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CONTENTS

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THE CARBON DIOXIDE AND HYDROGEN ION CONTENT OF THE LAKE WATERS OF NORTHEASTERN WISCONSIN

C. JUDAY, E. A. BIRGE AND V. W. MELOCHE

From the Limnological Laboratory of the Wisconsin Geological and Natural History Survey.* Notes and reports No. 55.

I. CARBON DIOXIDE

INTRODUCTION

Dissolved carbon dioxide plays a very important rôle in the biological economy of natural waters. It is one of the raw materials required by aquatic plants for the manufacture of organic substances in the process of photosynthesis. Its scarcity or abundance, therefore, is of vital importance not only to the aquatic plants but also to aquatic animals because the former serve as the source of the food of the latter, either directly or indirectly. Its significance from the standpoint of photosynthesis as well as from that of the chemical status of the water makes it necessary to study this gas quantitatively in order to get an idea of its ecological relations.

Such a quantitative study is particularly valuable for the lakes of northeastern Wisconsin because their waters show such a wide range in carbon dioxide content. The largest quantity of carbon dioxide, including free, half-bound and bound, found in any of these lakes was a little more than 75.0 mg/1, while the smallest amount was a little less than 1.0 mg/1; thus the quantity in the former sample was approximately eighty times as large as that in the latter. The waters of a large percentage of the lakes are quite soft. The Ca content in many instances is less than 1.0 mg/1.

The carbon dioxide supply of lake waters is derived from the atmosphere, from rain, from springs and streams, from the respiration of living organisms and from the decomposition of organic matter. Carbon dioxide is usually present in the at-

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*This investigation was made in co-operation with the U. S. Bureau of Fisheries and the results are published with the permission of the Commissioner of Fisheries.

mosphere in the ratio of 3 to 4 parts per 10,000 and pure water absorbs 1.0-2.0 mg/1 when freely exposed to the air. An experiment with distilled water in 1931 yielded an average of 1.7 mg/1 of free carbon dioxide after exposure to the air for several hours. Also a sample of rain water obtained on August 8, 1931, yielded 1.0 mg/1 of free carbon dioxide. In certain types of lakes, more especially the bog type, decomposition is the chief source of the carbon dioxide supply.

Natural waters usually contain dissolved substances which increase their capacity for carbon dioxide very materially. Calcium and magnesium play the most important rôle in that respect, but sodium and potassium play a part in some cases. Pure water that is free of carbon dioxide will dissolve about 13.0 mg/1 of $CaCO_3$ at 20° C. and about 60.0 mg/1 of $MgCO_3$; the bicarbonates of these two substances, however, are much more soluble.

Rain water contains only a small amount of free carbon dioxide when it falls on the land, but it acquires a larger supply as it passes through the soil and subsoil. When this water that is charged with free carbon dioxide comes into contact with calcium and magnesium carbonates in the earth, it converts them into bicarbonates which readily pass into solution. The quantity of bicarbonates present in the ground water will depend upon the amount of free carbon dioxide present in the percolating water and also upon the abundance of $CaCO_3$ and $MgCO_3$ in the geological strata through which the water passes.

Methods and Nomenclature

Detailed descriptions of the various methods used in making quantitative determinations of the carbon dioxide content of natural waters have been given by a number of authors, more recently by Werestschagin (1931) and Maucha (1932), so that they need not be included in this report. The carbon dioxide results presented here were obtained by titrating 100 cc samples of water with N/44 Na_2CO_3 and N/44 HCl, using phenolphthalein and methyl orange for indicators. Both of these titration methods have their shortcomings, however. The results obtained for free carbon dioxide are a little too low, but the error is negligible in waters that are as soft as most of these. Likewise the

HCl-methyl orange titration is subject to certain inaccuracies due chiefly to the personal error involved in reading the endpoint. On the other hand, both methods are the best that have been devised for field work and they give results that are accurate enough for general limnological purposes.

In previous reports dealing with the carbon dioxide content of Wisconsin lake waters, the terminology used by Seyler (1894) was employed, namely free, half-bound and fixed carbon dioxide. The term "bound" is now more generally used than "fixed" and it seems advisable to use the former instead of the latter word. Pia (1933) has recently proposed another type of classification; he uses the terms free and bound carbon dioxide, but separates each of these classes into two components. The two kinds of free are (1) "zugehörige freie Kohlensäure" and (2) "angreifende" (aggressive). The former is defined as "die notwendig ist, damit die vorhandenen Bikarbonate bestehen bleiben; this may be called "attached" free carbon dioxide because it is closely associated with the bicarbonate. The aggressive includes the free carbon dioxide that is present in excess of the "attached" (zugehörige); it is available for changing the monocarbonates to bicarbonates.

According to Pia, the bound carbon dioxide consists of (1) the "firmly-bound" (fest gebundene) and (2) the half-bound (halbgebundene). The firmly-bound carbon dioxide is that which changes CaO into $CaCO_3$ and the half-bound is that which changes $CaCO_3$ into $Ca(HCO_3)_2$ or that which converts the monocarbonates into bicarbonates. In the present report on Wisconsin lakes, the terms *bound* and *half-bound* are used; the former term is equivalent to the "firmly-bound" carbon dioxide, but the prefix "firmly" is omitted in order to simplify the expression.

Four different methods have been used by investigators for stating the results of the HCl-methyl orange titration, namely, (1) in terms of normality of the bicarbonates, (2) in cubic centimeters of N/10 HCl or N/HCl, (3) as $CaCO_3$ and (4) in terms of bound (fixed) carbon dioxide. It appears to the authors that the last form of statement (4) is most convenient for limnological purposes because the limnologist is interested primarily in the biological rather than in the purely chemical significance of the carbon dioxide content of natural waters. A knowledge of the amount of this gas that is available for the photosynthetic activities of the aquatic plants is especially important in bodies of water with such limited supplies as many of these northeastern lakes possess. If desired, the results given for bound (firmly bound) carbon dioxide in this report can be changed into terms of acid by dividing them by the number *five*; the respective quotients will represent the cubic centimeters of N/44 HCl used in titrating 100 cc samples of water with methyl orange as an indicator.

In the process of assimilation, aquatic plants are able to use all of the free (aggressive and attached) and all of the half-bound carbon dioxide. Also Schutow (1926), Maucha (1929), Neresheimer and Ruttner (1929) and Wiebe (1931) have reported that the bound or monocarbonate carbon dioxide can be utilized after the free and half-bound have been exhausted. In general however, the free and half-bound are the main sources upon which the plants depend for their supply of this gas.

In waters that give a neutral or acid reaction to phenolphthalein, the quantity of the half-bound is usually regarded as equal to that of the bound carbon dioxide; this is only approximately true, however, but the difference is not very great in waters that fall within the carbon dioxide range of these lakes. The carbon dioxide that is readily available for the aquatic plants, namely the free and the half-bound, is thus substantially equal to the sum of the free and the bound, while the total quantity is the sum of the free and twice the bound.

An alkaline reaction to phenolphthalein shows that a certain amount of normal or monocarbonate carbon dioxide is present and the quantity is determined by the titration with acid until the pink color is discharged. The samples that gave an alkaline reaction to phenolphthalein are indicated by a minus sign in the free carbon dioxide column of the tables of this report and also in the text; the number following the minus sign shows the quantity of the normal or monocarbonate carbon dioxide present. In the case of these lakes, it may also be regarded as representing the amount of half-bound carbon dioxide that has been utilized by the aquatic plants in the process of photosynthesis. The quantity of half-bound carbon dioxide remaining in these samples, therefore, is equal to the algebraic sum of the monocarbonate as indicated by the minus sign and the bound carbon dioxide, and the total is the sum of the half-bound and the bound.

Including both phenolphthalein and methyl orange titrations, approximately 5,600 carbon dioxide determinations were made on 2,800 samples of water during this investigation. This number represents 2,400 determinations on surface samples and 3,200 on samples taken at other depths. Readings were obtained from 537 lakes, but the results on 19 are omitted in the present report because either the free carbon dioxide or the hydrogen ion concentration was not determined on them. The observations were limited to a single surface sample on 283 lakes, but two or more samples were obtained from all of the others. Series of samples covering the entire depth were taken in 82 lakes; all of those known to have a maximum depth of 18 m. or more were included in the series as well as a number of lakes ranging from 4 m. to 18 m. in depth. The series taken on the various lakes consisted of 2 to 13 samples each, depending upon the depth of the lake and the status of the carbon dioxide at the different depths. The largest number of determinations was made on Trout Lake, namely 278.

Seepage and Drainage Lakes

A large number of the northeastern lakes do not have an inlet or an outlet; they receive water through direct precipitation on their surfaces and from the surface drainage of limited basins. Any gain from or loss to the ground water takes place through the process of seepage; hence they have been designated as "seepage" lakes. In general the seepage lakes are characterized by their very soft waters; results from 238 of them are included in this report.

Those bodies of water which have temporary or permanent outlets have been called "drainage" lakes. Some of them show characteristics akin to those of the seepage lakes because they have no inlets and their outlets possess water only for a brief period each year, or sometimes only at intervals of several years, depending upon the amount of precipitation. Observations on 280 drainage lakes are included in this report.

FREE CARBON DIOXIDE

Surface samples. Phenolphthalein titrations were made on 1,170 surface samples from 518 lakes. The largest number was made on Trout Lake, namely 26. In 121 samples the water gave an alkaline reaction to phenolphthalein; the reaction was neutral in 14 and acid in 1,035. Thus approximately 12 per cent of the samples gave a neutral or alkaline reaction to this indicator and 88 per cent an acid reaction.

Samples from 74 lakes gave an alkaline reaction to phenolphthalein ranging from a minimum of —0.1 mg/1 in Little St. Germain Lake to a maximum of —10.7 mg/1 in Mann Lake, when expressed in terms of carbon dioxide. This alkaline reaction to phenolphthalein was due to the photosynthetic activities of the various aquatic plants, chiefly to phytoplankton forms; these organisms removed some of the half-bound carbon dioxide from the bicarbonates during the process of assimilation, thus leaving a certain amount of normal carbonate in the water which gave it an alkaline reaction to phenolphthalein. All of the lakes on which this phenomenon was observed belong to the drainage class and their specific conductances ranged from a minimum of 23×10^{-6} in Adelaide Lake to a maximum of 132×10^{-6} in Wild Cat Lake.

The sample which gave the maximum alkaline reaction to phenolphthalein was obtained from Mann Lake on July 7, 1928; this lake has an area of about 100 ha. and a maximum depth of 2.5 m. It is fed by springs and has an outlet; the specific conductance of the water averages about 100×10^{-6}. The quantity of bound carbon dioxide on the above date was 25.6 mg/1, so that a little more than 41 per cent of the half-bound carbon dioxide had been utilized by the aquatic plants. The phytoplankton organisms numbered 3,200 cells and colonies per cubic centimeter on this date and there was also a luxuriant growth of the large aquatics. Six surface samples were obtained from Mann Lake between 1926 and 1930, inclusive; 5 of them gave an alkaline reaction to phenolphthalein ranging from —2.8 to —10.7 mg/1 and one gave an acid reaction equivalent to 4.0 mg/1 of free carbon dioxide.

Fourteen surface samples obtained from 11 different lakes gave a neutral reaction to phenolphthalein; with one exception these samples came from drainage lakes. The exception was Pallette Lake; the specific conductance of this seepage lake averaged 19×10^{-6} and the bound carbon dioxide was 3.8 mg/1. In the other 10 lakes whose surface samples gave a neutral reaction to phenolphthalein, the specific conductance varied from 53 to 120×10^{-6} and the bound carbon dioxide content fell between 11.8 and 30.5 mg/1. In 4 of these lakes, the surface water gave an alkaline reaction to phenolphthalein on other dates.

Allen or Brazell Lake ranked second in respect to its alkaline reaction to phenolphthalein; it was equivalent to —6.0 mg/1 of carbon dioxide on July 8, 1928. It is a drainage lake with a specific conductance of 62×10^{-6} and a bound carbon dioxide content of 15.0 mg/1; it has an area of 14 ha. and a maximum depth of 2 m. The algal population on the above date was 2,950 cells and colonies per cubic centimeter of water.

All of the other surface samples, namely 1,035, gave an acid reaction to phenolphthalein, thus indicating the presence of free carbon dioxide. The results obtained for free carbon dioxide in the various lakes are summarized in Tables I and II and they are shown graphically in Fig. 1. In compiling the tables, the mean of the various observations on a given lake has been used in assigning it to a particular group when more than one determination was made. In computing the means for some of the lakes in which the surface water gave an alkaline reaction to phenolphthalein the samples that gave an acid reaction more than balanced those that were alkaline in reaction; in such cases the lakes were placed in the acid groups. As a result, only 36 of the 74 lakes in which some of the surface samples gave an alkaline reaction to phenolphthalein fell permanently into the alkaline groups as shown in Table II. For purposes of comparison the 518 lakes have been separated into seepage and drainage types.

Seepage lakes. The mean results for free carbon dioxide in the 238 seepage lakes are given in Table I. The surface water of all lakes in this group gave an acid reaction to phenolphthalein. One surface sample from Pallette Lake gave a neutral reaction to phenolphthalein, but the other 5 samples from this lake gave an acid reaction to this indicator, so that the mean falls in the acid group.

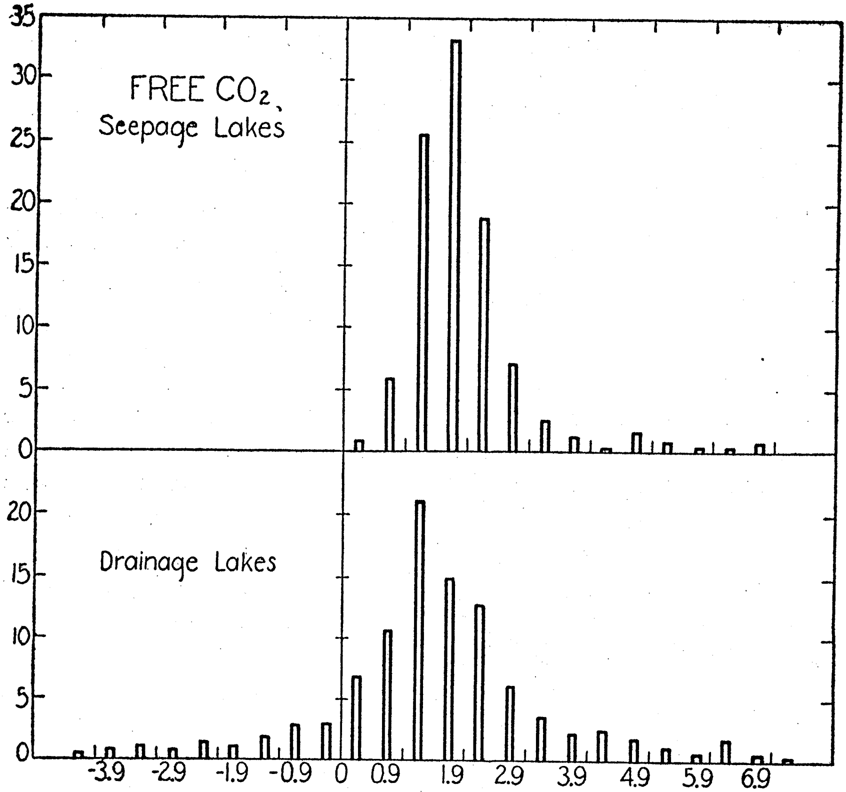

FIG. 1. Free carbon dioxide in surface waters of seepage and drainage lakes. The diagram is based on results from 238 seepage and 280 drainage lakes. The horizontal spaces show the amount of free carbon dioxide by 0.5 mg/1 intervals and the vertical scale indicates the percentage of lakes in each of the groups. The diagram is based on results given in Tables I and II.

The free carbon dioxide content of the surface waters of the seepage lakes ranged from a minimum of 0.3 mg/1 in Clear Bass Lake to a maximum mean of 7.0 mg/1 in the Cardinal Bog lakelet. Table I shows that the maximum number of lakes falls in the 1.5-1.9 mg/1 carbon dioxide group, namely 79 or 33 per cent of the 238 seepage lakes. The 1.0-1.4 mg/1 group is second with 61 lakes and the 2.0-2.4 group is third with 45. These three groups, therefore, include approximately 78 per cent of the total number of seepage lakes. The large percentage of lakes in these three groups is to be expected, however, since water with relatively small amounts of salts in solution usually contains 1.0 to 2.0 mg/1 of free carbon dioxide when freely exposed to the air;

this quantity is subject to modification in lake waters, however, through the processes of photosynthesis, respiration and decomposition. The percentage distribution of the lakes in the various groups is shown in Fig. 1.

The two seepage lakes with the minimum amounts of free carbon dioxide were populated with considerable numbers of phytoplankton organisms; one yielded 1,470 and the other 4,200 cells and colonies per cubic centimeter of water. The photosynthetic activities of these organisms had used up the greater part of the free carbon dioxide.

Table I shows 11 seepage lakes with 4.0 mg/1 or more of free carbon dioxide and 6 of them have 5.0 mg/1 or more. All of these lakes have more or less definite bog characteristics; the waters of most of them are highly colored, which indicates the presence of correspondingly large amounts of organic matter. The two with maximum amounts of free carbon dioxide are only small bodies of open water with wide margins of bog deposits.

The results on bog waters that are presented in this report, are to be regarded only as incidental to the general lake survey. Many bog ponds and lakelets are found in this district, but no careful study of them has been attempted because this would have interfered with the work on lakes. In order to obtain some idea of the chemico-biological status of the waters of these bog ponds and lakelets, however, a few of the more accessible ones were visited and some of the results obtained on them are discussed in this connection.

The largest amount of free carbon dioxide was found in the Forestry Bog pond, namely 10.7 mg/1 and the second in rank was the Cardinal Bog with 10.0 mg/1 at the surface. The open water in the former has an area of 990 sq. m. and a maximum depth of 2 m., while that of the latter has an area of 430 sq. m. and a maximum depth of 5 m. Decomposition is very active in these bog ponds and, as a result, the water receives a large supply of free carbon dioxide. On August 21, 1933, for example, a sample of water from a depth of 4.5 m. in the Cardinal Bog yielded 51.8 mg/1 of free carbon dioxide, with 7.9 mg/1 at the surface.

Drainage lakes. The mean quantities of free carbon dioxide in the 280 drainage lakes are given in Table II; the percentage of these lakes that fall in the different groups is shown graphically in Figure 1. The waters of 36 of the drainage lakes gave a mean alkaline reaction to phenolphthalein, so that the group is distributed through a wider range than the seepage lakes; this fact is well illustrated in Figure 1.

Since the drainage lakes are distributed through a larger number of groups, the percentage in the maximum group is smaller than that in the seepage lakes; a maximum of 21 per cent is found in the 1.0-1.4 group of drainage lakes, while a maximum of 33 per cent of the seepage lakes falls in the 1.5-1.9 mg/1 group. (Tables I and II). In the drainage lakes, the 1.5-1.9 group ranks second with 15 per cent and the 2.0-2.4 mg/1 group third with almost 13 per cent. These three groups contain 137 drainage lakes, or about 49 per cent of the total number. Adding this number to the 30 lakes of the 0.5-0.9 mg/1 group gives a total of 167 lakes in these four groups, which is almost 60 per cent of the total number of drainage lakes. In comparison with this, there are 185 seepage lakes, or 78 per cent of the total number, in the three groups between 1.0 and 2.4 mg/1. The two types of lakes are alike in that their maximum numbers fall within approximately the same range; that is, between 0.5 and 2.4 mg/1 of free carbon dioxide, which is generally about the quantity of free carbon dioxide absorbed by water when freely exposed to the atmosphere.

Thirty-six of the drainage lakes, or almost 13 per cent of the total number, gave a mean alkaline reaction to phenolphthalein. The quantity of monocarbonate carbon dioxide in them ranged from a minimum of —0.1 mg/1 to a maximum mean of —4.3 mg/1. Table III includes the 7 drainage lakes in which the largest amounts of monocarbonate carbon dioxide were found; in other words, they represent the maximum deficiencies of half-bound carbon dioxide. The maximum for a single sample was obtained at the surface of Mann Lake on July 7, 1928, namely —10.7 mg/1; the next in rank was —6.0 mg/1 in Allen of Brazell Lake. The hydrogen ion of these 7 samples ranged from pH 8.2 to 9.1 and the bound carbon dioxide content from 14.5 to 25.6 mg/1. In comparison with the drainage lakes, the surface waters of all of the seepage lakes gave a mean acid reaction to phenolphthalein.

The other drainage lakes, 244 in number, gave a mean acid reaction to phenolphthalein, ranging from a minimum of 0.1 mg/1 to a maximum of 7.0 mg/1 of free carbon dioxide. Of this number, the mean carbon dioxide content of 186 did not exceed 2.4 mg/1, while 58, or 20 per cent of the total number of drainage lakes, exceeded this amount. Only 37 seepage lakes, or 15 per cent of the total number, yielded means of 2.5 mg/1 or more of free carbon dioxide. In the drainage type, 13 lakes had 5.0 mg/1 or more as compared with 6 of the seepage type. The drainage lakes possessing this large amount of free carbon dioxide are similar to those of the seepage class in that they belong chiefly to the bog type and most of them have highly colored waters. In 9 of 13 drainage lakes with high free carbon dioxide, the color readings were well above 100 on the platinum-cobalt scale. The last column in Table IV shows that the waters of these 13 drainage lakes contained rather large amounts of organic carbon, thus indicating that they possessed corresponding amounts of organic matter; the decomposition of this organic matter would tend to increase the free carbon dioxide content of the water.

Variations in Free Carbon Dioxide

Observations were not made frequently enough on any one lake to show the seasonal or annual variations in the free carbon dioxide content of the surface water; in all lakes except Trout, the number of determinations was limited to one to three each year during the period of the general chemical survey; that is, from 1925 to 1930, inclusive. Certain quantitative differences were noted in some of the lakes in different years, however.

The maximum difference in free carbon dioxide content of the surface water was found in Mann Lake where the quantity ranged from —10.7 mg/1 on July 7, 1928 to 4.0 mg/1 on August 14, 1929, thus making a net difference of 14.7 mg/1 of carbon dioxide. Carroll Lake showed the next highest difference which ranged from —3.0 mg/1 to 2.7 mg/1, or a total of 5.7 mg/1. Upper Gresham was third with a maximum difference of 5.1 mg/1; 7 other lakes showed annual differences of 4.0 to 5.0 mg/1.

The largest number of free carbon dioxide determinations was made on the surface water of Trout Lake, namely 26; the quantity of free carbon dioxide varied from —0.9 mg/1 to 2.8, a difference of 3.7 mg/1. The mean quantity of free carbon dioxide in the 26 samples was 1.4 mg/1; only two of them gave an alkaline reaction to phenolphthalein.

