



Observations of distribution, abundance and production related aspects of aquatic macro-invertebrates in natural thermal gradients
by Richard Allen Oswald

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Zoology
Montana State University
© Copyright by Richard Allen Oswald (1979)

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.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Richard A. Oswald

Date May 29, 1929

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

by

RICHARD ALLEN OSWALD

A thesis submitted in partial fulfillment
of the requirements for the degree

of

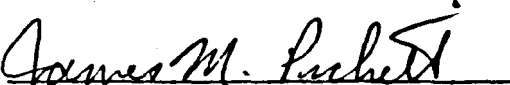
MASTER OF SCIENCE

in

Zoology

Approved:


Chairperson, Graduate Committee


Head, Major Department


Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1979

Bound By AMERICAN BINDERY, Topeka, Kansas.

ACKNOWLEDGMENT

The author wishes to express appreciation to those who assisted him during the study. Dr. George Roemhild directed the study and assisted in preparation of the manuscript. Drs. John Wright and Calvin Kaya critically reviewed the manuscript. Dr. William Gould provided helpful suggestions for the preparation of the manuscript and Dr. Patricia Medvick graciously consented to participate in the defense of thesis examination. Dalton Burkhalter provided valuable assistance in the computer analysis of the data. Sincere gratitude is also expressed to Jack and Louise Galt of Martinsdale, Montana and Mike and Doris Zankowsky of Norris, Montana on whose properties much of the research was conducted.

The research was supported by funds provided by U. S. Environmental Protection Agency Training Grant T-9000058.

TABLE OF CONTENTS

	<u>Page</u>
VITA	ii
ACKNOWLEDGMENT	iii
TABLE OF CONTENTS.	iv
LIST OF TABLES	vi
LIST OF FIGURES.	ix
ABSTRACT	xi
INTRODUCTION	1
DESCRIPTION OF STUDY AREAS	4
METHODS.	16
Physical.	16
Chemical.	17
Biological.	18
Statistical	20
RESULTS.	25
Qualitative	25
Quantitative.	48
Production Related Aspects.	74
DISCUSSION	87
Macroinvertebrate Thermal Maxima.	91
The Hot Spring Fauna.	92
Fauna Of The Thermal Gradients.	94
Comparison Of Sites Within The Thermal Gradients.	97
Comparison Of The Thermal Gradients	99
Total Numbers Of Invertebrates.	101
Numbers of Taxa Present	103
Abundance At The Ordinal Level.	103
Abundance At The Genus-Species Level.	104
Seasonal Variation.	106
Standing Crop (Biomass)	109

	<u>Page</u>
Colonization Rates.	110
Growth.	112
LITERATURE CITED	116
APPENDIX	125

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Mean discharges at low (summer and fall) flows of the hot springs and their receiving streams at Ringling and Norris	5
2. Maximum, minimum and mean observed temperatures (°C) for sample sites at Ringling, Norris and Potosi.	7
3. Selected chemical parameters at Ringling, Norris and Potosi.	9
4. Mean dissolved oxygen levels (mg/l) at Ringling, Norris and Potosi	10
5. Checklist and distributions of taxa collected at Ringling.	26
6. Checklist and distributions of taxa collected at Norris.	30
7. Checklist and distributions of taxa collected at Potosi.	33
8. Czekanowski indices of similarity (S) between sample sites at Ringling, Norris and Potosi	38
9. Distributional patterns of response to temperature based on the presence or absence of taxa at the specified series of sample sites at Ringling.	40
10. Distributional patterns of response to temperature based on the presence or absence of taxa at the specified series of sample sites at Norris.	41
11. Distributional patterns of response to temperature based on the presence or absence of taxa at the specified series of sample sites at Potosi.	42
12. Distributional patterns of response to temperature based on the frequency of occurrence of taxa in combined samples from Ringling, Norris and Potosi	45
13. Mean number of invertebrates per sample collected in bottom samples at Ringling, Norris and Potosi with a multifactor analysis of variance	49

