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ABSTRACT

THE DISTRIBUTION OF ALGAE
IN SIX THERMAL SPRING EFFLUENTS
OF WESTERN MONTANA

By Russell G. Kullberg

The study of algal distribution in six thermal spring effluents involved the description of stream characteristics, identification of algae, discussion of morphological anomalies, and several methods of data analysis.

Each of the spring effluents was mapped and the relief determined by a transit. Water volume, velocity, interval temperatures, and pH were measured, as were the concentrations of 17 dissolved substances. Temperature, the primary factor affecting algal distribution, ranged from 26 to 61.5 C.

The algae found were in the following divisions: Chlorophyta, Chrysophyta, and Cyanophyta. The Cyanophyta occurred in the effluents to the maximum temperature and were the only algae represented until the water cooled to approximately 40-42.5 C. The mean maximum temperature for the Chlorophyta was 38.1 C; for the Chrysophyta (Bacillariophyceae), 40.5 C. The dominant Cyanophyta were represented by seven previously undescribed taxa.

Water temperature had an inhibitory effect on the development of the oogonia, oospores, zygospores, and akinetes necessary for the

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identification of some forms to species. Except for the thermophile <u>Mastigocladus laminosus</u>, which existed to the highest temperatures of the stream in which it was found, growth of species with heterocysts was generally limited to maximum temperatures between 30 and 40 C. Temperature was also responsible, or at least related to, morphological anomalies in the degree of spiralling of one species, and in the development of granules.

Algae common to two spring effluents having nearly identical dissolved substances were found to have the mean maximum temperatures differ by 5.18 C. This difference was attributed to temperature variations of the effluent water after exposure to varying air temperatures. The algae tolerated the highest temperatures in the stream having the greatest variation of water temperature.

In addition to information specific for each alga given in the annotated list of the species, five methods were used to emphasize various levels of organization; that is, species, classes, discrete communities, and the inclusive thermal spring effluent communities. These methods are:

1) Presence lists of species in communities along temperature gradients. This method gives the species found during any phase of microscopic examination and readily indicates the species in each community and the general increase in species diversity with decreasing temperature.

2) Species curves of the spring effluent continua showing the percent volume contributed by the major species. A standard number of microscope fields was used for all communities in the spring effluents.

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The volume values were plotted against temperature and the lines of the curves smoothed to better show the continua.

3) Tables showing the combined frequencies and percent volumes of species in the divisions. This method shows the temperatures at which the divisions predominate and illustrates the discrepancy between frequency and percent volume when the impact of organisms on the community is to be demonstrated.

4) Dominance-diversity curves of discrete algal communities. The percent volume values for each species in a discrete community were plotted and the points joined to create a curve. Most communities were found to have a small number of dominants, a larger number of intermediate species, and a small number of relatively unimportant species.

5) Diversity indexes of the discrete communities comprising each inclusive thermal spring effluent community. The indexes were plotted against temperature to create curves that are expressions of the rate of increase of species diversification with decrease in temperature. The degree of scattering of the diversity indexes and the slope of the curves were correlated with several environmental factors, and comparisons were made among streams.

THE DISTRIBUTION OF ALGAE
IN SIX THERMAL SPRING EFFLUENTS
OF WESTERN MONTANA

By

Russell G. Kullberg

A THESIS

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Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Botany and Plant Pathology

1966

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I would like to express my sincere appreciation to Dr. G. W. Prescott, under whose guidance this study was conducted, for his willing assistance, suggestions, and wise counsel, which made progress toward completion of this study proceed more smoothly.

For helpful suggestions offered at the initial stage of the investigation I am grateful to Drs. Robert Ball and John Cantlon. Thanks are also accorded the members of my committee, Drs. W. E. Wade, F. W. Porter, and Gordon Guyer, for reading and offering constructive criticism of the completed dissertation.

Special thanks are due my wife, Mary, for the help rendered in various phases of the study.

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CHAPTER I

INTRODUCTION

Six thermal streams or stream groups of western Montana were selected in order to study the algal composition and distribution along temperature gradients. A preliminary survey of the possible streams was undertaken during the summer of 1961 to determine their suitability for study. The criteria used for their selection were distribution, accessibility, and stream characteristics.

Since it was necessary to travel to the streams from the Montana State University Biological Station at Flathead Lake, Montana, travel distance from this point had to be considered because frequent stream visitations were anticipated. The streams that were chosen were within an 800-mile round-trip route from Flathead Lake. This distance could have been reduced by using streams from one general area or by reducing the number of streams. It was felt, however, that a wide distribution of streams emitted from various rock strata would produce more information for this and future studies than streams chosen from a relatively small area.

Geographically closer streams in Idaho were not investigated since travel time around mountain ranges made their use impractical. Several thermal springs were accessible but were not available for study because they were so completely utilized commercially.

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Since the primary purpose of the investigation was to study the algae along temperature gradients, each chosen stream or stream group had to have a satisfactory temperature, volume, and length in order to produce a proper gradient. Streams with the temperature high enough to produce this gradient were found that filtered into the ground within a short distance because their volumes were insufficient. A similar lack of the satisfactory combinations of stream characteristics often was found in respect to the other criteria.

From over 15 thermal streams examined, those having the best combinations of criteria were: Alhambra, Boulder, Jackson, Lolo, Pipestone, and Sleeping Child Hot Springs. These springs are located in a general northwest direction from Yellowstone National Park, ranging approximately 62-197 miles from the boundary of the park.

The algae of thermal springs have been observed, collected, and identified since the early nineteenth century. When these algae were first observed living under such obviously severe conditions, investigators recorded the temperatures and classified the forms they found. It was, therefore, an accepted procedure for many years merely to record the temperature at the point of collection. Even today temperature is sometimes the only environmental measurement reported when algae are listed from thermal streams. More recently, however, the general trend in thermal stream investigations has been toward the taxonomy of the various groups concurrent with recordings of temperature, pH, and concentrations of some of the more common dissolved substances.

The investigation of thermal algae in this study follows the trend indicated above but also includes the numerical and volumetric mposition of algae w

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composition of algae within the algal communities along temperature gradients. Attempts have been made to correlate some of the biotic and abiotic factors with these measurements to create a better comprehension of thermal communities. To accomplish this, five methods of data presentation for each stream have been utilized; these include presence lists, frequency and volume by classes, dominance-diversity curves, continuum curves, and diversity indexes. In addition, information specific to each alga is given in the annotated list of the species.

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CHAPTER II

HISTORICAL BACKGROUND

In a review of the early literature on thermal springs, Walter Weed (1889b), a geologist, wrote that Sir Thomas Hooker, who visited Iceland in 1809, found "confervae" (an early term given to filamentous algae) at the borders of many of the hot springs where plants were exposed to the steam and heat of boiling water. Hooker found what he called *Conferva limosa* Dillw. as large dark green patches, *Conferva flavescens* Roth. in a brick red condition, and a species related to *Conferva rivularis*.

Weed also wrote that Agardh, in 1829, described the algae of the Carlsbad, Bohemia, springs, which were later described and illustrated by Corda in 1835. In 1837, Schwabe published a paper pertaining to the algae of these apparently readily accessible springs and listed the temperatures at which they were found.

Other early investigators who wrote of thermal algae were: Meneghini in 1842, Lindsay in 1861, Cohn in 1862, Baring-Gould in 1864, Ehrenberg in 1864, and Seyler in 1875. As new geographical areas were made more accessible, thermal springs were examined for algae in New Zeeland, the Azores, the Himilayas, the Philippine Islands, Java, and the Americas.

According to Peale (1894), Dr. John Bell was perhaps the first to write about the mineral springs in the eastern United States.

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Bell listed 21 mineral springs in 1831 and later, in 1855, increased the list to 181. Drs. J. J. Moonman and George Walton also listed the known springs in the United States in various publications from 1837 intermittently to 1883. In 1880, a committee of five doctors representing the American Medical Association published a compilation of about 500 spring areas.

Interest in the algae of United States' thermal springs began at a later date than in Europe. After the areas possessing thermal springs became more accessible in the United States, the algae of the thermal springs were often discussed in broad terms of philosophical interest and considerations for beauty rather than with specific taxonomic descriptions and temperature ranges in mind.

Brewer (1866), in reporting on the geysers along Pluton Creek, a branch of the Russian River in California, wrote that the highest temperature noted in which "low forms of vegetation occur" was 93 C. These plants were described as of the simplest kind, apparently single cells, of a bright green color. He found them to be the most abundant in water of 52 to 60 C. No mention was made of the kinds of algae except for a reference to the green coating around the steam jets which, he wrote, were like Nostoc. He also discussed the algae of Steamboat, Nevada, springs relative to their gelatinous mass, which he believed to be silicious.

During the time when algae were beginning to be described from the hot springs of Europe, the hot springs in the western United States were just being discovered by early explorers. John Coulter, who left the Lewis and Clark expedition to hunt and trap at the headwaters of the Missouri River, discovered the springs and geysers of the llowstone about 18

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Yellowstone about 1809. James Bridger described these springs in 1844 but his stories, like Coulter's, were discredited. Later, after more information was obtained from prospectors, explorers, and army officers, a geological and geographical survey of Yellowstone National Park was made by F. V. Hayden beginning in the year 1871. These discoveries in Yellowstone Park approximate the time when other thermal springs in the mountainous west were first seen.

The early investigations of western American hot springs were performed by geologists who were interested in the economic aspects of the minerals deposited by these waters. One of the publications relating to the mineral deposition by the water dealt with the mineral vein formation at Boulder Hot Springs, Montana, a group of springs used in this study (Weed, 1900). Doctors also centered their interest in the mineral content of the springs, but from the aspect of their medicinal properties. The following review will illustrate these areas of interest and the trend of study that began with the springs of eastern United States and later included springs of the West as they were discovered.

Edwards (1868) referred to some diatom frustules found in California hot springs but hastened to mention that they could have be been carried in by the air or other means. Although he was doubtful of the existence of living things in the hot water as described by Brewer, he did concede that European investigators had found algae under these conditions and briefly reviewed their work.

Weed (1889a, 1889b) wrote several articles that were general in nature pertaining to the vegetation of thermal springs, describing macroscopically the appearance of the depositions by the algae. He listed the various ter

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listed the various temperatures at which algae were found to exist and also made occasional references to the taxa. His primary interest in the algae was their role in mineral deposition; consequently, he ascribed the gelatinous sheaths of these forms to siliceous depositions by the algae.

Davis (1897) also largely discussed in the main the macroscopic appearance of some of the formations produced by algae in Yellowstone National Park. The shape and color of the algal mats and mineral formations were described in some detail, whereas the kinds of algae were mentioned only briefly. One illustration showing seven algae was given but no attempt was made to classify them farther than to the genera, which included Phormidium, Oscillatoria, Spirulina, and Gloeocapsa. In general, Davis' work is a result of critical and accurate observations, producing a worthwhile contribution to the early knowledge of thermal vegetation.

Tilden (1898) was one of the first phycologists to study the thermal algae in the United States. She named algae found by Walter Weed in Yellowstone National Park, Francis Lloyd in Oregon, and by herself in Salt Lake City, Utah; Banff, Alberta, Canada; and in Yellowstone National Park. She included algae from waters of no temperature designation or as "near tepid" as well as algae from water with recorded temperatures ranging from 23 to 74 C. From this wide range of locations and temperatures, 25 species of algae limited to the Cyanophyta were listed and described.

The most extensive work dealing with the thermal algae in the United States is that of Copeland (1936), whose study was limited to the Cyanophyta collected in Yellowstone National Park. In addition to gy and annotated lis

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keys and annotated lists of the species, he recorded the pH and temperature range at which they were found, the springs where they were located, and the other Cyanophyta with which they were associated. He found and described many new species and varieties, although not according to international nomenclature, in the varied ecological situations of Yellowstone National Park. Considering the number and variety of the springs involved in his six years of collecting and observing, it is not surprising that so many forms are represented in his work.

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CHAPTER III

PHYSICAL PROBLEMS RELATING TO THERMAL SPRINGS

Definition of Thermal Springs

The term "thermal spring" to the layman initially may be quite obvious and not require a definition since the term itself implies at least warm water. On further consideration, it is necessary to designate the lowest temperature for thermal water, a basis from which all such springs can be classified. This area of study being in the realm of geology, the geologists were, naturally, first to define such water.

Gilbert (1875), one of the first American geologists to compile and discuss thermal springs, listed only the springs which exceeded the mean annual temperature of the air by 15 F. Later, Meinzer (1923) described these springs as having a temperature appreciably above the mean annual temperature of the vicinity and further subdivided them into hot springs and warm springs. Hot springs were regarded as those having a higher temperature than the human body, whereas warm springs had a temperature lower than that of the human body but still above the mean annual temperature. Stearns, Stearns, and Waring (1937) included in their water supply paper springs whose temperature may not have exceeded 100 F, but they attempted to include springs that were locally recognized as being appreciably warmer than usual spring water.

Geologically, definitions of thermal springs relative to the mean annual temperature are necessary because water entering the found in places such a

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ground in places such as Florida will logically emerge in any average spring at a higher temperature than water from an average spring in Iceland. The water of Silver Springs, Florida, emerges from 22.3 to 23.3 C (H. T. Odum, 1957) and is not considered thermal, whereas spring water of this same temperature in Iceland definitely would be thermal, geologically speaking.

Biologically, the above attempts at classifying thermal springs are less useful. The criterion for the determination of thermal springs on the basis of the mean annual temperature of the air is advantageous when only the water is considered, but when living things are dealt with, their minimum, optimum, and maximum growth rates are of prime importance. Phormidium laminosum Gom. has been found in thermal springs of Spitzbergen by Strøm (1921), in Iceland by Peterson (1923), in Yellowstone National Park by Copeland (1936), in Greece by Anagnostidis (1961), and in Japan by Yoneda (1962), to mention a few locations in areas of different mean annual air temperatures. Other environmental factors being equal, however, the cardinal points for this alga are the same at each locality.

In defining thermal situations, the aquatic biologist also finds it necessary to determine temperatures arbitrarily. Whereas the geologist uses some temperature relative to the mean annual temperature of the air at each locality as a basis for defining thermal situations, the biologist can use the temperature range in which living things are found. The relatively wide range of temperatures under which living things are found necessitates several arbitrarily set points and terms to differentiate limits within this range. One such attempt to classify organisms relative to their thermal environment was proposed

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by Vouk (1948), who used the concepts of the ecological valences theory. In this proposed scheme he uses the term psychrobionta to distinguish the cold water organisms in the temperature range of 0 to 25 C from the thermobionta, which live in the range from 25 to 80 C. These two divisions are subdivided as follows:

I. Psychrobionta (Cold water organisms)
   A. Hypothermae (0 to 25 C)
      1. Microstenovalent (Narrow ecovalence completely within the range of 0 to 25 C)
      2. Microeuryvalent (Wide ecovalence with only the optimum growth within the range of 0 to 25 C)

II. Thermobionta (Thermal organisms)
   A. Euthermae (25 to 55 C)
      1. Mesostenovalent (Narrow ecovalence completely within the range of 25 to 55 C)
      2. Mesoeuryvalent (Wide ecovalence with only the optimum growth within the range of 25 to 55 C)
   B. Hyperthermae (55 to 80 C)
      1. Macrostenovalent (Narrow ecovalence completely within the range of 55 to 80 C)
      2. Macroeuryvalent (Wide ecovalence with only the optimum growth within the range of 55 to 80 C)

Of course, organisms are only placed in man-made schemes of classifications. Although it may often seem that there are as many exceptions as there are organisms that will fit into a category, the above scheme will serve as a means by which to classify organisms on the basis of wate

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Although there can be a considerable gradation of an alga's ecological valence among the above categories, this does give the biologist a basis for grouping organisms. A scheme such as this for classifying organisms is based on their cardinal points and frees the biologist from reliance on the local average annual temperature.

Sources of the Heat and Water

Literature on other thermal spring areas in the United States that have been studied by other investigators is reviewed below to reveal information of possible pertinence to the Montana springs.

Lassen National Park, California, has been studied by Day and Allen (1924,25). The source of heat for these thermal springs is magmatic, since lava flows and systems of faults are conspicuous in the neighborhood of the springs. The fact that many of the springs are in lines strongly suggest the presence and effect of these fissures. Amplifying this evidence of the volcanic effect is the almost invariable presence in the water of volcanic gases, consisting chiefly of carbon dioxide, with smaller amounts of hydrogen sulfide, hydrogen, nitrogen, and argon.

The source of water for these Lassen springs is probably meteoric, for when the spring floods are prevalent the water supply of the springs is increased and the temperature is decreased. As the season progresses, the surface supply is decreased, resulting in the expected decrease in spring flow and daily temperature variations.

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Some of the small springs of this area become almost completely dry as summer advances.

Although surface water is the main source for these springs of Lassen Park, at least a part of the water is considered to be magmatic, or juvenile--water that is emitted to the surface for the first time. Day and Allen found volcanic gases in the springs that led them to believe magmatic water was also present, since all igneous rock, when heated, invariably gives off more water vapor than all the other gases combined. They suggest that when water is heated by magmas, there will always be some magmatic water accompanying the meteoric water to varying degrees. The amount of magmatic water will vary in a given thermal spring according to the volume of meteoric water, which is the principal source, and the proximity of the magma.

Another type of thermal spring, if the source of heat may be used as a criterion for designation, is represented by those found in southeastern United States and in the Ozarks. The water for these thermal springs is considered to be wholly meteoric, entering porous rock aquifers in a recharge area at a higher elevation and emerging along fractures or faults at a lower elevation. Water entering confined aquifers and emerging some distance away is well known throughout the world, but most such water does not penetrate the earth to relatively deep rock formations, or, if it does penetrate deeply, it is cooled gradually as it slowly rises to the surface. The water in the areas mentioned here penetrates deeply and emerges relatively fast through disturbed rocks of the confining stratum.

The springs of the southeastern United States have water that ranges from slightly over the mean annual temperature to a maximum of

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41.1 C at the Stout Spring of Hot Springs, Virginia. This temperature is considered to be due to the downward increase in temperature with depth, since the springs occur in regions of sedimentary rocks rather than in regions of igneous rocks as in the western part of the United States. The rate of increase with depth is unknown for any of the thermal spring areas, but since the temperature increment is 1 F for each 60 feet of depth, the maximum depth of the aquifer will be less than 3,500 feet for the hottest springs at Hot Springs, Virginia.

The map of the United States, shown in Figure 1, indicates the location of thermal springs. The greatest number is in the geologically-young areas of the West, where recent quake and volcanic activities are frequently evident. The temperatures of many western springs range to over the boiling point of water, due to the proximity of the water with the magmas. The thermal springs of the East are found in areas of folded rock, as discussed above.

The six Montana springs of this study are widely scattered, small, and relatively insignificant considering the large number of hot springs throughout the United States; consequently, they have not been studied by geologists relative to their source of water and heat. It is highly probable, however, that they are affected by the magma underlying the region. The numerous springs south of this area in Yellowstone Park are similar in their magmatic source of heat to those studied by Day and Allen (1924,25), so these thermal springs of Montana can be presumed to be heated in the same way but to a lesser degree. It may also be presumed that since magmas probably heat the water, there is juvenile water of some small percentage emitted along with the meteoric water.

Figure 1. Distribution of the major thermal springs and spring groups in the United States. Modified from Stearns, Stearns, and Waring. 1937. Thermal Springs in the United States, U.S. Geol. Survey Water Supply Paper 679-B.

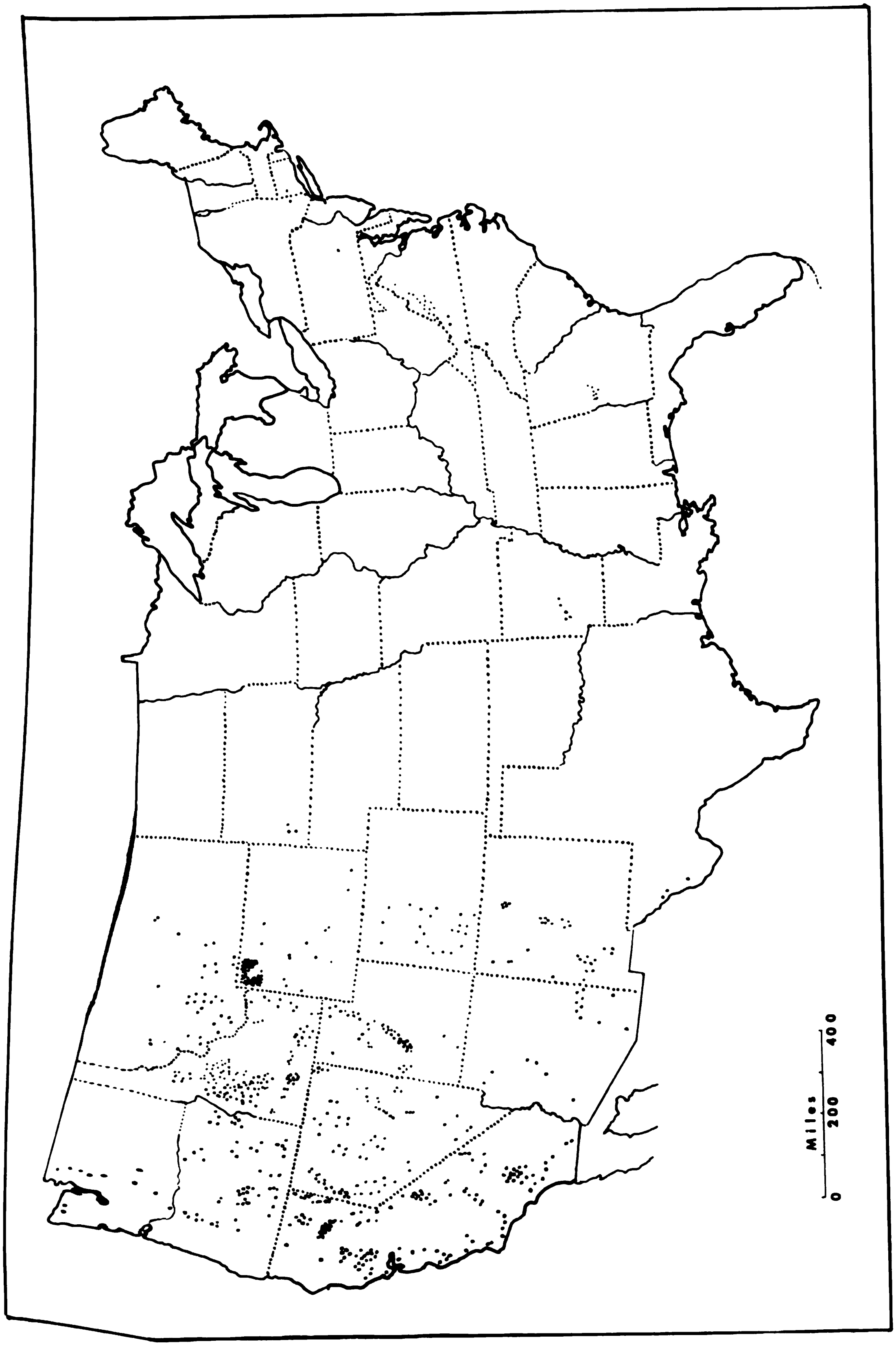
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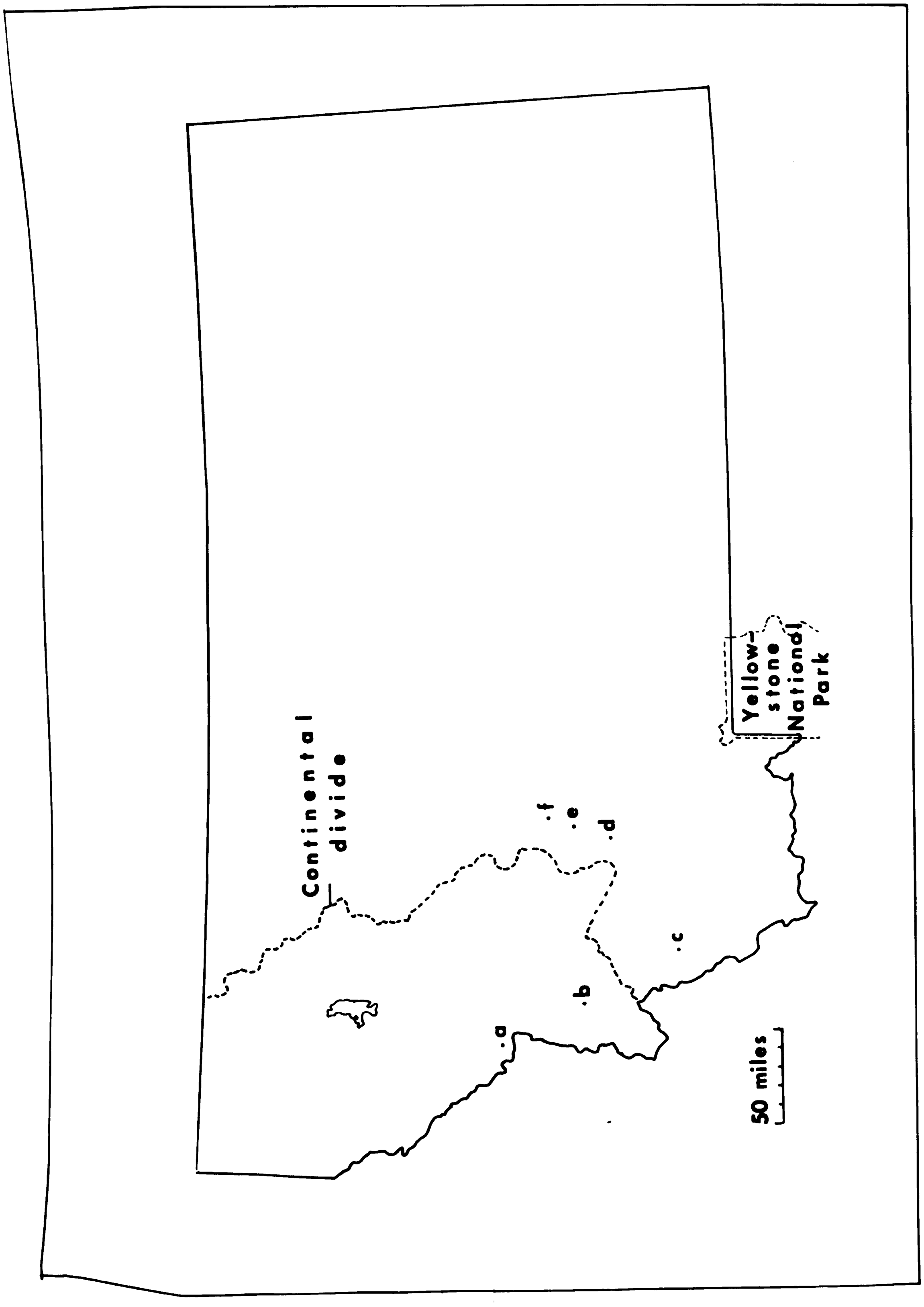
Figure 2. Approximate locations of the thermal springs in Montana that were used in this study. a. Lolo Hot Springs; b. Sleeping Child Hot Springs; c. Jackson Hot Springs; d. Pipestone Hot Springs; e. Boulder Hot Springs; f. Alhambra Hot Springs.



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CHAPTER IV

DISTRIBUTION AND DESCRIPTION OF THE STUDY AREAS

The thermal springs of Montana extend in a general northwesterly direction from Yellowstone National Park, where there is the greatest concentration of thermal springs in the world. Stearns, Stearns, and Waring (1937) list 40 springs in Montana with temperatures ranging up to 85 C. The locations of the springs used in this study are shown on the map of Montana (Figure 2).

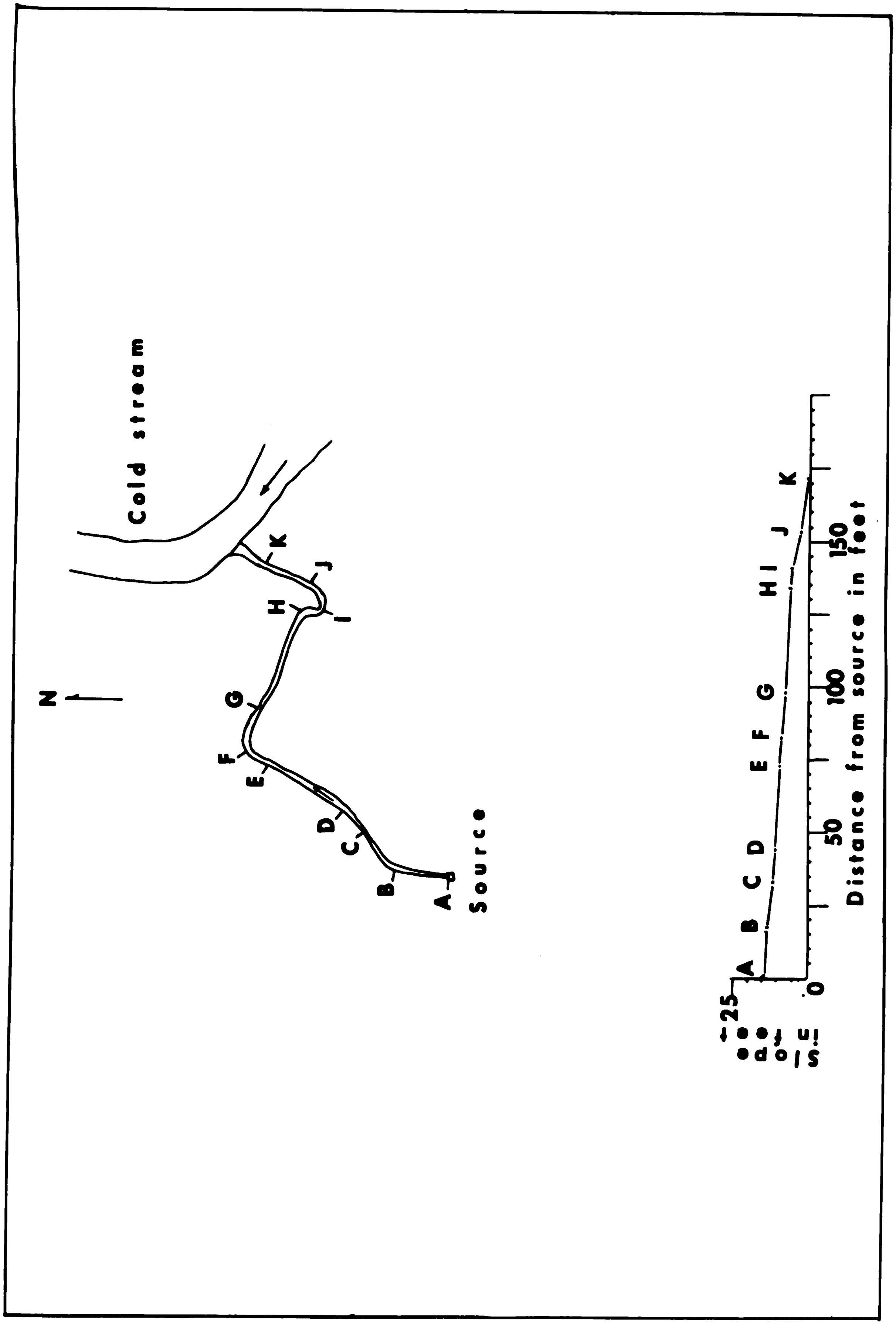
Alhambra Hot Springs

Alhambra Hot Springs are in the southeast corner of section 9, township 8 north, range 5 west, in Jefferson County, Montana, at an elevation of 4,350 feet.

The water is emitted from rocks of the Boulder batholith, which extends from a few miles south of Helena, Montana, to about 20 miles south of Butte. This batholith is predominately quartz monzonite and has dikes and masses of aplite, alaskite, diorite, and other rocks extending irregularly throughout.

The springs at Alhambra are divided into north and south groups, separated by a distance of about 400 feet. Both groups are used to varying degrees by a nearby rest home and by a swimming pool. The north series of springs are irregularly distributed on a hill, where excess water from the piped springs and small seepages flow into a

Figure 3. Map and profile view of the stream at Alhambra (South) Hot Springs, Montana. The points on the map (top) correspond with the same lettered points on the profile (bottom). The scale for the map is given in the profile view.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larger hot water stream of the second order. The large areas of these seepages and the lack of a main spring made this group of springs impractical to map with a transit. The temperature of the different springs and seepages of the north group varied with their number, the warmest being 54.4 C.

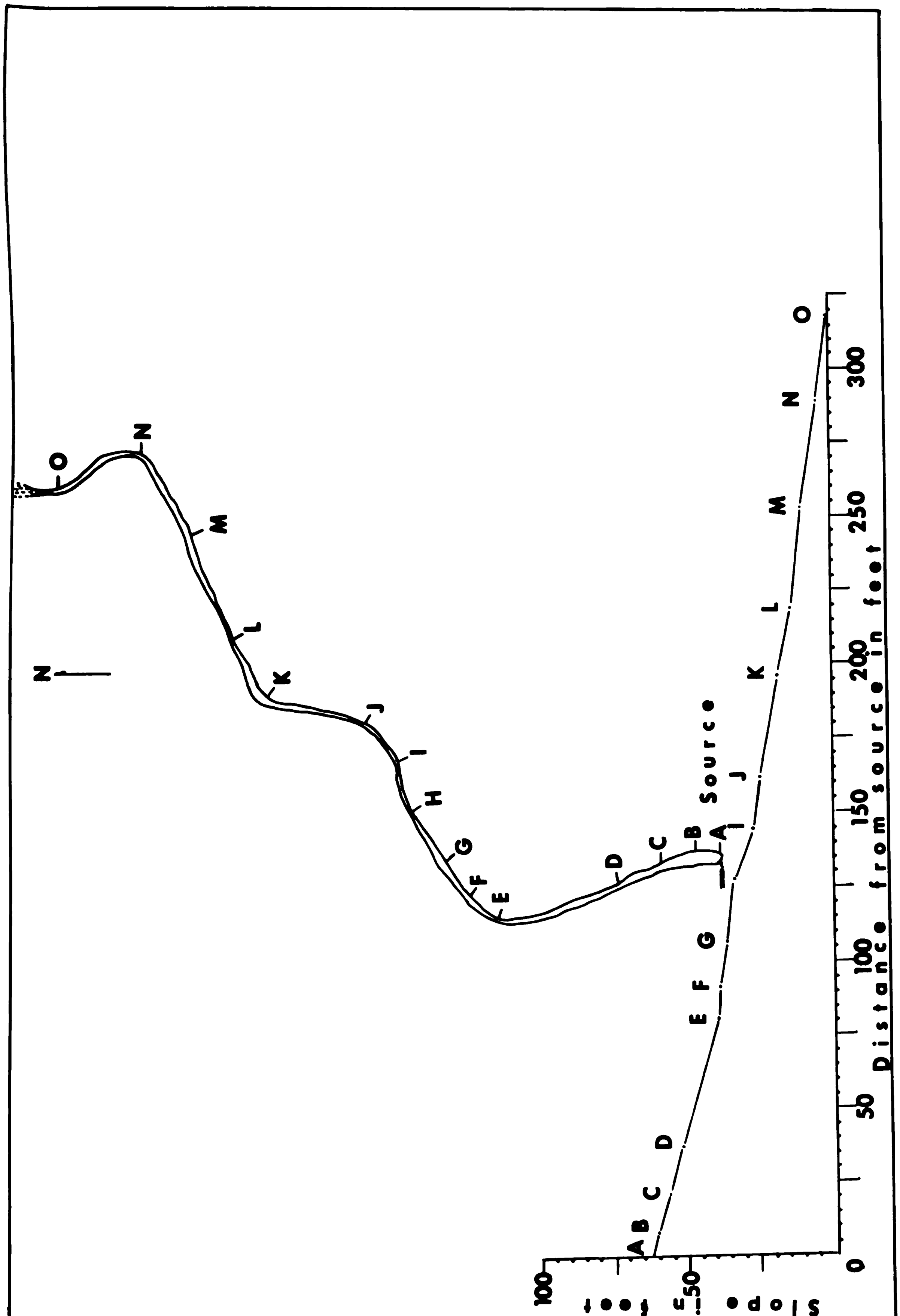
The south springs are located on a small travertine terrace, and, judging from the position and amount of travertine, the flow from this group must have been considerable at one time. During the summers of 1962 and 1963, the water of all but one of these springs was efficiently collected and temporarily stored in an enclosed concrete basin. The spring that was allowed to flow freely was mapped during this study from the source until it flowed over the terrace into a cold water stream. The relief of this thermal stream was approximately 8.72 feet per 100. During the summers of 1962 and 1963, the discharge of the stream was approximately 13 gpm, the mean velocity was 41.6 feet per minute, and the temperature at the source was 48.0 C.

Boulder Hot Springs

Boulder Hot Springs are in the east-central part of section 10, township 5 north, range 4 west of Jefferson County, Montana, at an elevation of 4,950 feet.

These springs are from the same Boulder batholith as at Alhambra, but at the eastern edge near the zone of contact with sedimentary rocks of the Tertiary. The nearby hotel uses all but a small part of the water. The water that is allowed to flow is emitted from a pipe and, as it winds down the hill, gradually drains into the soil, the stream terminating between 315 and 350 feet from the source. The

Figure 4. Map and profile view of the stream at Boulder Hot Springs, Montana. The points on the map (top) correspond with the same lettered points on the profile (bottom). The scale for the map is given in the profile view.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relief was 19.65 feet per 100. During the summers of 1962 and 1963, the discharge averaged 47 gpm, the mean velocity was 60 feet per minute and the temperature was 61.3 C as it flowed from the ground. A drop of about six feet from the pipe to the rocks below caused a splashing that quickly cooled the water to 55.0 C, after which it rejoined to make a small stream. It was at this latter temperature that algae were first collected.

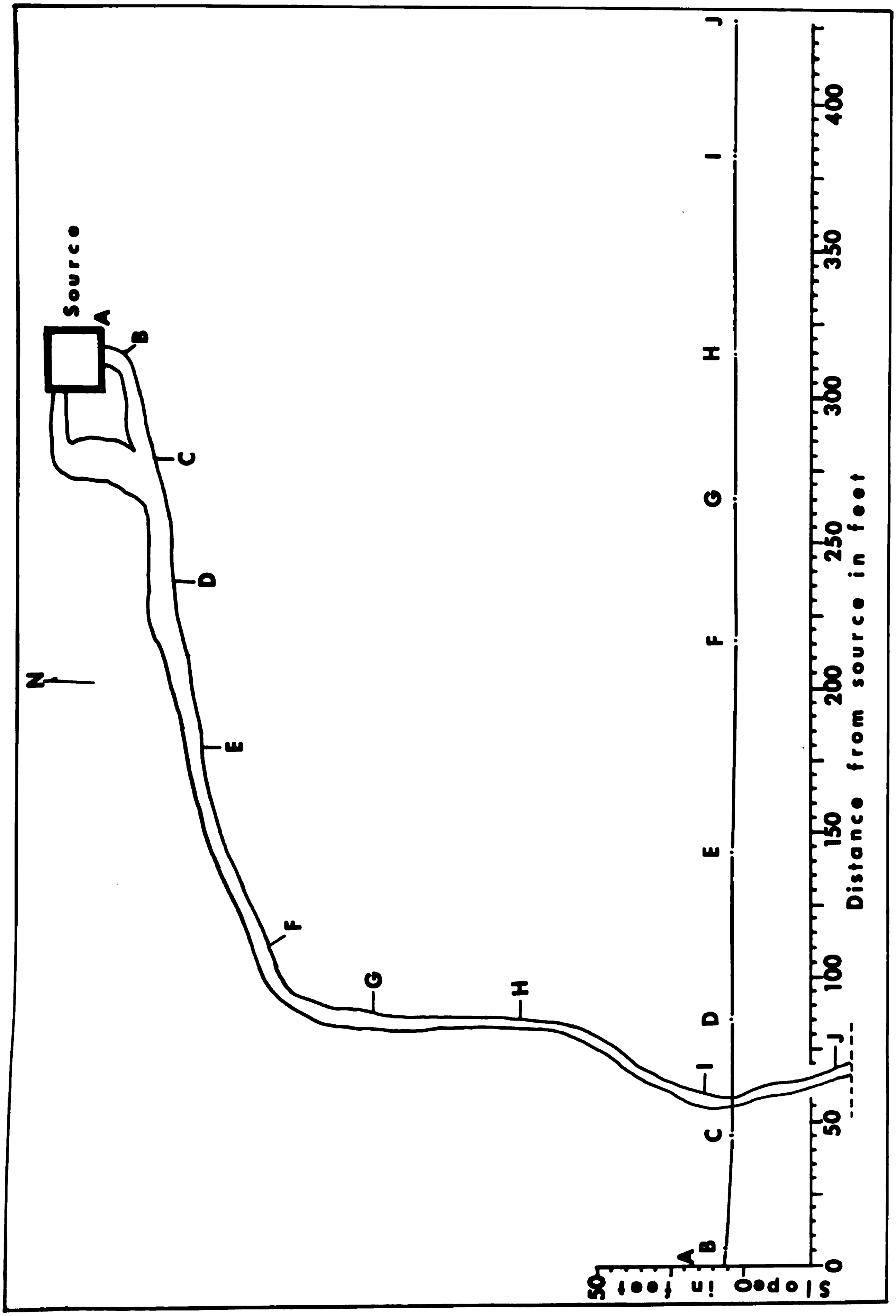
Jackson Hot Springs

Jackson Hot Springs are in the west-central part of section 25, township 25 south, range 15 west, Beaverhead County, Montana, at an elevation of 6,475 feet.

The water from this spring passes up through alluvium of the Big Hole Valley. Adjacent to this alluvium are Tertiary sedimentary rocks which meet the surrounding mountains of argillite and quartzitic argillite. It is feasible to assume that the argillite extends under the sedimentary rocks and the alluvium of the large plane of the valley floor and could contribute toward the heat of the water. The constant rise of much gas in the water, however, suggests the proximity of magmas to the water at a lower depth. If magmas give off more water vapor than all the other combined gases from heated igneous rock, as stated by Day and Allen (1924), a relatively high percentage of this water could be juvenile.

Concrete walls 20 by 20 feet surround the spring proper and create an open pool to retain the water for use in nearby homes and a hotel, but enough overflows to produce a good stream for study. The relief was 1.52 feet per 100, the discharge was approximately 244 gpm,

Figure 5. Map and profile view of the stream at Jackson Hot Springs, Montana. The points on the map (top) correspond with the same lettered points on the profile (bottom). The scale for the map is given in the profile view.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and the low mean velocity of 27.2 feet per minute alternately produced stream and pond-like habitats. The temperature in the pool was 61.5 C; the temperature at the initial point of algal sampling was 58.0 C.

Lolo Hot Springs

Lolo Hot Springs are in the north-central part of section 7, township 11 north, range 5 west, in Missoula County, Montana, at an elevation of 4,100 feet.

The water comes directly from crevices in the rocks at the eastern edge of the Idaho batholith, consisting of gneissic quartz, monzonite, granodiorite, and similar rocks, without passing through soil or travertine deposits.

A covered concrete reservoir retains the water of the main spring for use in the swimming pool. Unused water from this enclosed pool flowed from a pipe and created the stream that was studied. The relief for the first 125 feet from the source was 9.6 feet per 100; the relief for the remaining distance averaged 2.5 feet per 100. The discharge was approximately 21 gpm, and the mean velocity was 45 feet per minute. The temperature of the water changed from about 44.5 to 46.0 C at the source, depending upon whether the water from this enclosed reservoir was being used at the time to fill the nearby swimming pool. The water at the initial point of algal sampling was no lower than 44.5 C for the two years of study.

Pipestone Hot Springs

Pipestone Hot Springs are in the southeast corner of section 28, township 2 north, range 5 west, of Jefferson County, Montana, at an

Figure 6. Map and profile view of the stream at Lolo Hot Springs, Montana. The points on the map (top) correspond with the same lettered points on the profile (bottom). The scale for the map is given in the profile view.

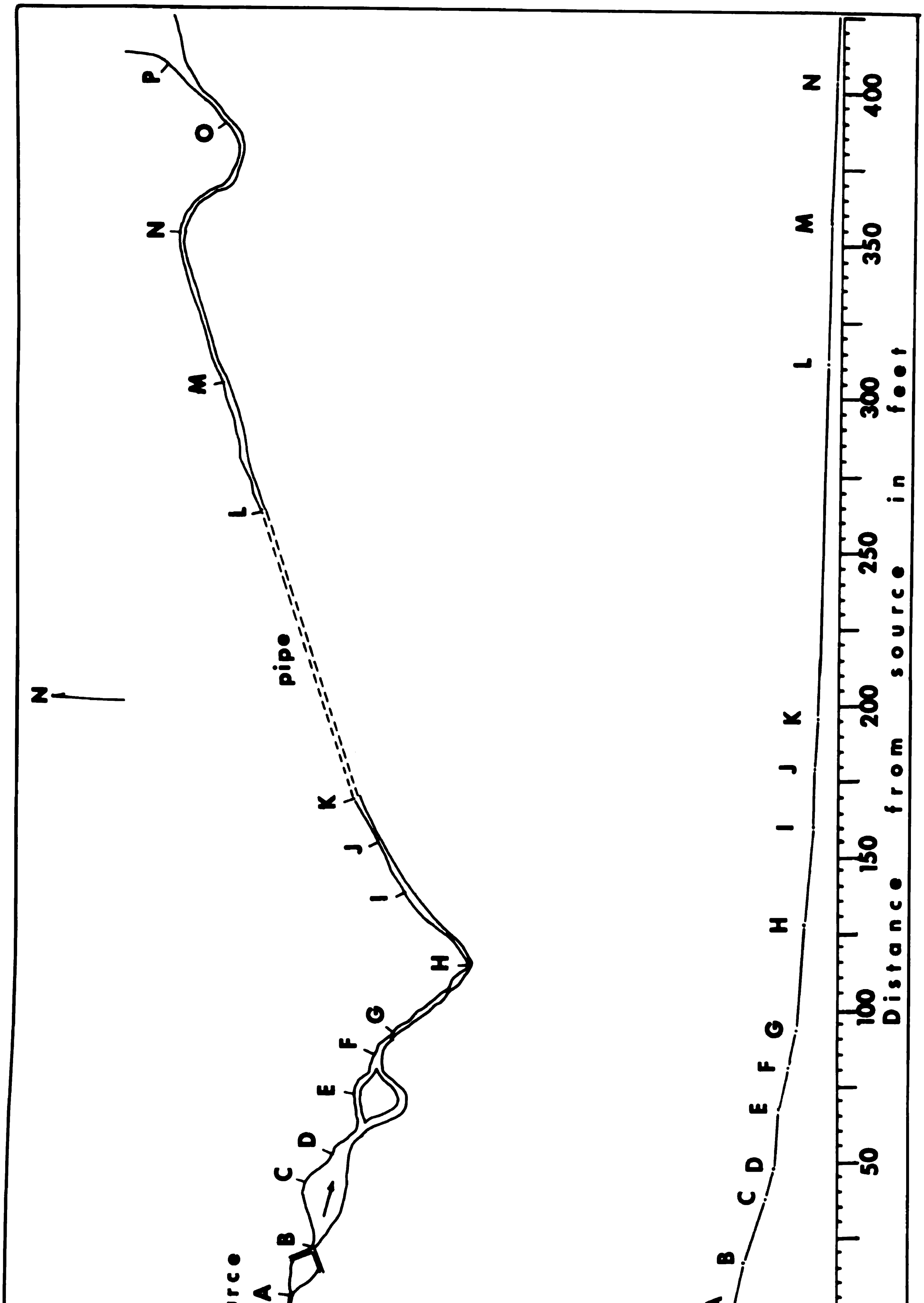
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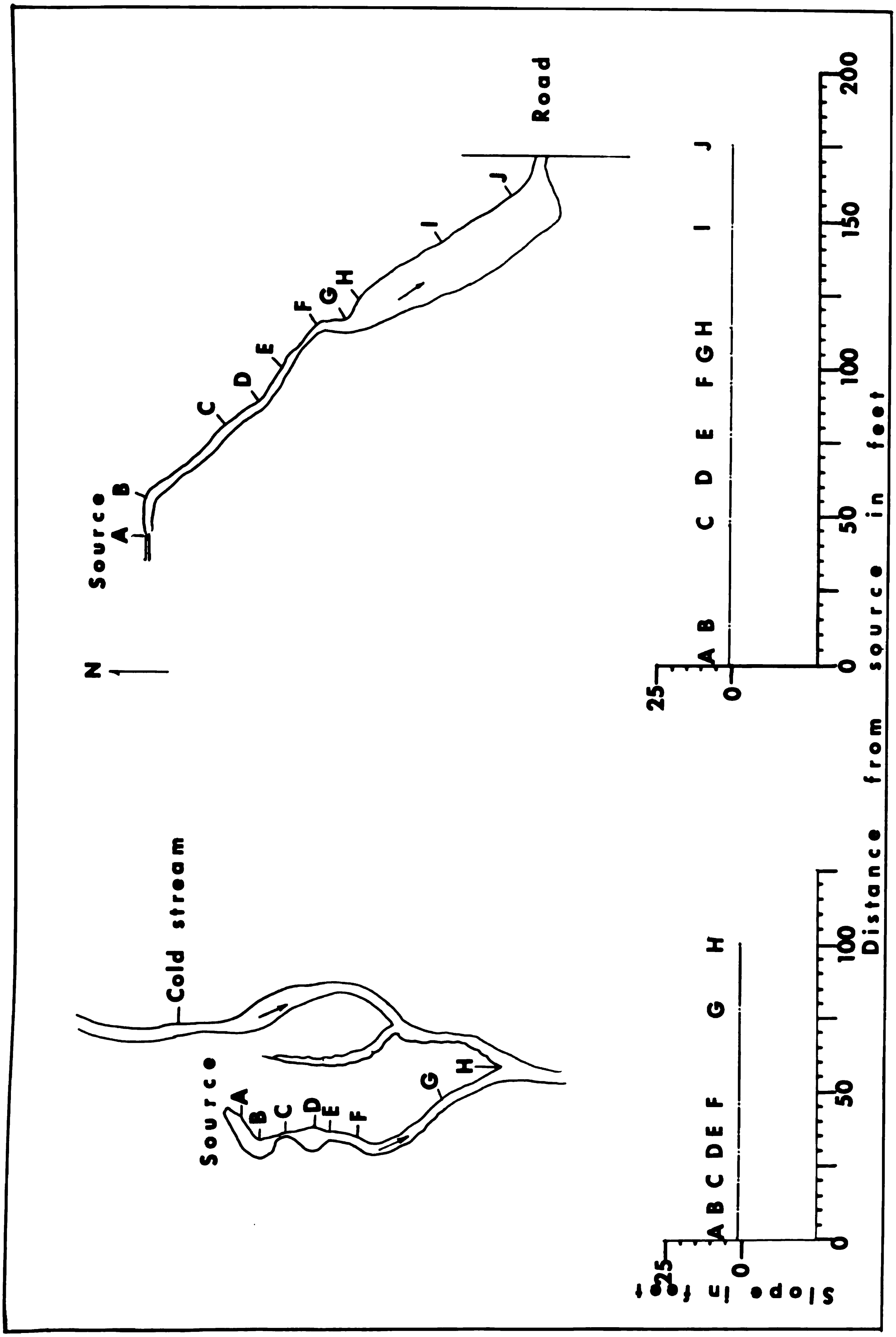
Figure 7. Maps and profile views of the west and east streams at Pipestone Hot Springs, Montana. The points on the maps (top) correspond with the same lettered points on the profiles (bottom). The scales for the maps are given in the profile views.



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The water passes up through alluvium deposited on Tertiary sedimentary rock (undifferentiated) that is adjacent to the southeastern edge of the Boulder batholith. The water also probably passes through an extension of the same type rock formation as is found in this nearby batholith.

These springs are mostly in two groups. The western springs are from three seepage areas and a spring where the water comes from an iron pipe, which produced the most water. The relief was 1 foot per 100; the combined discharge of this group was approximately 167 gpm. The temperature was 59.5 C at the source of the hottest spring and the mean velocity was 22.5 feet per minute.

The eastern group of springs produced the greatest flow, the stream used in this study having a relief of .57 feet per 100 and a discharge of approximately 370 gpm. The mean velocity was 33 feet per minute and the temperature at the source was 52.0 C.

Sleeping Child Hot Springs

Sleeping Child Hot Springs are in the northeast corner of section 18, township 4 north, range 21 east, in Ravalli County, Montana. at an elevation of 4,575 feet.

Although the rocks of this area are not well known, it is believed the water of these springs is emitted from rocks of the border zone of the Idaho batholith consisting of granite gneiss.

The water is emitted directly from bare rock on the side of a mountain without passing through soil, alluvium deposits, or travertine. The approximate relief was 18.63 feet per 100; the discharge was ximately

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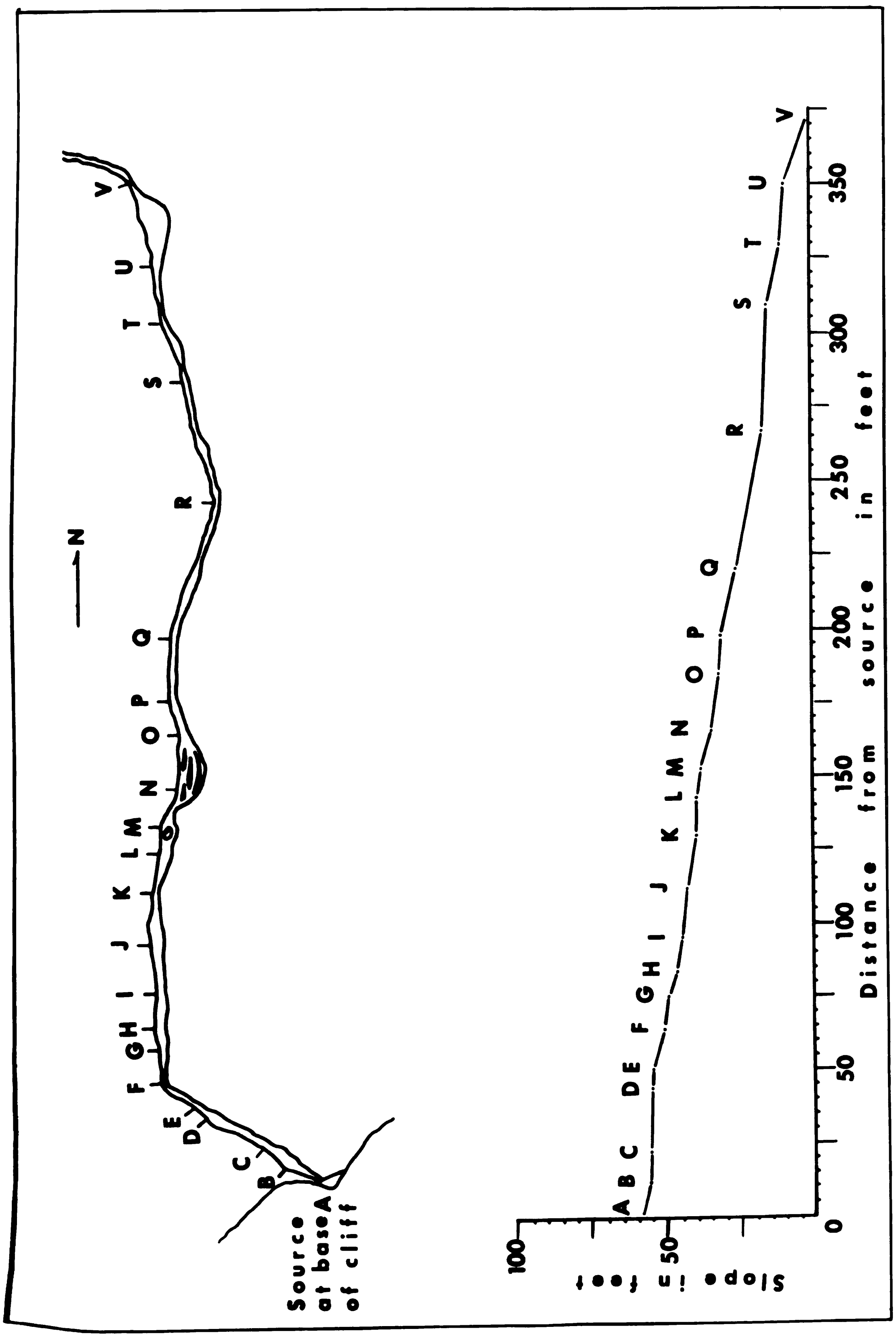
approximately 357 gpm. The mean velocity was 76.3 feet per minute, and the temperature at the source was 52.0 C.