In the lakes and bog lakelets whose surface waters always gave an acid reaction to phenolphthalein, the maximum difference in free carbon dioxide was found in the Forestry Bog where the amount varied from 4.7 to 10.7 mg/1 in four sets of observations. The Cardinal Bog was second; the quantity varied from 5.8 to 10.0 mg/1 in the five surface samples obtained from it.

In the larger bodies of water belonging to this group, and especially in those without any bog characteristics, the variations in the quantity of free carbon dioxide from year to year were not so marked; the mean difference for 163 lakes which were visited more than once was 1.2 mg/1. These differences ranged from zero to 4.5 mg/1; it exceeded 2.0 mg/1 in only 24 of the 163 lakes.

Vertical Distribution of Free Carbon Dioxide

The vertical distribution of the free carbon dioxide is substantially the same in the seepage and drainage lakes, so that the two types need not be separated for this discussion. Both classes are represented in the diagrams (Figs. 2-15 and 17-27) and the type to which each belongs is indicated in the explanations of the figures.

In lakes that are shallow enough for the wind to keep the water in complete circulation during the summer, the free carbon dioxide, as well as the other dissolved substances, is uniformly distributed from surface to bottom. This kind of distribution is shown in Bear Lake (Fig. 2). While there was a slight decrease in the temperature of the water at the bottom, there was no change in the dissolved gases 1 m. above the bottom. A slight stratification was noted in the deepest part of Dorothy Dunn Lake (Fig. 3) and this was accompanied by an increase in the quantity of free carbon dioxide near the bottom. Lake Laura shows a similar situation (Fig. 4) and somewhat larger amounts of free carbon dioxide were noted in the lower water of Finley and Weber lakes (Figs. 5, 6) and still larger quantities in Allequash, Blue and Bragonier (Figs. 7, 8, 9); the latter three had 9.0, 12.0 and 14.2 mg/1, respectively, in the deeper water. The maximum depths in these 8 lakes range from 6 to 13 m.

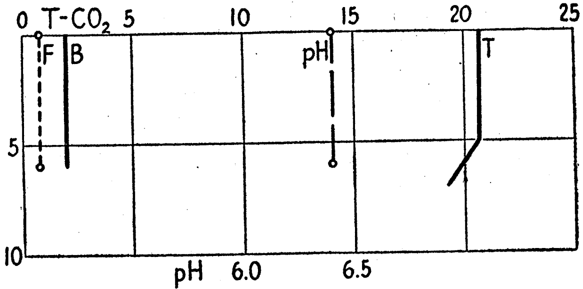

Fig. 2

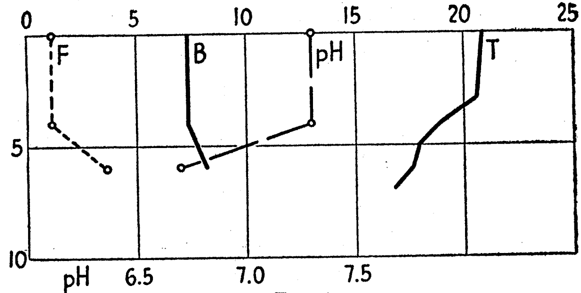

Fig. 3

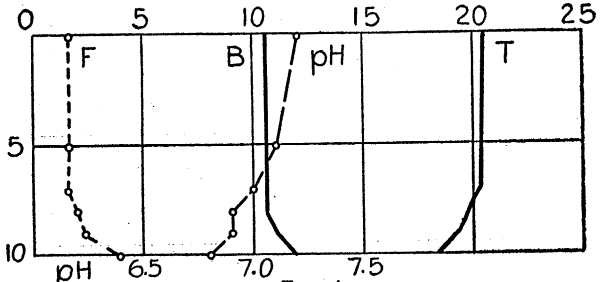

Fig. 4

FIG. 2. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Bear Lake, July 25, 1925. A seepage lake.

FIG. 3. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Dorothy Dunn Lake, August 28, 1926. A drainage lake.

FIG. 4. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Lake Laura, August 9, 1926. A seepage lake.

A rather large variation in the free carbon dioxide content of the lower water was found in lakes ranging from 15 to 20 m. in depth. Big Carr and Crystal lakes (Figs. 10, 11) belong to the seepage type and they show comparatively small increases in free carbon dioxide in the lower water; the amount was 5.6 mg/1 in the former and 5.0 mg/1 in the latter in the deepest samples. In Muskellunge, Papoose and Two Sisters lakes (Figs. 12, 13, 14), there was a more marked increase of free carbon dioxide in the thermocline and hypolimnion; a maximum of 21.5 mg/1 was found in the sample taken 1 m. above the bottom in Muskellunge Lake on August 25, 1932, while the deepest sample (18 m.) in Papoose Lake yielded 9.0 mg/1 on August 2, 1928. Nebish Lake, with a maximum depth of 15.8 m., yielded 21.6 mg/1 of free carbon dioxide at 14 m. on August 23, 1932 (Fig. 15).

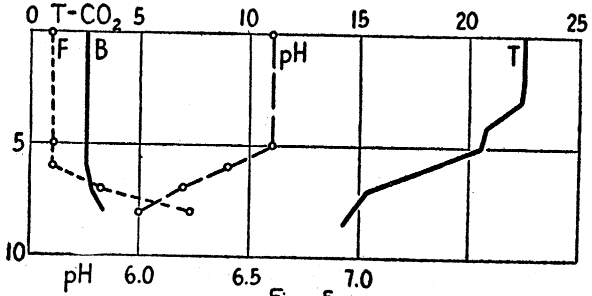

Fig. 5

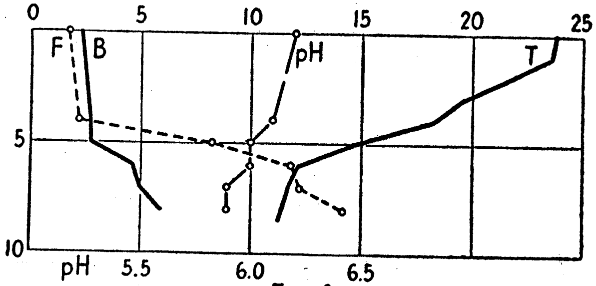

Fig. 6

FIG. 5. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Finley Lake, July 28, 1927. A seepage lake.

FIG. 6. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Bragonier Lake, July 28, 1927. A seepage lake with brown colored water. Compare with fig. 5.

Anderson, Pallette and Silver lakes (Figs. 17, 18, 19) showed a different type of vertical distribution of free carbon dioxide; there was a smaller amount in the thermocline than either above or below this stratum. These decreases in the carbon dioxide content of the water in the thermocline were due to the photosynthetic activities of the phytoplankton of this stratum. The maximum consumption of carbon dioxide in the thermocline was found in Pallette Lake on August 22, 1928 (Fig. 18); on this date all of the free and 2.6 mg/1 of the half-bound carbon dioxide at 8 m. had been used by the phytoplankton in the process of assimilation. Similar but smaller losses of half-bound carbon dioxide were observed in the thermocline of Pallette Lake on August 17, 1927 and on July 21, 1931. A maximum loss of —1.7 mg/1 of half-bound carbon dioxide was found at 7 m. in Anderson Lake on August 8, 1929 and of —1.2 mg/at 9 m. in Silver Lake on July 25, 1931. These decreases in the carbon dioxide content of the water of the thermocline were correlated with increases in dissolved oxygen and with higher pH values as shown in the diagrams. Attention may also be called to the marked rise in the free carbon dioxide content of the lower water in these three lakes; a maximum of 27.5 mg/1 was found at 18 m. in Silver Lake.

Figures 20 to 27 show the vertical distribution of the free carbon dioxide in some of the lakes that are more than 20 m. deep. In all of them except Presque Isle Lake, the water of the epilimnion contained free carbon dioxide; the amount ranged from 1.0 to 2.3 mg/1. In Presque Isle Lake, the upper water was alkaline to phenolphthalein; the maximum loss of half-bound carbon dioxide was equivalent to —1.0 mg/1 at a depth of 5 m. In all of these lakes, including Presque Isle, there was a more or less marked increase in the quantity of free carbon dioxide in the lower water; the amount ranged from 7.8 mg/1 in the bottom water of Fence Lake (Fig. 24) to 42.5 mg/1 in that of Lake Mary (Fig. 25).

BOUND CARBON DIOXIDE

Some 2,800 methyl orange titrations were made during this investigation for the purpose of determining the bound carbon dioxide content of the various waters. Of this number, 1,200 were surface samples and 1,600 came from other depths. These titrations showed that the 518 lakes and lakelets covered a wide range in bound carbon dioxide content; the quantity in the surface waters ranged from a minimum of 0.2 mg/1 in two lakes to a maximum of 39.0 mg/1 in a small spring-fed lakelet.

The seepage and drainage lakes showed marked differences in their bound carbon dioxide content in most cases and the various bodies of water have been separated into these two classes for purposes of comparison. Both types have been further separated into groups by one milligram intervals on the basis of the bound carbon dioxide content of the surface waters. The results of these groupings are given in Tables V and VII.

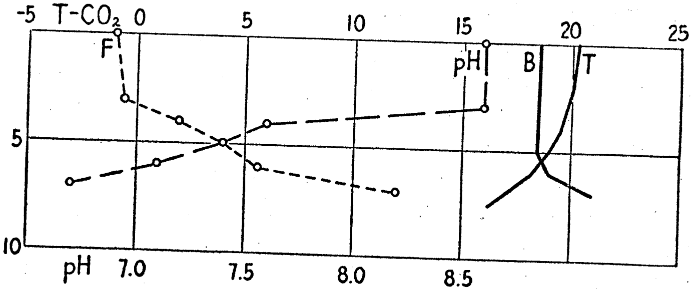

FIG. 7. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Allequash Lake, August 15, 1926. A drainage lake.

Seepage Lakes

Surface waters. The mean quantity of bound carbon dioxide in the surface waters of the seepage lakes is given for the various groups in Table V. This table includes results obtained from 238 lakes; of this number, 132 were single determinations on each lake, while from 2 to 17 surface samples were secured from each of the other lakes. The largest number (17) was taken in Weber Lake during the period from 1925 to 1932 inclusive; 14 surface determinations each were made on Crystal and Muskellunge lakes during the same period of time. In compiling Table V, the mean of the various analyses was used in grouping the 106 lakes visited more than once.

In a previous report (Juday and Birge 1933), it was pointed out that many of these seepage lakes have very low specific conductances, which indicates that their waters contain correspondingly small amounts of electrolytes. In view of this fact, it is not surprising that 29 of them, or a little more than 12 per cent of the number belonging to this class, yielded less than 1.0 mg/1 of bound carbon dioxide, while 106, or more than 44 per cent of the total, yielded between 1.0 and 1.9 mg/1; that is, the surface waters of 135 of these seepage lakes, which is more than 56 per cent of the total number, did not contain more than 1.9 mg/1 of bound carbon dioxide. The table also shows that only 16 of the seepage lakes (6.7 per cent of the total) yielded 5.0 mg/1 or more and none of them exceeded a mean of 11.3 mg/1.

Their distribution into the various groups is shown graphically in Figure 16, where they are grouped by 2.0 mg/1 intervals. This diagram serves to bring out more clearly the fact that only a very small percentage of the seepage lakes yielded as much as 4.0 mg/1 of bound carbon dioxide or more; nearly 89 per cent of them had less than 4.0 mg/1 and more than 56 per cent of them had less than 2.0 mg/1.

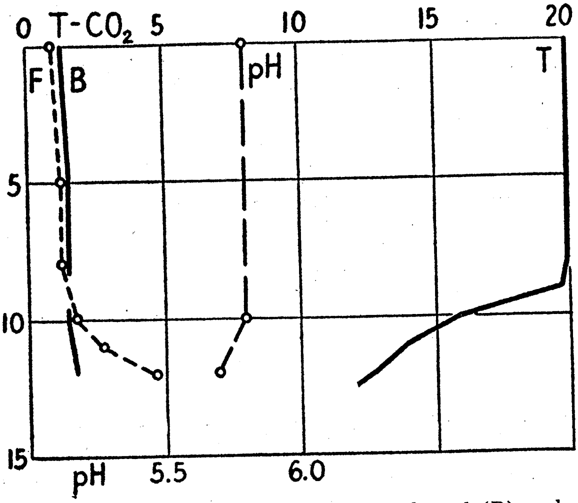

FIG. 8. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Weber Lake, August 29, 1928. A seepage lake. Compare with figs. 5 and 9.

The small amount of bound carbon dioxide found in the waters of a large percentage of the seepage lakes is due in part to the scarcity of calcium and magnesium in the glacial deposits of the region and in part to the isolation of the lake waters from the ground waters. While the glacial debris contained only a relatively small amount of calcareous material at the time of its deposition, the quantity of it has been reduced still further by the process of leaching; this is true especially of the upper or soil stratum. In some localities, for example, it would require from one to more than 5 metric tons of lime per hectare to correct the soil acidity for agricultural purposes. Thus the limited amount of water that drains into these lakes from the adjacent land contains only small amounts of carbonate substances in solution.

A maximum mean of 11.3 mg/1 of bound carbon dioxide was found in Forest Lake, which indicates that it lies in an area that is more abundantly supplied with calcareous material than most of the other seepage lakes. The next highest mean was 10.8 mg/1 in Lake Laura, while a single sample from the surface of Sandy Beach Lake also yielded 10.8 mg/1. None of the surface samples from the other seepage lakes contained as much as 10.0 mg/1 of bound carbon dioxide and only 4 of them fell between 9.0 and 10.0 mg/1.

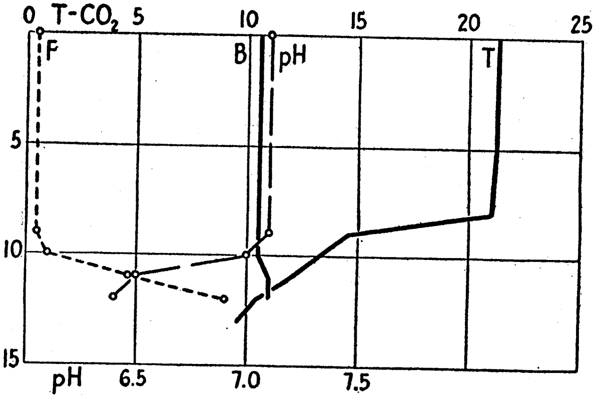

FIG. 9. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Blue Lake, August 6, 1929. A seepage lake. Compare with fig. 8.

Variations. Annual variations were noted in the bound carbon dioxide content of the surface waters of most of the seepage lakes that were visited more than once. A fourfold difference was found in Crystal Lake; the quantity ranged from 0.5 mg/1 on July 14, 1931 to 2.0 mg/1 on June 26, 1926, in 12 different samples. In 5 lakes the differences were three-fold and in 20 others they were twofold or more, but less than threefold. While these percentile differences seem large, the actual quantitative differences were comparatively small. In all of these high percentage cases, the quantitative difference exceeded 2.0 mg/1 of bound carbon dioxide in only one lake; it did not exceed 1.0 mg/1 in 8 lakes, so that the differences fell between 1.0 and 2.0 mg/1 in 17 of the high percentage lakes. Samples obtained from 4 of the seepage lakes in different years yielded the same quantity of this gas in both years.

In the 106 seepage lakes that were visited more than once, the variation in the bound carbon dioxide content of the surface water ranged from zero in these 4 lakes to a maximum of 3.5 mg/1 in Lake Laura; in the latter a minimum of 9.3 mg/1 was found on August 19, 1927 and a maximum of 12.8 mg/1 on August 23, 1929, so that the percentile difference was only a little more than 27 per cent of the maximum quantity. The range of variation in the various lakes is given in Table VI. In 71 of the 106 lakes, the annual differences in bound carbon dioxide content of the surface waters did not exceed 1.0 mg/1 and it exceeded 2.0 mg/1 in only 6 of them. In the great majority of the seepage lakes, therefore, these annual differences may be regarded as small from a quantitative standpoint. Results for a number of seepage lakes are given in Table XII.

Drainage Lakes

Surface waters. The drainage lakes fall into two general classes, namely, those which are not fed by permanent streams or springs and those which receive water from these sources. The drainage lakes which do not have streams or springs flowing

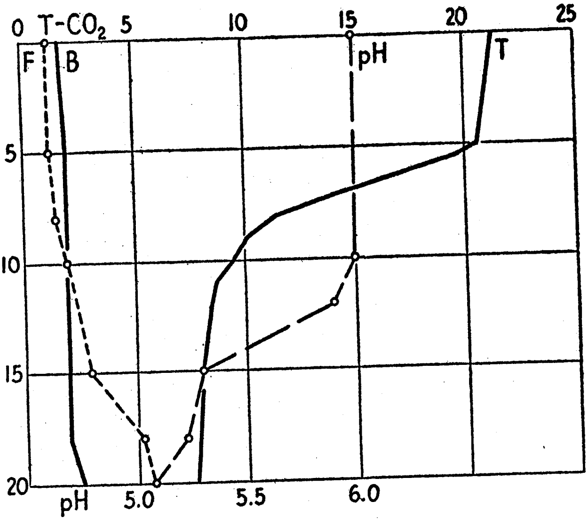

FIG. 10. Vertical distribution of free (F) and bound (B) carbon dioxide, pH and temperature in Big Carr Lake, July 12, 1929. A seepage lake.

into them possess certain seepage characteristics in that they have rather limited drainage basins and their waters contain relatively small amounts of electrolytes in solution. They make up the groups of drainage lakes which have the smallest amounts of bound carbon dioxide. Since they are the sources of small, more or less intermittent streams, however, they are classified as drainage lakes.

In the drainage lakes that are fed by springs and streams, the effect of the inflowing water upon the bound carbon dioxide content of the lake water depends chiefly upon the quantity of this gas in the former and upon the volume of the inflowing water in comparison with that of the lake. A large volume of stream or spring water flowing into a small lake will have a marked influence on the chemical status of the lake water, while the reverse would minimize the effect of the inflowing water. In general then, the lakes that are traversed by the larger streams, such as the Manitowish River, are affected to a greater degree by the inflowing water than those that lie in the courses of the smaller streams. In lakes of equal volume, the one receiving a large amount of spring water would be affected more than the one receiving a relatively small amount.

As a result of the modifications produced by the inflowing water as well as by other factors, the bound carbon dioxide content of the surface waters of the drainage lakes covers a much wider range than that of the seepage lakes. The quantity in the former ranged from a minimum of 1.0 mg/1 in Clear Lake (Langlade County) to a maximum of 39.0 mg/1 in the Inkpot, a small spring-fed lakelet lying a short distance north of Anderson and Black Oak lakes. Twin Island Lake was second highest with 31.5 mg/1 and Wild Cat was third with a mean of 30.5 mg/1. More than 60 per cent of the drainage lakes had a larger amount of bound carbon dioxide than the maximum quantity (11.3 mg/1) found in the seepage lakes.

The 280 drainage lakes have been separated into groups on the basis of the bound carbon dioxide content of their surface waters. These groupings are given in Table VII and the results are shown graphically in Figure 16. As indicated above, the drainage lakes with seepage characteristics are found in the groups having the smallest amounts of bound carbon dioxide.

None of these lakes had less than 1.0 mg/1, but 7 of them fell in the 1.0-1.9 mg/1 group and 13 in the 2.0-2.9 mg/1 group. In comparison with this, 186 seepage lakes, or 78 per cent of the total number in this class, did not exceed 2.9 mg/1, while only 20 drainage lakes, or 7 per cent of the total number, yielded such small amounts of bound carbon dioxide. The differences in the groupings of the two classes of lakes are shown in Figure 16, where the distribution of the seepage lakes is shown in the upper part of the diagram and the wider range of the drainage lakes in the lower part. The figure shows a maximum of 48 lakes, or a little more than 17 per cent of the total number, in the 14.0-15.9 mg/1 group of drainage lakes as compared with a maximum of 135 lakes, or more than 56 per cent of the total number, in the 0.0-1.9 mg/1 group of the seepage type. The 4 drainage lakes with 28.0 mg/1 of bound carbon dioxide or more have been omitted from the diagram, but they are represented in Table VII; they ranged from 28.0 mg/1 in Post Lake to 39.0 mg/1 in the Inkpot.

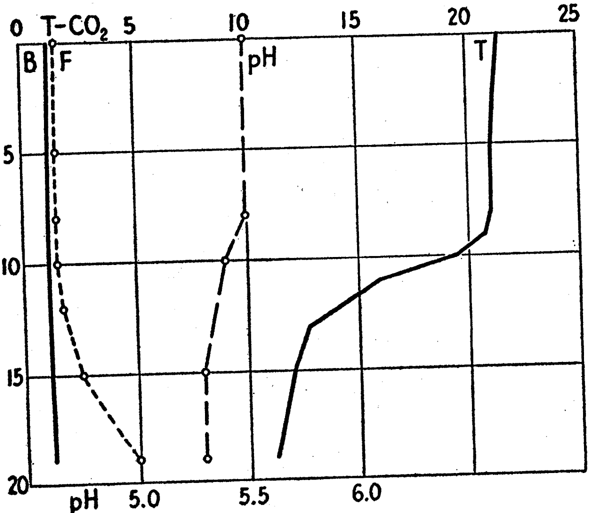

FIG. 11. Vertical distribution of free (F) and bound (B) carbon dioxide, pH and temperature (T) in Crystal Lake, August 11, 1932. A seepage lake with high transparency and unstained water. Note that the quantity of bound carbon dioxide is smaller than that of the free. Very soft water.

Variations. A summary of the variations in the bound carbon dioxide content of the surface waters of the drainage lakes that were visited more than once is given in Table VIII. In 29 of the 136 lakes included in the table, the maximum annual differences did not exceed 1.0 mg/1 and in 47 others they fell between 1.0 and 2.0 mg/1, so that in 76 of these lakes, or approximately 56 per cent of the number in this group, the differences did not exceed 2.0 mg/1. In comparison with this, 100 seepage lakes, or a little more than 94 per cent of the 106 that were visited more than once, fall in this same category.

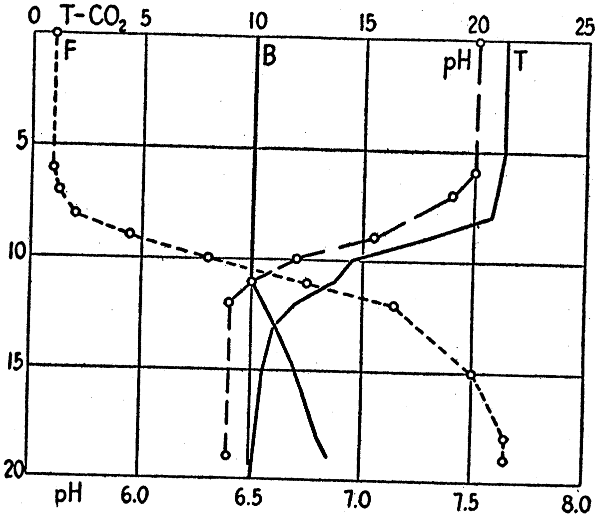

FIG. 12. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Muskellunge Lake, August 25, 1932. A seepage lake.

