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AN ECOLOGICAL CLASSIFICATION OF CERTAIN ONTARIO STREAMS

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AN ECOLOGICAL CLASSIFICATION OF CERTAIN ONTARIO STREAMS

Abstract

The standard methods of limnological investigation, which had previously been used, in Ontario, upon lakes almost exclusively, have been applied, with suitable modifications, to a study of streams in this province. It appears that the various organic and inorganic peculiarities of flowing waters may be correlated to a degree sufficient to allow of a useful, if rather arbitrary, classification being made. The features utilized in this way are of three kinds: (1) physical—character of the watershed; width, depth, and kind of bottom of the stream, temperature and rate of flow of the water; (2) chemical—kinds and quantities of gases and solids dissolved in the water; (3) biotic—kinds and numbers of plants and animals which are members of the stream community.

Such a classification is proposed in this paper, and the peculiarities of the streams of each division discussed in greater or less detail, with especial reference to the food relationships of game fish. Most attention has been given to streams cool enough to contain speckled trout (*Salvelinus fontinalis*), and particularly to one slow hard-water trout stream, the Mad river.

Economically, these studies should be of value to fish-culturists, as indicating what features may most profitably be included in their necessarily rapid "planting surveys", and as an aid in placing a stream in its proper category when only limited data are available.

Introduction

In the past two decades many biologists have been occupied in a study of the ecological relationships in which the fauna and flora of lakes are involved. To-day, not only is there available a large amount of detailed information on these bodies of water, but various methods of classification have been proposed which are, in their broader features at least, apparently of general application throughout the north temperate region. In comparison with this intensive study of lakes, rivers have been almost uniformly neglected. With a few exceptions, such ecological data as are at hand consist of notes made incidental to systematic studies, or of the very general observations made in connection with fish-planting surveys. The reason for this discrimination is probably to be found in the overwhelming variety of habitats presented in streams and rivers, the inadequate systematic treatment of their fauna, and the lesser economic importance of their fish.

Important information upon the general ecology of certain streams in which speckled trout live is to be found in publications by Hankinson (1922) and Kendall and Dence (1927). A study of the physical and biotic peculiarities of mountain streams has been made by Steinmann (1907) and Thienemann (1912) in Europe, and by Dodds and Hisaw (1924a, 1924b, 1925) and Muttkowski (1929) in America. A number of authors have concerned themselves with the physical and chemical characteristics of the waters of American streams: Belding (1928), Butcher *et al.* (1927), Coker (1925), Cowles and Schwitalla (1923), Creaser (1930), Faigenbaum (1930), Gutsell (1929), Powers (1928, 1929), Shelford (1925), and Wagner (1926, 1927, 1928). Publications dealing with the invertebrate fauna are numerous but widely scattered, are usually purely systematic, and generally deal with only one species or group of species. The papers of Clemens (1917), Leathers (1921), Muttkowski and Smith (1929), Needham and Christenson (1927), and some others have given an account of the place of certain aquatic insects in the life of a river.

In 1930-1, the author endeavoured to obtain information on all of the above points from a single stream habitat—a short section of the Mad river—so that an attempt could be made at discussing the relationships of flora and fauna to each other, and to the physical and chemical peculiarities of the water. During the course of this investigation the possibility suggested itself of extending to streams generally the systematic ecological treatment which lakes have already received.

APPARATUS AND METHODS

I. Water

Rate of flow was determined by finding the length of time in which a floating stick was carried a measured distance by the current.

Volume of flow was calculated from the rate plus the measured width and average depth of the section; no correction was made for "bottom drag".

Temperature was taken by means of a Tycos armoured centigrade thermometer, marked off in degrees and accurate to one-fifth of a degree. Unless otherwise stated, readings were taken three inches below the surface. On the Mad river a Negretti and Zambra continuous recording thermometer was also used. Its graph (figure 4) gives the temperature in degrees Fahrenheit. It was checked by a Negretti and Zambra standardized Fahrenheit thermometer. Owing to pointer drag, the recording thermometer registered 0.5° F. too low when the temperature was near a maximum, the same amount too high when approaching a minimum, and various lesser amounts elsewhere. It was impossible to correct for these variations. Correction has been made for a constant error: +1.2° F. in 1930, and +3.8° F. in 1931.

Air temperature was recorded by means of a maximum and minimum thermometer, accurate to one-half of a degree Fahrenheit; it was mounted near the river, in the shade of a thicket, five feet above the ground.

Oxygen content of the water was determined by a modification of Miller's method, using ferrous-ammonium sulphate for titration. The solutions were standardized by reference to Roscoe and Lunt's table of saturation values (Sutton, 1924, in appendix). Distilled water was saturated with atmospheric oxygen at 18° C., in the fashion described by Sutton. This standard solution was considered to be 100 per cent. saturated, its oxygen content, determined by titration, was compared with the figure given by Roscoe and Lunt (allowance being made for atmospheric pressure, as below), and a corrective factor found for each sulphate solution. In some of the earlier work this standardization was not done in the laboratory, so samples of water taken in the field, at the foot of a long series of rapids and falls, were considered to be 100 per cent. saturated, and the factor calculated from them.

All tables of saturation values are for an atmospheric pressure of 760 mm. (29.92 inches) of mercury. These must be corrected to give the value at the pressure prevailing when the determination was made. Pressure varies with the altitude of the station where work is done, and also varies daily according to weather conditions. In lieu of a barometer the author has used the following formula to obtain actual pressure; it is derived from one given by Geddes (1921, p. 110):

$$\log p = \log p_0 - 0.00001570\ H$$

where p = pressure at elevation H feet, and p_0 = pressure referred to sea-level, obtained from the daily weather bulletins issued by the Dominion Meteorological Service.

The elevation of most stations may be found in White (1925). The above formula is accurate at 15° C. air temperature. A deviation of 10° C. produces an error of only 0.2 per cent. at 1,500 feet altitude. For more accurate work, or at high altitudes, the following formula may be used:

$$\log p = \log p_0 - 0.00453\ \frac{H}{T}$$

where p, p_0, and H are as above, and T = absolute temperature of the air at elevation H feet. In the present work, corrections for atmospheric pressure have amounted to from two per cent. to six per cent.

Reference to Whipple and Whipple's table (Standard methods of water analysis, 1925, p. 62) shows that the lessening of solubility of oxygen because of salts dissolved in the water may be neglected in fresh waters which contain less than 250 parts per million of solids in solution.

Hydrogen-ion concentration has been measured using a La Motte colorimetric comparator, with bromthymol blue, phenol red, and thymol blue indicators. In hard waters, which contain much bicarbonate, these appear to be satisfactory; but in soft water it would seem that the pH of the indicator used (which is one-tenth of the volume of the water used) has a significant effect upon the pH of the resulting mixture. For example, the Oxtongue river had a bicarbonate content of less than ten parts per million, expressed as $CaCO_3$. On July 18, 1930, the pH reading was

6.2, using the usual amount of indicator. When only half of this amount was used, the intensity of the colour was, of course, reduced, but its hue also changed, and indicated a pH of about 6.6. However, pH readings from soft waters, even if not accurate absolutely, are comparable among themselves.

Determinations of free carbon dioxide (CO_2) and bicarbonate (HCO_3) were made by titrating with N/50 sodium carbonate and N/50 sulphuric acid, using phenol phthalein and methyl orange respectively, as outlined in Rept. Ont. Board of Health (1919). Hardness was tested by means of a standard soap solution. The author is indebted to Mr. E. S. Pentland for many determinations of the chemical composition of the water.

II. Invertebrates

Samples of the upper seven cm. of a river bed were taken by means of a dip net 14½ inches (36.7 cm.) in diameter. The bag, through which the water and mud were strained, was of marquisette, having 24 threads to an inch (9.4 per cm.). After taking a dredging, the area of the hole left on the bottom was measured, with a possible error of about ten per cent. For a few of the deeper water collections, an Eckman dredge having a gape of 77.5 square inches (500 square cm.) was used; the constant clogging of the jaws and the inconvenience of operating it from a canoe limited its usefulness. After a dredging was washed in the net, the living animals were carefully picked out of the weeds, sand, or debris which remained, and preserved in 70 to 80 per cent. alcohol. The larger and rarer invertebrates, such as *Benacus* or *Helisoma*, were often taken individually as they were seen. Imagos of aquatic insects were collected by means of a net, or from under leaves of trees.

In this paper four words denoting frequency of occurrence have been applied to the invertebrates of the stream bottom with the following arbitrary values:

More than 15 per square foot (=0.0929 square metre):	Abundant
6 to 15 per square foot (=0.0929 square metre):	Frequent
2 to 5 per square foot (=0.0929 square metre):	Occasional
Fewer than 2 per square foot (=0.0929 square metre):	Rare

III. Fish

Sculpins, sticklebacks, and trout less than one and a half inches long were often taken in a dip net. A ten-foot minnow seine was used to capture slightly larger trout and many other fish. Large trout, creek chub, shiners, *etc.*, were most often taken by angling, with either worm or fly as bait.

The length of a fish was measured in inches from tip of snout to fork of tail. Girth was measured immediately in front of the dorsal fin. Weight of fish heavier than one ounce (28.4 grammes) was measured by means of a postal scale which was accurate to the nearest tenth of an ounce. Lighter fish were weighed on a balance accurate to 0.01 grammes. With a few exceptions, fish more than six inches (15.2 cm.) long were measured and weighed soon after they were caught and while they were still fresh; fish less than that length were measured about seven months later, after being preserved in formalin and alcohol.

IV. Stomach analysis

The contents of the fish stomachs were analysed singly. The total volume of the contents of each stomach was found by displacement of alcohol or water in a graduate. Items were then sorted and counted and the percentage of the whole which each group formed was estimated. From this the actual volume of each kind of food in each stomach was obtained. Averages for a series of specimens were obtained by adding together these volumes, then calculating its percentage of the total volume of all the stomachs.

When only a few large items occurred in a stomach, their several volumes were often found separately, by displacement. In the case of very small fish, the total volume, as well as the percentages, was estimated.

CLASSIFICATION OF ONTARIO STREAMS

The factors to be considered in making a classification of streams are to a great extent interdependent, and are

consequently difficult to evaluate. The following is a list of the more important:

A. Chemical composition of the basic rocks and of the soil of the region through which the river flows, which determines the bicarbonate content and hardness of the water and with carbon dioxide content, its hydrogen-ion concentration. The waters of Ontario rivers are rather sharply divided into "soft or brown waters" and "hard or clear waters" corresponding roughly to the division of the province into a region of igneous rocks (including most of the pre-Cambrian shield) and regions of sedimentary rocks (mostly of Ordovician, Silurian, or Devonian age).

B. Type of soil and vegetation of the watershed, which are the principal factors in determining the turbidity of the water.

C. Speed of current, which may be divided into (1) slow —less than 1.5 feet (0.46 metre) per second, and (2) fast— more than 1.5 feet per second.

D. Type of bottom: Vegetable debris, mud, sand, gravel, stones, boulders, bedrock, or hardpan.

E. Temperature of the water.

F. Width and depth, which with C determine volume of flow.

G. Flora, which is determined by A, C, D, E, and probably F and H.

H. Fauna, which is determined by C, D, E, F, G, by geographical position, and by the presence of barriers to migration.

I. Oxygen and carbon dioxide content of the water, which are influenced by almost all of the above factors.

Carpenter (1928) has proposed a classification of the streams of Great Britain, on the basis of some of these factors. It is, however, incomplete in some respects when applied to Ontario waters, and includes some types which have no exact equivalent here. Shelford and Eddy (1929) and Needham and Lloyd (1930) have given some consideration to differences between various American streams, chiefly as regards their fauna, but they too omit many Ontario types. It has seemed better, therefore, to make a preliminary grouping of Ontario streams into natural, though intergrading, classes, without direct reference to previous work:

A. Creeks. Volume of flow less than ten cubic feet (0.28 cubic metre) per second on June 1; width less than ten feet (3.0 metres).

  1. Spring creeks. Permanent, usually spring fed; maximum summer temperature lower than 20° C.

    a. Stony bottom, moderate to rapid current, vegetation of aquatic mosses.

    b. Sandy bottom, moderate to rapid current, bare of vegetation.

    c. Mud bottom, slow current, vegetation usually water-cress, or none.

    d. Bottom of dead leaves and other vegetable debris, slow current, vegetation of mosses or none.

  2. Drainage creeks. Not spring fed, or far from springs, often completely dry in summer; maximum summer temperature above 20° C., usually much higher.

B. Rivers. Volume greater than ten cubic feet (0.28 cubic metre) per second on June 1; width greater than ten feet (3.0 metres).

  1. Trout streams. Maximum summer temperature not in excess of 24° C.; principal piscivorous fish, *Salvelinus fontinalis*.

    a. Slow trout streams. Mud over most of bottom; slow current; vegetation of *Nymphaea*, several species of *Potamogeton, etc.*

      (i) Slow hard waters. Bicarbonate content greater than 100 parts per million (expressed as $CaCO_3$), hardness more than 150 parts per million; vegetation including *Chara*, but not *Brasenia* or *Castalia*; volume of flow on June 1 not greater than 100 cubic feet (2.8 cubic metres) per second.

      (ii) Slow soft waters. Bicarbonate content less than 25 parts per million (expressed as $CaCO_3$), hardness less than 50 parts per million; vegetation including *Brasenia* or *Castalia*, never *Chara;* volume on June 1 up to 500 cubic feet (14 cubic metres) per second.

    b. Swift trout streams. Stony bottom; moderate to rapid current; vegetation of *Cladophora* or aquatic mosses; typical invertebrates Hydropsychidae, Heptagenidae, Simuliidae.

      (i) Swift hard waters. Bicarbonate content greater than 100 parts per million (expressed as $CaCO_3$), hardness more than 150 parts per million; *Simulium* larvae merely frequent; volume of flow on June 1 not greater than 150 cubic feet (4.2 cubic metres) per second.

      (ii) Swift soft water. Bicarbonate content less than 25 parts per million, hardness less than 50 parts per million; *Simulium* larvae extremely abundant; volume of flow on June 1 up to 500 cubic feet (14 cubic metres) per second.