Figure 8. Map and profile view of the stream at Sleeping Child Hot Springs, Montana. The points on the map (top) correspond with the same lettered points on the profile (bottom). The scale for the map is given in the profile view.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CHAPTER V

METHODS

Chemical-Physical Methods

The water of the streams was tested for the chemical and physical factors at various times throughout the summers of 1962 and 1963 to check for possible changes that might have occurred during each summer or from one year to another. All tests were made at intervals for the entire length of the streams. When it was observed that no changes occurred for the duration of the study, mean values were computed for the many tests made.

The tests for pH, alkalinity, and oxygen were always made at the collection site. If time permitted, other tests were performed at the collection site, but whenever they could not be completed at the stream, a few milliliters of chloroform were added to the sample for temporary preservation until returning to the Montana State University Biological Station, where they were completed.

Collection of all water samples was made in 250 ml. glass-stoppered bottles by allowing the water to enter the bottle slowly as it flowed over the rocks. An effort was made to allow the water to enter without bubbling at the surface, either with or without the use of a rubber tube, depending on the conditions. Wherever a pool situation was found, such as at the source of Sleeping Child, Alhambra, and

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Jackson Hot Springs, a Kemmerer bottle was used at the time of the initial collection for transfer to the glass bottles.

Determinations of oxygen were performed according to standard methods by the Alsterberg modification of the Winkler method. Tests for alkalinity were performed by titration with 0.02 N solution of H_2SO_4 to the phenolphthalein (pH 8.3) and methyl-orange (pH 4.6) end points. Nomographic determinations for the carbon dioxide were made by the use of a conversion chart modified from Theroux, Eldridge, and Mallman (1943).

A battery-operated Hach direct reading colorimeter was used to test for iron, ammonium nitrogen, nitrates, nitrites, ortho-phosphate, total phosphate, silica, and sulfate. The tests as prescribed by this company are taken from "Standard Methods for the Examination of Water and Wastewater," Eleventh Edition. Methods used for these tests are:

Iron - Phenanthroline method

Ammonium nitrogen - Direct Nesslerization method

Nitrate and nitrite nitrogen - Brucine method

Phosphate - Stannous chloride method

Silica - Molybdosilicate method

Sulfate - Turbidimetric method

A confirmation of the accuracy of the colorimeter and the operator was made by developing calibration curves using dilutions of standard solutions. The dilutions were tested concurrently with a 110-volt Bausch and Lomb Spectronic 20 Colorimeter-spectrophotometer.

The pH was measured by a Beckman model pH-180 Pocket pH Meter at intervals in the stream. As a check on the accuracy of the instrument, occasional determinations were made by a LaMotte color mparative pH ki

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The temperature was recorded with a glass bulb mercury thermometer graduated in degrees centigrade. The temperature was recorded to the nearest tenth of a degree at each point an algal sample was taken.

The tests for sodium, potassium, calcium, magnesium, chloride, zinc, and aluminum were performed by Leland M. Yates of the Chemistry Department at Montana State University.

Various methods were used to determine the velocity of the streams. The turbulence, narrow width of the streams, and rocks or other debris made flotation of materials unsatisfactory. Of the various soluble substances added to the water for measuring velocity, the best for visibility against the dark green of the algae was powdered milk.

The data for mapping the streams was obtained by a surveyor's transit and stadia rod. These instruments made it possible to precisely measure the relief, direction of flow, and width of the streams at measured distances from the source. Both transit and steel tape were used for the distances.

A pocket-type altimeter was borrowed from the Montana State University Botany Department. This instrument was corrected at the Missoula, Montana, air field before using.

Sampling and Enumerating the Algae

The algae were collected from the streams at distance intervals from the source. These were generally ten-foot intervals, but algae were also collected at other points if stream characteristics suggested a different algal flora, as in a pool or following an inflow of cold ater. Also, if

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water. Also, if at the ten-foot interval the stream passed under an obstacle such as a boulder or earthern bridge, a collection was made at the nearest point to the interval. Since the algal composition at any point in the stream is a function of the chemical and physical factors, the distance is actually irrelevant, being measured for later reference and for subsequent plotting of these factors.

The algae were not used from the sources of several springs. At Boulder, Lolo, and Pipestone (West) the water was emitted from pipes, and although algae were always present on the lip of the pipe, the environmental conditions were too variable to make a meaningful study. As an example, water moving by capillarity a distance of 0.2 cm. at the top edge of the pipe lip can have a temperature range of several degrees whereas at the bottom edge, where the water collects momentarily before dripping, a distance of 2 cm. may have water in the same temperature range. The Jackson spring was surrounded by a cement retaining wall to create a reservoir. The floating algae and those growing on the reservoir sides were also living under variable conditions that were too difficult to measure at 61.5 C (144.5 F).

The algae generally existed in one common mass and only rarely were there found pure "stands." These algal masses were found as strands trailing in the streams for up to two dm. or more, as upright clumps approximately 1-2 cm. wide and 6 cm. high, as masses growing close to the substratum, and as every conceivable intermediate form. Considering the numerous forms assumed by the algal masses, the most logical method of collection appeared to be by hand.

At a chosen interval, small clumps were taken at several points to obtain a representative sampling of the algae found growing at that nterval a

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interval and the temperature was recorded. The algae were preserved in vials of Transeau's solution (six parts water, three parts 95 percent alcohol, one part formalin). The algal samples were taken three times, or as often as conditions permitted, through the summers of 1962 and 1963. Samples were taken during the summer of 1961 at Lolo and Sleeping Child Hot Springs during an initial survey and search for suitable thermal springs.

The algae taken in 1962 were compared with those taken in 1963. When the differences in algal composition from year to year were found to be the same as from one sample to another, the samples taken in 1963 were used except for Alhambra (North). The water from this stream was diverted for local use in 1963, making it necessary to use the 1962 algae.

From the several algal masses taken at the stream for each vial, several smaller clumps were taken from scattered points in the vial for each of two microscope slide preparations. The invariably interwoven filaments were as completely torn apart as was deemed practical before adding the cover glass. The algae of each slide were then examined under 660 or 900 magnification for identification and survey of those present. All the algae encountered during this identification and survey phase were recorded and subsequently listed (Tables III, IV, VII, IX, XI, XIII, XV, and XVI) although some of these may not have been encountered during the quantitative enumeration when fewer microscope fields were used.

After careful examination under high magnification and when the algae could be confidently identified, they were enumerated under 440 magnification. A Whipple ocular was used for the enumeration. Since a great major

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great majority of thermal algae are 1-2 μ in diameter and interwoven, a microscope field of appropriate size had to chosen to facilitate enumeration. Enumerating interwoven filamentous forms in an oversized field can be exasperating and overly time consuming; in an undersized field the results may be inadequate. After a number of trials, the most appropriate field was found to be three laterally adjacent squares of the Whipple ocular. A rectangular field of this size enabled more readily the counting of filaments following tortuous courses. A rectangular field also obtains a more representative sampling of the algae than a square field, if a microscope field may be compared with terrestrial plots. There are inherent differences, of course, between the distribution of terrestrial plants and the distribution of algae on a microscope slide, and yet clumping will be found in both instances. Also, in both instances, the effect of clumping on the results of enumeration will be reduced by rectangular plots or, rather microscope fields.

The same three adjacent squares of the Whipple ocular were used for each counting field. To find a field, the microscope stage was turned to any point on the slide where the algae were counted; this was repeated, moving vertically and then horizontally on the slide until the algae in 20 fields were counted. The same process was repeated for the algae on a second slide, from the same vial, until the algae in 40 fields were counted. If the microscope slide stopped at a point where no algae were encountered, that field was not included since the percentage of the algae was to be determined and not the density.

In computing the volume occupied by single-celled algae, the mean dimensions of a species' cells in each stream were used to etermine separa

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The volume of filamentous forms was computed on the basis of an estimated length of 18 microns, the width of a square on the Whipple ocular. In the three laterally-adjacent squares of the Whipple ocular composing the field used for counting, some filaments entered a short distance or across a corner. Other filaments extended across the counting field lengthwise for the entire three squares (54 microns), while still others took a meandering course through the field. Each filament that entered the field was counted as one. To be objective in computing the volume of the filaments, the most logical approach was to arbitrarily use 18 microns, the width of the field used for counting, as the filament length for all filaments.

The various forms assumed by the diatoms presented a greater problem than the other algae comprised of spheres or cylinders. Dimensions and diagrams were used in estimating the volumes since convex and concave sides, tapered cells, and generally irregular shapes were common. The method of cellular division by diatoms also contributed to the difficulty.

The mean volume in micron units for a species was multiplied by the total number of that species counted in 40 fields to obtain the total algal volume of those counted. The sum of volumes of all algae counted was taken to compute percentages of the total volume contributed by each species. In addition to volume percentages, numerical percentages were also computed for each species found from each sample.

CHAPTER VI

RESULTS

Chemical-Physical Data

Oxygen

The dissolved oxygen in surface waters has probably been studied more extensively than any other gas. Its importance as a biological regulator and indicator of aquatic conditions has enabled limnologists to learn more about a body of water through its study than any other dissolved substance. Although the oxygen content in thermal streams may not be as decisive as in most aquatic situations, certain generalities pertaining to algal distribution in regard to its concentration may be observed. The water of these thermal streams was generously exposed to the atmosphere, enabling a rapid absorption of oxygen, so tests were made to learn the degree and rate of this absorption.

Whereas most dissolved substances in ground water exhibit a wide range of concentration, the oxygen content of emerging spring waters is generally predictable; that is, the concentration is usually zero. Percolating rain water gradually loses its oxygen as a result of the respiration of subsurface organisms until by the time water reaches the water table it is usually devoid of oxygen. The water table is the top level of the ground water and, since the latter is the source for all springs, the oxygen content of springs is also generally zero. This was illustrated during this study when the water at all the spring was found

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sources was found to be without measurable amounts of oxygen. Upon contact with air, the water at all streams began immediately to absorb oxygen and continued to do so until the point was reached where as much oxygen was absorbed by the water as was given off (Figures 9-14). This point of equilibrium, or solubility, is dependent upon the partial pressure of oxygen in the atmosphere, the concentration of the dissolved substances, and the water temperature.

The partial pressure of oxygen may show minor fluctuations as a result of local atmospheric conditions, but the major effects on the partial pressure will be the altitude. Correction factors of the percent saturation for the various altitudes (Rawson, 1944) are given below and were incorporated in the accompanying oxygen curves: Alhambra, 1.18; Boulder, 1.2; Jackson, 1.27; Lolo, 1.16; Pipestone, 1.19; Sleeping Child, 1.19.

The concentration of dissolved substances reduced the oxygen concentration with increasing salinity. Sea water, with 35 percent salinity, contains 1.5 cc/1 less oxygen at 15 C than fresh water (Reid, 1961). The salts in the stream with the maximum concentration of dissolved substances, Alhambra, would lower the oxygen content approximately 0.004 cc/1 (0.0057 ppm) at 15 C on this basis. The reduction in oxygen concentration would be even less at the higher temperatures of these streams, so the effect of salt concentration may be disregarded for the purposes of this study.

The effect of temperature on the solubility of oxygen is the reduction of oxygen concentration with increase in temperature. The solubility of oxygen at a pressure of 760 mm Hg at 0 C in pure water is 14.16 ppm; at 10 C, 10.92 ppm; at 20 C, 8.84 ppm; at 30 C, 7.53 ppm;

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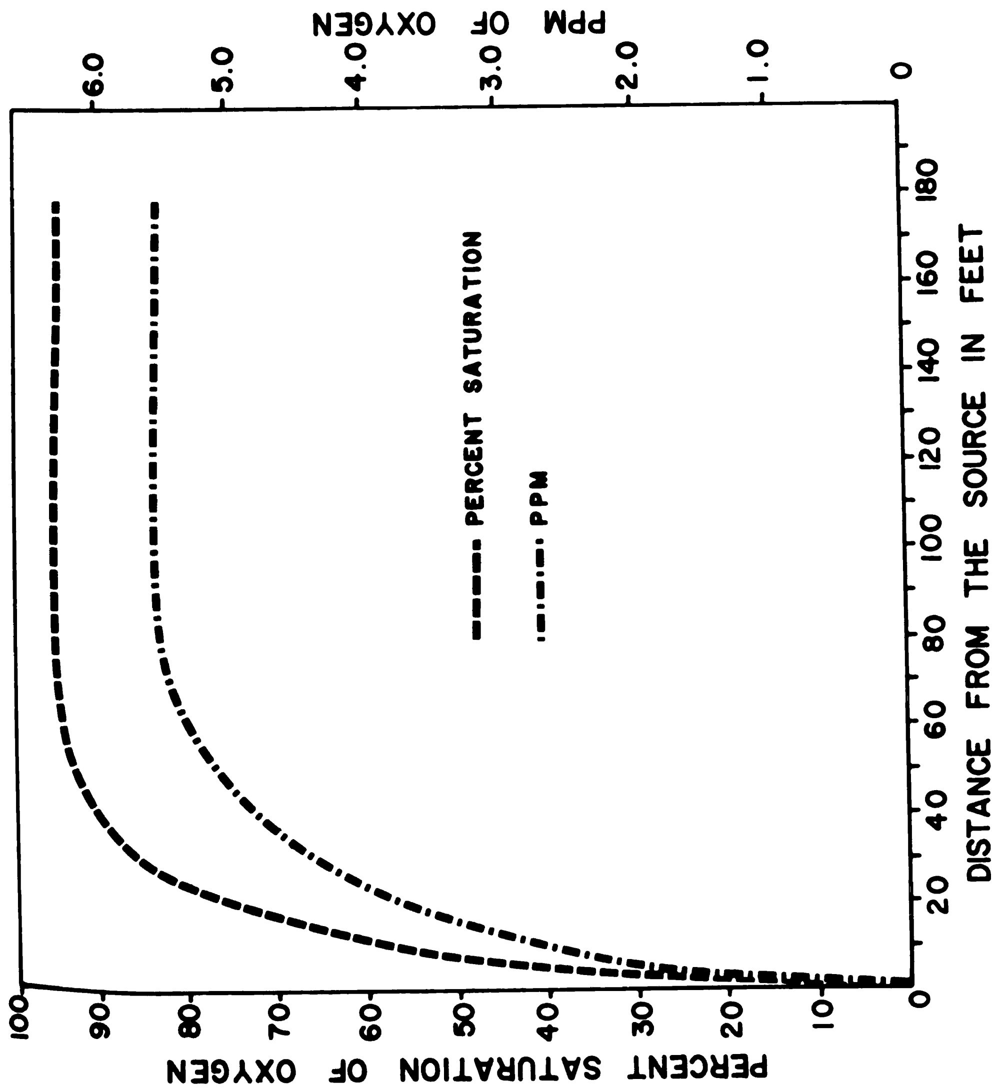
and at 35 C, 7.04 ppm (Truesdale, Downing and Lowden, 1955). This lowering of oxygen concentration with increasing temperature is responsible for the continued low concentration for the entire length of the streams, although the usually great exposure to the air by the water passing over rocks at shallow depths would normally allow for greater absorption of oxygen by the water of most natural streams.

Comments pertaining to the stream profiles and other characteristics of several streams will help to explain the rates at which oxygen is absorbed. The gradual incline of the Alhambra stream (Figure 3) and lack of turbulence were responsible for the relatively slow rate at which oxygen was absorbed (Figure 9). This may be compared with the Boulder stream (Figure 4) where water splashed violently upon rock rubble and flowed down a steep incline which allowed for a rapid oxygen absorption (Figure 10). The oxygen curve created from the data obtained at Pipestone (East) appears to be abnormal until the profile (Figure 7) is examined and other information is provided. This stream flowed in a narrow, steep-sided, artificial ditch for a greater part of the distance. The lack of riffles, confining nature of the stream bed, and quantity of water reduced the exposure to air and, therefore, tended to keep the oxygen at a lower concentration. At the point where this stream began to widen, other flows of warm water entered to keep the oxygen at a low level.

When the oxygen concentration of all streams, except those at Pipestone, reached a level commensurate with the water temperature, the rate of absorption was primarily regulated by the water temperature for the remaining length of the stream. Until the oxygen concentration in

Figure 9. Change of oxygen content in ppm and percent saturation with distance from the source at Alhambra (South) Hot Springs, Montana.



PERCENT SATURATION OF OXYGEN
PPM OF OXYGEN
DISTANCE FROM THE SOURCE IN FEET
PERCENT SATURATION
PPM
0
10
20
30
40
50
60
70
80
90
100
1.0
2.0
3.0
4.0
5.0
6.0
120
140
160
180

Figure 10. Change of oxygen content in ppm and percent saturation with distance from the source at Boulder Hot Springs, Montana.

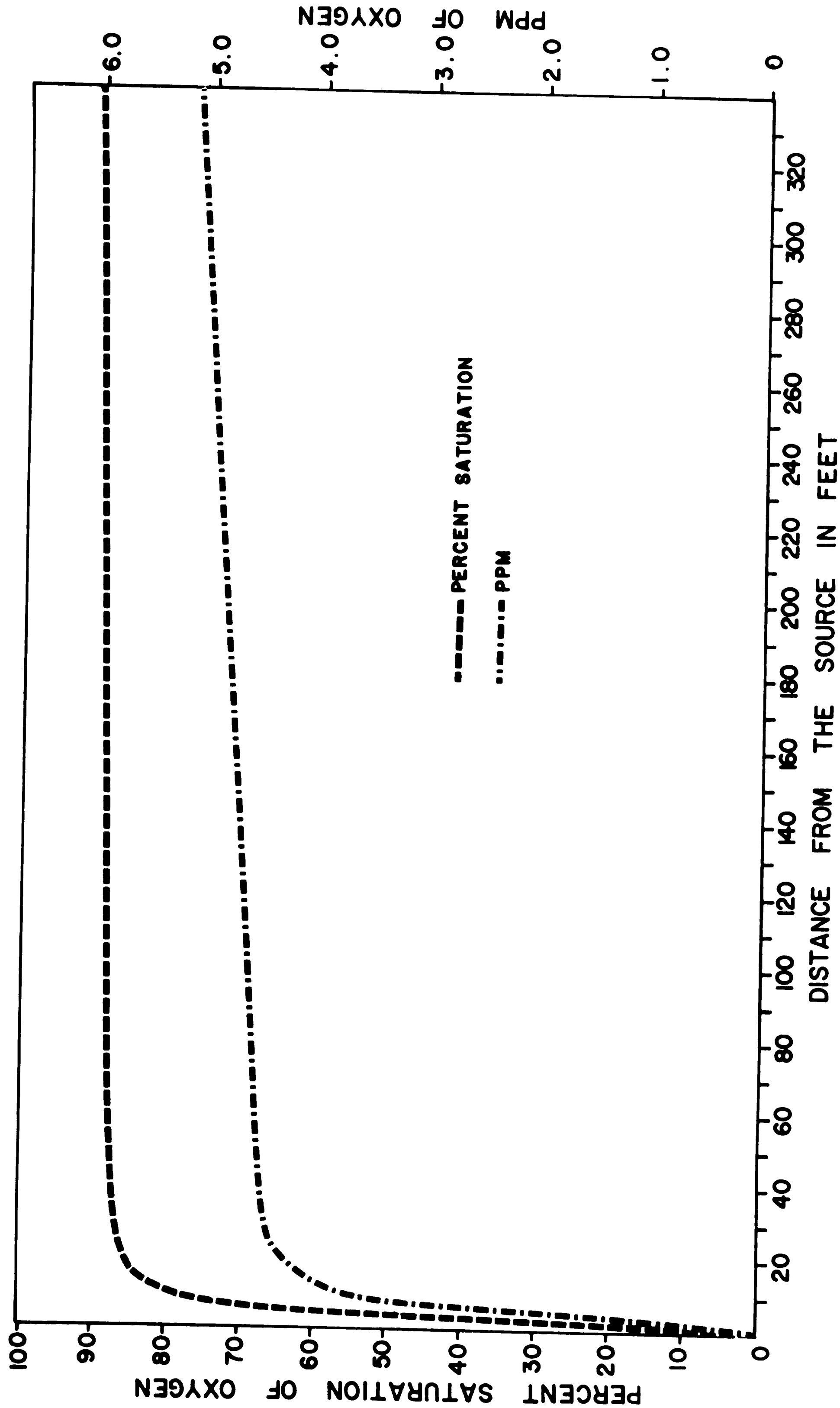

PPM OF OXYGEN
0
1.0
2.0
3.0
4.0
5.0
6.0
PERCENT SATURATION
PPM
DISTANCE FROM THE SOURCE IN FEET
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
PERCENT SATURATION OF OXYGEN
0
10
20
30
40
50
60
70
80
90
100

Figure 11. Change of oxygen content in ppm and percent saturation with distance from the source at Jackson Hot Springs, Montana.

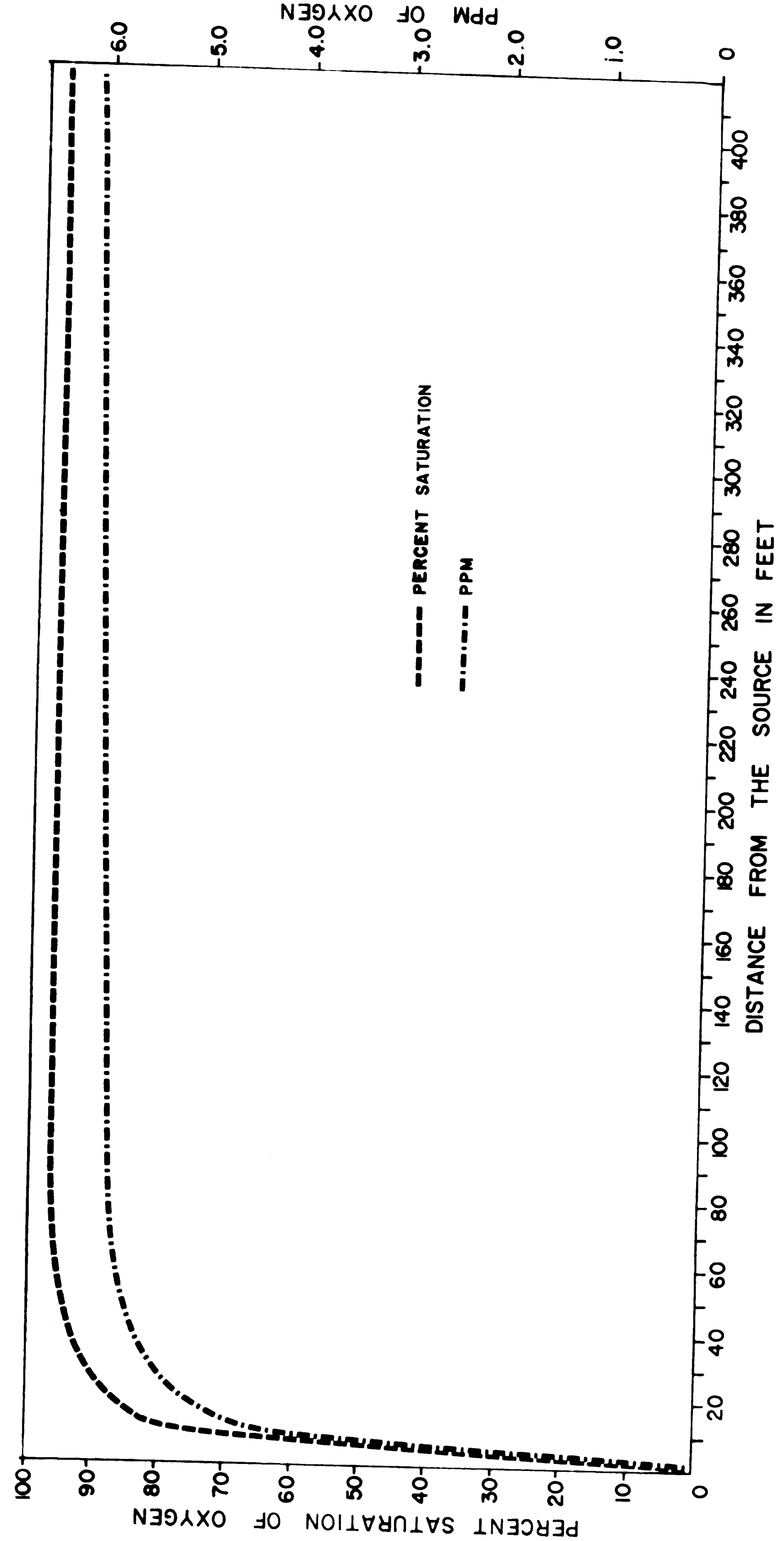

PPM OF OXYGEN
6.0
5.0
4.0
3.0
2.0
1.0
0
PERCENT SATURATION
PPM
DISTANCE FROM THE SOURCE IN FEET
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
PERCENT SATURATION OF OXYGEN
100
90
80
70
60
50
40
30
20
10
0

Figure 12. Change of oxygen content in ppm and percent saturation with distance from the source at Lolo Hot Springs, Montana.

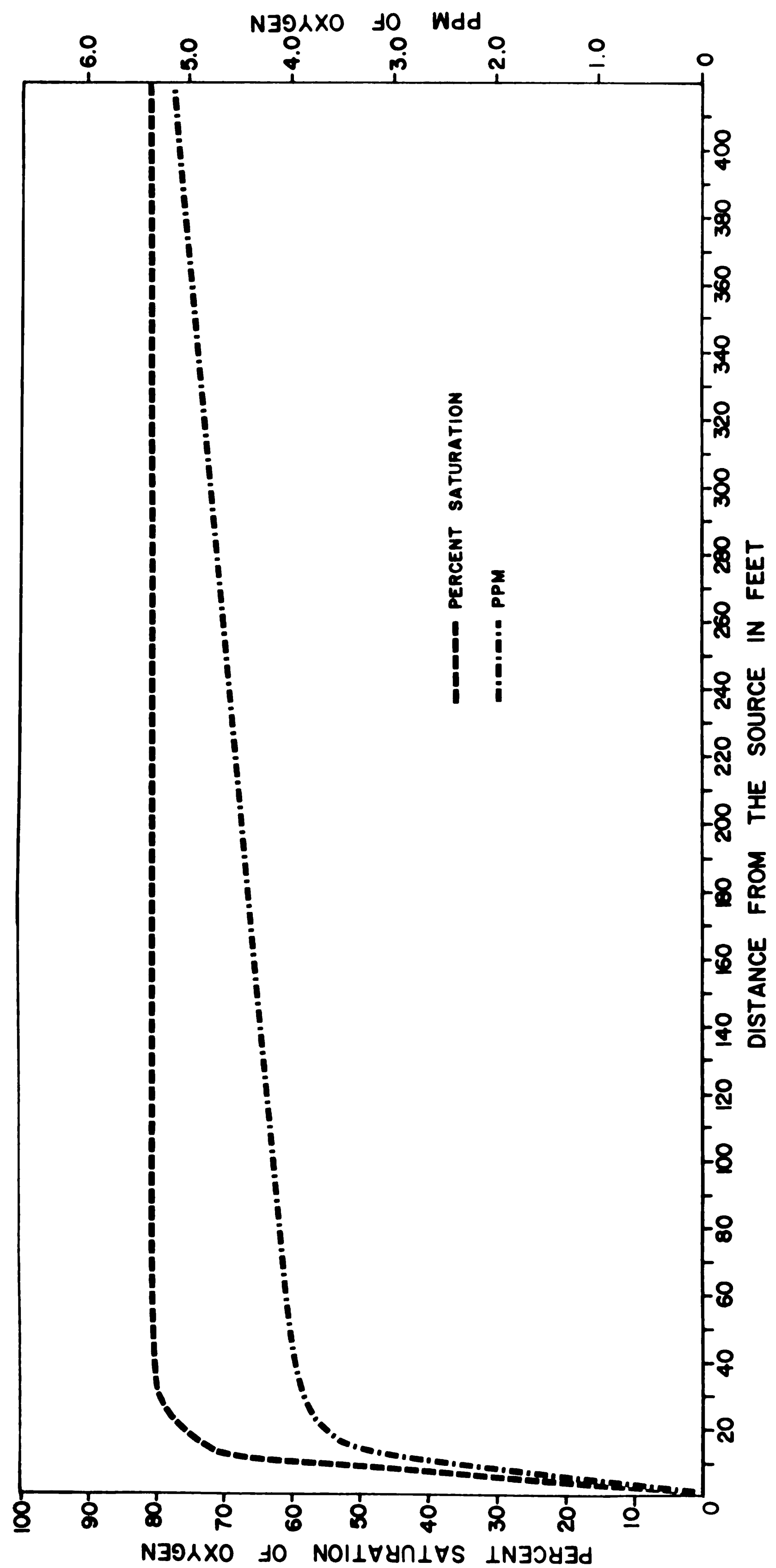

PPM OF OXYGEN
6.0
5.0
4.0
3.0
2.0
1.0
0
PERCENT SATURATION
PPM
DISTANCE FROM THE SOURCE IN FEET
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
PERCENT SATURATION OF OXYGEN
100
90
80
70
60
50
40
30
20
10
0

Figure 13. Change of oxygen content in ppm and percent saturation with distance from the source at Pipestone Hot Springs, Montana. (A) West springs; (B) East springs.

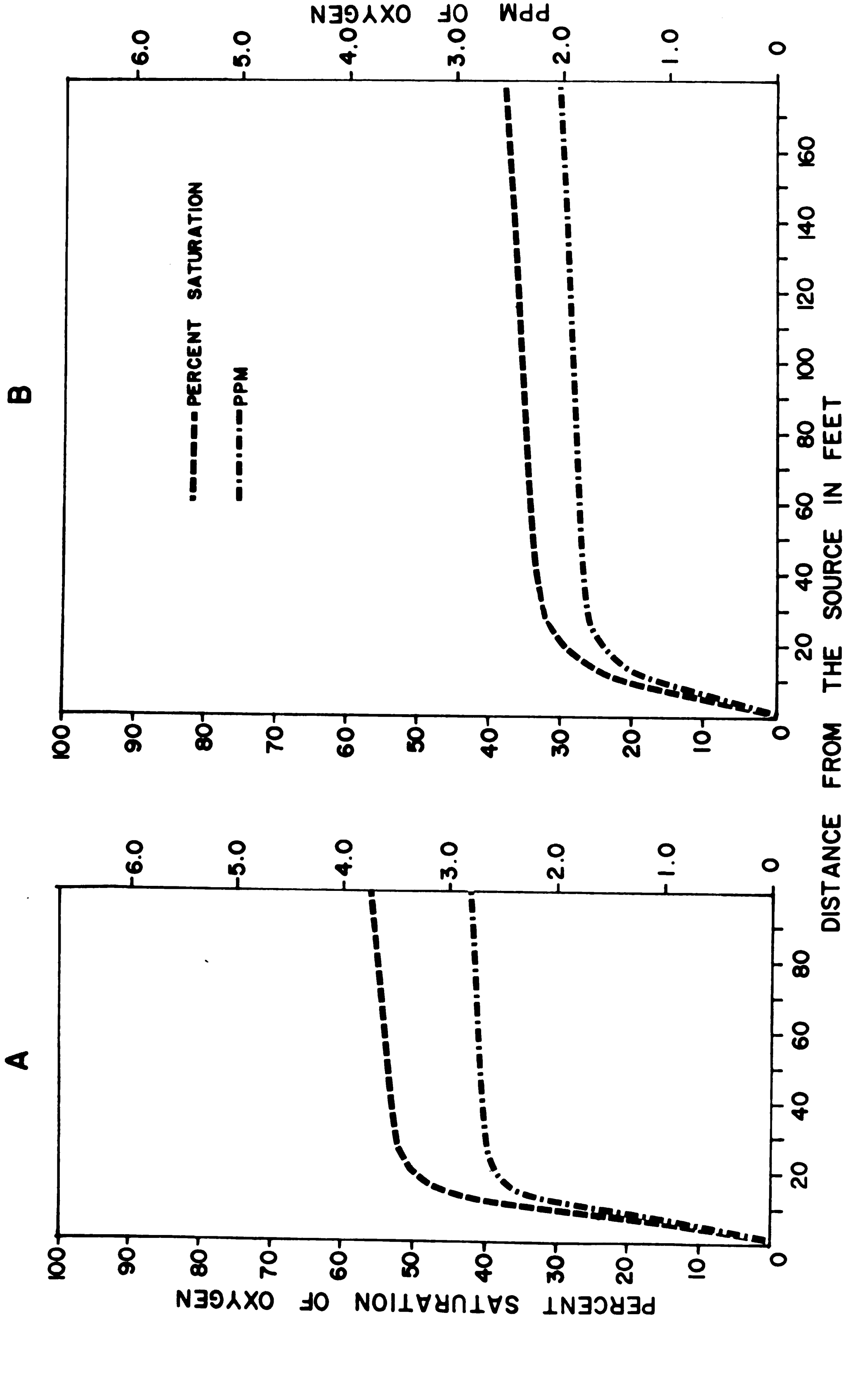
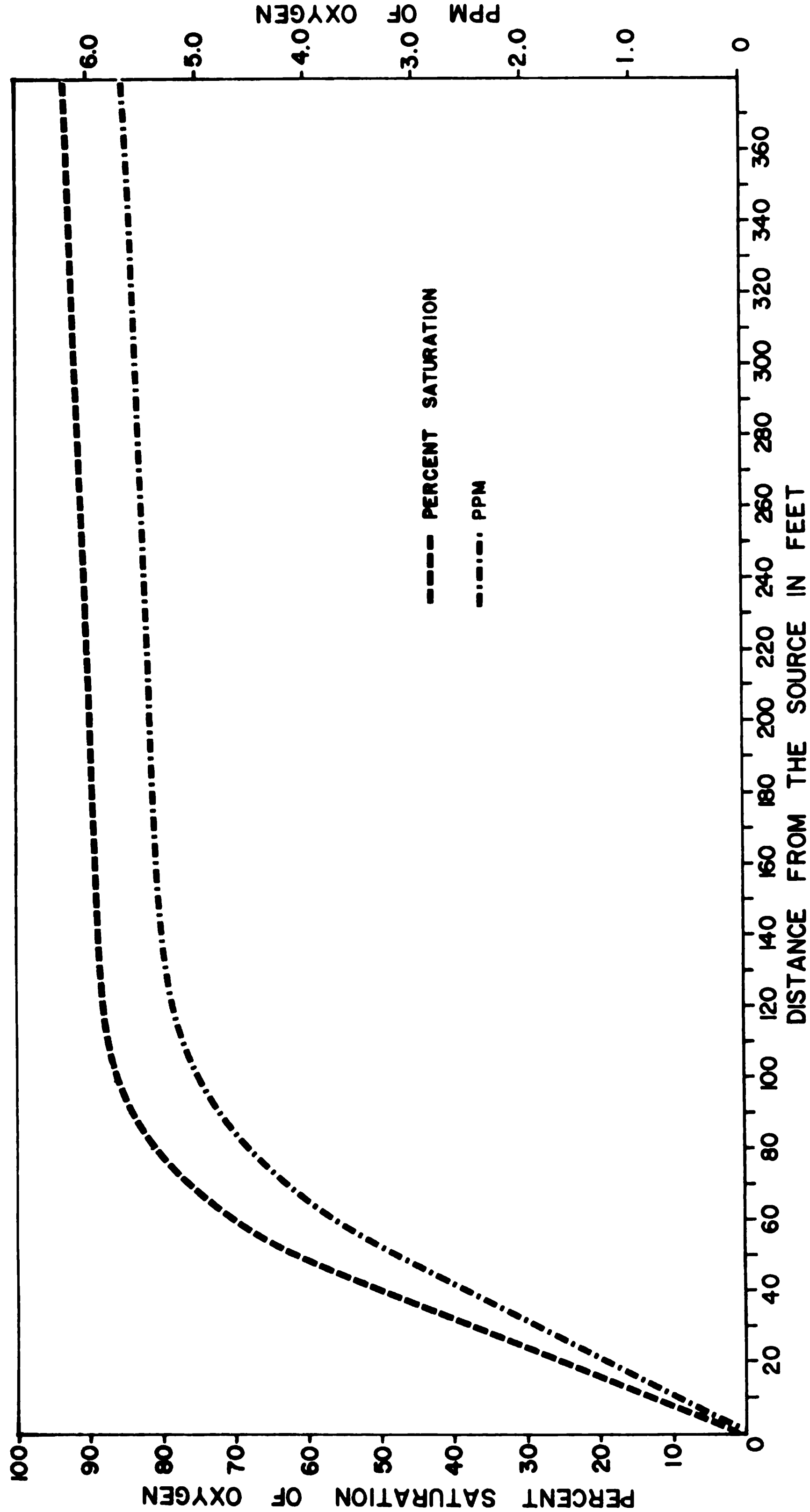

A
B
PERCENT SATURATION
PPM
PERCENT SATURATION OF OXYGEN
PPM OF OXYGEN
DISTANCE FROM THE SOURCE IN FEET
0
10
20
30
40
50
60
70
80
90
100
1.0
2.0
3.0
4.0
5.0
6.0
120
140
160

Figure 14. Change of oxygen content in ppm and percent saturation with distance from the source at Sleeping Child Hot Springs, Montana.


PERCENT SATURATION OF OXYGEN
PPM OF OXYGEN
DISTANCE FROM THE SOURCE IN FEET
PERCENT SATURATION
PPM
0
10
20
30
40
50
60
70
80
90
100
1.0
2.0
3.0
4.0
5.0
6.0
120
140
160
180
200
220
240
260
280
300
320
340
360

the water approached or reached a point of equilibrium with that in the air, stream characteristics such as width, depth, quantity and velocity of water, riffles, and pond-like flows created diverse situations that allowed oxygen to be absorbed at different rates.

Carbon dioxide, Alkalinity, and pH

Carbon dioxide and its associated ions and compounds present a more complex situation than does oxygen. Carbon dioxide in confined water is about 25 times more soluble than oxygen at 25 C (Reid, 1961) and five to ten times more soluble in the temperature ranges of these streams. Agitation, however, is a very effective method of eliminating free carbon dioxide from the water (Welch, 1935) so that as the water of these streams flows at shallow depths down relatively steep inclines the solubility is considerably reduced.

Water, upon combining with the carbon dioxide of the atmosphere and the product of respiration in the soil, forms H_2CO_3, carbonic acid. This dissociates into H^+ and HCO_3^-. As these come into contact with limestone, $CaCO_3$, the latter dissolves as $Ca(HCO_3)_2$. The $Ca(HCO_3)_2$ remains stable in the presence of free or equilibrium carbon dioxide represented by that in solution plus the CO_2 in H_2CO_3. The bicarbonate content of the emerging spring water is, therefore, generally dependent on the calcium content of the soil, the rock layers through which it passes, and on the carbon dioxide content of the water. Carbonates may also form from the sodium, potassium, and calcium in the feldspars of igneous rocks or be dissolved from deposits of magnesium, sodium, and potassium carbonates.

For calcium bicarbonate to be stable, a certain amount of surplus carbon dioxide must remain in solution. Loss of this surplus carbon dioxide (equilibrium CO_2) as the water emerges from the ground results in precipitation of $CaCO_3$ from the $Ca(HCO_3)_2$. When the concentration of $Ca(HCO_3)_2$ is high enough, as at Alhambra (South) Hot Springs, the $CaCO_3$ precipitates on any object with which it comes into contact. The Alhambra spring, possessing a total alkalinity of 637 ppm, has produced a travertine terrace, whereas approximately 200 yards to the north the spring group with a total alkalinity of 430 ppm did not produce a terrace.

The waters from both of the Alhambra springs and the Jackson spring, which had an alkalinity of 574 ppm, had high concentrations of free or equilibrium carbon dioxide as it was emitted from the ground, shown in Figure 15. This easily liberated excess carbon dioxide was given off rapidly until that which was liberated originated from the bicarbonates and carbonates and was produced at a slower rate. The dissociation is shown in the reaction:

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO_3^- \rightleftarrows H^+ + CO_3^=$$

The water in a confining aquifer has a high concentration of equilibrium carbon dioxide resulting in a shift to the right. This shift produces higher H^+ concentrations such as the pH values of 7.3 at Alhambra, North; 6.8 at Alhambra, South; and 7.1 at Jackson. Upon exposure of the water to the air, with subsequent loss of free carbon dioxide, there is a shift to the left whereby the pH is increased. Figures 15 and 16 illustrate this reciprocal relationship of these reactions.

The pH increased rapidly at the Alhambra and Jackson streams during the initial exposure to the atmosphere; this is shown in the

Figure 15. Curves showing changes in carbon dioxide content with distance at Alhambra (North), Alhambra (South), and Jackson. The mean values are given for Boulder, Lolo, Pipestone, and Sleeping Child, where the carbon dioxide content showed no change for the entire length of the streams. The carbon dioxide values were obtained by use of a nomogram from the Laboratory Manual for Chemical and Bacterial Analysis of Water and Sewage, Theroux, F. R., Eldridge, E. F., and Mallman, W. L., McGraw-Hill, New York, 1943.

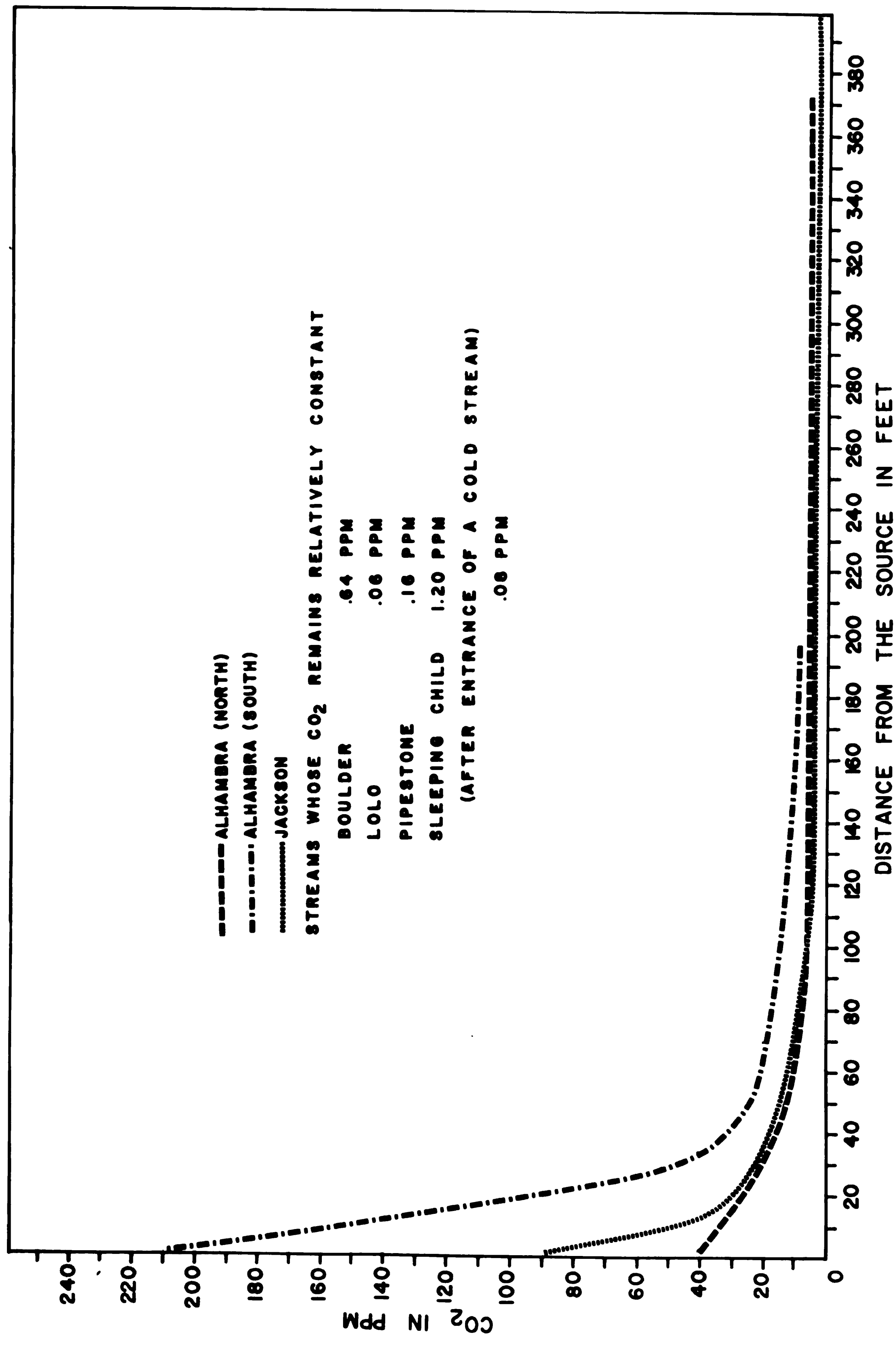
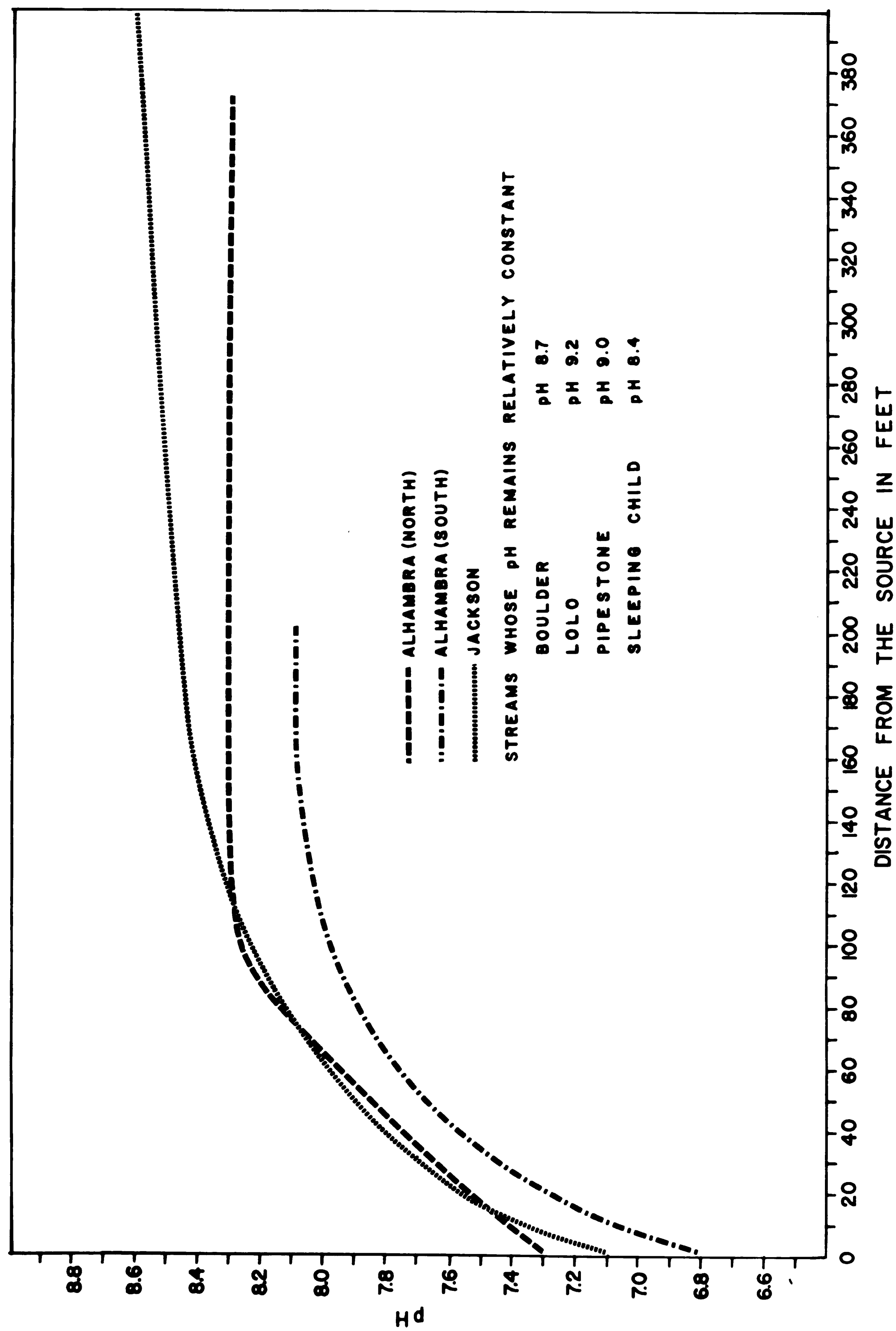

ALHAMBRA (NORTH)
ALHAMBRA (SOUTH)
JACKSON
STREAMS WHOSE CO_2 REMAINS RELATIVELY CONSTANT
BOULDER .64 PPM
LOLO .06 PPM
PIPESTONE .16 PPM
SLEEPING CHILD 1.20 PPM
(AFTER ENTRANCE OF A COLD STREAM) .08 PPM
CO_2 IN PPM
0
20
40
60
80
100
120
140
160
180
200
220
240
DISTANCE FROM THE SOURCE IN FEET
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380

Figure 16. Curves showing changes in pH with distance at Alhambra (North), Alhambra (South), and Jackson Hot Springs. The mean values are given for Boulder, Lolo, Pipestone, and Sleeping Child, in which the pH remained constant for the length of the stream.


ALHAMBRA (NORTH)
ALHAMBRA (SOUTH)
JACKSON
STREAMS WHOSE pH REMAINS RELATIVELY CONSTANT
BOULDER pH 8.7
LOLO pH 9.2
PIPESTONE pH 9.0
SLEEPING CHILD pH 8.4
pH
8.8
8.6
8.4
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
DISTANCE FROM THE SOURCE IN FEET

curves in Figure 16. As the emission rate for free carbon dioxide was reduced, the pH curves approached the asymtote. The pH curves for the Alhambra (North) stream appear to have reached the asymtote at approximately 100 feet from the source, whereas the pH values for the Alhambra (South) and Jackson streams indicate the asymtote would have been reached beyond the lengths of the thermal streams. These last two streams had the highest alkalinities and initially the highest carbon dioxide content, so there was a rapid emission of free carbon dioxide and accompanying increase in pH near the sources. The pH increased from 7.3 to a maximum of 8.3 at Alhambra (North), from 6.8 to 8.1 at Alhambra (South), and from 7.1 to 8.6 at Jackson. These changes in pH were from 1.0 to 1.5 units. The mean of the maximum pH values attained at all streams was 8.6, with maximum values ranging from 8.1 to 9.2.

The lower alkalinity of the water from the Boulder, Lolo, Pipestone, and Sleeping Child springs is responsible for the greatly reduced free or equilibrium carbon dioxide. The carbon dioxide in these springs was that in equilibrium, produced as a result of dissociation of the bicarbonate and carbonate ions. The alkalinity concentration, being relatively high throughout the length of the stream in comparison to the concentration of the carbon dioxide, accounted for the fact that the alkalinity was not noticeably affected by slight losses in carbon dioxide. The pH in these streams was probably raised somewhat by the loss of carbon dioxide, but the increase was not detected by the two methods used to record the pH.

<u>Dissolved substances</u>

The chemical nature of any water is a reflection of the chemical composition of the earth's crust through or over which it flows.

The chemical composition of both surface and ground water can exhibit wide ranges of concentration. Whereas the composition of surface water can be anticipated through knowledge of the surrounding terrain, the composition of ground water cannot be known *a priori*. Ordinarily, ground water contains a higher proportion of dissolved substances than surface water because it is exposed to soluble materials of the earth's crust to a greater degree. The concentration of these dissolved substances in ground water will be high in the water trapped for a long time, geologically, in isolated pockets of sedimentary rock or relatively low in water that flows rapidly through fissures of rather insoluble igneous rock.

The emerging thermal spring water will generally have a higher concentration of dissolved substances than most springs for one or more of the following reasons: (1) the great distance the water travels underground, (2) dissolved substances derived from magma, (3) water temperature.

Most thermal springs have continuous flows from artesian formations which are generally more extensive than the geologic formations responsible for other springs. In addition to some degree of horizontal flow, the water may also flow to great depths where it is heated.

Thermal water, in its usually unknown course, can pass through rocks in all ranges of solubility or through many combinations of rock type before it reaches the surface. As a rule, the greater the distance traveled, the more dissolved substances will be absorbed by the water.

As has been discussed in Chapter III, water in some thermal springs is partially composed of juvenile water derived from decomposing magmatic rocks. Simultaneous with the formation of juvenile water is the formation of gases and other substances that become dissolved in the meteoric water.

The third factor responsible for high concentration of dissolved substances in thermal springs is the well-known increase in chemical activity with increase in temperature. Generally speaking, for every 10 C increase in temperature, the chemical activity is doubled.

A summary of the major dissolved substances found in the streams during the summers of 1962 and 1963 is given in Table I. The proportions of these substances do not vary noticeably from what would be found in surface waters except for calcium and sodium. Sedimentary rocks comprise 75 percent of the land surface (Foster, 1942) in which calcium carbonate is important as a cementing material or as a major constituent. As a result of dissolving the calcium carbonate, the surface waters of North America have a mean calcium-sodium ratio of 2.6:1 (Clark, 1924). This may be compared with the mean calcium-sodium ratio in these streams of 1:30.