In 28 of the drainage lakes, the difference exceeded 3.0 mg/1, while only one of the seepage lakes exceeded this amount; the seepage lakes, therefore, as might be expected from their smaller bound carbon dioxide content, showed smaller quantitative annual variations than the drainage lakes, but their percentage differences were larger in many instances. The maximum percentile difference in the drainage lakes was found in Lake George and in Lake Helen; the waters of both of these lakes contained relatively small amounts of bound carbon dioxide. In 3 observations on Lake George, the surface water yielded a minimum of 2.0 mg/1 on July 10, 1927 and on August 4, 1930 and a maximum of 4.0 mg/1 on August 24, 1929. In 5 surface samples from Lake Helen, the bound carbon dioxide content varied from a minimum of 2.5 mg/1 on July 17, 1928 and on August 4, 1930 to a maximum of 5.0 mg/1 on August 18, 1929, so that there was a twofold variation in both of these lakes. In Harvey and Sand lakes, the same readings were obtained in the two different years that they were visited.

The maximum quantitative difference, 8.5 mg/1, was found in Mann Lake; the bound carbon dioxide content of the surface water of this lake was 30.5 mg/1 on August 14, 1929 and 22.0 mg/1 on May 5, 1927. Considering the 5 July and August determinations, however, the difference was only 5.5 mg/1, since the smallest summer reading was 25.0 mg/1. The second largest difference was 6.9 mg/1, which was noted in the surface water of Big Lake.

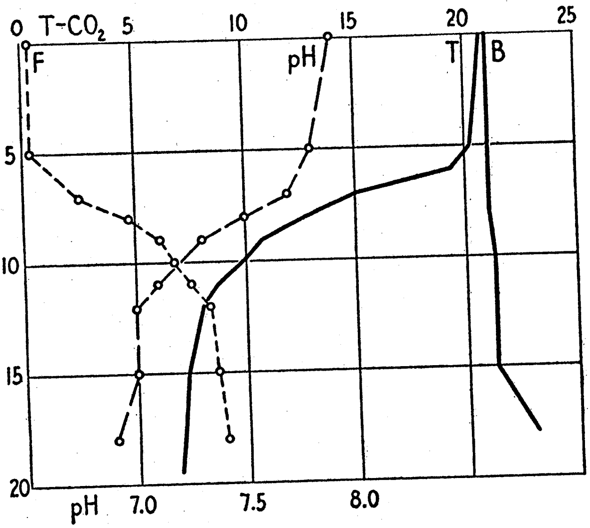

FIG. 13. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Papoose Lake, August 2, 1928. A drainage lake. Compare with fig. 12.

Vertical Distribution

The vertical distribution of the bound carbon dioxide is given for a number of lakes in Table XII, and the results for some of them are shown in Figures 2-15 and 17-27. The character of the vertical distribution is dependent to a large extent upon the thermal stratification of the water, which in turn depends chiefly upon the depth and area of the lake. In shallow lakes where the entire body of water is kept in circulation during the summer, the bound carbon dioxide is uniformly distributed from surface to bottom; where the water is deep enough to become thermally stratified, there may be more or less marked differences between the bound carbon dioxide content of the epilimnion and of the hypolimnion, but in lakes with a small bound carbon dioxide content the distribution is usually about uniform from surface to bottom even when the water is stratified. Owing to the small quantity of bound carbon dioxide generally present in the waters of the seepage lakes, the differences in vertical distribution are not as marked as in the drainage lakes; therefore, the two groups are discussed separately.

Seepage lakes. As already indicated, the surface-bottom differences in bound carbon dioxide content are not so great in the seepage lakes. A uniform distribution is shown by Bear Lake (Fig. 2) which is shallow enough to be kept in practically complete circulation in summer. A uniform distribution is shown also by Crystal Lake (Fig. 11) which is deep enough to be thermally stratified. In Weber Lake (Fig. 8), there was a slightly larger amount of bound carbon dioxide in the lower than in the upper water. Similar results are shown for Big Carr, Blue, Finley, Laura and Pallette lakes (Figs. 10, 9, 5, 4, 18).

The maximum difference between upper and lower strata was noted in Bragonier and in Muskellunge lakes (Figs. 6, 12). In the former lake, the surface water yielded 2.5 mg/1 and the 8 m. sample (0.5 m. above the bottom) 7.0 mg/1. In Muskellunge Lake the surface water contained 10.0 mg/1 and that at 20.3 m. yielded 14.5 mg/1 of bound carbon dioxide. Anderson Lake showed the next largest difference with 12.5 mg/1 at the surface and 16.5 mg/1 at 19 m.; Ike Walton was third with a difference of 3.3 mg/1. Two other seepage lakes, namely Clear (Oneida County) and Little John Jr., showed a difference of 2.0 mg/1 between surface and bottom, but in 23 others the differences were all less than 2.0 mg/1; in 12 of the latter, in fact, they were less than 1.0 mg/1.

Drainage lakes. As might well be expected, the larger bound carbon dioxide content of the great majority of the drainage lakes gave rise to more marked differences between the quantity of this gas in the epilimnion and that in the hypolimnion. In 33 drainage lakes on which series of samples were taken, the maximum difference was found in Wild Cat Lake; on August

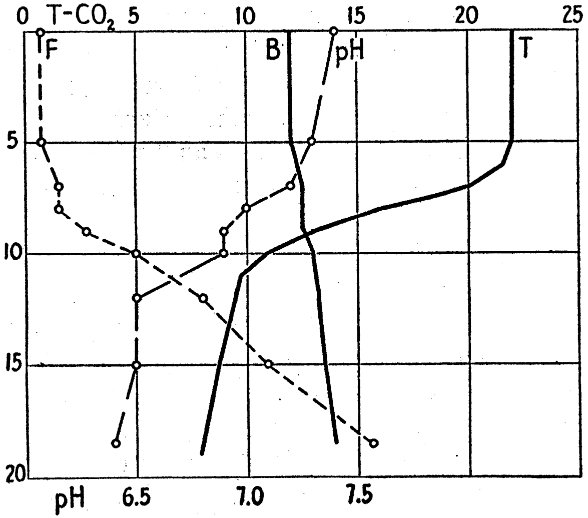

Fig. 14. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature in Two Sisters Lake, August 13, 1929. A drainage lake. Compare with figs. 12 and 13

24, 1926 the surface water of this lake yielded 30.8 mg/1 and that at 11 m. (1 m. above the bottom) contained 44.1 mg/1 of bound carbon dioxide, a difference of 13.3 mg/1. In 5 other series from this lake the differences between surface and bottom ranged from 4.6 to 11.5 mg/1. The next largest difference was noted in Nebish Lake; the bound carbon dioxide content of the surface water on August 29, 1931 was 3.5 mg/1 and that of the 14 m. sample was 13.0 mg/1, a difference of 9.5 mg/1. A series in which the bound carbon dioxide of this lake ranged from 4.0 mg/1 at the surface to 8.0 mg/1 at the bottom is shown in Figure 15.

A surface-bottom difference of 9.2 mg/1 was noted in the bound carbon dioxide of Lake Mary on July 12, 1926. A series taken in this lake on July 11, 1928 is represented in Fig. 25; in this instance the surface water yielded 3.7 mg/1 and that at 20 m. 11.5 mg/1. The surface water of Upper Gresham Lake contained 18.3 mg/1 and that at 7 m. (1 m. above the bottom) 25.6 mg/1, a difference of 7.3 mg/1. In the other 29 drainage lakes in which series were taken, the difference between the bound carbon dioxide content of the surface and the bottom strata ranged from zero in Stone Lake at Crandon to a maximum of 6.5 mg/1 in Silver Lake; the difference was less than

2.0 mg/1 in 11 of these lakes and did not exceed 1.0 mg/1 in 4 of them. Some of the moderate differences between the bound carbon dioxide content of the upper and lower strata are shown in the diagrams representing Adelaide, Black Oak, Crawling Stone, Dead Pike, Fence, Presque Isle, and Trout (Figs. 20-26); Lake Mary showed the largest difference represented in the diagrams.

While the photosynthetic activities of the phytoplankton gave the water of the thermocline an alkaline reaction to phenolphthalein in Anderson, Pallette and Silver lakes (Figs. 17, 19), there was no decrease in the bound carbon dioxide of these strata; this indicates that the quantity of monocarbonate which gave the water an alkaline reaction to phenolphthalein was not large enough to cause a precipitation of the calcium. Such decreases have been found in other Wisconsin lakes, however, where the water contained a larger amount of bound carbon dioxide than is found in the northeastern lakes.

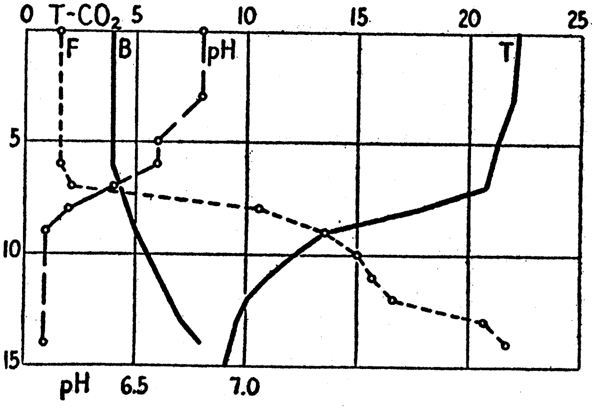

FIG. 15. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Nebish Lake, August 23, 1932. A drainage lake. Compare with fig. 14.

This phenomenon was observed in Beasley and Knights lakes, for example, which are situated in central Wisconsin. (Birge and Juday 1911). In Beasley Lake on August 3, 1908, the bound carbon dioxide content of the surface water was 73.8 mg/1, that at 5.5 m. was 63.8 mg/1 and that at 14 m. was 85.6 mg/1, so that the amount at 5.5 m. was 10.0 mg/1 less than that at the surface. The smaller quantity at 5.5 m. was correlated with a marked alkaline reaction of the water to phenolphthalein and with an excess of dissolved oxygen amounting to 20.3 mg/1, or 212 per cent of saturation. There was also a smaller amount of calcium at 5.5 m.; it decreased from 36.2 mg/1 at 4 m. to 30.0 mg/1 at 5.5 m. and then rose to 38.3 mg/1 at 7 m. Through the removal of half-bound carbon dioxide by the phytoplankton at 5.5 m., the normal calcium carbonate exceeded the saturation point and some of it was precipitated and sank into the lower water.

In Knights Lake on August 25, 1909, the bound carbon dioxide amounted to 82.4 mg/1 at the surface, 71.8 mg/1 at 4 m. and 104.2 mg/1 at 11 m., so that the quantity at 4 m. was 10.6 mg/1 less than that at the surface; the dissolved oxygen at 4 m. amounted to 31.1 mg/1, or 328 per cent of saturation.

Bound Carbon Dioxide Content of Other Lakes

In 1911 Birge and Juday published results on the bound carbon dioxide content of 151 Wisconsin lakes; 58 of these lakes belong to the northeastern group, 63 are situated in the northwestern quarter of the state and 30 in the southeastern quarter. Those belonging to the northeastern group are included in the present investigation. In the 63 lakes of the northwestern group, the bound carbon dioxide content of the surface water ranged from a minimum of 0.8 to a maximum of 43.1 mg/1; in 14 of them the quantity did not exceed 5.0 mg/1, while 4 yielded 40.0 mg/1 or more. Calcareous material is more plentiful in the southeastern quarter of the state, so that the lake waters of this section contain a larger amount of bound carbon dioxide. With one exception, the quantity ranged from 59.4 to 93.0 mg/1 in these lakes. The exception is Devils Lake which occupies a quartzite basin; its water yielded only 6.3 mg/1.

In 10 of the Finger lakes of New York, the quantity varied from 13.7 mg/1 in Canadice Lake to 47.6 mg/1 in Canandaigua; Canadice was the only one, however, that fell below 25.0 mg/1. Seneca and Cayuga lakes, the largest and deepest members of this group, yielded 43.6 mg/1. (Birge and Juday 1914).

Kemmerer, Bovard and Boorman (1923) found that the bound carbon dioxide content of 53 lakes situated in the northwestern part of the United States ranged from a minimum of

2.5 mg/1 to a maximum of 947.6 mg/1. The waters of 21 yielded less than 10.0 mg/1 and only 4 more than 60.0 mg/1. The deepest one, Crater Lake, contained 12.5 mg/1 and the next deepest, Lake Tahoe, 17.5 mg/1.

In some 70 Minnesota lakes, Johnson (1933) found that the bound carbon dioxide varied from 10.7 to 90.0 mg/1; only 3 of them yielded less than 25.0 mg/1.

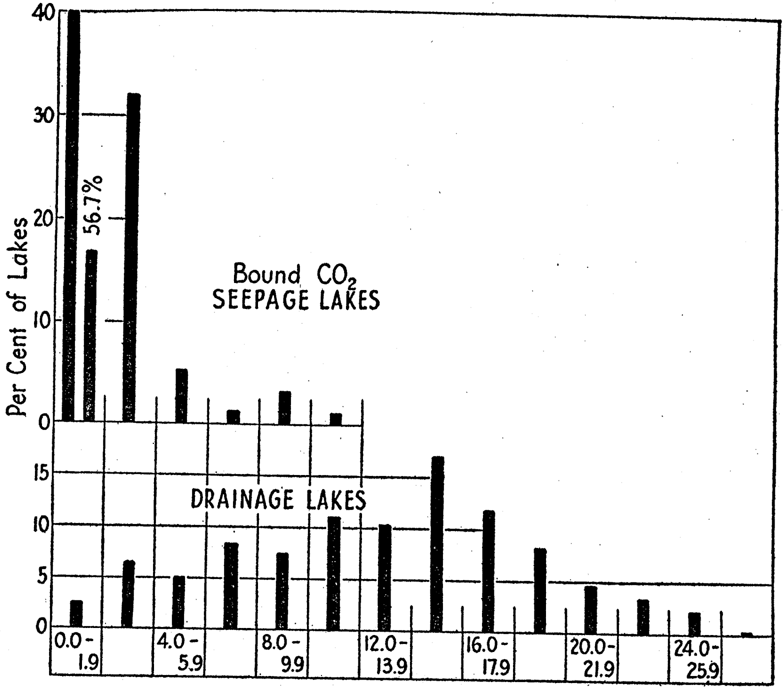

FIG. 16. This diagram shows the grouping of the seepage and drainage lakes on the basis of the bound carbon dioxide content of their surface waters. The vertical spaces represent the percentage of lakes in each group and the horizontal scale shows the amount of bound carbon dioxide. The diagram is based on results given in Tables V and VII. Compare with fig. 1.

In comparison with the above results, Table V shows that 222 seepage lakes of northeastern Wisconsin had less than 5.0 mg/1 of bound carbon dioxide; this is a little more than 93 per cent of the seepage lakes that were visited. The table also shows that 29 of them yielded less than 1.0 mg/1 and gave a mean of 0.7 mg/1. In the drainage group (Table VII), the surface waters of 33 lakes, or almost 12 per cent of the total number, yielded less than 5.0 mg/1. One of the most important characteristics of the waters of these northeastern lakes is the large percentage of them with very small quantities of bound carbon dioxide.

Bound Carbon Dioxide and Specific Conductance

The relation of the bound carbon dioxide of these lake waters to their specific conductance has been discussed in a previous report (Juday and Birge 1933). A definite correlation between these two factors was found; that is, small amounts of bound carbon dioxide were correlated with low specific conductances and large amounts with high conductances. The mean quantity of bound carbon dioxide rose from 1.4 mg/1 in the 5-9 $\times 10^{-6}$ conductance group to 26.2 mg/1 in the 100-124 $\times 10^{-6}$ group. Rather wide variations in the quantity of bound carbon dioxide were found in the same conductance group, but the general means of the various conductance groups showed a consistent correlation. These results confirm what has been noted in other data regarding these lakes; while there may be a rather wide range in the correlation between two factors in a single group, the means of the various groups yield a consistent relation when they represent an average of 15 cases or more in each group.

An average of the whole series of observations on the surface waters of the various lakes indicates that an increase of approximately 2.3 mg/1 in the bound carbon dioxide content is correlated with an increase of 10×10^{-6} in specific conductance. It was noted that relatively small changes in the bound carbon dioxide from year to year were not accompanied by similar changes in the specific conductance of the water, but there was a general shift in the latter in correlation with the more marked variations in the former. The coefficient of correlation between bound carbon dioxide and specific conductance was 0.89 in 241 seepage lakes and 0.94 in 292 drainage lakes.

Senior-White (1927) obtained similar results on 35 natural waters of Ceylon which he investigated. There was a close relationship between the specific conductance and the total carbon dioxide content of these waters. While he found considerable individual divergencies in some cases, there was a general increase in conductance with increasing amounts of carbon dioxide and the coefficient of correlation of the entire series was 0.88.

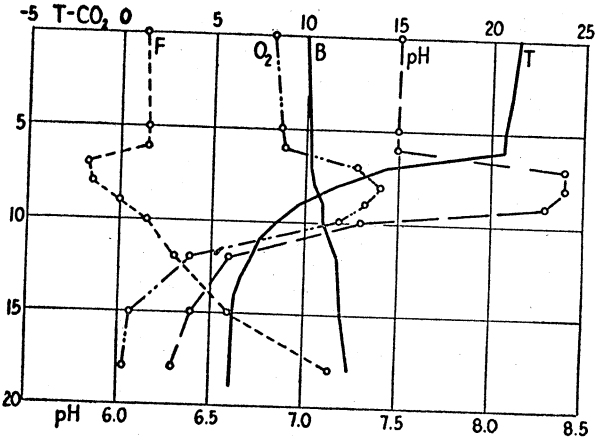

FIG. 17. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Anderson Lake, August 18, 1929. A seepage lake. Compare with figs. 14, 18, and 19.

An increase in specific conductance with increasing depth was noted in the Wisconsin lakes which yielded a larger quantity of bound carbon dioxide in their lower strata.

Bound Carbon Dioxide and Calcium

Table IX shows the relation between the quantity of bound carbon dioxide in the surface waters of 357 lakes and the amount of calcium found in the corresponding samples of water. A large percentage of these samples yielded only small amounts of calcium, and they also contained correspondingly small quantities of bound carbon dioxide. The second group in the table includes the largest number of lakes, namely 68, while the first group is second with 60 lakes; thus the first two groups include 128 lakes, or a little more than 35 per cent of the number on which calcium determinations were made. The surface waters of the lakes belonging to these two groups yielded less than 4.0 mg/1 of bound carbon dioxide and the mean quantity of calcium in them was 0.8 and 1.0 mg/1, respectively.

There is a more even distribution of the lakes falling between the 4.0-5.9 and the 18.0-19.9 mg/1 groups; 203 lakes, or about 57 per cent of those represented in the table, are included in these groups, with a maximum of 39 lakes in the 14.0-15.9 group. There are only 25 lakes in the last three groups because

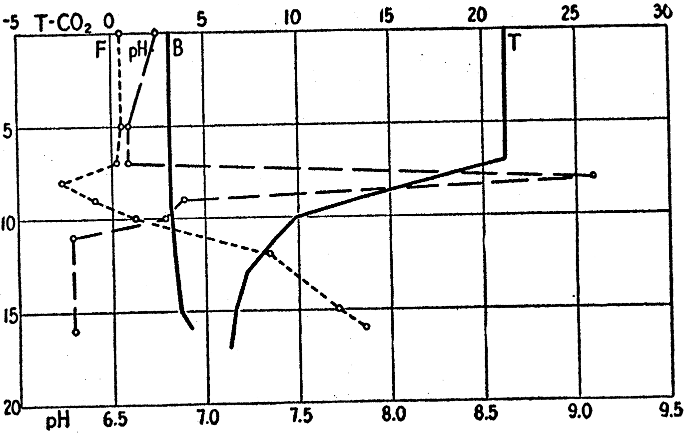

FIG. 18. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temptrature (T) in Pallette Lake, August 22, 1928. A seepage lake. Compare with figs. 17 and 19.

lakes with such large amounts of bound carbon dioxide constitute a relatively small percentage of the total number found in the Highland Lake District of Wisconsin.

While there is a wide range between the maximum and minimum amounts of calcium in the various carbon dioxide groups, the means for the different groups show a general increase in the quantity of calcium correlated with an increase in the amount of bound carbon dioxide. There is a general rise in the mean quantity of calcium from 0.8 mg/1 in the 0.0-1.9 mg/1 carbon dioxide group to a maximum mean of 14.8 mg/1 in the 24.0-31.9 group. The table shows a fourteenfold difference between the maximum and minimum amounts of calcium in the 0.0-1.9 mg/1 group, a twentyfourfold difference in the second group and a twentytwofold difference in the 4.0-5.9 mg/1 group. Beyond the latter group, however, the percentile differences are not so great; the difference between maximum and minimum in the 6.0-7.9 mg/1 group, for example, is only a little more than threefold, while all of those in the higher groups are less. The smallest percentile difference, as well as the smallest quantitative difference, is found in the 9 lakes belonging to the 20.0-21.9 mg/1 group. In spite of these marked differences between maxima and minima in the various groups, the analyses yield consistent means, especially where each group contains 18 lakes

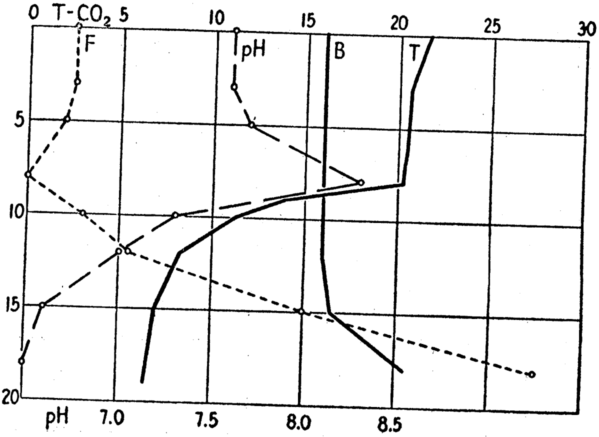

FIG. 19. Vertical distribution of free (F) and bound (B) carbon dioxide, pH and temperature (T) in Silver Lake, August 13, 1932. A drainage lake. Compare with figs. 17 and 18.

or more. In these cases the high results counterbalance the low ones in such a way as to yield a fair mean for the group.