  2. Warm rivers. Maximum summer temperature in excess of 24° C.; volume of flow with no upper limit; principal piscivorous fish of the families Centrarchidae and Esocidae.

    a. Stony bottom, moderate to swift current, supporting typically a *Cladophora*-Hydropsychidae-Etheostominae association (Shelford and Eddy, 1929).

    b. Mud bottom, slow current; with a very varied biota, including *Nymphaea*, Unionidae, Catostomidae, and many Cyprinidae.

The distinctions between swift-stony and slow-muddy types are, perhaps, the most fundamental, from the point of view of the biota, of any which were used in preparing the table. They have been relegated to the third rank for the sake of convenience, because swift and sluggish reaches often alternate along the course of a single stream.

The "warm rivers" are entitled to much greater subdivision than that shown, but almost no information is available which treats of Ontario examples.

The author has visited every kind of stream mentioned, but the amount of attention which each has received has by no means been uniform—varying from a single casual examination to a prolonged period of careful study. The Mad river has been most favoured, and the description of its various aspects will constitute the bulk of this paper. Nevertheless, each type will be discussed in its turn, following the order given in the above outline.

STONY SPRING CREEKS

"B" creek, one of the tributaries of Little Wonder pond, at Horning's Mills, Ontario, is in its upper reaches a typical stony spring stream. It rises from several springs in a small cedar copse, flows out into a small pool in an old farmyard, then through an open stony channel 200 feet (60 metres) long, which is the typical "upper section" of this description. Leaving the farmyard it enters a wood, mostly of evergreens, flows for about 300 yards (270 metres), and is joined by a larger creek which had its origin in springs about a mile (1.6 km.) above. The combined streams flow out into a grassy glade beset with scattered elms and poplars. Here the current again quickens and enters the typical "lower section", distinguished from the upper by a higher and more variable temperature and a greater volume of flow. The two sections are compared in table 1. On July 24 there was a temperature difference between the two of 5.4° C. The highest temperature recorded during the season was 18.5° C. at 3.00 p.m. on July 9—a very hot day; it seems probable

TABLE 1. Physical and chemical features of a spring creek (B creek)

Place	Date 1928	Time	Average width (feet)	Average depth (feet)	Rate of flow (ft. per sec.)	Vol. of flow (cu. ft. per sec.)	Temp. °C.	pH.	Oxygen cc/l.	Oxygen p.p.m.	Oxygen Per cent. sat.
Springs	July 24	3.30 p.m.	....	....	....	....	7.3	7.4	6.3	9.0	81
Upper section ...	July 24	3.30 p.m.	4	0.4	1.3*	2*	10.4	7.6	7.4	12.2	100
Lower section ...	July 24	3.30 p.m.	10	0.6	1.3	7	15.8	8.0	6.5	10.7	99

*Estimated values.

that the absolute maximum would not exceed 20° C. The pH was less in the upper section than in the lower, and the oxygen content greater, though the water of both reaches had reached saturation in this respect. Both were rich in lime and carbonates, to an extent of 150 to 200 parts per million. The volume of flow of the upper section was nearly constant throughout the summer; that of the lower increased to double its normal value after a heavy rain. On such occasions the water became rather turbid. Both sections had a moderately rapid current, and a bottom of gravel or small stones.

Aquatic vegetation in the stony sections of B creek consisted only of lithophilous and clinging algae, and mosses such as *Fissidens*, *Fontinalis*, and *Hygrohypnum*.

Several collections of aquatic invertebrates were made in the stream. Characteristic organisms were the stonefly *Nemoura* and the caddis *Hesperophylax designatus*. Both of these are more abundant in the cold upper section than in the warmer stretch below, and are absent or rare in larger streams. In the following rather incomplete list, the letter U indicates that the organism in question was found in the upper section; L, in the lower section of the creek.

Turbellaria
- *Planaria*. L, occasional.

Oligochaeta
- Lumbriculidae. U, rare.

Hirudinea
- *Glossiphonia complanata*. U, occasional.
- *Nephelopsis obscura*. U, rare.

Ephemeroptera
- *Leptophlebia*. L, frequent.
- *Ephemerella* spp. L, frequent.
- *Baetis* spp. L, abundant.
- *Iron pleuralis*. U, frequent; L, occasional.

Plecoptera
- *Chloroperla*. U, frequent.
- *Alloperla?* L, occasional.

- *Leuctra*. U and L, occasional.
- *Nemoura* sp. (with gills at neck). U, frequent; L, occasional.
- *Nemoura* sp. (gill-less). U, frequent.

Trichoptera
- *Rhyacophila fuscula*. L, occasional.
- *Mystrophora americana*. L, frequent.
- Hydropsychidae. U, occasional; L, frequent.
- *Philopotamus*. L, abundant, in moss.
- *Stenophylax scabripennis*. L, rare, in slower pools.
- *Neophylax*, cf. *automnus*. L, occasional.
- *Hesperophylax designatus*. U, abundant; L, occasional. Larvae, prepupae, pupae and imagos were taken on June 7. On September 7 young larvae were common.

Diptera
- Chironominae. U and L, frequent.
- Tanypinae. U and L, occasional.
- *Simulium*. L, frequent.

Coleoptera
- *Helmis*. L, occasional.

Gastropoda
- *Gyraulus*, cf. *parvus*. U, rare.
- *Physella*. U, rare; L, occasional.

Fish. Three species of fish were found in B creek:
- *Cottus cognatus*. Rare. One specimen was taken 50 feet from the head of the creek.
- *Eucalia inconstans*. Rare in side pools of the lower section.
- *Salvelinus fontinalis*. Fingerling speckled trout were abundant in both the upper and lower gravel sections, and fairly common in the slower intermediate reaches. Adults were not seen in the shallow exposed rapids, but were common in a few deep sheltered pools.

A few small trout were obtained for study, and the analysis of their stomachs is presented in table 2. In early June the fingerlings were not yet large enough to utilize any part of the rich invertebrate fauna except the Chironomid larvae and pupae, and a few other small insects. By August 1 their percentage consumption of midges had been reduced by one-half, and the gap was filled by mayflies, caddis, beetles, and terrestrial insects. Three yearling trout taken at the same time consumed a mixture of insects, chiefly caddis larvae.

TABLE 2. Food of speckled trout in B creek

	Upper section	Lower section	Upper section	Intermediate section
Date taken	June 7	June 7	August 1-2	August 1-2
Number of stomachs examined	4	1	9	3
Average length in inches	1.36	1.84	2.28	4.83
Variation in length	1.25-1.50	—	2.06-2.69	3.62-5.44
Average volume of contents in cubic mm	16	19	71	290
Average number of Nematoda	0	0	+	3
Vegetable matter	—	—	+	5
Aquatic Insecta				
Ephemeroptera: Baetidae	—	—	19	5
Plecoptera	—	37	5	2
Trichoptera: Larvae and pupae*	—	—	11	35
Cases	—	—	—	9
Heteroptera: Corixidae	—	—	+	2
Diptera: Chironomidae	94	16	47	8
Simuliidae	—	—	2	8
Others	6	37	2	1
Coleoptera	—	—	8	8
Terrestrial Insecta**	—	10	6	14
Total surface food	0	10	18	19
Total bottom food	100	90	82	81

*Includes Polycentropidae, Hydropsychidae, *Hesperophylax designatus*, and other Limnephilidae.

**Includes Thysanura, Homoptera, Diptera, Coleoptera.

Note: In this and all subsequent tables of stomach contents, a figure indicates what per cent. of the total volume of contents is made up of the item in question, a cross (+) shows that the item comprised less than one-half of one per cent. of the total, a dash (—) that it was entirely lacking.

SANDY SPRING CREEKS

Tally-Ho creek, flowing into Peninsula lake, near Huntsville, Ontario, is typical of this class. It is a soft-water

stream, rising from springs in a wooded valley and flowing out into a swampy meadow. Its average width is three feet (1 metre), and volume of flow 1.1 cubic feet (0.031 cubic metre) per second in May. A water analysis, made at 10.00 a.m. on May 27, 1930, was as follows: temperature 7.0° C., pH less than 6.8, oxygen content 7.8 cc. per litre, 11.2 parts per million and 100 per cent. saturated, acid carbonate (HCO_3) 12 p.p.m. expressed as $CaCO_3$, free carbon dioxide 1.3 p.p.m. In summer, the volume decreases to 0.8 cubic feet (0.023 cubic metres) per second, and the temperature rises to about 20° C. on hot days.

In the sandy beds which constitute most of the bottom of the stream, the author was unable to detect any life whatever. The trout in these places must eat either terrestrial organisms, or the insects which cling to logs, *etc.*, in the water, or insects washed down from a stony bottom.

The fish observed in this stream were the speckled trout, and, in the lower reaches, the creek chub (*Semotilus atromaculatus*). None of the trout seen was over seven inches (18 cm.) long, although longer specimens are said to have been captured.

Small cold creeks with sandy bottom are not as common in southern as in northern Ontario, but, when they occur, they seem to be equally deficient in living organisms. Evidently the carbonate content of the water is not an important factor in determining the dearth of life. It is interesting to note that the same condition is prevalent in lakes. For example, Rawson (1930) has shown that in lake Simcoe sandy beaches are much less productive than those with stony, muddy, or weed-covered bottom.

MUD-BOTTOM SPRING CREEKS

Dogwood creek, a tributary of the Mad river in Grey county, Ontario, rises from springs, and for most of its course flows with gentle current through an evergreen swamp. When it emerges from the tall timber, its channel, low hung with *Myrica Gale*, meanders through a swale of small willows (*Salix* sp.) and *Cornus stolonifera* until it meets the larger trout stream (figure 2). At this point its average width is about five feet (1.5 metres), and depth two feet (0.6 metre). In early summer its volume of flow was 4.6 cubic feet (0.13 cubic metre) per second; in August this was reduced to 2.0 cubic feet (0.057 cubic metre) per second which low level it maintained up to the end of the following March. Soon after, the spring floods filled the channel and submerged the surrounding land to a depth of two feet; the flow on April 20 was 30 cubic feet (0.85 cubic metre) per second.

One effect of spring water on streams is to steady their temperature; they remain cooler in summer and warmer in winter than do rivers which lack its ameliorating influence. The highest figure recorded in Dogwood creek was 16.0° C., at 4.00 p.m. on a hot afternoon in July; the lowest was 2.2° C. at 10.15 a.m. on October 20. The oxygen content of the water (taken during the day) hovered near 90 per cent. of saturation throughout the year; the pH was between 7.7 and 7.8, except at flood time, when it dropped to 7.3. Its water was normally rich in lime and carbonates. Complete data on water conditions are presented in table 3.

The bottom of Dogwood creek was of rather firm mud in the channel, and softer silt along the borders. About half of this remained bare throughout the year; the remainder became grown up with *Radicula Nasturtium-aquaticum*, *Ranunculus circonatus?*, and a species of *Sparganium* with trailing submerged leaves. The first of these was most abundant and most characteristic; it preferred a rather slower current than the other two.

Collections of the invertebrate fauna were made throughout the year, on a mud bottom only, at a depth of one foot (0.3 metre). Analysis of these dredgings has revealed a very characteristic association, which is not only entirely different from that of stony or sandy creeks, but also bears little specific resemblance to the mud banks of the adjacent, but warmer, Mad river.

TABLE 3. Water characteristics of Dogwood creek

Date	Time	Current speed (feet per second)	Volume of flow (cubic feet per second)	Temperature °C.	Temperature °F.	pH.	Oxygen cc/l.	Oxygen p.p.m.	Oxygen Per cent. sat.
May 22, 1930	3.00 p.m.	0.8	4.6	16.5	61.5	7.8	5.5	7.8	86
June 17, 1930	12.15 p.m.	1.0	4.6	13.7	57.	...	6.1	8.7	91
July 7, 1930	4.00 p.m.	...	...	16.0	61.	...	6.0	8.6	92
August 16, 1930	3.30 p.m.	0.7	2.0	15.0	59.	...	6.5	9.3	98
September 4, 1930	5.15 p.m.	...	...	12.9	55.	7.7	6.3	9.0	90
October 20, 1930	10.15 a.m.	...	...	2.2	36.	7.8	8.7	12.4	96
March 22, 1931	4.45 p.m.	...	1.5?	3.7	38.5	7.7	7.5	10.7	92
April 20, 1931	2.50 p.m.	0.8	31.	13.0	55.5	7.3	5.8	8.3	88

Oligochaeta
 Tubificidae. Frequent.
Hirudinea
 Glossiphonia complanata. Occasional.
 Haemopis plumbeus. Rare.
 Nephelopsis obscura. Rare.
Crustacea
 Hyalella knickerbockerii. Abundant.
Ephemeroptera
 Hexagenia. Rare.
 Ephemerella temporalis. Rare.
 Leptophlebia. Occasional.
Plecoptera
 Leuctra. Rare.
 Nemoura. Rare.
Trichoptera
 Limnephilus. Rare.
 Halesus guttifer. Rare.
 Unknown Limnephilid. Occasional.
Diptera
 Simulium. Rare.
 Chironomidae (det. Johannsen)
  Procladius (group *adumbratus*). Occasional.
  Pentaneuria (*Ablabesymia*) (group *flavifrons*). Occasional.
  Cryptochironomus. Occasional.
  Others. Occasional.
 Culicoides. Occasional.
 Chrysops. Rare.
Coleoptera
 Hydroporus depressus. Rare.
Pelecypoda (det. Sterki)
 Pisidium overi. Frequent.
 Pisidium variabile. Occasional.
 Pisidium cf. *sargenti.* Occasional.
 Pisidium cf. *milium.* Occasional.
Gastropoda
 Physella integra. Frequent (det. Clench)
 Valvata sp. cf. *sincera.* Abundant.

The fish found were: *Salvelinus fontinalis, Cottus bairdii, Eucalia inconstans*, and a small minnow. Only trout were common. The specimens seen were chiefly fingerlings, which early in the year frequented the very shallow borders, often resting on the bottom. A few yearlings and two-year-olds were captured, but they were not very common. In the fall the stream is frequented by adult trout, journeying to the springs above.

The food of some of the fingerlings is listed in table 4. A small creek of this sort produces large quantities of the preferred food of the smallest trout—Entomostraca and Chironomid larvae—but its supply of medium-sized aquatic insects (such as *Baetis*) is less generous. Hence in mid-summer, many of the fingerlings desert the creek for the river below where mayfly nymphs, *etc.*, are commoner. Those which remain feed to a great extent at the surface of the water, taking a variety of terrestrial insects. Many of the common invertebrates of the stream, *e.g.*, Oligochaetes, leeches, most caddis larvae, *Pisidium, Physella*, and *Valvata*, are unavailable to small trout, by reason either of their large size or of their secretive habits.