An explanation for the different ratios may be found in studies conducted along the Atlantic and Gulf Coastal Plains, where the same formations may contain both calcium and sodium waters. Calcium bicarbonate is found in the shallow rocks, whereas sodium bicarbonate is from the deeper rocks of these formations. This same phenomenon of increasing sodium content with increasing depth appears also to be effective in the formations of western Montana, considering that thermal water comes from deep formations. Since the two springs with the highest alkalinity, Alhambra and Jackson Hot Springs, also have the

Table I.--Summary of chemical data obtained from the thermal springs during the summers of 1962 and 1963

Ions and compounds in ppm.	Alhambra North	Alhambra South	Boulder	Jackson	Lolo	Pipestone	Sleeping Child
Total alkalinity	430	637	161	574	84	98	161 *
Total phosphate	1.0	1.2	1.1	0.99	0.95	0.89	0.76
Ortho phosphate	0.098	0.063	0.097	0.08	0.07	0.08	0.07
Nitrate	0.01	0.01	0.012	0.02	0.01	0.015	0.015
Nitrite	All samples less than .002 ppm. (limit of sensitivity of the method used)						
Iron	0.077	0.085	0.05	0.06	0.03	0.04	trace
Silicon	**	47	48.6	41.6	43	43	42
Sulfate	88.7	113	68	55	63	83	71
Sodium	**	219	110	238	48	90	119
Potassium	**	10.2	4.1	11.8	1.4	2.0	3.2
Calcium	**	9.7	2.4	7.9	1.5	2.4	4.0
Magnesium	**	5.7	0.0	3.6	0.3	0.0	1.0
Chloride	**	13.1	21.7	11.9	15.6	24.9	15.2
Zinc	**	All samples less than 1 ppm. (limit of sensitivity of the method used)					
Aluminum	**	All samples less than 0.1 ppm. (limit of sensitivity of the method used)					

* Alkalinity averaged 125.5 after the entrance of a cold stream at 100 feet from the source.
** Data not available

highest sodium concentration, it is quite probable that these ions were dissolved as sodium bicarbonate.

For comparison with other thermal springs, the chemical composition is given for spring groups from widely separated areas--Iceland, Yellowstone National Park, and Steamboat Springs, Nevada.

In a review of the literature pertaining to the chemical composition of Icelandic thermal springs, Tuxen (1944) lists the results of the work by 12 investigators who analyzed the water from 34 thermal springs. The information from his table is condensed in the following figures to facilitate comparison with the results obtained from the six Montana streams. To allow for individual differences in the method in which the samples were collected and tested, the medians are given rather than the means, since values obtained by some investigators would completely outweigh the values obtained by others. For example, of 33 values listed for calcium, 17 were below 10 mg/l, whereas one was at 555 mg/l, which would result in an unrealistic mean. Use of medians will also better take into account results listed as traces. The dissolved substances are followed by the ranges and then the medians. The values are in mg/l (ppm). SiO_2, 685-1 (213); Cl, 240-trace (72); Na, 688-8.7 (198); K, 32-trace (12); Ca, 555-trace (8.9); Mg, 148.4-trace (1.8).

The other area, Yellowstone National Park, contains the greatest concentration of thermal springs and geysers in the world. Since the area is composed of numerous spring groups, many of which have not been analyzed, it is perhaps best to list the partial composition of a few well-known groups as given by Allen and Day (1935). The following values are in ppm. For Lower Geyser Basin: SiO_2, 250;

Cl, 298; Na, 339; K, 13.8; Ca, 3; Mg, 0. For Shoshone: SiO_2, 294; Cl, 193; Na, 331; K, 17.8; Ca, 6.3; Mg, trace. For Firehole Lake: SiO_2, 152; Cl, 55; Na, 94; K, 17; Ca, 9; Mg, trace.

The composition of some prominent ions and compounds were also listed by Allen and Day (1935)for two Nevada thermal springs. Steamboat Springs: SiO_2, 343; Cl, 978; Na, 744; K, 77; Ca, 6; mg, trace. Beowawe Hot Springs: SiO_2, 449; Cl, 47; Na, 239; K, 33; Ca, 2; Mg, none.

Water Temperature

The water of artesian springs are noted for their constant temperature, the fluctuations of this dimension being inversely proportional to the distance the water travels. Although the water temperature of the springs used in this study may fluctuate throughout the year, the temperature remained constant during the summers of 1962 and 1963 at those springs where it could be measured as the water came directly from the ground. At Lolo Hot Springs a cement retaining wall was built around the main spring to create a reservoir of water used to fill a nearby swimming pool three days a week. During the time when the reservoir was being emptied or filled, the temperature of the water emitted from a pipe would vary from 44.5 to 46 C.

Although the water temperature remained constant at the other sources, differences were recorded at measured distances from the sources from one visitation to another. At the streams where these temperature differences were noted, the temperature was recorded at various times during the day. The temperature at any given point was found to vary according to the air temperature, cloud cover, and the angle at which the sun's radiation struck the water. To determine at which distance interval the temperature varied the most, two complete series of water temperature measurements were made at Sleeping Child Hot Springs. Each series consisted of 36 measurements made at five-foot intervals. Since the measurements could not be made simultaneously for either series, they were begun at the source each time and the median air temperature was obtained from values taken at the beginning and end of each series. The median air temperature for the first series was 20 C, for the second series, 28 C. In this air temperature interval the water temperature was found to vary up to 1.5 C. This figure is not important in itself since a different value would have been obtained if the series had been taken during any other atmospheric temperature fluctuation.

The amount of variance of water temperature with air temperature differed from stream to stream. At a point in the Boulder Hot Springs stream at 9:30 A.M. the water temperature was 52.5 C with an air temperature of 27 C. At 1:30 P.M., when the air temperature was 33 C, the water temperature at the same point was 54.5 C. At another point farther downstream when the air temperature was 27 C, the water was 45 C and as the air temperature rose to 33 C, the water was 49 C.

The difficulty in predicting the effect of various factors on changing stream temperature is shown when a difference of 8 C air temperature at Sleeping Child produced a change of 1.5 C in the water, whereas at Boulder a difference of 5 C air temperature produced a change of 4 C in the water. Therefore, the effect of a 10 C change of air temperature in the temperature range of about 20-30 C will produce a 1.87 C change in water temperature at Sleeping Child, whereas a 10 C change of air temperature at Boulder will change the water 6.6 C.

Whereas a stream such as that at Boulder exhibited relatively great changes in water temperature with air temperature, the stream at Pipestone (East) did not change to any measurable degree at any time during the two summers.

The temperature of each stream is controlled by characteristics of the terrain and by the stream itself. The factors that are effective are: width and depth of the stream, water volume, water velocity, riffles, and individual characteristics such as cliffs or ravine walls at Sleeping Child, overhanging vegetation at Alhambra (North), Boulder, Lolo, and Pipestone, alternating fast water and pond-like flows at Jackson and Lolo, incoming seepages of thermal water at Alhambra (North and South), Pipestone (East and West), incoming cold water at Sleeping Child. These factors, in addition to the angle of the sun's radiation on the water, variations in air temperature and cloud cover mentioned earlier, create innumerable situations that are, in all practicability, impossible to evaluate. Whereas it may be feasible to get an approximation of the degree to which water temperature is altered by the air temperature, it is not practical to take series of precise measurements throughout the day or week, as was described for Sleeping Child, since each series will vary throughout the year.

The point to present, however, is that temperatures do change in a thermal stream, so the possible fluctuations should be considered when an alga is reported to grow at a given temperature. Since the temperatures were not recorded throughout each day, no precise means could be obtained. Instead, approximate means were used of daytime temperatures observed at the times the streams were visited. These were taken to the nearest half degree except near the sources where

Figure 17. Curves produced from mean temperature values obtained from daytime observations during the summers of 1962 and 1963 in the streams at Alhambra Hot Springs (North and South), Montana.

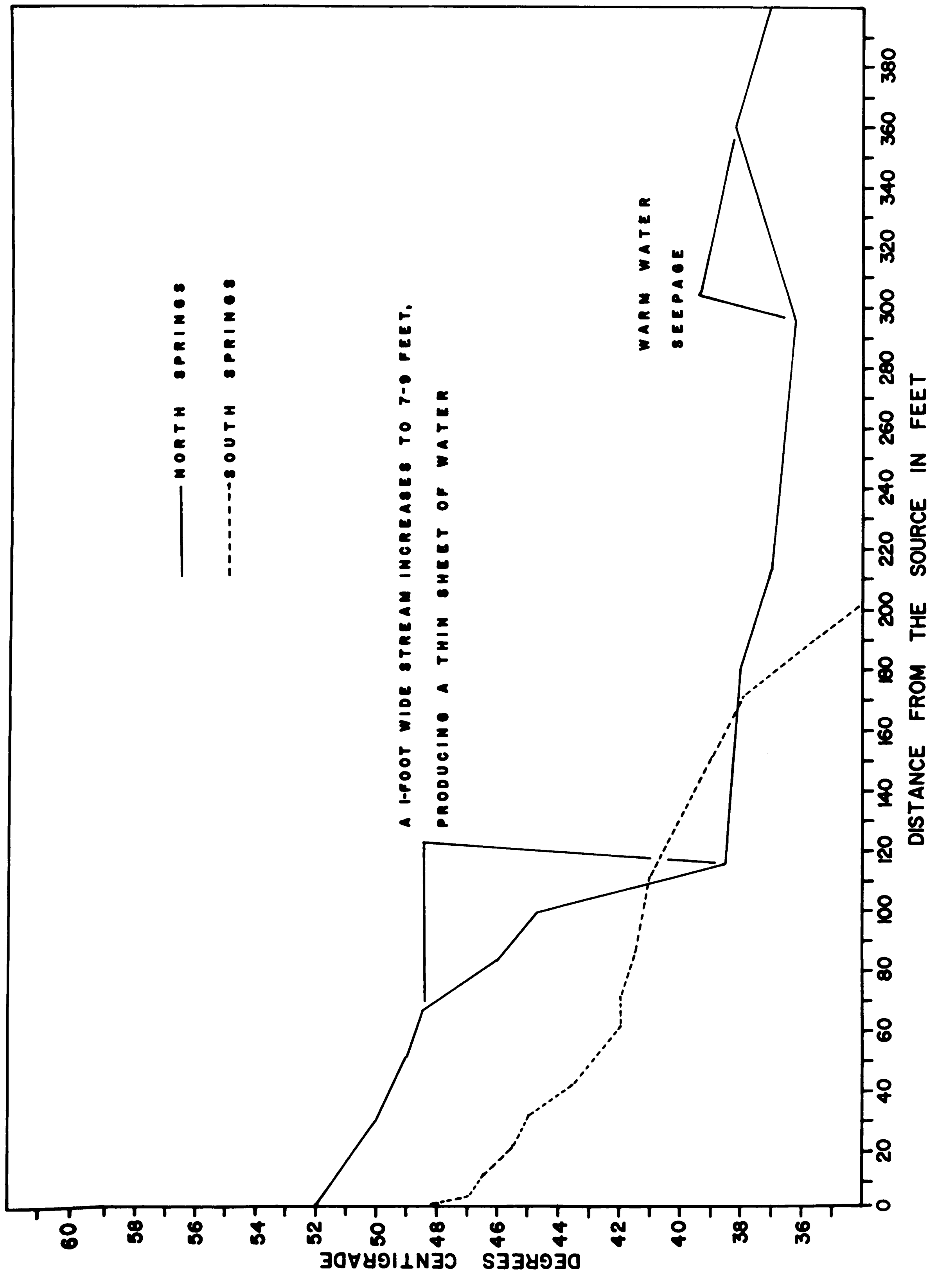
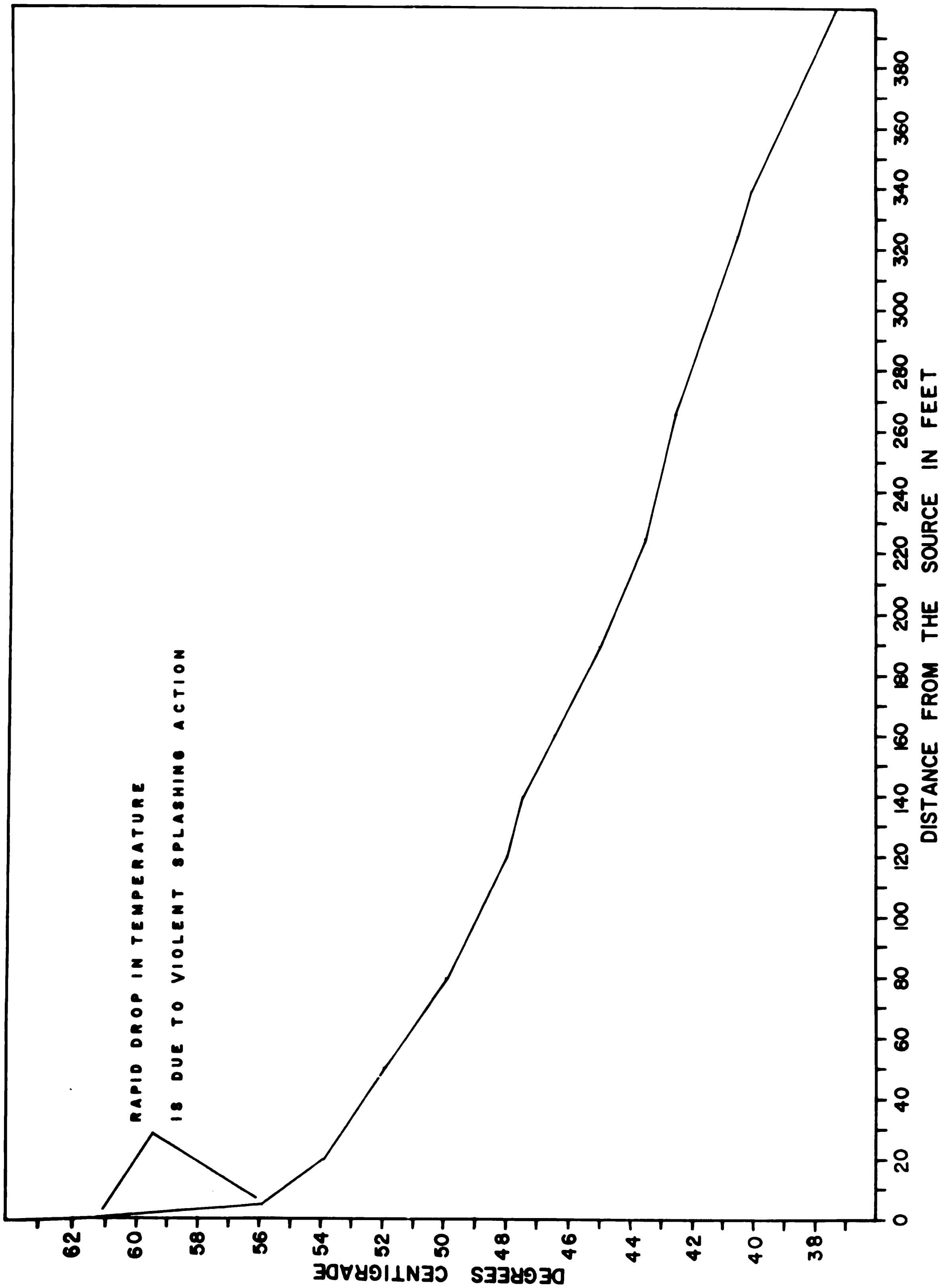

NORTH SPRINGS
SOUTH SPRINGS
A 1-FOOT WIDE STREAM INCREASES TO 7-9 FEET,
PRODUCING A THIN SHEET OF WATER
WARM WATER
SEEPAGE
DEGREES CENTIGRADE
60 58 56 54 52 50 48 46 44 42 40 38 36
DISTANCE FROM THE SOURCE IN FEET
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380

Figure 18. Curves produced from mean temperature values obtained from daytime observations during the summers of 1962 and 1963 in the stream at Boulder Hot Springs, Montana.



RAPID DROP IN TEMPERATURE
IS DUE TO VIOLENT SPLASHING ACTION
DISTANCE FROM THE SOURCE IN FEET
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380
DEGREES CENTIGRADE
62 60 58 56 54 52 50 48 46 44 42 40 38

Figure 19. Curve produced from mean temperature values obtained from daytime observations during the summers of 1962 and 1963 in the stream at Jackson Hot Springs, Montana.

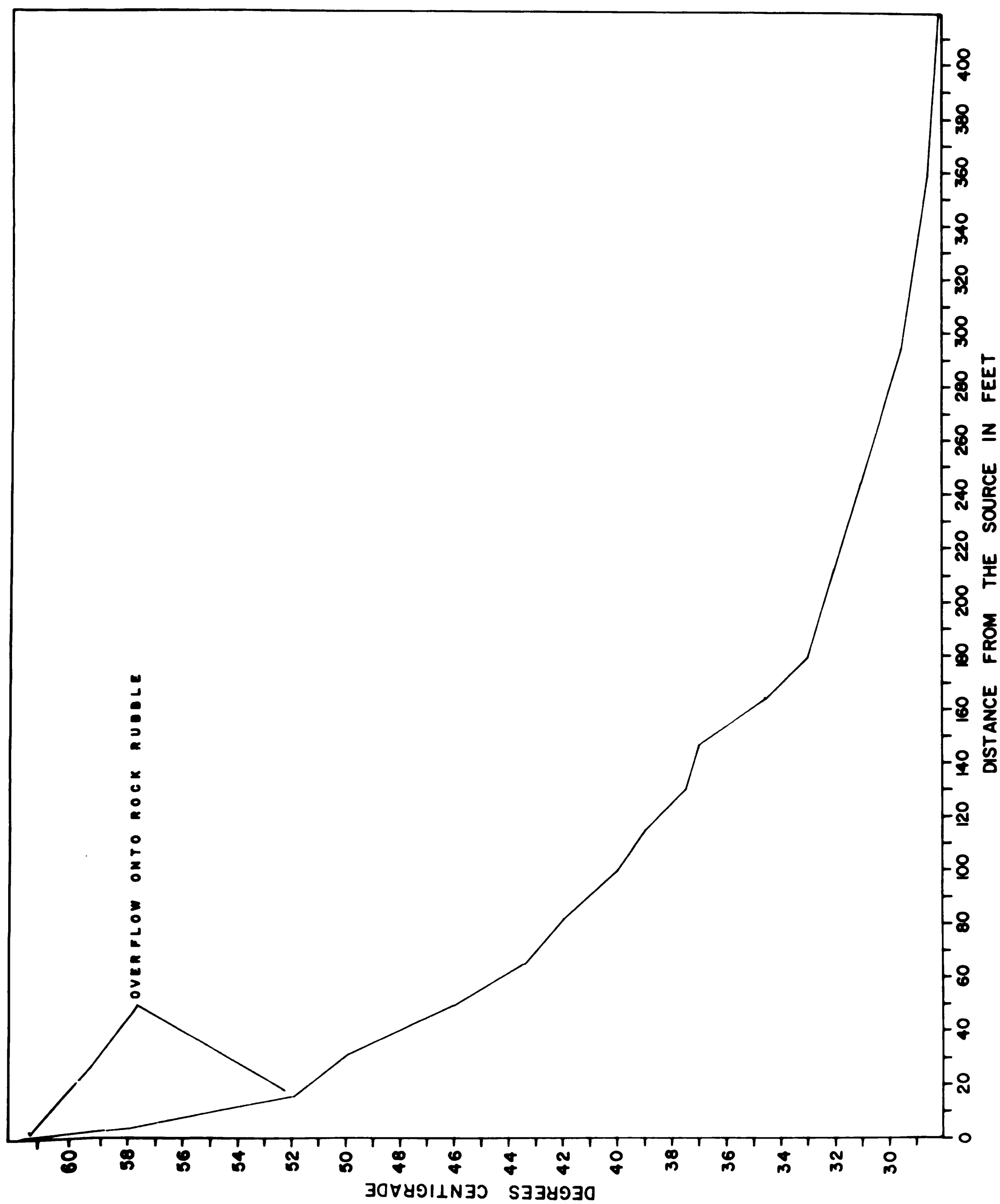

OVERFLOW ONTO ROCK RUBBLE
DISTANCE FROM THE SOURCE IN FEET
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400
DEGREES CENTIGRADE
60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30

Figure 20. Curve produced from mean temperature values obtained from daytime observations during the summers of 1962 and 1963 in the stream at Lolo Hot Springs, Montana.

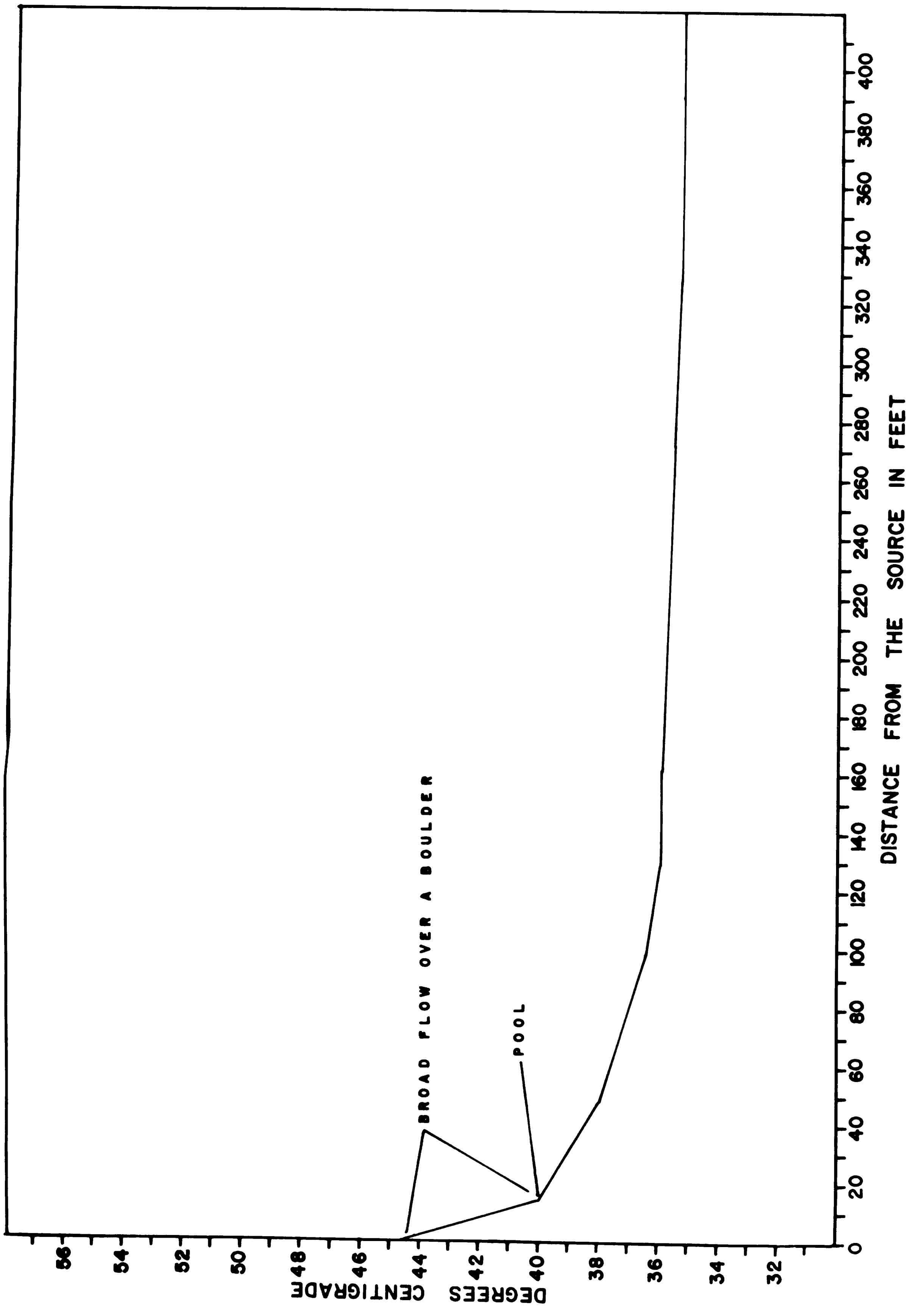

BROAD FLOW OVER A BOULDER
POOL
DISTANCE FROM THE SOURCE IN FEET
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400
DEGREES CENTIGRADE
56 54 52 50 48 46 44 42 40 38 36 34 32

Figure 21. Curves produced from mean temperature values obtained from daytime observations during the summers of 1962 and 1963 in the streams at Pipestone Hot Springs (West and East), Montana.

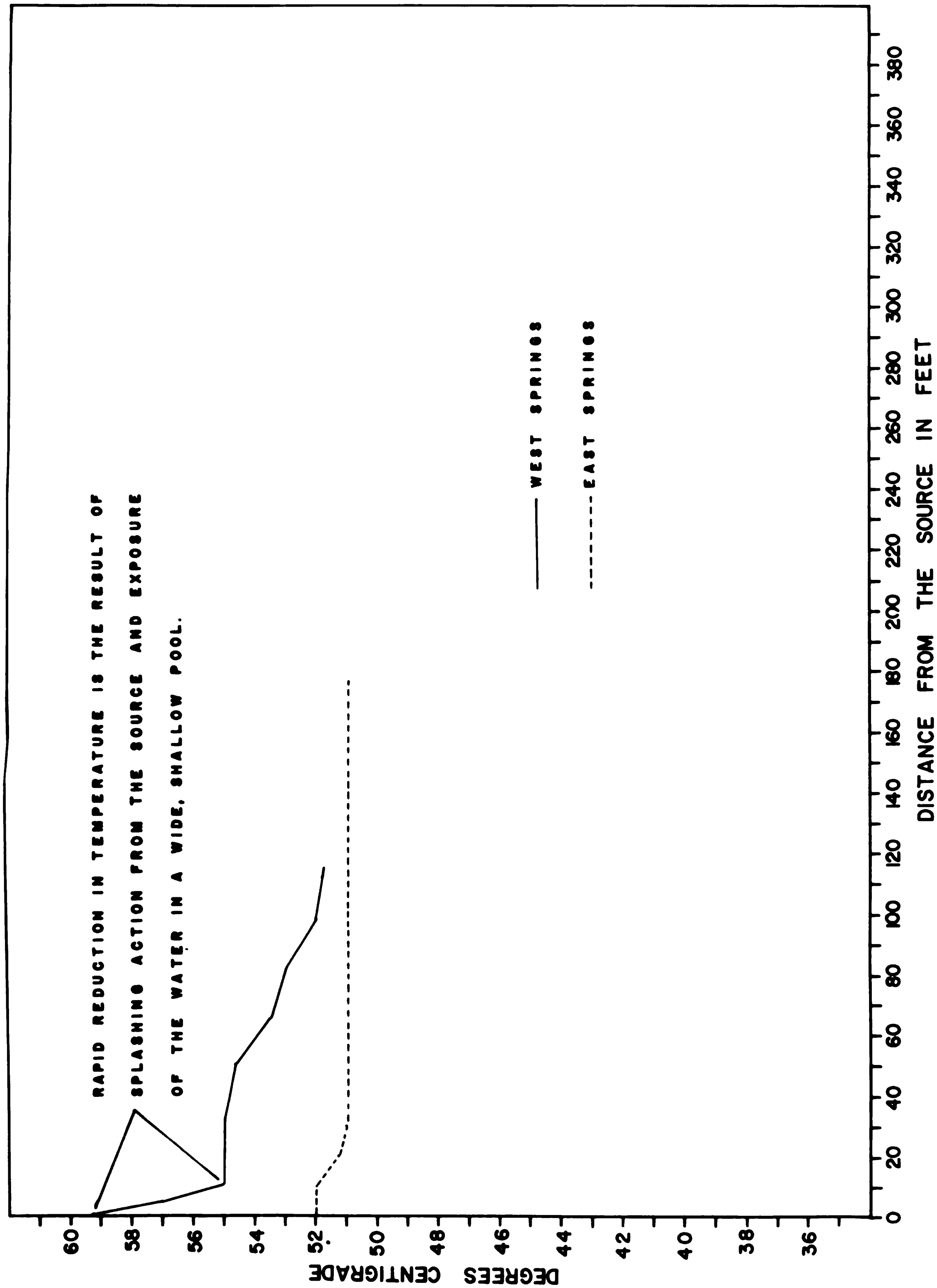
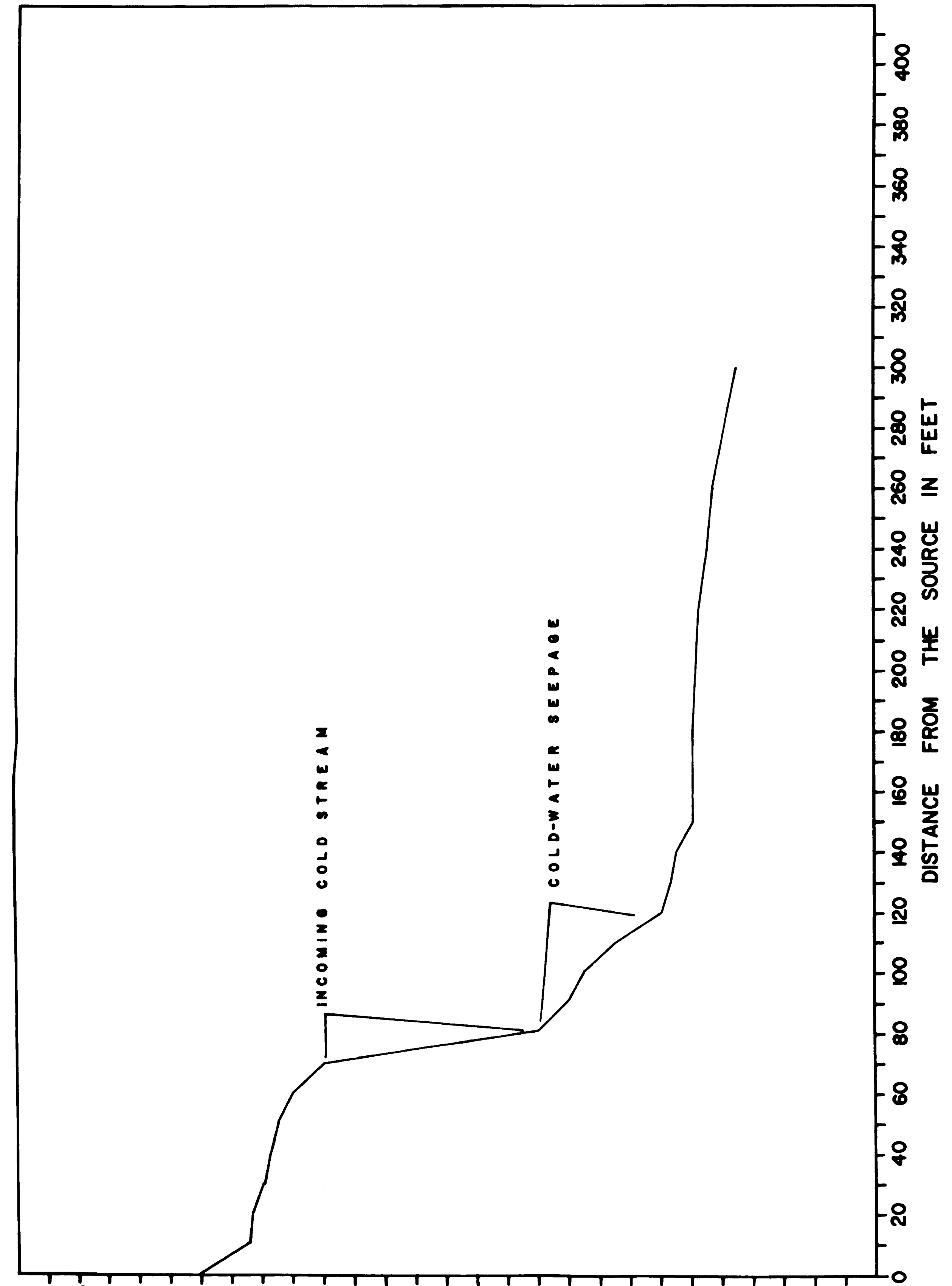

RAPID REDUCTION IN TEMPERATURE IS THE RESULT OF
SPLASHING ACTION FROM THE SOURCE AND EXPOSURE
OF THE WATER IN A WIDE, SHALLOW POOL.
WEST SPRINGS
EAST SPRINGS
DISTANCE FROM THE SOURCE IN FEET
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380
DEGREES CENTIGRADE
60 58 56 54 52 50 48 46 44 42 40 38 36

Figure 22. Curve produced from mean temperature values obtained from daytime observations during the summers of 1962 and 1963 in the stream at Sleeping Child Hot Springs, Montana.


INCOMING COLD STREAM
COLD-WATER SEEPAGE
DEGREES CENTIGRADE
56 54 52 50 48 46 44 42 40 38 36 34 32
DISTANCE FROM THE SOURCE IN FEET
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400

temporal fluctuations are minimal.

Annotated List of the Species

Included in the following list of algal species found during this study is information pertaining to their distribution along a temperature gradient. Under each taxa group the streams are listed in which an alga was found and its temperature range of occurrence. The number of points within this range in which the alga was collected are also given to indicate the regularity of occurrence along the temperature gradient. Rather than merely indicating that an alga was found in a given number of samples, a better concept of its distribution can be presented by indicating that it was found in a number of samples among the total number of samples collected within the temperature range. Thus, the fact that an alga was found in eight samples in a total of eight samples within a temperature range conveys different information from being found in eight of seventeen samples. An alga is not often evenly distributed within a given range of occurrence, but, rather, its occurrence will be clumped. This clumped nature is illustrated when an alga is shown to occur in eight of seventeen samples, whereas clumping is not as great for an alga that is represented in eight of eight samples.

To further convey information pertaining to distribution, the maximum numerical representation, maximum volumetric representation, and the temperature at which these values were attained are given for each alga at each stream. More than one value may be given for an alga if there is an unusual difference between the maximum value and values taken from other points in the stream. Two or more of the higher values may be similar, in which case they are all given. Therefore, the temperature range, the number of samples containing an alga in a total number of samples, the maximum representation, and the temperature at which this representation occurred are given in a concise manner. More detailed information is given in subsequent sections.

Descriptions of the species have largely been omitted except to facilitate discussion of morphological characteristics in some cases, or to describe new species or varieties. In the event information regarding a species is desired, the reader may use the appropriate literature, or he may refer to the illustrations accompanying this list. The illustrations have been limited to the Cyanophyta, a group well represented in thermal environments. Several illustrations of certain species are given to show morphological modifications resulting from possible environmental factors.

Every effort was made to identify the Cyanophyta and Chlorophyta to species, but because the spores necessary for identification of several Chlorophyta were absent, these were identified to genus. The Chrysophyta (Bacillariophyceae) were identified to genus since to proceed further requires the work of a specialist.

As described in the methods in the previous chapter, the percentage of the total algal volume and percentage of the total algae enumerated have been computed for each algae from each sample. In the following list of the algae, the numerical representation will be referred to as frequency since it is the ratio of the individuals of a species to the total number of all species in the sample. This mathematical treatment of the term frequency should be distinguished from the ecological. Ecologists have referred to frequency as the percentage of sample plots in which a species occurs. The manner in which the algae grew in tangled masses, and the manner in which the microscope slides had to be prepared, preclude the traditional ecological treatment of frequency.

When the maximum and minimum temperatures are given in which algae were found, it should be kept in mind that their ranges are limited by the upper and lower temperatures of the stream from which they were taken. The temperatures for each stream within which algal samples were taken are listed here for reference:

Alhambra (North), 36.0-54.4 C	Lolo, 34.0-45.5 C
Alhambra (South), 41.0-48.0 C	Pipestone (West), 52.0-57.0 C
Boulder, 36.0-56.0 C	Pipestone (East), 51.0-52.0 C
Jackson, 26.0-58.0 C	Sleeping Child, 34.5-52.0 C

Division: Chlorophyta

Class: Chlorophyceae

Order: Ulotrichales

Family: Ulotrichaceae

Ulothrix Kuetzing

Ulothrix subconstricta G. S. West

Distrubution:

Boulder, 37.0-40.5 C

In two of three samples, with maximum frequency of 1.83 percent and maximum volume of 1.29 percent at 37.0 C.

Jackson, 33.0-41.0 C

In six of nine samples, with maximum frequency of 43.1 percent and maximum volume of 45.6 percent at 41.0 C. *U. subconstricta* was not represented during enumeration in the other samples.

Lolo, 36.0 C

In three of three samples, with maximum frequency of 70.22 percent and maximum volume of 25.45 percent. The frequency values in the other two samples were 2.42 and 1.36 percent.

Sleeping Child, 34.5-42.0 C

In 15 of 15 samples, with maximum frequency of 23.71 percent and maximum volume of 27.58 percent at 37.0 C.

Mean maximum temperature: 39.9 C

Order: Chaetophorales

Family: Chaetophoraceae

Stigeoclonium Kuetzing

Stigeoclonium attenuatum (Hazen) Collins

Distribution:

Sleeping Child, 34.5-42.0 C

In 15 of 15 samples. *S. attenuatum* appeared in this stream at the junction of the warm water and an inflow of cold water. It made a slight appearance at 42.0 C, but from 40.0 to 39.5 C in three samples from 90 to 110 feet from the source, the mean frequency was 93.2 percent whereas the mean volume was 92.5 percent. Although the representation was lower in downstream samples, it remained one of the major algae to 34.5 C.

Order: Cladophorales

Family: Cladophoraceae

Rhizoclonium Kuetzing

Rhizoclonium fontanum Kuetzing

Distribution:

Boulder, 38.0 C

In one of one sample, with frequency of 8.37 percent and volume of 36.57 percent.

Sleeping Child, 34.5-36.0 C.

In six of six samples, with maximum frequency of 6.92 percent and maximum volume of 50.55 percent at 36.0 C.

Mean maximum temperature: 37.0 C

Rhizoclonium hieroglyphicum (Ag.) Kuetzing

Distribution:

Jackson, 26.0-32.0 C

In five of five samples, with maximum frequency of 18.68 percent at 27.5 C. Maximum volume of 84.7 percent was at 29.5 C.

Order: Oedogoniales

Family: Oedogoniaceae

Oedogonium Link

The vegetative filaments of Oedogonium found during the course of this study could not be differentiated to species since the oogonium necessary to do so was absent in each stream. Filaments within two diameter ranges were found, 20-25 μ and 11-14 μ. Filaments of 20-25 μ were found in one stream; those of 11-14 μ were found in six streams. It is logical to assume that the 20-25μ filaments are of one species. It is possible that the 11-14 μ filaments from six streams were also of one species since this range in diameters is the same or less than the range in diameters of many known species with comparable diameters. Filaments of the latter diameter, however, were from streams of different environmental conditions so the possibility of two or more species should be considered. Oedogonium filaments of the dimensions described above have been arbitrarily placed in two unnamed species. These have been distinguished by the mean diameters of the vegetative filaments which follow the generic name.

Oedogonium sp. A (12.5 μ)

Distribution:

Alhambra (North), 36.0-37.5 C

In three of three samples, with maximum frequency of 98.3 percent and maximum volume of 96.9 percent at 37.5 C.

Alhambra (South), 41.0-42.0 C

In four of four samples, with frequency values over 70 percent and volume values over 93 percent in all samples.

Boulder, 37.0-42.5 C

In three of four samples, with maximum frequency of 4.44 percent and maximum volume of 2.42 percent at 40.5 C

Jackson, 33.0-40.0 C

In five of seven samples. It was only slightly represented in all but the sample taken at 36.0 C where the frequency was 82.7 percent and the volume was 98.38 percent.

Lolo, 36.0-37.5 C

In four of four samples, with maximum frequency of 8.23 percent and maximum volume of 71.37 percent at 36.0 C (131 feet from the source).

Sleeping Child, 34.5-37.0 C

In three of 11 samples, with maximum frequency of 2.57 percent and maximum volume of 27.04 percent at 37.0 C.

Mean maximum temperature: 39.4 C

<u>Oedogonium</u> sp. B (25 μ)

Distribution:

Sleeping Child, 34.5-36.5 C

In ten of ten samples, with maximum frequency of 3.18 percent and maximum volume of 36.84 percent at 36.5 C.

Order: Chlorococcales

Family: Oocystaceae

<u>Oocystis</u> Naegeli

<u>Oocystis</u> <u>solitaria</u> Wittrock

Distribution:

Alhambra (North), 36.0 C

In one of one sample but was not represented during enumeration.

Lolo, 35.0 C

In one of one sample where the frequency was 0.42 percent and the volume was 5.15 percent.

Mean maximum temperature: 35.5 C

Order: Zygnematales

Family: Zygnemataceae

<u>Mougeotia</u> (Ag.) Wittrock

<u>Mougeotia</u> sp.

<u>Mougeotia</u> sp. found in the following streams had a diameter of 8 μ, but zygospores necessary for species identification were absent.

Distribution:

Jackson, 32.0 C

In one of one sample, but was not represented during enumeration.

Sleeping Child, 35.3-42.0 C

In two of 14 samples, with maximum frequency of 39.7 percent and maximum volume of 83.93 percent at 42.0 C. The sample taken at 42.0 C was from the point where a small cold stream entered the warm stream. Since Mougeotia sp. did not appear again until the water cooled to 35.3 C (130 feet from the source), it is possible short intervals of increased flow from the cold stream or small temporary eddies of cold water cooled the alga found at 42.0 C sufficiently to enable it to endure a higher temperature.

Mean maximum temperature: 33.6 C

Spirogyra Link

Spirogyra spp. found during this study were without the zygospores necessary for species identification. All the filaments were within five diameter ranges, with mean diameters of 27, 32, 38.5, 48, and 54 μ. Filaments with a mean diameter of 32 μ were found in two streams, whereas filaments of the other diameters were found in separate streams. Although filaments of a given diameter from one stream may be of the same species with algae of a different diameter from another stream (i.e., 27 and 32 μ or 48 and 54 μ), they have been arbitrarily distinguished on the basis of their size. In the following list the diameters are given after the genus for differentiation.

Spirogyra sp. A (22 μ)

Distribution:

Alhambra (North), 36.0-37.5 C

In three of three samples with maximum frequency of 3.2 percent and maximum volume of 10.0 percent at 36.5 C.

Spirogyra sp. B (27 μ)

Distribution:

Jackson, 26.0-40.0 C

In eight of 11 samples. From 32.0 C downstream to 26.0 C it was the dominant alga, with frequency over 20 percent and volume over 60 percent in three of the samples.

Spirogyra sp. C (32 μ)

Distribution:

Boulder, 36.0-42.5 C

In five of five samples. It abruptly represented 30.09 percent of the algae and 81.24 percent of the algal volume at 42.5 C. In four of the five samples it was volumetrically the major alga.

Lolo, 34.0-38.0 C

In eight of eight samples. At 38.0 C its frequency was 2.49 percent whereas the volume was 95.8 percent. This discrepancy in figures is due to the small diameters of the coexisting algae, primarily Phormidium angustissimum, which was 82.29 percent of the algae but 3.48 percent of the algal volume.

Mean maximum temperature: 40.2 C

Spirogyra sp. D (38.5 μ)

Distribution:

Sleeping Child, 34.5-36.0

In seven of eight samples. This alga did not exceed one percent of the total algae but was approximately 15 percent of the algal volume in three samples.

Spirogyra sp. E (48 μ)

Distribution:

Boulder, 36.0 C

In one of one sample but was not represented during enumeration.

Spirogyra sp. F (54 μ)

Distribution:

Jackson, 36.0-41.0 C

In six of seven samples. It abruptly represented 80.9 percent of the algae and 99.8 percent of the algal volume in its first appearance at 41.0 C. In four of the samples it represented 85 percent or more of the volume.

Mean maximum temperature of all species of Spirogyra spp.: 38.9 C.

Family: Desmidiaceae

Cosmarium Corda

Cosmarium obtusatum Schmidle

Distribution:

Boulder, 36.0 C

In one of one sample but was not represented during enumeration.

Lolo, 34.0-38.0 C

In eight of eight samples, with maximum frequency of 4.71 percent and maximum volume of 55.05 percent at 35.5 C.

Sleeping Child, 35.3 C

In one of one sample, but was not represented during enumeration.

Mean maximum temperature: 36.4 C

Division: Chrysophyta

Class: Bacillariophyceae

Order: Pennales

Family: Fragilariaceae

Fragilaria Lyngbye

Fragilaria sp.

Distribution:

Sleeping Child, 34.5-40.0 C

In 13 of 14 samples, with maximum frequency of 9.78 percent and maximum volume of 27.9 percent at 36.0 C (160 feet from the source). In all other samples the frequency was less than two percent.

Family: Achnanthaceae

Achnanthes Bory

Achnanthes spp.

Distribution:

Alhambra (North), 36.5-39.0 C

In three of three samples, with a maximum frequency of 0.80 percent and maximum volume of 0.07 percent at 37.5 C.

Alhambra (South), 41.0-43.5 C

In four of five samples, with maximum frequency of 0.80 percent and maximum volume of 0.79 percent at 42.0 C.

Boulder, 36.0-51.0 C

In 12 of 16 samples, with maximum frequency of 19.11 percent at 42.5 C and maximum volume of 5.48 percent at 43.5 C.

Jackson, 26.0-44.5 C

In 17 of 18 samples, with maximum frequency of 15.62 percent and maximum volume of 29.1 percent at 33.0 C.

Lolo, 34.0-36.5 C

In seven of seven samples, but neither the frequency nor the volume exceeded one percent at any point.

Sleeping Child, 34.5-40.0 C

In eight of 13 samples, but was represented during enumeration at only 35.8 C where it attained 0.36 percent of the algae and 0.05 percent of the algal volume.

Mean maximum temperature: 42.4 C

Family: Naviculaceae

Navicula Bory

Navicula spp.

Distribution:

Alhambra (North) 36.0-36.5 C

In two of two samples, but was not represented during enumeration.

Alhambra (South), 41.5-43.5 C

In four of four samples, but was not represented during enumeration.

Boulder, 36.0-42.5 C

In four of five samples, with maximum frequency of 13.4 percent and maximum volume of 9.31 percent at 38.0 C.

Jackson, 36.0-44.5 C

In seven of 12 samples, with maximum frequency of 11.11 percent at 31.0 C, whereas the maximum volume of slightly over eight percent was at 37.0 and 38.0 C.

Lolo, 34.0-36.0 C

In two of five samples, but was not represented during enumeration.

Sleeping Child, 36.5 C

In one of one sample, but was not represented during enumeration.

Mean maximum temperature: 39.9 C

Pinnularia Ehrenberg

Pinnularia spp.

Distribution:

Alhambra (North), 36.0-39.0 C

In three of four samples, but was not represented during enumeration.

Alhambra (South), 41.0-41.5 C

In two of two samples, but was not represented during enumeration.

Boulder, 38.0-42.5 C

In three of three samples, with maximum frequency of 11.0 percent and maximum volume of 9.16 percent at 37.0 C.

Jackson, 26.0-42.5 C

In eight of 15 samples, with maximum frequency of 3.17 percent at 40.0 C, whereas the maximum volume of 27.9 percent was at 33.0 C. The volume representation at all other points was 1.39 percent or less.

Lolo, 34.0-39.5 C

In four of nine samples, but was not represented during enumeration.

Mean maximum temperature: 41.0 C

Pleurosigma Smith

Pleurosigma sp.

Distribution:

Jackson, 37.5 C

In one of one sample, but was not represented during enumeration.

Family Gomphonemataceae

Gomphonema Agardh

Gomphonema spp.

Distribution:

Alhambra (North), 36.5 C

In one of one sample but was not represented during enumeration.

Alhambra (South), 41.0-42.0 C

In three of four samples, but was not represented during enumeration.

Boulder, 37.0-42.5 C

In four of four samples with maximum frequency of 22.34 percent at 38.0 C and maximum volume of 3.66 percent at 37.0 C.

Jackson, 26.0-40.0 C

In five of 11 samples. Gomphonema sp. was present at 40.0 C but did not reappear until the water had cooled to 32.0 C, where it was found in five consecutive samples. The maximum frequency of 10.22 percent was at 29.5 C and maximum volume of 0.68 percent was at 27.5 C.

Lolo, 34.0-36.5 C

In seven of seven samples, with maximum frequency of 19.54 percent and maximum volume of 5.44 percent at 36.0 C.

Sleeping Child, 34.5-42.0 C

In 14 of 15 samples with maximum frequency of 3.59 percent and maximum volume of 1.14 percent at 36.0 C.

Mean maximum temperature: 39.9 C.

Family: Cymbellaceae

Amphora Ehrenberg

Amphora spp.

Distribution:

Alhambra (North), 36.0-39.0 C

In three of three samples, but was not represented during enumeration.

Boulder, 37.0 C

In one of one sample where it represented 4.58 percent of the algae and 10.05 percent of the algal volume.

Lolo, 36.0 C

In one of one sample, but was not represented during enumeration.

Sleeping Child, 35.5 C

In one of one sample, but was not represented during enumeration.

Mean maximum temperature: 36.9 C

Epithemia de Brébisson

Epithemia spp.

Distribution:

Alhambra (North), 39.0 C

In one of one sample but was not represented during enumeration.

Alhambra (South), 41.0-42.0 C

In three of three samples, but was not represented during enumeration.

Boulder, 36.0-42.5 C

In four of five samples. Frequency values of 2.38 and 2.91 percent were attained at 36.0 and 42.5 C. The volume was 1.42 percent or less at all temperatures.

Lolo, 36.0 C

In three of three samples, but was not represented during enumeration.

Mean maximum temperature: 39.9 C

Epithemia sp.

This species of *Epithemia* was decidedly different from that listed above.

Distribution:

Boulder, 36.0-42.5 C

In three of five samples, with maximum frequency of 1.94 percent and maximum volume of 0.94 percent at 42.5 C.

Family: Nitzschiaceae

Nitzschia Hassall

Nitzschia sp.

Distribution:

Alhambra (North), 36.0-36.5 C

In two of two samples, but was not represented during enumeration.

Boulder, 36.0-45.0 C

In five of seven samples with maximum frequency of 3.57 percent at 36.0 C and maximum volume of 0.43 percent at 38.0 C.

Lolo, 34.0-36.0 C

In two of four samples, but was not represented during enumeration.

Sleeping Child, 34.5-40.0 C

In three of three samples from 40.0 C downstream to 39.5 C. It did not make an appearance again until the water cooled to 35.8 C (110 feet from the source). From 35.8 C to 34.5 C it appeared in four of four samples. At no point was it represented during enumeration.

Mean maximum temperature: 39.3 C

Denticula Kuetzing

Denticula spp.

Distribution:

Alhambra (North), 36.0-39.0 C

In three of three samples, with maximum frequency of 1.0 percent and maximum volume of 0.5 percent at 36.5 C.

Alhambra (South), 41.0-45.0 C

In five of six samples, but was not represented during enumeration.

Boulder, 36.0-50.0 C

In eight of 14 samples. The two points of highest frequency were 3.57 and 3.88 percent attained at 36.0 and 42.5 C.

Mean maximum temperature: 43.1 C

Family: Surirellaceae

Surirella Turpin

Surirella sp.

Distribution:

Boulder, 36.0 C

In one of one sample but was not represented during enumeration.

Division: Cyanophyta

Class: Myxophyceae

Order: Chroococcales

Family: Chroococcaceae

Chroococcus Naegeli

Chroococcus minor (Kuetz.) Naegeli

Distribution:

Alhambra (North), 36.5-37.5 C

In two of two samples, with maximum frequency of 2.1 percent **and maximum volume of** 0.01 percent at 36.5 C.

Alhambra (South), 41.5-42.0 C

In three of four samples, with maximum frequency of 9.4 percent **and maximum volume of** 0.1 percent at 42.0 C.

Boulder, 45.0 C

In one of one sample, with 0.88 percent frequency and 3.8 percent **of total volume.**

Jackson, 31.0-41.0 C

In six of 11 samples, reaching maximum frequency of 11.11 percent **at 31.0 C and maximum** volume of 1.37 percent at 38.0 C.

Lolo, 34.0-36.0 C

In two of six samples, with maximum frequency of 1.45 percent **at 36.0 C (131 feet from the source).**

Sleeping Child, 50.5-52.0 C

In three of three samples but not represented during enumeration.

Mean maximum temperature not limited by stream temperature: 42.2 C

Chroococcus minutus (Kuetz.) Naegeli

Distribution:

Alhambra (North), 36.5-39.0 C

In two of three samples but not represented during enumeration.

Alhambra (South), 41.0-41.5 C

In two of two samples but not represented during enumeration.

Boulder, 37.0-45.0 C

In five of six samples, with maximum frequency of 31.28 percent at 38.0 C and maximum volume of 50.42 percent at 43.5 C.

Jackson, 39.0-44.5 C

In four of eight samples but not represented during enumeration.

Lolo, 34.0-40.0 C

In ten of ten samples, with maximum frequency of 5.31 percent and maximum volume of 7.69 percent at 36.5 C.

Mean maximum temperature: 42.0

Chroococcus turgidus (Kuetz.) Naegeli

Distribution:

Alhambra (North), 36.0-37.5 C

In three of three samples but not represented during enumeration.

Alhambra (South), 41.0-42.0 C

In four of four samples, with maximum frequency of 3.1 percent at both 41.0 and 42.0 C. The maximum volume of 6.7 percent was attained at 41.0 C.

Boulder, 37.0-46.0 C

In six of seven samples, with maximum frequency of 6.66 percent and maximum volume of 0.27 percent at 40.5 C

Jackson, 32.0-41.0 C

In five of ten samples with maximum frequency of 12.7 percent and maximum volume of 8.7 percent at 41.0 C.

Sleeping Child, 35.8 C

In one of one sample but was not represented during enumeration.

Mean maximum temperature: 40.5 C

Synechocystis Sauvageau

Synechocystis aquatilis Sauvageau

Distribution:

Alhambra (North), 36.5 C

In one of one sample but was not represented during enumeration.

Synechocystis crassa Woronichin

Plate I Figure 1

Distribution:

Boulder, 38.0-40.5 C

In two of two samples, with maximum frequency of 3.35 percent and maximum volume of 0.46 percent at 38.0 C.

Lolo, 34.0-36.5 C

In five of seven samples, with maximum frequency of 0.23 percent, maximum volume of 1.32 percent at 36.5 C.

Mean maximum temperature: 38.5 C

<u>Synechocystis</u> <u>minuscula</u> Woronichin

Plate I Figure 2

Distribution:

Jackson, 31.0-46.0 C

In four of 17 samples. The sporadic appearance of this alga is exemplified by the enumeration only at 42.0 C, where it represented 82.8 percent of the algae and 65.4 percent of the algal volume.

<u>Synechocystis</u> <u>salina</u> Wislouch

Plate I Figure 3

Distribution:

Boulder, 40.5-42.5 C

In two of two samples, with maximum frequency of 3.33 percent at 42.5 C. The volume in both samples was less than 0.01 percent.

Lolo, 36.0-40.0 C

In six of ten samples, with maximum frequency of 11.53 percent at 36.0 C (295 feet from the source). The maximum volume of 5.63 percent was in the pool at 40.0 C.

