	0.0
Zaetzevia parvula	1.6	6.3	0.0	0.0	0.0	0.0
Haliplus sp.	9.4	3.1	0.0	12.5	0.0	0.0
Diptera						
Dicranota spp.	3.1	4.2	0.0	2.1	0.0	0.0
Hexatoma spp.	43.8	18.8	12.5	0.0	0.0	0.0
Tipula sp. A	1.6	0.0	0.0	0.0	0.0	0.0
Tipula sp. B	3.1	0.0	0.0	0.0	0.0	0.0
Tipula sp. C	21.9	12.5	6.3	0.0	0.0	–
Telmatoscopus sp.	0.0	12.5	6.3	0.0	0.0	–
Aedes sp.	0.0	0.0	3.1	0.0	0.0	0.0
Simulium spp.	38.5	33.9	27.5	12.5	0.0	0.0
Conchapelopia spp.	29.8	37.5	60.0	33.9	6.9	0.0
Procladius spp.	8.3	10.4	12.5	8.3	0.0	0.0

Table 29 (continued).

	Thermal Levels*					
	1	2	3	4	5	6
Diamesa spp.	23.1	16.1	0.0	10.7	0.0	0.0
Odontomesa sp.	34.3	31.3	–	43.8	0.0	–
Chironomus spp.	5.2	2.1	0.0	0.0	0.0	0.0
Cladopelma sp.	0.0	6.3	0.0	0.0	0.0	0.0
Cladotanytarsus spp.	8.3	2.5	15.0	17.5	0.0	0.0
Cryptochironomus spp.	8.3	4.2	12.5	14.6	0.0	0.0
Dicrotendipes sp.	31.3	28.1	21.9	21.9	0.0	0.0
Endochironomus sp.	6.3	0.0	0.0	0.0	0.0	0.0
Micropsectra spp.	45.2	26.8	47.5	35.7	0.0	0.0
Microtendipes sp.	43.8	12.5	–	18.8	0.0	0.0
Paratendipes sp.	17.2	15.6	25.0	12.5	0.0	0.0
Phaenopsectra sp.	2.1	4.2	0.0	0.0	0.0	0.0
Polypedilum spp.	3.8	10.7	12.5	1.8	0.0	0.0
Rheotanytarsus spp.	47.2	62.5	65.0	42.5	5.0	0.0
Stictochironomus sp.	3.1	0.0	0.0	0.0	0.0	0.0
Tanytarsus spp.	1.0	1.8	0.0	3.6	0.0	0.0
Acricotopus sp.	3.1	0.0	6.3	8.3	1.6	0.0
Cricotopus spp.	26.0	26.8	27.5	30.4	0.0	0.0
Eukiefferiella spp.	2.9	17.9	5.0	10.7	2.8	0.0
Hydrobaenus sp.	25.0	0.0	0.0	0.0	0.0	–
Lymnophyes sp.	0.0	0.0	–	0.0	12.5	–
Orthocladius spp.	39.6	39.6	18.8	35.4	0.0	0.0
Paraphaenocladius sp.	0.0	0.0	0.0	0.0	0.0	3.1
Pseudosmittia sp.	0.0	0.0	0.0	0.0	6.3	0.0
Alluaudomyia sp.	0.0	3.1	0.0	0.0	0.0	0.0
Atrichopogon sp.	0.0	0.0	0.0	0.0	25.0	–
Tr. *Stilobezziini*	12.5	22.5	12.5	7.5	5.0	0.0
Eulalia sp.	0.0	0.0	0.0	12.5	3.1	0.0
Stratiomyia sp.	0.0	0.0	0.0	2.5	10.0	0.0
Chrysops spp.	10.4	4.2	6.3	6.3	0.0	0.0
Tabanus sp.	0.0	3.1	0.0	0.0	0.0	0.0
Hydrophorus sp.	1.6	0.0	0.0	0.0	0.0	0.0
Empididae	5.2	12.5	0.0	0.0	0.0	0.0
Muscidae	0.0	0.0	0.0	0.0	6.3	0.0
Limnophora aequifrons	4.2	2.1	0.0	0.0	0.0	0.0
L. torreyae	0.0	0.0	3.1	0.0	0.0	0.0
Notiphila sp.	0.0	3.1	0.0	0.0	0.0	0.0

Table 29 (continued).