Figure 28 shows graphically the relation between the bound carbon dioxide and the calcium as represented in Table IX. The quantity of calcium is platted at the middle of each bound carbon dioxide group. The diagram contains curves representing the maximum and minimum, as well as the mean, quantities of calcium in the various groups. The middle curve, represented by a solid line, indicates the mean amounts; there are three points in this curve where the gradients are not as steep as they are in the other groups, but the whole curve shows clearly the general increase in bound carbon dioxide content with increasing amounts of calcium.

The upper curve in Figure 28, consisting of a broken line, connects the points representing the maximum amounts of calcium in the different groups, while the lower broken line curve shows the minimum quantities. The irregularities in these two curves are not very great, except the one for the minimum quantity of calcium in the 20.0-21.9 mg/1 group; this group has an unusually large minimum, but a larger number of lakes would undoubtedly modify this result. The small number of lakes in the three groups above 18.0-19.9 mg/1 are hardly sufficient to give fair means, but they match the means of the other groups as well as could be expected for such a small number of lakes in each group.

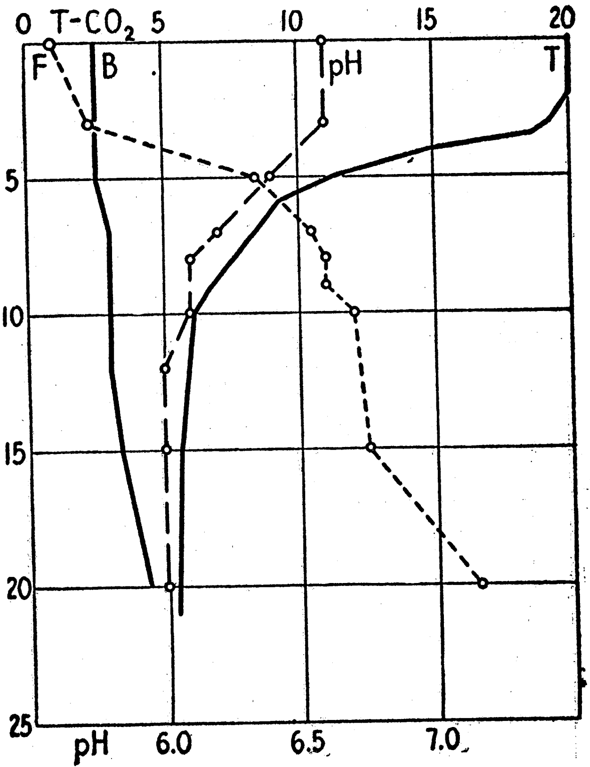

FIG. 20. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Adelaide Lake, August 5, 1927. A drainage lake with a small amount of bound carbon dioxide.

CARBON DIOXIDE OF GROUND WATERS

Observations were made on the carbon dioxide content of 149 well waters and of 7 spring waters in this investigation for the purpose of comparing them with the lake waters. All of the wells except 9 and all of the springs except one are situated on the immediate shores of 80 different lakes. Samples were obtained from only one well on each of 52 lakes, while from 2 to 19 samples were taken from wells and springs located on the shores of each of the other 28 lakes. The maximum number of well samples (19) was taken on Trout Lake; Plum Lake was second with 10 and Muskellunge third with 6. In the other 25 cases, the well and spring samples numbered only 2 to 4 on each lake. Nine samples were obtained from wells that were situated half a kilometer or more from the nearest lake and one spring was about half a kilometer from any lake.

The depth of 112 wells was ascertained, while that of 37 was unknown to the individuals in charge of them at the time the samples were taken. The shallowest well was an open one only 2.5 m. deep, while the deepest one was a drilled well with a depth of 58.2 m. In 84 cases the depth did not exceed 15 m. and only 6 were deeper than 30 m. The great majority of them were driven wells, especially those that did not exceed 15 m. in depth.

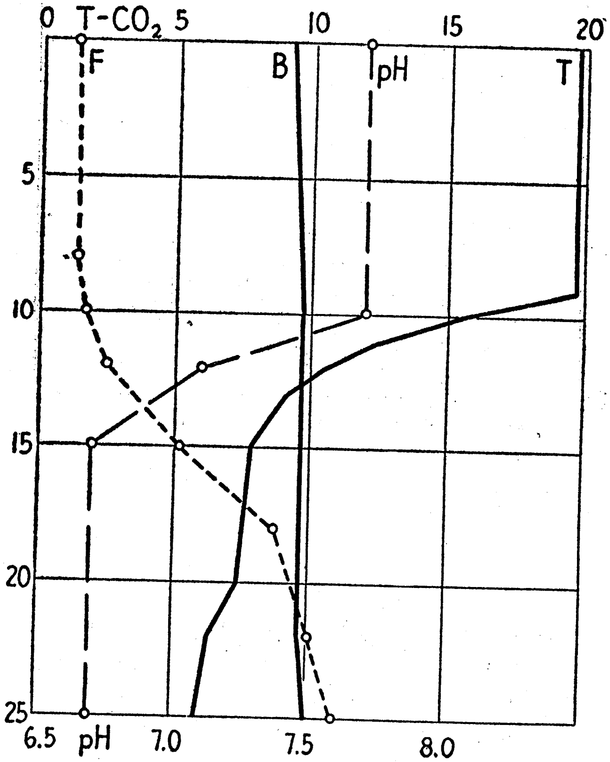

FIG. 21. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Black Oak Lake, August 24, 1928. A drainage lake. Compare with figs. 22 and 23.

Free Carbon Dioxide

The water of 3 wells gave an alkaline reaction to phenolphthalein, thus showing the presence of normal carbonate carbon dioxide; the latter was equivalent to —0.5 mg/1 of carbon dioxide. Two of these wells are about a kilometer from the nearest lake, but the third one is on the immediate shore of Beaver Lake. The results obtained on some of the wells are given in Table XI.

All of the other well samples gave an acid reaction to phenolphthalein; the free carbon dioxide in them ranged from a minimum of 0.5 mg/1 in the Forestry Headquarters well at Trout Lake to a maximum of 67.5 mg/1 in the Warner well on Plum Lake. The second largest amount was noted in the Stover well located on the shore of Clear Lake (Oneida County), namely 58.0 mg/1. Only 8 wells, however, yielded more than 40.0 mg/1, but the amount reached 20 mg/1 or more in 49 cases; it did not exceed 10.0 mg/1 in 45 of the wells.

With one exception, the waters from wells situated on the immediate shores of the various lakes yielded a considerably larger amount of free carbon dioxide than the surface waters of the corresponding lakes. Both the well water and the surface water of Beaver Lake gave alkaline reactions to phenolphthalein; in both cases the amount of monocarbonate present was equivalent to —0.5 mg/1 of carbon dioxide. In 11 other instances, the surface water of the lakes gave an alkaline reaction to phenolphthalein, but all of the well waters of their respective shores gave an acid reaction to this indicator.

The quantity of free carbon dioxide in the waters of the 7 springs ranged from a minimum of 4.0 mg/1 to a maximum of 41.0 mg/1; in the other 5 springs, it varied from 5.5 to 17.5 mg/1.

The general results indicate that there is no direct correlation between the free carbon dioxide content of the ground waters as represented by these wells and springs and that of the corresponding lake waters. Even the wells situated on the shores of the same lake show a wide variation in free carbon dioxide content. This fact is well shown by the results given in Table XI for Muskellunge, Plum and Trout lakes.

Bound Carbon Dioxide

There was a wide variation in the bound carbon dioxide content of the 149 well waters; the minimum was 2.0 mg/1 and the maximum 100.0 mg/1, which represents a fiftyfold range in quantity.

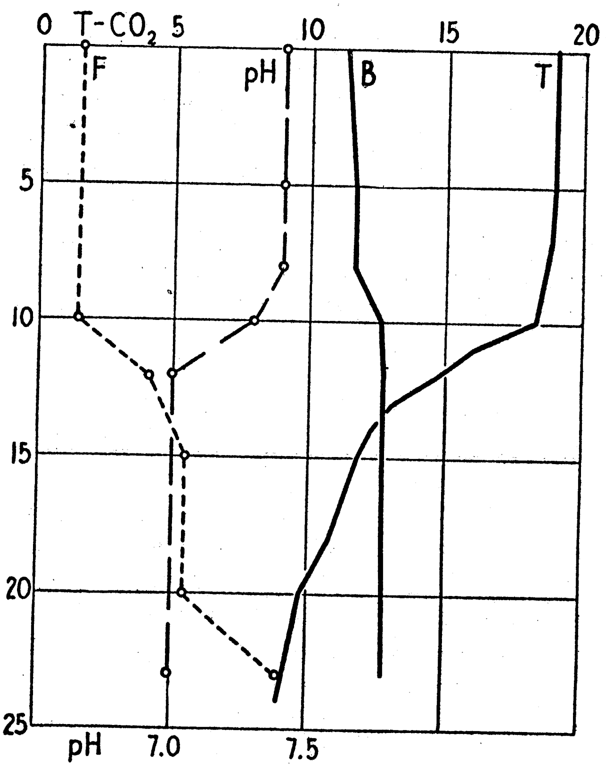

FIG. 22. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Crawling Stone Lake, August 10, 1927. A drainage lake. Compare with figs. 23 and 24.

The smallest amount (2.0 mg/1) of bound carbon dioxide was noted in the water from a well at the State Fish Hatchery near Woodruff; this well is only 3.3 m. deep. This water yielded 25.0 mg/1 of free carbon dioxide and the hydrogen ion concentration was pH 5.5. The well is located along the outlet stream of Madeline Lake and some 200 meters from the shore of this lake. The surface water of the lake gave an alkaline reaction to phenolphthalein and it yielded 20.5 mg/1 of bound carbon dioxide, or more than ten times as much as the well water.

The second smallest amount of bound carbon dioxide was 2.7 mg/1; this quantity was found in the water of a well at Sisson's Resort on Little St. Germain Lake, in that of a well at the Pines Resort on Nokomis Lake and in that of Paquette's well at Boulder Junction which is about half a kilometer from

Little Rice Lake. The surface water of Little St. Germain Lake yielded five times as much bound carbon dioxide as the well at Sissons's Resort, while that of Nokomis Lake was four times as large as that of the Pines Resort well and that of Little Rice Lake was four times as large as that of Paquette's well. Four other well waters yielded only 3.0 mg/1 of bound carbon dioxide and the amount did not exceed 5.0 mg/1 in 24 of the 149 wells.

In Table XII the wells have been divided into groups on the basis of their bound carbon dioxide content. The maximum number of wells (49) falls in the 5.0-9.9 mg/1 group, while the 10.0-14.9 group is second with 27 wells and the 0.0-4.9 group is third with 19. Thus the waters of 95 wells, or more than 63 per cent of the 149, yielded less than 15.0 mg/1 of bound carbon dioxide. This result compares favorably with the surface waters of the 280 drainage lakes; approximately 59 per cent of them contained less than 15.0 mg/1 of bound carbon dioxide. The surface waters of all of the seepage lakes fell below this amount; the maximum amount in them was 11.3 mg/1.

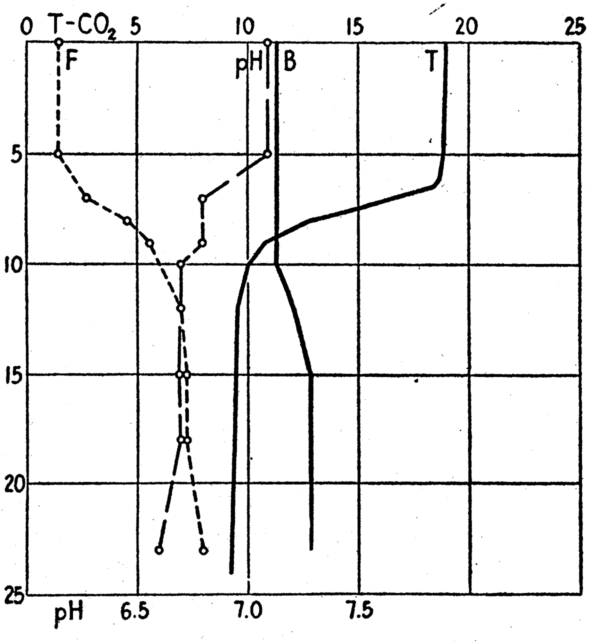

FIG. 23. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Dead Pike Lake, August 9, 1927. A drainage lake.

The largest quantity of bound carbon dioxide (100.0 mg/1) was observed in the water of the hotel well in the village of Winegar; this well is about 150 m. from the shore of Little Horsehead Lake whose surface water yielded 11.1 mg/1. This well water also showed the maximum specific conductance, namely 550×10^{-6}. The second largest amount of bound carbon dioxide was noted in a well water at Oxbow Park on Oxbow Lake; it yielded 82.0 mg/1 and the specific conductance was 300×10^{-6}. These two wells were the only ones in which the quantity of bound carbon dioxide exceeded 60.0 mg/1 and only 9 of the 149 wells yielded 50.0 mg/1 or more. The two wells with the largest amounts of bound carbon dioxide and two springs whose waters contained more than 60.0 mg/1 lie within the borders of the Winegar Moraine; these results seem to indicate that the morainic deposit contains a larger amount of calcerous material than the outwash deposit in which the majority of the wells are situated. Two wells located in the outwash plain, however, yielded 55.5 and 56.0 mg/1 of bound carbon dioxide, respectively.

The results given in Table XI show that there is no correlation between the bound carbon dioxide content of the well waters and that of the surface or bottom waters of the lakes on whose shores they are situated. In some cases the well waters yielded a larger amount of bound carbon dioxide than the corresponding lake waters, in other instances it was smaller and in still others both types of well waters were found on the shores of the same lake. The first type is represented in Table XI by such lakes as Adelaide, Anderson (spring) and Clear; the second type includes Fishtrap, Little St. Germain and Wild Cat. The mixed type is well illustrated by the wells situated on the shores of Muskellunge, Plum and Trout lakes.

Two of the well waters from the shores of Muskellunge Lake had a smaller amount of bound carbon dioxide than the surface water of the lake and three had a larger quantity. Six of the wells on Plum Lake had smaller amounts than the surface water of the lake and three had larger amounts; the well at Warner's Resort yielded approximately twice as much bound carbon dioxide as the surface water of the lake and that at Wolff's Cottages contained less than a quarter as much as the surface water of the lake.

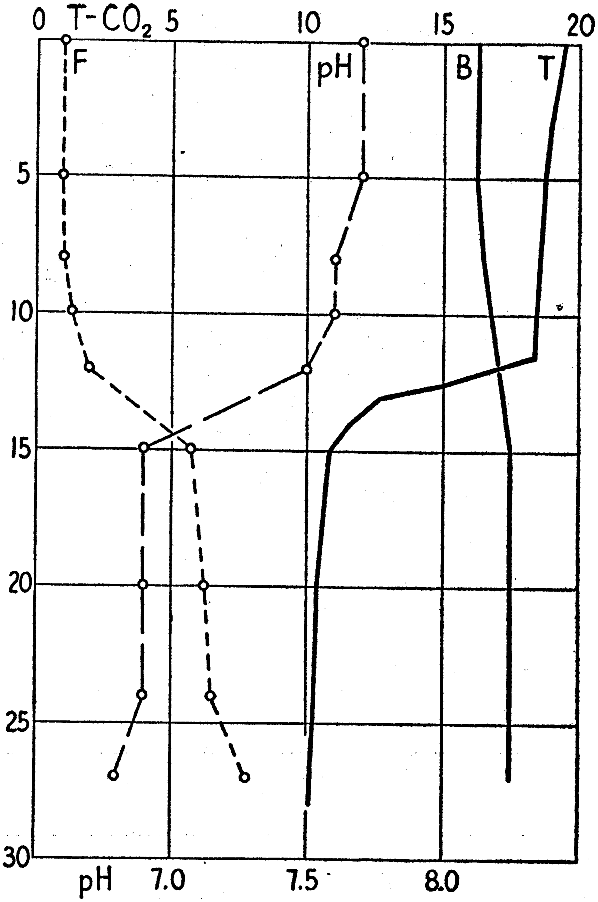

FIG. 24. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Fence Lake, August 23, 1929. A drainage lake. Compare with figs. 21-23.

In the case of Trout Lake, 11 wells had a smaller and 8 a larger bound carbon dioxide content than the surface water of the lake; the Kern well contained the smallest amount (4.0 mg/1) and that of the Forestry Headquarters house the largest quantity (35.0 mg/1). The latter yielded almost nine times as much as the former well.

The variations in the bound carbon dioxide content do not seem to be correlated with the depth of the wells; 12 wells ranging from 3 m. to 4.9 m. in depth varied from 2.0 to 21.0 mg/1. In 55 wells between 5 m. and 9.9 m. in depth, the bound carbon dioxide ranged from 2.7 to 100.0 mg/1, while the second deepest well (45.7 m.) contained only 7.2 mg/1. The variations in the bound carbon dioxide content of the well waters, as well as of the spring waters, appears to be due to the irregular distribution of calcium and magnesium compounds in the glacial deposits of this lake district.

The 7 spring waters showed a little more than a tenfold difference in bound carbon dioxide content; the quantity ranged from a minimum of 6.0 mg/1 in a spring situated on the shore of Clear Lake (Manitowish waters) to a maximum of 64.0 mg/1 in one located on the shore of Little Horsehead Lake at Winegar. Three of the spring waters yielded between 60.0 and 64.0 mg/1, while the other four contained 44.0, 30.0, 9.5 and 6.0 mg/1, respectively. These marked variations in the bound carbon dioxide content of the spring waters is also a good indication of the irregular distribution of calcareous material in the strata through which the water passes.

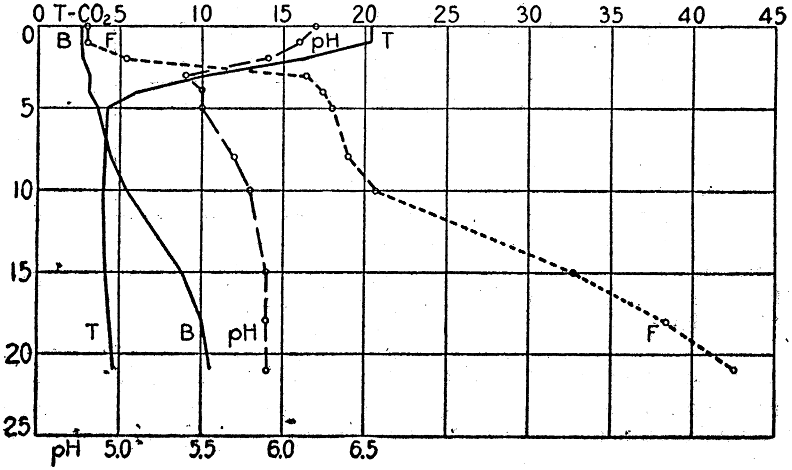

FIG. 25. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Lake Mary, July 11, 1928. A drainage lake with brown colored water. Compare with figs. 23 and 24. Note the unusual stratification of the pH.

II. HYDROGEN ION CONCENTRATION

INTRODUCTION

Hydrogen ion observations have been made on natural waters by many investigators during the past decade and a large amount of literature dealing with this subject has been published during this time. Some of the studies have consisted of single or only a few determinations on a lake or a stream, while others have included regular observations for considerable periods of time. Investigations of the latter type have served to bring out the diurnal, seasonal and annual changes of these waters. Under natural conditions these changes were brought about largely by biological processes; that is, the removal of carbon dioxide from the dissolved bicarbonates by aquatic plants during the process of photosynthesis gives the water a more alkaline reaction, while the addition of free carbon dioxide to the water in the processes of respiration and decomposition tends to give it a more acid reaction. The latter is true also of the carbon dioxide obtained from the atmosphere.

These changes in reaction may be quite marked in the course of a relatively short period of time. Skadowsky (1926) found diurnal differences of 2.6 pH units in the surface waters of some ponds and Philip (1927) noted daily fluctuations of 2.45 units (pH 7.35 to 9.8) in the shallow water of Crystal Lake, Minnesota.

In general, natural waters show a wide range in hydrogen ion concentration; the range is from about pH 3.0 on the acid side to pH 12.0 on the alkaline side. Jewell and Brown (1929) obtained readings of pH 3.3 on the waters of pools in the sphagnum margin of a Michigan bog lake and Skadowsky (1926) reported readings of pH 3.4-3.8 for the waters of some Russian bogs. Strom (1925) has reported readings as low as pH 3.8 in the waters of peaty bogs of Norway. Yoshimura (1933) obtained a reading of pH 1.4 in a Japanese lake which received water from a volcanic region; the SO_4 content of the lake water was 474 mg/1. In general however, readings below pH 4.0 are not found in natural waters except under extreme bog conditions, or in cases of pollution with mineral acids.

On the alkaline side, Jenkin (1932) obtained readings of pH 12.0 for the water of Lake Nakuru and of pH 10.7-11.1 for that of Lake Elmenteita; these two lakes are situated in an African Rift Valley and the high alkalinity is due to the presence of sodium carbonate derived from volcanic rocks of their respective drainage basins.

Methods

Regular observations were made on the hydrogen ion concentration of the waters of the Highland Lake District during the progress of these investigations. Up to the summer of 1932, the readings were taken colorimetrically; a standard La Motte outfit with a range from pH 4.0 to 9.8 was employed most of the time. The buffers covered 0.2 pH intervals so that the readings were made to the nearest 0.1 pH.

Certain differences were noted in the results when overlapping indicators were used on the same sample of water. These differences were observed particularly in the soft waters which had only small amounts of salts in solution and which, therefore,

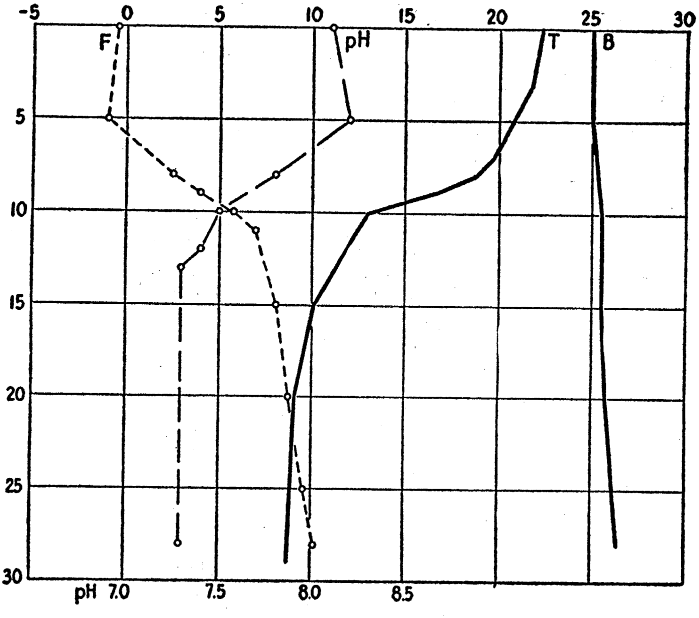

FIG. 26. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Presque Isle Lake, August 9, 1928. A drainage lake. Compare with figs. 24 and 27.

were weakly buffered. In order to obtain a better understanding of the significance of these differences, both colorimetric and electrometric methods were used during the summer of 1932. The quinhydrone system was used for the latter method.