HUMUS-BOTTOM SPRING CREEKS

When a spring creek flows with a gentle current through a deciduous forest, dead leaves accumulate on the bottom, and with other decaying vegetable materials, form a rich bed of humus. The invertebrate population of such creeks is often very great in numbers, though not especially varied. Needham and Lloyd (1930, p. 36) describe such streams as they are found near Ithaca, N.Y.: their fauna consists, in the typical leaf beds, of *Tipula abdominalis, Nemoura, Baetis, Leptophlebia*, and *Gammarus*, and on the more open silty bottom of the large caddis *Halesus guttifer, Sphaerium, Cordulegaster, Boyeria*, Gerridae, burrowing mayflies, and "a considerable variety of the lesser midges".

"Sahara" creek, one mile north of Oliphant beach, Bruce county, Ontario, is of this type. The country in which it rises consists of sand dunes mostly covered by a thick growth of beech and sugar maple. When examined on July 12, 1930, its volume of flow was 1.5 cubic feet (0.042 cubic metre) per second, and temperature 11.3°C. at 9.10 a.m. Its average width was four feet (1.2 metres), and depth eight

TABLE 4. Food of fingerling trout in Dogwood creek

	May 22, 1930	July 25, 1930
Number of specimens examined	10	3
Average length in inches	1.14	2.29
Variation in length	1.00-1.30	2.00-2.50
Average volume of contents in cubic mm.	4.8	35.
Average number of Nematoda	0	+
Vegetable matter	—	3
Entomostraca		
Cyclops	5	—
Canthacamptus	18	—
Ostracoda	4	—
Hyalella knickerbockerii	4	—
Aquatic Insecta		
Nymphs of Plecoptera	—	5
Larvae of Trichoptera	—	8
Simuliidae	3	—
Larvae and pupae of Culicidae	11	—
Larvae and pupae of Chironominae	35	15
Larvae of Tanypinae and *Culicoides*	12	—
Adult Coleoptera (*Hydroporus*)	—	31
Terrestrial Insecta		
Homoptera	—	4
Lepidoptera	—	2
Diptera	+	23
Coleoptera	—	4
Hymenoptera	—	5
Total surface food	3	38
Total submersed food	97	62

inches (20 cm.). The bottom was of sand covered by a light layer of silt with many leaves, sticks, bits of bark, *etc.*, and with logs frequently blocking the channel. The fauna was found to include an abundance of *Gammarus limnaeus*, *Pisidium idahoense* (det. Sterki), and Limnephilid larvae (not *Halesus guttifer*, however). Chironomid larvae and

Physella were occasional, *Limnephilus*, a Hydrophilid beetle, and a big *Tipula* rare. No fish were seen in the stream.

DRAINAGE CREEKS

Because of their high temperature and irregular water supply, drainage creeks are not suitable for most fish, and have not been studied.

SLOW HARD-WATER TROUT STREAMS: THE MAD RIVER

Streams of this type appear to be rare in Ontario, because in most regions of calcareous sedimentary rocks, the land has been cleared of vegetation to such an extent that any large slow stream is hot enough to be classed among the "warm rivers". The one example studied by the author —the Mad river—is a rather famous trout stream.

I. Physiography

The Mad river is situated in Gray and Simcoe counties, Ontario, in longitude 80° 15′ W. and latitude 44° 20′ N. Its total length from the source to its confluence with the Nottawasaga river is about 40 miles (64 km.). Rising in an evergreen swamp a mile north-east of Badjeros, it flows north and east seven miles (11 km.) to Singhampton; turning south-east it runs for seven miles, and is joined by the Noisy river, an important tributary of nearly equal volume. The combined streams continue south and east, passing through Creemore, then turning northward to join the Nottawasaga river 20 miles (32 km.) from the point where the latter stream empties into Georgian bay.

The section here studied is in the upper reaches of the river, six miles (10 km.) from its source. It is one and one-half miles (2.4 km.) long, extending from a point on the gravel road a mile south and west of Singhampton, down to the glen half a mile east of that town. At its lower end is a mill dam, which has flooded the banks for some distance

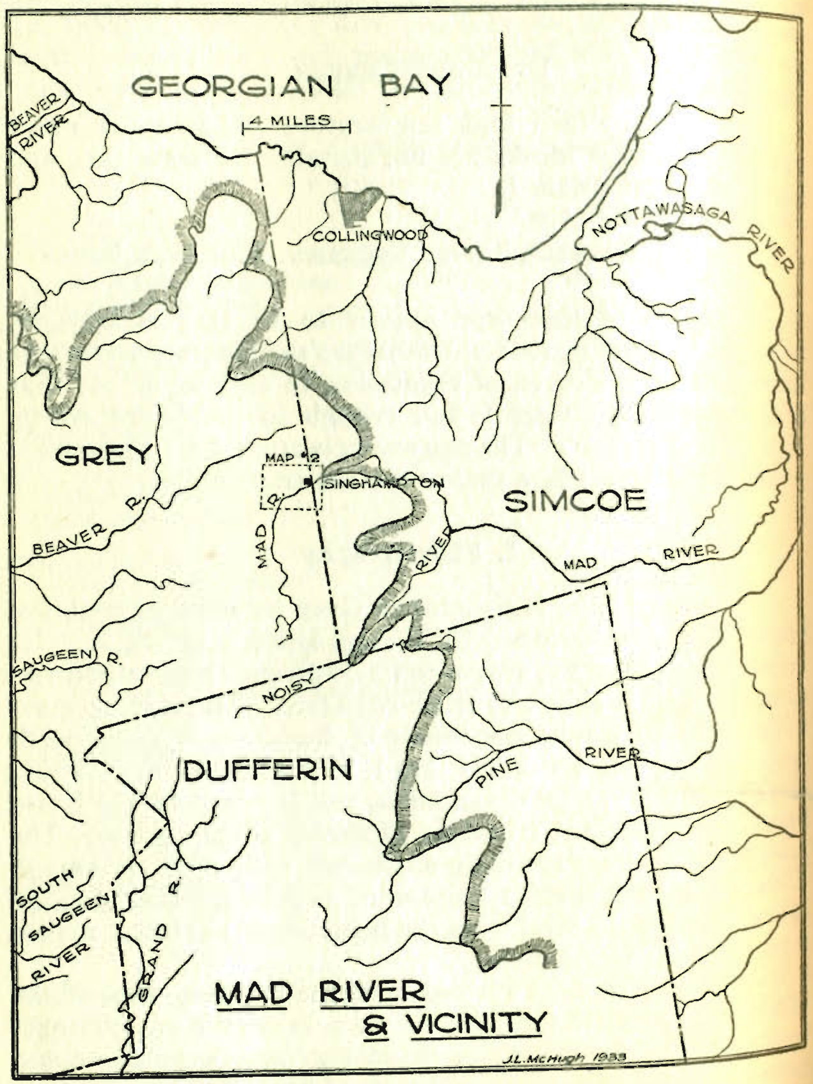

Figure 1. Map of Mad river and vicinity

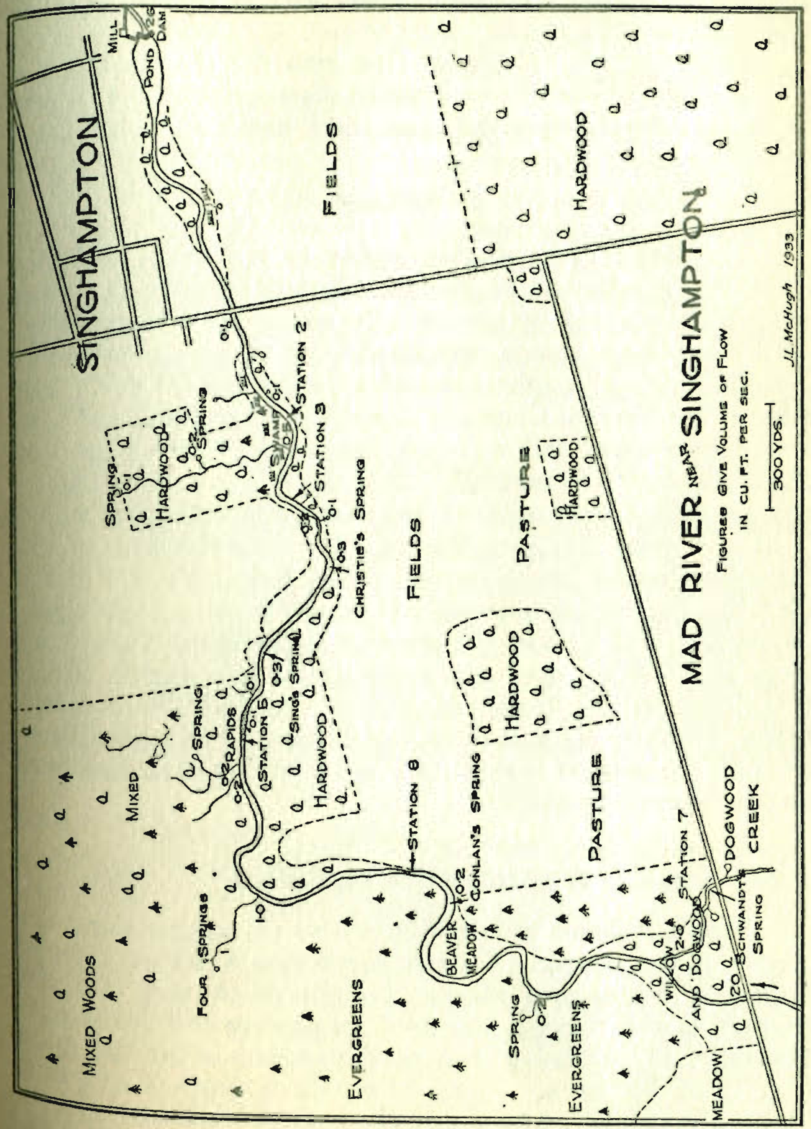

Figure 2. Map of Mad river near Singhampton

back. The mill has been in operation for at least 75 years. The extent of the river and of the section studied is illustrated in figures 1 and 2.

Several small tributaries flow into the river along the course of the mile and a half under observation. The largest of these, entering near the upper end, has been called Dogwood creek.

1. Geology

The basic rock of this region is the hard Lockport dolomite, a sediment of Middle Silurian age. It is almost completely covered by glacial drift, consisting of sandy clay, with many large stones, mostly of lime, though a few are of igneous origin, brought from afar during the ice age. The edge of the Niagara Cuesta is close to Singhampton, and over it the river must fall to reach the plain below—a drop of about 600 feet (180 metres). In doing this it has cut a steep narrow valley three miles (5 km.) long, the bottom of which is at one point 300 feet (90 metres) below the level of the table-land immediately above. Along the north side of the glen the uppermost massive layers of dolomite form a perpendicular cliff 50 feet (15 metres) high. In the valley, the river runs swiftly over a stony bottom; this section is distinguished as the "lower Mad river", and will be discussed below. Above the mill dam, which marks the beginning of the fall, the current is slow; this is the section described here and is referred to simply as "Mad river".

2. Surrounding Vegetation

Figure 2 shows the distribution of vegetation along the course of the stream. On the north-west a forest extends unbroken for several miles. To the south and east the country is well cleared, and used for pasture and field crops. However, the actual course of the stream is for the most part lined by trees. Near its southern (upper) end is a "beaver meadow"; a swale of *Carex* marking the site of an old beaver pond. The forest consists of the common deciduous hardwoods on most of the high ground, mixed with black ash, white elm, cedar, or even tamarack in moister locations, as at the river's edge. Pine seems to have been rare, even in early days; a few stands of balsam and white spruce occur on sandy knolls.

The Mad river has suffered less from deforestation of its headwaters than have many Ontario streams. Many hundred acres of land just south of the area under study are covered by damp forests of cedar, balsam, spruce, and tamarack; the effect of this large area of bush is to retain the water, lessen the spring floods, and give permanence to the many springs of the region. Certainly, however, enough of the land has been cleared to make the river's volume of flow higher in the spring and lower in the summer than was formerly the case.

3. Climate

Singhampton is situated in the highlands of south-western Ontario, at an altitude of about 1,500 feet (460 metres). This has a rather important effect on the climate: *Temperature.* Not extreme. The maximum summer temperature in 1930 was 86° F. (30° C.), while the nights were always cool. The earth freezes and is covered with snow some time in December; it does not thaw until the latter part of March. Winter minimum temperatures would probably be −25° to −40° F. (−32° to −40° C.).

Wind. Proximity to lake Huron may account for a very noticeable tendency toward strong steady westerly winds, especially in the winter and early spring.

Rainfall. The average precipitation in the Mad river region is fairly constant throughout the year, at about three inches (7.6 cm.) per month. It is least in August and greatest in December. In every month of 1930, considerably less than the usual amount of moisture fell, culminating in a drought during August and September. Table 5, showing precipitation at Eugenia, a town 13 miles (21 km.) west of

TABLE 5. Precipitation at Eugenia, Ontario, in inches*

		Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	De.
Average for 15 years	Rainfall	0.4	0.4	1.6	2.0	3.0	3.5	3.3	2.2	2.9	2.9	2.0	1.0
	Snowfall	26.7	22.3	10.7	3.6	1.7	...	...	...	0.1	3.6	14.5	24.8
	Total**	3.0	2.6	2.7	2.3	3.1	3.5	3.3	2.2	2.9	3.3	3.4	3.5
1930	Rainfall	0.4	0.7	0.3	0.9	2.1	2.7	1.0	0.2	0.6	0.3	0.1	0.2
	Snowfall	13.5	12.5	13.5	4.0	...	...	...	...	...	18.0	9.0	12.5
	Total**	1.7	1.9	1.6	1.3	2.1	2.7	1.0	0.2	0.6	2.1	1.0	1.4

*These figures are for the years 1916-30. **Ten inches of snow equals 1 inch of rain.

Singhampton and at nearly the same elevation, has been supplied through the courtesy of Dr. J. Patterson, director of the Canadian Meteorological Service.