Mean maximum temperature: 41.2 C

<u>Microcystis</u> Kuetzing

<u>Microcystis</u> <u>densa</u> G. S. West

Distribution:

Jackson, 38.0 C

In one of one sample where it represented 14.5 percent of the algae and 16.16 percent of the algal volume.

Microcystis _holsatica_ Lemmermann

Distribution:

Sleeping Child, 36.0 C

In one of one sample but was not represented during enumeration.

Microcystis _incerta_ Lemmermann

Distribution:

Alhambra (North), 36.5-37.5 C

In two of two samples, with maximum frequency of 10.7 percent and maximum volume of 0.01 percent at 36.5 C.

Alhambra (South), 41.0-41.5 C

In two of two samples, with maximum frequency of 23.6 percent and maximum volume of 0.1 percent at 41.0 C.

Boulder, 42.5 C

In one of one sample where the frequency was 0.97 percent and the volume was less than 0.01 percent.

Sleeping Child, 35.3 C

In one of one sample where frequency was 4.71 percent and the volume was 0.90 percent.

Mean maximum temperature: 38.9 C

Synechococcus Naegeli

The characteristics of cell diameter and length, degree of curvature, and degree of granulization are often not sufficiently definite to consistently differentiate the species of _Synechococcus_ found in this study. Variations of each characteristic can produce a number of combinations that often cause considerable doubt upon identification to species. If, during the course of this study, _Synechococcus_ spp.

had been examined from arbitrarily chosen points in the streams without regard given to an environmental gradient, more confidence could have been realized in identification. By careful examination of members of this genus along temperature gradients in several streams, however, a number of possible ecotypes were observed that created considerable doubt as to their true identity.

Descriptions of Synechococcus found during this study are given to illustrate areas that may lead to difficulty when gradations between characteristics arise.

Synechococcus arcuatus Copeland

Plate I Figure 4

Cells cylindrical, strongly and evenly curved, 1.5-2.0 μ in diameter, 6-11 μ in length. Cells scattered among other algae or forming a loose flocculent gray-green to dull blue-green stratum. Cell contents homogenous, without prominent granules, dull blue-green.

Distribution:

Boulder, 48.0-54.7 C

In five of ten samples.

Jackson, 42.0-58.0 C

In 11 of 16 samples.

Pipestone (West), 52.0-53.0 C

In two of two samples.

Pipestone (East), 51.0-52.0 C

In three of eight samples.

Synechococcus Cedrorum Sauvageau

Plate I Figure 5

Cells ellipsoidal, seldom cylindrical, 3-4 μ in diameter, 5-10 μ in length, single or in two's, pale blue-green.

Distribution:

Jackson, 33.0-46.0 C

In eight of 15 samples.

Lolo, 39.5-42.0 C

In four of five samples.

Pipestone (West), 52.0 C

In one of one sample.

Synechococcus elongatus Naegeli

Plate I Figure 6

Cells cylindrical, straight, 1.4-2.0 μ in diameter, 2-6 μ in length, single or in chains of two to four cells.

Distribution:

Jackson, 38.5-58.0 C

In 19 of 21 samples.

Lolo, 36.0-42.0 C

In seven of seven samples.

Pipestone (East), 51.0 C

In five of six samples.

Synechococcus eximus Copeland

Plate I Figure 7

Cells ovoid to subcylindrical, 1.8-2.5 μ in diameter, 2.2-3.5 μ in length; cells single or during division in two's, pale blue-green, with homogenous contents.

Distribution:

Jackson, 48.0-56.7 C

In three of eight samples.

Synechococcus lividus Copeland

Plate I Figure 8

Cells cylindrical, usually straight or sometimes feebly curved, 1.2-1.4 μ in diameter, 5-10 μ in length, separating soon after division, but frequently in linear pairs. Plant mass flocculent, livid blue-green. Cell contents usually with one or two granules, polar in position, sometimes absent; olive-green to dull blue-green.

Distribution;

Alhambra (North), 39.0-54.4 C

In eight of eight samples.

Alhambra (South), 43.5-48.0 C

In five of five samples.

Boulder, 43.5-56.0 C

In 17 of 17 samples.

Jackson, 33.0-58.0 C

In 16 of 25 samples.

Lolo, 38.0-45.5 C

In six of six samples.

Pipestone (West), 53.0-55.5 C

In five of five samples.

Synechococcus lividus Copeland var. nov.

Plate I Figure 10

Cells cylindrical, curved; 0.7-0.9 μ in diameter, 4.5-7.0 μ in length. Granules, when present, indefinite in position.

Distribution:

Boulder, 49.5-54.7 C

In four of eight samples.

Jackson, 42.0-52.8 C

In seven of 12 samples.

Pipestone (West), 52.0-53.0 C

In two of two samples.

<u>Synechococcus</u> <u>lividus</u> var. <u>curvatus</u> Copeland

Plate I Figure 9

Cells cylindrical, uniformly curved; 1.7-2.2 μ in diameter, 6-13 μ in length. Cell pale blue-green, with usually one or two granules indefinite in position.

Distribution:

Boulder, 54.7 C

In one of one sample.

Jackson, 42.0-52.8 C

In seven of 12 samples.

Pipestone (West), 52.0-53.0 C

In two of two samples.

<u>Synechococcus</u> <u>lividus</u> var. <u>siderophilus</u> Copeland

Plate II Figure 2

Cells cylindrical, 1.5-1.8 μ in diameter, 8-15 μ in length. Cells pale blue-green, usually with one or two granules indefinite in position. Cells straight, or usually obtusely bent.

Distribution:

Boulder, 52.0-53.0 C

In two of two samples.

Synechococcus vescus Copeland

Plate II Figure 3

Cells cylindrical, evenly curved up to an arc of one-fifth of a circle or occasionally almost straight; 1.8-2.1 μ in diameter, 8-26 μ in length (usually 10-20), 7-22 μ across the arc. Polar granules single or in unequal pairs, variable in shape and size, usually large and highly refractile. When pairs are present the terminal one larger.

Distribution:

Jackson, 46.0-56.7 C

In three of ten samples.

Synechococcus viridissimus Copeland

Plate II Figure 4

Cells cylindrical, straight or occasionally feebly curved; 2.0-2.5 μ in diameter, 4-11 μ long. Cell contents light blue-green, usually with one (0-3) small, conspicuous, flattened refractile granule indefinite in position.

Distribution:

Jackson, 46.0-58.0 C

In six of 12 samples.

Pipestone (West), 53.5 C

In one of one sample.

Pipestone (East), 53.0 C

In one of one sample.

Synechococcus vulcanus Copeland

Plate II Figure 5

Cells cylindrical, straight or feebly curved; 2.1-2.4 μ in diameter, 7-17 μ in length. Cell contents homogenous, pale yellowish-green.

Distribution:

Jackson, 39.0-56.7 C

In four of 18 samples.

The above descriptions illustrate the overlapping of dimensions and the reliance upon the degree of curvature and degree of granulization for species differentiation. When individual cells were examined, the variance of the curvature and granules created problems that could usually be resolved. The enumeration of hundreds of cells from one sample, however, created an entirely different situation. The granules were often impossible to see under the magnification used during enumeration and would have required a return to higher power to find, count, and determine their position in many individual cases. The curved cells whose arcs were vertical appeared to be straight, but in counting them it would have been impractical to individually roll them over. It would also have been impractical to measure or otherwise determine each borderline modification produced by some factor of the environment. Considering these problems, the species and varieties were grouped under the genus for computing frequency and volume in those streams or areas of streams where more than one species was encountered. The streams and the temperatures at which the species have been found, however, were given in the above annotated list.

Except for S. Cedrorum, the species of Synechococcus were generally found at or near the upper temperature limits of the streams. Since they can apparently exist at higher temperatures, it was not feasible to list the maximum temperatures in the few cases where the algae were not limited by the upper temperature limits of the streams. The mean minimum temperature, in all but the short Pipestone streams with lower temperature limits in the low 50's, was 38.9 C.

Aphanothece Naegeli

Aphanothece Castagnei (de Bréb.) Rabenhorst

Plate II Figure 7

Distribution:

Jackson, 33.0-44.5 C

In four of 13 samples but was not represented during enumeration.

Aphanothece saxicola Naegeli

Distribution:

Jackson, 38.5 C

In one of one sample but was not represented during enumeration.

Aphanothece stagnina (Spreng.) A. Braun

Distribution:

Lolo, 36.0-44.0 C

In eight of nine samples, with maximum frequency of 14.92 percent and maximum volume of 9.56 percent in the small pool at 40.0 C. *A. stagnina* was 0.24 percent or less of the total algae in all other samples.

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Order: Chamaesiphonales

Family: Pleurocapsaceae

Xenococcus Thuret

Xenococcus Kerneri Hansgirg

Plate III Figure 4

Distribution:

Jackson, 26.0-32.0 C

In four of five samples, with the two high frequency values of 21.21 and 21.45 percent at 27.5 and 26.0 C. The volumes for these temperatures were 0.19 and 0.12 percent respectively.

Family: Dermocarpaceae

Dermocarpa Crouan

Dermocarpa rostrata Copeland

Plate III Figure 6

Distribution:

Jackson, 26.0-32.0 C

In five of five samples, with the maximum frequency of 29.54 percent at 29.5 C and the maximum volume of 0.28 percent at 32.0 C.

Family: Chamaesiphonaceae

Chamaesiphon Braun and Gronow

Chamaesiphon sp. nov.

Plate III Figure 5

Cells solitary or gregarious, fusiform to almost cylindrical, straight or slightly curved; 0.3-0.5 μ wide tapering to 0.1-0.3 μ at the base; pseudovagina thin and delicate. Exospores spherical, usually 3-5. Often three-fourths of the protoplast divided into mospores.

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Distribution:

Jackson, 41.0-42.0 C

In two of two samples but was not represented during enumeration.

Chamaesiphon cylindricus Peterson

Plate III Figure 2

Distribution:

Alhambra (North), 36.0 C

In one of one sample but was not represented during enumeration.

Alhambra (South), 41.0-42.0 C

In four of four samples, with maximum frequency of 12.7 percent and maximum volume of 0.31 percent at 42.0 C.

Chamaesiphon minimus Schmidle

Plate III Figure 1

Distribution:

Jackson, 29.5-36.0 C

In three of five samples but was not represented during enumeration.

Chamaesiphon gracilis Rabenhorst

Plate III Figure 3

Distribution:

Jackson, 26.0-32.0 C

In five of five samples. *C. gracilis* was somewhat evenly distributed with frequency values ranging from 17.61 to 33.5 percent and the volume from 0.08 to 0.29 percent. Both frequency and volume maxima were at 32.0 C.

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Order: Hormogonales

Suborder: Homocystinae

Family: Oscillatoriaceae

Isocystis Borzi

Isocystis pallida Woronichin

Plate III Figure 7

Distribution:

Alhambra (North), 46.0 C

In one of one sample, with a frequency of 3.2 percent and volume of 8.9 percent.

Alhambra (South), 48.0 C.

In one of one sample, but was not represented during enumeration.

Jackson, 39.0-52.0 C

In 17 of 20 samples. Although the presence value was high, I. pallida attained only 4.0 percent of the total algae and 4.6 percent of the algal volume at 41.0 C.

Lolo, 40.0 C

In one of one sample, but was not represented during enumeration.

Pipestone (West), 52.0-53.0 C

In one of one sample before and after the flooding but was not represented during the enumeration.

Pipestone (East), 51.0 C

In five of five samples, with a maximum frequency of 1.89 percent and maximum volume of 2.06 percent.

Mean maximum temperature not limited by stream temperature: 47.8 C

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Spirulina Turpin

Spirulina Corakiana Playfair

Plate IV Figure 1

Distribution:

Alhambra (South), 48.0 C

In one of one sample but was not represented during enumeration.

Boulder, 49.5 C

In one of one sample where its frequency was 0.27 percent and volume 0.07 percent.

Jackson, 33.0-52.0 C

In five of twenty samples but not represented during enumeration.

Mean maximum temperature: 47.4 C

Spirulina subtillissima Kuetzing

Plate IV Figure 2

Distribution:

Alhambra (North), 36.5 C

In one of one sample but was not represented during enumeration.

Oscillatoria Vaucher

Oscillatoria amphibia Agardh

Plate IV Figure 3

Distribution:

Boulder, 45.0-50.5 C

In five of nine samples with maximum frequency of 7.48 percent and maximum volume of 18.51 percent at 45.0 C. The percent frequency at other points in this stream ranged up to 1.30 percent.

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In one of one sample but was not represented during enumeration.

Oscillatoria Boryana Bory

Plate IV Figure 4-7

Similar trichomes were found at Jackson with characteristics of Arthrospira Jenneri Stiz = Spirulina Jenneri (Stiz) Geitl., Oscillatoria terebriformis Ag., and Oscillatoria Boryana Bory. The following brief descriptions of these species are given for comparison and to facilitate a discussion of them.

Arthrospira Jenneri. Trichome not or very slightly constricted, sometimes fine granules at the cross-walls, 5-8 µ wide, end not attenuated, more or less regularly spiralled. Spirals 9-15 µ wide and 21-31 µ between spirals. Cells are as wide as they are long or somewhat shorter than wide, the end cell is broadly rounded.

Oscillatoria terebreformis. Trichomes with no constrictions at the cross-walls, 4-6.5 µ wide, end slightly attenuated, spiralled at the end. Cells as wide as they are long or half as long as wide, the end-cell rounded or almost truncate. Trichome is not capitate and no calyptra is present.

Oscillatoria Boryana. Trichome constricted at the cross-walls, often slightly granular at the cross-walls, 6-8 µ wide, completely spiralled or only at the end but many times straight. Cells are as wide as they are long to half as long as wide, the end-cell rounded or more or less accuminate. Trichome not capitate and no calyptra is present.

The trichomes found at Jackson were slightly constricted or not constricted at the cross-walls, 5.5-6.5 µ wide, end attenuated, rounded, or truncate,

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or truncate, regularly spiralled the entire length or only at the ends. Spirals from 10.3 μ wide to those that are barely perceptible, 31 μ from spiral to spiral. Cells as long as wide to half as long as wide, contents homogenous or coarsely granular.

Trichomes could have been placed in any one of the named species depending on the point from which they were taken, since trichomes with all variations of spirals, end-cells, granulations, and cross-wall constrictions had common diameters of 5.5-6.5 μ.

The effect of an environmental gradient on the spirals is shown by the following figures. At 52.8 C, 100 percent of the trichomes had spirals the entire length. At 48.0 C, 70 percent of the trichomes were spiralled the entire length, while the remaining 30 percent were spiralled only at the ends. At 41.0 C downstream to 37.5 C, approximately 5 percent were spiralled, the spirals ranging from those that were readily perceptible to those that were almost imperceptible. This change in the degree of spiralling from 52.8 C downstream to 37.5 may be the result of the temperature change, but within this temperature range the pH increased from 7.5 to 8.2 and the carbon dioxide decreased from 35 to 8 ppm.

No attempt was made to quantify the degree of granulization of cell contents. Concerning the sizes and numbers of granules, all that can be mentioned is that cell contents became more homogenous with decreasing temperature.

None of the discussed species was found in samples from the other streams so the probability of the coexistence of three such similar forms in one stream is slight. Since there were gradations in spirals and since the trichome dimensions were the same at all points in the strea

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in the stream, probably one species was present.

Although no mention is made of the spiral width or length in the description for O. Boryana, the fact that the trichomes may be completely spiralled or only spiralled at the end but many times straight, is characteristic of trichomes found at Jackson. The acuminate end-cell of many trichomes also suggests O. Boryana.

Distribution:

Jackson, 37.5-54.0 C

In 16 of 16 samples. The two points of high frequency are at 42.5 and 54.0 C where values of 38.38 and 20.48 percent were attained. The volumes were 95.8 and 99.5 percent for the temperatures, respectively. The frequency values in the other samples were 3.49 percent or less.

Oscillatoria brevis (Kuetz.) Gomont

Plate V Figure 1

Distribution:

Alhambra (North) 39.0 C

In one of one sample but was not represented during enumeration.

Boulder, 47.0 C

In one of one sample where the frequency was 1.73 percent and the volume was 27.84 percent.

Jackson, 37.0-42.5 C

In four of eight samples, with maximum frequency of 1.58 percent and maximum volume of 0.02 percent at 40.0 C.

Lolo, 34.0-36.0 C

In four of five samples, with maximum frequency of 88.23 percent and maximum volume of 91.63 percent at 34.0 C.

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Mean maximum temperature: 43.3 C

Oscillatoria chalybea Mertens

Distribution:

Boulder, 48.0 C

In one of one sample but was not represented during enumeration.

Oscillatoria chalybea var. depauperata Copeland

Distribution:

Pipestone (West), 48.0-51.5 C

This alga was present in samples from a seepage area near Pipestone (West) but this was not enumerated.

Oscillatoria geminata Meneghini

Plate V Figures 2-4

Plant mass dull yellowish-green. Trichomes 2.3-4.0 μ in diameter, curved. Cross walls clearly constricted, thick, translucent, not granulated at the cross walls. Cells variable in length, as long as wide or longer than wide, 2.3-16 μ long; end cell rounded.

Trichomes with characteristics of O. geminata were found during this study having diameters that ranged from 1.0 μ to 3.5 μ. Since O. geminata is described as having a diameter of 2.3-4.0 μ, trichomes above 2.3 μ were placed in O. geminata, those 1.7-2.0 μ were placed in O. geminata var. tenella Copeland, and those 1.0-1.6 μ in O. geminata var. tenella fa. nov.

O. geminata trichomes and its varieties have been described and named as they were found; as a result, Copeland (1936) used the variety tenella for those trichomes he found that were 1.7-2.0 μ in diameter. The range of four microns (1.7-2.0) for variety tenella may be rather narrow, but

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narrow, but had Copeland found trichomes down to 1.0 μ, as in this study, the size range for this variety would have been extended.

Since trichomes of _O_. _geminata_ with large and small diameters were often found in the same samples, they cannot be considered ecological variants and must be judged for what they appeared to be at the time of collection, _O_. _geminata_, _O_. _geminata_ var. _tenella_, and _O_. _geminata_ var. _tenella_ fa. nov.

Distribution:

Alhambra (North), 48.5-52.0 C

In three of three samples with maximum frequency of 13.5 percent and maximum volume of 10.3 percent at 52.0 C.

Alhambra (South), 41.0-48.0 C

In seven of nine samples, with maximum frequency of 5.7 percent and maximum volume of 8.9 percent at 45.0 C.

Boulder, 45.0-55.0 C

In seven of 14 samples, with maximum frequency of 21.17 percent and maximum volume of 41.0 percent at 50.5 C. The other frequency values were 0.61 percent or less.

Jackson, 36.0-52.0 C

In 16 of 19 samples, with highest frequency values of 23.2 and 21.7 percent at 43.5 and 51.0 C. The maximum volume of 46.9 percent was at 46.0 C.

Pipestone (West), 52.0 C

In one of one sample but was not represented during enumeration.

Pipestone (East), 51.0 C

In three of three samples but was not represented during enumeration.

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Sleeping Child, 42.0-50.0 C

In six of six samples, with maximum frequency of 10.76 percent and maximum volume of 8.12 percent at 50.0 C.

Mean maximum temperature not limited by stream temperature: 52.2 C

Oscillatoria geminata var. _tenella_ Copeland

Plate V Figures 5, 6

Trichome diameter 1.7-2.0 μ. Otherwise as in the species.

Distribution:

Lolo, 34.0-36.0 C

In six of six samples, with maximum frequency of 3.63 percent and maximum volume of 1.42 percent at 36.0 (196 feet from the source).

Oscillatoria geminata var. _tenella_ fa. nov.

Plate V Figures 7-10

Trichome diameter (1.0)-1.2-1.4-(1.6) μ. Cells 1-4 diameters in length. Otherwise as in the species.

Distribution:

Alhambra (North), 39.0-44.5 C

In three of three samples, with maximum frequency of 24.8 percent and maximum volume of 6.8 percent at 44.5 C.

Alhambra (South), 41.5-48.0 C

In eight of eight samples, with maximum frequency of 47.1 percent and maximum volume of 33.5 percent at 48.0 C. The other frequency values were 7.8 percent or less.

Boulder, 42.5-52.0 C

In 14 of 17 samples. The two samples in which this variety was most abundant were obtained at 47.0 and 50.5 C, where frequency values were 70.43 and 47.05 percent and volume values were 51.89 and 32.96 percent respectively. Frequency values of 15 percent or less were attained at the other points of sampling.

Jackson, 36.0-43.5 C

In six of 11 samples, with frequency of 12.8 percent and volume of 55.0 percent at 43.5. Other frequency values were 4.04 percent or less.

Mean maximum temperature not limited by stream temperature: 46.6 C

Oscillatoria geminata var. fragilis Copeland fa. nov.

Plate V Figures 11-13

Trichomes short, 3-8 cells long, (1.0)-1.2-1.8-(2.2) μ in diameter. Cells 1-2 diameters in length. Otherwise as in the species.

These trichomes were not so variable in length as to give the impression of pieces of trichomes broken randomly but, rather, were of relatively uniform length. The mean trichome length was 3 cells at Alhambra (South), 4 cells at Lolo, and 5-6 cells at Jackson. The diameters of these trichomes also varied from stream to stream. The mean diameters were 1.2 μ at Alhambra (South), 1.6 μ at Lolo, and 1.8 μ at Jackson.

The usual trichome diameters of 1.2-1.8 μ and trichome length of from 3 to 8 cells should be compared with the variety fragilis, which is 2.2 μ in diameter and 6-12 cells long. Copeland (1936) found the variety to be more common than the species in Yellowstone National Park, whereas the converse is true for this new form.

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Alhambra (South), 41.5-43.5 C

In three of four samples, with maximum frequency of 4.0 percent and maximum volume of 0.07 percent at 42.0 C

Jackson, 33.0-38.5 C

In two of five samples but was not represented during enumeration.

Lolo, 36.0-44.0 C

In ten of ten samples. The frequency was no greater than 1.5-1.8 percent found in three samples.

Mean maximum temperature: 40.6 C

Oscillatoria limnetica Lemmermann

Plate VI Figure 1

Distribution:

Boulder, 49.5-50.0 C

In two of three samples but was not represented during enumeration.

Oscillatoria limosa Agardh

Plate VI Figure 2

Distribution:

Boulder, 36.7-43.5 C

In five of five samples with maximum frequency of 11.17 percent and maximum volume of 39.49 percent at 38.0 C.

Oscillatoria princeps Vaucher

Plate VI Figure 3

Distribution:

Sleeping Child, 36.0 C

In one of one sample but was not represented during enumeration.

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Oscillatoria tenuis Ag. var. *tergestina* Rabenhorst

Distribution:

Sleeping Child, 36.0 C

In one of one sample but was not represented during enumeration.

Phormidium Kuetzing

Phormidium sp. nov.

Plate VII Figures 10, 11

Trichome curved, constricted at the cross walls, end gradually attenuate, 0.7-0.9 μ in diameter. Sheath colorless, confluent. Cells cylindrical, 4-7 times longer than wide, generally 4.0 μ long, no granules at the cross walls, capitate end cell.

The characteristics of cell dimensions, no granules at the cross walls, and constricted cross walls are suggestive of *P. angustissimum* West and West, but may be distinguished from it by the distinct shape of the end cell. Trichomes were observed with characteristics of *P. angustissimum* from 54.7 C downstream to 51.0 C, whereas from 50.5 C downstream to 37.5 C the *Phormidium* with the capitate end cell was present. When the algae were counted, trichomes were observed that extended from the counting squares well out of view. It was impossible to follow each trichome out of the randomly chosen counting area in an attempt to find the end cell to determine whether this cell was the capitate *Phormidium* or *P. angustissimum* and then again find the original counting area. For this reason, the trichomes from 50.5 to 37.5 C were all considered to be the new species with the capitate end cell, although the two may exist in this temperature range.

It is possible that the *Phormidium* trichomes above 50.5 C at Boulder with the characteristics described above are also of the capitate

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capitate species, but the characteristic end cell may not be able to be produced above this temperature. Since the two types of trichomes were observed, however, the enumeration was performed on the assumption that they did exist and that the temperature of demarcation was 50.5 C.

Distribution:

Boulder, 37.0-50.5 C

In eight of 13 samples, with maximum frequency of 65.39 percent and maximum volume of 43.4 percent at 48.0 C.

<u>Phormidium</u> <u>africanum</u> Lemmermann

Plate VI Figure 5

Distribution:

Pipestone (West), 52.0 C

In two of two samples with a maximum frequency of 10.28 percent and maximum volume of 8.67 percent.

Pipestone (East), 51.0-52.0 C

In seven of nine samples with a maximum frequency of 56.13 percent and maximum volume of 61.43 percent at 52.0 C. The entire temperature gradient at this stream was only 1 C, from 52.0 to 51.0 C. At the emergence, 52.0 C, this algae was 1.1 percent of the total volume, but it was not until the water had traveled 60 feet that it attained 61.43 percent. This suggests that within this temperature interval some other factor may have been responsible for the increase.

Mean maximum temperature: 52.0 C

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Phormidium angustissimum W. and G. S. West

Plate VI Figures 6-8

Distribution:

Alhambra (North), 39.0-52.0 C

In seven of seven samples, with maximum frequency of 63.8 percent and maximum volume of 13.4 percent at 39.0 C.

Boulder, 51.0-54.7 C

In two of four samples but was not represented during enumeration. The possibility of trichomes with characteristics of P. angustissimum in this temperature range being another species is discussed under Phormidium sp. nov.

Jackson, 33.0-52.0 C

In 18 of 20 samples. P. angustissimum had several points of comparably high frequency and volume values sporadically scattered along this temperature gradient. These are given, along with the temperatures, to briefly show its relative importance: 35.4 percent at 52.0 C; 76.6 percent at 44.5 C; 65.3 percent at 42.5 C; and 87.4 percent at 37.0 C. The volume contribution was often considerably less due to its small size.

Lolo, 34.0-40.0 C

In 11 of 11 samples. P. angustissimum was enumerated in ten of the samples, with frequency values ranging from 7.48 percent at 34.0 C to 82.29 percent at 38.0 C.

Pipestone (West), 53.5 C

In one of one sample but was not represented during enumeration.

Sleeping Child, 36.0-52.0 C

In ten of ten samples from 52.0 C downstream to 42.0 C, but was not presen

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present again for 90 feet, where it was meagerly represented at 36.5 and 36.0 C. The occurrence changed abruptly from a high of 70.03 percent at 51.0 C to a low of 0.28 percent at 50.5 C. Otherwise,the occurrence values ranged from approximately 11 to 45 percent.

Mean maximum temperature: 50.7 C.

Phormidium bigranulatum Gardner

Plate VI Figure 9

Distribution:

Pipestone (West), 48.0-52.0 C

In one of one sample but was not represented during enumeration.

Phormidium Bohneri Schmidle

Plate VI Figure 10

Distribution:

Lolo, 36.0 C

In two of two samples at 36.0 C. In one sample it represented 0.57 percent of the algae and 0.01 percent of the volume.

Phormidium frigidum Fritsch

Plate VI Figure 12

The trichomes of this alga usually have a granule at the cross walls. This characteristic created some difficulty since there was a gradation in trichomes with many granules to those with no granules. This raised the question as to whether these trichomes without granules were actually P. frigidum, Oscillatoria geminata var. nov., or P. africanum. While it is true that the genus Phormidium has a sheath and

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Oscillatoria does not, the sheaths are very often confluent in a thermal environment. The confluent nature of the sheathing material coupled with gradation of granules created such nebulous criteria for differentiation that one species could easily be taken for the other. Considering the confluency of the sheathing material and similarity of the trichomes, separation was made, which is admittedly weak, on the basis of granules. In compliance with the present literature, however, this appears to be the most logical choice until such trichomes can be cultured or examined in the field under more varied environmental conditions.

Distribution:

Pipestone (West), 48.0 C

P. frigidum was found in a seepage area near Pipestone (West) but the algae here were not enumerated.

Pipestone (East), 51.0 C

In four of four samples, with a maximum frequency of 4.3 percent and a maximum volume of 0.6 percent.

Mean maximum temperature: 49.5 C

Phormidium Jenkelianum Schmidle

Plate VII Figure 7

Distribution:

Sleeping Child, 34.5 C.

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Phormidium laminosum Gomont

Plate VII Figures 1-6

Phormidium laminosum has been found in thermal environments of relatively high temperatures throughout the world. It has been found at or near the upper temperature limits in the streams of this study, making it impossible to approximate its maximum tolerable temperature in combination with the other environmental factors. Tilden (1898) found it up to 55.0 C in an overflow from a spring that issued at 91.0 91.0 C in Yellowstone National Park. She also found it at 75.0 C, which Copeland (1936) considered too high. On the basis of many observations at Yellowstone Park, Copeland believed it existed up to 65-66 C.

This species was extremely variable in appearance, as shown by a few examples on Plate VII, Figures 1-6. It would not be worthwhile to comment on the many forms except to compare it with a similar species, P. tenue. The similarity of the two was attested to by Peterson (1928), who wrote, "To distinguish P. laminosum from P. tenue is often attended with considerable difficulties partly because they are both possessed of extremely thin trichomes, partly because the distinguishing characters cannot always be seen with sufficient distinctness. Therefore it has been necessary to leave a number of specimens undetermined, although great pains have been bestowed on the determinations."

A brief summary of the major distinguishing characteristics of P. laminosum and P. tenue will facilitate discussion and serve as a basis for subsequent comments.

P. laminosum is 1.0-1.5 μ or up to 2.0 μ (f. homogenea Wille), has no constricted cross walls, has granules at the cross walls, and has a pointed, conical end cell.

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P. tenue is 1.0-2.0 μ wide, cross walls slightly constricted, no granules at the cross walls, and has a long, conical end cell.

Granules on each side of the cross wall of P. laminosum produce a translucent area, the lateral boundaries of which are difficult to distinguish, perhaps in part due to the sheath. If granules are present, the determination of P. laminosum is assured; if they are absent, it would be assumed the trichomes are P. tenue. Within a stream, however, trichomes characteristic of P. laminosum were found that often graded from granules in every cell to granules in none of the cells.

At Pipestone, trichomes which appeared to be P. tenue and P. laminosum were found together at some points, but the granules that were visible were very indistinct. Granuleless trichomes, probably P. tenue, were more abundant at the higher temperatures, whereas those with granules were more abundant at the lower temperatures.

In the Jackson stream, trichomes with and without granules were also present in approximately the same temperature range. At 33.0 C, the lowest temperature at which they were found in this stream, trichomes of both species had only rounded end cells rather than the characteristic conical ones. At this temperature very few trichomes exceeded 80 μ, a relatively short length for either of these species.

At Boulder, the trichomes of P. laminosum found at 46.0 C, the lowest temperature for the species in this stream, also had rounded end cells. If these trichomes had only been collected at 46.0 C, they could have been placed in P. frigidum with confidence, if the implication of the name were disregarded, since the granules at the cross walls constricted cross walls, and trichome dimensions are similar for both species. The character that clearly distinguishes these species is the end cell--P.

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end cell--*P. laminosum* with a conical end cell, *P. frigidum* with a rounded end cell.

The temperatures at which *P. laminosum* and *P. tenue* coexisted were markedly similar in the investigated streams. The streams in which they were both found and their temperature ranges to the nearest whole degree centigrade are given as follows:

	Alh(N)	Bould.	Jack.	Lolo	Pipe(W)	Pipe(E)
P. laminosum	37-46	46-56	33-52	35-42	48-55	51-52
P. tenue	39-52	44-55	33-48	34-40	52-55	51

Distribution:

Alhambra (North), 37.5-46.0 C

In five of five samples, with maximum frequency of 32.4 percent and maximum volume of 32.6 percent at 46.0 C. The frequency was 5.8 percent or less in the other samples.

Boulder, 46.0-56.0 C

In ten of 14 samples with the highest frequency values between 10.81 and 9.66 percent at four intermittant points.

Jackson, 33.0-52.0 C

In 13 of 20 samples, with maximum frequency of 18.75 percent at 33.0 C and maximum volume of 5.6 percent at 42.5 C. It did not represent over 3.15 percent of the algae in any other sample.

Lolo, 35.0-40.0 C

In six of 12 samples, but was not represented during enumeration.

Pipestone (West), 48.0-54.7 C

In four of four samples taken in 1962. The maximum frequency of 6.55 percent and maximum volume of 10.5 percent was at 52.0 C.

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Pipestone (East), 51.0-52.0 C

In six of eight samples, with maximum frequency of 49.47 percent and maximum volume of 39.8 percent at 51.0 C (100 feet from the source).

Mean maximum temperature not limited by stream temperatures: 49.7 C

Phormidium lignicola Fremy

Plate VII Figure 12

Distribution:

Jackson, 38.5-51.0 C

In nine of 15 samples, with maximum frequency of 16.99 percent at 38.0 C and maximum volume of 12.6 percent at 42.5 C.

Phormidium tenue (Menegh.) Gomont

Plate VII Figures 8, 9

Phormidium tenue was the only alga found in all the streams used in this study, including both the north and south streams of Alhambra and the east and west streams of Pipestone. Comments pertaining to its relationship with *P. laminosum* are given on pages 131 and 132.

Distribution:

Alhambra (North), 39.0-50.0 C

In six of seven samples, with frequency values of 13.5 to 14.9 percent in three samples. All volume values were 4.6 percent or less except for 15.0 percent at 46.0 C.

Alhambra (South), 41.5-48.0 C

In six of eight samples, with maximum frequency of 58.2 percent and maximum volume of 37.2 percent at 45.5 C.

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Boulder, 46.0-55.0 C

In 14 of 15 samples, with frequency values between 17 and 40 percent in ten samples.

Jackson, 33.0-48.0 C

In seven of 16 samples, with a maximum frequency of 58.2 percent and maximum volume of 75.8 percent at 48.0 C.

Lolo, 34.0-40.0 C

In five of 11 samples. Although this alga was found at 40.0 C, it was not until the water cooled to 36.0 C (after traveling a distance of 270 feet) that it appeared in sufficient numbers to be enumerated. At this latter temperature and distance the alga reached its maximum frequency of 5.97 percent.

Pipestone (West), 52.0-55.0 C

In five of five samples but was enumerated only at 52.0 and 53.0 C. At these temperatures the frequency was 18.22 and 17.82 percent respectively.

Pipestone (East), 51.0 C

In five of six samples, with maximum frequency of 85.39 percent and maximum volume of 76.1 percent 50 feet from the source.

Sleeping Child, 39.0-50.0 C

In six of nine samples, with maximum frequency of 5.15 percent and maximum volume of 1.01 percent at 49.8 C.

Mean maximum temperature: 49.6 C

Phormidium truncatum Lemmermann

Plate VII Figures 13, 14

Distribution:

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Lolo, 34.0-45.5 C

In eight of eight samples. This alga was the dominant alga from 45.5 C downstream to 44.0 C and was well represented to 39.5 C. Below 39.5 C it represented 2.74 percent or less in every sample.

Pipestone (East), 51.0-52.0 C

In seven of eight samples, with maximum frequency of 76.35 percent and maximum volume of 74.75 percent at 51.0 C (20 feet from the source).

Sleeping Child, 34.5-52.0 C

In 17 of 22 samples. For a distance of 30 feet, from 52.0 C downstream to 50.5 C, P. truncatum represented the major alga with frequency values from 28.79 to 98.63 percent. From 50.0 C downstream to 34.5 C, only two samples had more than ten percent frequency and only one sample had more than 1.25 percent volume.

Present to the upper and lower temperature of each stream. Mean temperature of the upper temperature limits: 49.8 C.

Lyngbya Agardh

Lyngbya Diguetii Gomont

Plate VIII Figure 2

Distribution:

Sleeping Child, 35.8-42.0 C

In seven of 12 samples but was represented during enumeration only at 42.0 C where the frequency was 21.06 percent and the volume was 11.11 percent.

Lyngbya nana Tilden

Plate VIII Figure 1

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Distribution:

Alhambra (North), 39.0 C

In one of one sample where the frequency was 2.4 percent and the volume 2.8 percent.

Pseudanabaena Lauterborn

Trichome single, without a sheath, not forming a thallus. Cells clearly separated from one another, cylindrical and rounded or oval at the ends.

The members of this genus do not normally form heterocysts and on this basis Geitler (1932) placed the genus in the Oscillatoriaceae. The indecision among phycologists as to how *Pseudanabaena constricta* (Szaf.) Lauterb. should be treated is reflected in the fact that it was first placed under *Oscillatoria constricta* Szaf. and then under *Anabaena constricta* (Szaf.) Geitler. Lauterborn (1914-17) removed it from *Anabaena* and created *Pseudanabaena* on the basis of the generally heterocystless condition.

If the cells of *Pseudanabaena* are cylindrical, rounded at the ends and distinctly separated from one another, then it is feasible to add that the cell walls are constricted and very possibly possess a thick cross wall. These characteristics may lead a student of the group to err by placing such species as *Oscillatoria geminata* and its varieties (Plate V, Figures 5-10) in *Pseudanabaena* since *O. geminata* has cylindrical cells and thick, translucent cross walls which can give the impression of being clearly separated from one another.

Trichomes without heterocysts and with cylindrical to oval cells that appeared separate from one another were found in the Sleeping

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Child Hot Springs stream for a distance of 210 feet. These had an Anabaena-like appearance and may actually be members of this species whose ability to produce heterocysts and akinetes have been inhibited by the environmental conditions of this thermal stream. Although heterocysts and akinites may form under different conditions, the trichomes have been judged on the basis of their characteristics at the time of collection, i. e., Pseudanabaena, but with reservations.

Pseudanabaena sp. nov.

Plate VIII Figure 3

Cells spherical to sub-cylindrical, end cell rounded, conical; 4.6 μ in diameter, up to 7.0 μ in length. Although this appears to be a new species, the possibility of this being Anabaena sp. without heterocysts and akinetes has been discussed above.

Distribution:

Sleeping Child, 34.5-40.0 C

In 11 of 14 samples. Its frequency exceeded 1 percent at only 36.5 C (130 feet from the source) where it reached 11.11 percent. The volume at this point was 4.85 percent.

Suborder: Heterocystinae

Family: Nostocaceae

Anabaena Bory

Anabaena sp.

No akinetes were found, making it impossible to determine the species.

Distribution:

Sleeping Child, 34.5 C

In one of one sample but was not represented during enumeration.

Anabaenopsis (Wolosz.) Miller

Anabaenopsis circularis (G. S. West) Wolosz and Miller

Trichome free-living, very short, usually spiralled, with 1-1.5 turns, very seldom straight, 4.5-6 μ wide. Cells spherical or somewhat longer than wide, with a large granule. Heterocysts spherical, 5-8 μ wide. Akinete unknown.

Anabaenopsis circularis var. nov.

Plate VIII Figures 5-7

Trichome short, 1-3 spirals. Cells without gas vacuoles, 2.3-3 μ wide, spherical to short cylindrical, 2.5-4 μ long. Terminal heterocysts generally spherical, sometimes slightly elongate, 1.8-2.5 μ wide; intercalary heterocysts spherical, single, 1.8-2.5 μ wide.

Distribution:

Boulder, 43.5-45.0 C

In two of three samples, reaching a maximum frequency of 22.9 percent and a maximum volume of 34.56 percent at 45.0 C.

Nodularia Mertens

Nodularia Harveyana (Thw.) Thuret

Plate VIII Figure 4

The filaments of N. Harveyana found during this investigation varied somewhat from the species. Whereas the species calls for spherical or disc-shaped akinetes always removed from the heterocysts, filaments were found with elongate akinetes adjacent to the heterocysts. Since these filaments more nearly fit the description for N. Harveyana, it is be

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Distribution:

Boulder, 36.7-47.2 C

In four of eight samples, with maximum frequency of 5.5 percent at 37.0 C; maximum volume of 16.53 percent at 43.5 C.

Sleeping Child, 36.0 C

In two of two samples, but not represented during enumeration.

Cylindrospermum Kuetzing

Cylindrospermum sp.

Cylindrospermum sp. is described as having heterocysts at the ends of trichomes and akinetes always adjacent to the heterocysts. The akinetes necessary for identification to species, however, were not found in any of the samples. Heterocysts were also absent from 52.0 C, where the trichomes made their first appearance, downstream to 41.0 C. At 41.0 C the heterocysts began to appear and increased in number with decreasing temperature.

The cell contents were homogenous at the higher temperatures but became more coarsely granular with decreasing temperature. The percent of trichomes that were coarsely granular and the temperatures at which they were randomly counted are given as follows: 0 percent at 52.0 C, 10 percent at 49.5 C, 56 percent at 41.0 C, 79 percent at 38.5 C, 82 percent at 37.0 C, and 95 percent at 33.0 C.

Distribution:

Jackson, 32.0-52.0 C.

In 11 of 21 samples, with maximum frequency of 9.27 percent at

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37.0 C and maximum volume of 20.90 percent at 52.0 C.

Family: Stigonemataceae

Mastigocladus Cohn

Mastigocladus laminosus Cohn

Syn. Hapalosiphon laminosus (Kuetz.) Hansg.

Plate VIII Figure 8-10

Mastigocladus is a monotypic genus possessing a great variety of forms ranging from filaments with Anabaena-like characteristics to tho those with characteristics of Phormidium. Upon an initial examination of representative forms of the species from various thermal environments, or even from one stream or one sample, an investigator may feel inclined to create new varieties, species, or perhaps genera to categorize all that he finds. His samples may reveal cylindrical cells at the ends of filaments primarily composed of spherical cells and heterocysts, or branching filaments composed of variously-shaped cells. The samples may have filaments without heterocysts and entirely of spherical cells or cylindrical cells. Also, there will be every conceivable combination of intermediate types.

Realizing that all such filamentous types are actually one species, investigators have created forms and varieties in an attempt to cope with the problem of morphological differences. Peterson (1928) recognized three basic types and created fa. typica, fa. anabaenoides, and fa. phormidioides.

Forma typica. Branching, with distinct difference between the primary and secondary trichomes. Primary branches with spherical to elliptic cells, secondary branches of cylindrical cells. Heterocysts well developed. Sheaths usually firm, distinct, and color a pronounced violet with chloro-zinc-iodine.

Forma anabaenoides. Without branching. All the filaments similar with more or less spherical cells and distinct heterocysts. Cells largest in the middle of the trichomes, generally decreasing toward the terminal ends. Sheaths more or less confluent and color faintly or not at all with chloro-zinc-iodine.

Forma phormidiodes. Trichomes almost similar, without heterocysts, cross walls often feebly constricted. Sheaths confluent and do not color with chloro-zinc-iodine.

Although these are the basic types, it is obvious that there would be many intermediate trichomes, whether they are recognized as growth forms or as distinct varieties. Peterson assumed they were growth forms, with fa. phormidioides as the first or youngest stage and fa. typica as the oldest; in the event conditions were unfavorable for growth, the trichomes would remain in the first developmental stage. Copeland (1936) created varieties of fa. phormidioides and fa. anabaenoides on his assumption that they were not developmental stages since they were usually found in separate springs. He also found them coexisting which, in his judgment, eliminated the possibility of their being ecological forms. Fremy (1936) differentiated 25 forms and subforms, whereas Anagnostidis (1961) observed more than 29 forms and subforms obtained from thermal springs in Greece. Anagnostidis states that even in one microscope preparation up to five forms were established.

If two or three clearly differentiated forms could be recognized, it would be logical to count them for percentage determination as has been done for other species. With many intermediate forms within one species, however, enumeration of these forms would be almost impossible. Enumeration of the forms within one stream would be problem enough, but to name and count intermediate forms from the various streams would require constant rechecking to assure the counting of the same forms. Since one of the main purposes of this study was to determine the percent frequency and percent volume of the species along an environmental gradient, it was considered the most practical to group all forms under the species.

Distribution:

Alhambra (North), 39.0-54.4 C

In eight of eight samples, with the highest frequency values of 67.8 and 66.8 percent attained at 50.0 and 52.0 C. The maximum volume of 96.3 percent was at 50.0 C.

Alhambra (South), 41.5-48.0 C

In six of six samples, with maximum frequency of 46.4 percent and maximum volume of 83.7 percent at 45.0 C.

Boulder, 43.5-56.0 C

In 16 of 17 samples. The frequency and volume fluctuated considerably in this stream. The frequency exceeded 25 percent and the volume 70 percent at three widely separated points--56.0, 46.0 and 44.0 C.

Pipestone (West), 48.0-57.0 C

In seven of seven samples. The highest frequency values of 13.16 and 13.48 percent and highest volume values of 71.77 and 73.86 percent were at 55.0 and 54.7 C.

Sleeping Child, 34.5-52.0 C

In 20 of 24 samples. It was most abundant from 50.5 C downstream to 42.0 C, reaching a maximum frequency of 78.83 percent and maximum volume of 97.44 percent at 49.5 C. Another area of high representation in this stream was from 36.5 to 34.5 C where a high frequency of 55.22 percent and high volume of 6.39 percent was at 35.8 C.

Present to the upper temperature limit of each stream. The mean of these limits: 53.5 C

Family: Rivulariaceae

Calothrix Agardh

Calothrix Braunii Bornet & Flahault

Distribution:

Boulder, 43.5 C

In one of one sample but was not represented during enumeration.

Calothrix Kossinskajae Poljansky

Distribution:

Boulder, 45.0 C

In one of one sample, representing 0.44 percent of the algae and 0.42 percent of the algal volume.

Calothrix thermalis (Schwabe) Hansgirg

Distribution:

Jackson, 26.0-43.0 C

In four of 17 samples, with maximum frequency of 1.45 percent and maximum volume of 17.29 percent at 38.0 C.

Dichothrix Zanardini

Dichothrix montana Tilden

Distribution:

Lolo, 36.0-40.0 C

In seven of seven samples, with maximum frequency of 1.67 percent and maximum volume of 29.91 percent at 40.0 C. The type specimen of this species was taken from this stream.

Gloeotrichia Agardh

Gloeotrichia echinulata (Smith) Richter

Distribution:

Jackson, 33.0 C

In one of one sample, representing 15.0 percent of the algae and 23.65 percent of the algal volume.

Plate I

Figure 1. Synechocystis crassa Woronichin

Figure 2. Synechocystis minuscula Woronichin

Figure 3. Synechocystis salina Wislouch

Figure 4. Synechococcus arcuatus Copeland

Figure 5. Synechococcus Cedrorum Sauvageau

Figure 6. Synechococcus elongatus Nageli

Figure 7. Synechococcus eximus Copeland

Figure 8. Synechococcus lividus Copeland

Figure 9. Synechococcus lividus var. curvatus Copeland

Figure 10. Synechococcus lividus var. nov.

Plate II

Figure 1. Synechococcus lividus var. nov.

Figure 2. Synechococcus lividus var. siderophilus Copeland

Figure 3. Synechococcus vescus Copeland

Figure 4. Synechococcus viridissimus Copeland

Figure 5. Synechococcus vulcanus Copeland

Figure 6. Aphanothece nidulans Richter

Figure 7. Aphanothece Castagnei (Bréb.) Rabenhorst

Figure 8. Aphanothece nidulans Richter

Plate III

Figure 1. Chamaesiphon minimus Schmidle

Figure 2. Chamaesiphon cylindricus Peterson

Figure 3. Chamaesiphon gracilis Rabenhorst

Figure 4. Xenococcus Kerneri Hansgirg

Figure 5. Chamaesiphon sp. nov.

Figure 6. Dermocarpa rostrata Copeland

Figure 7. Isocystis pallida Woronichin

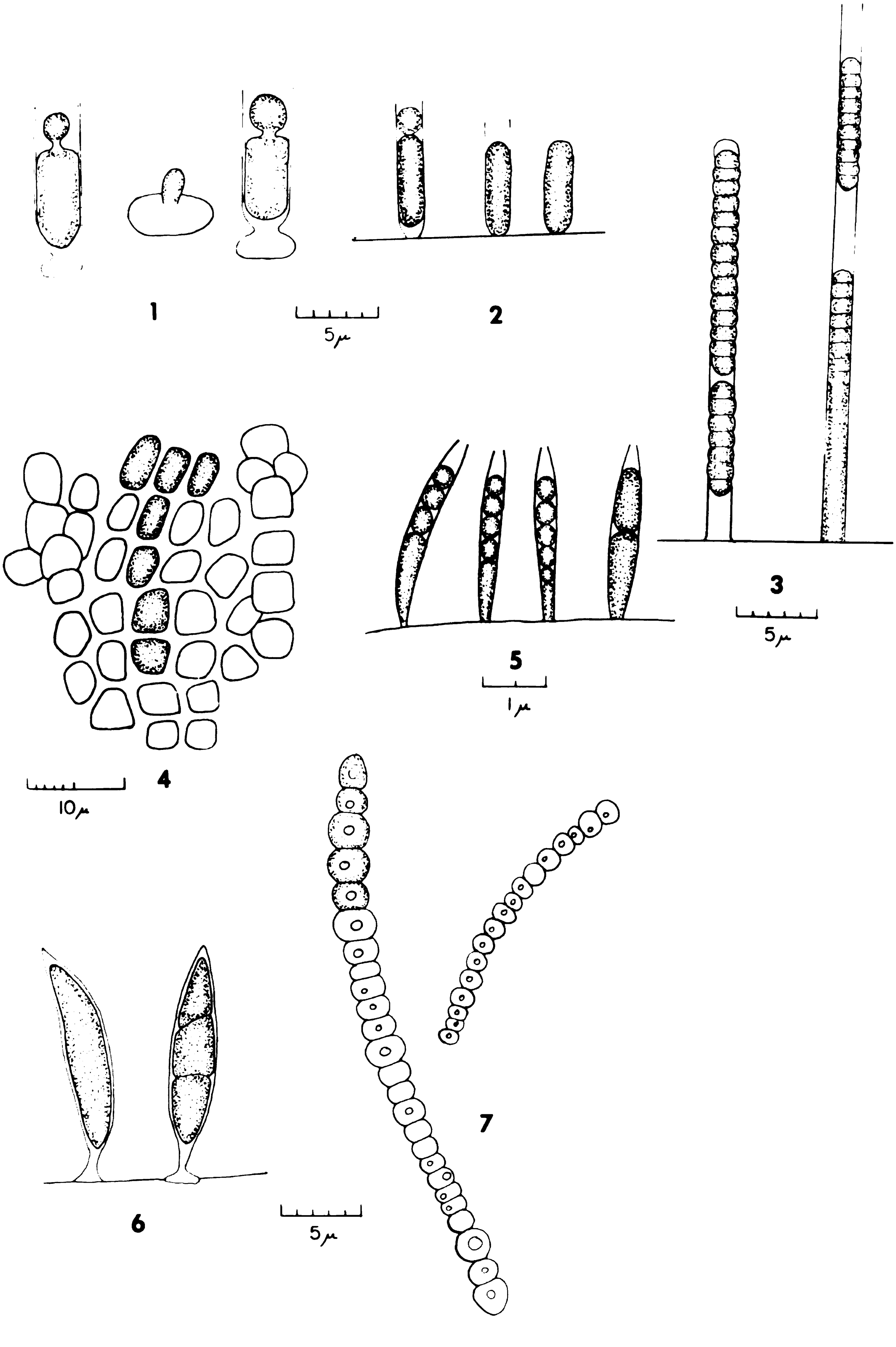
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Plate IV

Figure 1. Spirulina Corakiana Playfair

Figure 2. Spirulina subtilissima Kuetzing

Figure 3. Oscillatoria amphibia Agardh

Figure 4-7. Oscillatoria Boryana Bory, 4 and 5, two types of trichome ends; 6, trichome illustrating the width and length of the spirals and the degree of granulation in some cases; 7-9 illustrate the gradation from spirals readily perceptible to those that are barely perceptible and eventually disappear.

Plate V

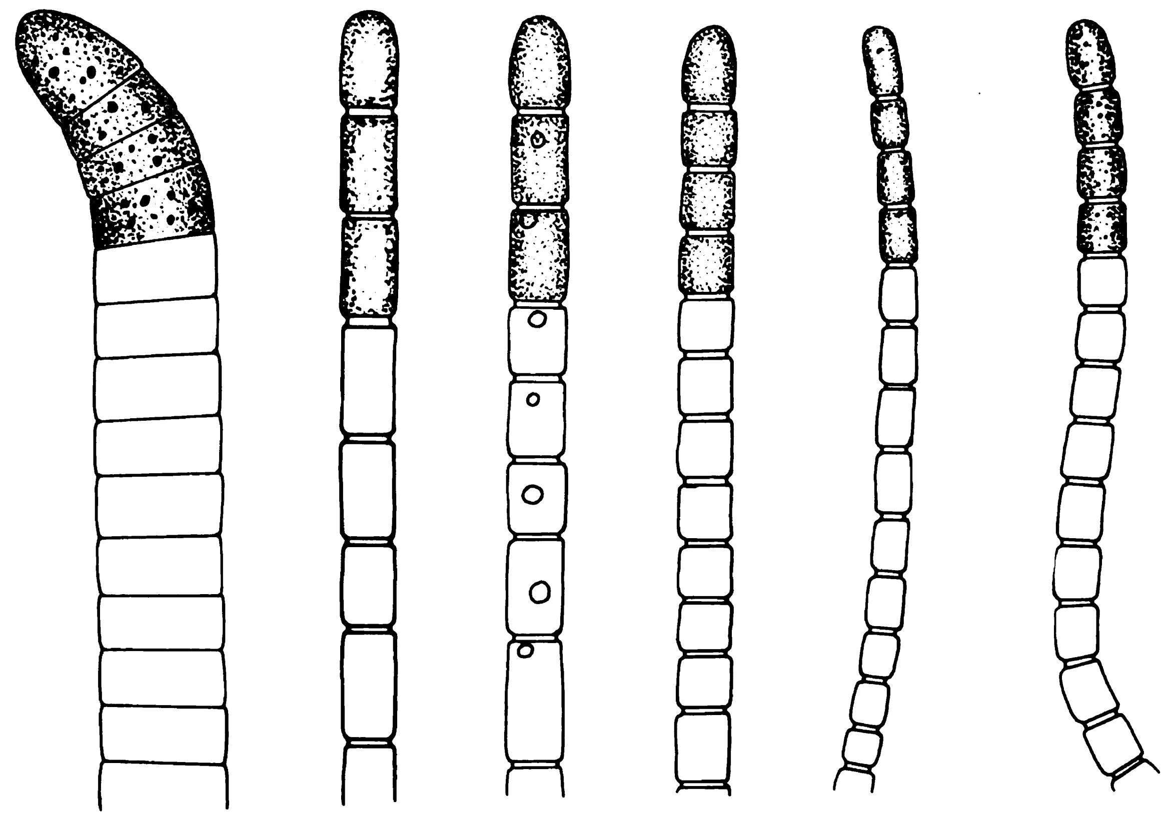
Figure 1. Oscillatoria brevis (Kuetz.) Gomont

Figures 2-4. Oscillatoria geminata Menighini

Figures 5,6. Oscillatoria geminata var. tenella Copeland

Figures 7-10. Oscillatoria geminata var. tenella fa. nov.