In general reasonably close agreements were found between the results obtained by these two methods in waters where the readings did not fall below pH 6; in such cases the differences were not greater than 0.1-0.2 pH. Below pH 6, however, larger differences were noted at times; they ranged from 0.3 to 0.6 pH, or even larger below pH 5. When the pH of the indicator was adjusted to that of the weakly buffered waters, on the other hand, the results obtained by the two methods agreed within 0.2 pH; most frequently the difference did not exceed 0.1 pH. The larger differences obtained with the unadjusted indicators were due, apparently, to the buffering effects of the indicators. Investigations by Saunders (1926), Pierre and Fudge (1928), Fawcett and Acree (1929) Acree and Fawcett (1930) and Kolthoff (1931) have shown that colorimetric methods yield unreliable results when employed on poorly buffered solutions unless the indicators are specifically adjusted for the various samples.

The general results obtained by the quinhydrone method showed that most of the readings for the soft water lakes were not greatly in error. In fact the differences were well within the range of the seasonal and annual variations in pH noted in these waters, so that it has not been necessary to discard any of the colorimetric readings of the soft water lakes. Table XIII shows a comparison between the quinhydrone readings and the means of the readings obtained by colorimetric methods on 24 lakes. The colorimetric results represent the means of two to 27 determinations made on the surface water at different times in the summer and in different years. The maximum difference between the means of the colorimetric readings and of the quinhydrone readings of 1932 in these 24 lakes was 0.4 pH; there are five cases showing a difference of this amount, while 14 cases do not exceed 0.1 pH, leaving only two with a difference of 0.3 and three with 0.2 pH. Among those showing the maximum difference, the colorimetric mean was above the quinhydrone reading in four lakes and below in one, while the latter was higher in both instances showing a difference of 0.3 pH. In the lakes showing differences of 0.1 to 0.2 pH, the colorimetric means were above the quinhydrone readings in about half of the cases and below in the other half.

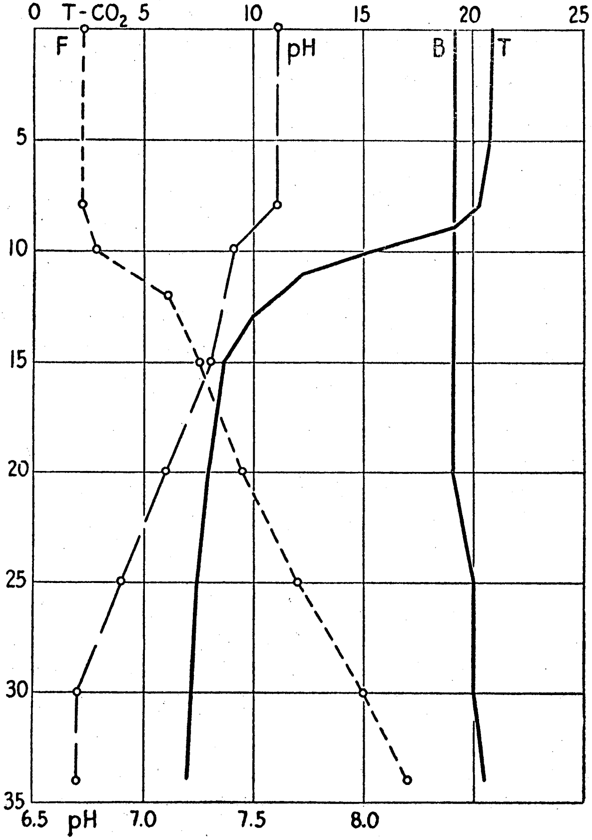

FIG. 27. Vertical distribution of the free (F) and bound (B) carbon dioxide, pH and temperature (T) in Trout Lake, August 22, 1932. A drainage lake. Compare with figs. 22-26.

The question arose also as to whether there was any change in the hydrogen ion when a sample of water was brought to the surface from the lower strata and exposed to the air while the pH reading was being taken either colorimetrically or electrometrically. That is, do the changes in temperature and pressure, and the slight exposure to the air when the sample is brought to the surface for the reading, have an appreciable effect upon the actual reaction of the water? In order to answer this question, a quinhydrone-calomel deep-water cell was designed which made it possible to take pH readings at various depths *in situ*. A description of this instrument and some results obtained with it have recently been published by Freeman, Meloche and Juday (1933). The general results obtained with this apparatus show that the readings taken with a standard quinhydrone cell by bringing the samples to the surface are in substantial agreement with those secured with the deep-water cell at the various depths. The sample that is brought to the surface, however, should be guarded against exposure to the air as much as possible and the readings should be made promptly in order to secure concordant results.

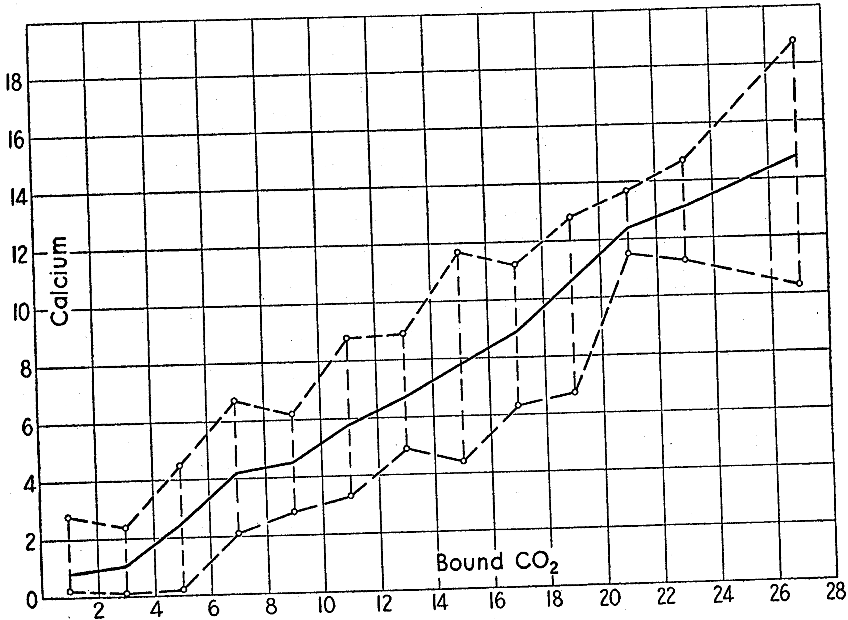

FIG. 28. This diagram shows the correlation between the bound carbon dioxide and the calcium content of the surface waters of 357 lakes. It is based on the results given in Table IX.

Surface Samples

Between 1925 and 1932 inclusive, pH readings were taken on 1,225 surface samples; a summary of the results obtained on them is given in Table XIV. The readings ranged from pH 4.4 in 4 very soft water lakes having specific conductances of

8 to 10 × 10^{-6} up to pH 9.4 in Clear Lake (Manitowish waters) with a specific conductance of 71 × 10^{-6}. The high alkalinity of the surface water of Clear Lake on August 19, 1925 was correlated with a large crop of phytoplankton which yielded 7.0 mg/1 of dry organic matter; the water contained —2.2 mg/1 of monocarbonate carbon dioxide at this time. In 3 surface samples taken from Clear Lake in different years, the readings varied from pH 7.2 to 9.4.

The 4 samples with readings of pH 4.4 were obtained from small lakes with much bog along their shores, but they were not completely surrounded by bog. The color of their waters varied from 16 to 41 on the platinum-cobalt scale, which indicates that they do not belong to the extreme bog type.

No surface samples fell in the pH 4.5-4.6 group, but one gave a reading of pH 4.7, 3 pH 4.8 and 5 pH 4.9. Some of these bodies of water are lakelets entirely surrounded by bogs, while others have varying amounts of bog tributary to them. The color of their waters ranged from 8 to 230; the specific conductance of these 9 samples varied from 7 to 19 × 10^{-6}. The latter was found in Knife Lake which belongs to the drainage type, since it is the source of a small intermittent stream. All of the other samples falling in the pH 4.4-4.9 group came from seepage lakes and the maximum specific conductance found in them was 13 × 10^{-6}.

At the alkaline end of the series, there were 31 surface samples from 22 different lakes which gave readings of pH 8.5 to 9.4. All of these samples were obtained from drainage lakes. The surface waters of all of these lakes except one had a comparatively large amount of inorganic material in solution; the specific conductance ranged from 37 to 111 × 10^{-6}, the bound carbon dioxide from 4.0 to 26.9 mg/1, the calcium from 2.4 to 18.8 mg/1 and the magnesium from 1.9 to 15.0 mg/1. Adelaide Lake had the smallest amount of inorganic material and yielded the above minimum amounts of these substances. The second lowest was Little Star Lake with a conductance of 39 × 10^{-6}, bound carbon dioxide 9.5 mg/1, calcium 5.4 and magnesium 1.5 mg/1; thus the bound carbon dioxide and calcium were more than twice as large in this lake as in Adelaide.

Three of the samples giving readings of pH 8.5 or more were obtained in early May soon after the ice had disappeared from the lakes, but all of the others were found in July and August, 10 in the former and 18 in the latter month. In some cases these high alkalinities were correlated with large crops of phytoplankton, others with large growths of the larger aquatic plants and still others with large crops of both large aquatics and phytoplankton.

Table XIV shows that 630 of the surface samples fall in the groups between pH 4.4 and 6.9, and 595 of them in the groups between pH 7.0 and 9.4, so that just a few more than half of them were below the neutral point (pH 7.0).

The seepage lakes, in general, contain a smaller amount of dissolved inorganic substances which will serve as buffers than the drainage lakes and this produces a characteristic difference between the two types with respect to their hydrogen ion. The differences found in the surface waters of the various lakes are indicated in Table XV and they are shown graphically in Figure 29. In the table and diagram, the results are grouped by lakes and not by individual samples; where more than one observation has been made on a lake, the mean of the various results has been used to determine the group to which the lake belongs.

Figure 29 shows clearly the characteristic difference between the pH of the seepage and of the drainage lakes. In the seepage type, there are 205 lakes, or 86 per cent of those belonging to this class, lying btween pH 4.4 and 6.5, and only 33 lakes, or 14 per cent, above the latter group. The pH 5.8-5.9 group contains the largest number of lakes, namely 35, or 14.7 per cent of the total number. In the drainage lakes on the other hand, 251 or approximately 90 per cent of those belonging to this type, fall between pH 6.6 and 8.9, with a maximum of 42 lakes or 15 per cent of the total number in the pH 7.6-7.7 group. (Table XV).

The 33 seepage lakes with readings above pH 6.5 overlap onto some of the larger groups of drainage lakes. These seepage lakes are located in areas where the glacial drift contains a larger amount of calcareous material, so that their waters yield greater pH values.

The 29 drainage lakes with readings below pH 6.6 possess certain characteristics of the seepage type in that they have

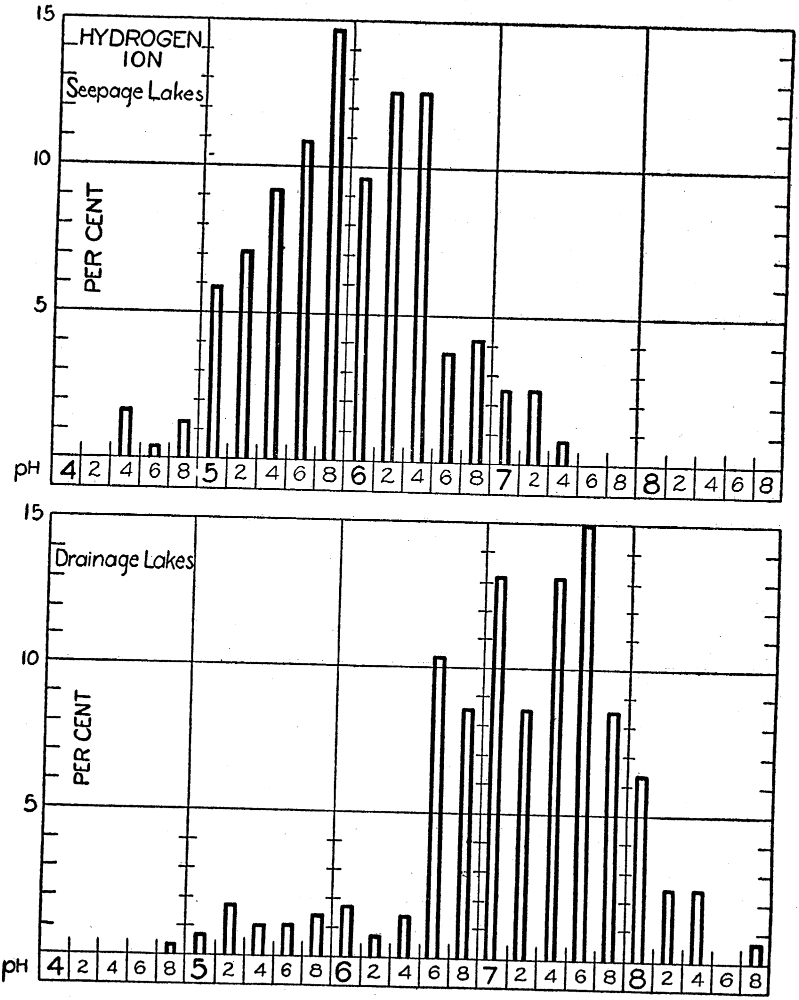

FIG. 29. This diagram shows the hydrogen ion content of the surface waters of 238 seepage and 280 drainage lakes. The vertical spaces show the percentage of lakes in the various pH groups. Note the striking difference in the grouping of the two types of lakes. Compare with fig. 1.

very soft waters and yield low pH values. While these bodies of water have natural outlets and thus belong to the drainage class, they are the sources of small intermittent streams which contain out-flowing water only when the water level of the lake reaches a rather high stage. They have no inlets, so that their outlet streams may be dry for the greater part of the year, or for several years in some instances, depending upon the amount of the annual precipitation.

Variations in pH Readings

Annual. During the progress of this investigation, surface samples were obtained from 245 lakes in different years; a few of the observations were limited to two but most of them included three or more years. Table XVI shows the maximum pH differences found in these lakes in the different years. The first group includes those in which the readings did not differ more than 0.4 of a pH in the various years; 65 lakes, or 26 per cent of the total number, fall in this group. Five of these 65 lakes gave the same readings in two or more years and 16 others showed differences of only 0.1 pH. In 106 lakes, or 43 per cent of the total number, the pH differences in the different years were between 0.5 and 0.9; this is the largest number of lakes in any of the groups. These two groups, therefore, include 69 per cent of the lakes that were visited more than once. That is, the greatest difference found in the surface waters of these lakes over periods of two to six years was less than one pH unit in 69 per cent of them. Adding the third group to the first and second gives 222 lakes, or 90 per cent of the total number, in which the difference did not exceed 1.4 pH units in the various years.

In 6 lakes the annual differences exceeded two pH units; the maximum difference was found in Adelaide Lake where the readings varied from pH 6.3 on August 29, 1929 to pH 8.8 on August 23, 1925. Nine readings were made on the surface water of Adelaide Lake between 1925 and 1930, inclusive, and the two obtained in the summer of 1925 where the only ones which exceeded pH 6.8. On July 20, 1925, the surface water was pH 7.1 and the free carbon dioxide amounted to 1.2 mg/1; on August 23, 1925, the reading was pH 8.8 and this was correlated with a phenolphthalein alkalinity equivalent to —0.5 mg/1 of carbon dioxide. The water of this lake is quite soft; the mean quantity of bound carbon dioxide was 3.2 mg/1 and the calcium content 2.4 mg/1. Thus, a relatively small change in the carbon dioxide content of the water during the process of photosynthesis causes a marked change in the reaction. In 1925 the change in hydrogen ion was correlated with an increase in dissolved oxygen from 7.9 mg/1 on July 20 to 9.1 mg/1 on August 23.

Spring and Summer. Hydrogen ion observations were made on the surface waters of 36 lakes in the spring and again in the summer of the same year. Such sets of readings were taken on some of the lakes for two or three different years, so that 57 pairs of readings were secured on the 36 lakes. In 13 of the pairs, the summer pH value was lower than that of the spring; the maximum decline was noted in Crystal Lake in 1930 where the reading on April 26 was pH 5.8 and on the following July 9 it was pH 5.1, thus showing a decrease of 0.7 pH. Second in rank were Weber Lake with a surface reading of pH 5.8 on April 26 and pH 5.2 on August 14, 1930, and Little Arbor Vitae Lake with pH 8.2 on May 4 and pH 7.6 on July 7, 1927. There was a summer decline of 0.5 pH in Little John Jr. Lake, but none of the other pairs showed a summer decrease of more than 0.3 pH.

In 9 pairs of readings the spring and summer results were the same, thus leaving 35 pairs in which the summer surface samples were more alkaline than those taken in the spring. The maximum increase in alkalinity was noted in Little Tomahawk Lake where the readings were pH 7.2 on May 6 and pH 8.1 on July 25, 1927. In four samples the increase in the summer alkalinity amounted to 0.7 pH, in one case 0.6 and in three cases 0.5; all of the other increases were below the latter amount.

Autumn. Readings were obtained on the surface water of four lakes in the month of November 1930; all of them were lower than those noted during the previous summer. The maximum autumnal decrease was found in Weber Lake where the reading was pH 6.7 on June 29 and pH 6.0 on November 16, a difference of 0.7 pH. In Trout Lake the hydrogen ion was pH 7.7 on August 27 and pH 7.2 on November 15. The smallest difference was noted in Crystal Lake with pH 6.0 on August 20 and pH 5.9 on November 16. The difference in High Lake was 0.3 of a unit.

Diurnal changes. In order to determine the extent of the diurnal fluctuations in the hydrogen ion of the surface water of Trout Lake, a series of observations was made on August 15,

1933. On this date the sky was clear until about mid-forenoon, then partly cloudy until mid-afternoon, after which it was clear again. There was a slight southwest wind (on-shore) and the disc reading was 4.5 m. Surface samples were taken at two stations every hour from 8 a.m. to 4 p.m. and again at 8 and 10 p. m. One series of these samples was taken at the end of the laboratory dock or about 15 m. from the shore, while the other was taken about 200 m. further out in the lake where the water had a depth of about 5 m. During the day time, the readings obtained at the two stations fell between pH 7.5 and 7.7, but they were somewhat lower in the evening, or pH 7.2 to 7.3. Thus the maximum diurnal difference noted in these observations was 0.5 pH. Large aquatic plants are scarce in Trout Lake and the crop of phytoplankton is usually of moderate size, so that only a relatively small diurnal fluctuation in the hydrogen ion readings is to be expected in the open water.

Vertical Distribution

The pH values at different depths are given for a number of lakes in Table X and some of the results are represented in Figs. 2-15 and 17-27. The various types of lakes are included in both the table and the diagrams.

In a shallow lake like Bear (Fig. 2) where the entire body of water is kept in circulation during the summer, the pH readings were uniform from surface to bottom. In all of the lakes which had a bottom stratum that did not take part in the general circulation during the summer, there was a decrease in the pH values in the lower water. This phenomenon is well illustrated in such shallow lakes as Dorothy Dunn, Finley and Bragonier (Figs. 3, 5, 6) and in the deeper ones which have a more definite thermal stratification, such as Crystal, Fence, Muskellunge, Presque Isle and Trout (Figs. 11, 12, 24, 26 and 27).

Crystal Lake showed a relatively small difference between surface and bottom; the former reading was pH 5.5 and that at 19 m. (1 m. above the mud) was pH 5.3 on August 11, 1932. In Crawling Stone Lake (Fig. 22), the difference between surface and bottom readings was 0.4 pH, in Black Oak, Presque Isle, and Trout lakes 1.0 pH and in Muskellunge 1.8. In Adelaide Lake, the surface reading was pH 8.8 and that at 20 m. was 6.2 on

August 23, 1925; this difference of 2.6 pH units represents the maximum between surface and bottom readings. This maximum is exceeded by that of Pallette Lake (Fig. 18) if the reading at 8 m. is compared with that at 16 m. on August 22, 1928; the former was pH 9.1 and the latter 6.3, a difference of 2.8 pH units.

Some of the vertical series taken in Anderson, Pallette and Silver lakes (Figs. 17-19) deserve special mention. The samples obtained in the thermocline of these lakes were more alkaline in some cases than those of the epilimnion or the hypolimnion. A maximum reading of pH 9.1 was noted in Pallette Lake at 8 m. on August 22, 1928, while that at the surface was pH 6.7 and at the bottom pH 6.3; the alkaline stratum was sharply defined as the reading changed from pH 6.6 at 7 m. to 9.1 at 8 m. and then back to 6.9 at 9 m. The most alkaline water found in Anderson Lake was pH 8.4 at 7 and 8 m. on August 8, 1929, and pH 8.3 in Silver Lake on August 13, 1932. These more alkaline readings were correlated with excess oxygen and also with a more or less marked decrease in the carbon dioxide content of the water in these strata as shown in the diagrams; all of these changes were due to the photosynthetic activities of the phytoplankton populations of these strata.

Calculated pH Values

The last column in Table X shows the pH values that have been computed from the carbon dioxide determinations by means of Kolthoff's formula. This formula, however, is intended primarily for the computation of the free carbon dioxide from the pH and bicarbonate results in as much as free carbon dioxide titrations may be subject to certain inaccuracies under field conditions.

In the great majority of the samples, the calculated pH values are in reasonable agreement with the actual readings; in most cases represented in the table the difference did not exceed 0.2 pH. In some samples the difference amounts to as much as 0.4 pH; these larger differences are found most frequently in the region of the thermocline where temperature and chemical conditions show rapid changes with increasing depth and also in lakes having very soft waters. A more complete study of this problem is included in plans for future investigations.

Even larger differences between calculated and observed pH values are indicated in some of the well waters in Table XI. No satisfactory explanation for these discrepancies has yet been found and this problem also remains for future investigation.

Dichotomous Stratification of Hydrogen Ion

In a recent paper Yoshimura (1932) describes an unusual type of vertical distribution of the hydrogen ion in some Japanese lakes. Minimum pH readings were obtained by him in the upper part of the hypolimnion, with higher values both above and below this more acid layer. He applied the term "dichotomous stratification" to this type of vertical distribution. In the most common type, the lowest pH values are found in the lower part of the hypolimnion, or in the bottom stratum.