4. Physical Features of the River

Contour and bottom. An ideal cross-section of the Mad river in the section under consideration would be as in figure 3. It consists of a central channel (B) and on each side a

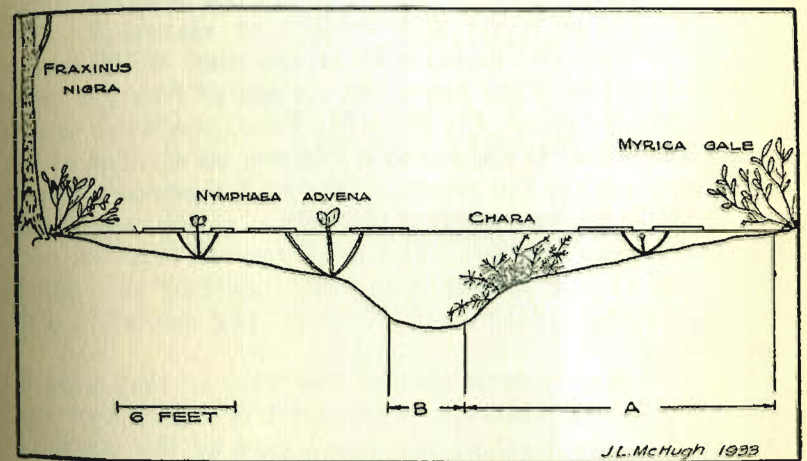

FIGURE 3. Cross-section of Mad river

shallow flat (A). The bottom of region A is of mud, and supports a flora of mud-loving plants. Its depth is 0 to 3.5 feet (1.2 metres). The central region B has an average depth of about four feet, its bottom is of "marl gravel"—small bits of limestone about one cm. in diameter; it may hold a profuse growth of aquatic plants, but is often bare. Logs and sticks are abundant, chiefly in the shallow area, and soon become lime-encrusted.

This typical section is fairly well represented at station 3 or station 8. (The location of the various stations is shown in figure 2.) Variations are of three sorts: first, an increase in the width and depth of the channel, chiefly at bends, which form pools up to nine feet (2.7 metres) in depth, as at station 2; second, an increase in the extent of the shallow region, best represented by the broad flooded borders of the river near the mill dam; third, a decrease in depth of the channel and absence of mud flats, with which is correlated an increase in current speed and a bottom of larger stones—*i.e.* an approach to the rapid water conditions seen in the lower Mad river. Station 5 is of this type.

Rate and volume of flow. Table 6 shows the determinations made of current speed and volume at station 5. The greatest volume was determined at the time of the spring flood in 1931; in other years the volume of flow has risen far above this figure. On the other hand, the lower figures are probably near the absolute minimum, on account of the extreme dryness of the season. Station 5 represents almost the maximum current speed in this section of the river during the time it was studied. The more typical sections, such as station 3, had speeds somewhat less than this figure, averaging perhaps 0.2 feet (0.06 metre) per second in July and August.

The variations in volume of flow were accompanied by corresponding variations in water-level of about two feet. In addition, the level of the lower part of the stream is controlled by the stop logs of the mill dam. Its influence was felt up-stream past Christie's spring to the first shoal, a distance of five-eighths of a mile (one km.). This section was subject to daily variations in level of about a foot, during the summer, due to the intermittent flow of water through the mill. Hence all levels in this section have been referred to a standard, which is taken as the level on May 20, 1930.

Water supply. Most of the water in this section of the stream comes from the upper reaches, but added to this is the flow of the small spring feeders and of springs in the river bed. Each of these has been marked on figure 2, along with its estimated volume of flow on July 25, 1930. It will be

TABLE 6. Physical and chemical characteristics of the Mad river at stations 3 and 5

			Rate of flow (feet per second)	Volume of flow (cubic feet per second)	Temperature		pH.	Oxygen		
					°C.	°F.		cc/l.	p.p.m.	Per cent. saturation
Station 3	May 21, 1930	3.00 p.m.	...	...	13.0	55.5	7.8	7.5	10.7	103
	June 9, 1930	12.00 noon	...	...	14.5	58.	7.8	7.0	10.0	100
	July 4, 1930	2.30 p.m.	...	...	17.6	63.5	...	7.5	10.8	114
	July 25, 1930	3.00 p.m.	...	...	21.0	70.	...	5.3	7.6	86
	August 16, 1930	5.10 p.m.	...	...	19.8	67.7	...	7.0	10.0	111
	September 4, 1930	12.30 p.m.	...	...	14.7	58.5	7.8	5.4	7.7	77
	October 20, 1930	3.45 p.m.	...	...	4.2	39.5	7.8	8.8	12.5	100
	November 20, 1930	4.00 p.m.	...	...	8.8	48.	...	...	...	...
	January 17, 1931	2.00 p.m.	...	...	0.8	33.5	7.5	6.9	9.8	71
	March 21, 1931	3.40 p.m.	...	...	0.4	33.	7.7	8.0	11.4	82
	April 19, 1931	2.10 p.m.	...	...	11.3	52.5	7.3	6.3	9.0	87
Station 5	May 17, 1930	1.00 p.m.	1.3	65	12.0	53.5	7.8	7.0	10.0	94
	June 11, 1930	3.00 p.m.	...	...	14.5	58.	...	...	...	...
	July 22, 1930	4.15 p.m.	0.5	25	22.0	71.5	...	...	...	...
	September 3, 1930	5.00 p.m.	0.3	12	19.2	66.5	8.0	7.0	10.0	110
	October 20, 1930	12.00 noon	0.4	13	2.2	36.	7.7	8.4	12.6	90
	January 18, 1931	12.00 noon	...	...	0.9	33.5	7.6	8.0	11.4	83
	March 21, 1931	12.15 p.m.	...	8	0.2	32.5	7.7	7.5	10.7	79
	April 20, 1931	11.30 a.m.	1.7	250	10.8	51.5	7.4	5.6	8.6	78

seen that of a total flow of 26 cubic feet (0.74 cubic metre) per second at the mill, about 20 cubic feet per second comes from the main stream, and six cubic feet per second from feeders. Springs are numerous throughout the region, but not all are permanent.

II. Physical and Chemical Properties of the Water

1. Temperature

A recording thermometer was mounted at station 2, with its bulb lying in the shade of a small log at a depth of four feet (3.3 metres) on the edge of the channel zone. It was in action almost continuously from June 13 to September 7. Figure 4 is an example of one of the records. From these graphs and the daily record of maximum and minimum air temperature, we may draw the following conclusions:

a. The water reaches its maximum temperature between 4.30 and 6.00 p.m. It averaged 5.30 p.m. for the week ending June 28, and 5.00 p.m. for the first week in September. On cloudy days the maximum is reached one and a half hours earlier than on clear days.

The water drops to its minimum temperature between 7.00 and 9.00 a.m., averaging 7.45 in June and 8.30 in September, on bright days. On dull days the temperature may continue to drop until noon or even until 3.00 p.m.

Although no definite figures are available, it is clear that these maxima and minima lag behind the corresponding air temperatures. In summer the minimum air temperature is reached about 5.30 a.m., and the maximum about 3.30 p.m. Figure 5 illustrates this lag graphically.

b. The factor most influential in warming the water during the day is the direct radiation of the sun, rather than the temperature of the surrounding air. This is illustrated in figure 4; July 26 was the only dull day in the week, the others had a sky nearly free of clouds. Even more striking is figure 6A, in which maximum air and water temperatures

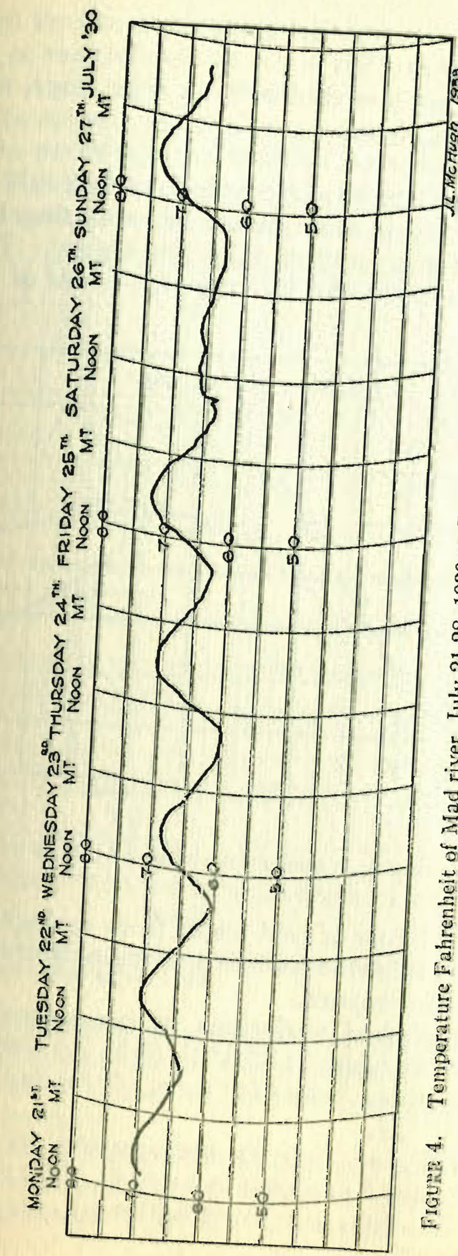

FIGURE 4. Temperature Fahrenheit of Mad river, July 21-28, 1930. Corrected for constant error of thermometer.

are plotted together. On five different occasions the water temperature rose *above* that of the air, in one case as much as 6° F. (3.3° C.) This occurred only on clear days, when the sun's radiation was strong.

The relation between minimum temperature of air and water, shown in figure 6B, is less obvious, but it is probable that air temperature is more active in regulating the lower extreme of water temperature than the higher. The other factor tending to lower the water temperature of the river

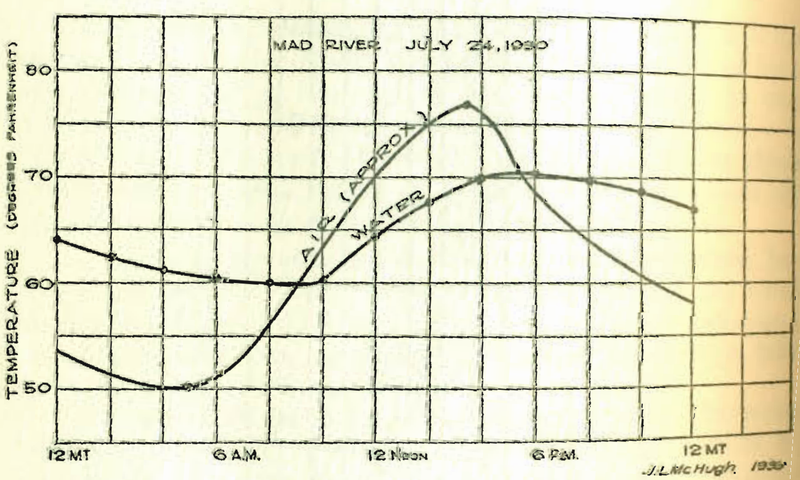

FIGURE 5. Daily fluctuation in temperature of air and water at the Mad river

is, of course, the influx of cold water from springs and creeks. On one occasion this was sufficient to cause a drop below the minimum air temperature.

In winter diurnal variations in temperature are very slight, as shown in figure 7; 33.6° F. (0.9° C.) was the highest temperature recorded, while for most of the day it remained at 32.0° F. (0.0° C.).

c. Seasonal variation in temperature in the section near stations 3 and 5 is shown in table 6. The readings were taken on a bright day, usually at 3.30 p.m.

2. Dissolved Oxygen

The water of a river would tend to be saturated with respect to oxygen at all times, were it not for the following factors:

a. Variation in atmospheric pressure; solubility of oxygen increases with increase in pressure.

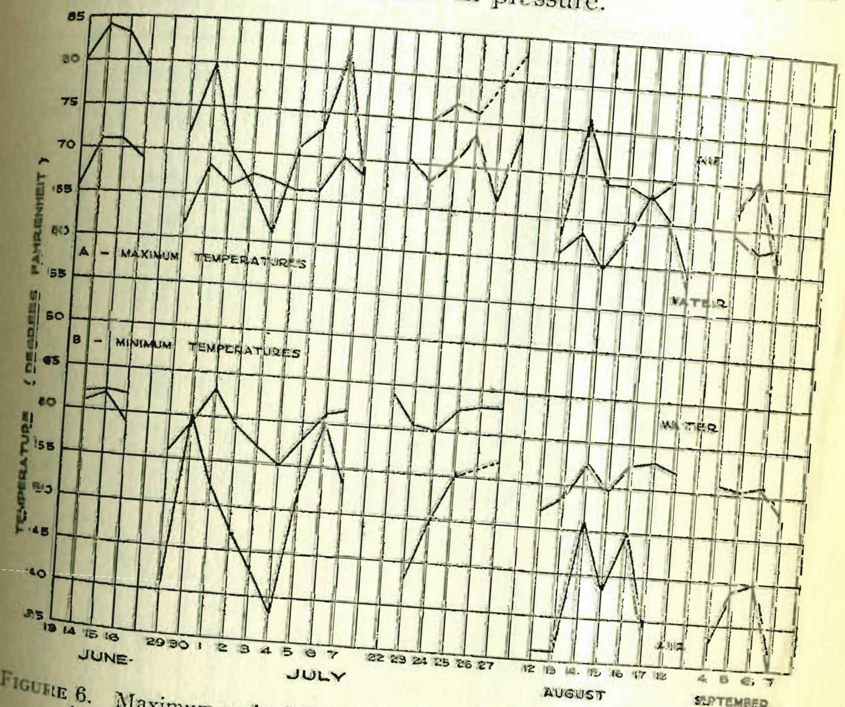

FIGURE 6. Maximum and minimum temperatures of air and water at the Mad river, June-September, 1930

b. Variation in temperature of the water; solubility decreases with increase of temperature.

c. Influx of water of different oxygen content from springs or elsewhere.

d. Photosynthetic activity of green plants, which tends to increase the amount of dissolved oxygen; this occurs only in the presence of the sun's radiation.

e. Respiratory activity of plants and animals of all sorts, which tends to decrease the amount of dissolved oxygen; this continues at all times, but during the day its effect upon the oxygen content of the water may be obscured by the reverse process, plant photosynthesis.