<u>Table</u>	<u>Page</u>
14. Annual and seasonal correlation coefficients and coefficients of determination ^a for the mean number of invertebrates per sample collected in bottom samples at Ringling, Norris and Potosi as correlated with temperature	52
15. Mean number of taxa per sample collected in bottom samples at Ringling, Norris and Potosi with a multifactor analysis of variance	55
16. Annual and seasonal correlation coefficients and coefficients of determination ^a for the mean number of taxa at the genus-species level per bottom sample at Ringling, Norris and Potosi as correlated with temperature.	58
17. Mean ordinal number and mean percent contribution ^a per bottom sample at Ringling, Norris and Potosi with a multifactor analysis of variance	60
18. Annual and seasonal correlation coefficients and coefficients of determination ^a for the mean number of taxa at the ordinal level per bottom sample at Ringling, Norris and Potosi as correlated with temperature	64
19. Patterns of numerical response to temperature for selected ^a genera and species from bottom samples at Ringling, Norris and Potosi.	66
20. Annual and seasonal correlation coefficients and coefficients of determination ^a for mean genus-species number per bottom sample at Ringling, Norris and Potosi as correlated with temperature	70
21. Mean biomass (g) of invertebrates per Surber (.1 m ²) and Ekman (.023 m ²) sample from Ringling with multifactor analysis of variance.	75
22. Mean biomass (g) and numbers of organisms collected in Ringling Surber samples on each sample date	76
23. Mean weight (mg) per individual organism, by sample site and season, from the Ringling Surber samples.	76

<u>Table</u>	<u>Page</u>
24. Correlation coefficients and coefficients of determination ^a for mean biomass per sample ^b for Ringling Surber samples . .	77
25. Colonization rates of macroinvertebrates on Hester-Dendy samplers with multifactor analysis of variance, Ringling . .	80
26. Mean numbers* of invertebrates per m ² at Ringling, Norris and Potosi	102
27. Mean daily maximum, minimum and median temperatures per month and monthly maxima and minima measured from February 1975 through January 1976 at Ringling.	124
28. Taxa collected within the undiluted flows of the hot springs at temperatures above 30°C at Ringling, Norris and Potosi	125
29. Genus-species frequency of occurrence (x 100) in pooled samples collected by all sampling methods at thermal levels composed of samples sites at Ringling, Norris and Potosi with similar thermal regimes	126
30. Mean genus-species number and percent contribution ^a per bottom sample at Ringling, Norris and Potosi with the results of a multifactor analysis of variance.	130
31. Annual and seasonal correlation coefficients and coefficients of determination ^a for mean genus-species percent contribution per bottom samples at Ringling, Norris and Potosi with a multifactor analysis of variance	134
32. Mean weight (mg) of selected taxa from fall and winter samples at Ringling.	137

LIST OF FIGURES

<u>Figure</u>	<u>Date</u>
1. Map of Ringling study area showing macroinvertebrate sample sites	6
2. Map of Norris study area showing macroinvertebrate sample sites.	12
3. Map of Potosi study area showing macroinvertebrate sample sites.	14
4. Significant linear regressions of total numbers of invertebrates collected per Ringling Surber (solid line), Ringling Ekman (dotted line) and Norris Surber (dashed line) samples vs. temperature (°C)	54
5. Significant linear regressions of numbers of invertebrate taxa collected per Ringling Surber (solid line), Ringling Ekman (dotted line), Norris Surber (dashed line) and Potosi Ekman (dotted and dashed line) samples vs. temperature (°C).	59
6. Linear regression of macroinvertebrate biomass and temperature from Surber samples collected at Ringling	79
7. Head width (<i>Tricorythodes minutus</i>) and head length (<i>Choroterpes albiannulata</i>) frequency histograms used to estimate instar groups (numbers above modes) from samples collected Oct. 5, 1974 at Ringling	83
8. Instar group frequency based on head width measurements of <i>Tricorythodes minutus</i> collected Oct. 5, 1974 at Ringling.	84
9. Instar group frequency, based on head length measurements, of <i>Choroterpes albiannulata</i> collected Oct. 5, 1974 at Ringling	85
10. Head length frequency of <i>Hyaella azteca</i> collected Oct. 5, 1974 at Ringling.	87
11. Head length frequency of <i>Cheumatopsyche</i> spp. collected Oct. 5, 1974 at Ringling	88

<u>Figure</u>	<u>Page</u>
12. Interaction between temperature and season as it affects number of taxa per sample (N) collected from selected sites at Ringling	107

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, longitudinal 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 literature 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 operational requirements (Wurtz and Renn 1965), the presence of other forms of pollutants (Langford 1971, Wurtz 1969) and relatively small elevations 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 macroinvertebrates. 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 rheocene 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 $.05 \text{ m}^3 \text{ sec}^{-1}$ (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.