Figures 11-13. Oscillatoria geminata var. fragilis Copeland fa. nov.



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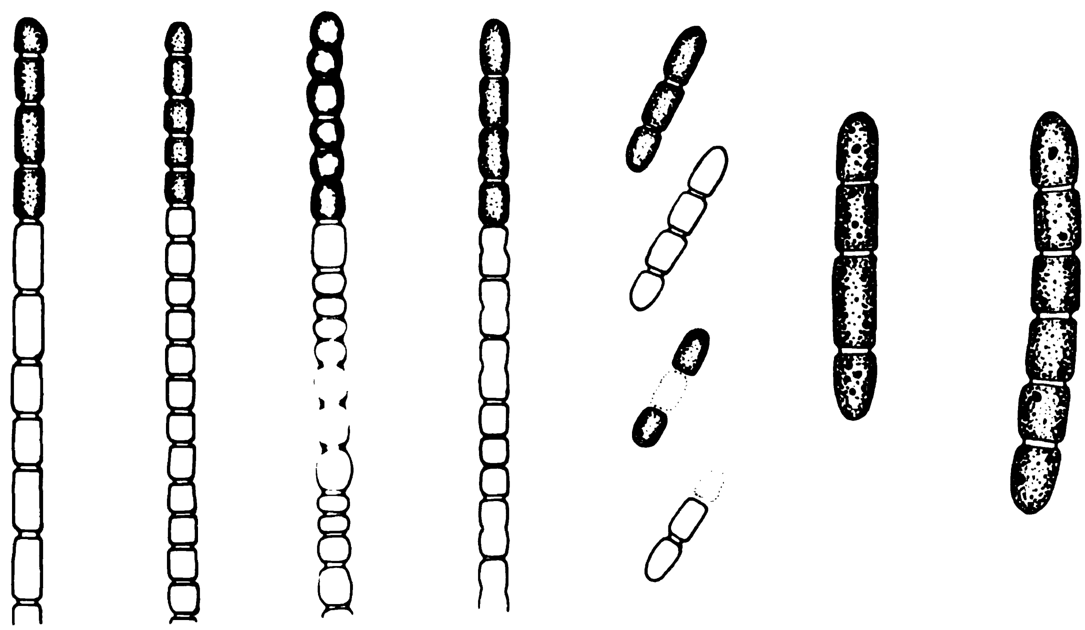

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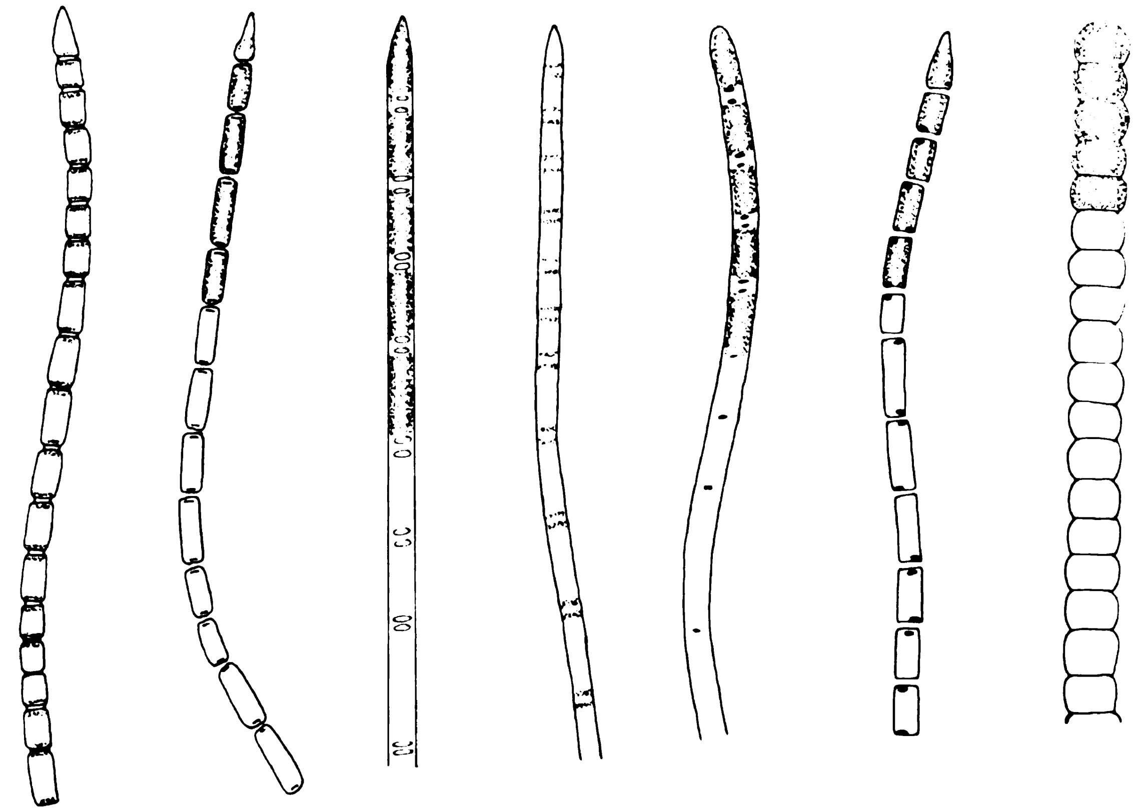
Plate VI

Figure	1.	Oscillatoria limnetica Lemmermann
Figure	2.	Oscillatoria limosa Agardh
Figure	3.	Oscillatoria princeps Vaucher
Figure	4.	Oscillatoria tenuis Agardh var. tergestina Rabenhorst
Figure	5.	Phormidium africanum Lemmermann
Figures	6- 8.	Phormidium angustissimum W. and G. S. West
Figure	9.	Phormidium bigranulatum Gardner
Figure	10.	Phormidium Bohneri Schmidle
Figure	11.	Phormidium foveolarum Gomont
Figure	12.	Phormidium frigidum Fritsch

Plate VII

Figures	1-6.	Phormidium laminosum Gomont Examples showing several types of cross wall granulation and trichome structure.
Figure	7.	Phormidium Jenkelianum Schmidle
Figures	8, 9.	Phormidium tenue (Menegh.) Gomont
Figures	10, 11.	Phormidium sp. nov.
Figure	12.	Phormidium lignicola Fremy
Figures	13, 14.	Phormidium truncatum Lemmermann



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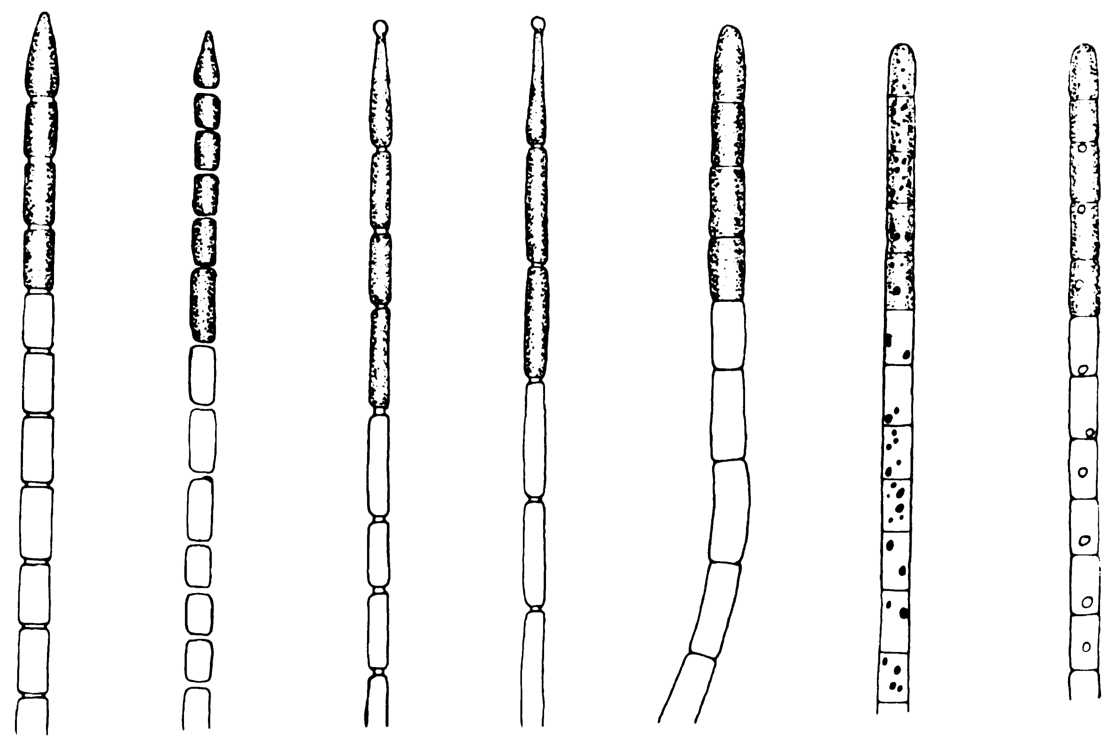

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Plate VIII

Figure 1. Lyngbya nana Tilden

Figure 2. Lyngbya Diguetii Gomont

Figure 3. Pseudanabaena sp. Lauterborn

Portions of the same trichome showing kinds of cell forms that may be taken.

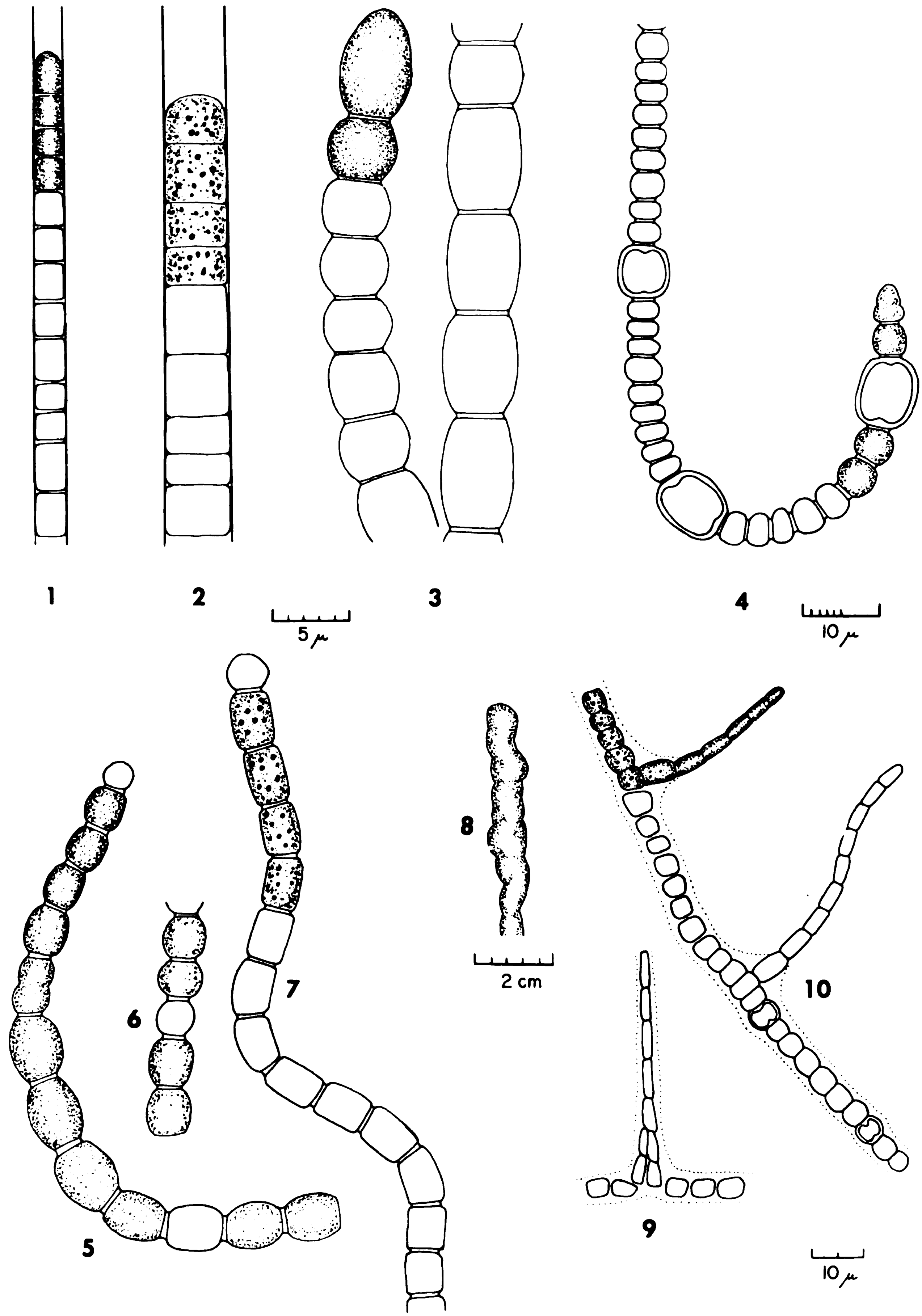
Figure 4. Nodularia Harveyana Thuret

Figures 5- 7. Anabaenopsis circularis (G. S. West) var. nov. Wolosz. and Miller var. nov.

5, Trichome with two kinds of heterocysts and larger cells that may be developing or aborted akinetes; 6, portion of a trichome with a heterocyst of the same spherical form as those that are terminal; 7, trichome showing a portion of the spirals, and granulation assumed in some cases.

Figures 8-10. Mastigocladus laminosus Cohn.

8, habit sketch; 9, 10, differences in cell forms between the main and branching trichomes. Also shown are two methods of branching.


1
2
5 μ
3
4
10 μ
7
8
2 cm
10
6
5
9
10 μ
5 μ

Methods Used to Present Data

The complexity of many natural communities requires many approaches in making an analytical study. Many biological communities are composed of such a great variety of species that the number of possible approaches to their study is often limited, for practical purposes, by the time involved for each approach. On the other hand, the various approaches may be used more readily in the study of thermal stream algae because the communities are composed of relatively few species. Each approach used will contribute to the comprehension of community composition and algal distribution, and, as in the investigation of any problem, the greater the number of approaches used, the greater the comprehension. Each additional approach used, therefore, will create a cumulative effect toward the total comprehension.

To create this cumulative effect, five procedures of data presentation are used in addition to the annotated list of the species previously presented. These procedures are: (1) presence lists of species in communities along temperature gradients; (2) comparisons of combined frequencies and percent volumes of species in the divisions represented in the study; (3) dominance-diversity curves of the algal communities along temperature gradients; (4) continuum curves showing the percent volume contributed by the major species along temperature gradients; (5) diversity indexes of the algal communities along temperature gradients.

Presence Lists of the Species

In reference to the first mentioned approach, a cursory examination of the presence list of algae found in the *Aufwuch* communities will reveal increased diversity with decreasing temperature (Tables III, IV, VII, IX, XI, XIII, XIV, XV, and XVI). The algae listed on these tables were found while observing and identifying the algae from each community, without respect to the number of individuals for each species. Since the time spent studying the algae of each community was not equated in this procedure, the numbers of species found are not as reliable for comparisons of communities as those obtained by using predetermined slide areas. These tables, however, do give a better representation of the species present in a community because more time was spent with each community sample during this phase than during the enumeration phase, resulting in a greater coverage of microscope slide areas. This is the result of the principle of increased species representation with the logarithm of the sample area (Gleason, 1922). Tables of this type may emphasize the scattered distribution of the algae but if each community had been completely examined, many more of the intermediate points on the tables within a temperature range would have been checked. As in most distribution studies, such a thorough examination of all individuals would have been impractical.

Frequencies and Percent Volumes of the Divisions

Whereas the first approach to the study of algal communities lists only the kinds of species found during the identification phase, the four other approaches require the numbers of individuals. From these values the frequency and the percent volume have been computed for each species. In the second approach the sum of the frequencies and volumes have been taken for taxa of the divisions represented in each sampled community (Tables V, VI, VIII, X, XII, and XVII).

Combining the percent values for the taxa of a division tends to mask the differences between frequency and volume, but these differences become more obvious when there are noticeable variations in the sizes. For example, in one community, Phormidium spp., having diameters of 1-1.5 μ may be numerous, with high frequency values and comparable volume when living in association with other species of small diameter; in another community, when living in association with species having diameters of 30-60 μ, the frequency may be relatively high but the volume contribution will be low. Although the influence of an algal population on the total community is better demonstrated by population volume than by frequency of occurrence, the two are listed by divisions to permit comparisons of the two methods of population presentation. These tables also demonstrate the temperatures at which the divisions were first able to develop in a stream, and the degree to which they were represented.

Dominance-diversity Curves

The third approach emphasizes the communities by the use of dominance-diversity curves (Figures 23, 27, 30, 33, 36, and 40). The species found in a community during enumeration are arranged in order of their volumetric importance and plotted on a log scale. The point at the top of a curve is for the species which occupied the greatest volume and is directly beneath the temperature at which all the species along the curve were found. Each subsequent point on the curve is the sequence by which the species are represented in declining order of their importance and is placed one unit to the right on the abscissa (species sequence) from the point preceding it. Rather than using numerous separate graphs, the curves have been placed on one graph so the temperatures along the top are not spaced in numerical sequence but, rather, are arranged for the convenient spacing of the curves. In ranking the species by importance, the unequal contribution of each species is better illustrated. Also, by plotting the values on a log scale, the contribution of the minor species toward the diversity of the community is better illustrated.

Continuum Curves

Whereas the dominance-diversity curves emphasize the community, the continuum curves emphasize the species through the presentation of the volumetric contributions of the major species. The contributions are illustrated by the curves produced in plotting percent algal volume against the temperature (Figures 24, 28, 31, 34, 37, and 41). Such graphic presentations of the continua illustrate the role of populations along a thermal gradient and in this way the effects of the biotic and abiotic environment on the populations are better understood. The possible stenothermal and eurythermal species are also differentiated more readily.

Diversity Index

Although the presence of algae in communities along a temperature gradient shows an increase in the number of species with decreasing temperature, as illustrated in the first described approach, diversity may be shown on a more equitable basis by using the diversity index. The value requires the number of species and the number of individuals in the equation $D = S/\log N$, where S is the number of species and N is the number of individuals (Gleason, 1922). Margalef (1958) altered this somewhat to make $D = (S-1)/\log N$, the equation used

Table II.--List of the taxa enumerated from algal communities in the thermal streams at Alhambra, Boulder, Jackson, Lolo, Pipestone, and Sleeping Child Hot Springs, Montana. The code numbers used on the dominance-diversity curves (Figures 23, 27, 30, 33, 36, and 40) are given after each taxa name.

Taxa	Code No.		Code No.
Anabaena sp.	A 1	Dermocarpa rostrata	P 1
Anabaenopsis circularis var. nov.	B 1	Dichothrix montana	Q 1
Aphanothece Castagnei	C 1	Gloeotrichia echinulata	R 1
Aphanothece stagnina	D 1	Isocystis pallida	S 1
Aphanothece saxicola	E 1	Lyngbya Diguetii	T 1
Calothrix Braunii	F 1	Lyngbya nana	U 1
Calothrix Kossinskajae	G 1	Mastigocladus laminosus	V 1
Calothrix thermalis	H 1	Microcystis densa	W 1
Chamaesiphon sp. nov.	I 1	Microcystis holsatica	X 1
Chamaesiphon cylindricus	J 1	Microcystis pulverea	Z 1
Chamaesiphon gracilis	K 1	Nodularia Harveyana	A 2
Chroococcus minor	L 1	Oscillatoria amphibia	B 2
Chroococcus minutus	M 1	Oscillatoria Boryana	C 2
Chroococcus turgidus	N 1	Oscillatoria brevis	D 2
Cylindrospermum sp.	O 1	Oscillatoria chalybea	E 2

Table II.--Continued

Taxa	Code No.	Taxa	Code No.
Oscillatoria chalybea var. depauperata	F 2	Phormidium tenue	W 2
Oscillatoria geminata	G 2	Phormidium truncatum	X 2
Oscillatoria geminata var. tenella fa. nov.	H 2	Pseudanabaena sp.	Y 2
Oscillatoria geminata var. fragilis fa. nov.	I 2	Spirulina Corakiana	Z 2
Oscillatoria limnetica	J 2	Spirulina subtilissima	A 3
Oscillatoria limosa	K 2	Synechococcus arcuatus	B 3
Oscillatoria princeps	L 2	Synechococcus Cedrorum	C 3
Oscillatoria tenuis var. tergestina	M 2	Synechococcus elongatus	D 3
Phormidium sp. nov.	N 2	Synechococcus eximus	B 3
Phormidium africanum	O 2	Synechococcus lividus	B 3
Phormidium angustissimum	P 2	Synechococcus lividus var. nov.	B 3
Phormidium bigranulatum	Q 2	Synechococcus lividus var. curvatus	B 3
Phormidium Bohneri	R 2	Synechococcus lividus var. siderophilus	B 3
Phormidium frigidum	S 2	Synechococcus minervae	B 3
Phormidium Jenkelianum	T 2	Synechococcus vescus	B 3
Phormidium laminosum	U 2	Synechococcus viridissimus	B 3
Phormidium lignicola	V 2	Synechococcus vulcanus	B 3

Table II.--Continued

Taxa	Code No.	Taxa	Code No.
Synechocystis aquatilis	E 3	Spirogyra sp. F (54 μ)	V 3
Synechocystis crassa	F 3	Stigeoclonium attenuatum	W 3
Synechocystis minuscula	G 3	Ulothrix subconstricta	X 3
Synechocystis salina	H 3	Achnanthes sp.	Y 3
Xenococcus Kerneri	I 3	Amphora sp.	Z 3
Cosmarium obtusatum	J 3	Campyloneis sp.	A 4
Mougeotia sp.	K 3	Denticula sp.	B 4
Oedogonium sp. A (12.5 μ)	L 3	Epithemia sp. A	C 4
Oedogonium sp. B (25 μ)	M 3	Epithemia sp. B	D 4
Oocystis solitaria	N 3	Fragilaria sp.	E 4
Rhizoclonium fontanum	O 3	Gomphonema sp.	F 4
Rhizoclonium hieroglyphicum	P 3	Navicula sp.	G 4
Spirogyra sp. A (22 μ)	Q 3	Nitzschia sp.	H 4
Spirogyra sp. B (27 μ)	R 3	Pinnularia sp.	I 4
Spirogyra sp. C (32 μ)	S 3	Pleurosigma sp.	J 4
Spirogyra sp. D (38.5 μ)	T 3	Surirella sp.	K 4
Spirogyra sp. E (48 μ)	U 3		

in this study. The diversity indexes have been computed for the communities of each stream and were plotted against the water temperatures from which the communities were taken. Scatter diagrams were developed and, where applicable, the slope of the line was computed using $y = a + bx$. The slope indicates the rate at which community diversity changes with change in temperature.

Species Distribution

Temperature ranges, frequencies, volume percentages, and other information pertinent to the species have been presented in the annotated list of the species. Additional information pertinent to the communities has been presented through the use of the presence lists, frequency and volume percentage of the algal divisions, dominance-diversity curves, continuum curves, and diversity indexes by the various tables and graphs. Since all taxa have been identified in the tables and graphs, it was not deemed practical to consider further the data obtained of taxa distribution, except to comment on some of the more prominent species and the distribution of the divisions in each of the streams. The comments under the stream titles are more often of a general nature, in an attempt to explain the effect of the environmental factors, or when the distribution illustrated an ecological concept. Also included are comments relative to stream characteristics that are not shown, or only inferred in the graphs of the abiotic factors or in the maps or profiles.

Alhambra Hot Springs

Figure 24 illustrates the leading roles played by several species in the thermal communities of the Alhambra streams. Mastigocladus laminosus and Oedogonium sp. (12.5 μ) share the dominant role in respect to volume but at different points in the streams. In the south stream (Figure 24A) M. laminosus is dominant from the source, 48.0 C, to approximately 44.0 C. In the north stream (Figure 24B) the distinct dominance of M. laminosus extends from the source, 54.4 C, to approximately 38.5 C. Oedogonium sp. assumed the dominant role beginning at approximately 42.5 C in the south stream and 38.0 C in the north stream.

The difference of 6 C in the maximum tolerable temperature for Oedogonium sp. at the Alhambra streams (Tables III and IV) was probably the result of a difference in habitats. It would be assumed that the difference in maximum tolerable temperatures of this species in the two streams would be less if one considers the similarity of their chemical composition and their proximity. This difference in tolerable temperatures may be explained as follows. At the north stream, the water came from a wooden pipe and flowed in a narrow stream for 70 feet. In this distance the water cooled from 54.4 to 48.5 C. From 70 to 112 feet the water flowed rapidly down a much steeper incline in a shallow stream 7-9 feet wide, cooling rapidly from 48.5 to 38.5 C. After the relatively steep incline, the water flowed more slowly to produce habitats more suitable for Oedogonium sp. In the south stream, the water flowed at a uniformly low velocity for the entire length of the stream to create more uniform and suitable habitats. This uniformity of flow allowed the alga to advance upstream to a point dictated more by the temperature and chemical factors than by velocity of the water. This is in contrast to the maximum tolerable temperature of the same probable species of Oedogonium in the north stream, whose distribution upstream was halted at the base of the steep incline.

The steepest section of the north stream was at approximately 46.0 C. Referring to the dominance-diversity curve at this temperature (Figure 23), it can be seen that rapidly flowing water has an obvious effect on the algal composition. While Mastigocladus laminosus (V 1) is the dominant species in most communities from 54.4 to 38.5 C, it is ranked second at 46.0 C. Phormidium laminosum (U 2) makes an abrupt appearance at this temperature as the dominant form, but as the slope becomes more gradual, its importance diminishes to sixth and then to third.

The division Chlorophyta was represented by three species in the north stream (36.0-54.4 C) with a maximum total frequency of 99.1 percent and maximum total volume of 99.8 percent at 37.5 C. In the south stream (41.0-48.0 C) this division was represented by one species, and, during enumeration, a maximum frequency of 100 percent was attained at 41.5 C. The maximum temperature at which the Chlorophyta existed was 37.5 C in the north stream and 43.5 C in the south stream.

The Chrysophyta (Bacillariophyceae) was represented by eight species in the north stream with a maximum frequency of 2.0 percent and maximum volume of 0.52 percent at 36.5 C. Six species of Chrysophyta (Bacillariophyceae)were in the south stream, with a maximum combined frequency of 0.8 percent and volume of 0.1 percent at 42.0 C. This class appeared to tolerate a maximum temperature of 39.0 C in the north stream, but this first appearance was near the base of the small hill over which the water flowed rapidly. If the water had flowed more slowly for the entire length of the stream, perhaps this class could

TABLE III.--Algal composition in aufwuchs communities along a temperature gradient at Alhambra (North) Hot Springs, Montana.

Taxa	Temperature in degrees Centigrade										
	54.4	52.0	50.0	48.5	46.0	44.5	42.5	39.0	37.5	36.5	36.0
Synechococcus lividus	x	x	x	x	x	x	x	x	x	x	x
Mastigocladus laminosus	x	x	x	x	x	x	x	x	x	x	x
Oscillatoria geminata		x	x	x							
Phormidium angustissimum		x	x	x	x	x	x	x	x	x	x
Phormidium tenue		x	x	x	x	x	x	x	x		x
Isocystis pallida					x						
Phormidium laminosum					x	x	x	x	x		
Oscillatoria geminata var. tenella fa. nov.						x	x	x			
Achnanthes sp.								x	x	x	
Pinnularia sp.								x	x		x
Amphora sp.								x	x	x	
Epithemia sp.								x			
Denticula sp.								x	x	x	
Chroococcus minutus								x		x	
Oscillatoria brevis								x			
Lyngbya nana								x			
Oedogonium sp. (12.5 u)									x	x	x
Spirogyra sp. (22 u)									x	x	x
Chroococcus minor									x	x	
Chroococcus turgidus									x	x	x
Microcystis pulverea									x	x	
Navicula sp.										x	x
Gomphonema sp.										x	
Nitzschia sp.										x	x
Synechocystis aquatilis										x	
Spirulina subtilissima										x	
Oocystis solitaria											x
Chamaesiphon cylindricus											x

TABLE IV.--Algal composition in aufwuchs communities along a temperature gradient at Alhambra (South) Hot Springs, Montana.

Taxa	Temperature in degrees Centigrade 48.0	46.5	45.5	45.0	43.5	42.0	4[illegible].0	41.5	41.0
Synechococcus lividus	x	x	x	x	x				
Isocystis pallida	x								
Spirulina Corakiana	x								
Oscillatoria geminata	x	x	x	x		x	x		x
Oscillatoria geminata var. tenella fa. nov.	x	x	x	x	x	x	x	x	
Phormidium angustissimum	x	x	x	x	x				
Phormidium tenue	x	x	x	x		x		x	
Mastigocladus laminosus	x	x	x	x	x	x			
Denticula sp.				x		x	x	x	x
Achnanthes sp.					x	x	x		x
Navicula sp.					x	x	x	x	
Oscillatoria geminata var. fragilis fa. nov.					x		x	x	
Oedogonium sp. (12.5 u)					x	x	x	x	x
Gomphonema sp.						x		x	x
Chroococcus minor						x	x		x
Chroococcus turgidus						x	x	x	x
Chamaesiphon cylindricus						x	x	x	x
Epithemia sp.							x	x	x
Pinnularia sp.								x	x
Chroococcus minutus								x	x
Microcystis pulverea								x	x

Table V.--Frequency and percent volume of algae by divisions along a temperature gradient at Alhambra (North) Hot Springs, Montana

Temp. in °C	Chlorophyta		Chrysophyta		Cyanophyta	
	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume
54.4	0.00	0.00	0.00	0.00	100	100
52.0	0.00	0.00	0.00	0.00	100	100
50.0	0.00	0.00	0.00	0.00	100	100
48.5	0.00	0.00	0.00	0.00	100	100
46.0	0.00	0.00	0.00	0.00	100	100
44.5	0.00	0.00	0.00	0.00	100	100
42.5	0.00	0.00	0.00	0.00	100	100
39.0	0.00	0.00	0.00	0.00	100	100
37.5	99.10	99.80	0.90	0.20	0.00	0.00
36.5	84.90	99.20	2.00	0.52	13.10	0.28
36.0	---	---	---	---	---	---

Table VI.--Frequency and percent volume of algae by divisions along a temperature gradient at Alhambra (South) Hot Springs, Montana

Temp. in °C	Chlorophyta		Chrysophyta		Cyanophyta	
	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume
48.0	0.00	0.00	0.00	0.00	100	100
46.5	0.00	0.00	0.00	0.00	100	100
45.5	0.00	0.00	0.00	0.00	100	100
45.0	0.00	0.00	0.00	0.00	100	100
43.5	0.00	0.00	0.00	0.00	100	100
42.0	78.10	99.10	0.80	0.10	21.10	0.80
41.5	100	100	0.00	0.00	0.00	0.00
41.0	70.30	93.20	0.00	0.00	29.70	6.80

Figure 23. Dominance-diversity curves for algal communities along a temperature gradient at Alhambra Hot Springs, Montana. Section A represents those communities in the north stream, Section B the south stream. Names for the code numbers are found on Table II.

Each point along a curve, representing one species, is the percent of the total algal volume on the ordinate. The points at the top of the curves are those of species which occupied the greatest volume, and are directly beneath the temperature at which all the species represented on the curve were found. Each subsequent point on the curve is the sequence by which the species are represented in declining order of their importance. Each point on a curve is placed one unit to the right on the abscissa (species sequence) from the point preceding it. The temperatures along the top are not spaced in numerical sequence but, rather, are arranged for the convenient spacing of the curves.

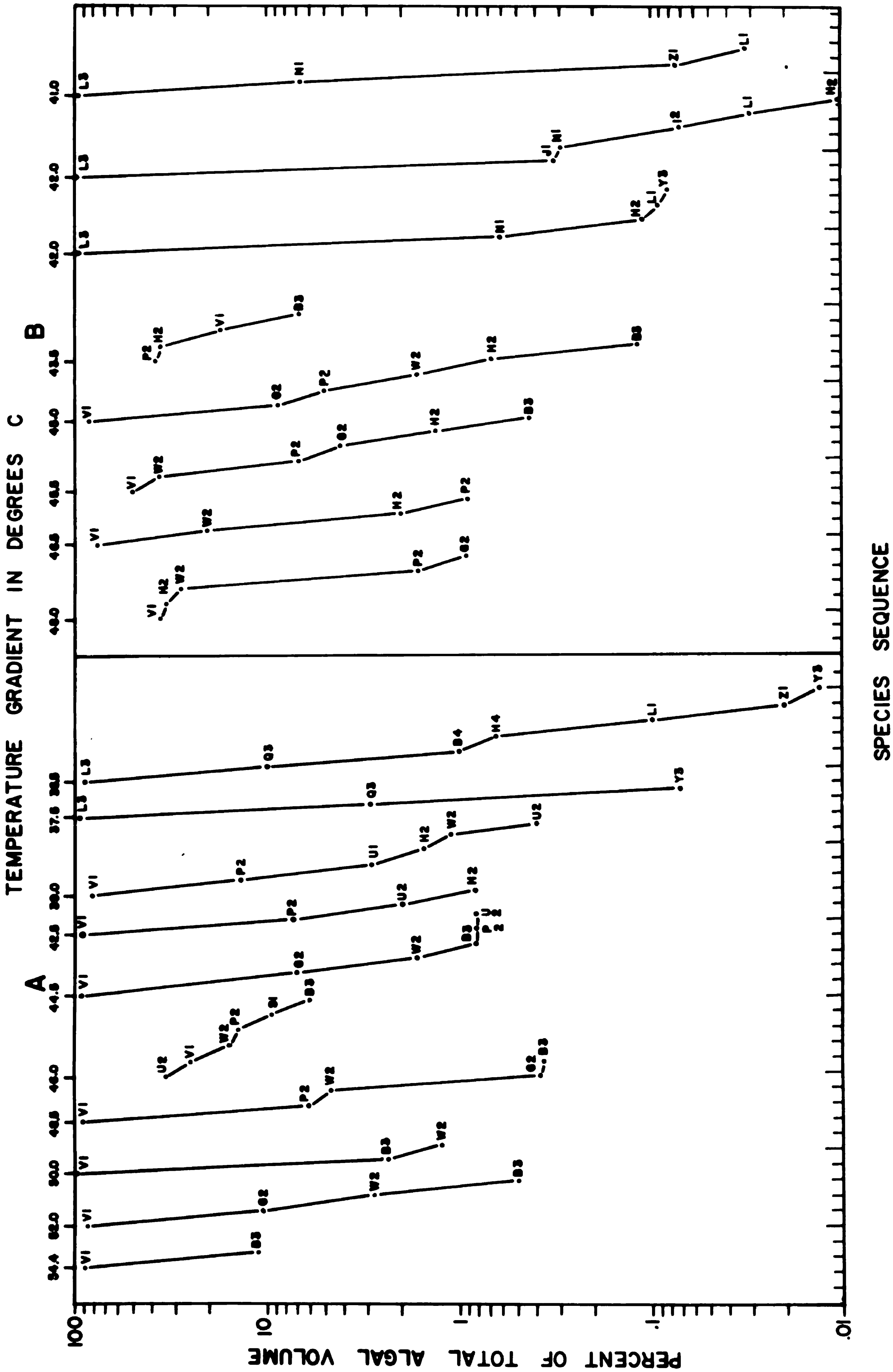

TEMPERATURE GRADIENT IN DEGREES C
SPECIES SEQUENCE
PERCENT OF TOTAL ALGAL VOLUME
A
B
100
10
1
.1
.01

Figure 24. Percent volume of the major species of algae plotted along a temperature gradient at Alhambra Hot Springs, Montana. Graph A represents those algae found in the south stream, Graph B the north stream. The numbers represent the species found in Alhambra (South) as follows: (1) Mastigocladus laminosus, (2) Oscillatoria geminata var. tenella fa. nov., (3) Phormidium tenue, (4) Phormidium angustissimum, (5) Oscillatoria geminata, (6) Synechococcus lividus, (7) Oedogonium sp., 12.5 μ, (8) Chroococcus turgidus. The numbers for those in the Alhambra (North) stream are as follows: (1) Mastigocladus laminosus, (2) Synechococcus spp., (3) Oscillatoria geminata, (4) Phormidium tenue, (5) Phormidium angustissimum, (6) Phormidium laminosum, (7) Isocystis pallida, (8) Oscillatoria geminata var. tenella fa. nov., (9) Lyngbya nana, (10) Oedogonium sp., 12.5 μ), (11) Spirogyra sp. (22 μ).

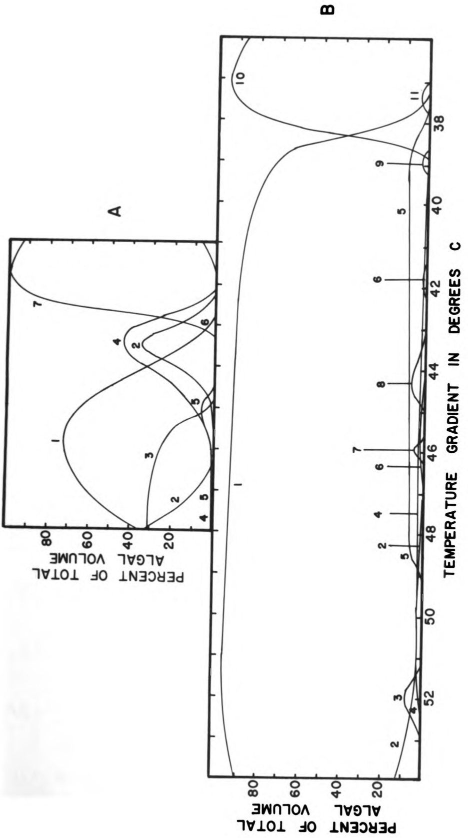

A
B
PERCENT OF TOTAL ALGAL VOLUME
80
60
40
20
PERCENT OF TOTAL ALGAL VOLUME
80
60
40
20
TEMPERATURE GRADIENT IN DEGREES C
38
40
42
44
46
48
50
52

Figure 25. The relationship between the diversity index [(S-1)/log N] of the algal communities and the temperature at the north stream of Alhambra Hot Springs, Montana. The slope of the line is 0.0445.

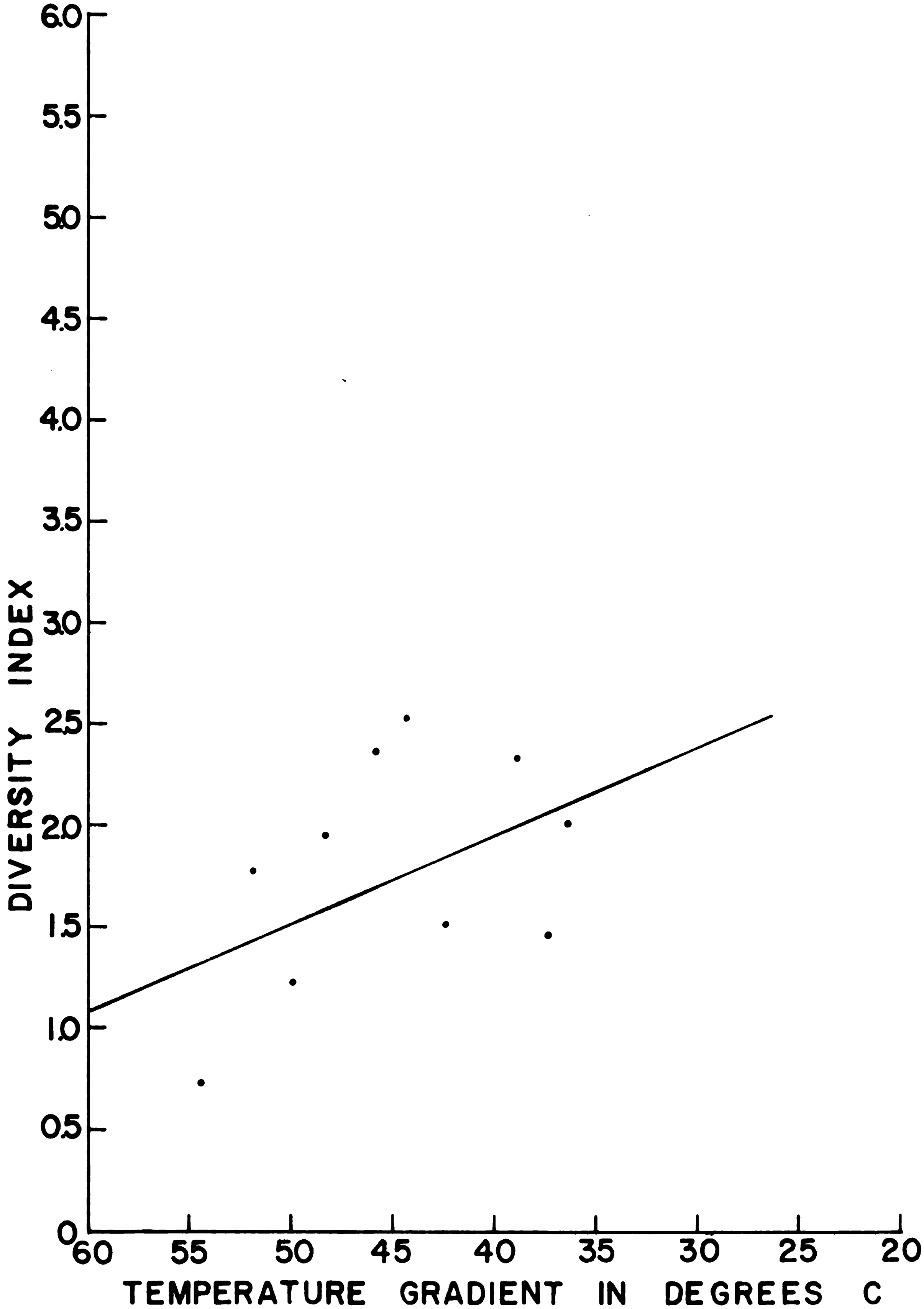
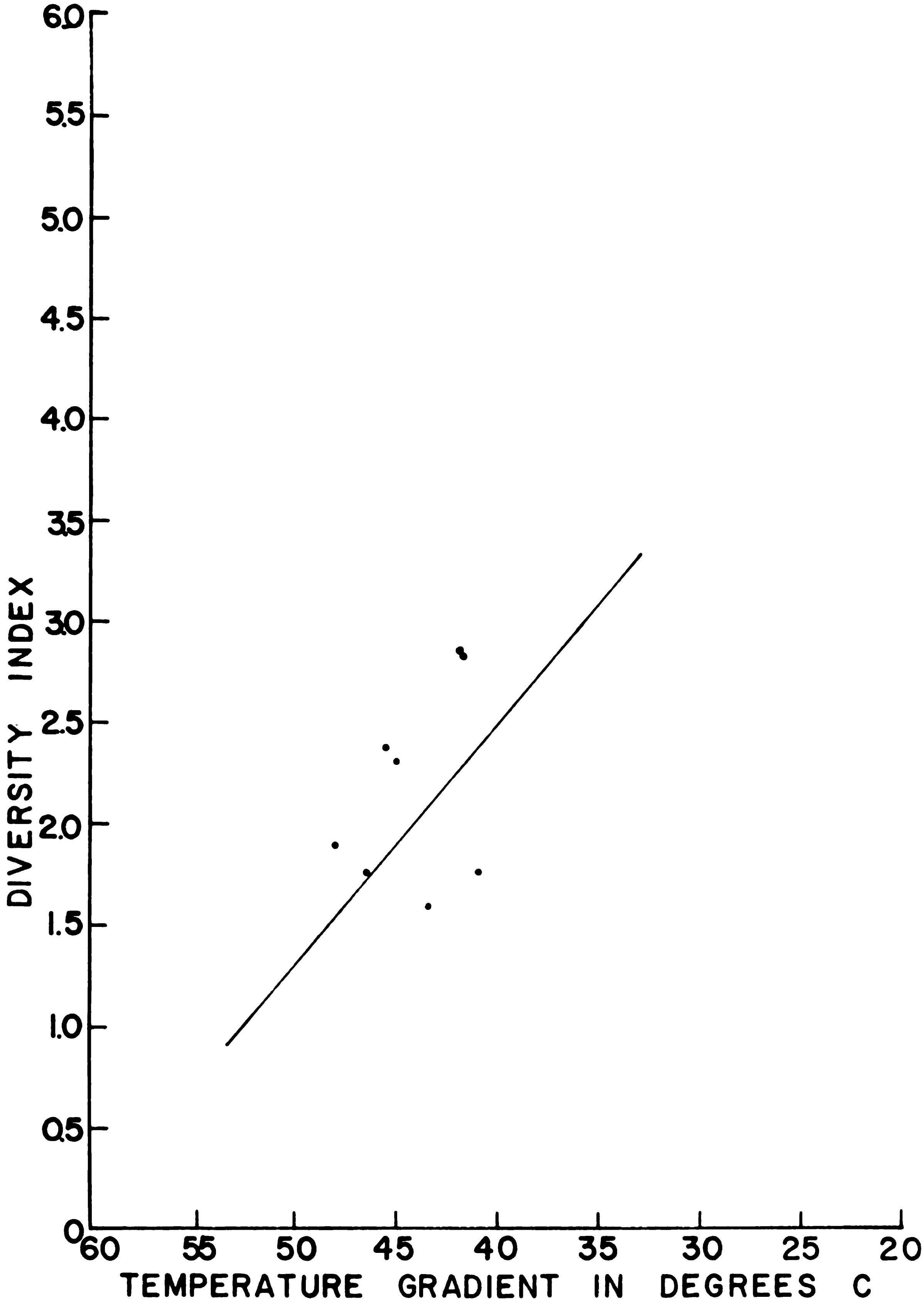

DIVERSITY INDEX
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
60
55
50
45
40
35
30
25
20
TEMPERATURE GRADIENT IN DEGREES C

Figure 26. Diversity indexes [(S-1)/log N] of algal communities along a temperature gradient in the south stream of Alhambra Hot Springs, Montana.



6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
DIVERSITY INDEX
60
55
50
45
40
35
30
25
20
TEMPERATURE GRADIENT IN DEGREES C

have grown at a higher temperature. In the south stream, with its slower flow, the Chrysophyta (Bacillariophyceae) tolerated water up to 45.0 C (Denticula sp.).

The division Cyanophyta was represented by six species and one variety in the north stream (36.0-54.4 C). In the south stream (41.0-48.0 C) this division had 12 species and three varieties. The dominance of Cyanophyta is largely the result of the high temperatures in these streams. Although temperatures in the north stream do extend down to 36.0 C, the physical conditions described earlier are not conducive to the growth of algae in the other divisions that would offer competition. As a result, the range of dominance extends from 54.4 C through 39.0 C, in which the division accounted for 100 percent of the algae enumerated.

Boulder Hot Springs

The most dominant algae in the warmer parts of the stream are Mastigocladus laminosus, Synechococcus spp. and Phormidium tenue, followed by Phormidium sp. nov. and Oscillatoria geminata var. tenella fa. nov. At approximately 42.5 C the dominance was assumed by Spirogyra sp. (32 μ) which remained in that position to 36.0 C except for a temporary showing at 38.0 C of Rhizoclonium sp. and Oscillatoria limosa.

Phormidium laminosus, a prominent thermal alga through the world, has approximately the same temperature range (46.0-56.0 C) as Phormidium tenue (44.0-55.0 C). The most easily recognized distinguishing characteristic of these species is the presence or absence of granules at the cross walls. The possibility of the two forms being the same species in this stream has been discussed earlier.

The division Chlorophyta was represented by six species, with a maximum total frequency of 85.71 percent at 36.0 C and a maximum total volume of 98.9 percent at 40.5 C. The maximum tolerable temperature was 42.5 C, where Oedogonium sp. (12.5 μ) and Spirogyra sp. (32 μ) made simultaneous appearances.

The class Bacillariophyceae of the Chrysophyta was represented by nine species that were individually sparse. To illustrate the part this class plays in the ecological picture, the sum of the volumes for nine species was plotted for a volume curve in Figure 25 (No. 5). As a group these nine species reached a maximum total frequency of 43.64 percent at 42.5 C and a maximum total volume of 23.37 percent at 37.0 C. Achnanthes sp. had a maximum tolerable temperature of 50.0 C, where it attained 2.1 percent of the volume. Although it appeared during scanning of the sample at 48.5 C, it was not enumerated again until the water cooled to 46.0 C. At this latter temperature, Campyloneis sp. also made an appearance.

The Cyanophyta accounted for 97.9 percent or more of the algal volume from the source (56.0 C) downstream to 43.5 C, whereas the frequency was 99.2 percent or more in this temperature range. This division accounted for 28 species or varieties.

The water at Boulder was emitted from a pipe at 61.3 C and, as it splashed on the rocks, cooled rapidly to 56.0 C. This splashing action also permitted the rapid absorption of oxygen. After this initial splashing, the gradual slope was responsible for gradual cooling of the water. It would appear, therefore, that the environmental conditions would be conducive to more uniform occurrences of algal species than is shown in Table VII. There were, however, noticeable

TABLE VII.--Algal composition in aufwuchs communities along a temperature gradient at Boulder Hot Springs, Montana.

Taxa	Temperature in degree Centigrade																					
	56.0	55.0	54.7	53.0	52.0	51.0	50.5	50.0	50.0	49.5	48.5	48.0	47.0	46.0	45.0	44.0	43.5	42.5	40.5	38.0	37.0	36.0
Synechococcus lividus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Phormidium laminosum	x		x	x	x	x		x		x	x		x	x								
Mastigocladus laminosus	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x					
Oscillatoria geminata		x	x					x	x	x		x										
Oscillatoria geminata var. tenella fa. nov.		x			x	x	x	x	x	x		x	x	x	x	x	x	x				
Phormidium tenue		x	x	x	x	x	x	x	x	x	x	x		x	x	x						
Synechococcus arcuatus			x	x		x					x	x										
Synechococcus lividus var. curvatus			x																			
Synechococcus lividus var. nov.			x			x			x	x												
Phormidium angustissimum			x			x																
Synechococcus lividus var. siderophilus				x	x																	
Oscillatoria amphibia							x				x	x	x		x							
Phormidium sp. nov.							x		x		x	x	x	x			x			x		
Achnanthes sp.								x			x			x				x	x	x	x	x
Oscillatoria limnetica								x		x												
Spirulina Corakiana										x												
Oscillatoria chalybea												x										
Oscillatoria brevis													x									
Nodularia Harveyana													x				x			x	x	
														x				x		x		

Chroococcus turgidus	x	x		x	x	x	x	
Nitzchia sp.		x		x	x	x		x
Chroococcus minor		x						
Chroococcus minutus		x	x	x		x	x	
Anabaenopsis circularis var. nov.		x	x					
Calothrix Kossinskajae		x						
Oscillatoria limosa			x	x	x	x	x	
Calothrix Braunii			x					
Oedogonium sp. (12.5 u)				x	x		x	
Spirogyra sp. (32 u)				x	x	x	x	x
Navicula sp.				x	x	x		x
Pinnularia sp.				x	x	x		
Gomphonema sp.				x	x	x	x	
Epithemia sp.				x	x	x		x
Epithemia sp.				x	x			x
Synechocystis salina				x	x			
Microcystis pulverea				x				
Ulothrix sp.					x		x	
Synechocystis crassa					x	x		
Rhizoclonium sp.						x		
Cosmarium obtusatum						x		
Amphora sp.							x	
Spirogyra sp. (48 u)								x
Surirella sp.								x

Table VIII.--Frequency and percent volume of algae by divisions along a temperature gradient at Boulder Hot Springs, Montana

Temp. in °C	Chlorophyta		Chrysophyta		Cyanophyta	
	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume
56.0	0.00	0.00	0.00	0.00	100	100
55.0	0.00	0.00	0.00	0.00	100	100
54.7	0.00	0.00	0.00	0.00	100	100
53.0	0.00	0.00	0.00	0.00	100	100
51.0	0.00	0.00	0.00	0.00	100	100
50.5	0.00	0.00	0.00	0.00	100	100
50.0	0.00	0.00	0.30	2.10	99.70	97.90
49.5	0.00	0.00	0.00	0.00	100	100
48.5	0.00	0.00	0.00	0.00	100	100
48.0	0.00	0.00	0.00	0.00	100	100
47.0	0.00	0.00	0.00	0.00	100	100

46.0	0.00	0.00	0.88	1.50	99.12	98.50
45.0	0.00	0.00	0.00	0.00	100	100
43.5	0.00	0.00	0.00	0.00	100	100
42.5	31.06	82.15	43.64	8.65	25.30	9.20
40.5	62.21	92.15	13.32	0.82	24.47	7.03
38.0	8.92	42.81	42.53	14.48	48.55	42.71
37.0	9.16	60.19	30.30	23.37	60.54	16.44
36.0	85.71	98.90	14.29	1.10	0.00	0.00

Figure 27. Dominance-diversity curves for algal communities along a temperature gradient at Boulder Hot Springs, Montana. Explanation of the curves accompanies Figure 23. Names for the code numbers are found in Table II.