	Thermal Levels*					
	1	2	3	4	5	6
Haplotaxida						
Eiseniella tetraedra	1.4	20.8	6.3	2.1	0.0	0.0
Limnodrilus claparedianus	9.7	2.5	0.0	0.0	0.0	0.0
L. hoffmeisteri	15.6	35.4	18.8	47.9	20.8	0.0
L. spiralis	25.0	0.0	0.0	0.0	0.0	–
L. udekemianus	5.7	8.9	2.5	1.8	2.8	0.0
Limnodrilus spp. (immatures)	32.7	21.4	0.0	17.9	0.0	0.0
Peloscolex ferox	28.8	25.0	17.5	32.1	2.8	0.0
Ophidonais serpentina	3.8	5.4	7.5	1.8	0.0	0.0
Hirudinea						
Dina anoculata	1.0	0.0	0.0	3.6	0.0	0.0
Helobdella stagnalis	1.0	5.4	0.0	0.0	0.0	0.0
Hydracarina						
Sperchon sp.	6.3	0.0	0.0	0.0	0.0	0.0
Pulmonata						
Physa spp.	30.8	30.4	45.0	42.9	22.0	0.0
Lymnaea spp.	9.4	3.1	0.0	3.1	12.5	0.0
Gyraulus sp.	0.0	3.1	3.1	0.0	0.0	0.0
Heterodonta						
Pisidium spp.	19.2	5.4	0.0	5.4	0.0	0.0
Ostracoda						
Cypris sp.	0.0	0.0	0.0	0.0	12.5	0.0
Iliocypris sp.	50.0	12.5	0.0	0.0	0.0	–
Amphipoda						
Hyalella azteca	22.1	37.5	40.0	25.0	2.8	0.0
Gammarus lacustris	6.3	0.0	0.0	0.0	0.0	0.0

*Thermal Level 1 = Sites 2 and 8 Ringling, 1 and 4 Norris and 5 Potosi
          2 = Sites 7 Ringling, 2 Norris and 4 Potosi
          3 = Sites 6 Ringling and 3 Potosi
          4 = Sites 1 Ringling, 3 Norris and 1 Potosi
          5 = Sites 3 Ringling, 5 and 6 Norris and 2 Potosi
          6 = Site 4 Ringling

Table 30.   Mean genus-species number and percent contribution per bottom sample at Ringling, Norris and Potosi, with the results of multifactor analysis of variance.