Where water is in contact with the atmosphere, there is an exchange of gases, which counteracts the action of these factors and tends toward saturation. In a slow stream like the Mad river, this process is comparatively weak, and consequently the water is often supersaturated with respect to oxygen by day, and unsaturated by night. Below important falls or long rapids, the water of a river is usually saturated with respect to oxygen both day and night. Diurnal

TABLE 7. Diurnal variation in water conditions of the Mad river at station 2

Date	Time	Temperature		pH.	Oxygen		
		°C.	°F.		cc/1	p.p.m.	Per cent. sat.
1930	8.30 a.m.	14.8	58.7	...	4.5	6.4	64
August 16	12.30 p.m.	16.6	61.9	...	5.8	8.3	86
"	5.15 p.m.	19.8	67.7	...	6.4	9.1	101
"	8.40 p.m.	18.9	66.0	...	7.0	10.0	110
"	12.30 a.m.	17.4	63.4	...	6.0	8.6	91
August 17	4.30 a.m.	15.6	60.0	...	4.7	6.7	68
"	7.15 a.m.	15.0	59.0	...	5.0	7.1	72
"							
1931	8.15 a.m.	0.0	32.0	7.7	7.0	10.0	69
March 23	10.15 a.m.	0.2	32.5	7.7	7.5	10.7	73
" 21	12.30 p.m.	0.4	33.0	7.7	...	....	..
" 22	3.40 p.m.	0.4	33.0	7.7	8.0	11.4	78
" 21	5.30 p.m.	0.6	33.0	7.7	8.4	12.0	81
" 22	9.35 p.m.	0.0	32.0	7.7	7.8	11.1	76
" 21	12.15 a.m.	0.0	32.0	7.7	7.3	10.4	71
" 22							
	10.00 a.m.	8.4	47.2	7.3	5.9	8.4	77
April 19	2.10 p.m.	11.3	52.3	7.3	6.3	9.0	87
"	5.35 p.m.	12.6	54.6	7.4	6.1	8.7	87
"	8.00 p.m.	12.2	54.0	7.4	5.9	8.4	83
"	11.15 p.m.	11.4	52.6	7.4	5.5	7.9	77
"	6.30 a.m.	9.5	49.1	7.2	5.3	7.6	71
April 20	9.15 a.m.	9.8	49.7	7.3	5.5	7.9	74
"	12.20 p.m.	11.5	52.7	7.3	6.0	8.6	84
"							

variation of the oxygen content of the water in August and March is shown in table 7 and illustrated in figures 7 and 8.

In summer the time of maximum oxygen content follows that of maximum temperature by about two hours, *i.e.* at 8.00 p.m., while the time of minimum oxygen content occurs about three hours earlier than the minimum temperature, at 5.00 a.m. It is interesting also to note that

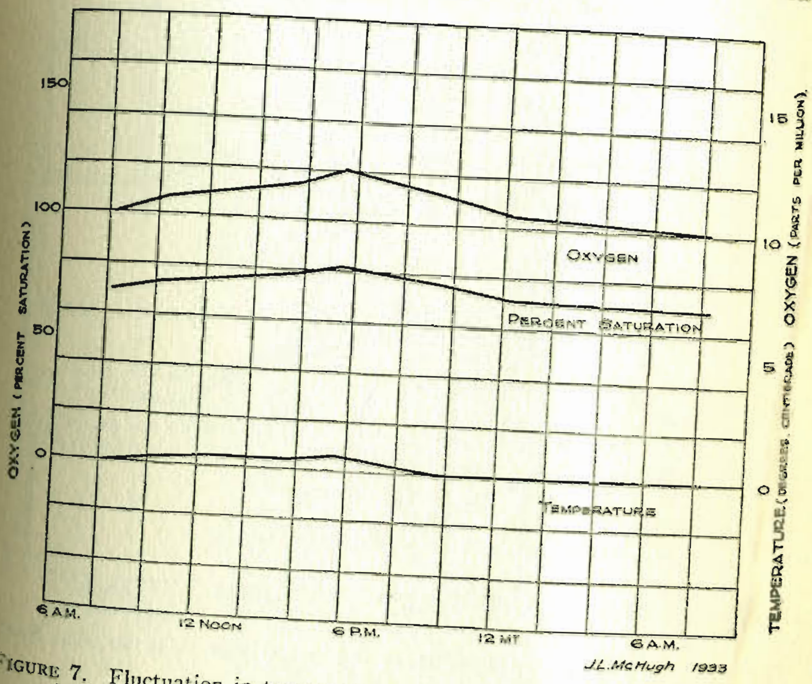

FIGURE 7. Fluctuation in temperature and oxygen content of the Mad river, March 21-23, 1931

from 5.00 p.m. to 10.00 p.m. the water was supersaturated with oxygen, this reaching 110 per cent. about eight o'clock in the evening. Determinations made on other occasions showed even higher supersaturation. In this slow and fairly deep section of the river, the principal agents in aerating the water are green plants. The effect of the sun's radiation on the photosynthetic activity of plants becomes apparent earlier in the morning and continues later in the evening than its effect on the water temperature.

In winter, the processes of respiration and photosynthesis are retarded by the low temperatures; hence the amount of oxygen dissolved in the water varies much less than in summer, only between 10.0 and 12.0 parts per

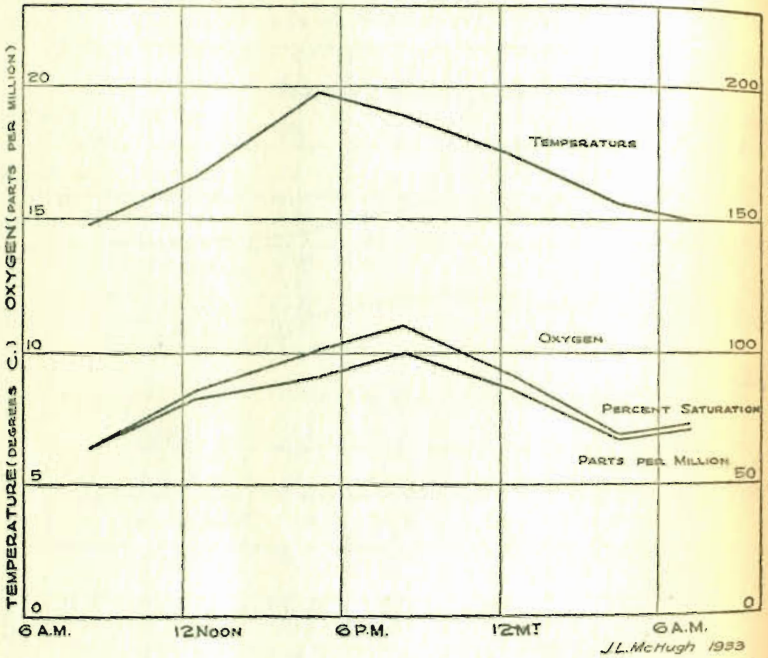

FIGURE 8. Fluctuation in temperature and oxygen content of the Mad river, August 16-17, 1930

million. The peak is reached about 6.00 p.m., and the minimum probably about 7.00 a.m.

The seasonal variation in oxygen content is shown in table 6 and figure 9. Most, but not all, of the readings were taken about 3.00 p.m., and when varying weather conditions are taken into account, it is obvious that these determinations cannot be very exactly representative of the month in which they were taken. Nevertheless, on the basis of these and

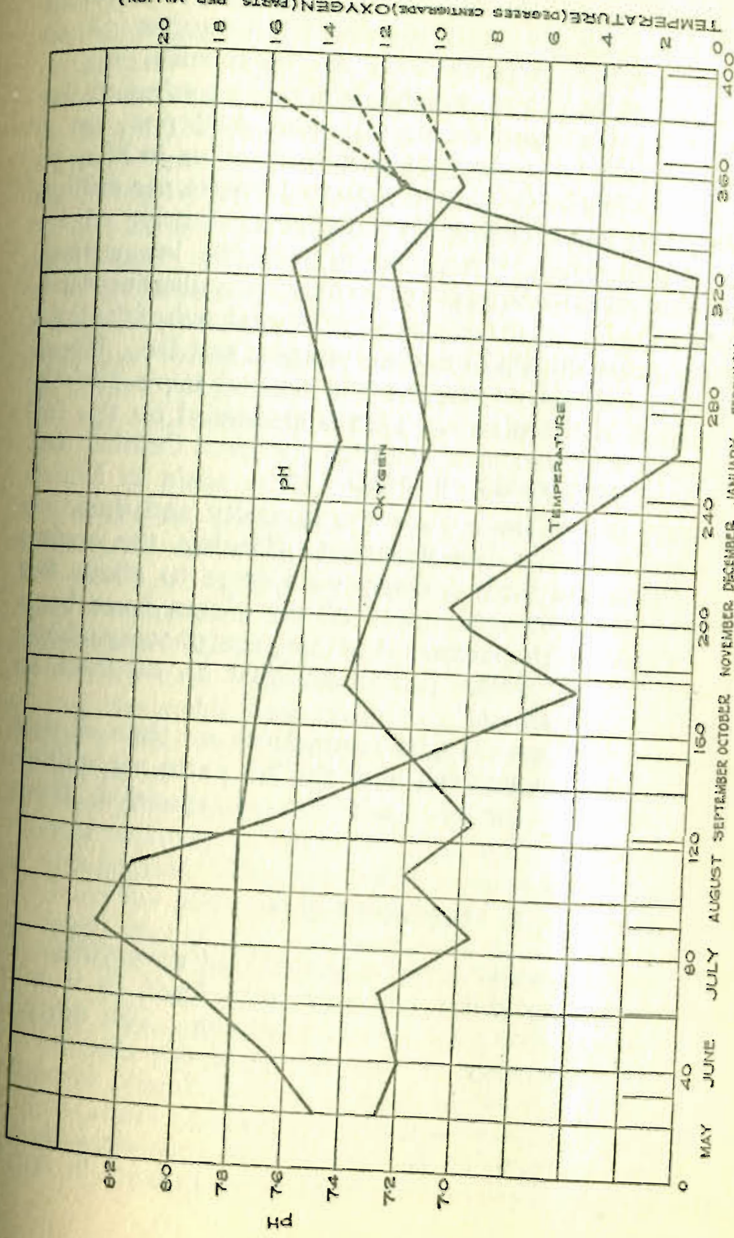

FIGURE 9. Seasonal variation in temperature, pH, and oxygen content of the Mad river, 1930-1931

other observations, the seasonal tendencies might be accounted for as follows: from May to December plant photosynthesis is more than sufficient to saturate the water with oxygen, with the result that the oxygen content is controlled by temperature. Considering the value at 3.30 p.m. on a bright day, it falls from about 11 parts per million in May to 9 parts per million in July, then rises to 13 parts per million when the water has cooled again in October. During winter respiratory processes are retarded only by the lower temperature; photosynthesis, on the other hand, may also be retarded by the shortening of the day and by the weakness of the light which penetrates the thick mantle of snow and ice. Hence the amount of dissolved oxygen will depend more directly on the output of the plants. This is evidenced by the fall of the oxygen with decreasing sunlight between October and January from 12.5 to 9.8; and by its rise again in March to 11.4 parts per million, when the intensity and duration of the solar radiation has increased. During the spring flood, in April, the oxygen drops once more to about 9.0 parts per million, because many of the plants have been swept away from the stream bed and the photosynthetic activity of the remainder is not sufficient to saturate so large a volume of water.

On one point we may be assured: at no time of day or year does the amount fall near the 2.5 parts per million minimum required for the existence of speckled trout (Gutsell, 1929).

3. Carbon Dioxide

The carbon dioxide content of the Mad river (table 8) was quite low throughout the year. On April 19 it was greater in the morning than in the evening. The diurnal changes would probably be the reverse of the changes in oxygen content, *i.e.* an increase in carbon dioxide at night owing to respiration of organisms of every kind, and a decrease by day resulting from the photosynthetic activity of green plants. Carbon dioxide is never present in large

quantities in the stream, because any excess combines with the abundant lime of the stream bed to form a soluble acid carbonate. Conversely, the carbon dioxide content is not reduced to zero by the assimilating plants, because many of them are able to free the carbon dioxide from this combination and use it in their metabolism, depositing the normal carbonate either in their own tissues (*Chara*), or on the surface of their stems and leaves (*Potamogeton*), or on sticks and stones of the river bed (some microscopic algae). In weed-filled ponds, particularly those containing much *Spirogyra*, carbon dioxide is often reduced to zero on bright summer days, and streams flowing from such ponds may be alkaline to phenol phthalein, *i.e.* contain normal carbonates. Such was the case below the mill pond on the Noisy river (table 8).

4. Dissolved Solids

Titration with methyl orange revealed the presence of large quantities of acid carbonate in the Mad river (nearly 200 parts per million expressed as $CaCO_3$) and a rough test with soap solution showed a high proportion of calcium and magnesium (270 parts per million as $CaCO_3$). These quantities were reduced to one-half of their normal value during the spring flood (table 8). The limited data available indicate that the withdrawal of carbon dioxide and precipitation of normal calcium carbonate during the course of plant photosynthesis are not sufficient to cause significant diurnal variation in the acid carbonate content of the water of this stream. The low value in spring is, of course, the result of the influx of a large volume of melted snow. It is probable that at this season much of the lime precipitated on the stream bed during summer is redissolved and carried away. The net result over a period of years is, however, a gradual accumulation of carbonate, which forms the "marl-gravel" bottom of the stream. In the Pine river the author has seen stones up to four inches in diameter, formed by the addition of concentric layers of precipitated lime about a small stick or pebble; such stones crumble easily in the hand.

5. Hydrogen-ion Concentration

Greenfield (1920) has shown that the carbon dioxide content, acid carbonate content, and hydrogen-ion concentration of natural waters are connected by the following formula:

$$(H^+) = \frac{4.0 \times CO_2 \times 10^{-7}}{(HCO_3^-)} + 1 \times 10^{-8}$$

where (H^+) is the hydrogen-ion concentration, in grammes per litre, CO_2 is the carbon dioxide content, expressed as parts per million of CO_2, (HCO_3^-) is the bicarbonate content (or "alkalinity") expressed as parts per million of $CaCO_3$. This relationship he has more conveniently expressed in the form of a nomogram published by Shelford (1925). From these calculations we may deduce that:

(1) the pH of a river will decrease (become more acid) with increase in carbon dioxide content;

(2) the pH of a river will increase (become more alkaline) with increase in bicarbonate content;

(3) if the pH of a river is greater than 8.0 it contains no free carbon dioxide;

(4) if the pH of a river is less than 8.0, it in all probability contains some free carbon dioxide. (Free mineral acids have the same effect, but are not found in unpolluted waters.)