	<u>Hot Spring</u>	<u>S. Fk. Smith River</u>
Ringling	.050 m ³ /sec (1.80 cfs)	.027 m ³ /sec (.98 cfs)
	<u>Hot Spring</u>	<u>Hot Spring Creek</u>
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

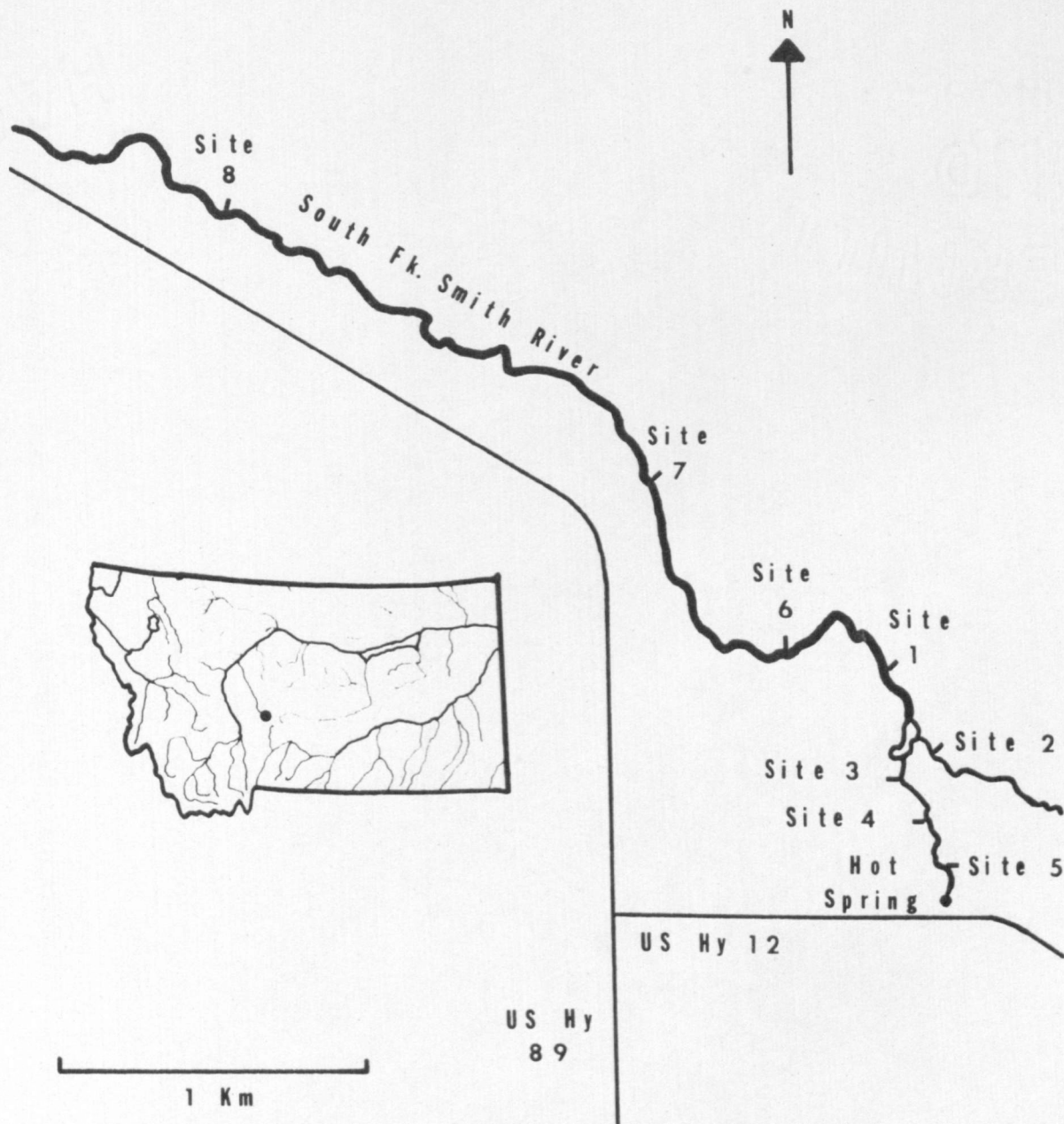


Figure 1. Map of Ringling study area showing macroinvertebrate sample sites.

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			

7

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/l)	2.62	2.67	3.22	3.09	3.17	6.30	6.30	4.32	3.05	2.99	.95
Ca ⁺² (mg/l)	302	307	276	156	121	18.4	18.4	37.6	42.4	44.8	10.8
Mg ⁺² (mg/l)	63.7	60.8	45.2	34.0	24.0	3.4	3.4	6.3	8.8	11.2	0.2
Na ⁺ (mg/l)	8.6	8.4	42.0	39.0	59.0	189	187	96.0	27.0	22.0	17.4
K ⁺ (mg/l)	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/l)	958	918	788	408	357	137	114	42.0	26.0	31.0	104
Cl ⁻ (mg/l)	1.8	1.7	2.8	2.8	5.3	22.0	22.0	12.0	9.2	8.7	6.6
F ⁻ (mg/l)	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/l)	28.8	28.8	28.0	26.0	28.0	94.0	94.0	50.0	44.0	40.0	49.2

6