		Sample Sites					Analysis of Variance		
Ringling, Surber	3	1	6	7	8	2	Date	Site	Date x Site
EPHEMEROPTERA									
Baetis sp. A	0.0	0.0	9.8	20.8	52.7	2.2	HS	HS	S
	(0.0)	(0.0)	(2.0)	(1.6)	(5.4)	(0.5)	HS	HS	HS
Baetis sp. B	0.0	0.0	2.6	7.5	1.0	0.0	HS	HS	S
	(0.0)	(0.0)	(0.4)	(0.5)	(0.4)	(0.0)	HS	HS	HS
Caenis simulans	0.0	0.7	1.7	2.7	25.3	15.9	S	NS	NS
	(0.0)	(0.3)	(0.3)	(0.3)	(0.8)	(4.2)	S	S	S
Choroterpes albiannulata	0.0	2.1	128.4	151.4	87.3	5.6	HS	HS	S
	(0.0)	(0.6)	(10.0)	(14.2)	(2.8)	(1.3)	HS	HS	HS
Tricorythodes minutus	0.0	0.3	59.4	133.3	60.2	0.1	HS	HS	HS
	(0.0)	(0.1)	(9.9)	(9.2)	(2.1)	(0.2)	HS	HS	HS
TRICHOPTERA									
Cheumatopsyche spp.	0.0	115.8	180.4	533.9	403.7	204.0	HS	HS	HS
	(0.0)	(32.7)	(29.2)	(37.2)	(18.9)	(48.3)	HS	HS	HS
Hydropsyche sp. A	0.0	0.0	4.3	15.2	203.7	1.1	HS	HS	HS
	(0.0)	(0.0)	(0.8)	(1.0)	(10.8)	(0.3)	HS	HS	HS
Hydropsyche sp. B	0.0	0.1	0.6	1.5	6.5	0.0	NS	HS	NS
	(0.0)	(0.04)	(0.6)	(0.2)	(0.4)	(0.0)	S	S	NS
COLEOPTERA									
Dubiraphia minima	0.0	5.5	2.5	2.1	0.6	26.0	HS	HS	HS
	(0.0)	(4.0)	(1.6)	(0.4)	(0.02)	(8.6)	HS	HS	HS
Microcylloepus pusillus	0.0	7.6	47.6	153.5	18.5	0.0	HS	HS	HS
	(0.0)	(8.5)	(8.3)	(15.3)	(0.7)	(0.0)	S	HS	S
Optioservus quadrimaculatus	0.0	7.6	2.3	1.3	8.9	13.2	HS	HS	HS
	(0.0)	(2.9)	(0.4)	(0.1)	(0.6)	(5.0)	S	HS	HS
DIPTERA									
Simulium spp.	0.0	4.3	2.6	3.9	148.8	11.4	NS	HS	S
	(0.0)	(5.2)	(2.7)	(0.3)	(15.0)	(2.8)	S	HS	HS
Conchapelopia sp.	0.0	4.5	7.9	1.5	7.5	2.4	HS	NS	S
	(0.0)	(2.0)	(1.4)	(0.3)	(0.3)	(0.5)	HS	HS	HS
Cricotopus spp.	0.0	15.9	29.8	9.9	27.5	10.0	HS	HS	HS
	(0.8)	(6.6)	(5.8)	(0.8)	(2.3)	(5.1)	HS	HS	HS
Diamesa spp.	0.0	1.0	0.0	1.0	9.1	1.0	HS	HS	HS
	(0.0)	(0.8)	(0.0)	(0.3)	(0.7)	(0.6)	HS	NS	NS
Micropsectra spp.	0.0	5.3	13.7	3.6	3.5	18.4	S	NS	S
	(0.0)	(2.3)	(2.5)	(0.3)	(0.4)	(5.6)	HS	HS	HS
Orthocladius spp.	0.0	4.2	10.8	12.2	122.4	6.2	HS	HS	HS
	(0.0)	(4.9)	(8.1)	(5.7)	(13.4)	(2.9)	HS	NS	S
Rheotanytarsus spp.	0.0	10.1	34.1	51.4	167.6	0.4	HS	HS	HS
	(0.0)	(4.5)	(7.1)	(3.9)	(5.2)	(0.1)	HS	HS	HS
OLIGOCHAETA									
Limnodrilus hoffmeisteri	9.7	7.0	1.2	0.6	0.0	0.0	NS	NS	NS
	(30.8)	(5.9)	(0.9)	(0.1)	(0.0)	(0.0)	S	HS	HS
Limnodrilus (immatures)	0.0	0.0	0.0	0.4	0.8	0.4	S	HS	HS
	(0.0)	(0.0)	(0.0)	(0.04)	(0.1)	(0.1)	S	S	HS
PULMONATA									
Physa spp.	79.6	6.0	6.2	6.8	2.4	18.2	HS	HS	HS
	(16.1)	(2.2)	(1.3)	(0.6)	(0.1)	(4.1)	HS	HS	HS
AMPHIPODA									
Hyalella azteca	0.0	10.0	4.4	2.3	34.1	6.5	HS	S	HS
	(0.0)	(4.7)	(0.7)	(0.5)	(1.2)	(1.5)	HS	HS	HS

Table 30 (continued).