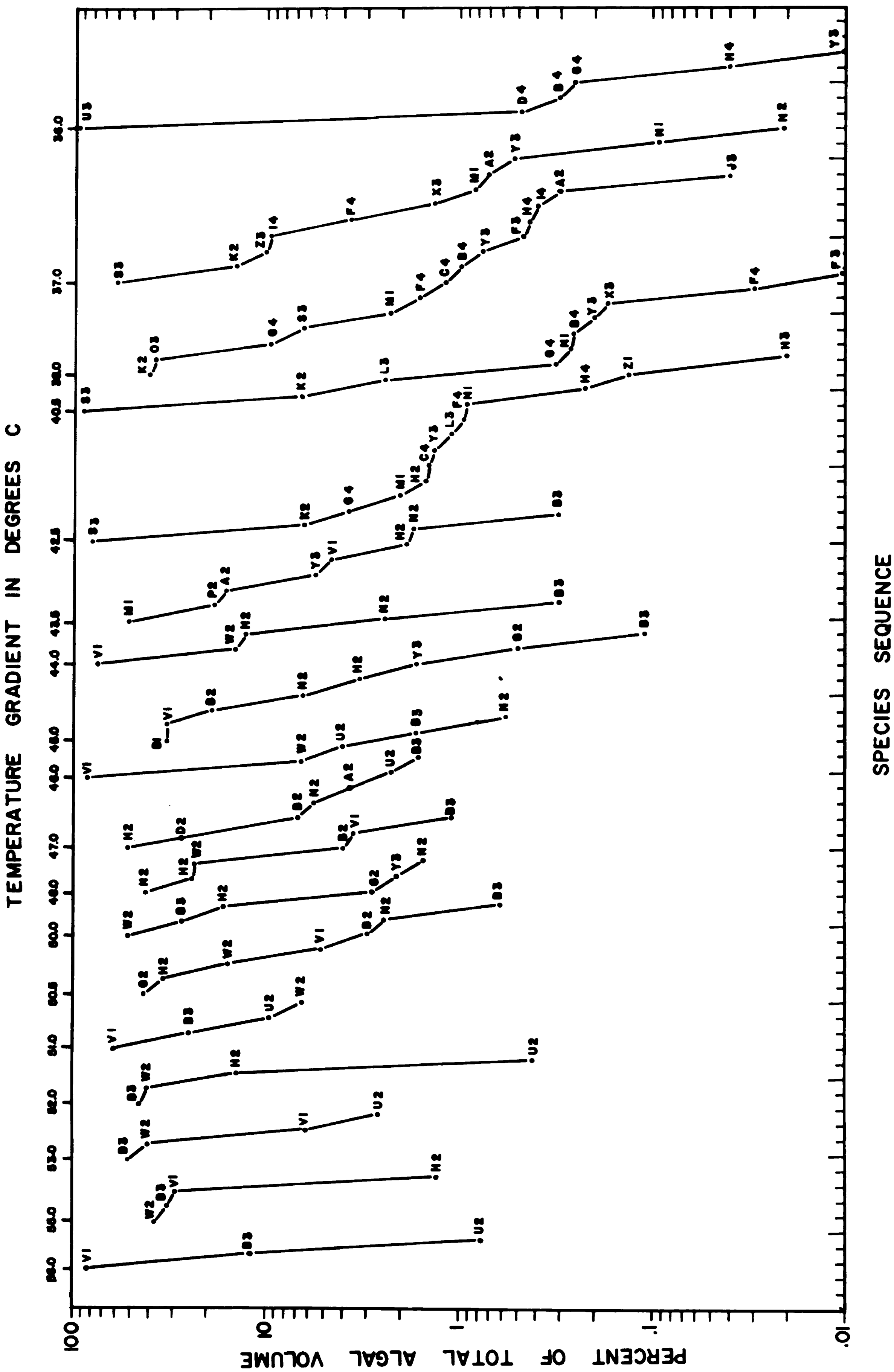

TEMPERATURE GRADIENT IN DEGREES C
SPECIES SEQUENCE
PERCENT OF TOTAL ALGAL VOLUME
100
10
1
.1
.01

Figure 28. Percent volume of the major species of algae plotted along a temperature gradient at Boulder Hot Springs, Montana. The graphs have been constructed in three units to reduce the confusion that may be caused by many curves on one graph. The species are represented as follows: (1) Phormidium tenue, (2) Phormidium laminosum, (3) Achnanthes sp., (4) Oscillatoria brevis, (5) Chrysophyta (Bacillariophyceae) - Amphora sp., Campyloneis sp., Epithemia sp. A, Epithemia sp. B, Gomphonema sp., Navicula sp., Nitzschia sp., Pinnularia sp., Surirella sp., (6) Chroococcus minutus, (7) Oedogonium sp. (12.5 μ), (8) Ulothrix sp. (9) Mastigocladus laminosus, (10) Phormidium sp. nov., (11) Nodularia Harveyana, (12) Anabaenopsis circularis var. nov., (13) Spirogyra sp. (32 μ), (14) Rhizoclonium sp., (15) Synechococcus spp., (16) Oscillatoria geminata, (17) Oscillatoria geminata var. tenella fa. nov., (18) Oscillatoria amphibia, (19) Oscillatoria limosa.

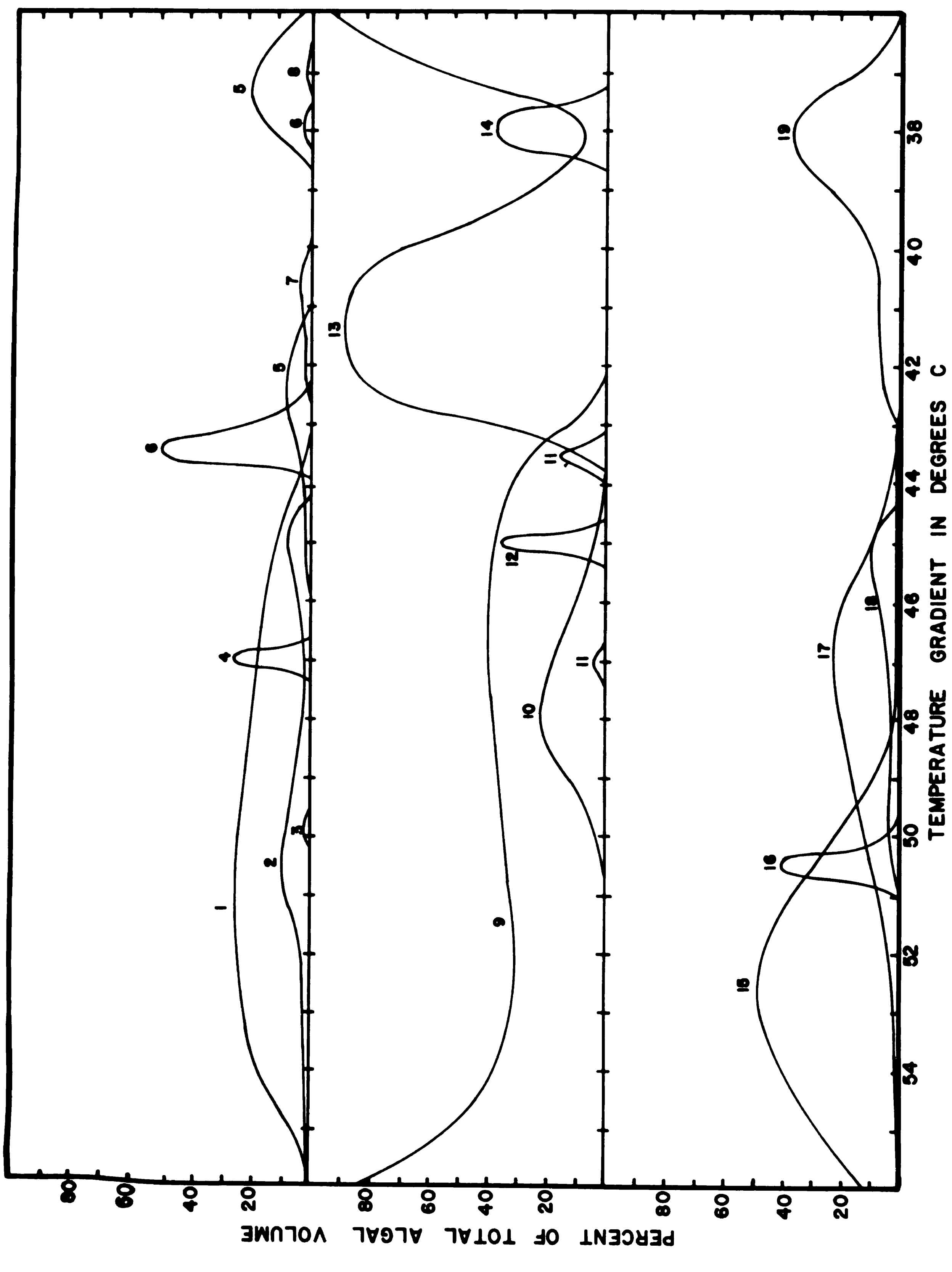
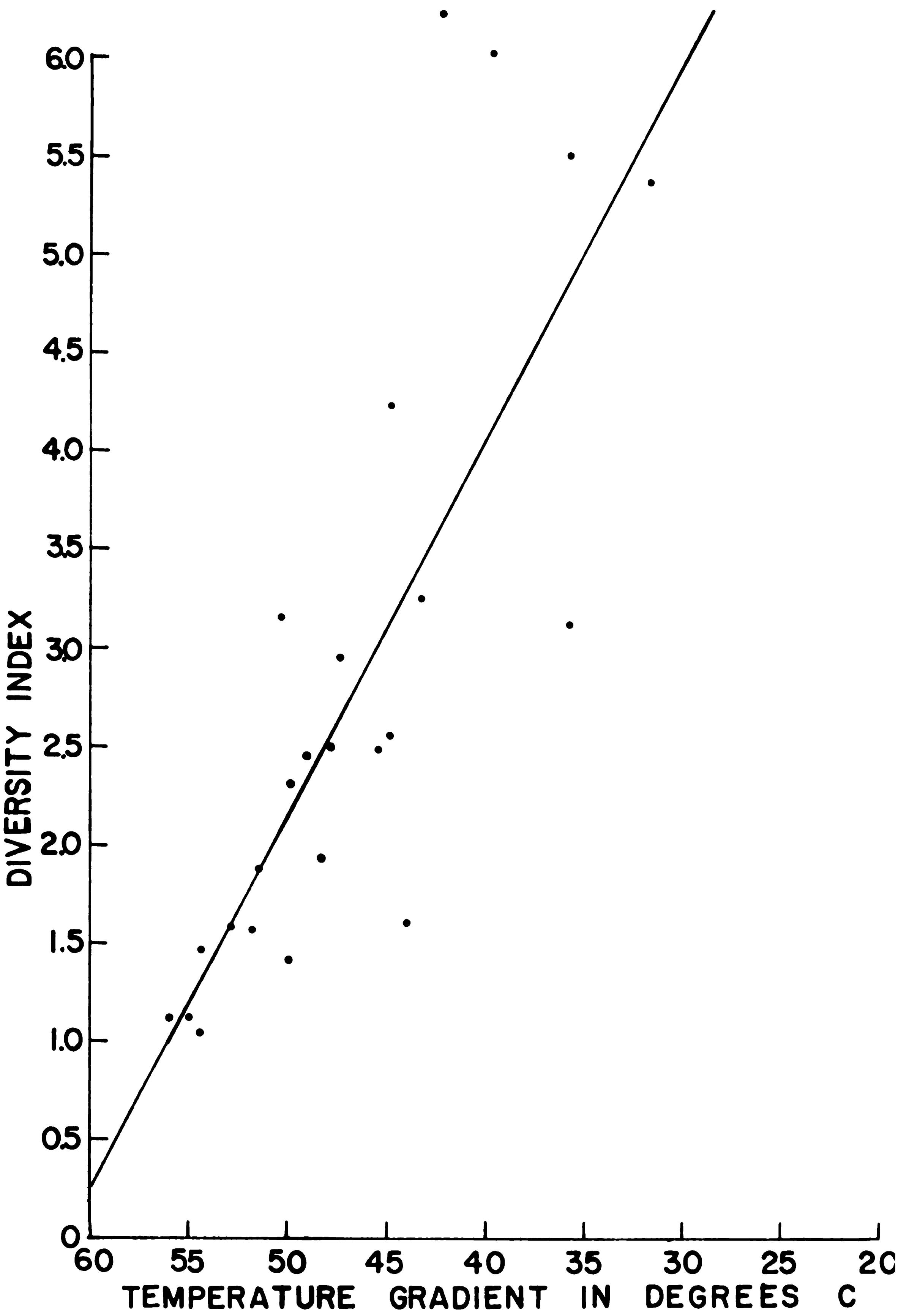

PERCENT OF TOTAL ALGAL VOLUME
20
40
60
80
TEMPERATURE GRADIENT IN DEGREES C
38
40
42
44
46
48
50
52
54
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

Figure 29. Diversity indexes [(S-1)/log N] of algal communities along a temperature gradient at Boulder Hot Springs, Montana. The slope of the line is 0.2028.



DIVERSITY INDEX
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
60
55
50
45
40
35
30
25
20
TEMPERATURE GRADIENT IN DEGREES C

differences in the micro-habitats caused by numerous strands of decaying Cyperaceae and Gramineae that had fallen into the stream. These alternated irregularly with the rocky substrate to produce relatively diverse habitats that were conducive to greater diversification of algal flora than one would find in streams with only rock or sand beds.

Jackson Hot Springs

The water at Jackson Hot Springs overflowed a cement retaining wall and passed over rock rubble in a braided network of streamlets before it entered the stream proper. Synechococcus spp. covered these rocks in a thin, tightly adhering layer that were necessary to remove with a knife blade. After a distance of several feet, the water entered the relatively slow-moving stream, whose alternating velocity created various habitats. The Cyanophyta in the pond-like environments often grew in vertical clumps or tufts attached to the bottom, whereas the Chlorophyta were in long, loosely-attached strands that were at or near the surface. The algae in the small riffles were largely Chrysophyta (Bacillariophyceae) and Cyanophyta that were closely attached in gelatinous masses. This lack of uniformity in habitats appeared to be the primary cause for the irregular representation of the species shown by curves in Figure 31.

The division Chlorophyta was represented by six species. The highest temperature tolerated by this division was 42.0 C, where Ulothrix sp. first appeared. This alga was immediately followed at 41.0 C by Spirogyra sp. (54 μ), and at 39.0 C by Oedogonium sp. (12.5 μ) and Spirogyra sp. (27 μ). From 42.0 C to the end of the stream at 26.0 C, dominance of algal volume was by Spirogyra sp. (54 μ), Oedogonium sp. (12.5 μ), Rhizoclonium sp., and Spirogyra sp. (27 μ). The volume in nine of 11 communities between 40.0 and 26.0 C consisted of over 90 percent Chlorophyta, whereas in communities in small riffles (at 33.0 and 39.0 C) the division was markedly reduced in number and volume.

The Chrysophyta (Bacillariophyceae) was represented by six species whose maximum frequency of 23.67 percent occurred at 31.0 C and maximum volume of 57.0 percent at 33.0 C. Most communities had combined volumes for all species of 8.43 percent or less. The maximum temperature tolerated was 46.0 C.

The Cyanophyta was the only division represented from the source (56.7 C) downstream to 46.0 C. This division was represented by 37 species and varieties, 11 of which were species or varieties of Synechococcus. Since the characters necessary for identification of Synechococcus species are difficult to observe during enumeration, all species have been included under the genus for determination of frequency and volume. The slow flow of water may enable members of this genus to be represented better since in this type habitat they are less dependent on the mucilage of filamentous forms for anchorage. Synechococcus spp. were the only algae found from the source to 54.0 C. From this temperature to approximately 42.0 C, the dominant species were Synechococcus spp., Oscillatoria Boryana, O. geminata, Phormidium angustissimum and P. tenue. The generally common thermal alga, Mastigocladus laminosus, had a limited representation at 52.8 C, with a frequency of 1.89 percent and a volume of 7.5 percent.

TABLE IX.--Algal composition in aufwuchs communities along a temperature gradient at Jackson Hot Springs, Montana.

Taxa	Temperature in degrees Centigrade													
	58.0	57.0	56.7	54.0	52.8	52.0	51.0	50.5	49.5	48.0	46.0	46.0	44.5	43.5
Synechococcus arcuatus	x	x	x	x	x	x		x		x	x			
Synechococcus elongatus	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Synechococcus lividus	x	x	x	x		x		x	x			x	x	x
Synechococcus viridissimus	x	x	x		x					x		x		
Synechococcus eximus			x				x			x				
Synechococcus lividus var. curvatus			x											
Synechococcus vescus			x			x						x		
Synechococcus vulcanus			x				x					x		
Synechococcus lividus var. nov.					x	x		x	x		x		x	
Oscillatoria Boryana				x	x	x	x	x	x	x	x	x	x	x
Mastigocladus laminosus					x									
Synechococcus elongatus var. vestitus						x								
Isocystis pallida						x	x	x	x	x	x	x		
Spirulina Corakiana						x		x				x		
Oscillatoria geminata						x	x	x	x	x	x	x	x	x
Phormidium angustissimum						x	x	x	x	x	x	x	x	
Phormidium laminosum						x				x				
Cylindrospermum sp.						x		x	x					
Phormidium lignicola							x	x			x	x	x	
Phormidium tenue										x			x	
Synechocystis minuscula											x			
Synechococcus Cedrorum											x	x		x
Achnanthes sp.												x	x	x
Navicula sp.													x	x
Chroococcus minutus													x	
Aphanothece Castagnei													x	x
Oscillatoria geminata var. tenella fa. nov.														x
Calothrix thermalis														x
Pinnularia sp.														
Oscillatoria brevis														
Ulothrix sp.														
Chroococcus minor														
Chroococcus turgidus														
Chamaesiphon sp. nov.														
Spirogyra sp. (54 u)														
Oedogonium sp.														
Spirogyra sp. (27 u)														
Gomphonema sp.														
Denticula sp.														
Aphanothece saxicola														
Oscillatoria geminata var. fragilis fa. nov.														
Pleurosigma sp.														
Microcystis densa														
Chamaesiphon minimus														
Chamaesiphon gracilis														
Gleotrichia echinulata														
Rhizoclonium sp.														
Mougeotia sp.														
Xenococcus acervatus														
Dermocarpa rostrata														

42.5	42.0	42.0	41.0	40.0	39.0	38.5	37.5	37.0	36.0	33.0	32.0	31.0	29.5	27.0	26.0
x	x														
x	x	x	x			x									
	x			x	x		x		x	x					
					x										
	x														
x	x	x	x	x	x	x	x								
x	x	x	x	x	x	x	x	x		x					
	x									x					
x	x	x	x	x	x				x						
x	x	x	x	x	x	x	x	x		x					
x	x	x	x			x	x	x		x					
		x	x			x	x	x	x	x	x				
x	x				x	x									
		x	x					x		x					
	x									x					
x	x		x			x				x					
x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
	x			x	x		x		x						
	x	x			x										
	x									x					
x	x	x			x				x						
					x									x	x
	x			x	x					x		x	x	x	x
	x			x	x			x							
		x	x				x	x	x	x					
		x	x			x	x	x				x			
		x	x			x			x		x				
		x	x												
			x	x		x	x	x	x						
				x	x		x		x	x					
				x				x		x	x	x	x	x	x
				x							x	x	x	x	x
						x									
						x									
						x				x					
							x								
									x						
									x		x		x		
										x	x	x	x	x	x
										x					
											x	x	x	x	x
											x				
											x		x	x	x
											x	x	x	x	x

Table X.--Frequency and percent volume of algae by divisions along a temperature gradient at Jackson Hot Springs, Montana

Temp. in °C	Chlorophyta		Chrysophyta		Cyanophyta	
	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume
58.0	0.00	0.00	0.00	0.00	100	100
57.0	0.00	0.00	0.00	0.00	100	100
56.7	0.00	0.00	0.00	0.00	100	100
54.0	0.00	0.00	0.00	0.00	100	100
52.8	0.00	0.00	0.00	0.00	100	100
52.0	0.00	0.00	0.00	0.00	100	100
51.0	0.00	0.00	0.00	0.00	100	100
50.5	0.00	0.00	0.00	0.00	100	100
49.5	0.00	0.00	0.00	0.00	100	100
48.0	0.00	0.00	0.00	0.00	100	100
46.0	0.00	0.00	0.00	0.00	100	100
46.0	0.00	0.00	0.49	5.80	99.51	94.20
44.5	0.00	0.00	0.00	0.00	100	100

43.5	0.00	0.00	1.60	5.10	98.40	94.90
42.5	0.00	0.00	0.00	0.00	100	100
42.5	---	---	---	---	---	---
42.0	0.00	0.00	1.04	4.90	98.96	95.10
41.0	26.00	46.10	0.00	0.00	74.00	53.90
40.0	77.72	99.52	14.27	0.35	8.01	0.13
39.0	0.00	0.00	2.93	20.40	97.07	79.60
37.5	90.10	99.90	7.00	0.03	2.90	0.07
37.0	41.68	91.72	4.86	4.84	53.46	3.44
36.0	82.70	96.52	9.07	1.42	8.27	2.06
33.0	0.00	0.00	16.87	57.00	83.13	43.00
32.0	26.96	98.72	0.40	0.43	72.64	0.85
31.0	58.00	94.23	23.67	5.66	16.33	0.11
29.5	19.88	91.04	19.30	8.43	60.77	0.53
27.0	31.48	96.56	11.10	2.72	57.42	0.72
26.0	35.62	96.97	9.42	2.52	54.95	0.51

Figure 30. Dominance-diversity curves for algal communities along a temperature gradient at Jackson Hot Springs, Montana. Explanation of the curves accompanies Figure 23. Names for the code numbers are found in Table II.

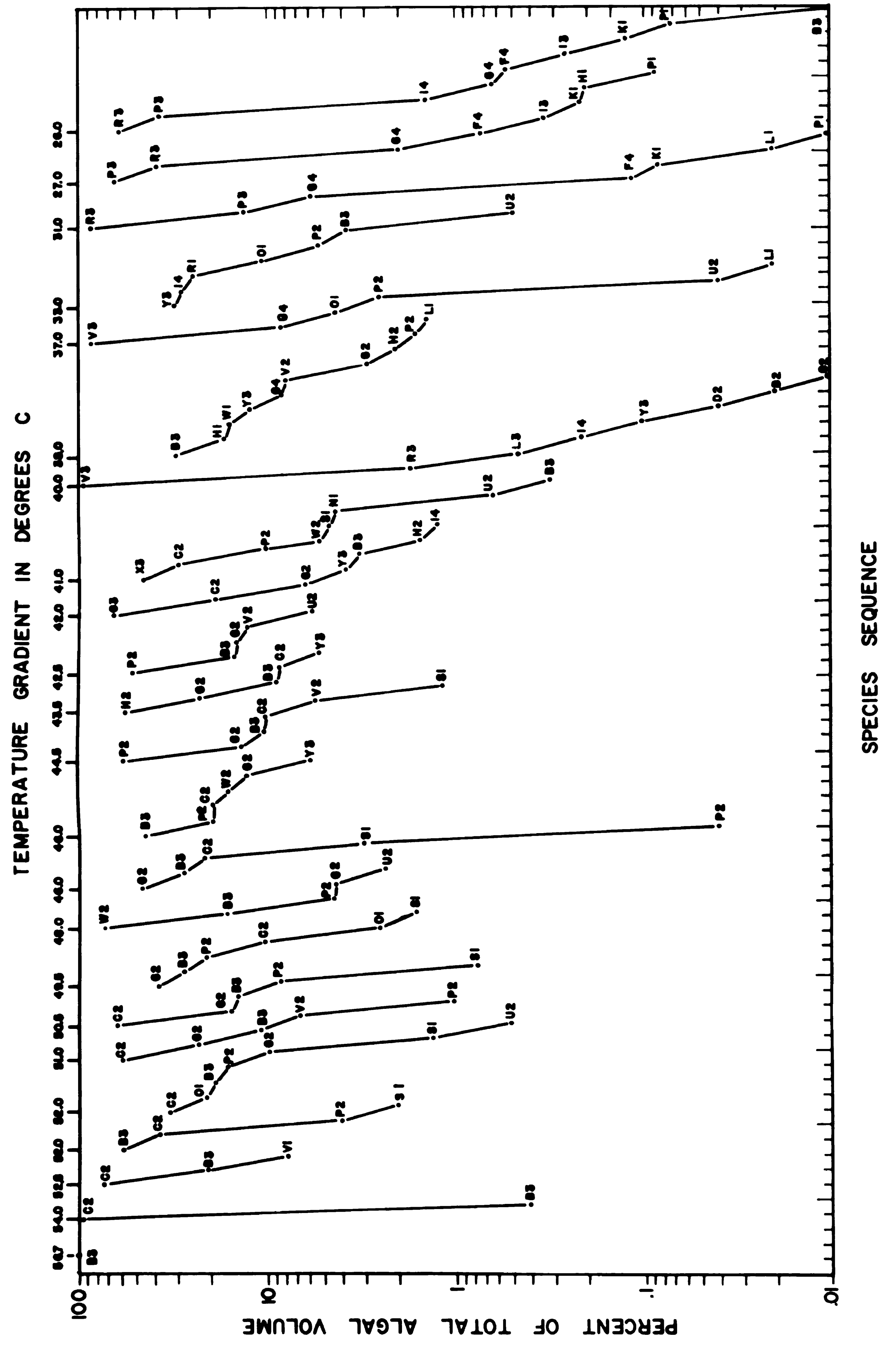

TEMPERATURE GRADIENT IN DEGREES C
PERCENT OF TOTAL ALGAL VOLUME
SPECIES SEQUENCE
100
10
1
.1
.01

Figure 31. Percent volume of the major species of algae plotted along a temperature gradient at Jackson Hot Springs, Montana. The graphs have been constructed in three units to reduce the confusion that may be caused by many curves on one graph. The numbers represent the species as follows: (1) Oscillatoria geminata, (2) Cylindrospermum sp., (3) Phormidium laminosum, (4) Isocystis pallida, (5) Synechocystis minuscula, (6) Frustulia sp., (7) Calothrix thermalis, (8) Navicula sp., (9) Gloeotrichia echinulata, (10) Spirogyra, 27 μ, (11) Oscillatoria Boryana, (12) Mastigocladus laminosus, (13) Phormidium lignicola, (14) Phormidium tenue, (15) Oscillatoria geminata var. tenella fa. nov., (16) Chroococcus turgidus, (17) Spirogyra sp., 54 μ, (18) Microcystis densa, (19) Oedogonium sp. 12.5 μ, (20) Pinnularia sp., (21) Rhizoclonium sp., (22) Synechococcus spp., (23) Phormidium angustissimum, (24) Achnanthes sp., (25) Ulothrix sp.

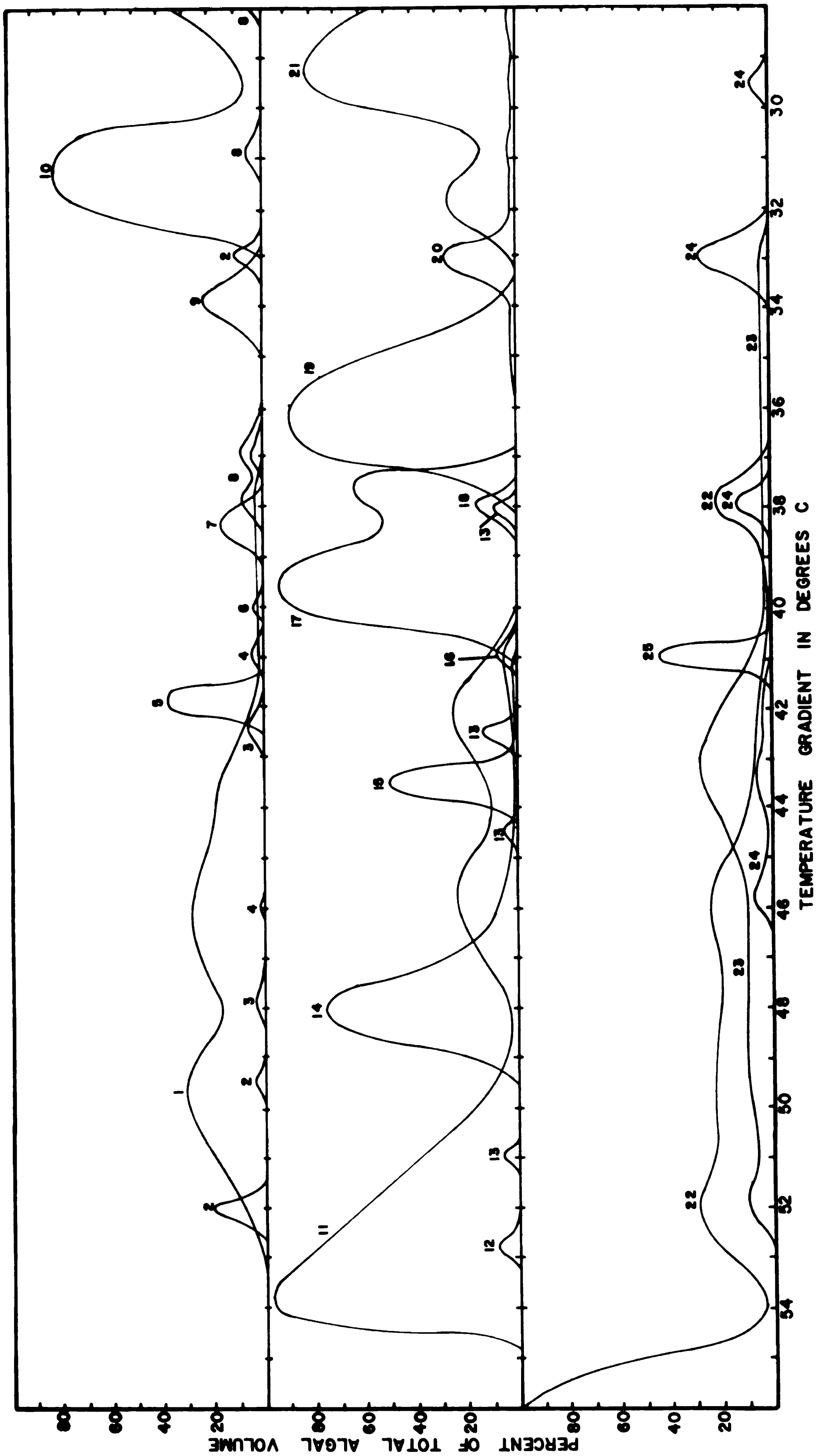
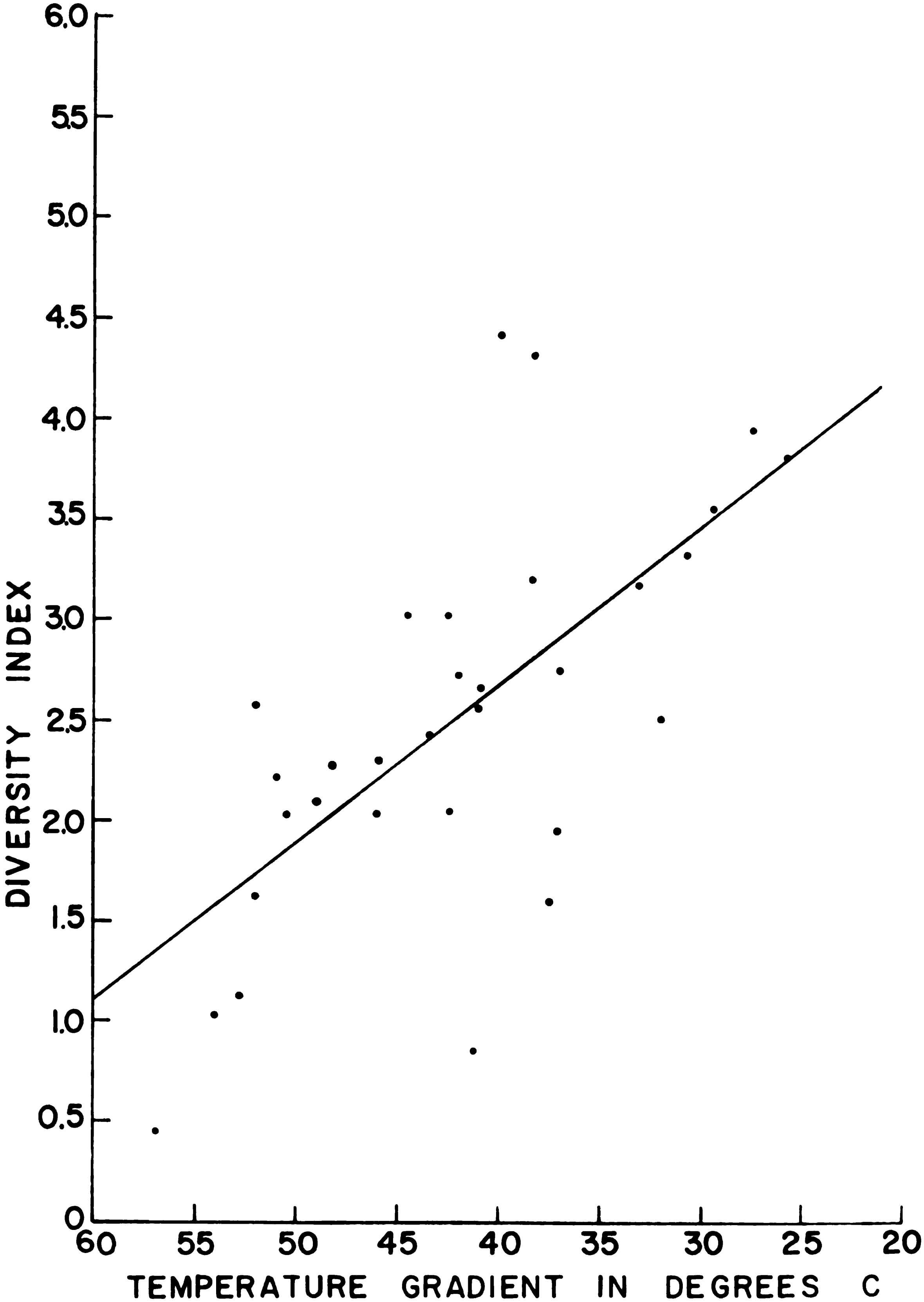

PERCENT OF TOTAL ALGAL VOLUME
TEMPERATURE GRADIENT IN DEGREES C
30
32
34
36
38
40
42
44
46
48
50
52
54
20
40
60
80

Figure 32. Diversity indexes [(S-1)/log N] of the algal communities along a temperature gradient in the stream at Jackson Hot Springs, Montana. The slope of the line is 0.08025.


DIVERSITY INDEX
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
60
55
50
45
40
35
30
25
20
TEMPERATURE GRADIENT IN DEGREES C

Lolo Hot Springs

A two-sided retaining wall had been constructed along the side of a boulder at Lolo Hot Springs to create a small pool (Figure 6). The algal samples taken from the pool and above and below the pool were examined to compare species diversity in still and moving water. Eight species were taken from immediately above the pool at 42.0 C, 15 species from the pool itself at 40.0 C, and seven species from the water as it left the pool at 40.0 C. The species in communities above and below the pool were also found in the pool, but the tendency was for a higher percentage of filamentous forms to be in waters of higher velocity. Eight of the 15 species found in the pool were filamentous forms whereas five of the seven species found in the effluent water were filamentous. Although it is logical to assume that every species in the pool would probably flow out, many of these species were apparently not well adapted to live in rapidly flowing water.

Chlorophyta appeared at 38.0 C with a frequency of 2.49 percent and a volume of 5.8 percent. The division retained its dominance in all but one community for the remainder of the stream to 34.0 C, a distance of approximately 370 feet. This dominance for the major length of the stream was accomplished by five of the 34 taxa found in the stream.

The highest temperature the Chrysophyta (Bacillariophyceae) were found to tolerate was the 40.0 C of the pool, where Denticula sp. comprised 0.24 percent of the algae and 14.35 percent of the volume. The highest frequency for this division at Lolo was 20.89 percent at 36.0 C (196 feet from the source). The other frequencies were 8.95 percent or less and except for the 14.35 percent at 40.0 C, the maximum

TABLE XI.--Algal composition in aufwuchs communities along a temperature gradient at Lolo Hot Springs, Montana.

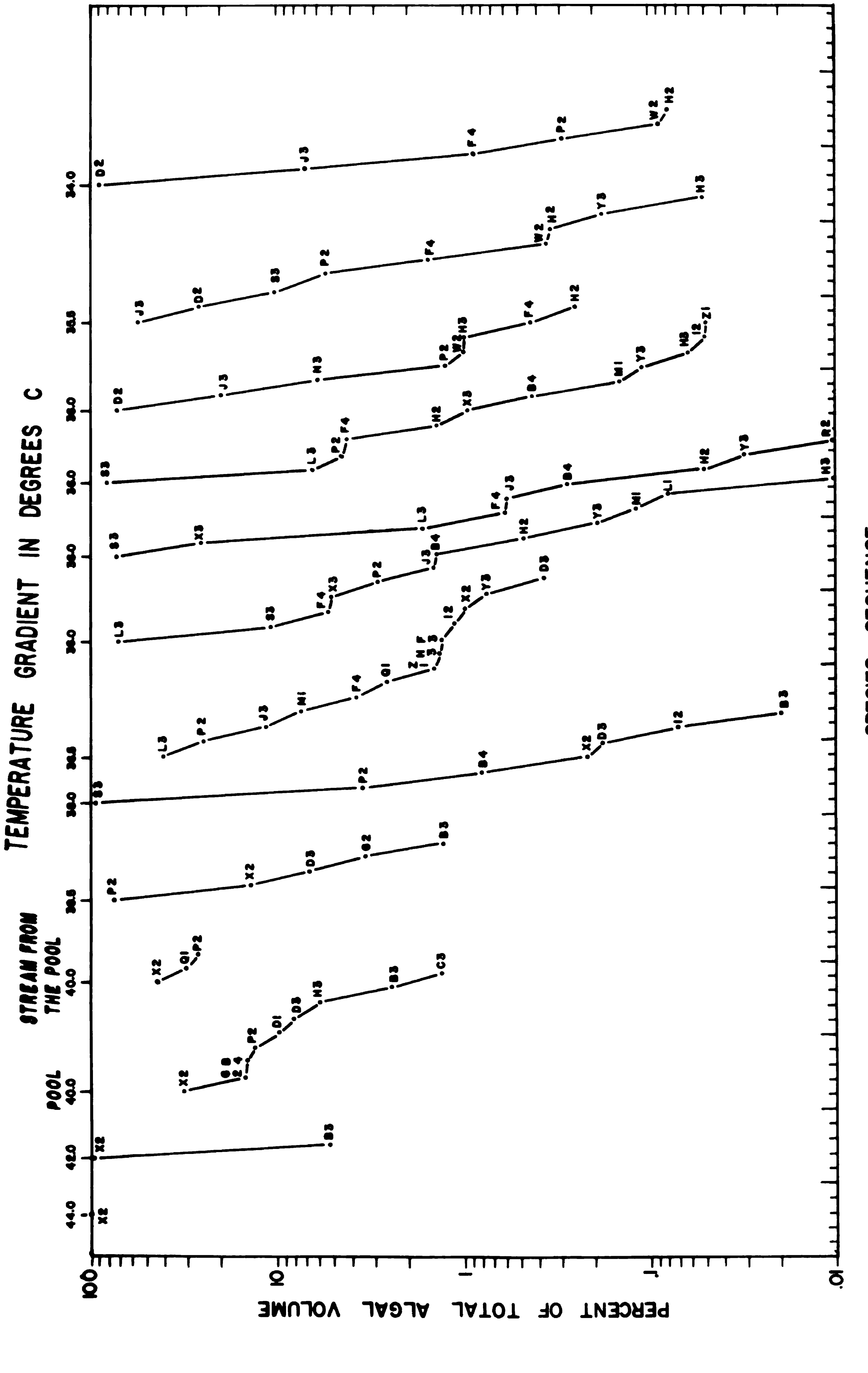
	Temperature in degrees Centigrade													
	45.5	44.0	42.0	40.0	40.0	39.5	38.0	36.5	36.0	36.0	36.0	36.0	35.5	34.0
Synechococcus lividus	x	x	x	x	x	x	x							
Phormidium truncatum	x	x	x	x	x	x	x	x						
Synechococcus Cedrorum		x	x	x		x								
Aphanothece stagnina		x	x	x		x	x	x	x	x				
Oscillatoria geminata var. fragilis fa. nov.		x	x	x	x	x	x	x	x	x	x			
Phormidium laminosum		x	x	x		x						x	x	
Synechococcus elongatus			x	x	x	x	x	x	x					
Dichothrix montana			x	x	x	x	x	x	x					
Denticula sp.				x		x		x	x	x	x		x	
Chroococcus minutus				x		x		x	x	x	x	x	x	x
Synechocystis salina				x				x	x		x	x	x	
Isocystis pallida				x										
Spirulina Corakiana				x										
Phormidium angustissimum				x	x	x	x	x	x	x	x	x	x	x
Phormidium tenue				x	x							x	x	x
Pinnularia sp.						x			x		x			x

Spirogyra sp. (32 u)	x	x	x	x	x	x	x	x
Cosmarium obtusatum	x	x	x	x	x	x	x	x
Oedogonium sp. (12.5 u)		x	x	x	x			
Achnanthes sp.		x	x	x	x	x	x	x
Gomphonema sp.		x	x	x	x	x	x	x
Microcystis pulverea		x	x	x	x	x		
Synechocystis crassa		x	x	x	x	x		x
Ulothrix sp.			x	x				
Epithemia sp.			x	x	x			
Chroococcus minor			x					x
Oscillatoria amphibia			x					
Oscillatoria geminata var. tenella			x	x	x	x	x	x
Navicula sp.			x					x
Amphora sp.			x					
Oscillatoria brevis				x		x	x	x
Phormidium Bohneri				x	x			
Nitzschia sp.					x			x
Oocystis solitaria						x		

Table XII.--Frequency and percent volume of algae by divisions along a temperature gradient at Lolo Hot Springs, Montana

Temp. in °C	Chlorophyta		Chrysophyta		Cyanophyta	
	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume
45.5	0.00	0.00	0.00	0.00	100	100
44.0	0.00	0.00	0.00	0.00	100	100
42.0	0.00	0.00	0.00	0.00	100	100
40.0	0.00	0.00	0.24	14.35	99.76	85.60
39.5	0.00	0.00	0.00	0.00	100	100
38.0	2.49	95.80	0.24	0.80	97.20	3.40
36.5	0.69	53.43	0.92	4.59	98.39	41.98
36.0	11.37	89.35	8.95	7.05	79.68	3.60
36.0	90.43	99.02	6.17	0.87	3.40	0.11
36.0	14.53	87.79	20.89	4.77	64.58	6.44
36.0	2.55	25.15	0.42	0.44	97.45	74.41
35.5	4.94	65.44	1.40	1.70	93.66	32.86
34.0	55.83	96.82	1.76	0.10	42.41	3.08

Figure 33. Dominance-diversity curves for algal communities along a temperature gradient at Lolo Hot Springs, Montana. Explanation of the curves accompanies Figure 23. Names for the code numbers are found in Table II.



TEMPERATURE GRADIENT IN DEGREES C
POOL
STREAM FROM THE POOL
SPECIES SEQUENCE
PERCENT OF TOTAL ALGAL VOLUME
100
10
1
.1
.01

Figure 34. Percent volume of the major species of algae plotted along a temperature gradient at Lolo Hot Springs, Montana. The graphs have been constructed in three units to reduce the confusion that may be caused by many curves on one graph. The numbers represent the species as follows: (1) Dichothrix montana, (2) Phormidium angustissimum, (3) Synechocystis salina, (4) Oscillatoria geminata var. fragilis fa. nov., (5) Ulothrix subconstricta, (6) Aphanothece stagnina, (7) Denticula sp., (8) Spirogyra sp. 32 μ, (9) Oedogonium sp. 12.5 μ, (10) Oscillatoria brevis, (11) Gomphonema sp., (12) Phormidium truncatum, (13) Synechococcus spp., (14) Oscillatoria geminata var. tenella, (15) Chroococcus minutus, (16) Cosmarium obtusatum.

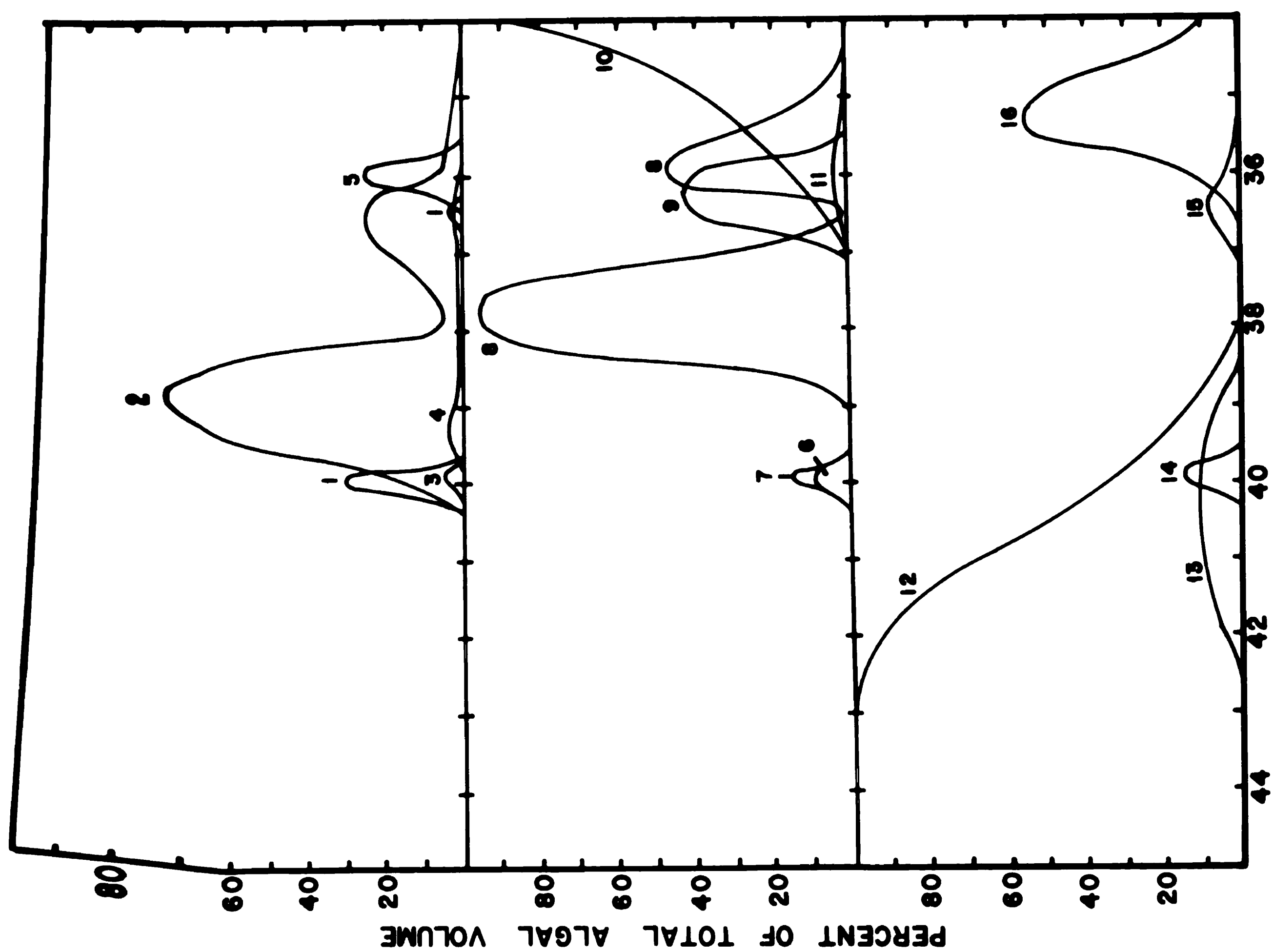
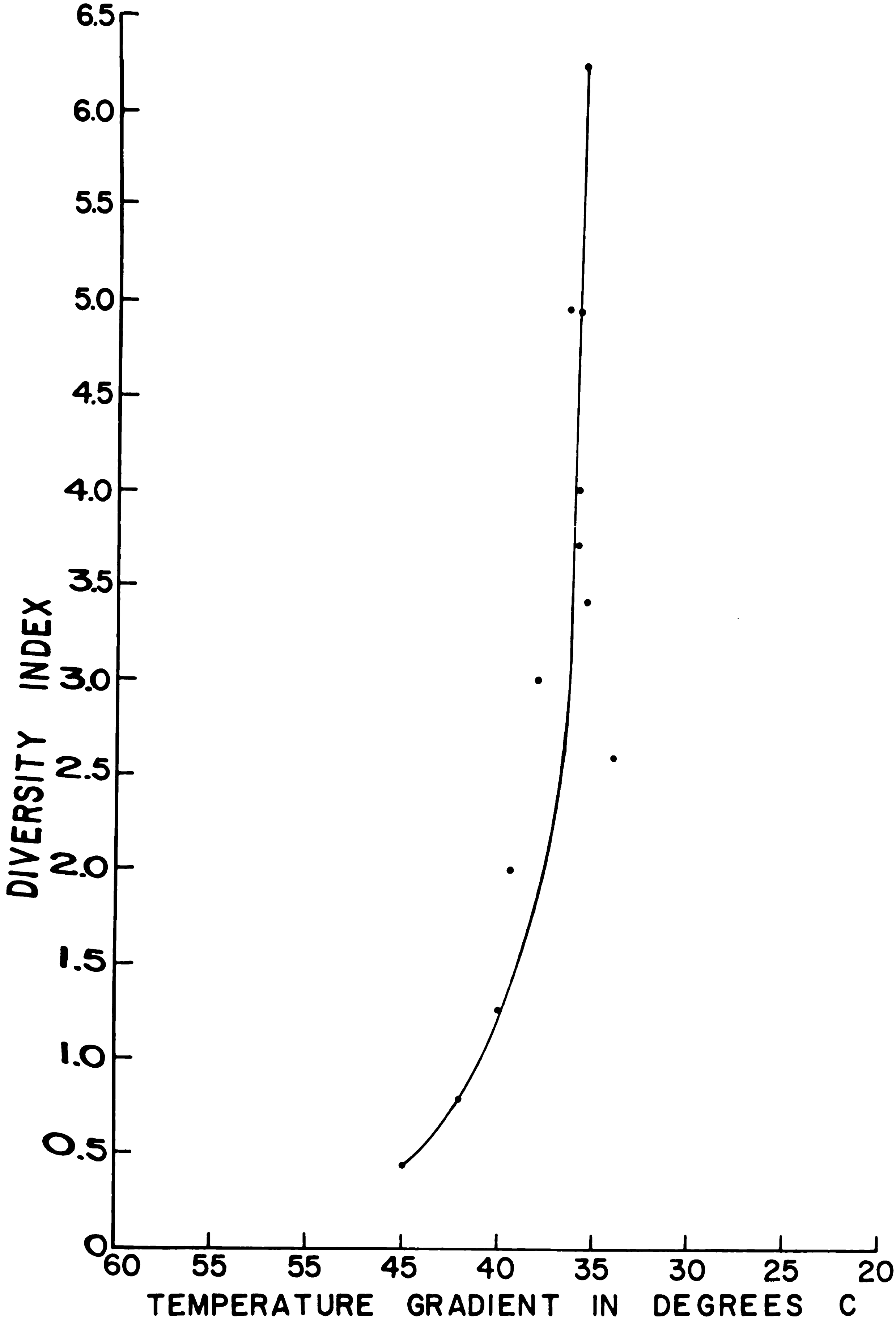

PERCENT OF TOTAL ALGAL VOLUME
80
60
40
20
TEMPERATURE GRADIENT IN DEGREES C
44
42
40
38
36

Figure 35. Diversity indexes [(S-1)/log N] of the algal communities along a temperature gradient in the stream at Lolo Hot Springs, Montana. The diversity index of the pool is omitted.


DIVERSITY INDEX
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
60
55
55
45
40
35
30
25
20
TEMPERATURE GRADIENT IN DEGREES C

total volume for any community was 7.05 percent at 36.0 C (131 feet from the source). Eight species of Chrysophyta were found at Lolo. Species of Cyanophyta were dominant in number and volume from the source to a downstream point where the temperature was 39.5 C. At 38.0 C, however, the Cyanophyta accounted for 97.2 percent of the total algae, but they occupied only 3.4 percent of the algal volume. This difference is the result of the sudden appearance of *Spirogyra* sp. (32 μ) that competes successfully for space with species having diameters of 1-2 μ, such as *Phormidium truncatum*, *P. angustissimum*, *Synechococcus lividus* and *S. elongatus*. This division was represented by 21 species or varieties.

Pipestone Hot Springs

The water temperature of the west Pipestone spring was 59.5 C, but the temperature of the pool into which it splashed was 57.0 C. The algae were collected from water of the latter temperature downstream to 51.5 C, a distance of 100 feet. Within this temperature range, 13 species were identified from 1962 samples and 14 from the 1963 samples. The water of the east stream was emitted at 52.0 C and in a distance of 150 feet cooled to 51.0 C. Within this range 13 species were identified.

The species composition remained the same in the west stream throughout 1962, but in 1963, four weeks after being scoured out by an overflowing cold stream, the composition was noticeably changed. Thirteen species were found in 1962, and although 14 were found in 1963, only eight were common for both years. This change in composition is discussed in the following chapter.

TABLE XIII.--Algal composition in aufwuchs communities along a temperature gradient at Pipestone (West) Hot Springs, Montana (1962).

Taxa	Temperature in degrees Centigrade 57.0	55.5	55.0	54.7	53.5	53.0	52.0
Synechococcus vescus	x	x	x	x	x	x	x
Synechococcus lividus		x	x	x	x	x	x
Mastigocladus laminosus		x	x	x	x	x	x
Phormidium tenue			x		x	x	x
Phormidium laminosum				x	x	x	x
Synechococcus viridissimus					x		
Phormidium angustissimum					x		
Phormidium bigranulatum					x		
Snyechococcus arcuatus						x	x
Synechococcus lividus var. nov.						x	x
Isocystis pallida						x	
Synechococcus Minervae							x
Oscillatoria geminata							x

TABLE XIV.--Algal composition in *aufwuchs* communities along a temperature gradient at Pipestone (West) Hot Springs, Montana (1963).

Taxa	Temperature in degrees Centigrade							
	57.0	55.0	54.0	54.0	53.0	52.0	52.0	51.5
Synechococcus elongatus	x		x	x	x	x	x	x
Mastigocladus laminosus	x	x	x	x	x	x	x	x
Synechococcus lividus var. curvatus		x	x	x			x	
Synechococcus viridissimus		x	x	x	x		x	
Phormidium laminosum		x	x		x	x	x	x
Synechococcus arcuatus			x	x				x
Oscillatoria geminata					x			x
Phormidium africanum						x	x	
Isocystis pallida							x	
Oscillatoria brevis							x	
Phormidum bigranulatum							x	
Phormidium tenue							x	
Oscillatoria chalybea var. depauperata								x
Phormidium frigidum								x

TABLE XV.--*Algal composition in aufwuchs communities along a temperature gradient at Pipestone (East) Hot Springs, Montana.*

	Distance from the source in feet								
	0	10	20	30	40	50	60	75	100
	Temperature in degrees Centigrade								
Taxa	52.0	52.0	51.0	51.0	51.0	51.0	51.0	51.0	51.0
Synechococcus arcuatus	x	x						x	
Phormidium africanum	x	x	x		x		x	x	
Phormidium truncatum	x	x	x	x	x		x	x	
Mastigocladus laminosus	x	x	x	x	x	x	x		x
Phormidium foveolarum		x	x	x	x	x	x	x	x
Phormidium laminosum		x	x		x	x		x	x
Synechococcus elongatus			x	x		x	x	x	
Synechococcus lividus var. curvatus			x		x		x		
Oscillatoria geminata			x	x	x				
Phormidium frigidum			x	x	x	x			
Phormidium tenue			x		x	x	x	x	
Isocystis pallida					x	x	x	x	x
Synechococcus viridissimus					x				

Figure 36. Dominance-diversity curves for algal communities along temperature gradients at Pipestone Hot Springs, Montana. Section A contains the curves of communities sampled at the west stream during 1962. Section B contains the curves of communities sampled at the west stream four weeks after a severe flooding and scouring in 1963. Section C contains the curves of communities from the east stream during 1963.