Yoshimura computed the pH for some of the Wisconsin lakes on the basis of their carbon dioxide content and found that they also showed a dichotomous stratification. Two of the lakes mentioned by him as showing this type belong to the group included in this report, namely Allequash and Mary lakes. Allequash Lake has a maximum depth of only 7.5 m., so that it does not show a very marked thermal stratification in summer; in fact it can hardly be regarded as possessing a hypolimnion. A series of samples taken at various depths on August 15, 1926 showed the usual type of pH stratification; that is, the hydrogen ion changed from pH 8.6 at the surface and 3 m. to a minimum of pH 6.7 at 7 m.

The dichotomous type of stratification was observed in Lake Mary, however; this lake has an area of 1.2 ha. and a maximum depth of 22 m., which is an unusual depth for a glacial lake of this size. During this investigation, 5 series of samples covering the entire depth of the lake were taken, but only two of them showed dichotomous stratification. On July 11, 1928, the reading was pH 6.2 at the surface and 5.4 at 3 m.; below the latter depth the readings gradually rose to pH 5.9 in the 15-21 m. stratum. The results of these observations are given in Table XVII and they are shown graphically in Figure 25: the latter brings out clearly the minimum value obtained at 3 m. The series taken on July 29, 1927 showed a similar type of pH stratification, with a minimum of pH 5.8 again at 3 m. and pH 6.2

at both surface and bottom. In the series of August 21, 1926, the reading was pH 6.2 at the surface, 5.8 in the 3-5 m. stratum. and 5.9 from 8 to 20 m.; this small increase of 0.1 pH in the lower water can hardly be regarded as a definite case of dichotomous stratification because it falls within the limit of error of the colorimetric method of hydrogen ion determination. The pH readings were uniform throughout the hypolimnion in the other two series of observations, so that two series showed a definite dichotomous stratification and the other three did not.

Serial observations were made on 71 other lakes which were deep enough to have a well marked hypolimnion, but no clear cut examples of dichotomous stratification were found in them. Some evidence of it was noted in 4 of them, but the pH value of the bottom water was only 0.2 pH above that of the minimum intermediate layer. In Mud Lake for example, with a maximum depth of 14.5 m., the reading was pH 6.3 at the surface, 5.7 in the 5-8 m. stratum, and 5.9 at 13 m. This difference, however, is not regarded as large enough to constitute a definite dichotomous stratification.

In the Japanese lakes of this class, Yoshimura found that the minimum pH reading always appeared in the layer of water immediately above the anaerobic stratum. The same result was obtained in Lake Mary; the minimum reading of pH 5.4 at 3 m. was correlated with an oxygen content of 0.4 mg/1 at that depth and no oxygen was found below this depth.

According to Yoshimura, this type of pH stratification is found only in lakes with a bottom stratum which has no dissolved oxygen but which possesses a larger or smaller amount of free carbon dioxide. This water which is charged with free carbon dioxide, attacks the calcium, iron and manganese compounds in the bottom deposits and converts them to bicarbonates which readily pass into solution. These dissolved substances increase the pH value in spite of the free carbon dioxide that is present.

Table XVII and Figure 25 show that there was a marked increase in the bound carbon dioxide with increasing depth in Lake Mary on July 11, 1928. On this date also the specific conductance ranged from 21×10^{-6} at the surface to 58×10^{-6} at 21 m.; likewise the total residue increased from 51.3 mg/1 at the surface to 82.8 mg/1 at 21 m. and the calcium rose from 1.3 mg/1 at the surface to 2.7 mg/1 at the bottom. No determinations of the iron and manganese have been made so that their vertical distribution is not known. Similar increases in the bound carbon dioxide, the specific conductance and the total residue were noted in the lower water in the three series which did not show a dichotomous stratification and this seems to indicate that some other factor or factors play a part in producing the phenomenon. Iron and manganese are regarded as the chief factors by Yoshimura, but the lake which showed the most marked increase of these two substances in the lower water in this investigation, gave no indication whatever of a dichotomous stratification in three sets of observations.

A reverse type of hydrogen ion stratification is described and illustrated for Anderson, Pallette and Silver lakes. (Figs. 18-20). In these bodies of water, the highest pH values were found in the intermediate stratum, while in the type described by Yoshimura the lowest pH values were located in the intermediate stratum. Both cases represent a dichotomous stratification of the hydrogen ion, but one is the opposite of the other. In order to distinguish the two types, the term acid dichotomous stratification may be used to designate that in which the minimum pH value is found in the intermediate zone of the lake and alkaline dichotomous stratification for that in which the highest pH value falls in the intermediate layer.

An alkaline stratification was observed by Kusnetzow and Schtcherbakow (1927) in Lake Baikal. The readings in the upper 2 m. of water varied from pH 7.6 to 7.8, rose to pH 8.15 in the 6-10 m. stratum and then declined to pH 7.6 at 25 m. where it remained for the rest of the series, namely down to 104 m.

Hutchinson and Pickford (1932) also found an intermediate stratum in Mountain Lake, Virginia with somewhat higher pH values than those above and below it; the hydrogen ion changed from pH 6.4 at the surface to 6.6 at 5 m. and 7 m. and then fell to 6.5 at 11 m. and 19 m.

Hydrogen Ion and Carbon Dioxide

Carbon dioxide plays a very important rôle in determining the reaction of lake waters. The supply of this gas is derived from the atmosphere, from inflowing waters, especially that of springs, and from the decomposition and respiration that take place within the lakes. Aquatic plants withdraw a certain amount of this carbon dioxide in their processes of assimilation, so that the quantity actually found at any particular time is the resultant of the processes which tend to augment the supply and of those which reduce the supply. Thus the interplay between these two types of activities bears a close relation to the hydrogen ion content of the water.

Under certain conditions, the reaction of the water is affected by other factors; in typical bog lakes and lakelets for example, the humic acids play a part in determining this reaction. In the great majority of the lakes that have been visited in this investigation, however, the hydrogen ion concentration was chiefly or wholly a function of the carbon dioxide content of the water.

Free carbon dioxide. The relation between the free carbon dioxide and the hydrogen ion of the surface waters is given for the various pH groups in Table XVIII; the results are also shown graphically in Fig. 30. As already indicated, the bog waters

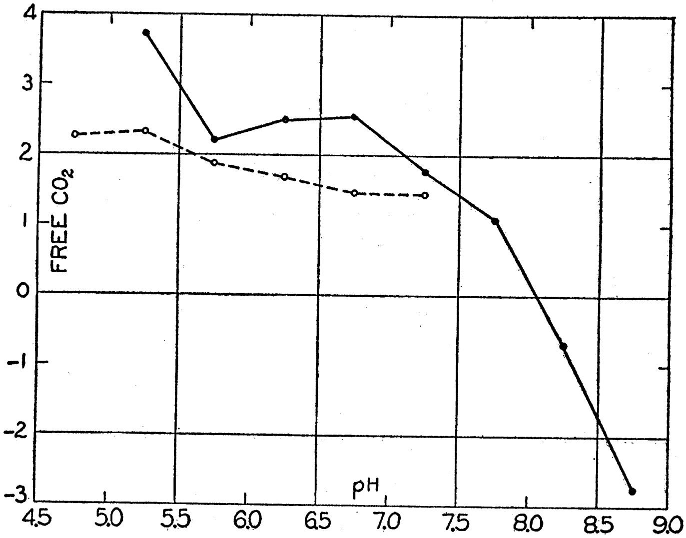

FIG. 30. Relation between the hydrogen ion and the free carbon dioxide content of the surface waters of 499 lakes. The solid line repreesnts drainage lakes and the broken line seepage lakes.

gave a rather high acid reaction to phenolphthalein; thus they may be regarded as representing a special type of water. In compiling the data for Table XVIII, therefore, all of the samples which contained more than 4.0 mg/1 of free carbon dioxide have been omitted.

In the seepage lakes, the mean quantity of free carbon dioxide decreased from 2.3 mg/1 in the pH 4.4-4.9 group to 1.4 mg/1 in the 7.0-7.4 group; this is a decrease of only 0.9 mg/1 of free carbon dioxide for the entire range from pH 4.4 to 7.4, an unusually small change for such a marked difference in hydrogen ion activity. (Fig. 30).

In the drainage lakes, the free carbon dioxide fell from 3.7 mg/1 in the pH 5.0-5.4 group to 2.4 mg/1 in the 5.5-5.9 group; the quantity remained substantially the same as the latter in the two following groups, but the 7.0-7.4 group showed an appreciable decrease in free carbon dioxide, with a further decline in the 7.5-7.9 group. (Fig. 30). This marked decrease in free carbon dioxide continued beyond the latter group. Both the table and the diagram show that the most marked decrease in the quantity of free carbon dioxide came in the region of pH 8.0 where the water begins to give an alkaline reaction to phenolphthalein, thus indicating the presence of normal or monocarbonate carbon dioxide. It will be noted that the seepage lakes yielded a smaller mean quantity of free carbon dioxide than the drainage lakes belonging to the same pH groups; this fact is shown clearly in Figure 30.

The vertical distribution of the hydrogen ion and the free carbon dioxide is shown in Figures 2-15 and 17-27. In the shallower lakes a striking correlation between the increase of free carbon dioxide in the lower stratum and the decrease of the pH values was noted in Allequash Lake (Fig. 7). In Crystal Lake (Fig. 11), the change in both pH and free carbon dioxide was not very marked in the lower water. The changes were much more marked in Muskellunge Lake (Fig. 12), as well as in Fence and Trout lakes (Figs. 24, 27). An interesting correlation between hydrogen ion and free carbon dioxide in the thermocline of Anderson, Pallette and Silver lakes (Figs. 17-19) was found; the phytoplankton removed enough carbon dioxide from this stratum in the process of photosynthesis to produce a sharp rise in the pH values.

Bound carbon dioxide. Table XVIII shows the relation between the hydrogen ion concentration and the bound carbon dioxide content of the surface waters of 499 lakes; of this number 227 are seepage and 272 drainage lakes. It will be noted that the groups with low pH values contain only a small amount of bound carbon dioxide. Between pH 4.4 and 5.9 for example, the mean quantity of bound carbon dioxide in the surface waters of the seepage lakes varies from 1.3 to 1.6 mg/1; between pH 6.0 and 7.4 however, there is an increase in the mean bound carbon dioxide content of the water from 2.0 to 7.7 mg/1.

In the drainage lakes, the first two groups have rather small carbon dioxide means, but the pH 6.0-6.4 group shows an appreciable increase over the first two; this increase continues in the following groups so that it rises to 19.3 mg/1 in the pH 8.5-8.9 group.

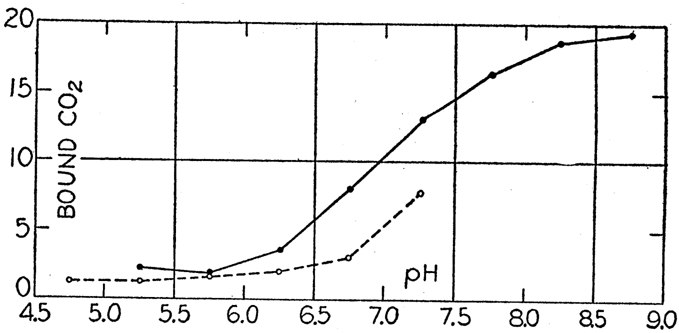

FIG. 31. Relation between the hydrogen ion and the bound carbon dioxide content of the surface waters of 499 lakes.

Figure 31 shows the results for hydrogen ion and bound carbon dioxide in a graphic form. The curves of this diagram serve to bring out clearly the relatively slight variations in the bound carbon dioxide of the low pH groups of both seepage and drainage lakes and the increases in amount which are found in the more alkaline waters of both types of lakes. They show also that there is only a small difference in the mean bound carbon dioxide content of the seepage and drainage lakes up to about pH 6.0, but at the higher pH values the waters of the drainage lakes contain a larger amount of bound carbon dioxide for corresponding pH values than the seepage lakes. This difference may be accounted for by the fact that the waters of the drainage lakes have a somewhat larger free carbon dioxide content than those of the corresponding seepage lake groups.

Hydrogen Ion and Calcium

The relation between the hydrogen ion and the calcium content of the waters of 358 lakes is given in Table XIX. In the pH 4.8-6.1 range, the mean quantity of calcium varies from 0.5 to 1.49 mg/1; the latter amount is found in the pH 5.6-5.7 group and it is followed by a decline to a mean of about 1.0 mg/1 in the next two groups. The increased amount of calcium in the pH 5.6-5.7 group is due to the fact that three of the 8 lakes in this group yielded from 2.1 to 2.8 mg/1 of calcium. A larger number of lakes falling in this group would probably give a lower mean.

Beginning with pH 6.2, there is an increase of the mean calcium content of the successive pH groups, rising to 10.2 mg/1 in the 8.2-9.2 group. All of the results above pH 8.2 have been combined into one group in order to get enough lakes to give a fair mean. Likewise, one lake with a reading of pH 4.4 has been included in the 4.8-4.9 group because the calcium content of this water fell within the range of that group. No calcium determinations were made on the other lakes that gave readings below pH 4.8.

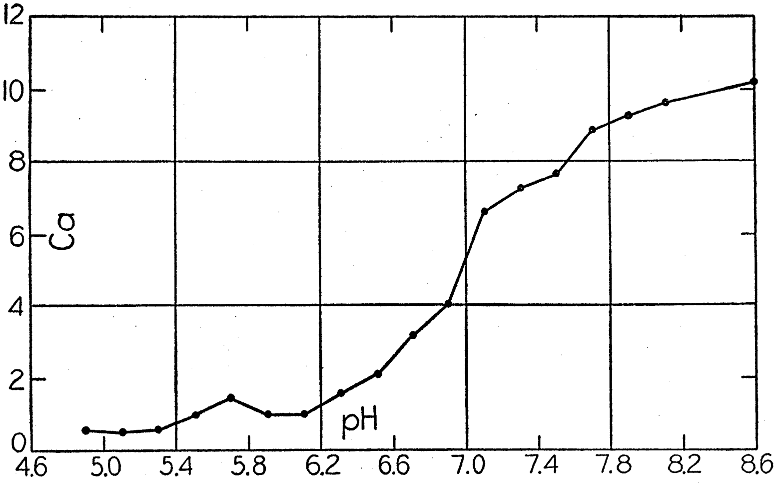

FIG. 32. Relation between the hydrogen ion and the calcium content of the surface waters of 358 lakes.

The results are shown graphically in Figure 32. The curve in this diagram brings out clearly the variations in the mean quantity of calcium between pH 4.8 and 6.1. These variations are due, in part at least, to differences in the free carbon dioxide content of the various lake waters falling within this hydrogen ion range. Relatively small differences in free carbon dioxide content have an important effect upon the hydrogen ion readings in waters with as small amounts of buffers as those found in this particular group of lakes.

Beyond pH 6.1 the curve shows a gradual increase in the mean calcium content of the water correlated with rising pH values. It is interesting to note that the steepest part of the curve falls in the region of neutrality (pH 7.0). The entire curve falls roughly into three parts; the first part includes that in which there is very little gradient in the curve, extending from pH 4.8 to 6.1. The second part extends from pH 6.2 to 7.8 and includes the region with the steepest gradient, while the third part is represented by the more gentle gradient above pH 7.8. The maximum quantity of calcium was 18.8 mg/1; it was correlated with a hydrogen ion of pH 8.5. The highest pH value found in the lakes on which calcium determinations were made (pH 9.2) was correlated with 8.2 mg/1 of calcium.

Hydrogen Ion and Biota

During the past decade or two, many investigations have dealt with the relation of the hydrogen ion activity of natural waters to the various living organisms found in them. A large amount of biological material has been collected from the Wisconsin lakes during these studies, but much of this material must be studied more thoroughly before a profitable discussion of the relation of the physical and chemical factors to the biological phenomena can be presented.

A general physico-chemical correlation is planned, however, rather than one between a single factor, such as hydrogen ion, and the biota. The hydrogen ion activity of these lake waters is regarded mainly as an index of certain underlying chemical conditions which obtain in them and which represent the fundamental basis for the particular reactions that have been found. That is, a number of chemical factors must be taken into consideration in order to obtain a complete picture of the relationships which exist between the reactions of the water and the lake biota. This general idea has been well expressed by Strom (1925) in the following statement: "The specific reaction of the water is a potential factor in determining the character of the biota, especially the algal flora, but it must always be regarded in conjunction with the other physical and chemical properties of the medium."

Brief mention may be made of the work of Morrison (1932) on the Mollusca of these Wisconsin lakes in relation to hydrogen ion and bound carbon dioxide. He found Pisidium and Campeloma in some of the very soft water lakes where the hydrogen ion was pH 5.7 and the bound carbon dioxide content was only 1.0 mg/1. In the bog type of soft waters, large specimens of Pisidium were found where the reaction was pH 5.1. The Valvatidae, on the other hand, were not found in waters with a reaction below pH 7.1 or with less than 8.0 mg/1 of bound carbon dioxide. In the other groups, some species preferred acid and others preferred alkaline water.

Hydrogen Ion of Well and Spring Waters

Hydrogen ion readings were taken on 149 well and 7 spring waters. In the well waters each tenth of a pH was represented from pH 5.3 to 8.1; in addition, one sample gave a reading of pH 5.0, so that only two groups were missing between pH 5.0 and 8.1, namely pH 5.1 and 5.2. Representative results obtained on various well waters are given in Table XI.

The maximum number of these well waters fell in the pH 6.3 group, namely 21. The next largest number was 13 in the pH 6.2 group, which was followed by 10 at pH 5.9. Three of the waters gave readings of pH 7.0, with a like number at pH 6.9 and 6 at pH 7.1, so that 12 of the 149 samples were grouped around the neutral point. Two samples gave readings of pH 8.0 and 3 pH 8.1; the latter was the highest pH value obtained in any of the well waters.

The various samples are combined into larger groups on the hydrogen ion basis in Table XX. This table shows the maximum number of well waters in the pH 6.0-6.4 group, namely 54, or 36 per cent of the total number of wells represented. The pH 6.5-

6.9 group was second with 27 wells, or 18 per cent of the total number. Three of the waters gave a neutral reaction, while 104 were on the acid side of neutrality and 42 on the alkaline side.

Of the 140 wells situated on the immediate shores of lakes, the water from 99 of them gave lower pH readings than the surface waters of the respective lakes and 33 gave higher pH values, thus leaving 8 samples in which the surface and well waters were the same. The maximum difference between lake and well water was noted at Madeline Lake where a reading of pH 8.8 was obtained for the former and pH 5.5 for the latter, a difference of 3.3 pH. The second largest difference was found at Lost Lake where the surface water was pH 8.1 and the well water pH 5.9, a difference of 2.2 pH. In the well waters which were more alkaline than the lake waters, the maximum difference was obtained at Lake George where the reaction of the lake water was pH 6.0 and that of the well water was pH 7.8.

The waters from wells situated on the shores of very soft water lakes usually had somewhat higher pH values than the surface waters of the respective lakes; this was true particularly of lake waters which gave readings between pH 4.5 and 6.0. Certain exceptions were noted, however. The well and surface water of McGrath Lake were both pH 5.0. Some of the lake waters with values above pH 6.0 were also exceeded by their respective well waters. The surface of Oxbow Lake, for example, was pH 7.3 and two well waters on its shores gave readings of pH 8.1 and 7.8.

The 19 wells listed on Trout Lake in Table XIII show that there is a marked variation in the hydrogen ion content of the waters of wells situated on the shores of a single lake; the range of the hydrogen ion in these wells was from pH 5.6 in the Kern well to pH 7.9 in the barn well at the State Forestry Headquarters; one of these well waters was neutral, while 10 were on the acid side and 8 on the alkaline side of neutrality. In the 9 wells situated on the shores of Plum Lake, the range was from pH 5.7 to 7.5; only one of them was alkaline. These variations in hydrogen ion content, together with those noted in the carbon dioxide content, show clearly the marked local variations in the chemical composition of the ground waters of this region as represented by these wells.

There was a general correlation between the depths of the Trout Lake wells and the hydrogen ion content of their waters. Depth records were obtained for 14 of the 19 wells on this lake. Of this number, 6 wells ranged from 4 to 6.7 m. in depth and the mean of the readings was pH 6.1; 5 of them varied from 8 to 13.7 m. in depth and their mean value was pH 7.0. The depth of three of them fell between 21 and 25 m. and their mean was pH 7.6. Thus there was an apparent increase in the alkalinity of the water with increasing depth of the wells.

This did not hold true for the 9 Plum Lake wells, however; the deepest one (13.7) in that group gave a reading of pH 6.3 and the shallowest one (4 m.) pH 6.2 and this difference is too small to have any significance.

The hydrogen ion content of the Trout Lake well waters was not correlated with that of the lower water of the lake. In 25 series the mean reading at a depth of 32 m. was pH 6.9, while the well waters varied from pH 5.6 to 7.9. This was true of Plum Lake also where the mean for the bottom samples (17 m.) in 4 series was pH 6.9 and the well waters ranged from pH 5.7 to 7.5.

Hydrogen Ion and Carbon Dioxide in Well Waters

Free carbon dioxide. Table XX shows the general relation between the hydrogen ion activity and the free carbon dioxide content of 149 well waters. The first group (pH 5.0-5.4) shows a somewhat smaller mean quantity of free carbon dioxide than the second and third, but there are only 3 wells in this group, which is too small a number to give a fair mean. Beginning with the pH 5.5-5.9 group, the mean quantity of free carbon dioxide declines from a maximum of 22.0 mg/1 to a minimum of 1.9 mg/1 in the 8.0-8.4 group. It will be noted, however, that the mean of the pH 7.0-7.4 group is a little smaller than that of the 7.5-7.9 group.

Bound carbon dioxide. The mean quantity of bound carbon dioxide is given for the various pH groups in Table XX. The amount of the former rises from 2.9 mg/1 in the pH 5.0-5.4 group to 44.4 mg/1 in the 7.5-7.9 group. The mean then declines to 33.4 mg/1 in the 8.0-8.4 group, but this represents only 5 well waters, which is insufficient for a fair mean. This difference is due in part also to the fact that the pH 7.5-7.9 group contains two well waters with unusually large amounts of bound carbon dioxide; one of them yielded 100.0 mg/1 and the other 82.0 mg/1. If these two were omitted, the mean for this group falls to a little less than 40.0 mg/1 instead of the 44.4 mg/1 indicated in the table.