Ringling, Ekman	Sample Sites						Analysis of Variance		
	3	1	6	7	8	2	Date	Site	Date x Site
EPHEMEROPTERA									
Caenis simulans	0.0	0.1	1.8	3.8	2.4	0.5	HS	S	HS
	(0.0)	(0.1)	(5.5)	(2.7)	(2.9)	(0.8)	HS	HS	HS
COLEOPTERA									
Dubiraphia minima	0.0	10.3	4.7	5.0	3.6	7.9	HS	NS	HS
	(0.0)	(24.5)	(14.3)	(5.0)	(4.5)	(11.7)	HS	S	HS
Microcylloepus pusillus	0.0	0.0	0.7	2.1	0.1	0.0	NS	HS	NS
	(0.0)	(0.0)	(2.3)	(3.4)	(4.4)	(0.0)	HS	HS	HS
DIPTERA									
Cladotanytarsus spp.	0.0	1.8	0.3	0.0	0.4	0.0	HS	HS	HS
	(0.0)	(3.4)	(3.5)	(0.0)	(2.7)	(0.0)	HS	S	HS
Conchapelopia sp.	0.0	0.7	2.8	9.9	0.4	0.4	HS	HS	HS
	(0.0)	(0.3)	(13.2)	(5.0)	(0.7)	(0.2)	HS	HS	HS
Cryptochironomus sp.	0.0	0.4	1.3	0.4	1.2	0.2	HS	NS	NS
	(0.0)	(8.6)	(2.5)	(2.1)	(3.2)	(0.3)	HS	HS	HS
Dicrotendipes sp.	0.0	0.9	5.6	7.5	0.9	2.1	HS	HS	HS
	(0.0)	(1.6)	(12.3)	(5.8)	(16.1)	(1.3)	HS	HS	HS
Micropsectra spp.	0.0	0.7	2.3	3.6	8.3	9.6	HS	HS	HS
	(0.0)	(2.1)	(4.5)	(5.8)	(12.5)	(5.9)	S	HS	S
Paratendipes sp.	0.0	1.5	23.3	7.2	7.1	3.7	HS	HS	HS
	(0.0)	(18.0)	(27.4)	(27.1)	(15.0)	(9.1)	HS	S	HS
Rheotanytarsus spp.	0.0	0.1	0.3	1.7	0.9	0.2	HS	HS	HS
	(0.0)	(0.1)	(0.9)	(3.3)	(1.3)	(0.1)	HS	NS	NS
OLIGOCHAETA									
Limnodrilus hoffmeisteri	1.5	0.8	1.0	0.6	1.3	4.4	HS	HS	HS
	(32.1)	(14.9)	(1.9)	(2.7)	(2.7)	(9.2)	HS	HS	HS
Limnodrilus (immatures)	0.0	0.0	0.0	0.0	14.6	2.3	HS	HS	HS
	(0.0)	(0.0)	(0.0)	(0.0)	(12.6)	(4.5)	HS	HS	HS
Peloscolex ferox	0.3	1.8	4.9	1.4	1.1	14.3	S	HS	NS
	(0.8)	(4.6)	(9.7)	(5.6)	(1.1)	(18.0)	S	HS	S
PULMONATA									
Physa spp.	3.1	11.1	0.0	0.1	0.1	0.6	S	NS	HS
	(13.9)	(9.1)	(0.0)	(1.4)	(0.1)	(9.3)	NS	NS	S
AMPHIPODA									
Hyalella azteca	0.0	1.3	0.0	23.2	5.2	0.1	HS	HS	HS
	(0.0)	(0.8)	(0.0)	(16.6)	(6.4)	(0.1)	HS	HS	HS

Norris, Surber	Sample Sites								
	3	2	1	4					
PLECOPTERA									
Diura knowltoni	0.0	0.4	1.1	1.0			NS	NS	NS
	(0.0)	(0.8)	(0.6)	(0.7)			NS	NS	NS
Isoperla fulva	0.0	1.0	7.8	19.4			HS	HS	HS
	(0.0)	(3.6)	(3.0)	(5.3)			NS	HS	HS
Pteronarcella badia	0.0	0.6	3.4	5.0			HS	HS	HS
	(0.0)	(1.0)	(1.3)	(1.1)			NS	NS	NS
EPHEMEROPTERA									
Baetis sp. A	0.1	1.3	2.1	2.9			NS	NS	NS
	(0.7)	(2.1)	(0.4)	(1.9)			S	NS	NS
Ephemerella inermis	1.3	4.4	49.8	39.0			NS	HS	NS
	(8.5)	(11.7)	(16.6)	(11.5)			HS	NS	NS
Paraleptophlebia heteronea	0.3	1.1	6.1	7.8			HS	HS	HS
	(0.6)	(1.9)	(1.0)	(1.5)			HS	NS	NS
Tricorythodes minutus	0.0	0.0	1.8	1.0			NS	NS	NS
	(0.0)	(0.0)	(0.2)	(0.9)			NS	NS	NS

Table 30 (continued).