The large proportion of acid carbonate in the Mad river is responsible for the rather low hydrogen-ion concentrations (high pH) recorded throughout the year (tables 6, 7, 8). In summer the pH ranged from 7.8 to (rarely) 8.0, but did not exceed that figure, as it often does in ponds (Ricker, 1932b). The lesser values recorded during winter (7.5 in January and 7.7 in March) are probably the result of an increased carbon dioxide content at this time, which in turn is the result of the decreased photosynthetic activity, as explained above. At the time of the spring flood, the alkalinity of the water is cut in half, and the pH has the correspondingly low value of 7.4.

TABLE 8. Analyses of spring and river waters. Acid carbonate, normal carbonate, and hardness are expressed as parts per million of calcium carbonate ($CaCO_3$)

Body of water	Date	Time	Temperature °C.	Temperature °F.	pH.	Oxygen cc/l.	Oxygen p.p.m.	Oxygen Per cent. sat.	Acid carbonate (HCO_3)	Normal carbonate (CO_3)	*Free carbon dioxide (CO_2) p.p.m.	Hardness Drops of soap sol.	Hardness p.p.m.
Mad river, near source	June 11, 1930	....	12.0	53.5	7.6	7.8	11.2	105	180	0	2.	12.	200
Mad river, station 2	June 9, 1930	9.15 a.m.	12.8	55.	7.8	7.4	10.6	101	193	0	3.5	16.	270
Mad river, station 2	March 23, 1931	8.15 a.m.	0.0	32.	7.7	7.0	10.0	71	187	0	0.7	16.	270
Mad river, station 2	April 19, 1931	10.00 a.m.	8.5	47.2	7.3	5.9	8.4	77	97	0	2.2	6.	100
Mad river, station 2	April 19, 1931	8.30 p.m.	12.2	54.0	7.4	5.9	8.4	83	100	0	1.1	6.5	110
Dogwood creek	April 20, 1931	2.50 p.m.	13.0	55.5	7.3	5.8	8.3	82	120	0	...	7.5	130
Noisy river	June 11, 1930	....	16.0	61.	8.0	7.8	11.1	114	178	16	0	14.	240
B. N. spring	June 13, 1930	....	6.5	43.5	7.1	2.6	3.7	31	189	0	7.	14.	240
B. N. spring	March 22, 1931	10.30 a.m.	7.5	45.5	7.1	3.4	4.9	41	187	0	7.	17.	290
B. N. spring	April 21, 1931	10.45 a.m.	5.8	42.5	7.2	4.7	6.7	59	135	0	4.4	9.	150

*See p. 46.

Diurnal variations in pH could not be certainly detected during the summer nor in March, owing to the buffer action of the acid carbonate. In April, when the last named was less abundant, the pH rose to 7.4 during the day and fell to 7.2 at night.

It may be noted here that the author has found no very close agreement with Greenfield's formula in the CO_2, HCO_3, and pH determinations he has made, owing perhaps to faulty technique in titrating for carbon dioxide. The figures given for carbon dioxide concentration in table 8 should be compared only among themselves.

6. Springs

Springs are somewhat different from the main stream in the physical and chemical properties of their waters. They probably show no significant diurnal variation in these respects. The peculiar characteristics of spring water as compared with the river would seem to be: temperature low and nearly constant at about 6.5° C., low oxygen content of about four parts per million, low pH—7.1, and a high carbon dioxide content. As the water flows away from the spring, it quickly gains oxygen, and more slowly loses carbon dioxide and rises in temperature. Many springs, however, have an oxygen content much higher than the above, sometimes as much as ten parts per million. Seasonal variation, in the case of B. N. spring (figure 2) was evident chiefly in temperature and carbon dioxide content, as shown in table 8. The temperature was lowest in April at the time of the floods, and the highest recorded was during the winter. No readings were taken at midsummer, however. It would seem that in spring the flood waters enter the spring, lowering its temperature, increasing its oxygen content, and decreasing its carbon dioxide content, alkalinity, and hardness. The effect of this admixture does not last more than a month.

Some animals appear to be susceptible to the peculiarities of spring water. Trout congregate on the three riverbed springs of the Mad river to some extent during summer, and very noticeably during the spawning season—probably a temperature reaction. *Gammarus* was not found in the Mad river, nor yet in its tributary, Dogwood creek, except in one situation in each stream, where spring water was coming up from below.

III. Aquatic Vegetation

1. Emergent Littoral Plants

In some places, typical woodland or pasture flora extends down to the bank of the river, and gives way at once to the aquatic forms. Usually, however, the shore area is marked by a distinct littoral association of plants, some of which are partly submerged at all seasons, some during high water only. The more important, in order of their occurrence from the land toward the water, are as follows. (The letter following the name of a plant indicates how common was its occurrence: A—abundant, F—frequent, O—occasional, R—rare, in descending order of magnitude.) Mr. R. F. Cain, of the University of Toronto, has assisted in making the determinations.

Cornus stolonifera. A.

Myrica Gale. A, the commonest plant of the shore region. Like the preceding, it forms dense tangles at the water's edge.

Carex spp. F, various species of sedge are abundant in the "beaver meadow" but are found only in scattered patches elsewhere.

Phalaris arundinacea. O, forms clumps of "marsh grass" at intervals along the lower stretches of the stream.

Eleocharis spp. R, found rarely as an outlier of *Phalaris* or *Carex*.

The above plants were submerged only in the spring. Those to follow grew with stems in the water throughout the summer.

Equisetium fluviatile. R, seen commonly near station 8.

Sparganium sp. R, the emergent form of this reed was not common.

Sagittaria latifolia. O.

Radicula nasturtium—aquaticum. O, common in some parts of the beaver meadow section. It might equally well be classified with the true aquatic plants.

2. True Aquatic Plants

About nine-tenths of the total bottom area of the stream provided anchorage for various sorts of aquatics. The bare tenth was of three types: (*a*) parts of the channel marl; (*b*) muddy borders where the plants were killed by summer fluctuations in water-level; and (*c*) deeper mud banks whose vegetation had been washed away by the spring floods.

Plants of the mud flats

Nymphaea advena. A, although perhaps strictly speaking an emergent species, this is characteristic of the zone of true aquatics. It was the most abundant plant of the mud flats in the slower parts of the river.

Chara sp. A, grew in all situations up to a depth of five or six feet (two metres): common in all parts of the river. It apparently gives way to the more deeply rooted *Nymphaea*.

Ranunculus circonatus (?). O, the white water-crowfoot resembled *Chara* in habit but was much less common.

There was a reciprocal relation between the distribution of the last two plants, and the muddiness of the bottom. While the plants preferred a soft substratum, their tangled stems were themselves efficient collectors of silt, so that the muddy areas encroached upon the comparatively bare marl.

Plants of the central channel

Hippuris vulgaris. O.

Potamogeton natans. R.

Sparganium sp. F.

Sagittaria sp. O.

Potamogeton amplifolius. F.

These five were characteristic of the marl of the channel. Their roots did not collect mud as did the above forms, so that the water flowed through them comparatively rapidly. The first three were almost confined to the reaches above station 5; the last two were also seen in the slower reaches below. Both the *Sparganium* and the *Sagittaria* were not of the typical upright form, but had linear and flexible leaves which waved in the current. Absence of fruiting bodies made specific determination impossible.

Mosses. Submerged logs were often covered with mosses, especially if they stood out from the bottom.

Algae. No particular study was made of the distribution of algae other than *Chara*. Large filamentous forms occasionally attracted notice on the bottom, and, with diatoms, appear in the food of some fish.

IV. Aquatic Invertebrates

1. List of Species

Oligochaeta

Tubificidae. Occasional.
Lumbriculidae. Rare.

Hirudinea

Helobdella stagnalis (L.). Occasional.
Glossiphonia complanata (L.). Occasional.
Macrobdella decora (Say). Rare.
?*Haemopis marmoratis* (Say). Occasional.
Haemopis plumbeus Moore. Frequent.

Crustacea

Cladocera, Copepoda, and Ostracoda occurred in abundance, but were not studied systematically.

Amphipoda

Hyalella knickerbockerii (Bate). Frequent.

Decapoda

Cambarus propinquus Girard. Frequent. The food of five specimens consisted chiefly of fragments of vascular plants with some diatoms and other algae, and one Baetid nymph.

C. bartonii robustus. Rare.

Insecta

Ephemeroptera. Imagos and nymphs were identified by Mr. F. P. Ide of the University of Toronto.

Ephemeridae

Hexagenia viridescens. Occasional.

Ephemera sp. cf. *simulans.* Abundant. The alimentary canals of seven specimens, taken May to November, contained much sand, organic debris, fragments of vascular plants, and a few diatoms and filamentous algae.

Baetidae

Leptophlebia mollis. Occasional.

Leptophlebia debilis. Rare.

Blasturus nebulosus. Abundant.

Ephemerella temporalis. Frequent.

Caenis sp. Frequent.

Baetis pygmaeus. Occasional.

Centroptilum convexum. Rare.

Centroptilum bellum. Rare.

Chloeon sp. Rare.

Heptagenidae

Siphlonurus sp. Frequent.

Ecdyurus tripunctata. Frequent.

Ecdyurus canadensis. Occasional.

Ecdyurus sp. (*fusca* group). Rare.

Heptagenia hebe. Rare.

Odonata. Imagos and nymphs were identified by Dr. E. M. Walker of the University of Toronto.

Zygoptera

Ischnura verticalis (Say). Rare.

Enallagma ebrium (Hagen). Rare.

Enallagma boreale (Selys).

Agrion aequabile (Say). Occasional.

Agrion maculatum Beauvois. Rare.

Anisoptera

Aeshna umbrosa Walker. Rare.

Tetragoneuria spinigera Say. Rare.

Somatochlora minor (Calvert). Rare.

Neuroptera

Sialis sp. Frequent.

Chauliodes sp. Rare.

Trichoptera. Larvae were identified with the aid of Lloyd (1921), Lestage (1921), and Needham and Needham (1930). Dr. Cornelius Betten of Cornell University has identified the imagos collected.

Hydroptilidae

Hydroptila sp. Rare.

Hydropsychidae. Collected rarely in the stony section.

Polycentropidae

Neureclipsis sp. Occasional. The loose nets of this species were commonly seen trailing from logs in a moderate to slow current.

?*Polycentropus* spp. Occasional. Three species of larvae which appear to fall into this genus were found in the stream, on marl or stony bottom.

Plectrocnemia canadensis Bks. Imagos, 12. vi. 30.

Plectrocnemia sp. 8. Imagos, 27. vii. 30. The larvae referred to *Polycentropus* may belong here.

Phylocentropus sp. Frequent. Imagos, *P. placidus* Bks., 8-12. vi. 30.

Lype sp. Imago only, 7. vi. 30.

Sericostomatidae

Goera sp. Rare.

Lepidostoma sp. Rare.

Helicopsyche borealis Hagen. Frequent. Imagos, 2-7. vii. 30.

Molannidae

Molanna sp. Occasional. Imago, *M. cinerea* Hagen, 17. vi. 30.

Leptoceridae

Leptocerus sp. Imagos only, 12-13. vi. 30.

Oecetis sp. Occasional. Imago, *Oe. incerta*, 8.vii.30.

Triaenodes sp. Occasional. Imagos, 12. vii. 30.

Mystacides sepulchralis Walker. Abundant. Imagos, 8. vii.-14. viii. 30.

Phryganeidae. Larvae of two species were occasional in early spring, and common in trout stomachs. The food of four specimens was chiefly of animal matter: Chironomine larvae and a Hydroptilid caddis larva, with about 15 per cent. vegetable debris.

Imagos, *Ptilostomis* sp., 15. vi. 30; *P. semifasciata*, 12. vi. 30; *Phryganea*? *sayi*♀

Limnephilidae. Many of the larvae taken could not be identified even as far as genus.

Limnephilus indivisus. Imagos, 12-23. vi. 30. Larvae of this species were abundant in April in temporary pools, and may occur in the river itself.

Limnephilus sp. 34. Imagos, 5. ix. 30. A common cross-stick larva of the river is probably to be referred to this species.

Rheophylax submonilifer. Imago, 8. vii. 30.

Anabolia bimaculata. Imago, 4. viii. 30.

Halesus guttifer. Imagos, 5. ix. 30. Larvae frequent; many specimens have the dorsal spacing hump partially or wholly inverted, in which case they resemble *Stenophylax scabripennis* as described by Lloyd (1921).

Neophylax sp. cf. *autumnus*. Larvae rare.

Heteroptera. Corixidae have been identified by Mr. G. Stuart Walley, of the Entomological Branch, Ottawa.

Corixidae

Palmacorixa nana Walley. Frequent.

Arctocorixa modesta Abb. Occasional.

Arctocorixa vulgaris Hungfd. Occasional.

Belostomidae

Benacus griseus. Rare.

Nepidae

Ranatra americana. Rare.

Nepa apiculata. Rare.

Gerridae

Gerris sp. Occasional.

Diptera. Larvae of Chironomidae were identified by Dr. O. A. Johannsen of Cornell University, imagos of Tabanidae and Empididae by Dr. C. H. Curran, of the American Museum of Natural History.

Tipulidae

Antocha sp. Rare.

Ceratopogonidae

Culicoides sp. Frequent.

Chironomidae

Tanypinae

Pentaneura (*Ablabesmyia*) group *flavifrons*.

Pentaneura (*Ablabesmyia*) group *monilis*.

Procladius group *adumbratus*.

Clinotanypus.

Chironominae

Chironomus subgenus *Cryptochironomus*.

Chironomus subgenus *Microtendipes*.

Chironomus subgenus *Endochironomus*.

Tanytarsus.

Simuliidae

Simulium sp. Occasional.

Tabanidae

Chrysops indus O.S.

Chrysops carbonarius Walker.

Larvae of *Chrysops* were rare.

Empididae
Rhamphomyia irregularis Loew. Imagos were rather common in May, swarming close to the water.