Hydrogen Ion of Spring Waters

In the 7 spring waters, the hydrogen ion ranged from pH 6.2 to 8.4; a second one gave a reading of pH 6.3, but the other 5 fell on the alkaline side of the neutral point. Four of them varied from pH 7.3 to 7.8, while the fifth one was pH 8.4. The spring water which gave a reading of pH 6.2 yielded 13.0 mg/1 of free and 6.0 mg/1 of bound carbon dioxide; the one giving a reading of pH 8.4 yielded 9.5 mg/1 of free and 64.0 mg/1 of bound carbon dioxide. These were the minimum and maximum amounts of bound carbon dioxide in the spring waters; the free carbon dioxide ranged from a minimum of 4.0 to a maximum of 41.0 mg/1.

SUMMARY

1. Quantitative determinations of free and bound carbon dioxide and of hydrogen ion concentration were made on the surface waters of 518 lakes.

2. The surface waters of 238 seepage lakes (those without inlets or outlets) gave an acid reaction to phenolphthalein which varied from 0.3 to 10.7 mg/1 when expressed in terms of free carbon dioxide. The hydrogen ion readings fell on the acid side of neutrality (pH 7.0) in the surface waters of 93 per cent of the seepage lakes.

3. The surface waters of 36 drainage lakes (those with outlets) gave a mean alkaline reaction to phenolphthalein which was equivalent to —0.1 to —10.7 mg/1 when expressed in terms of carbon dioxide. The surface waters of 244 additional drainage lakes gave a mean acid reaction to phenolphthalein equivalent to 0.1 to 7.0 mg/1 of free carbon dioxide. The hydrogen ion readings were on the acid side in 28 per cent of the drainage lakes, while the others were either neutral or alkaline.

4. Annual variations in free carbon dioxide range from zero up to 14.7 mg/1 in the surface waters of the various lakes; these were due to the photosynthetic activities of the phytoplankton. Similar variations were noted in the hydrogen ion content of the water.

5. The free carbon dioxide was uniformly distributed from surface to bottom in some lakes, while the lower water of others yielded a much larger amount than the upper. A marked decrease of free carbon dioxide was noted in the thermocline of 3 lakes.

6. The waters of seepage lakes yielded from 0.2 to 11.3 mg/1 of bound carbon dioxide; in the drainage lakes the range was from 1.0 to 39.0 mg/1.

7. In most of the seepage lakes, the annual variations in bound carbon dioxide were small; in 56 per cent of the drainage lakes, these annual differences did not exceed 2.0 mg/1, while one gave a maximum difference of 8.5 mg/1.

8. The differences between the bound carbon dioxide content of surface and bottom waters varied from zero to 13.3 mg/1.

9. An average increase of about 2.3 mg/1 of bound carbon dioxide was correlated with an increase of 10×10^{-6} in the specific conductance of the water.

10. The free carbon dioxide content of the 149 well waters ranged from —0.5 to 67.5 mg/1 and the bound carbon dioxide from 2.0 to 100.0 mg/1.

11. In 7 spring waters, the free carbon dioxide varied from 4.0 to 41.0 mg/1 and the bound carbon dioxide from 6.0 to 64.0 mg/1.

12. The free and bound carbon dioxide content of the lake waters was independent of that of the ground water as represented in the springs and wells.

13. The hydrogen ion readings of the surface waters ranged from pH 4.4 to 9.4.

14. The annual variations in the hydrogen ion activity of

the surface waters varied from zero to 2.5 pH units. Likewise the differences between surface and bottom waters varied from zero to 2.6 units.

15. The acid type of dichotomous stratification of hydrogen ion was found in one lake and the alkaline type in three.

16. The hydrogen ion concentration showed a fairly definite correlation with both free and bound carbon dioxide and with the calcium content of the water.

17. Three of the well waters were neutral (pH 7.0), 103 were acid (pH 5.0-6.9) and 43 were alkaline (pH 7.1-8.4).

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TABLE I

Mean quantity of free carbon dioxide in the surface waters of 238 seepage lakes. The lakes are grouped by 0.5 mg. intervals; the number of lakes in the various groups is indicated, together with the percentage of the total number. The results for free carbon dioxide are expressed in milligrams per liter of water.

Group	Number of lakes	Percentage of total number	Mean quantity of free carbon dioxide
0.0-0.4	2	0.84	0.35
0.5-0.9	14	5.88	0.65
1.0-1.4	61	25.63	1.18
1.5-1.9	79	33.20	1.67
2.0-2.4	45	18.91	2.11
2.5-2.9	17	7.14	2.40
3.0-3.4	6	2.52	3.08
3.5-3.9	3	1.26	3.58
4.0-4.4	1	0.42	4.20
4.5-4.9	4	1.68	4.50
5.0-5.4	2	0.84	5.10
5.5-5.9	1	0.42	5.70
6.0-6.4	1	0.42	6.02
6.5-6.9	2	0.84	6.78

TABLE II.

Mean quantity of free carbon dioxide in the surface waters of 280 drainage lakes. The lakes are grouped by 0.5mg. intervals. The number of lakes in each group is indicated, together with the percentage of the total number. The means are expressed in terms of milligrams of carbon dioxide per liter of water. The minus sign indicates that the water gave an alkaline reaction to phenolphthalein, which was due to the presence of a certain amount of normal or monocarbonate carbon dioxide.

Group	Number of lakes	Percentage of total number	Mean quantity of free carbon dioxide
—4.0-4.4	1	0.36	—4.20
—3.5-3.9	2	0.71	—3.65
—3.0-3.4	3	1.07	—3.20
—2.5-2.9	2	0.71	—2.66
—2.0-2.4	4	1.43	—2.06
—1.5-1.9	3	1.07	—1.60
—1.0-1.4	5	1.78	—1.08
—0.5-0.9	8	2.86	—0.63
—0.0-0.4	8	2.86	—0.28
0.0-0.4	19	6.79	0.24
0.5-0.9	30	10.72	0.71
1.0-1.4	59	21.08	1.16
1.5-1.9	42	15.00	1.70
2.0-2.4	36	12.87	2.14
2.5-2.9	17	6.07	2.66
3.0-3.4	10	3.57	3.06
3.5-3.9	6	2.14	3.64
4.0-4.4	7	2.50	4.13
4.5-4.9	5	1.78	4.61
5.0-5.4	3	1.07	5.08
5.5-5.9	2	0.71	5.50
6.0-6.4	5	1.78	6.15
6.5-6.9	2	0.71	6.60
7.0-7.4	1	0.36	7.00

TABLE III

The 7 drainage lakes which gave the highest alkaline reaction to phenolphthalein. The color of the water is indicated on the platinum-cobalt scale. Carbon dioxide and the organic carbon are stated in milligrams per liter of water. The minus sign in the free carbon dioxide column shows that the water gave an alkaline reaction to phenolphthalein due to the presence of normal or monocarbonate carbon dioxide.

Lake	Date	Color	pH	Carbon dioxide		Organic carbon
				Free	Bound	
Allen	July 8, 1928	314	9.1	—6.0	15.0	25.8
Boot	Aug. 12, 1928	32	8.9	—3.2	14.5	13.0
Horsehead	Aug. 7, 1930	30	8.4+	—5.0	15.5	6.0
Mann	July 7, 1928	34	9.0	—10.7	25.6	7.8
Spring	July 20, 1930	106	8.4+	—3.0	25.0	16.0
Sweeney	Aug. 25, 1929	52	8.2	—3.8	18.3	11.3
West Ellerson	July 15, 1927	26	8.5	—4.3	22.1	6.0

TABLE IV

The seepage and drainage lakes which gave the maximum acid reaction to phenolphthalein. The color of the various waters is indicated on the platinum-cobalt scale. The free and bound carbon dioxide and the organic carbon are stated in milligrams per liter of water.

Seepage Lakes

Lake	Date	Color	pH	Carbon dioxide		Organic carbon
				Free	Bound	
Cardinal Bog	Aug. 20, 1927	49	5.4	10.0	2.1	6.9
Forestry Bog	July 25, 1926	40	5.2	10.7	1.0	12.3
Helmet Bog	Aug. 9, 1930	268	5.6	5.0	2.0	25.3
Henry	Aug. 5, 1928	200	5.7	5.2	1.5	22.6
Nell	Aug. 5, 1928	190	5.3	6.6	0.4	19.2
Nixon Bog	June 29, 1930	100	5.0	5.7	1.1	10.1
Drainage Lakes						
Big Stone	June 30, 1929	114	6.8	6.5	9.0	13.7
Deer	June 30, 1929	140	6.7	6.0	10.0	15.8
Dog	June 30, 1929	138	6.9	6.7	11.0	15.9
Goodyear	July 4, 1929	126	7.6	6.2	18.5	12.1
Inkpot	Aug. 15, 1932	92	8.1	5.5	39.0	8.4
Julia	June 30, 1929	64	7.1	6.2	18.0	10.5
Knife	Aug. 9, 1930	230	4.9	7.0	2.0	21.8
Laurel	June 30, 1929	126	6.7	6.2	10.3	12.2
Little Muskellunge	July 4, 1929	40	7.7	5.2	19.5	7.3
Noseeum	July 18, 1930	148	5.2	5.0	4.0	18.0
Puddle	Aug. 11, 1926	43	6.6	5.0	12.9	8.0
Red Bass	Aug. 9, 1930	182	5.2	5.5	2.0	22.1
Rice	June 28, 1930	115	7.0	6.0	15.5	7.6

TABLE V

Mean quantity of bound carbon dioxide in the surface waters of 238 seepage lakes. The lakes are grouped by 1 mg. intervals; the number of lakes in each group is indicated, as well as the percentage of the total number. The carbon dioxide means are expressed in milligrams per liter of water.

Group	Number of lakes	Percentage of total	Mean quantity of bound carbon dioxide
0- 0.9	29	12.19	0.7
1- 1.9	106	44.54	1.4
2- 2.9	51	21.43	2.3
3- 3.9	25	10.50	3.3
4- 4.9	11	4.62	4.3
5- 5.9	2	0.84	5.4
6- 6.9	1	0.42	6.7
7- 7.9	2	0.84	7.7
8- 8.9	4	1.68	8.4
9- 9.9	4	1.68	9.7
10-10.9	2	0.84	10.8
11-11.9	1	0.42	11.3

TABLE VI

Annual variations in the bound carbon dioxide content of the surface waters of 106 seepage lakes.

Range of variation	Number of lakes in group
0.0-0.5	39
0.6-1.0	32
1.1-1.5	16
1.6-2.0	13
2.1-3.5	6

TABLE VII

Mean quantity of bound carbon dioxide in the surface waters of 280 drainage lakes. The lakes are grouped by 1 mg. intervals; the number of lakes in each group is indicated, as well as the percentage of the total number. The means are expressed in milligrams of bound carbon dioxide per liter of water.

Group	Number of lakes	Percentage of total	Mean quantity of bound carbon dioxide
0- 0.9	....	......	....
1- 1.9	7	2.50	1.45
2- 2.9	13	4.64	2.40
3- 3.9	5	1.79	3.26
4- 4.9	8	2.86	4.30
5- 5.9	6	2.14	5.36
6- 6.9	10	3.57	6.29
7- 7.9	13	4.64	7.50
8- 8.9	8	2.86	8.30
9- 9.9	13	4.64	9.40
10-10.9	19	6.79	10.43
11-11.9	12	4.28	11.40
12-12.9	12	4.28	12.30
13-13.9	17	6.07	13.31
14-14.9	22	7.85	14.50
15-15.9	26	9.28	15.41
16-16.9	15	5.35	16.43
17-17.9	18	6.44	17.40
18-18.9	16	5.72	18.35
19-19.9	7	2.50	19.40
20-20.9	10	3.57	20.33
21-21.9	3	1.07	21.43
22-22.9	8	2.86	22.40
23-23.9	1	0.36	23.00
24-24.9	3	1.07	24.56
25-25.9	3	1.07	25.43
26-26.9	1	0.36	26.00
28-28.9	1	0.36	28.00
30-30.9	1	0.36	30.50
31-31.9	1	0.36	31.50
39-39.9	1	0.36	39.00

TABLE VIII

Annual variations in the bound carbon dioxide content of the surface waters of 136 drainage lakes.

Range of variation	Number of lakes in group
0.0-1.0	29
1.1-2.0	47
2.1-3.0	32
3.1-4.0	15
4.1-5.0	7
5.1-6.0	2
6.1-7.0	3
7.1-8.5	1

TABLE IX

Calcium content of the various bound carbon dioxide groups of lakes. The results are expressed in milligrams per liter of water. The lake waters are grouped by 2 mg. intervals, and the maximum, minimum and mean quantities of calcium are given for the various groups, based on surface samples of 357 lakes.

Carbon dioxide group	Number of lakes	Calcium		
		Maximum	Minimum	Mean
0.0- 1.9	60	2.8	0.2	0.80
2.0- 3.9	68	2.4	0.1	1.00
4.0- 5.9	21	4.5	0.2	2.45
6.0- 7.9	18	6.7	2.1	4.24
8.0- 9.9	22	6.2	2.8	4.48
10.0-11.9	30	8.8	3.3	5.78
12.0-13.9	22	8.9	4.9	6.71
14.0-15.9	39	11.7	4.4	7.84
16.0-17.9	32	11.2	6.3	8.87
18.0-19.9	19	12.8	6.7	10.64
20.0-21.9	9	13.7	11.5	12.40
22.0-23.9	7	14.7	11.2	13.13
24.0-31.9	9	18.8	10.3	14.81

TABLE X

Carbon dioxide and hydrogen ion results obtained on a number of lakes representing the different types. The quantity of carbon dioxide is stated in milligrams per liter. The waters that gave an alkaline reaction to phenolphthalein are indicated by a minus sign in the free carbon dioxide column.

Lake	Date	Depth in meters	Temperature °C.	Carbon dioxide		Hydrogen ion (pH)	
				Free	Bound	Determined	Calculated
Adelaide	Aug. 23, 1925	0	20.9	—0.5	3.9	8.8	....
	Aug. 21, 1926	0	18.7	2.1	3.2	6.6	6.7
	Aug. 5, 1927	0	20.0	1.0	2.6	6.6	6.7
		3	19.3	2.5	2.6	6.6	6.5
		5	11.3	8.5	2.6	6.4	6.0
		8	7.6	11.0	3.1	6.1	5.9
		10	6.1	12.0	3.1	6.1	5.9
		15	5.6	12.5	3.4	6.0	5.9
		20	5.4	16.5	4.4	6.0	5.9
Allequash	Aug. 15, 1926	0	20.2	—1.0	18.4	8.6	....
		3	19.8	—0.7	18.4	8.6	....
		4	19.5	2.0	18.8	7.6	7.5
		5	19.0	2.0	18.8	7.5	7.5
		6	18.2	5.6	19.2	7.1	7.1
		7	16.3	12.0	21.0	6.7	6.8
Anderson	Aug. 8, 1929	0	21.4	1.2	10.0	7.5	7.4
		5	20.8	1.5	10.2	7.5	7.4
		6	20.0	1.5	10.2	7.5	7.4
		7	14.5	—1.8	10.2	8.4	....
		8	11.7	—1.5	10.5	8.4	....
		9	9.8	0.0	11.0	8.3	....
		10	8.5	1.5	11.0	7.3	7.4
		12	7.2	3.0	11.8	6.6	7.1
		15	6.2	6.0	12.0	6.4	6.8
		18	6.1	11.5	12.5	6.3	6.6
Bear	July 25, 1925	0	20.6	1.5	2.0	6.4	6.7
		6	20.0	1.5	2.0	6.4	6.7
	July 9, 1927	0	19.9	2.4	2.0	6.3	6.4
Black Oak	Aug. 15, 1927	0	19.4	1.1	8.8	7.4	7.4
	Aug. 24, 1928	0	19.8	1.2	9.3	7.7	7.4
		10	15.7	1.7	9.7	7.6	7.3
		15	7.9	6.3	9.7	6.7	6.7
		20	7.4	9.4	9.7	6.7	6.5
		25	6.1	11.0	10.0	6.7	6.5
Brazell (Allen)	July 8, 1928	0	26.2	—6.0	15.0	9.1	....
	July 29, 1930	0	22.5	—1.0	13.0	7.9	....
Carroll	Aug. 12, 1926	0	21.0	2.7	23.7	7.6	7.5
	Aug. 13, 1927	0	20.4	—2.0	20.3	8.5	....
	Aug. 3, 1928	0	22.2	—1.2	21.0	7.9	....
	July 8, 1930	0	22.5	—3.0	22.5	9.0	....

TABLE X—Continued

Lake	Date	Depth in meters	Temperature °C.	Carbon dioxide		Hydrogen ion (pH)	
				Free	Bound	Determined	Calculated
Clear (Oneida Co.)	Aug. 19, 1932	0	20.9	1.6	2.5	6.5	6.7
		5	20.9	1.6	2.5	6.5	6.7
		10	18.5	1.6	2.5	6.5	6.7
		12	12.4	2.6	2.5	6.4	6.5
		15	9.9	5.1	2.5	6.2	6.2
		20	8.6	7.1	2.5	6.1	6.1
		26	8.0	10.6	2.5	6.0	5.9
Cornell	July 29, 1928	0	22.2	1.7	0.2	5.7	5.6
Ike Walton	Aug. 4, 1927	0	19.5	1.2	1.3	6.5	6.6
		8	19.2	2.0	1.8	6.4	6.5
		12	17.2	5.0	1.8	6.2	6.1
		14	14.3	8.2	2.6	6.0	6.0
		17	11.7	15.5	4.6	6.0	6.0
Lost Canoe	Aug. 3, 1932	0	21.8	1.1	11.0	7.8	7.5
		6	21.6	1.1	11.0	7.8	7.5
		7	15.7	4.1	11.5	7.3	7.0
		8	12.4	8.1	11.5	7.0	6.7
		9	10.6	15.1	12.5	6.7	6.4
		10	9.2	19.6	14.0	6.7	6.4
		11	8.6	32.1	17.5	6.6	6.3
		12	8.2	37.6	19.5	6.5	6.2
Mann	Aug. 15, 1926	0	20.0	—3.2	26.0	9.0	....
	May 5, 1927	0	10.5	—2.8	22.0	8.7	....
	Aug. 26, 1927	0	19.4	—2.8	25.0	8.4	....
	July 7, 1928	0	23.8	—10.7	25.6	9.0+	....
	Aug. 14, 1929	0	18.2	4.0	30.5	7.1	....
	July 23, 1930	0	22.7	—5.0	25.0	8.4+	....
Muskellunge	Aug. 8, 1925	0	21.9	—0.5	10.0	8.2	....
	Sept. 25, 1925	0	16.2	2.2	10.0	7.1	7.1
	Aug. 20, 1926	0	19.2	2.7	10.0	7.0	7.0
	May 8, 1927	0	10.4	2.9	9.2	6.8	6.9
	July 2, 1927	0	20.9	0.9	9.0	7.1	7.4
	June 27, 1928	0	15.5	1.8	9.3	7.1	7.2
	July 19, 1929	0	22.0	0.5	9.0	7.5	7.7
	Aug. 25, 1932	0	21.3	0.6	10.0	7.5	7.7
Nebish	Aug. 23, 1932	0	22.1	1.6	4.0	6.8	6.9
		3	22.0	1.6	4.0	6.8	6.9
		5	21.3	1.6	4.0	6.6	6.9
		7	20.8	2.1	4.0	6.4	6.7
		8	17.7	10.6	4.5	6.2	6.2
		10	12.2	15.1	5.5	6.1	6.0
		12	10.1	16.6	6.5	6.1	6.0
		14	9.1	21.6	8.0	6.1	6.0
Trout	Aug. 28, 1925	0	19.8	—0.5	20.0	8.2	....
	Sept. 21, 1925	0	17.5	0.8	19.6	7.6	7.8
	May 8, 1926	0	3.9	2.7	20.0	7.4	7.3

TABLE X—Continued

Lake	Date	Depth in meters	Temperature °C.	Carbon dioxide		Hydrogen ion (pH)	
				Free	Bound	Determined	Calculated
	Aug. 23, 1926	0	19.0	1.9	18.8	7.4	7.4
	Aug. 20, 1927	0	18.3	1.5	19.0	7.6	7.5
	June 24, 1928	0	14.8	1.5	19.0	7.6	7.5
	July 25, 1928	0	22.0	—0.9	18.5	8.2	....
	Aug. 25, 1928	0	19.3	1.0	17.8	7.9	7.7
	Aug. 27, 1929	0	20.0	0.8	19.0	7.7	7.8
	Aug. 22, 1930	0	20.6	1.0	18.5	7.6	7.6
	Aug. 27, 1931	0	19.9	0.5	18.5	7.7	7.7
	Aug. 22, 1932	0	20.7	1.8	19.0	7.6	7.5
		8	20.1	1.8	19.0	7.6	7.5
		10	15.5	2.3	19.0	7.4	7.4
		15	8.6	7.1	19.0	7.3	6.9
		20	7.9	9.1	19.0	7.1	6.8
		25	7.4	11.6	19.5	6.9	6.7
		30	7.2	14.6	20.0	6.7	6.6
		33	7.0	16.6	20.0	6.6	6.5
Wild Cat	Aug. 3, 1925	0	21.3	—0.5	33.5	8.4	....
	Sept. 22, 1925	0	16.8	0.0	32.3	8.1	....
	Aug. 24, 1926	0	19.0	2.6	30.8	7.6	7.6
		5	18.4	3.4	30.8	7.5	7.5
		7	17.6	6.0	30.8	7.2	7.2
		9	12.5	10.4	39.4	7.1	7.1
		11	11.7	23.2	44.1	6.8	6.8
	Aug. 17, 1928	0	23.2	—0.4	29.0	8.3	....
	July 20, 1929	0	21.9	3.0	30.5	7.7	7.5
	April 26, 1930	0	8.0	0.0	33.2	8.0	....

TABLE XI

Carbon dioxide content and hydrogen ion concentration of some of the well waters, together with similar data on the surface and bottom waters of the lakes on which the wells are situated. The carbon dioxide is indicated in milligrams per liter. The minus sign in the free carbon dioxide column indicates that the water gave an alkaline reaction to phenolphthalein.