	Sample Sites					Analysis of Variance		
Norris, Surber	3	2	1	4		Date	Site	Date x Site
TRICHOPTERA								
Brachycentrus sp.	0.0	0.9	26.5	48.1		NS	HS	NS
	(0.0)	(1.5)	(8.2)	(4.3)		S	HS	NS
Hydropsyche sp. D	0.1	2.5	82.9	112.4		S	S	NS
	(5.3)	(5.6)	(8.7)	(16.3)		HS	HS	HS
COLEOPTERA								
Optioservus quadrimaculatus	0.0	4.8	23.9	33.5		NS	NS	NS
	(0.0)	(7.9)	(5.6)	(5.9)		HS	HS	HS
DIPTERA								
Hexatoma spp.	0.8	0.4	16.6	24.5		NS	NS	NS
	(4.9)	(0.2)	(6.4)	(12.7)		S	NS	NS
Tipula spp.	0.0	0.4	2.9	6.0		NS	NS	NS
	(0.0)	(3.2)	(1.3)	(1.7)		HS	NS	HS
Diamesa spp.	1.4	1.8	1.1	7.9		NS	NS	NS
	(2.5)	(9.2)	(0.2)	(3.1)		HS	HS	HS
Microtendipes sp.	0.4	0.6	109.5	30.3		S	HS	S
	(1.0)	(1.0)	(25.5)	(4.7)		HS	HS	HS
Orthocladius spp.	4.8	9.6	20.0	40.3		HS	NS	NS
	(12.9)	(18.8)	(4.2)	(6.0)		HS	HS	HS
OLIGOCHAETA								
Limnodrilus hoffmeisteri	9.3	1.1	2.5	1.5		HS	HS	HS
	(30.3)	(17.3)	(2.5)	(4.3)		HS	HS	HS
Limnodrilus (immatures)	3.0	0.3	4.6	5.0		NS	NS	NS
	(5.8)	(0.4)	(0.7)	(0.9)		HS	HS	HS
Peloscolex ferox	2.3	0.6	0.8	4.0		NS	NS	NS
	(22.7)	(8.0)	(0.6)	(1.9)		HS	HS	HS
PULMONATA								
Physa spp.	2.0	0.4	1.6	6.0		NS	S	HS
	(5.7)	(0.6)	(1.1)	(1.1)		HS	HS	HS
Norris, Ekman								
DIPTERA								
Hexatoma spp.	0.9	0.3	1.0	1.5		NS	NS	NS
	(1.4)	(0.6)	(19.2)	(10.2)		HS	HS	HS
Odontomesa sp.	1.9	3.3	7.1	1.9		NS	NS	NS
	(3.3)	(11.2)	(14.5)	(7.0)		NS	NS	NS
Orthocladius spp.	3.4	0.8	2.8	1.3		HS	HS	HS
	(5.8)	(3.4)	(8.0)	(1.2)		NS	NS	NS
OLIGOCHAETA								
Limnodrilus hoffmeisteri	24.5	10.8	0.0	0.4		NS	S	NS
	(32.8)	(37.4)	(0.0)	(2.9)		NS	HS	HS
Limnodrilus (immatures)	17.4	9.4	7.6	8.9		HS	NS	NS
	(26.2)	(15.9)	(10.3)	(23.4)		NS	S	S
Peloscolex ferox	3.6	13.8	21.0	17.8		HS	NS	HS
	(7.3)	(21.8)	(17.9)	(22.8)		HS	S	HS
HETERODONTA								
Pisidium spp.	0.3	0.8	1.4	2.3		NS	NS	NS
	(0.7)	(0.6)	(2.0)	(11.8)		NS	S	NS

Table 30 (continued).

	Sample Sites					Analysis of Variance		
Potosí, Ekman	2	1	3	4	5	Date	Site	Date x Site
COLEOPTERA								
Microcylloepus pusillus	29.3	8.4	10.0	6.9	1.0	HS	HS	HS
	(55.3)	(38.8)	(51.6)	(21.4)	(2.7)	HS	HS	NS
DIPTERA								
Conchapelopia sp.	1.5	0.9	4.4	3.8	4.8	S	HS	HS
	(10.2)	(4.3)	(19.5)	(11.5)	(10.5)	NS	HS	HS
Polypedilum spp.	0.0	0.0	0.5	1.1	4.0	HS	HS	HS
	(0.0)	(0.0)	(3.3)	(3.1)	(10.4)	HS	HS	HS
Rheotanytarsus spp.	3.0	5.6	0.5	1.3	0.0	S	NS	NS
	(15.3)	(12.6)	(3.2)	(3.1)	(0.0)	HS	S	HS
OLIGOCHAETA								
Limnodrilus udekemianus	0.5	0.0	0.1	1.6	3.0	NS	NS	NS
	(2.6)	(0.0)	(0.4)	(4.3)	(5.7)	NS	S	HS
PULMONATA								
Physa spp.	3.9	1.5	0.4	0.4	0.0	HS	HS	HS
	(10.8)	(8.1)	(1.1)	(1.1)	(0.0)	HS	HS	HS
AMPHIPODA								
Hyalella azteca	0.5	2.4	2.5	11.9	3.3	S	HS	S
	(2.4)	(10.8)	(11.2)	(31.9)	(13.1)	HS	HS	NS

[a] in parentheses
* HS = highly significant difference (P≤.01)
  S = significant difference (P≤.05)
  NS = differences non-significant

Table 31. Annual and seasonal correlation coefficients and coeffi-
cients of determination[a] for mean genus-species percent
contribution per bottom sample at Ringling, Norris and
Potosi, as correlated with temperature.