Coleoptera. Imagos of this order were determined by Mr. W. J. Brown, of the Entomological Branch, Ottawa.

Haliplidae
Haliplus immaculicollis Harr. Rare.

Dytiscidae
Hydroporus depressus Fab. Occasional.
Hydroporus solitarius Sharp. Occasional.

Gyrinidae
Gyrinus sp. Rare. Larva taken.

Hydrophilidae. Rare.

Helmidae
Helmis quadrinotatus Say. Occasional.

Chrysomelidae
Donacia proxima Kby. Rare.
Donacia hirticollis Kby. Rare.
Donacia pusilla Say. Rare.

Arachnida

Hydracarina. Water mites were occasionally collected but have received no systematic attention.

Mollusca

Gastropoda. Chief Justice F. R. Latchford, of Toronto, has determined most of the species.

Valvatidae
Valvata tricarinata (Say). Frequent.

Amnicolidae
?*Amnicola limosa* (Say). Rare.

Lymnaeidae
Lymnaea stagnalis L. Rare.
Stagnicola caperata (Say). Rare.

Planorbidae
Helisoma trivolvis (Say). Rare.
Gyraulus parvus (Say). Frequent.
Gyraulus deflectus (Say). Rare.

Ancylidae
Ferissia rivularis (Say). Rare.
Ferissia parallela (Haldeman). Rare.

Pelycypoda. The Sphaeriidae have been determined by Dr. V. Sterki, of New Philadelphia, Ohio.
Pisidium compressum Say. Frequent.
Pisidium variable Prime. Frequent.
Pisidium sargenti Sterki. Occasional.
Pisidium sp. (near *sargenti*). Frequent.
Pisidium sp. Occasional.
Musculium sp. (immature). Rare.
Sphaerium rhomboideum (Say). Frequent.

2. Ecological Distribution of Invertebrates

The distribution of the invertebrates in the above list will be discussed, by a reference to typical habitats. Unless otherwise indicated, records of insects are based on immature stages. The unit of bottom studied was 144 square inches (929 square cm.). As explained above, *abundant* species are represented by 16 or more examples in that area, *frequent* species by 6 to 15 examples, *occasional* species by two to five and *rare* species by only one.

Shore region.

(*a*) Among the grass along the shore (*Phalaris arundinacea*); depth of water 0 to 4 inches. From June to January this region was dry. One collection: May 20, 1930.

Abundant forms
Arctocorixa adults and nymphs of *Palmacorixa.*

Frequent forms
Ephemerella temporalis, *Siphlonurus* sp., *Limnephilid* B.

Occasional forms

Limnephilid C, *Chrysops*, *Culicoides*, *Stagnicola*.

Rare forms

Oligochaeta, *Helobdella stagnalis*, *Hyalella knickerbockerii*, *Halesus guttifer*, *Limnephilid* A, *Pentaneura* (group *flavifrons*), four species of Chironominae, *Haliplus immaculicollis*, *Lymnaea stagnalis* (immature), *Gyraulus deflectus*, *Pisidium*.

(*b*) Mud bottom, near shore, partly covered by leaves, grass stems, and small sticks; depth 0 to 3 inches. One collection: June 17, 1930.

Occasional forms

Corixidae, *Chrysops*, *Chironominae*, *Culicoides*, *Pisidium*.

Rare forms

Oligochaeta, *Macrobdella decora*, *Haemopis plumbeus*, *Helobdella stagnalis*, *Limnephilid* E, *Stagnicola*, *Gyraulus parvus*, *Helmis* sp.

Mud-Nymphaea region. Bottom of mud in which are buried the fleshy stems of *Nymphaea*, the leaves of which appear early in spring, and reach the surface in June. Three series of collections were made in this important section: at depths of one, one and a half, and two feet, referred to the standard May level. By June 25 the water had fallen so that the first of these was at times quite dry, the second, barely under water. These fluctuations caused considerable destruction of life; the following species were noted dead on the bottom, presumably killed by desiccation: *Haemopis marmoratis*, *Halesus guttifer*, *Lymnaea stagnalis*, *Planorbis trivolvis*.

(*a*) Depth one foot in May, dry in summer. Collections taken May 20 and June 18.

Abundant forms

Corixidae. Nymphs of *Palmacorixa* were frequent in May; in June the nymphs had disappeared, but adults of *P. nana* were abundant.

Chironomidae. *Procladius* (*adumbratus* group) were occasional in May, and abundant in June, when they were evidently about to pupate. Chironomine D abundant in May.

Sphaeriidae. *Pisidium* was abundant at both times.

Frequent forms

Culicoides. Frequent in May and June.

Clinotanypus A (*pinguis* group). In June some were ready to pupate.

Occasional forms

Hyalella knickerbockerii was occasional in June, absent in May.

Halesus guttifer. Two specimens taken in May.

Arctocorixa sp. Occasional in May.

Tanypine C.

Chironomine N. Occasional in May.

Chironomus (*Endochironomus*) A. Occasional in May.

Chironomine sp.?

Sphaerium rhomboideum.

Rare forms

Oligochaeta, *Ephemera* cf. *simulans*, *Mystacides sepulchralis*, *Phylocentropus* sp., *Sialis* sp., *Clinotanypus* G, other Tanypinae and Chironominae, *Musculium*.

(*b*) Depth 18 inches in May, fluctuates in summer to a minimum of one inch. Collections taken May 21, June 9, July 4, July 27, August 12, September 4, October 20, January 17.

Abundant forms

Palmacorixa nana. Nymphs frequent in May, adults frequent in June and abundant in early July.

Culicoides. Abundant in May and June, occasional at other times.

Clinotanypus A (*pinguis* group). Abundant in winter, and frequent in May and June.

Chironomine Q. Abundant in winter, not found at other times.

Pisidium. Abundant in May and June, frequent at other times.

Frequent forms

Hyalella knickerbockerii. Frequent in winter and early spring; occasional or rare at other times.

Ephemera cf. *simulans.* Of scattered distribution in the silt beds; abundant in some collections and rare in others.

Phylocentropus sp. Pupae taken up to early June; young larvae first appear late in July, and are occasional to frequent until the following June.

Clinotanypus A (*pinguis* group). Abundant in winter, frequent in May and June.

Clinotanypus H. Frequent to rare from early July to October.

Procladius B (*adumbratus* group). Mostly occasional or rare, but abundant in early July.

Chironomus (*Microtendipes*) I. Abundant in winter, not found again.

Chironomine Q. Abundant in winter, not found again.

Occasional forms

Tubificidae. Usually occur.

Haemopis plumbeus. Occasional or rare throughout the year.

Sialis sp. Usually rare, but small larvae were abundant early in September.

Blasturus nebulosus. Frequent in winter, absent at other times.

Arctocorixa modesta. September and October.

Tanypine C. Absent from late July to September, occasional at other times.

Chironomus (*Endochironomus*) A. Occasional in May and June.

Chironomus (*Cryptochironomus*) B. Occasional from May to early July.

Chironominae. Several small species found occasionally or rarely in some of the collections.

Rare forms

Lumbriculidae, *Glossiphonia complanata*, *Dina parva?*, *Hexagenia viridescens*, *Baetis pygmaeus*, *Mystacides sepulchralis*, *Halesus guttifer*, *Limnephilid* B, *Phryganea* sp., *Pentaneura* E (group *flavifrons*), *Clinotanypus* G, other Tanypinae, *Helmis quadrinotatus*, *Hydroporus solitarius*, *Hydroporus depressus*, *Sphaerium rhomboideum*.

(*c*) Depth 24 inches in May, minimum summer level six inches. Collections made on May 20, June 14, July 5, July 27, August 13, September 4, October 20, January 17.

Abundant forms

Phylocentropus sp. Frequent to abundant, except during emergence in June and early July.

Arctocorixa modesta. Abundant in late summer and fall.

Procladius B (*adumbratus* group). Occasional in spring, abundant in summer and fall.

Frequent forms

Hyalella knickerbockerii. Frequent in summer and fall, occasional in winter and spring.

Culicoides. Frequent or occasional, except in June.

Clinotanypus A (group *pinguis*). Frequent in May and June.

Clinotanypus H. Frequent during July and August.

Tanypine C. Frequent from September to spring.

Chironominae. Several small species frequent in certain dredgings.

Pisidium. Occasional in spring, frequent from summer to winter.

Occasional forms

Haemopis plumbeus. Occasional or rare.

Hexagenia viridescens. Of scattered distribution in this area.

Ephemera cf. *simulans.* Commoner than the last, but equally irregular in appearance.

Sialis sp. Usually occasional in occurrence, frequent in winter.

Arctocorixa sp. This spring form was occasional in June.

Palmocorixa nana. Occasional in June.

Sphaerium rhomboideum. Frequent to absent.

Musculium sp. Occasional or absent.

Rare forms

Tubificidae, *Glossiphonia complanata*, *Cambarus propinquus*, *Caenis* sp., *Ephemerella temporalis*, *Agrion aequabile*, *Halesus guttifer*, *Limnephilid* C, Limnephilid D, Phryganeid A, *Chironomus* (*Microtendipes*) I, *Chironomus* (*Cryptochironomus*) B, *Chironomus* (*Endochironomus*) A, *Chrysops* sp., *Helmis* sp., *Valvata tricarinata*, *Helisoma trivolvis* (young), *Ferissia parallela*.

Summary of the mud-Nymphaea section. This region is characterized chiefly by the abundance of Chironomoidea: Chironominae in shallower water and Tanypinae in deeper water, with Culicoides throughout. Corixidae are common at moderate depths, with three different species reaching peaks of abundance about June 1, July 1, and September 15 respectively. The abundant caddis is *Phylocentropus*, which builds its branching mud tubes in the deeper water. Among mayflies, *Hexagenia viridescens* and *Ephemera* cf. *simulans* form scattered colonies; *Blasturus nebulosus* is frequent in winter. *Hyalella knickerbockerii* is a frequent species occurring in fairly constant numbers. Clams were common, *Sphaerium rhomboideum* in deep water, and several species of *Pisidium* in shallow water, though the latter may migrate outward during the summer drought. The large *Helisoma trivolvis* and *Lymnaea stagnalis* were often observed upon the stems and leaves of *Nymphaea*, but only rarely appear in the samples. *Haemopis plumbeus* and *Sialis* sp. were of occasional occurrence throughout.

In addition to the above typical forms, stragglers from the shore region, from the deeper waters, or from the weed beds, appear in the collections. In the first class are included the large caddis larvae such as *Halesus guttifer*, Limnephilids C and D, *Phryganea* A, and also *Glossiphonia complanata*, *Ephemerella temporalis*, *Chrysops* sp., *etc.* Weed-bed forms include *Valvata tricarinata*, *Gyraulus parvus*, *Ferissia parallela*, *Baetis pygmaeus*, *Helmis* sp., *Hydroporus* spp., and others, while *Mystacides sepulchralis* and *Caenis* sp. are more at home in the marl gravel of the deeper water.

Muddy weed-bed region. The two aquatic plants most efficient in trapping silt among the stems and roots are *Chara* and *Ranunculus*. Of these *Chara* was much the commoner. It grew at depths from six feet up to water so shallow that its stems were killed from exposure to air during summer. The most extensive beds were at a depth of one and a half to three feet in May.

(*a*) *Chara beds.* Collections were made at station 2 on May 21, June 9, July 4, July 25, August 12, September 4, October 20, and January 17, and one on July 3 at station 8. The location was near mid-stream, at a depth of 6 to 24 inches, or 14 to 32 inches referred to the May standard.

Abundant forms

Culicoides. Abundant from May to early July, occasional at other times.

Chironomine D. This small member of the Chironominae was abundant from May to early July but absent thereafter.

Pisidium. Abundant up to September, but rare in fall and winter.

Frequent forms

Tubificidae. Frequent from May to July, rare later.

Haemopis plumbeus. Frequent or occasional throughout.

Hyalella knickerbockerii. Frequent or occasional, except in late summer.

Cambarus propinquus. Not only were small individuals common, but even large specimens were surprisingly frequent in some collections.

Blasturus nebulosus. Frequent in winter only, absent at other times.
Clinotanypus A (*pinguis* group). Found in spring only.
Tanypine H. Frequent from late July to January.
Procladius B (*adumbratus* group). Frequent to rare; commoner from July to January.

Occasional forms
Lumbriculidae.
Phylocentropus sp. Occasional except in early summer.
Triaenodes sp. Larvae frequent on July 4, one pupa taken July 25.
Arctocorixa sp.
Tanypine C. Occasional in winter, spring, and early summer.
Chironomine G. Frequent in winter.
Helmis quadrinotatus. Larvae occasional; adults taken in early June.
Hydroporus solitarius. Adults taken in August and October; larvae of *Hydroporus* were occasional in late July and August.
Sphaerium rhomboideum. Occasional in most collections.
Gyraulus parvus. In three collections.

Rare forms
Glossiphonia complanata, *Haemopis marmoratis*, *Hexagenia viridescens*, *Ephemera* cf. *simulans*, *Siphlonurus* sp., *Baetis pygmaeus*, *Centroptilium convexum*, *Somatochlora minor*, *Oectis* sp., *Halesus guttifer*, *Lepidostoma* sp., *Palmacorixa nana*, *Pentaneura* K (*flavifrons* group), *Pentaneura* I (*monilis* group), *Procladius* G, several small Chironominae not included above, *Chironomus* (*Cryptochironomus*) B, *Chironomus* (*Microtendipes*) G, *Chironomus* (*Microtendipes*) I, *Hydroporus depressus*, *Musculium* sp., *Valvata tricarinata*, *Amnicola limnosa?*.

(*b*) *Ranunculus beds*. Only two collections made: on June 18 near station 2, depth 12 inches, current speed about 0.5 feet per second; and on July 3 at station 8, depth about eight inches, and current speed about 1.5 feet per second.

Abundant forms
Arctocorixa sp. June only.
Pisidium spp. Abundant in both situations.
Valvata tricarinata. June only.

Frequent forms
Tubificidae. July only.
Glossiphonia complanata. July only.
Helobdella stagnalis. July only.
Hyalella knickerbockerii. July only.
Limnephilid B. June only.
Chironomine M. Both collections.
Helmis quadrinotatus. Adults and larvae frequent in July.
Donacia sp. Two larvae and three pupae on July 3. Adults of *D. hirticollis* were common on July 25.
Gyraulus parvus. Frequent in both situations.