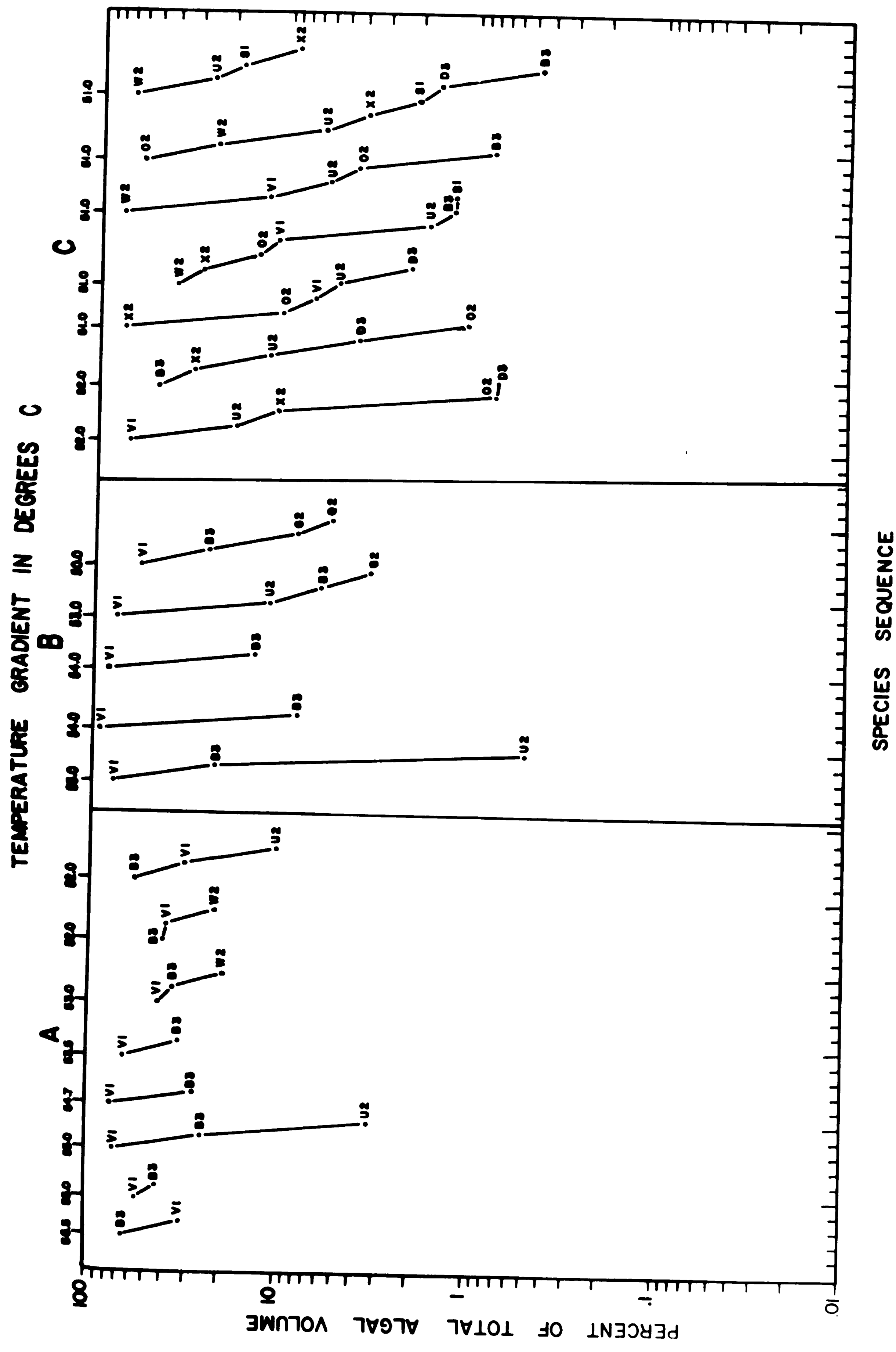

TEMPERATURE GRADIENT IN DEGREES C
A
B
C
SPECIES SEQUENCE
PERCENT OF TOTAL ALGAL VOLUME
100
10
1
.1
.01

Figure 37. Percent volume of the major species of algae plotted along a temperature gradient at Pipestone Hot Springs, Montana. Graph A represents the algal volume as found in samples taken in 1962. Graph B represents the algal volume at least four weeks after a flooding and severe scouring in 1963. The numbers represent the species as follows: (1) Synechococcus spp., (2) Mastigocladus laminosus, (3) Phormidium laminosum, (4) Phormidium tenue, (5) Oscillatoria geminata, (6) Phormidium africanum.

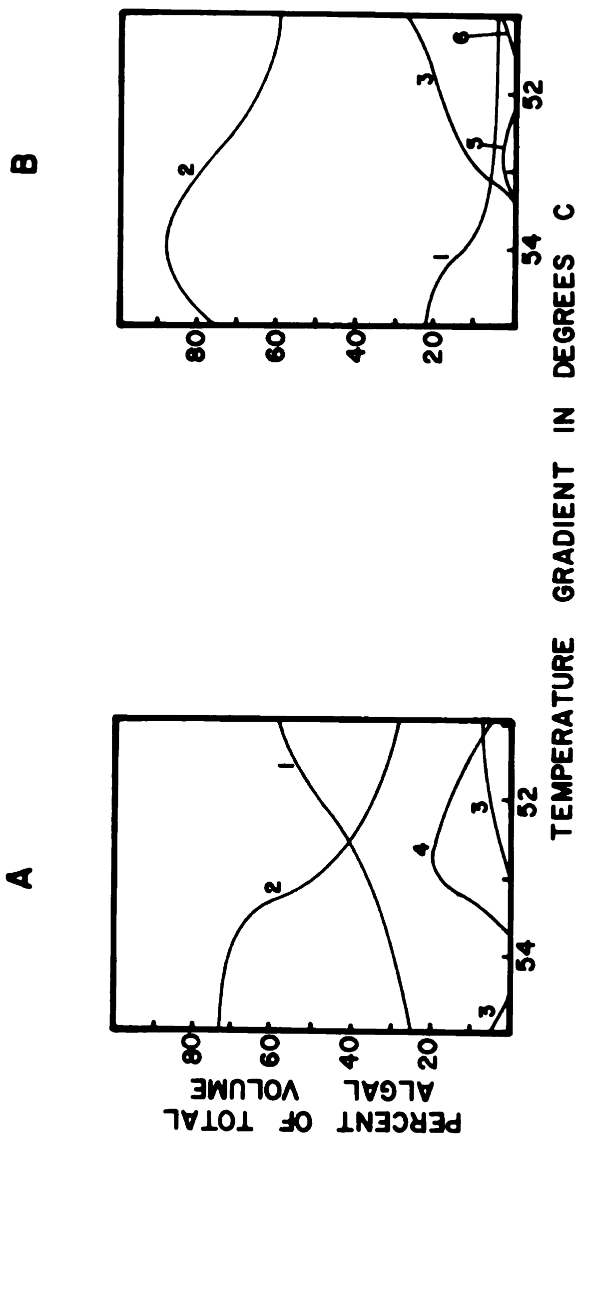

A
B
PERCENT OF TOTAL ALGAL VOLUME
80
60
40
20
54
52
TEMPERATURE GRADIENT IN DEGREES C
1
2
3
4
5
6

Figure 38. Diversity indexes [(S-1)/log N] of the algal communities along a temperature gradient in the west stream at Pipestone Hot Springs, Montana, during the summer of 1962. The slope of the line is 0.289.

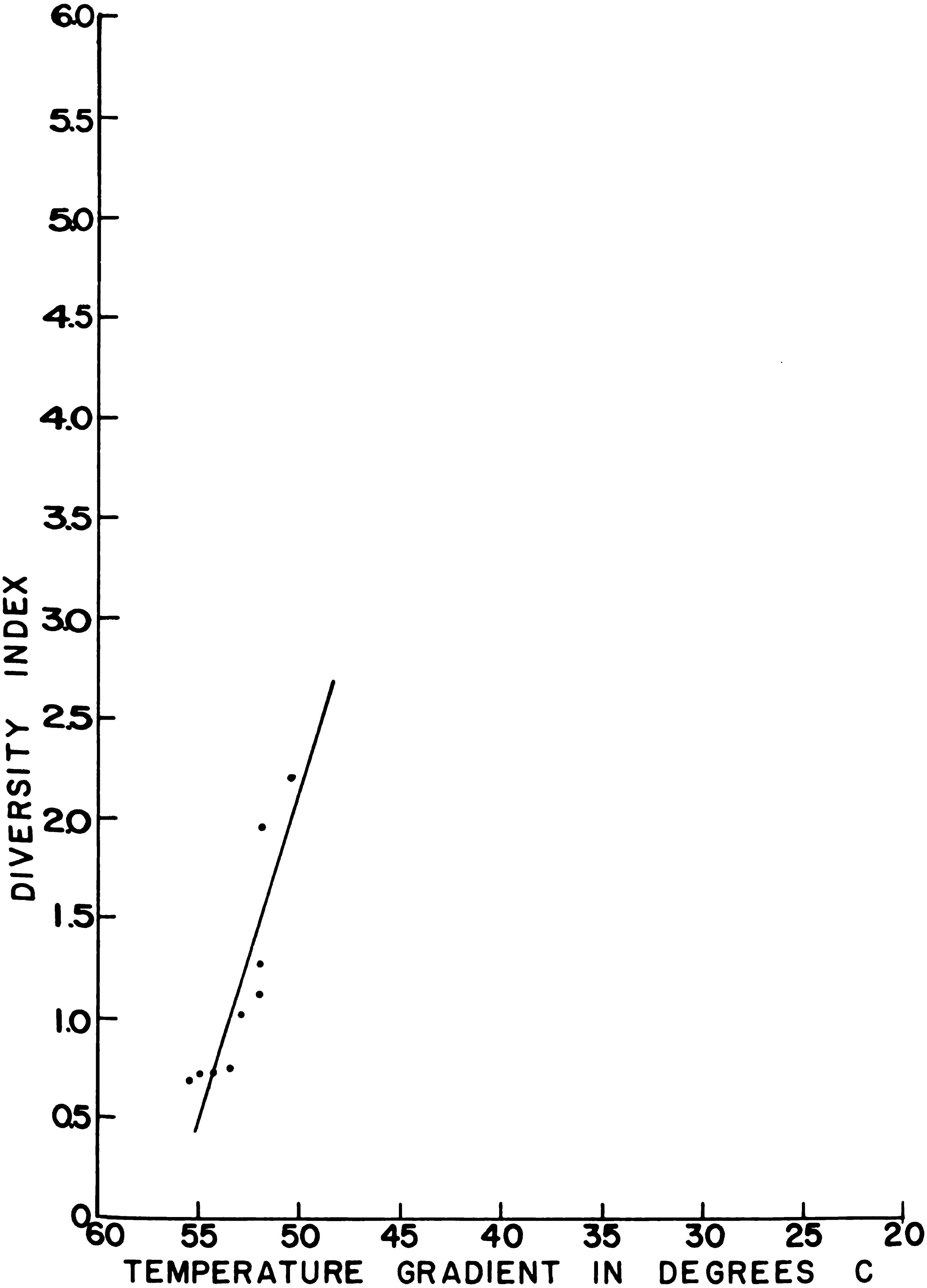
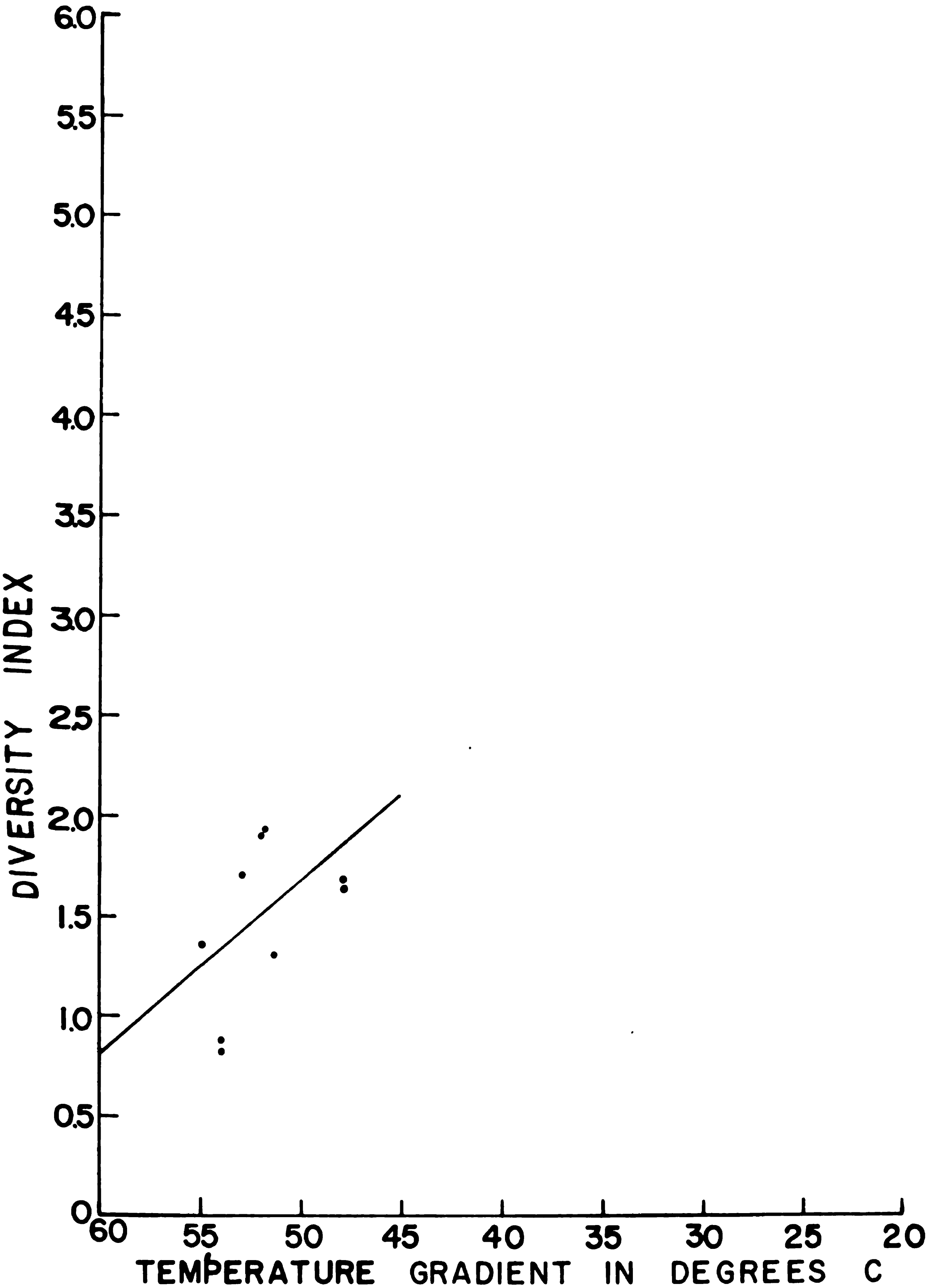

6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
DIVERSITY INDEX
60
55
50
45
40
35
30
25
20
TEMPERATURE GRADIENT IN DEGREES C

Figure 39. Diversity indexes [(S-1) /log N] of the algal communities along a temperature gradient in the west stream at Pipestone Hot Springs, Montana, during the summer of 1963. The slope of the line is 0.0869.


6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
DIVERSITY INDEX
60
55
50
45
40
35
30
25
20
TEMPERATURE GRADIENT IN DEGREES C

Cyanophyta was the only division represented at Pipestone. The lowest temperature recorded for the streams was 51.0 C, which apparently was too high for the Chlorophyta or Chrysophyta. Samples were taken from a small seepage area near the west stream that had temperatures as low as 48.0 C, but here also only Cyanophyta was represented.

Sleeping Child Hot Springs

The dominant algae beginning at the source at 52.0 C and extending downstream to 48.0 C at Sleeping Child Hot Springs were *Phormidium truncatum*, *P. angustissimum*, and *Mastigocladus laminosus*. At 48.0 C the entrance of a cold water stream abruptly lowered the water temperature to 42.0 C. A sample was taken at the downstream point from where the cold and warm water met and where the water had become mixed. At this temperature, 42. C, *Mougeotia* sp. was the dominant alga, having a volume of 83.9 percent. Water eddies at the point of sampling could furnish enough cold water at intervals to enable *Mougeotia* sp. to tolerate a relatively high temperature. The only other point in the stream where this species occurred was at 35.3 C but was observed only during a preliminary scanning of the microscope slide and as a result it was not enumerated. After the water had been thoroughly mixed, *Stigeoclonium attenuatum* assumed the dominant role at 40.0 C and continued as such for the distance the algae were sampled, a distance to 210 feet to where the water had cooled to 34.5 C.

The Chlorophyta tolerated a maximum temperature of 42.0 C, where *Ulothrix subconstricta*, *Stigeoclonium attenuatum*, and *Mougeotia* sp. were found. This division was represented by eight species whose combined frequencies from 34.5 yo 40.0 C averaged 75.85 percent and combined volumes averaged 91.38 percent. Within this temperature range there was no trend of increased representation with decreasing temperature as often is observed in this class but, rather, the representation was relatively constant.

The Chrysophyta (Bacillariophyceae) tolerated a maximum temperature of 40.0 C. The six species had a mean combined frequency of 2.17 percent and a mean volume of 5.34 percent in the range of its occurrence. The maximum frequency of 13.37 percent and maximum volume of 29.04 percent occurred at 36.0 C, 160 feet from the source.

The Cyanophyta were the only algae present from the source to 48.0 C. At 42.0 C this division represented 60.3 percent of the total algae and 16.07 percent of the volume. From 40.0 C downstream to 34.5 C, the maximum frequency was 66.4 percent at 35.8 C and the maximum volume was 7.38 percent. In this temperature range, the mean frequency was 21.97 percent and the mean volume was 3.28 percent.

TABLE XVI.--Algal composition in aufwuchs communities along a temperature gradient at Sleeping Child Hot Springs, Montana.

Taxa	Temperature in degrees Centigrade																						
	52.0	51.0	50.5	50.5	50.0	49.8	49.5	49.0	48.0	4[illegible].0	40.0	39.5	39.5	37.0	36.5	36.5	36.0	36.0	36.0	36.0	35.8	35.5	35.3	34.5
Chroococcus minor	x	x	x																					
Phormidium angustissimum	x	x	x	x	x	x	x	x	x	x														
Phormidium truncatum	x	x	x	x	x				x	x	x	x	x		x		x		x	x	x		x	x
Mastigocladus laminosus	x	x	x	x	x	x	x	x	x	x			x			x	x	x	x	x	x	x	x	x
Oscillatoria geminata					x	x	x	x	x	x														
Phormidium tenue					x	x	x	x	x	x														
Ulothrix subconstricta										x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Stigeoclonium attenuatum										x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mougeotia sp.										x													x	
Lyngbya Diguetii										x		x	x	x	x					x	x			
Fragilaria sp.											x	x		x	x	x	x	x	x	x	x	x	x	x
Achnanthes sp.											x		x			x		x			x	x	x	x
Nitzchia sp.											x	x	x								x	x	x	x
Pseudanabaena sp.											x	x	x	x	x	x	x		x	x	x			x
Oedogonium sp. (12.5 u)														x	x									x
Oedogonium sp. (25 u)															x	x	x	x	x	x	x	x	x	x
Navicula sp.															x									
Oscillatoria limosa																x								
Spirogyra sp. (38.5 u)																	x	x	x	x	x		x	x
Rhizoclonium fontanum																		x	x	x	x	x	x	x
Nodularia Harveyana																			x	x				
Microcystis holsatica																				x				
Oscillatoria princeps																				x				
Oscillatoria tenuis																				x				
Chroococcus turgidus																					x			
Calothrix thermalis																						x	x	x
Cosmarium obtusatum																							x	
Amphora sp.																							x	
Epithemia sp.																							x	
Microcystis pulverea																							x	
Phormidium Jenkelianum																								x
Anabaena sp.																								x

Table XVII.--Frequency and percent volume of algae by divisions along a temperature gradient at Sleeping Child Hot Springs, Montana

Temp. in °C	Chlorophyta		Chrysophyta		Cyanophyta	
	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume	% of total taxa enum.	% of total volume
52.0	0.00	0.00	0.00	0.00	100	100
51.0	0.00	0.00	0.00	0.00	100	100
50.5	0.00	0.00	0.00	0.00	100	100
50.5	0.00	0.00	0.00	0.00	100	100
50.0	0.00	0.00	0.00	0.00	100	100
49.8	0.00	0.00	0.00	0.00	100	100
49.5	0.00	0.00	0.00	0.00	100	100
49.0	0.00	0.00	0.00	0.00	100	100
48.0	0.00	0.00	0.00	0.00	100	100
42.0	39.70	83.93	0.00	0.00	60.30	16.07
40.0	92.46	97.09	0.50	2.60	7.04	0.31

39.5	95.87	94.33	0.96	4.66	3.17	1.01
39.5	97.03	96.36	0.59	2.79	2.38	0.85
37.0	93.28	93.60	2.06	6.03	4.66	0.37
36.5	82.31	94.90	0.00	0.00	17.69	5.10
36.5	84.08	97.13	0.00	0.00	15.92	2.87
36.0	65.17	90.85	0.45	1.79	34.38	7.38
36.0	54.75	65.83	13.37	29.04	31.88	5.13
36.0	63.83	94.16	1.14	1.94	35.03	3.90
36.0	62.17	93.84	1.12	2.19	36.71	3.97
35.8	30.63	89.23	2.97	4.04	66.40	6.73
35.5	93.35	95.41	1.56	3.72	5.09	0.87
35.3	81.15	89.77	3.29	7.92	15.56	2.31
34.5	65.87	86.83	2.46	8.02	31.67	5.15

Figure 40. Dominance-diversity curves for algal communities along a temperature gradient at Sleeping Child Hot Springs, Montana. Explanation of the curves accompanies Figure 23. Names for the code numbers are found in Table II.

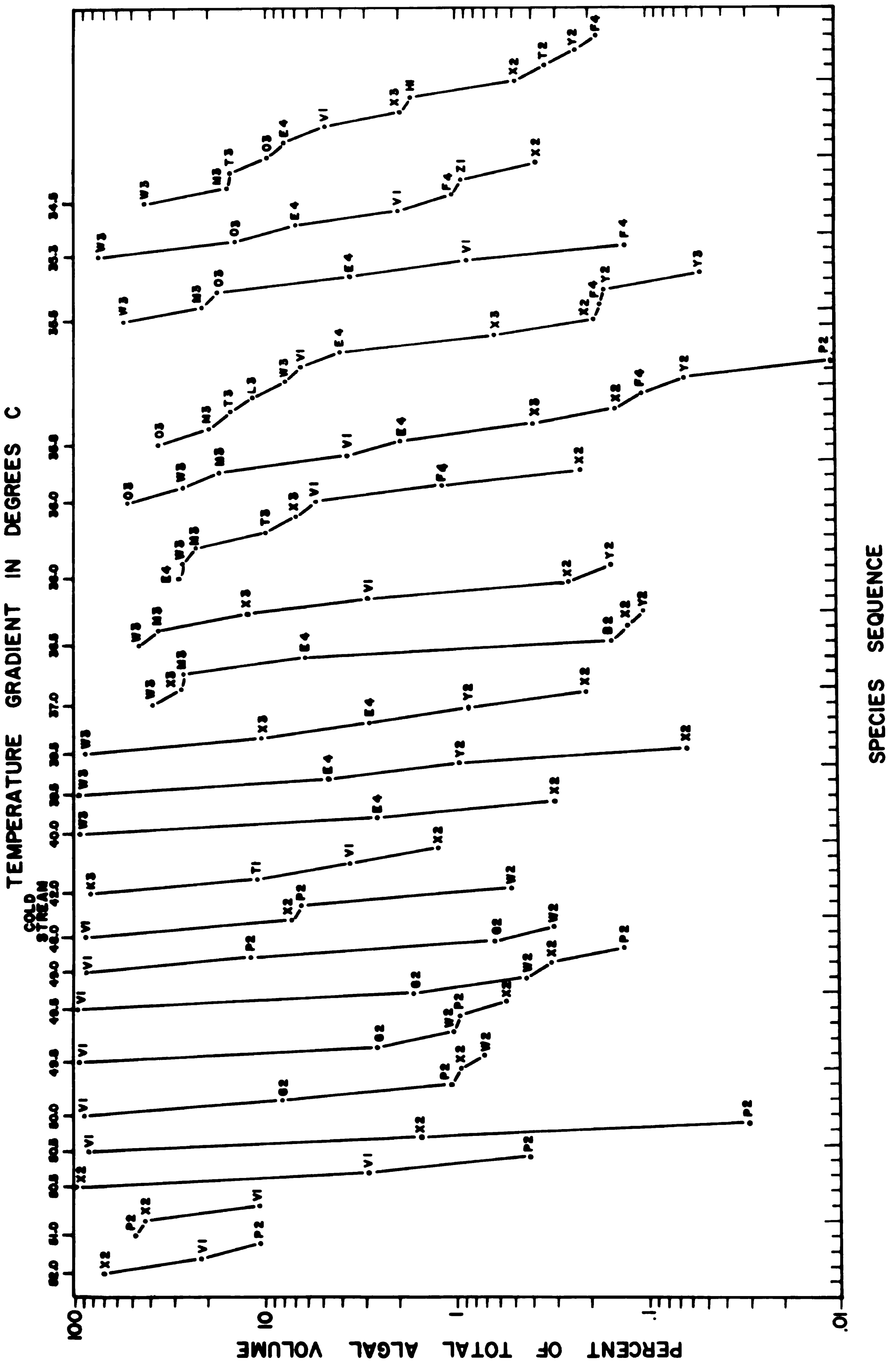

TEMPERATURE GRADIENT IN DEGREES C
COLD STREAM
SPECIES SEQUENCE
PERCENT OF TOTAL ALGAL VOLUME

Figure 41. Percent volume of the major species of algae plotted along a temperature gradient at Sleeping Child Hot Springs, Montana. The graphs have been constructed in three units to reduce the confusion that may be caused by many curves on one graph. The numbers represent the species as follows: (1) Phormidium angustissimum, (2) Lyngbya Diguetii (3) Fragilaria sp., (4) Oedogonium sp., 25 μ, (5) Mastigocladus laminosus, (6) Oscillatoria geminata, (7) Stigeoclonium attenuatum, (8) Oedogonium sp., 12.5 μ, (9) Phormidium truncatum, (10) Mougeotia sp., (11) Ulothrix subconstricta, (12) Rhizoclonium fontanum, (13) Spirogyra sp., 38.5 μ.

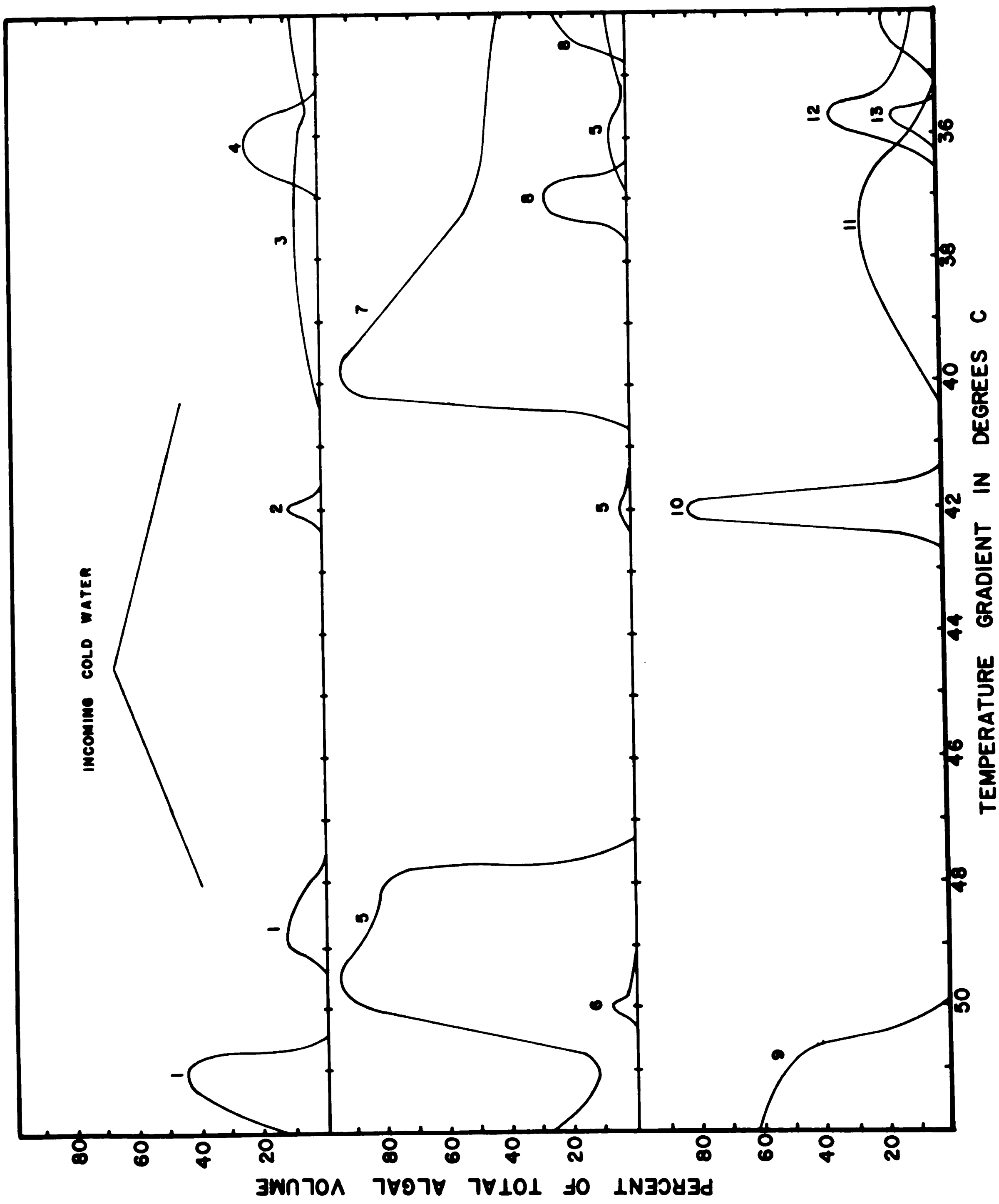
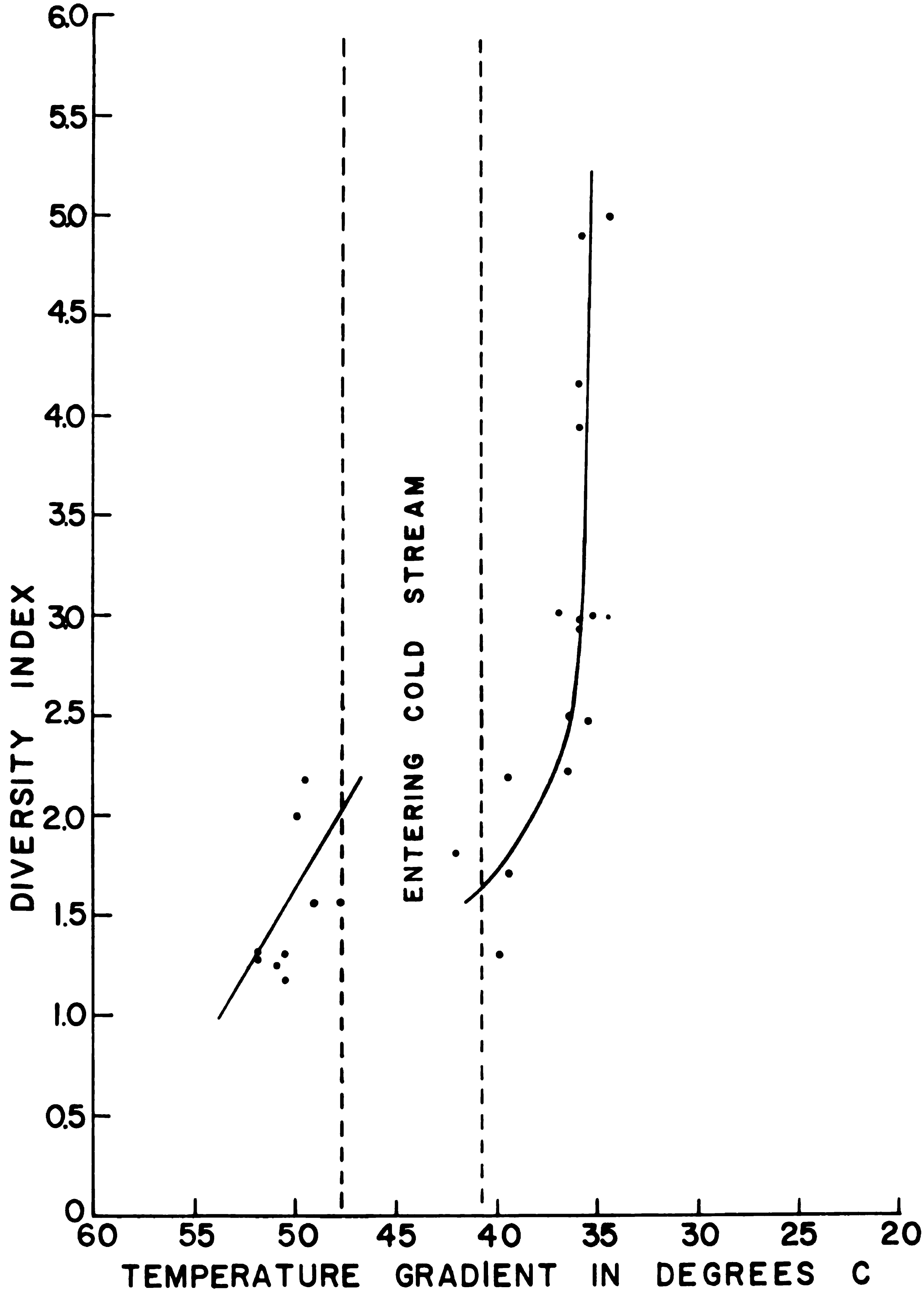
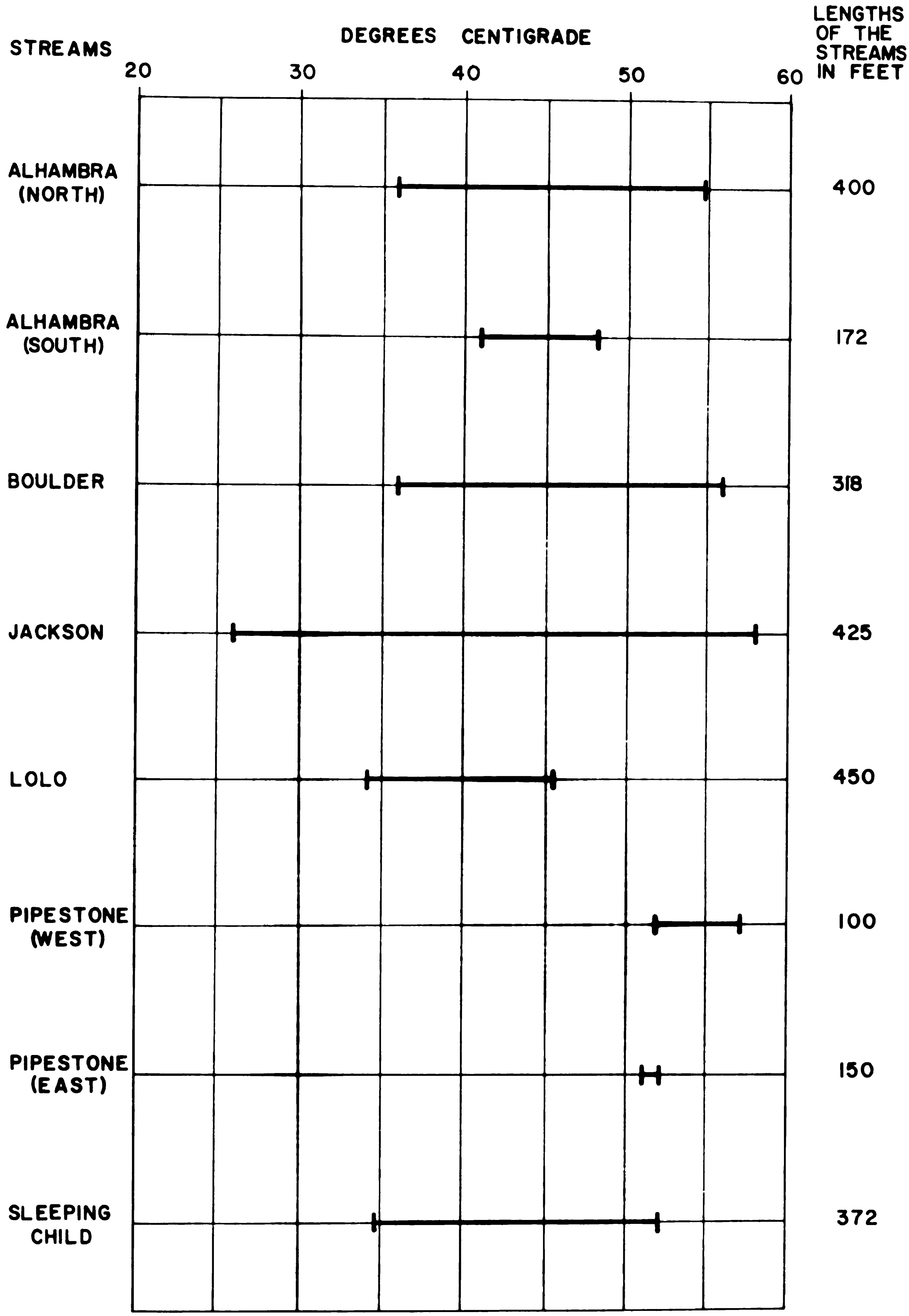

INCOMING COLD WATER
TEMPERATURE GRADIENT IN DEGREES C
36
38
40
42
44
46
48
50
PERCENT OF TOTAL ALGAL VOLUME
80
60
40
20
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 42. Diversity indexes [(S-1)/log N] of the algal communities along a temperature gradient in the stream at Sleeping Child Hot Springs, Montana. The area between the veil lines indicates the amount the temperature dropped when a cold stream entered. Two separate curves were constructed to show the rate of diversity increase before and after the entrance of the cold stream.



DIVERSITY INDEX
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
60
55
50
45
40
35
30
25
20
ENTERING COLD STREAM
TEMPERATURE GRADIENT IN DEGREES C

Figure 43. Comparisons of the temperature ranges and lengths of the streams used in this study.


STREAMS
DEGREES CENTIGRADE
20
30
40
50
60
LENGTHS OF THE STREAMS IN FEET
ALHAMBRA (NORTH)
400
ALHAMBRA (SOUTH)
172
BOULDER
318
JACKSON
425
LOLO
450
PIPESTONE (WEST)
100
PIPESTONE (EAST)
150
SLEEPING CHILD
372

CHAPTER VII

DISCUSSION

Representative Thermal Algae

The term "thermal algae" has the implication that these organisms are found only in thermal waters or are limited primarily to thermal waters. The relativity of the term thermal to the environment of the stream or to organisms within the stream has been discussed earlier. Only through arbitrarily defining temperatures of reference, as suggested by Vouk (1948), can meaning be given to the term for the biologist. As a review of the terms proposed by Vouk, hypothermae are those temperature environments with a range of 0-25 C, euthermae with a range of 25-55 C, and hyperthermae with a range of 55-80 C. An organism whose cardinal points (maximum, optimum, minimum) are entirely within the hyperthermae range is described as macrostenovalent, whereas if an organism has the optimum growth in the hyperthermae range but also existing outside this range, it may be called macroeuryvalent. The prefix meso- is used with reference to organisms with optimum growth in the euthermae range and micro- for those in the hypothermae range.

A review of the algae in the annotated list will reveal how few are actually limited to thermal conditions. Most species may be found under more moderate conditions and are probably microeuryvalent; their optimum growth is accomplished in the range of 0 to 25 C but also may be found in the euthermae or hyperthermae range. There were, however, algae found during this study that may give the impression of being microeuryvalent or macroeuryvalent when they are actually mesoeury-valent, but competition with other species better adapted to given combinations of conditions within the euthermae range has limited their development and distribution. Also, mesoeuryvalent species may be interpreted as being macroeuryvalent if they were the dominant forms at the upper temperature limit of the euthermae range, 55 C, but again, competition with species in the mid-euthermae range has inhibited growth. Conversely, an examination of the continuum curves developed for the major species found during this study will reveal many cases of apparent optimum growth within the euthermae range, whereas in fact this cardinal point may be in the hypothermae or hyperthermae range.

The terms proposed by Vouk may be utilized best as applied to the results of laboratory studies when the cardinal points of one species are to be determined. Even under controlled conditions, it may be possible only to make approximations since the possible combination of abiotic factors responsible for growth are innumerable. Ecologically, it will be necessary to summarize the results of many studies before the true character of thermal algae may be determined. The ecovalence concept cannot be utilized in this study in view of the fact that six thermal springs or spring groups were used, and that the algae were not collected in the hyperthermae range. Therefore, it is not the purpose of this study to determine the cardinal points, but rather to present the composition and distribution of the thermal algae in these Montana streams as they were found under natural conditions.

Examples of several commonly recognized thermal algae are given below in conjunction with the temperatures at which they were found in representative thermal streams of worldwide distribution. The temperatures at which they were reported only suggest that they may be macro-euyvalent and may be compared with those given in the annotated list of the species and the continuum curves of this study. The temperature reported by an investigator often does not indicate whether that temperature is the only point where an alga was found or whether only one sample was taken. Also, when the temperatures are given it is not possible to know, in many instances, whether the algae were found at the source of the stream or whether they appeared after the water had cooled somewhat. For example, an alga with a listed range of 40-45 C may have been found in a stream with a maximum temperature of 45 C. Such information gives no indication what temperature the alga can tolerate but only that it was found in a particular stream at a particular temperature. Therefore, rather than listing a series of temperatures at which the algae were found, several of the maximum temperatures will be given to suggest the temperature that recognized thermal algae can tolerate.

One of the most widely known and thoroughly investigated thermal alga is _Mastigocladus laminosus_. This species was found by Tilden (1898) near Lower Geyser Basin, Yellowstone National Park. It occurred at the source of a spring at a temperature of 61 C and ranged down to 51 C, having the "most growth........at a temperature of 54 C." Copeland (1936) found it to be abundant in Yellowstone National Park, where it was found at temperatures up to 55.8 C. West (1902) found this alga at 55 C in a spring near Hveravellir, Iceland. Also in Iceland, Peterson (1923) reported this alga from 13 locations with temperatures ranging up to 61 C. Upon examining material collected from Kamtchatka by Eric Hultén, Peterson (1946) reported that the temperatures for this species ranged up to 77 C. It appears, however, that most of the samples were taken from 30 to 50 C. Yoneda (1938; 1939b; 1941; 1942a, b, c; 1952; 1962) has found M. laminosus in many streams throughout Japan. Although many of the temperatures listed may be at the upper limits for the stream, several of the higher temperatures are 65.5, 68.0, and 68.3 C. The maximum temperature tolerated by this alga collected in Japan by Emoto and Hirose (1940) was 64 C. In studies of the algae from eight thermal springs in Greece, Anagnostidis (1961) found M. laminosus in water up to 53.6 C, being especially abundant from 49 to 53 C.

Phormidium laminosum is another very common thermal alga reported from thermal streams throughout the world. Tilden (1898) reported finding it at 51-55 C in water flowing from a spring at 91 C at Yellowstone National Park. Although the upper temperatures of the streams were not indicated, Tilden also found it at 41, 55, 63, and 75.5 C. She found "this species to be by far the most widespread and abundant of any alga in the hot waters of the park. Its habit of growth is extremely varied, so it is not easily recognized." Copeland (1936), in his extensive study of the thermal algae in Yellowstone Park, suggested that Tilden's report of this species occurring at 75.5 C was not in agreement with his many observations and indicated that it occurs up to 65-66 C. The maximum temperatures at which P. laminosum was found in Iceland (Peterson, 1923) appear to be rather low in comparison with other areas. Peterson did not indicate whether the alga was found at the sources of the streams, but gave 24, 25, 40, and 42 C as the highest temperatures. Peterson (1946) lists 73 C as the maximum temperature at which Eric Hultén found P. laminosum on Kamtchatka, but it was found also at 63, 66, and 67 C. Anagnostidis (1961) lists 52.8 and 53.6 C as two of the highest temperatures at which it was found in Greece.

Generally speaking, the genus Synechococcus had not been considered thermal until relatively recently, but with discoveries of many species in thermal streams by Copeland, Emoto and Hirose, Anagnostidis and myself, they have become some of the more prominently recognized thermal algae. Species of this genus have been found by Copeland to tolerate the highest temperatures recorded for algae at Yellowstone National Park. Examples of several species and their maximum temperatures at the park are: S. elongatus var. amphigranulatus, 63 C; S eximus, 83.6 C; S. lividus, 68 C; S. lividus var. curvatus, 68 C; S. minervae, 64.1 C; S. viridissimus, 69.5 C; and S. vulcanus, 84 C. Examples of numerous observations in Japan are: Yoneda (1939b) reported S. elongatus var. vestitus up to 64.2 C; S. elongatus at 60.3 C (1939 c); and S. elongatus var. amphigranulatus up to 72 C (1942a). Emoto and Hirose reported S. arcuatus, S. lividus, and S. vescus up to 63 C. The four species of Synechococcus and the temperatures at which they were found in Greece by Anagnostidis were: S. elongatus var. amphigranulatus, 80 C; S. elongatus fa. thermalis, 65 C; S. minervae, 55 C; and S. minervae var. maior, 60 C.

Mastigocladus laminosus was found in five of the six stream groups of this study. Except for the stream at Jackson Hot Springs, M. laminosus was one of the dominant algae in those streams in which it occurred. It was relatively insignificant in the Jackson stream, appearing in one sample at 52.8 C with a volume of only 7.5 percent. The alga did not appear in any of the Lolo Hot Springs samples. By examining all the physical and chemical data for Jackson and Lolo Hot Springs, there appears to be no factor common to both streams that is unusually different from the other streams where it was found. Of the streams investigated, the water at Jackson contains some of the highest concentrations of total alkalinity, 574 ppm; sodium, 238 ppm; calcium, 7.9 ppm; and potassium, 11.8 ppm; while the water at Lolo contains the lowest concentrations of these dissolved substances, 84 ppm, 48 ppm, 1.5 ppm, and 1.4 ppm, respectively. It is conceivable that *M. laminosus* requires one or more of these dissolved substances in a concentration between the extremes. It is also possible that the absence or poor representation of this alga may be due to an overabundance or scarcity of an ion for which no test was performed.

The Effect of Atmospheric Temperature Change on Algal Distribution

The study of the algae in these thermal streams was directed toward the determination of algal composition and distribution in response to the chemical and physical factors within the water. The effect of air temperature on the water temperature and, consequently, the effect on the algal distribution was learned as a by-product of the original problem when the data of algal distribution, water volume, water velocity, and air temperature were analyzed. Since the effects of the air temperature were not part of the original problem, the data are incomplete in respect to all streams. Rather than to omit the data available, however, the results have been presented with this

realization. The subsequent discussion is an analysis of the observations presented earlier in this paper to show how much air temperature actually affected the maximum temperature tolerated by the algae at Boulder and Sleeping Child Hot Springs.

These two streams were well suited for comparison since their characteristics were similar. The temperature range of the water used for algal collections was 36.0 to 56.0 C for Boulder and 34.5 to 52.0 C for Sleeping Child. The relief was 19.65 feet per 100 at Boulder and 18.63 feet per 100 at Sleeping Child. Although they are 195 miles apart and on opposite sides of the continental divide, their sums of dissolved substances were almost identical--417.05 ppm at Boulder and 417.24 ppm at Sleeping Child--and, by coincidence, the total alkalinities were exactly the same at 161 ppm. Comparisons of the individual dissolved substances in Table I show the extent to which these were similar. Of the abiotic factors, the two that differed most were the water volume and velocity. At Boulder the volume was approximately 47 gpm and velocity 60 feet per minute, whereas at Sleeping Child the volume was approximately 357 gpm and the velocity 76.3 feet per minute. These two factors were primarily responsible for the differences in water temperature for a given change in air temperature.

The degree to which the water of any thermal stream cools is the result of the combined effect of the volume and exposure to the air. The amount of heat contained in water is proportional to the volume of water so that, other factors being equal, the temperatures of large streams will be reduced at slower rates than the temperatures of small streams. Also, water exposed to the atmosphere for shorter lengths of time will, due to higher velocity, lose less heat than those exposed for a longer time. The stream at Sleeping Child, therefore, having greater volume and velocity than the Boulder stream, was affected less by given changes in air temperatures. It should be recalled that a 1 C change in air temperature changed the water temperature up to 0.187 C at Sleeping Child Hot Springs. In approximately the same air temperature range, 1 C of air temperature change caused the water to change up to 0.66 C at Boulder Hot Springs.

How does the change in water temperature at any given point in the stream affect the maximum tolerable temperature of the algae? The maximum temperatures of 19 species were recorded that were common to both the Boulder and Sleeping Child streams but were not limited by the highest temperatures of the water. In other words, an alga common to both streams was not considered if it existed at the upper temperature limit of a stream, since it may have been able to tolerate an even greater temperature. Summing the maximum temperatures for the combined algae from each stream that were common to both streams and determining the means, a value of 44.54 C was obtained for the algae from Boulder and 39.36 C for the same algae from Sleeping Child, the difference in mean maximum temperatures being 5.18 C.

The conversion of the air and water temperatures to the same base for both streams was shown earlier to be 0.66 C change of water temperature for each 1 C change in air temperature at Boulder and 0.187 C change in water temperature for 1 C change in air temperature at Sleeping Child. It should be reiterated that this change of water temperature was the maximum observed for the chosen time intervals, and that each point along each stream would have a different temperature throughout the day every day of the year, depending on the atmospheric conditions. It can be seen, therefore, that the values 0.66 and 0.187 C are not construed to be precise and unalterable but, rather, approximations of the water change within a given range of air temperature change. Although the vapor pressure and solar radiation will affect these values to some degree, these temperature approximations are sufficient to illustrate the effect of air temperature change on the water temperature.

The next step is to associate the difference in the mean maximum temperatures tolerated by the combined algal communities of each stream with the water temperature change. If 0.66 C and 0.187 C are values for water temperature change for 1 C change in air temperature, values can be estimated for the diurnal change in temperature. Each 24-hour period will have a different temperature range, but for illustrative purposes the average maximum and minimum temperatures can be arbitrarily taken. At the locations of these springs, the temperature commonly fluctuates during the summer months from approximately 15 C (59 F) to 30 C (86 F), a difference of 15 C. (This is conservative since many times the temperature at night was 45 to 50 F and in the daytime, 90 to 100 F). Using 15 C as an approximate value for diurnal air temperature fluctuation and multiplying it by the effect 1 C air temperature change has on the water at Boulder (0.66 C), we find the water temperature will be altered 9.9 C by 15 C of changing air temperature. Repeating the process for Sleeping Child, where 1 C of changing air temperature alters the water temperature 0.187 C, we obtain 2.8 C. The difference between the two is 7.1 C. Since the difference in the mean maximum temperature of the algae common to both streams is 5.18 C, it can be seen in this illustration that approximately 7.1 diurnal change in water te

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water temperature accounts for a difference of 5.18 C in tolerable temperature by the algae.

Although the values of the diurnal fluctuations during the summer are approximations, the point being made is that temperatures reported for thermal algae are dependent on changes of air temperature as well as on the chemical and physical factors of the water.

These results may help to explain the difference in temperatures reported for thermal algae by the various investigators. Since it is customary merely to report the temperatures at which the algae were found, it is impossible to know what factors are responsible for the variances in tolerable temperatures. Although the relationship between air and water temperature has generally been disregarded, a reference to this relationship was made by Tuxen (1944) in his study of the animal populations associated with the thermal streams of Iceland. In this report he briefly mentioned the fluctuations of pool and stream temperatures as a result of air temperature, but did not consider the effects of these changes on the distribution of the organisms.

The temperatures given in the previous discussion of three representative thermal algae illustrate the wide temperature range at which a species may be found. Although this temperature may be limited by the highest temperature of the stream, many undoubtedly are the result of fluctuating stream temperatures which affect the maximum tolerable temperatures.

For plants in general, the heat-killing temperature varies inversely with the exposure time, the relationship being exponential (Levitt, 1956). (The heat-killing temperature may vary approximately with the heat-limiting temperature, or the maximum tolerable

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temperature as referred to here.) From this it can be seen why the mean maximum temperature for the algae is less at Sleeping Child; the algae are exposed to water of a relatively uniform temperature and, thus, there is a great exposure time. The greater fluctuations of water temperature at Boulder permit the algae to tolerate higher temperatures since the exposure time to high temperature is of a short duration, while most of a 24-hour period is spent at lower temperatures.

The effects of this exposure time were found by Holton (1962) as a by-product of his main experiments. He found, in working with the thermophile Mastigocladus laminosus in the laboratory, that it can grow for short lengths of time at a higher than normal temperature. After 77 hours at 60 C this alga ceased growing and, when it was transferred to 45 C, growth could not be induced. In another experiment, the alga was grown for 41 hours at 60 C and when transferred to 45 C it did resume growth.

Streams that are more responsive to higher temperatures during the day logically will be more responsive to the lower temperatures during the night. If the temperatures were recorded at night for a given number of algae common to both Boulder and Sleeping Child Hot Springs, it is very probable that the mean temperature for those at Boulder would be considerably lower than for those found at Sleeping Child. Diurnal changes in air temperature will affect the water temperature, the amount depending on the volume and velocity of the water. Although this aspect was not considered at the outset of the study, any future studies of thermal algae by this investigator and others should include these factors rather than limiting the data to water temperature at the moment of sampling and the chemical factors.

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The Effect of the Chemical Factors on Algal Distribution

The effects of the chemical factors on algal distribution are extremely difficult to ascertain because the dissolved substances of each stream differ concurrently with various water velocities, turbulence, temperature, rate of cooling, light, and substrates. The dissolved substances were comparatively abundant in these streams so that high concentrations of substances were more likely to be the controlling factors for algal composition and distribution in the communities than low concentrations. Examples of the possible effect of the high concentrations of substances are shown in the distribution of several members of the order Chamaesiphonales, which were found only in the Alhambra and Jackson streams, where alkalinity, sodium, potassium, calcium, and magnesium concentrations were considerably higher than in the other streams. One species of this order was found in the north and south streams of Alhambra and five in the Jackson stream. The highest temperatures for the order were 41.0 C, tolerated by *Chamaesiphon* sp. nov. at Jackson, and 42.0 C, tolerated by *C. cylindricus* at the south Alhambra stream. The highest tolerated temperatures for the other species of the order were at or below the lowest recorded temperatures of the other streams, so it is possible that representatives of this order could have lived in all the streams if the water had cooled sufficiently before entering nearby cold streams.