			Time of Sample			
Ringling, Surber	Annual	Fall '74	Winter	Spring	Summer	Fall '75
EPHEMEROPTERA						
Baetis sp. A	-.065	-.199	-.654	-.556	-.751*	-.620
	(<.01)	(.04)	(.43)	(.31)	(.56)	(.39)
Baetis sp. B	+.053	-.231	-.199	.000	-.193	+.031
	(<.01)	(.05)	(.04)	(.00)	(.04)	(<.01)
Caenis simulans	-.101	-.630	+.021	-.655	+.779*	-.262
	(.01)	(.40)	(.00)	(.43)	(.61)	(.07)
Choroterpes albiannulata	-.317*	-.794*	-.125	-.351	-.328	-.328
	(.10)	(.63)	(.02)	(.12)	(.11)	(.10)
Tricorythodes minutus	-.252	-.346	-.100	-.426	-.604	-.337
	(.06)	(.12)	(.01)	(.18)	(.37)	(.11)
TRICHOPTERA						
Cheumatopsyche spp.	+.342*	+.712*	-.089	-.307	-.494	+.870**
	(.12)	(.51)	(.01)	(.09)	(.24)	(.76)
Hydropsyche sp. A	-.216	-.851**	-.489	-.651	-.848**	-.679
	(.05)	(.73)	(.24)	(.42)	(.72)	(.46)
Hydropsyche sp. B	-.137	-.126	-.329	.000	-.771*	-.317
	(.02)	(.02)	(.15)	(.00)	(.59)	(.10)
COLEOPTERA						
Dubiraphia minima	+.192	+.745*	+.602	+.089	+.729*	+.680
	(.04)	(.56)	(.36)	(.01)	(.53)	(.46)
Microcylloepus pusillus	-.043	+.024	+.723	-.249	-.221	-.096
	(<.01)	(<.01)	(.52)	(.06)	(.05)	(.01)
Optioservus quadrimaculatus	+.380*	+.656	+.741*	-.608	-.768*	+.757*
	(.14)	(.43)	(.55)	(.37)	(.59)	(.57)
DIPTERA						
Simulium spp.	-.321*	-.673	-.553	+.839**	-.765*	-.655
	(.10)	(.45)	(.31)	(.71)	(.59)	(.43)
Conchapelopia sp.	+.521**	+.137	+.036	-.175	+.879**	+.546
	(.27)	(.02)	(<.01)	(.03)	(.77)	(.30)
Cricotopus spp.	+.609**	+.693	-.362	.000	+.819*	+.678
	(.37)	(.48)	(.13)	(.00)	(.67)	(.46)
Micropsectra spp.	+.570**	+.529	-.481	-.553	+.933**	+.183
	(.33)	(.28)	(.23)	(.31)	(.87)	(.03)
Rheotanytarsus spp.	+.226	-.814*	-.200	.000	+.925**	-.082
	(.05)	(.66)	(.04)	(.00)	(.86)	(.01)
OLIGOCHAETA						
Limnodrilus hoffmeisteri	+.317*	+.216	+.786**	+.279	.000	+.475
	(.10)	(.05)	(.62)	(.08)	(.00)	(.23)
Limnodrilus (immatures)	-.408**	-.763*	-.530	.000	-.386	-.299
	(.17)	(.58)	(.28)	(.00)	(.15)	(.09)
PULMONATA						
Physa spp.	+.282*	+.275	+.630	+.905**	+.098	-.184
	(.08)	(.08)	(.40)	(.82)	(.01)	(.03)
AMPHIPODA						
Hyalella azteca	+.375*	-.645	-.283	-.105	+.754	.000
	(.14)	(.42)	(.08)	(.01)	(.57)	(.00)
Ringling, Ekman						
EPHEMEROPTERA						
Caenis simulans	-.172	-.601	-.032	-.426	.000	+.156
	(.03)	(.36)	(<.01)	(.18)	(.00)	(.02)
COLEOPTERA						
Dubiraphia minima	+.300	+.352	+.777*	-.463	+.016	+.756*
	(.09)	(.12)	(.60)	(.21)	(.00)	(.57)
Microcylloepus pusillus	-.351*	-.786*	-.062	-.226	.000	-.269
	(.12)	(.62)	(<.01)	(.05)	(.00)	(.07)

Table 31 (continued).