Occasional forms
Cambarus propinquus. Both situations.
Baetinae. Specimens lost.
Halesus guttifer. Prepupae and pupae in July.
Triaenodes sp. Larvae and pupae in July.
Oecetis sp. Pupae in July.
Pentaneura K (*flavifrons* group). July only.
Chironomus (*Cryptochironomus*) B.
Chironomus (*Endochironomus*) H.

Rare forms
Lumbriculidae, Limnephilid C, Limnephilid D, *Culicoides* sp., *Clinotanypus* A (*pinguis* group), Tanypine C, two small Chironominae, *Tanytarsus* sp., *Hydroporus depressus*, *Sphaerium rhomboideum*.

Summary of muddy weed beds. The fauna of these weed beds may be divided into two parts: (1) those animals living on or among the stems and leaves of the plants, and (2) those living on or in the mud below. In the first class may be included *Triaenodes* sp., *Helmis quadrinotatus*, *Arctocorixa* sp., Chironomine D., Chironomine M, *Hydroporus* spp., *Valvata tricarinata*, and *Gyraulus parvus*. Those frequenting the mud include the Oligochaetes and leeches, *Hyalella*, *Cambarus propinquus*, *Blasturus nebulosus*, *Phylocentropus* sp., various *Limnephilids*, *Culicoides*, *Procladius* B (*adumbratus* group) and other Tanypines, the large Chironomines, and the Sphaeriidae.

The striking feature of the association is the large number of crayfish present; among these plants they find shelter denied to them elsewhere in the stream. Next in bulk come the leeches, chiefly *Haemopis plumbeus*, which are likewise of common occurrence. The burrowing mayflies are almost entirely absent; they seem to avoid loose silt. Among caddis, the interesting *Triaenodes* seems peculiar to this habitat; *Oecetis* and certain Limnephilids also occur. Midges are chiefly represented by the abundant *Culicoides*, a frequent Tanypine (Procladius), and a small Chironomine which probably lives on the surface of the weeds; other forms are commoner on the surrounding bare mud. The diving beetles *Hydroporus solitarius* and *H. depressus*, while abundant nowhere in the stream, were commonest in this association; *Helmis quadrinotatus* was occasional. Sphaeriidae, especially *Pisidium*, were present in good numbers.

The above remarks apply chiefly to *Chara*. The principal differences noted in the *Ranunculus* were a much greater abundance of *Arctocorixa* sp. among the stems, the presence of larvae and pupae of *Donacia* sp., and the larger numbers of leaf-living gastropods *Valvata tricarinata* and *Gyraulus parvus*.

Bare marl region. Typically the channel of the river had a bottom of bare marl-gravel, with a few small lime-encrusted sticks. In places it was grown up with ribbon-leaved plants such as *Sparganium* (see below). Two series were collected in this area, at standard depths of four and seven feet respectively. Only the series from the lesser depth has been examined in detail, but the other appears to be essentially the same.

Shallow series: collections were made on May 21, June 9, July 4, July 26, August 12, September 4, October 20, and January 17.

Abundant forms

Ephemera cf. *simulans*. Extraordinarily abundant in spring and early summer; as many as 250 have been taken per square foot. From September to June both generations occur.

Frequent forms

Caenis sp. Commonest in September.

Mystacides sepulchralis. Larvae September to July, emerging throughout the summer.

Helicopsyche sp. May to September.

Penteneura E (*flavifrons* group). October to June.

Chironomus (*Microtendipes*) G. January to May.

Occasional forms

Hyalella knickerbockerii. Frequent to absent.

Sialis sp.

Molanna sp. Of regular occurrence throughout the year.

Oecetis sp. Larvae in May, pupae in June.

Chironomus (*Microtendipes*) I. Frequent in October.

Chironomine Q. January only.

Small Chironominae.

Rare forms

Tubificidae, *Haemopis plumbeus*, *Hexagenia viridescens*, *Ecdyonurus tripunctata*, *Agrion aequabile*, Polycentropus B, *Halesus guttifer*, *Arctocorixa* sp., *Procladius* B (*adumbratus* group), *Pentaneura* I (*monilis* group), Tanypine C, *Chironomus* (*Endochironomus*) A, *Chironomus* (*Endochironomus*) H, *Helmis quadrinotatus*, *Pisidium* sp., *Sphaerium rhomboideum*, *Gyraulus parvus*.

Summary of bare marl region. The outstanding feature of this habitat is the relatively enormous number of nymphs of *Ephemera*, which constitute over 95 per cent. of its fauna by bulk. *Caenis* was the only other common mayfly. The characteristic caddis larvae bore cases made of sand grains, *Molanna, Helicopsyche*, and *Oecetis;* the beautiful *Mystacides sepulchralis* used small bits of wood; *Polycentropus* had no portable case. The Chironomoids were poor in species and in individuals. *Pentaneura* E (group *flavifrons*) and *Chironomus* (*Microtendipes*) G were characteristic, but not abundant; the latter used stones for its case also. A fair number of stragglers from other habitats completed the fauna.

Marl weed beds. The plants of the marly bottom were usually long and slender, and did not collect mud among their stems. The most typical were aquatic forms of *Sparganium* and *Sagittaria*, and *Potamogeton amplifolius*. Unfortunately little collecting was done in this area.

(*a*) *Sparganium.* A single collection on July 3 at station 8 revealed the presence of the common marl organisms, including abundant *Ephemera* nymphs, and a caddis not found at the lower station; *Goera* sp. *Valvata tricarinata* and *Perlinella?* were probably from the leaves of the plant.

(*b*) *Potamogeton amplifolius.* Collections from among the leaves and stems on September 4 revealed occasional nymphs of *Agrion aequabile*.

Summary of weed beds. Observations upon the "weeds" of the Mad river show that submerged aquatic plants may affect stream life directly in four ways:

1. They harbour a few animals which cling closely to their leaves or stems, and feed there, *e.g.* small gastropods, *Helmis* and probably certain Chironomines.

2. They harbour some animals which merely rest among the foliage, *e.g. Triaenodes, Arctocorixa* sp., *Cambarus propinquus*.

3. They provide more sheltered situations for some animals of the surrounding mud bottom, and hence increaes

their abundance, *e.g. Haemopis plumbeus, Blasturus nebulosus, Procladius* B (*adumbratus* group), *Pisidium, etc.*

4. Because of accumulation of loose silt or in some other way, they provide a less favourable habitat for others of the same fauna, which accordingly are rare or absent, *e.g. Ephemera*, most Tanypinae, and Chironominae, *Phylocentropus*.

In the case of *Sparganium, Sagittaria, Hippuris*, and *Potamogeton natans*, the first two effects were the only ones observed; in the case of *Chara* and *Ranunculus* the last two were also apparent.

In addition, certain facts of distribution are not explained by any of the four influences listed above, *e.g.* Corixidae are rarely found in *Chara*, but do not object to *Ranunculus*.

3. Seasonal Variation in Invertebrate Life

From this point of view, bottom organisms may be divided into (1) those which for a considerable part of the year are not in the water, and (2) those which are present in fairly constant numbers throughout the year. This is *almost* equivalent to dividing them into (1) insects, and (2) other organisms.

The second group is less numerous and less important. Oligochaeta, Hirudinea, Crustacea, Corixidae, Dytiscidae, Sphaeriidae, and Gastropoda are the principal representatives. Of these the Corixidae, although almost confined to the water, are not uniformly common throughout the year, but one species follows another in a series of waves. Of the remainder, only two species, *Cambarus propinquus* and *Haemopis plumbeus*, are common in the food of the speckled trout.

The occurrence of most insects in the stream is interrupted by the fact that they live their adult lives out of water. From the time they emerge until their eggs have hatched and the nymphs grown to macroscopic size, they are not available to the larger fish of the stream. In the case of Ephemerine mayflies greater continuity of distribution is ensured by the fact that two years must elapse before maturity is reached, and hence there is always at least one generation in the water.

Most of the mayflies and midges, the Phryganeids and many smaller caddis flies, emerge during May and June, and are hence absent from the stream in July. The large Limnephilid caddis emerge in the fall, but spend most of the summer in the dormant prepupal and pupal stages, so that they too are not easily found after July 1. Even the Corixids are relatively uncommon by the middle of that month. Midsummer—July and August—is the time when the insect life of the stream is at its lowest ebb, the only common forms being *Ephemera*, *Caenis*, and a few Chironomids.

Many species of invertebrates are regularly eaten by fish, as is evident from tables 9 to 15. Insects are most readily taken, by trout at least, during the actual act of emergence: in the case of midges the pupal state, in the case of mayflies either late nymphal or sub-imaginal. Caddis flies, however, are usually eaten as larvae. Other vertebrates also help to reduce the numbers of the invertebrates, *e.g.* mergansers and other ducks, bitterns, sandpipers, kingfishers, flycatchers, swallows, bats, *etc.*

4. Summary of Invertebrate Life

Insecta are the most important of the larger invertebrates in the Mad river, but Oligochaeta, Hirudinea, Crustacea, Hydrachnida, Pelycypoda, and Gastropoda also occur. The orders of insects represented are Ephemeroptera (three families), Odonata (four families), Neuroptera (two families), Trichoptera (eight families), Heteroptera (four families), Diptera (five families), and Coleoptera (six families). Of these, Ephemeroptera, Trichoptera, and Diptera are outstanding in number of species and individuals.

The three principal types of *faunal associations* in the Mad river are (1) the shore fauna, (2) the mud-flat fauna, and (3) the marl-gravel fauna, each of which is again divisible into a bare bottom and a weed-bed association. The shore fauna is characterized by the large Baetid mayflies *Siphlonurus* and *Ephemerella temporalis*, and large caddis of the families Limnephilidae and Phryganeidae. Typical members of the *mud-flat fauna* are the mayfly *Blasturus*, the caddis *Phylocentropus*, Sphaeriidae, and particularly larvae of Chironomidae. The marl gravel has as an outstanding inhabitant the burrowing mayfly *Ephemera*, and in lesser numbers the caddis *Molanna* and *Mystacides sepulchralis*.

The total quantity of invertebrate life is not constant the year round. In spring the shore area supports the greatest total weight of organisms, the marl is next, while the mud flats are least productive. In summer the marl is richest, then the mud flats, while the shore is dry and barren. The average dry weight of bottom fauna is comparable to that of small shallow *Chara* ponds and lakes, and greatly in excess of that found in larger lakes.

Seasonal variation in invertebrate life is chiefly the result of the emergence from the water of most insects during their adult life. A majority of the species transform in May and June, so that the invertebrate fauna of the stream is at its lowest ebb during summer and early fall.

An important biological factor, affecting the numbers of aquatic invertebrates, is their destruction by fish and other vertebrates. In the case of insects, this may occur at any stage in their life history, but many species are particularly susceptible during the time of transformation, in the pupal or subimaginal state.

5. Fish other than Trout

The nomenclature and systematic arrangement is that of Jordan's *Manual of the Vertebrates*, 13th edition. Examples of every species have been identified by Professor J. R. Dymond of the University of Toronto. Lengths are in inches measured to the fork of the caudal fin; 1 inch = 2.54 cm.

1. *Chrosomus erythrogaster* Rafinesque. Several specimens were taken in the stream two miles above the section considered here, and they may occur farther down.
2. *Margariscus margarita nachtriebi* (U. Cox). The only specimen, taken July 25, was 2.75 inches long.
3. *Semotilus atromaculatus* (Mitchill). Occasionally taken on a hook, and schools of young about one inch long were seen in stony sections. It is said to have been much commoner about 20 years ago.

Spawning of the creek chub takes place early in June; on June 9, 1930, two ripe males and a female extruding eggs were taken.

The food of five specimens 0.88 to 1.38 inches long taken August 14, 1930, was as follows:

	Per cent. by volume
Larvae of Polycentropidae	40
Other? caddis larvae and pupae	13
Larvae of Chironomidae	20
Adult terrestrial fly	7
Gastropod	20

The result of the examination of the stomachs of six specimens 3.5 to 7.5 inches long taken May 17 to June 9, 1930, is as follows:

	Per cent. by volume
Diatoms, fragments of vascular plants and bottom ooze	52
Heptagenid nymphs	5
Unidentified insect	5
Gastropod (*Lymnaea stagnalis*)	38

The young chub were not found where small trout or most other small fish occur, hence they do not come directly into competition with other stream fish. For the larger specimens, six stomachs are not sufficient for a generalization, but the principal items listed are not found in trout stomachs. The absence of crayfish is surprising. In any case, the scarcity of the species makes it an unimportant factor in the life of the stream as enemy, competitor, or food of the trout.

4. *Rhinichthys atronasus* (Mitchill). Occasional or perhaps frequent in the beaver-meadow section, not seen below. The examples collected ranged from 1.5

to 2.75 inches in length. Stomachs of nine specimens taken July 12, 1928, and one taken July 25, 1930, contained the following:

	Per cent. by volume
Nymphs of *Ephemera*	16
Nymphs of Baetidae	20
Larvae of Chironominae	50
Pupae of Chironominae	3
Terrestrial insects	11

This is very similar to the food of sculpins taken at the same time.

TABLE 9. Stomach contents of *Eucalia inconstans*

	7 specimens 0.19-0.63 inches July 21, 1930	11 specimens 1.00-2.06 inches June 17-September 4, 1930
Entomostraca		
Cyclops	11	7
Chydorus	—	7
Bosmina	11	1
Pleuroxus	—	4
Ostracoda	36	18
Hyalella knickerbockerii	—	8
Insecta		
Nymphs of Baetidae	—	5
Nymphs of Corixidae	—	11
Larvae of Tanypinae	—	2
Larvae of Chironominae	28	11
Pupae of Chironomidae	14	4
Larvae of Tipulidae?	—	15
Adult terrestrial fly	—	3
Gyraulus parvus	—	4

5. *Eucalia inconstans* (Kirtland). Frequent in the lower section, below station 5. Specimens of the stickleback were most easily obtained in late summer and fall. It was often seen lurking in the shelter of logs, lily pads, *Potamogeton*, or *Chara*. Several individuals appear in the stomachs of the speckled trout.

The food of specimens collected June 17 to September 4, 1930, is presented in table 9.