The effect of low oxygen concentrations on algal distribution is difficult to ascertain because the stream areas where the concentrations were the lowest were also the areas where the temperatures were

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the highest. The area within which the oxygen would be effectively low is very limited since oxygen is absorbed from the air so rapidly as a result of the splashing effect of the water or as a result of the water flowing over rocks in shallow "sheets" as it comes from the source.

The low oxygen concentration may have had an effect of reducing the number of species at Lolo Hot Springs. Near the source of this stream, in the temperature range of 42.0-44.5 C, the number of species is considerably lower than in this temperature range of the other streams. The dominance-diversity curves in this range show a mean of 1.5 species at Lolo, whereas the mean number of species was five at the Alhambra streams, 8.6 at Boulder, 5.7 at Jackson, and four at Sleeping Child. This correlation of low species diversity and low oxygen concentration at Lolo may have been a coincidence because in this area of the stream the water flows uniformly over a large boulder or in streamlets where the habitats are uniform. Although it may appear that the low oxygen concentration may have reduced species diversity, it is my opinion that the uniform habitat is the primary limiting factor of diversity at this temperature of the Lolo stream. Since the lowest oxygen concentrations and the highest stream temperatures exist in conjunction, and since temperatures are the most influential in controlling the distribution of thermal algae, it would be best to withhold further conjectures regarding the effect of oxygen until numerous thermal streams can be sampled or until controlled experiments can be performed in the laboratory.

The effect of carbon dioxide is also difficult to determine. Whereas oxygen is absorbed rapidly, free carbon dioxide is emitted rapidly until a point is reached where that which is emitted comes from the dis

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the dissociation of the carbonate and bicarbonate ions. There appears to be no lack of carbon dioxide for photosynthesis in any stream. The high concentration of carbon dioxide often found in eutrophic lakes and rivers is usually found in combination with a correspondingly low concentration of oxygen, which can have a detrimental effect on the organisms. The emission of free carbon dioxide in thermal streams as the water comes from the ground is concurrent with an absorption of oxygen, so, as a consequence, the amelioration of the water creates an environment potentially conducive to algal growth.

The somewhat lower pH near the sources of the Alhambra (6.8 and 7.3) and Jackson (7.1) streams appears to have had no apparent effect on the kinds of algae present because the same species were found at the same temperatures in streams of higher pH. The change of pH in these streams was also apparently not great enough to affect algal distribution since the changes were only from 1.0 to 1.5 units within a relatively short distance. In addition, there were no definite trends of algal types from stream to stream where maximum pH values ranged from 8.1 to 9.2. If pH is effective in determining species presence or distribution in this relatively narrow range, it cannot be determined by the number of streams used in this study. Although the effects of pH and the dissolved substances on individual species are impossible to determine with certainty, perhaps the information presented in this study can be assembled with that of future studies on other thermal streams for a significant contribution.

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Dominance-diversity

A community includes all the populations of a prescribed area (Odum, 1953). A community may be sharply delineated or it may blend gradually into other communities, the extent of delineation often arbitrarily determined by the investigator. Since the community is not a definite entity in itself, it is often difficult to describe or label, so that characteristics of the major biotic components or abiotic environment are generally used for its description. Communities, therefore, can be referred to as beech-maple, benthic, or thermal stream communities.

If a community, by definition, is composed of all the populations in a prescribed area, the area may be assumed to possess the same environmental factors or a gradation from one combination of factors to another. Using the first approach, the algal populations of a thermal stream may comprise many communities as the water cools in its flow downstream. Each temperature may be used as a designation for a community, so that there may be an infinite number of communities along a temperature gradient, or a number of communities arbitrarily determined. The other concept is to consider all the populations as constituting a vegetational continuum type of community (Curtis and McIntosh, 1951) for the entire length of the stream where there is a gradation of one community to another as the combinations of environmental factors change along a gradient. Reference often will be made in the subsequent discussions to the community, in which instance the concept will pertain to the populations of a given point in the stream. Through such usage, a community at 47 C is distinguished from the community at

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49 C. There also will be occasions to refer to the aggregate algal populations of the entire stream (the continuum) when the term thermal communities will be used.

A habitat is the locality where an organism lives (Odum, 1953). Rather than limiting the term to one organism, it is customary to refer to habitat in terms of a species or population and, in some cases, a community habitat. Use of this term can be general or specific by referring to macrohabitats or microhabitats. Since these terms are relative, the thermal stream may be considered a macrohabitat, whereas a specific area in the stream or the point where Synechococcus lividus lives among the mucilage of Phormidium laminosum is the microhabitat. The outer boundaries of a habitat often are impossible to delimit, whether of an individual or a community. The inner boundaries are also often nebulous since it is sometimes difficult to know where the organism ends and the environment begins (Yapp, 1922). Consider the confluent mucilage possessed by many thermal algae whose consistency diminishes with increasing distance from the plant.

Closely allied to the term habitat is that of the niche. Whereas habitat is the locality where an organism lives, the niche is the sum of an organism's ecological activities. The niche is the role which an organism plays in a habitat through its nutritional requirements, rate of metabolism and growth, and the effect on other organisms and the environment (Odum). When the phrases "fill a niche" or "occupy a niche" are used, consideration should be given to all activities. Niches are dependent upon habitats, so a very severe environment such as a high temperature may offer a suitable habitat for only one organism and, as a result, there is one niche. An area of diversified habitats

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habitats offers many niches, or it may be said, diversified habitats create many niches.

The complexity of a community is measured by the number of niches that are filled. A community with few niches is simple and as more niches are filled as a result of time, it becomes more complex. Margalef (1963) equates complexity with maturity so with time an ecosystem or community tends to proceed from a less complex (immature) to a more complex (mature) state. Within a given time and habitat, however, not all niches are filled to the same degree because not all species are equally successful. One or a few species, the dominants, overshadow all others in their biological importance, while the intermediate and rare species determine the community's diversity (Whittaker 1965).

Plant ecologists (Raunkiaer, 1918, 1934; Gleason, 1920) were the earliest to recognize the relationship between numbers of individuals in connection with the importance of the species. The number of species were found to increase with an increase in the number of quadrats, and, when the number of species were plotted against the area, a curve resembling a quadrant of an ellipse was obtained, indicating a progressive decrease in the rate of increase of diversity. The more common species were found in most sampled quadrats, whereas an increasing number of quadrats were required to find the increasingly rarer species. This concept eventually evolved into the species-area curve (Arrhenius, 1921; Gleason, 1922).

The first important mathematical contribution in regard to comparing the degree of dominance with the number of individuals was that of Fisher, Corbet, and Williams (1943) who noted that a regular curve is deve

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is developed when numbers of individuals are plotted against the species ranked in order of importance. In their collection of 15,609 moths consisting of 240 species, 12 species were represented by 282 or more individuals and constituted over half of the total moths. Over half of the species, however, were represented by 13 individuals or less. Mathematical models dealing with numbers of ranked species and numbers of individuals have also been devised by Hairston (1959) and MacArthur (1960) to comprehend more thoroughly community composition through work on soil arthropods and bird populations.

Whittaker (1965), through use of data obtained from vascular plant communities in the Great Smoky Mountains, compared the net annual production of the various species by ranking the species in the order of their productivity rather than in numerical order. In plotting the net annual production against the ranked species, curves were created which were referred to as dominance-diversity curves. Treating the data in such a manner, values of net annual production or biomass can be used for organisms of various sizes to give a better comcept of the community composition than by the use of numbers of individuals. Also, a population may be compared more readily with any other population by the use of a factor that illustrates the impact of a population on the entire community. Species ranked only by numbers of individuals may be satisfactory when the individuals are of similar size, but when dealing with herbs, shrubs and trees, numbers of individuals lose much of their significance. In ranking the species according to annual production, Whittaker found that the dominance-diversity curves representing communities of low species-diversity were steeply oblique. As the annual production of more complex communities were plotted, different curves

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were created that were often variations of the sigmoid curve. Most communities were found to have a small group of dominants, a larger group of moderately important species, and a smaller number of rare species.

In the same way that measurement of biomass or productivity of species in vascular communities is a better method than numbers of individuals to determine the influence species have on the community, the volumetric method is also more realistic. The volumetric method, as used in this study of thermal communities, illustrates the impact each population has on the entire community and can be used to compare one-celled species with filamentous species, small species with the large. By taking the volume of a number of individuals for each species in a community and plotting the values in declining order of importance, a curve is created for each community that also can be used for comparing one community with another. This comparison can be conveniently shown by plotting a series of dominance-diversity curves for the communities found along a continuum on the same graph.

MacArthur (1960) postulates that there are alternatives in communities: (1) the abundances of different species are truly independent from one another, or (2) the total number of individuals of all species is essentially constant. An example of the first alternative would be the number of aquatic insects inhabiting the surface of a pond and the number of phytoplankton beneath the surface, where the number of one does not affect the number of the other. Another example would be the various bird species inhabiting different niches in a forest. The second alternative is applicable to thermal communities. The number of individuals is essentially the same because in a given amount of space w

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space where the algae grow, no amount of packing together can place more individuals.

Given a space within which to grow, there is, therefore, competition for this space. Although competition among organisms in all types of communities, or habitats, is actually competition for niche space, many materials for metabolism are of low concentration in most habitats, so it has been logical to consider as competition only the competition for these scarce materials. Rather than low concentrations organisms in a thermal stream are exposed to a constant supply of dissolved substances, generally of a relatively high concentration. Diffusion of these substances into the algal mass and diffusion of metabolic products from the mass creates the same growth potential for each alga, so that the differences in growth are dependent on the efficiency of utilization of these substances. Therefore, whether an organism is in a habitat with high or low concentrations of substances, the emphasis should not be on the concentration of these substances but, rather, competition for their efficient utilization. The differences in the utilization of the substances may be due to a combination of the different growth rates inherent within the various algae found under any combination of environmental conditions and the environmental factors in a given habitat. It is obvious that the efficiency of utilization of substances in a thermal macrohabitat is largely controlled by the temperature, but the concentration of certain dissolved substances also may be influential.

The concept that there are essentially the same number of individuals in the various areas of a stream would suggest that an increase in volume of any species is accomplished at the expense of the coexist

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coexisting species. Although this is self-evident when the importance values are considered volumetrically, it is not as obvious numerically where increases of one of two species often are not considered to have any effect on the numerical values of the other species. This reciprocal relationship among species is intensified by phytoplankton that can create blooms at apparently slight environmental provocation. The intensification is produced by the three-dimensional growth made possible by an aquatic habitat and may be compared with the largely two-dimensional growth of terrestrial organisms. Slight environmental differences in a three-dimensional habitat may be intensified by growth as a function of spherical volume ($4.189\ r^3$) rather than a function of circular area ($3.1416\ r^2$) for two-dimensional habitats. Although the benthic algae of thermal streams are most limited than planktonic forms in spatial expansion, they can increase three-dimensionally within their microhabitats. This three-dimensional growth can, as a result, magnify differences in recorded volumes that will be elaborated upon in subsequent discussions.

Just as the dominance-diversity curves for simple terrestrial communities are steeply oblique, those for simple thermal stream communities show the same pattern. The similarity with terrestrial communities also is shown by the greater number of intermediate species in the more complex communities, accompanied by a few of the rare species, which created approximate sigmoid curves (Figure 27). In addition to the curves expressing the effects of various environmental conditions, they also indicate the degree of success expressed by species in the communities in relation to the success of coexisting species or, as it were, the efficiency of utilization of the raw materials under the influenc

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Although a niche is the sum of all the ecological activities, only the results of these activities can be shown by the points on the curves. For convenience these points may be considered niches. These niches should not be construed to be solely the degree of efficient metabolism by activities of each species alone, but, rather, a species is in a niche as a result of its activities in combination with the activities of other species. It would be more proper to think of a species being forced into a niche by the coexisting species because the metabolic efficiency of a species is relative to the activities of all the species in the community. A species in a niche at the bottom of a six-niche dominance-diversity curve is there primarily as a result of coexisting species because if the other five were removed from the community, it would appear to be very successful.

The dominance-diversity curves demonstrate the widely diverse niche spaces especially noticeable in the simpler communities where only rarely were the volume percentages of similar or equal values. The communities from the higher temperatures were generally the simpler ones where often the same species predominated in each stream. By using the species that occupied the greatest volume in the more simple communities from five streams at 48 C and above, their cumulative volumetric values from all streams are given in descending order of importance as follows: *Mastigocladus laminosus*, *Synechococcus* spp., *Phormidium tenue*, *P. angustissimum*, *Oscillatoria geminata*, *P. truncatum*, *O. Boryana*, *O. geminata* var. nov., and *P. laminosum*. The temperatures of the waters where the communities were first sampled after emission from the sources were: 54.4 C, Alhambra, North; 56.0 C, Boulder;

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56.7 C, Jackson; 55.5 C, Pipestone; and 52.0 C, Sleeping Child; the mean being 54.9 C. The fact that Mastigocladus laminosus is the dominant alga of these streams in the temperature range of 48.0 to 54.9 C may substantiate the investigations at Yellowstone National Park by Tilden (1898), who found the alga to be most abundant at 54 C, and by Copeland (1936), who found it up to 55.8 C. M. laminosus was found in Greece in the temperature range of 42.3 to 53.0 C, being especially abundant at 49 to 53 C (Anagnostidis, 1961). Although another well-known thermal alga, Phormidium laminosum, may thrive at higher temperatures than found at these streams (see discussion, page 131-133), the low representation in the above temperature range indicates a probable poor acclimation to this range in combination with a better acclimation by the competitive species. Since P. laminosum can assume a great variety of forms, it is possible this species cannot develop the typical characteristics at these temperatures and may revert to characteristics of P. tenue, to which it is very similar. If this is true, then P. laminosum and P. tenue may be the same species with different characteristics at different temperatures; in this case P. laminosum would be ranked following Synechococcus spp. in this temperature range.

The macrohabitat for a number of species may be uniform in respect to the temperature and dissolved substances but the microhabitats may vary considerably. The flow of water over and among the rocks of the stream, producing innumerable combinations of turbulence, may be the most important factor in the creation of the various microhabitats. Differences in the angles of the impending solar radiation among these rocks may also contribute to these variations. In every thermal stream of this study, there were general inverse trends between the number of species

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species and the temperature. Communities found at the highest temperatures have few species, and as the water cools to create a more moderate environment, there is a trend toward more species. Although the trend is toward greater community complexity with decreasing temperature, the effects of the microhabitats are shown in the variety of forms taken in the dominance-diversity curves in all streams.

The effect that different microhabitats have on the success of various species may be shown in the dominance-diversity curves for communities in the north Alhambra stream from 39 to 54.4 C (Figure 23). Within this temperature range, Mastigocladus laminosus was by far the most successful species, generally occupying 90 percent or more of the total volume. The habitats of these communities have a moderate water velocity except at 46 C, where the water passed over a steep embankment. Whereas the volume of M. laminosus was usually over 90 percent upstream and downstream from this temperature, the volume of this alga was only 24 percent at this point, having lost its dominant position to Phormidium laminosum. Immediately upstream from this microhabitat of higher water velocity, five species were represented on the dominance-diversity curve at 48.5 C, six on the steep embankment at 46 C, and six downstream from this habitat at 44.5 C. Also, four species on the embankment were common to the upstream community, whereas five species were common to the downstream community. Essentially the same species were found at 48.5 C as at 44.5 C except for an introduced species at 44.5 C. Not only are the communities immediately adjacent to the community on the embankment similar, but the other dominance-diversity curves in the temperature range of 39 C to 54.4 C all have a similar pattern; that is, they are steeply oblique. These oblique slopes are larg

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largely the result of M. laminosus, a species apparently better adapted to water of a moderate velocity. The noticeably less oblique dominance-diversity curve, representing the community on the embankment, indicates each species was more equally acclimated to a microhabitat where the water was of higher velocity. Generally speaking, the uniformity of the macrohabitat, in regard to most environmental factors, controls the kinds of algae present; but the differences in the microhabitat, in this instance water velocity, influence the volumes of the various species.

The dominance of M. laminosum is also shown by the dominance-diversity curves for the communities of the south Alhambra stream, approximately 200 yeard from the north stream. Although the dissolved substances for which tests were made were very similar for both streams the degree and uniformity of this dominance was considerably less in the south stream. The smaller degree of dominance in the south stream is difficult to ascertain because the water velocity was less than in the north stream; this appears to be in contradiction to the data. In the north stream, M. laminosus markedly lost its dominance in the water of considerably higher velocity, whereas in the south stream the less pronounced dominance is found in water of relatively low velocity (Figure 23B). The greater irregularity of volume coincides with the alternating water velocities in the south stream, where small riffles alternate with pond-like conditions. The habitat of the south stream where water overflows a retaining wall is similar to the enbankment habitat in the north stream. In both habitats M. laminosus occupies less volume than in adjacent communities, whereas four of the five species in each community are common to both.

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The comparisons made of communities within each Alhambra stream and between these streams by the use of dominance-diversity curves illustrate the importance of water velocity in competition for niche space. The importance value of a species, either directly or indirectly, may be affected by the effect the water velocity has on the growth rate of coexisting species. The successful competition for the first ranked position by Phormidium laminosum at 46.0 C in the north Alhambra stream, therefore, may be the result of being better adapted for higher velocity water or the lack of adaption by M. laminosus, or a combination of both factors.

The sensitivity of M. laminosus to changes in the microhabitats may also be shown in the stream at Sleeping Child Hot Springs (Figure 40). The same three species, M. laminosus, Phormidium truncatum, and Phormidium angustissimum, were found at the source and at intervals where the temperatures were 52.0, 51.0 and 50.5 C. In this temperature range and within 20 feet from the source, the habitats changed from that of a pool to various stream habitats where the communities were sampled. At the source, where a pool habitat prevailed, 68.52 percent of the volume was occupied by P. truncatum, 21.03 percent by M. laminosus, and 10.43 percent by P. angustissimum. Five feet from the source, as the water overflowed the pool at 51 C, the dominant position was assumed by P. angustissimum, which occupied 46.24 percent of the volume. At 10 feet from the source, where the stream flowed over rock rubble at 50.5 C, P. truncatum was again the dominant form by occupying 96.81 percent of the volume, followed by M. laminosus with 2.70 percent. The water temperature was the same at 20 feet from the source as at 10 feet (50.5 C) but in the 20-foot community the positions of

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P. *truncatum* and *M*. *laminosus* were reversed, occupying 1.52 percent and 94.68 percent of the volume. The community at 20 feet was the first one in the subsequent 50 feet where the water flowed down a gradual incline with very little turbulence over an algal mat 2-3 cm. thick.

The first four dominance-diversity curves for Sleeping Child graphically illustrate the effect of the differences in microhabitats where the relatively abrupt changes in rank of the three species involved are a reflection of these differences. As the water flowed down a gradual incline over the algal mat, *M*. *laminosus* occupied 90 percent or more of the volume until a cold stream entered, lowering the temperature abruptly from 48 to 42 C. Whereas the differences in habitats were probably responsible for great variations in the volume of each species in the first four sampled communities, the uniformity of community habitats from 50.5 to 48 C also may have been responsible for the comparatively uniform volumes.

The north Alhambra and Sleeping Child streams better illustrate the effects of microhabitat differences on the community composition than do most streams because relatively long portions of the streams exhibited uniform habitats that were interrupted by those markedly different. Had all streams flown in stream-beds of uniform width, depth, inclines, and substrates, interrupted by similar changes in the microhabitats, many more species would have exhibited similar habitat preferences. Most streams or portions of streams, however, possessed such a varied combination of habitats that it is difficult to determine precisely the effect of the environmental factors.

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The dominance-diversity curves illustrate the volumetric contributions of each species at given temperatures and, by such a presentation, emphasis is placed on the communities. Although the volumes of each alga are presented in these curves, the algal contributions in the entire stream along a temperature gradient often are difficult to visualize when dominance-diversity curves are plotted separately. Visualization of species importance also is made difficult when the various volumes are plotted on a log scale, since such a scale apparently tends to place more importance on the minor species of the communities. The proper emphasis on the species, therefore, can be shown more correctly by plotting the percent volumes of the species from the various communities against the temperatures and then smoothing the lines of each species from one community to another to show the continuum more easily. The continuum curves thus created along a temperature gradient show at a glance the volumetric contributions of the species the entire length of the stream. Information obtained from the continuum curves also may be made more meaningful by referring to the other data presented in this study, such as the annotated list of the species, volume contributions by divisions, diversity indexes, and the chemical-physical data.

Distributions of the species and, therefore, the shapes of the continuum curves may be the result of environmental factors such as variations in substrate, in water velocity, and in water temperature; algal translocations, or difference of growth inherent within the algae as a result of innumerable chemical and physical factors. The shapes of the species curves in the continuum reveal the distribution during the ti

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the time of sampling, which, for the major species, remained relatively constant during the study. Only minor fluctuations were observed throughout the two summers and were largely restricted to the minor species.

For clarification, a minor species may be designated as one that has a low volume in a community or series of individual communities by arbitrary determination. Since the volumetric contribution of a species in the communities is a measure of the area inside a continuum curve, determination of this contribution may be obtained most rapidly through visual inspection. Whereas one species may attain a maximum volume of only ten percent in any community and have a temperature range of two degrees, another species with ten percent maximum volume may have a temperature range of ten degrees. The total area within the curve in the first example will be considerably less than the second. The second alga, with a wide temperature range, may have the same total curve area as a third alga whose volume attains 80 percent but is limited to a three degree temperature range. In view of these differences in total algal volume, the disignation of minor and major species for subsequent discussions has been arbitrarily determined on a community basis (a given temperature) rather than for the stream as a whole, since to do otherwise would require considerable mathematical computations for the numerous variously-shaped curves.

Of the various curves, those with one mode are the most common and largely represent the minor species or the major species found where the environmental factors, such as water velocities and substrates, were comparatively constant, or where the regular flows of the streams were sharply interrupted by a pool or steep incline. In the

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instance of the constant environment, where small differences of the microhabitats may be disregarded, the continuum curves of the south Alhambra stream (Figure 24A), Boulder (Figure 28), Pipestone (Figure 37), and the lower part of the Sleeping Child stream (Figure 41) are a reflection of the environment. As the change occurred along temperature gradients, there was generally a gradual occurrence and replacement of the dominant species and equally gradual occurrence of the minor species among the dominant forms; only rarely will a bimodal curve be found. Where such conditions prevail, steno-ecological species can be differentiated readily from the eury-ecological. In the second-described instance where noticeably different habitats were found in a stream of a more uniform nature, certain species were often the decided dominants, or the dominance was shared. In either instance the curves were uniformly unimodal. The volume curve of Phormidium truncatum from the Lolo stream is an example of a steep incline as a limiting factor in species diversity. In this instance the water flowed in a thin layer or in rivulets over a large boulder, cooling rapidly from 45 to 41.5 C. The temperature was not the limiting factor since many algae thrive in this range in other streams. The pool at Lolo (40 C) was also noticeably different from the usual thermal stream habitat. The unimodal curves of Dichothrix montana, Synechocystis salina, Denticula sp., Aphanothece stagnina, and Oscillatoria geminata var. tenella from Lolo show that these species are especially adapted to a narrow range of ecological conditions. The same can be said for Lyngbya Diguetii and Mougeotia sp., found at the entrance of a cold-water seepage into the Sleeping Child stream where the uni-modal curves are pronounced.

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The minor species generally have a narrow range of occurrence and as a result have little opportunity to develop more than one mode for a given area, or, if they are found at various points in a stream, the resultant curves are uni-modal. In effect, a scattered distribution is multi-modal, but each individual curve in itself is usually uni-modal since the fact that an alga is a minor species often means it has been forced into a narrow range by the more dominant species. Exceptions to the restriction of minor species to a narrow temperature range may be found primarily in those streams of higher velocity, such as the north Alhambra stream (Figure 24B) where Oscillatoria geminata var. tenella fa. nov. represented 13 percent of the algal volume at the source (54 C) and gradually diminished in importance to its lowest point of occurrence at approximately 47 C. Oscillatoria geminata first appeared at 49 C and maintained a relatively uniform representation of approximately 10 percent to the downstream point where the temperature reached 37.5 C. A third example of a minor species with a wide range was Phormidium angustissimum, which extended from 52 to 39 C and averaged only three percent of the volume in the communities. Another stream of comparatively high velocity was Boulder (Figure 28). Several minor species in this stream also were found in a wide temperature range; these included Phormidium laminosum (56 to 44 C), Oscillatoria limosa (43 to 36 C) and the species of Bacillariophyceae (46 to 41 C). Explanations of the probable causes of wider distribution in streams of higher velocity will be made in a subsequent discussion.

Multi-modal curves were developed for algae from several streams but were most prevalent for those from streams or stream areas where the water was of lower velocity. The stream at Jackson Hot Springs will

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will be used primarily to illustrate the effect of lower velocity, since this criterion was most frequently exhibited at this stream.

As the water overflowed a cement retaining wall of the reservoir at Jackson, it passed over rock rubble down a small incline of 30 to 40 degrees. The continuum curves for Jackson (Figure 31) indicate that Synechococcus spp. (No. 22) were the only species found on the incline, at a temperature of 56 to 54.5 C. As the water velocity decreased at the base of the incline, Oscillatoria Boryana (No. 11) abruptly assumed the dominant role, resulting in a reciprocal decline of importance for Synechococcus spp. The presence of Synechococcus spp. at the higher temperatures does not preclude the presence of O. Boryana if the volumetric contributions (shape of the curve) may be used as a criterion for judgment. The fact that O. Boryana suddenly appeared in the dominant role at 54 C and continued downstream in coexistence with other species to 40 C indicates that it very likely could have tolerated a higher temperature if it were not for the harsh limiting factors of the bare rocks and higher water velocity on the incline. Beginning at 54 C the relief was 1.52 feet per 100, resulting in a generally low velocity so it is apparent O. Boryana is best acclimated to this type habitat. The tri-modal curve of O. Boryana with high representation at approximately 54 to 51 C may be a result of the inability of the other species to successfully compete with it at the higher temperatures and the inability of O. Boryana to successfully compete with the other species at the lower temperatures.

Although the Jackson stream was of generally low velocity, it was also one of varying velocities where lotic conditions alternated with those tending toward the lentic. In addition to the effect of dif

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differing habitats on the algal composition, algal masses initially growing upstream occasionally detached from the main clone and drifted downstream where they often became established at various points in the slowly flowing water. Such translocations were actually observed on numerous occasions. This is not profound, but would be expected in lentic-like situations, and is recalled merely to help explain what appears to be discrepancies in the continuum curves, that is, where the multi-modal curves occur.

The nature of filamentous forms is to grow in interwoven masses, so in addition to single filaments breaking off and moving downstream, relatively large masses were involved which also included the unicellular forms growing among the filaments. When unicells grow in large numbers but not entangled with the filaments they tended to break off the main clones at more regular rates and, being smaller, their impact on the total translocated algal volume was not as great. The unicellular algae, therefore, tended to have more uniform volumetric distributions except where filamentous clones had become established.

The translocated algae were, of course, exposed to various combinations of environmental conditions where growth was likely to be retarded or inhibited. The actual growth rate of translocated algae may not have been affected in the new location, but if they lived among algae better acclimated to the new location, competition soon would have caused them to be overwhelmed. If the communities were sampled shortly after translocation, however, the plotted volume values would create curves with more than one mode and would appear to be discrepant. It is obvious that the longer the interval between translocation and sampling, the more moderate the curve. Generally speaking, it may be a

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be assumed arbitrarily that steno-thermal algae from an area of optimum growth transported a short distance may be able to exist under the lower temperature conditions, but with retarded growth. This retarded growth, in combination with competition with actively-growing forms normally found at the location, would gradually cause them to be eliminated. The farther downstream they moved, the less they could grow and, therefore, the competition from other species would be more effective. Eurythermal algae would be similarly affected, but to a lesser degree. The amount of translocated algal volume, distance of translocation, and length of time between translocation and sampling would be reflected in the volume curves; however, in such a study as was undertaken, this information cannot be determined.

The major species, or ecological dominants with multi-modal curves, logically may be translocated, but it is difficult to ascertain whether the modes are the result of their translocation or the result of competition with coexisting species that are better adapted to an undetermined combination of environmental factors. The same can be said for the minor species, although the replacement by coexisting species is much less obvious. Since dominance in the continuum is a measure of the area inside a continuum curve, determination of dominance by examination of these many irregular curves can be decided most rapidly through visual inspection. Granted that dominance is thus arbitratily determined, examination of the continuum curves for all the streams reveals much less scattering of the major species along the temperature gradients than of the minor species; that is, fewer dominant species are separated by areas of the stream with no representation than are the minor species. By inspection of curves for all the

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streams, it was found that scattered representation along a temperature gradient was more prevalent among the minor species than the dominant species by an 8:1 ratio. The gradient in a thermal stream is, perhaps, more spectacular than terrestrial gradients, but it can be assumed that the same principles apply to both. On this assumption, it is feasible to refer to a distributional study of soil arthropods by Hairston (1959) where it was suggested that "the rarer a species is, the more likely it is to be strongly clumped because it only finds suitable habitat in a few places in the community." While this may be true in many cases of sporadic distribution, the effects of coexisting species (discussed earlier) and effect of moving water are also responsible, but to unknown degrees.

Of the various causes for the scattered distribution of minor species and multi-modal curves of the dominant species, water velocity appears to be the most important. The ecological effects of translocation are probably more prevalent in a stream of low velocity because an algal mass can develop into a large volume before breaking off, whereas in a stream of high velocity, the algae are apt to break off at more regular rates because of the greater stress on the individual filaments. A comparison of two of the longer streams, Jackson and Boulder, whose velocities are noticeably different--27.2 and 60 feet per minute--will reveal a much more sporadic occurrence in the stream of lower velocity. Jackson (27.2 feet per minute) had eight species with more than one mode and six species found at scattered points in the stream, whereas Boulder (60 feet per minute) had three species with more than one mode and three that were distributed at different points. Combining the species possessing multi-modal curves with those having sporadic

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distributions, we get 14 for Jackson and six for Boulder, although the total numbers of plotted species for each stream, 25 and 19, would not warrant this difference.

The disproportionate amount of discussion devoted to translocation may convey the impression that it is of major importance in algal distribution. While translocation may contribute to the distribution of the algae in varying degrees, the more important factors appear to be the chemical and physical environment, and the interactions of co-existing species. Examples of the effects of the environment on the species in several communities have been given in the discussion of the dominance-diversity curves, and, since the influence of these factors is more obvious through examination of the continuum curves, it will not be necessary to treat in detail the many (98) species curves produced along the temperature gradients. Interactions of the many species may be seen also in the continuum curves, so examples will be taken only from the Jackson stream, where the interactions of coexisting species sppear to be the most pronounced.

For the Jackson stream the volume curve of Synechococcus spp. (Figure 21, No. 22), a unicellular alga, indicates that this species would probably be gradually diminished in importance with increasing distance from the source if it were not for the sudden increase in importance of Oscillatoria Boryana at approximately 53 to 54 C. There is not the gradual diminishing of one (Synechococcus spp.) and the gradual replacement by the other (O. Boryana) as would be expected but, rather, each species has developed a multi-modal curve as a result of the effect on one another, or the effect of other species farther downstream. Reciprocal relationships also are seen for Spirogyra sp. 54 μ

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(No. 17) and the coexisting species, Calothrix thermalis (No. 7), Microcystis densa (No. 18), Synechococcus spp. (No. 22), and Achnanthes sp. (No. 24), where the curve for Spirogyra sp. is bimodal as a result of the concurrent presence of the other species at 38 C. A third obvious example of interrelated volumes is that of Spirogyra sp. 27 μ (No. 10) and Rhizoclonium sp. (No. 21), each developing a curve approximating a reciprocal of the other.

The above discussion of algal distribution along a continuum presents some of the main factors,in addition to the temperature gradient, responsible for such distribution. The distribution of the algae in a stream is not merely the result of a gradual change in tempera perature, but it also is dependent on other factors such as those described above. The shapes of the continuum curves are reflections of these factors and often can be explained. Many times, however, the shapes of the curves cannot be explained, since the numerous microhabitats, varying water velocity, algal translocation, differences of inherent growth, and the effect of coexisting species often result in curves that depart considerably from the expected "bell-shaped" distribution normally found in many continua. As would be anticipated, the more uniform thermal environment results in more uniform curves; since each stream has different characteristics, however, compilation of similar data is restricted so that the shapes of the curves cannot be determined a priori.

Interactions of many biotic and abiotic factors are effective in any natural community, so that only under a controlled laboratory environment are the effects of these factors accurately determined. It may be profitable to digress from the discussion of algae briefly to mention the effect of a controlled environment on competition among flour beetles as performed in the laboratory, since some of the more prominent work of this area of study has been performed with organisms other than algae. In a study of environment-controlled competition, Neyman, Park, and Scott (1958) worked with two species of beetles, _Tribolium_ _castaneum_ and _T_. _confusum_. Using temperatures of 24, 29 and 34 C and humidities of 30 and 70 percent, they grew these beetles in six combinations of controlled environments: hot-moist, hot-arid, temperate-moist, temperate-arid, cool-moist, and cool-arid. Separately each species grew at different rates in the six environments. When they lived together in each environment only one species survived, the results being generally predictable. In the hot-moist environment _T_. _castaneum_ always survived, but in the cool-arid environment, _T_. _confusum_ always survived. In the intermediate range one species was completely dominant over the other a greater percentage of the time. It is interesting to note that under one set of conditions, _T_. _confusum_ usually wins over _T_. _castaneum_, but when the species are isolated, _T_. _castaneum_ maintains a higher population under the same environmental conditions.

The effect of six controlled factors of the environment on two species of beetles, with and without interference by the other species, suggests the extremely complicated nature of natural thermal stream communities when innumerable combinations of environmental factors are involved, coupled with the introduction of many species. Compare the three definite temperatures, two humidities, and the flour as the one source of energy used in the above experiment with the temperature ranges and the many chemical-physical factors in a thermal stream, and it ca

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it can be seen that a statistical treatment for the latter would be extremely complex. Whittaker (1965), in reference to extensive studies of forest communities by himself, co-workers, and others, stated that in most instances it was not possible to make statistical tests. If each of the stream communities had been exposed to thermal gradients in otherwise uniform habitats, rather than the many varied microhabitats, the interrelationships of the algae could be seen more easily and the effects of the chemical factors could be compared. Perhaps when data from scores or hundreds of thermal streams are available, the biotic and abiotic relationships may be determined statistically. Without data from many streams or from controlled laboratory studies, the investigator can make only comparisons of distributions among streams, or areas in one stream, and speculate as to the probable causes of distribution. This has been done by the use of the dominance diversity curves and elaborated upon by the continuum curves.

Diversity Index

The development of the species diversity concept through the contributions of Gleason, Raunkaier, Arrhenius, Fisher, MacArthur, *et. al.*, has been discussed earlier. In presenting data relating to species diversity, it often has been a practice to plot the number of species against the number of individuals for a community and then compare the resulting curve with curves obtained from other communities. The slope of the community curve has been considered a measure of species diversity (Fisher, Corbet, and Williams, 1943). If the cumulative number of species is divided by the cumulative number of individuals in a comm

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a community, a ratio is obtained which has been termed the diversity index. Since the numbers of individuals in most sampling is large, the logarithm of the number of individuals is used to obtain $D = S/\log N$ (Gleason, 1922). As discussed earlier, the equation used to obtain the diversity index for this study, $D = (S-1)/\log N$, was proposed by Margalef (1958).

The small number of species but large number of individuals has been recognized as a characteristic of harsh environments (Odum, 1953; Hutchinson, 1959). Where the environment is ameliorated in a community with time, or when there is an amelioration of limiting factors in a continuum community, there is a splitting of niches as more species enter and, as a result, the community becomes more diverse or complex. If the number of individuals remain essentially the same in similar communities with any change in the number of species (MacArthur, 1960), then direct comparisons of community diversities can be made through the use of the diversity indexes. In this study of thermal streams, the diversity indexes were computed for the sampled communities of each stream and the results were plotted along temperature gradients to obtain scatter diagrams. Then by using $y = a + bx$, slopes were produced which indicated the rates at which the thermal continuum communities increased in diversity as a function of temperature change. This increase in the diversity index is also a measure of the increase in complexity, and if diversity or complexity are equated with maturity (Margalef, 1963), the slopes may then be indications of the rates of the streams' maturation.

Since the diversity index is a ratio of the number of species and the number of individuals, and since the number of individuals in

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a given algal volume is essentially constant, then any factor that alters species composition has a direct bearing on the diversity index. These have been discussed in previous sections relative to changes from one community to another by the use of dominance-diversity curves, and changes of species' dominance by the continuum curves. As a result, the discussion of differences in composition has been largely restricted to the individual community and species on the microhabitat level by the nature of the methods of presentation. An overall picture of the thermal stream can be obtained by the use of these approaches, each with a specific emphasis, but a more conclusive picture may be obtained of the entire thermal stream community through the use of the diversity index.

The increase of diversity index values in the entire continuum of the thermal stream is primarily dependent on two factors: (1) the increase in the number of species with decreasing temperature, and (2) the cumulative effect of species number as a function of distance from the source. Without exception there was a general trend toward increase of species with decreasing temperature within the temperature range of these streams. The effects of the first factor have been observed in the presence lists, dominance-diversity curves, and continuum curves along the temperature gradients. Since this trend of species increase with decreasing temperature has also been discussed on several occasions, it would be redundant to elaborate further on this point.

The factor of the cumulative effect on increasing species diversity along a thermal stream continuum is probably functional in all the streams although it is most pronounced at Lolo and Sleeping Child Hot Springs. An examination of the temperature curves for Lolo (Figure 20)

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and Sleeping Child (Figure 22) will reveal a very gradual cooling of the water within relatively long distances. Since the water cooled only a few degrees, the diversity index curves should show gradual increases as a function of distance rather than such abrupt increases as indicated by Figures 35 and 42. (The break in the slope at Sleeping Child is the result of an entering cold stream, which lowered the temperature rapidly from 48.0 to 42.0 C). These rapid increases in the diversity indexes may be explained by the fact that in a given temperature range a greater number of species can be established at a point downstream than upstream. If a number of species were initially distributed at random in a stream for a given distance where the temperature was constant, the growth of the upstream species would cause them to separate from the main mass occasionally. Upon being carried downstream, a certain percentage of them will become established in various downstream communities, at least temporarily, until overcome by competition with the existing species. Although many will live temporarily in the new location, others will become permanently established; during the sampling of the communities, however, there is no way to differentiate between them. The net effect, nevertheless, is an increase in the number of species and, therefore, an increase in diversity index.

The cumulative effect was observed when microscope slides were placed in the Sleeping Child stream with the prospect of observing algal growth at intervals. In one week the sharp outside edges of the slides and their containers were so completely matted over by allochthonous algae that none could become established on the inside surfaces meant for their growth. The translocation of algae also was observed at Jackson and has been discussed earlier in the section relating to the

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If the diversity of downstream communities is increased, it must be accomplished at the expense of the upstream communities. The constant export of biomass from upstream communities will, of necessity, keep diversity at a lower level. Since diversity, or complexity, is a measure of maturity, loss of biomass by any constant loss of individuals will keep maturity at a reduced level. Margalef (1963) refers to the export of biomass by planktonic forms that settle to the filter feeders at the bottom. He states that "in the upper layers plankton becomes diluted or dispersed and at the lower levels it is concentrated. The continuous drain of a part of the surface plankton needs to be countered by an excess production and does not allow a great increase in organization. Other similar models, where the horizontal dimensions are more important,.....represent running water in general, in which the increase in maturity is always downstream."

Granted that translocation of algae always takes place in moving water, the greatest amount of relocation of upstream species will take place in water of lower velocity where they will settle out much like microscopic mineral matter. Where the entire stream was of relatively uniform velocity, as at Boulder and Jackson Hot Springs, the relocation should be comparably uniform for the length of the stream. The computed slopes for the diversity indexes of these streams (Figures 29 and 32) are a reflection of this uniformity and show a steady increase of the diversity index values. These slopes may be compared with the slopes of Lolo and Sleeping Child Hot Springs (Figures 35 and 42) which are nearly vertical for portions of the stream. These rapid increases in the diversity indexes coincide with the stream areas of the lowest

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water velocity and, as discussed earlier, they are in the stream areas of the least temperature change. (See stream profiles, Figures 6 and 8, also temperature curves, Figures 20 and 22).

In conjunction with the physical effect of water dropping more algae in stream areas of lower velocity is that of the biological effect. More species are able to live in water of low velocity. This may be demonstrated by comparing the number of species in the small pool at Lolo and the effluent stream from the pool. (This pool is upstream from the area of low water velocity--see the map and stream profile, Figure 6). The pool had 15 species and a diversity index of 3.07 whereas the effluent stream had seven species and a diversity index of 0.84, both habitats having a temperature of 40 C. This stream location was chosen for illustration because the species in the pool would logically flow out at some time and yet they all cannot become established in the effluent stream. It is apparent that some of the pool species are not acclimated to higher velocity water even through they are continually exposed to it as they flow out of the pool.

The scatter diagram of the diversity indexes at Jackson Hot Springs (Figure 32) illustrates the wide range of species diversity within short temperature and distance ranges. This appears to be the result of the alternating lotic and lentic-like flows discussed in previous sections. The riffles have the effect of reducing species diversity, while the lentic-like flows generally increase diversity. This often is made more complex by the fact that the lentic conditions harbor species such as Spirogyra spp. that produce bloom conditions that have the effect of reducing the importance of the other species, many times to their apparent exclusion. Although the rapid growth of some

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thermal stream species is intermittant and limited to stream areas less affected by the limiting factor of higher water velocity, it may be analogous with streams of generally higher productivity where the flow is more uniform. Yount (1956), in his Silver Spring, Florida, study, found that the number of species decreased more rapidly in areas of high productivity. Yount explains that those species better adapted to the conditions of a habitat become more numerous at the expense of the others and in the areas of high productivity the competition is greater so that a point is reached more rapidly when the least adapted species are overwhelmed. The low productive areas permit many species to grow at slower rates since even the more competitive species under better conditions are impeded.

The scattering of the diversity index values for the species at Jackson (Figure 32), where conditions are conducive to the prolific growth of some species at the expense of the others, may be compared with the values obtained for the species at Sleeping Child below the entrance of the cold water seepage (Figure 42). The more uniform distribution of the values at Sleeping Child is likely related to the limiting factor of higher water velocity where relatively slower growth for all species prevails. Comparison of the relief and water velocity will help to explain these differences. At Jackson the relief was 1.52 feet per 100, and the water velocity was 27.2 feet per minute; at Sleeping Child the relief below the cold water seepage was 16 feet per 100 and the water velocity was 76.3 feet per minute. What appears to be a discrepancy between the relief and the velocity of the two streams may be explained by the fact that at Sleeping Child there were numerous rocks over which the water flowed that impeded the flow of water,

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whereas at Jackson the flow was more laminar. The turbulence produced by the rocks in the Sleeping Child stream results in a great variation of microhabitats, but bloom conditions are prevented because much of the biomass is removed and there is a constant replenishment of raw materials for all species. At Jackson the laminar flow allows the more prolific species, for a given combination of environmental factors, to accumulate and, therefore, greatly alter the diversity.

The Boulder stream had a variation of habitats, because of differing substrates composed of decaying fallen vascular vegetation and mineral material, but the diversity of habitats was not as extreme as in the case of the Jackson stream since the Boulder stream lacks the lentic-like situations. The fewer conditions for the proliferation of some species at the expense of the others at Boulder permits greater diversity of species and, as a result, the rate of increase of diversity index values at Boulder (Figure 29) is much greater than the rate of increase at Jackson (Figure 32). The greater water velocity at Boulder, 60 feet per minute compared with 27.2 feet per minute at Jackson, also inhibits the accumulation of any given species that would tend to reduce diversity.

Another factor that may affect the rates of increase in diversity indexes should be mentioned. Generally speaking, the rates of increase for the diversity indexes for the north Alhambra and Jackson streams are less than the rate of increase at the other streams. In these two streams the alkalinity is much higher--430 ppm for Alhambra and 574 ppm for Jackson. These compare with 161 ppm for Boulder, 84 ppm for Lolo, 98 ppm for Pipestone, and 125.5 ppm for the portion of the Sleeping Child stream referred to in the above discussion of di

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diversity index. It is conceivable that the high alkalinity also contributed to the lower rate of increase in diversity index, although the data from six streams or stream groups is little on which to base the hypothesis. Environments of extremely high alkalinity, such as the Great Salt Lake, are known to have few species, but the effect of the alkalinity of Alhambra and Jackson in conjunction with those of temperature, habitat differences, and other chemical factors create unreliable speculation at this point. Although it is logical to assume the alkalinity of Alhambra and Jackson had a depressive effect on the diversity index, more data will be required to know if alkalinity is effective in this range.

Another area of study in which the diversity indexes are useful is that of equilibrium comparisons. The algae were examined at intervals in the summer of 1962 at the west stream of Pipestone Hot Springs. During this time the algal composition remained relatively constant; that is, the differences in community composition from one stream visitation to another were no greater than the differences found in samplings from one community taken at one stream visitation. It will be recalled from earlier discussion of the results that this west stream was flooded by an overflowing cold stream a short time before the first visitation in 1963, completely scouring out all visible algal growth. Four weeks after this visitation, the communities were sampled. The results of the diversity indexes are plotted on Figure 38 for 1962, and on Figure 39 for 1963. The scatter diagram for 1962 indicates the diversity indexes are less varied, and the rate of increase for the diversity indexes much greater than in 1963. Since the water composition, temperature, stream profile, substrate, and all other recognizable

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features were the same for both summers, the differences in diversity are apparently the result of different rates of algal growth. In 1962, equilibrium had been attained among the species of the communities, resulting in a relatively uniform rate of increase in diversity with decreasing temperature. The greater distribution of diversity index values for the 1963 communities indicate that equilibrium among the species had not yet been attained after they had become reestablished. If diversity is equated with maturity, then the scouring of the stream had the effect of reducing maturity. This, of course, is reasonable and could be assumed _a priori_, but the scatter diagram verified any predetermined hypotheses. Had it been possible to do so, weekly samplings of the communities throughout the summer of 1963 would probably have indicated less variation in diversity indexes with time and an increase in maturity until a stream condition was reached much as it was in 1962.

Scatter diagrams of the diversity indexes are particularly suitable for the study of thermal communities to show trends in species diversity. The high temperatures at the sources will keep diversity at a low level, but as the water cools the diversity will increase at a rate controlled by the biotic and abiotic factors. Since the combinations of environmental factors affecting algal growth in natural thermal streams are astronomical, the communities in each stream will develop innumerable patterns of scatter diagrams. Although the diversity index values will vary at different points along the vegetational continuum, the combined values will be characteristic for each stream. Not only do the resultant slopes indicate the rate of diversity increase, but by visual inspection the scattered points indicate the variation in divers

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diversity that often can be correlated with other data. Until many similar streams can be investigated, however, statistical treatment by regression analysis would be impossible considering the number of variables involved.

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CHAPTER VIII

SUMMARY

From 15 thermal springs or spring groups that were considered for study in western Montana, six were chosen on the basis of distribution, accessibility, and stream characteristics. The six springs are in a general northwest direction from Yellowstone National Park, ranging approximately 62 to 197 miles from the boundary. The maximum east-west distance between springs is approximately 124 miles. The springs, their maximum temperatures, and temperatures within which the algae were collected are: North Alhambra, 54.4 C (36-54.4 C); South Alhambra, 48 C (41-48 C); Boulder, 61.3 C (36-56 C); Jackson, 61.5 C (26-58 C); Lolo, 46 C (34-46 C); West Pipestone, 59.5 C (52-57 C); East Pipestone, 52 C (51-52 C); Sleeping Child, 52 C (34.5-52 C).

Within the above temperature ranges, 28 taxa of algae were found at the north Alhambra stream, 21 at the south Alhambra stream, 43 at Boulder, 50 at Jackson, 34 at Lolo, 19 at west Pipestone, 13 at East Pipestone, and 32 at Sleeping Child. The division Chlorophyta was represented by eight genera, the Chrysophyta (Bacillariophyceae) by 11, and the Cyanophyta by 22. There is little significance in the number of genera within the Chlorophyta or Chrysophyta because with continued decrease in the stream temperature there would be progressively more algae represented in these divisions. More significant are the temperatures at which these divisions were found in the streams. The decided dominance

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dominance by the Cyanophyta at the higher temperatures is shown by the fact that members of this division were generally the only algae present from the spring sources downstream to approximately 40 to 42.5 C, where the Chlorophyta and Chrysophyta (Bacillariophyceae) appeared. The mean maximum temperature tolerated by the Chlorophyta was 38.1 C, by the Chrysophyta (Bacillariophyceae), 40.5 C.

Within the 22 genera of the Cyanophyta there were 64 species, seven varieties, and two forms, comprising a total of 70 taxa. Of this total, there were seven undescribed taxa--three at the species level, two varieties, and two forms. The new species were of *Chamaesiphon*, *Phormidium*, and *Pseudanabaena*; the varieties were of *Synechococcus lividus* and *Anabaenopsis circularis*; the forms were of *Oscillatoria geminata* var. *tenella* and *O. geminata* var. *fragilis*.

The observed effects of the environmental factors on the species' morphological characters were often too indistinct to describe or characterize. There were instances, however, when the most probable factor--temperature--had an obvious effect. The oogonia and oospores necessary for identification of *Oedogonium* to species were never found, nor were the zygospores of *Mougeotia* and *Spirogyra*. Temperature apparently also prevented the akinetes of *Anabaena* and *Cylindrospermum* from forming. Except for the recognized thermophile, Mastogocladus laminosus, which was found in the highest temperatures of the streams, species with heterocysts were generally limited by the higher temperatures. *Cylindrospermum* sp. trichomes were found without heterocysts from 52 C downstream to 41 C. At 41 C, heterocysts of this species began to appear and persisted to 32 C. Other species with heterocysts and the highest temperatures at which the species were found are:

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Anabaena sp., 34.5 C; Anabaenopsis circularis var. nov., 45 C; Nodularia Harveyana, 47.2 C; Calothrix Braunii, 43.5 C; Calothrix Kossinskajae, 45 C; Calothrix thermalis, 43 C; Dichothrix montana, 40 C; and Gloeotrichia echinulata, 33 C.

Oscillatoria Boryana was found in only the Jackson stream, but here it also displayed characteristics of O. terebreformis and Arthrospira Jenneri. Several of its characters were randomly different in any community sampling. Spiralling and granules did, however, vary with the temperature. The length of the trichome section with spirals and the width of spirals increased with higher temperature. The size and number of granules also increased with higher temperatures.

Temperature appeared to have the opposite effect on the production of granules in Cylindrospermum sp., where fewer granules were found with increasing temperature. Two similar species of Phormidium, P. laminosus and P. tenue, are largely differentiated by the presence or absence of granules. It has been discussed that trichomes with granules grade into those without granules from community to community, also that granular and granuleless trichomes exist in the same community. It has been suggested that these two may in fact be one species.

The mean maximum tolerable temperatures for the algae common to two spring effluents, Boulder and Sleeping Child Hot Springs, were compared and found to differ ty 5.18 C. The values for 15 individual dissolved substances for each stream were very similar; the sums of these substances were 417.05 ppm for Boulder and 417.24 ppm for Sleeping Child. The main differences of the abiotic factors were the water velocities and volumes. These differences accounted for 0.66 C change of water temperature for 1 C change of air temperature at Boulder and 0.187 C change of water temperature for 1 C change of air temperature at Sleeping Child. Of the species common to both streams, the mean maximum temperature for those at Boulder was 44.54 C, and 39.36 C at Sleeping Child.

In addition to the measured chemical and physical factors and information specific for each alga given in the annotated list of the species, five methods were used to present the data of algal distribution in the thermal spring effluents. These methods emphasize various levels of organization; that is, species, classes, individual communities, and the thermal stream community. The methods are: (1) presence lists of species in communities along temperature gradients, (2) species curves along the thermal stream continua showing the percent volume contributed by the major species, (3) tables showing the combined frequencies and percent volumes of species in the classes, (4) dominance-diversity curves of algal communities along temperature gradients (5) diversity indexes of the algal communities along temperature gradients.

The species in the presence lists are not only those found when the same number of microscope slide areas were used for each community, but also those found during any phase of community analysis. The increased slide areas examined for each community, therefore, often have revealed more species in the presence lists than during the enumeration, when a standard number of microscope slide areas were used. The other four methods of presenting the data required a standard number of microscope slide areas for each community.

The percent volume curves for the major species along temperature gradients have shown the interrelations among species in the thermal stream continua. It was possible in many instances to correlate these interrelations with the various measured abiotic factors of the environment.

Tables of frequencies and percent volumes of the combined species of the divisions have shown the importance of each division in the total algal composition along temperature gradients. These tables also illustrate the differences between frequency and percent volume. Although these differences often were masked by combining species' values of a division, they were sufficient to show the impropriety of using frequency to illustrate the impact which organisms have on a community.

The dominance-diversity method emphasized the individual thermal communities by showing the percent volume of the species in each community. The contributions of the species in several communities of a stream were then correlated with various biotic and abiotic factors. Dominance-diversity curves illustrate the degree of species diversity. Most communities were found to have a small number of volumetric dominants, a larger number of intermediate species, and a small number of volumetrically insignificant species. The simpler communities were represented by steeply oblique diversity curves, whereas the more complex communities were represented by curves tending toward the sigmoid.

Whereas the dominance-diversity curves placed emphasis on the individual communities, the curves produced by plotting the diversity indexes of the communities against the temperatures illustrate the rate of increase in diversity with decreasing temperature for the entire thermal stream community. The curves of the diversity indexes enabled the rates of diversity increase to be compared for all the streams.

Within the temperature ranges of these spring effluents there were no observable increases of species diversity with the occurrence of additional algal divisions but, rather, the diversity continued to increase only with decreasing temperature. Had the thermal stream temperatures decreased to those possessed by other streams of the various localities, the curves of the diversity indexes probably would have reached the asymtote and more than likely would have shown a decrease in diversity at some temperature. The temperature at which diversity is no longer increased will probably vary with the numerous abiotic factors in the same way that these factors have been observed to influence the rate of increase in diversity within the streams of this study. Since there can be great variance in the rates of diversity increase, analyses of the algae and abiotic factors of many thermal streams will be required to determine the mean temperature of diversity equilibrium.

The study of numerous streams should reveal more precisely the mean maximum temperatures for the species and algal divisions under natural conditions. It may be possible in future studies also to determine the factors responsible for the various degrees of successful growth, to correlate several abiotic factors with kinds and numbers of species, and determine more precisely the structure of thermal stream communities through the use of dominance-diversity curves. Pertinent information of this study that can contribute to the knowledge of thermal algae ecology include the temperature ranges of the species in each stream and the mean maximum temperature for the species from all streams given in the annotated list of the species, the concentration of dissolved substances, and the five methods of data presentation discussed earlier. It is the hope of the author that the information given in this study will contribute to the knowledge of thermal stream ecology, and that it will suggest methods of analysis for future studies.

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