Ringling, Ekman	Annual	Fall '74	Winter	Spring	Summer	Fall '75
DIPTERA						
Cladotanytarsus spp.	+.376* (.14)	.000 (.00)	+.569 (.32)	+.075 (.01)	-.219 (.05)	+.713* (.51)
Conchapelopia sp.	+.022 (.00)	+.199 (.04)	+.014 (.00)	.000 (.00)	.000 (.00)	-.364 (.13)
Cryptochironomus sp.	+.346* (.12)	.000 (.00)	-.339 (.12)	-.646 (.42)	+.575 (.33)	+.195 (.04)
Dicrotendipes sp.	-.170 (.03)	+.164 (.03)	-.547 (.30)	.000 (.00)	-.673 (.45)	-.499 (.25)
Micropsectra spp.	-.377* (.14)	-.637 (.41)	-.634 (.41)	+.157 (.02)	-.734* (.54)	-.920** (.85)
Paratendipes sp.	-.090 (.01)	.000 (.00)	-.346 (.12)	+.369 (.14)	-.118 (.01)	+.219 (.05)
Procladius sp.	+.417 (.17)	+.591 (.35)	-.237 (.06)	.000 (.00)	+.350 (.12)	+.918** (.84)
OLIGOCHAETA						
Limnodrilus hoffmeisteri	+.394** (.16)	.000 (.00)	+.762* (.58)	+.736 (.54)	+.341 (.12)	+.472 (.22)
Limnodrilus (immatures)	-.235 (.06)	.000 (.00)	-.571 (.33)	-.318 (.10)	.000 (.00)	-.581 (.34)
Peloscolex ferox	-.092 (.01)	-.208 (.04)	-.253 (.06)	+.562 (.32)	+.078 (.01)	+.036 (<.01)
AMPHIPODA						
Hyalella azteca	-.183 (.03)	-.830** (.69)	.000 (.00)	-.426 (.18)	.000 (.00)	-.380 (.14)

Norris, Surber						
PLECOPTERA						
Isoperla fulva	-.568** (.32)	-.504 (.25)	-.926** (.86)	-.156 (.02)		-.551 (.30)
TRICHOPTERA						
Brachycentrus sp.	-.427* (.18)	-.363 (.13)	-.462 (.21)	-.609 (.37)		-.781* (.61)
Hydropsyche sp. D	-.450* (.18)	-.641 (.13)	-.767* (.21)	+.107 (.37)		-.765* (.61)
COLEOPTERA						
Optioservus quadrimaculatus	-.325 (.11)	-.683 (.47)	-.744* (.55)	-.314 (.10)		-.691* (.48)
DIPTERA						
Diamesa spp.	-.040 (.01)	.000 (.00)	-.198 (.04)	.000 (.00)		-.892** (.80)
Microtendipes sp.	-.319 (.10)	-.481 (.23)	-.450 (.20)	-.270 (.07)		-.676 (.46)
Orthocladius spp.	+.314 (.10)	-.553 (.31)	-.101 (.01)	-.270 (.07)		+.675 (.46)
OLIGOCHAETA						
Limnodrilus hoffmeisteri	+.459** (.21)	+.531 (.28)	+.944** (.89)	+.020 (.00)		.000 (.00)
Limnodrilus (immatures)	+.307 (.09)	-.307 (.09)	+.912** (.83)	-.158 (.03)		-.477 (.23)
Peloscolex ferox	+.535** (.29)	+.953** (.91)	+.079 (.01)	+.957** (.92)		+.931** (.87)

Table 31 (continued).

			Time of Sample			
Norris, Ekman	Annual	Fall '74	Winter	Spring	Summer	Fall '75
DIPTERA						
Hexatoma spp.	-.416*	-.366	-.575	-.657		+.664
	(.17)	(.13)	(.33)	(.43)		(.44)
OLIGOCHAETA						
Limnodrilus hoffmeisteri	+.452**	+.865**	+.458	+.579		+.102
	(.20)	(.74)	(.21)	(.34)		(.01)
Peloscolex ferox	-.186	-.309	+.489	+.046		-.763*
	(.04)	(.10)	(.24)	(.01)		(.58)
HETERODONTA						
Pisidium spp.	-.242	-.452	-.466	-.227		-.602
	(.06)	(.20)	(.22)	(.05)		(.36)
Potosi, Ekman						
COLEOPTERA						
Microcylloepus pusillus	+.450**	-.153	+.791**	+.863**		+.215
	(.20)	(.02)	(.63)	(.75)		(.05)
DIPTERA						
Conchapelopia sp.	-.088	+.040	-.756**	-.635*		+.731*
	(.08)	(.01)	(.57)	(.40)		(.54)
Polypedilum spp.	-.347*	.000	-.327	-.715*		-.181
	(.12)	(.00)	(.11)	(.51)		(.03)
Rheotanytarsus spp.	+.313*	+.771**	.000	.000		+.031
	(.10)	(.59)	(.00)	(.00)		(<.01)
OLIGOCHAETA						
Limnodrilus udekemianus	-.287	+.445	-.667*	-.257		-.273
	(.08)	(.20)	(.45)	(.07)		(.08)
AMPHIPODA						
Hyalella azteca	-.347*	-.312	-.804**	-.678**		-.373
	(.12)	(.10)	(.65)	(.46)		(.14)

[a] in parentheses
* significant (P≤.05)
**highly significant (P≤.01)

Table 32. Mean weight (mg) of selected taxa from fall and winter samples at Ringling.

Samples sites	Fall '74				Winter				Fall '75			
	1	6	7	8	1	6	7	8	1	6	7	8
EPHEMEROPTERA												
Baetis sp. A	–	.67	.87	.22	–	4.45	1.13	1.29	–	.86	1.04	.50
Baetis sp. B	–	.84	.66	.66	–	.94	.84	–	–	1.02	.98	–
Caenis simulans	.70	.45	.42	.49	–	1.14	.51	–	–	.45	.69	–
Choroterpes albiannulata	.98	.58	.32	.25	–	1.37	.91	–	2.98	.88	.72	1.30
Tricorythodes minutus	–	.80	.32	.25	–	1.00	.74	–	1.25	.64	.38	.25
ODONATA												
Ishnura sp.	14.79	–	10.89	.63	–	1.40	12.30	–	–	–	–	–
Ophiogomphus sp.	22.50	47.66	301.90	.38	98.60	64.08	–	–	235.18	.60	48.90	–
TRICHOPTERA												
Cheumatopsyche spp.	3.36	3.38	3.56	4.11	6.46	5.41	3.11	1.30	3.14	3.46	5.01	5.55
Hydropsyche sp. A.	–	13.80	7.79	2.26	–	5.58	10.19	7.57	–	8.73	5.28	4.44
Hydropsyche sp. B	–	7.97	6.50	5.31	–	24.80	–	1.25	7.85	7.88	6.44	12.56
Polycentropus sp.	8.70	1.15	–	4.90	–	4.10	–	–	–	–	3.72	–
COLEOPTERA												
Dubiraphia minima (1)*	.88	.58	.51	.25	.71	.33	.30	–	.43	.70	.58	–
Microcylloepus pusillus (1)	–	.38	.53	.70	.45	.51	.39	–	–	.40	.42	.43
M. pusillus (a)*	–	.54	.55	.63	–	–	.61	–	–	.55	.34	.49
Optioservus quadrimaculatus (1)	.23	.57	.15	.29	.54	.80	–	–	.51	.67	–	.91
O. quadrimaculatus (a)	–	.82	.99	1.17	–	–	1.00	–	–	.60	–	.99
DIPTERA												
Simulium spp.	–	–	.62	.40	–	.15	.91	1.63	–	–	2.78	1.11
Conchapelopia sp.	.56	.18	.10	.36	–	.57	.68	–	.35	–	.23	–
Cricotopus spp.	.16	.19	.37	.26	–	–	.54	–	.36	.33	.41	.94
Dicrotendipes sp.	.49	.23	.19	1.49	–	.69	.60	2.68	.14	.55	.47	.48
Micropsectra spp.	.11	.04	–	.05	–	1.20	.30	.25	.07	.13	.05	.35
Orthocladius spp.	–	–	.07	–	.15	.45	.38	.73	–	–	.10	.96
Rheotanytarsus spp.	–	.08	.13	.04	–	.20	.20	.07	.10	.15	.08	.15
PULMONATA												
Physa spp.	24.45	6.67	4.73	1.80	17.08	30.86	4.78	–	9.76	7.71	9.00	19.97
AMPHIPODA												
Hyalella azteca	–	1.42	.73	.72	–	1.60	.83	–	–	–	–	–

* (1) larvae
(a) adults