Lakes and wells	Depth in meters	Temperature °C.	Carbon dioxide		Hydrogen ion (pH)	
			Free	Bound	Determined	Calculated
Adelaide	0	20.0	1.0	2.6	6.6	6.9
	20	5.4	16.5	4.4	6.0	6.0
Resort well	29.6	9.0	11.0	40.0	7.7	7.1
Anderson	0	21.4	1.2	10.0	7.5	7.4
	18	6.1	11.5	12.5	6.3	6.6
Spring	0	8.3	5.5	30.0	7.6	7.3
Clear	0	20.9	1.6	2.5	6.5	6.7
	26	8.0	10.6	2.5	6.0	5.9
Boyd well	....	7.6	25.0	14.0	6.3	6.3
Krogman	....	8.3	41.0	13.0	6.0	6.0
Stover	6.7	7.7	58.0	17.5	6.1	6.0
Fishtrap	0	19.4	1.9	18.3	7.4	7.5
	9	11.3	9.5	20.2	7.1	6.8
Kenilworth well	8	7.2	14.2	5.7	6.2	6.1
Meyer	6.7	7.2	12.0	5.5	6.2	6.2
Engel	32	8.2	5.5	6.5	6.3	6.6
Little St. Germain	0	20.0	—0.5	13.5	8.0	....
Sisson's Resort	12	8.0	7.7	2.7	6.0	6.1
Muskellunge	0	18.6	1.3	9.8	7.2	7.4
	19	9.5	13.0	13.0	6.5	6.5
Brannum well	....	8.2	22.0	9.0	6.1	6.1
North Camp	6	10.3	13.0	12.0	6.4	6.5
South Camp	4.6	8.2	20.0	8.0	5.9	6.1
Christensen—N.	25	9.0	22.0	22.5	6.8	6.5
Christensen—S.	7	9.5	12.5	11.5	6.3	6.4
Pearse	....	8.5	16.0	7.5	6.2	6.2
Plum	0	20.8	2.2	17.7	7.6	7.4
	17	11.2	8.5	18.7	6.9	6.8
Camp Highlands	6.4	8.0	18.0	15.0	6.5	6.4
Warwick Woods	4.5	6.5	16.0	5.0	5.9	6.0
Public Camp	9	8.0	38.0	25.0	6.8	6.3
Ranger Station	12	......	10.0	30.5	7.5	7.0
Sayner's Resort	4	8.0	41.5	9.5	6.2	5.9
Sunny Crest	13.7	9.5	29.0	9.5	6.3	6.0
Trail's End	7.6	8.0	25.0	11.5	6.4	6.2
Warner's Resort	8.5	8.5	67.5	34.0	6.4	6.2
Wolff's Cottages	6	7.5	9.0	4.0	5.7	6.2

TABLE XI—Continued

Lakes and wells	Depth in meters	Temperature °C.	Carbon dioxide		Hydrogen ion (pH)	
			Free	Bound	Determined	Calculated
Trout	0	20.6	0.5	18.5	7.7	7.7
	33	7.0	17.0	19.5	6.9	6.6
Armour Camp	9	7.3	5.0	10.5	7.1	6.8
Blaisdell	6.7	7.5	16.0	20.0	6.4	6.6
Camp Franklin	3.4	9.0	18.5	14.5	6.3	6.4
Cardinal Lodge	8	8.0	21.0	12.0	6.2	6.3
Forestry Barn	9	7.8	0.5	22.5	7.9	8.2
Forestry House	25	7.8	10.0	35.0	7.7	7.1
Hart	14	9.0	11.0	17.0	6.9	6.7
Heinemann	....	8.5	11.5	19.6	6.9	6.8
Kern	6	......	16.0	4.0	5.6	5.9
Laboratory	4.5	15.2	19.3	12.0	6.3	6.3
Latimer	21	8.0	3.5	26.5	7.3	7.3
McClain	22	7.8	1.0	25.5	7.8	8.0
Meade	....	10.0	40.0	9.0	5.7	5.9
Murphy	7.6	......	28.5	7.5	5.8	6.2
Red Arrow	5	......	21.0	7.5	5.9	6.1
Red Crown	....	11.0	14.2	24.5	7.0	6.8
Sand Beach	....	15.0	4.0	29.5	7.7	7.4
Smith	....	8.0	8.5	15.5	7.1	6.8
The Point	4.5	7.3	11.5	6.5	6.3	6.3
Wild Cat	0	19.0	2.6	30.8	7.6	7.6
	11	11.8	23.2	44.1	6.8	6.9
Ranger Cabin	23	8.2	7.0	19.5	7.1	7.0
Wild Cat Inn	12	8.0	21.7	18.5	6.5	6.5

TABLE XII

The 149 wells are divided into groups on the basis of the bound carbon dioxide content of their waters; the mean quantity found in the different groups is indicated in milligrams per liter of water.

Group	Number of wells	Percent of total number	Mean quantity of bound carbon dioxide
0.0- 4.9	19	12.8	3.8
5.0- 9.9	49	33.0	7.3
10.0-14.9	27	18.1	12.0
15.0-19.9	12	8.1	17.6
20.0-24.9	9	6.0	22.2
25.0-29.9	9	6.0	27.2
30.0-39.9	8	5.4	33.6
40.0-49.9	7	4.7	42.4
50.0-59.9	7	4.7	55.6
80.0-89.9	1	0.6	82.0
100.0-109.9	1	0.6	100.0

TABLE XIII

Comparison between the mean of the colorimetric pH readings and those obtained with the quinhydrone system in 1932.

Lake	Colorimetric readings		Quinhydrone Readings	Difference
	Number	Mean		
Adelaide	9	6.9	6.5	0.4
Anderson	3	7.2	7.3	0.1
Anna	3	6.1	6.0	0.1
Bear	6	6.2	6.2	0.0
Big Carr	7	5.9	5.5	0.4
Cardinal Bog	5	5.4	5.5	0.1
Clear	10	6.6	6.5	0.1
Crystal	13	6.1	5.7	0.4
Day	6	5.9	5.9	0.0
Diamond	6	5.9	5.4	0.4
Edith	2	5.4	5.7	0.3
Helen	5	6.1	6.2	0.1
Helmet	2	5.6	5.8	0.2
Jag	5	5.9	5.9	0.0
Lynx	2	5.8	6.2	0.4
Mary	7	6.0	6.1	0.1
Mc Grath	3	5.2	5.0	0.2
Mud	2	6.3	6.3	0.0
Pallette	6	6.7	6.6	0.1
Red Bass	2	5.2	5.5	0.3
Sterrett	6	6.4	6.3	0.1
Trout	27	7.5	7.6	0.1
Weber	15	6.2	6.0	0.2
Yolanda	2	5.8	5.9	0.1

TABLE XIV

This table shows the range of the hydrogen ion concentration (pH) in 1,225 surface samples obtained from 538 lakes and lakelets of northeastern Wisconsin.

pH groups	Number of samples	pH groups	Number of samples
4.4	4	7.0-7.4	249
4.5-4.9	9	7.5-7.9	230
5.0-5.4	97	8.0-8.4	85
5.5-5.9	119	8.5-8.9	19
6.0-6.4	201	9.0-9.4	12
6.5-6.9	200		

TABLE XV

The 238 seepage and 280 drainage lakes are grouped on the basis of the hydrogen ion concentration of their surface waters. The mean pH has been used in classifying the lakes that were visited more than once.

Seepage Lakes		
	Lakes	
pH groups	Number	Per cent
4.4-4.5	4	1.7
4.6-4.7	1	0.4
4.8-4.9	3	1.3
5.0-5.1	14	5.9
5.2-5.3	17	7.1
5.4-5.5	22	9.2
5.6-5.7	26	10.9
5.8-5.9	35	14.8
6.0-6.1	23	9.7
6.2-6.3	30	12.6
6.4-6.5	30	12.6
6.6-6.7	9	3.8
6.8-6.9	10	4.2
7.0-7.1	6	2.5
7.2-7.3	6	2.5
7.4-7.5	2	0.8

Drainage Lakes		
	Lakes	
pH groups	Number	Per cent
4.8-4.9	1	0.4
5.0-5.1	2	0.7
5.2-5.3	5	1.8
5.4-5.5	3	1.1
5.6-5.7	3	1.1
5.8-5.9	4	1.4
6.0-6.1	5	1.8
6.2-6.3	2	0.7
6.4-6.5	4	1.4
6.6-6.7	29	10.3
6.8-6.9	24	8.6
7.0-7.1	37	13.2
7.2-7.3	24	8.6
7.4-7.5	37	13.2
7.6-7.7	42	15.0
7.8-7.9	24	8.6
8.0-8.1	18	6.4
8.2-8.3	7	2.5
8.4-8.5	7	2.5
8.6-8.7	0	0.0
8.8-8.9	2	0.7

TABLE XVI

Annual variations of the hydrogen ion content of the surface waters of 245 lakes that were visited in more than one year during this investigation.

pH differences	Number of lakes	Per cent of lakes
0.0-0.4	65	26.5
0.5-0.9	106	43.3
1.0-1.4	51	20.8
1.5-1.9	17	7.0
2.0-2.5	6	2.4

TABLE XVII

The dichotomous stratification of the pH in Lake Mary on July 11, 1928. Results for other determinations made on this date are given for purposes of comparison. The results for carbon dioxide, oxygen, chloride and residue or total solids are indicated in milligrams per liter of water.

Depth in meters	Temperature °C.	pH	Carbon dioxide		Oxygen	Chloride	Residue
			Free	Bound			
0	20.8	6.2	3.0	2.8	6.7	1.0	51.4
1	20.7	6.1	3.0	2.8	6.8	....	......
2	16.4	5.9	5.4	2.8	6.4	....	......
3	10.2	5.4	16.2	3.1	0.4	....	......
4	6.0	5.5	17.4	3.1	0.0	....	......
5	4.6	5.5	18.0	3.6	0.0	1.0	58.1
8	4.1	5.7	18.9	4.3	0.0	....	......
10	4.0	5.8	20.6	5.3	0.0	1.0	65.6
15	4.2	5.9	32.7	8.8	0.0	0.8	74.1
18	......	5.9	38.4	10.0	0.0	0.8	77.4
21	4.6	5.9	42.5	10.5	0.0	0.8	82.8

TABLE XVIII

Mean quantity of free and bound carbon dioxide in milligrams per liter in the various hydrogen ion groups. The table includes the results for 227 seepage and 272 drainage lakes. See figs. 30 and 31.

pH group	Number of lakes	Carbon dioxide	
		Free	Bound
Seepage Lakes			
4.4-4.9	7	2.3	1.3
5.0-5.4	38	2.3	1.3
5.5-5.9	71	1.9	1.6
6.0-6.4	66	1.7	2.0
6.5-6.9	31	1.5	3.0
7.0-7.4	14	1.4	7.7
Drainage Lakes			
5.0-5.4	8	3.7	2.3
5.5-5.9	8	2.4	1.9
6.0-6.4	6	2.5	3.6
6.5-6.9	56	2.5	8.0
7.0-7.4	81	1.8	13.1
7.5-7.9	79	1.1	16.4
8.0-8.4	29	—0.7	18.8
8.5-8.9	5	—2.7	19.3

TABLE XIX

Relation between the hydrogen ion and the calcium content of the surface waters of 358 lakes; the results for the latter are indicated in milligrams of Ca per liter of water.

pH group	Number of lakes	Ca	pH group	Number of lakes	Ca
4.8-4.9	7	0.58	6.6-6.7	25	3.20
5.0-5.1	30	0.50	6.8-6.9	16	4.07
5.2-5.3	17	0.61	7.0-7.1	41	6.65
5.4-5.5	17	1.03	7.2-7.3	26	7.34
5.6-5.7	8	1.49	7.4-7.5	26	7.70
5.8-5.9	11	0.98	7.6-7.7	28	8.87
6.0-6.1	9	1.00	7.8-7.9	23	9.27
6.2-6.3	14	1.64	8.0-8.1	18	9.86
6.4-6.5	24	2.11	8.2-9.2	18	10.20

TABLE XX

Relation of the hydrogen ion to the free and bound carbon dioxide of the well waters. The free and bound carbon dioxide are given in milligrams per liter of water.

pH group	Wells		Carbon dioxide	
	Number	Per cent	Free	Bound
5.0-5.4	3	2.0	17.6	2.9
5.5-5.9	21	13.4	22.0	5.6
6.0-6.4	53	36.3	21.6	10.1
6.5-6.9	27	18.1	15.7	13.6
7.0-7.4	18	12.1	8.0	20.1
7.5-7.9	22	14.8	10.7	44.4
8.0-8.4	5	3.3	1.9	33.4

FURTHER NOTES ON THE OCCURRENCE OF PARASITIC COPEPODS ON FISH OF THE TROUT LAKE REGION, WITH A DESCRIPTION OF THE MALE OF *Argulus biramosus*[*]

RUBY BERE

From the Limnological Laboratory of the Wisconsin Geological and Natural History Survey. Notes and reports No. 56.

In conjunction with the general fish parasite work being conducted by the Wisconsin Geological and Natural History Survey at the Trout Lake Laboratory during the summers of 1931 and 1932, certain observations were made regarding the parasitic copepods which, together with the material collected, have been turned over to the writer. It was noted that these parasites were present in greater numbers in 1932 than in 1931. In the former year as many as 43 per cent of the ciscoes and 30 per cent of the perch in Trout Lake were parasitized while in 1931 only about one-half this per cent were infected.

As in 1930, the Ergasilids were present in greatest numbers in the two succeeding years and again all the specimens collected belonged to the species *Ergasilus confusus*. *Achtheres micropteri,* only one specimen of which was collected in 1930, was quite abundant in 1932 but not in 1931. The majority of the specimens were attached to the roof of the mouth cavity and the gill arches of rock bass caught in Muskellunge Lake. *Achtheres coregoni,* however, was no more plentiful than in 1930; no specimens were noted during the summers of 1931 and 1932 but in October, 1932, two specimens were taken from the fin of a whitefish caught in Trout Lake. In both 1931 and 1932 many *Arguli* were observed, whereas in 1930 only two specimens were found. However, most of the *Arguli* occurred on the sucker, only 13 of which were examined in 1930. Of the 128 *Arguli* comprising the 1931 and 1932 collections, 16 per cent have proved to be *Argulus biramosus,* the remainder being *A. catastomi*. *A. biramosus* was found on rock bass and possibly

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also on wall-eyed pike, and *A. catastomi* on the sucker. In the present instance the hosts of the these two species can only be conjectured as the various species of fish were brought to the laboratory in one bucket and many of the parasites had left the fish and were swimming about in the water of the bucket.

In 1930 no parasitic copepods were observed on any of the fish from the five soft water lakes included in the study. During the two succeeding years fish from three of these lakes, Nebish, Weber and Crystal, were examined for parasites but no copepods were found, although the same species of fish harbor them in the lakes with harder water. A total of 1088 fish has now been examined from the three lakes just mentioned. These lakes, as well as Nelson, and Geneva in which no parasitic copepods were found in 1930, are of the seepage type, i.e., they possess neither inlets nor outlets. On the other hand, parasitized lakes in which these parasitic copepods do occur are of the drainage type. Clear Lake is also a seepage lake and during 1931 and 1932, 146 fish, the majority of which were ciscoes, were examined but no copepods were found.

The question arises as to why these soft water lakes are without parasitic copepods. Internal helminth parasities are also quite rare. Other forms of life occur abundantly in Nebish and Weber lakes and to a lesser extent in Crystal. There are at least two possibilities. The parasites may never have been introduced into these lakes for the fish with which the lakes were originally populated may have been free of these parasites and invasion by new fish is impossible since the lakes possess neither inlets nor outlets. On the other hand, parasitized fish may have been among the original population but the copepods may not have been able to adapt themselves to the chemical and physical conditions existing, or which subsequently developed, in these isolated bodies of water. This phase of the problem is open to experiment and might be answered by placing parasitized and non-parasitized fish in cages and setting them in the lakes mentioned above. *E. confusus* and the two species of *Achtheres* do not leave the host after they have become attached but the larval stages are free living. Therefore, in order for non-parasitized fish to become infected the parasites would first have to pass through their life cycle in the open water.

In 1930 when *Argulus biramosus* was first described, no males were available and a short description of the male is given now. It displays the three specific characters of the female, on the basis of which the species was established, viz. 1) the biramous character of the terminal portion of the first antennae; 2) the shape of the respiratory areas (Fig. 1) ; and 3) the character of the supporting rods in the margin of the sucking disks. The third and fourth legs are highly modified in structure and as a result it is possible to distinguish the sexes with the naked eye.

The basipod of the fourth leg carries a very large leaf-like appendage (Fig. 2). The peg on the anterior margin of the basipod is much like that of many other species. Posterior to the basal portion of the peg is a small narrow area which is covered with minute spines. The endopod is two jointed but the distal segment is much reduced in size; this modified segment and the very large flap on the basipod give the leg a very characteristic appearance.

Attached to the lateral ventral wall of the basipod of the third leg is a large lobe which is fringed with long setae on its posterior border and short spines on its outer border (Fig. 3). A large scythe-like appendage, partly covered with spines, extends from the anterior margin of the basipod. Arising from the proximal basipod segment are two lobes which are thickly covered with small spines and which lie on either side of the scythe-like structure, partially covering its base. The semen receptacle is located in the posterior portion of the distal basipod segment and anterior to it, on the dorsal surface, is a circular concave area bearing many spines.

The basal joint of the second leg bears a flap which carries three plumose setae at the outer anterior corner, but the posterior border and part of the lateral surface are thickly covered with short spines (Fig. 4).

The specimens had been preserved in alcohol and are almost colorless, no trace of the prominent markings found on the thorax of the female being apparent.

The ten males range in length from 4-6.5 mm. and in width from 3-5 mm. The 12 females range in length from 2.5-7 mm. and in width from 2-5 mm.

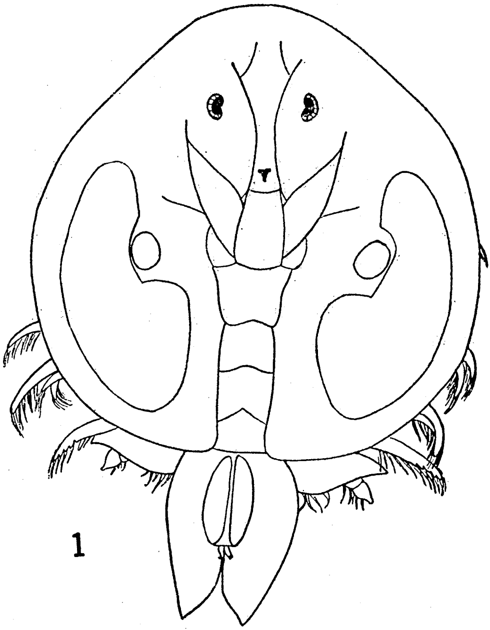
PLATE I

FIG. 1. Dorsal view of Argulus biramosus, male.

FIG. 2. Ventral view of fourth swimming leg.

FIG. 3. Ventral view of third swimming leg.

FIG. 4. Ventral view of second swimming leg.



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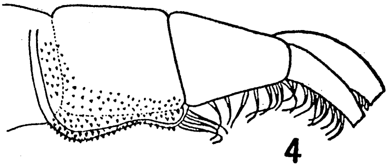

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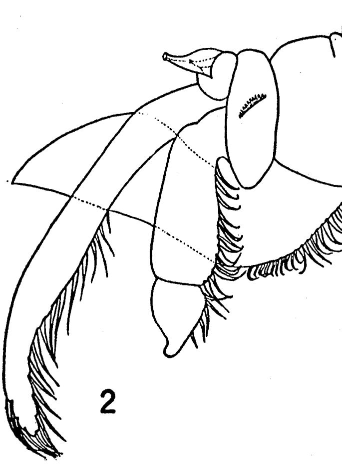

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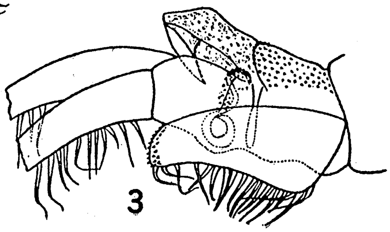

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TWO NEW SUBSPECIES OF FISHES FROM WISCONSIN

CARL L. HUBBS AND C. WILLARD GREENE

During the course of the survey of the Wisconsin fish fauna, which we have been conducting for the Wisconsin Geological and Natural History Survey, three new subspecies of fishes have been discovered. One of these, *Notropis nux richardsoni,* was described by us in 1926 (Hubbs, 1926: 39, pl. 3, fig. 2); originally this form was regarded as a subspecies of *N. heterodon,* but later studies showed that it was connected rather with *N. nux* (see Hubbs and Greene, 1928: 372). The other new subspecies are described in this report, under the following names:

Campostoma anomalum oligolepis

Boleosoma nigrum eulepis

The very interesting distribution and the probable origin and history of these forms, will be treated in a subsequent paper by the junior author.

Most of the counts and measurements as tabulated in this paper were made for us by Dr. Canuto G. Manuel.

1. *Campostoma anomalum oligolepis,* new subspecies

Plate II, Fig. 1.

Holotype, a breeding male 92 mm. long to caudal, collected by Greene and Stuart in Little Rib River 2½ miles east of Hamburg, Marathon County, Wisconsin, on June 19, 1927; Cat. No. 75582, Museum of Zoology, University of Michigan. Numerous paratypes are preserved in that museum and also in the University of Wisconsin.

In identifying the many hundred specimens of *Campostoma anomalum* collected in Wisconsin, it early became apparent that two rather sharply differentiated forms occur in this state. Subsequent study of the species throughout its wide range has indicated that one of these forms, occurring in southwestern Wisconsin, is of wide distribution toward the southwest, as far as Mexico. Its proper name appears to be *Campostoma anomalum pullum* (Agassiz). A photograph of a nuptial male of *C. a.*

pullum is reproduced in Plate II, Figure 2. The other form which we have not yet encountered outside of Wisconsin, appears to have never been named. Although it occurs here and there (with *C. a. pullum*) through the southwestern part of the state; its main range is to the northward and eastward. It occurs in both the Lake Michigan and the Mississippi River basins. The distinctive features of the two subspecies of *Campostoma anomalum* occurring in Wisconsin are listed in tabular form in Table I.

TABLE I

Distinctive features of Compostoma anomalum in Wisconsin.

	C. a. oligolepis	*C. a. pullum*
Scales:		
Imbrication	Less strong	More strong
Exposed surfaces	Nearly round	Narrower
Number, lateral line to caudal base:		
Extreme range	41 to 48	47 to 58
Usual range	43 to 47	49 to 55
Average	45.1	52.0
Lateral line anterior to vertical from origin of pelvic fin	15 to 19	18 to 24
Above lateral line	Usually 6½	Usually 8½
Lateral line to lateral line, inclusive, just in front of dorsal	15 to 18	18 to 22
Around body, just before dorsal		
Extreme range	29 to 38	38 to 50
Usual range	31 to 36	39 to 46
Average	33.3	42.3
Form of body	Generally robust	Generally slender
Depth [very variable], typically about	4.5	4.0
Form of head usually	Flat-topped	Arched at nape
Snout (from side or above)	More globose	More pointed
Width of head typically	1.5 to 1.7	1.7 to 1.9
Interorbital width typically	3.3 to 3.5	3.5 to 4.0
Forward convergence of sensory lines on frontal region of skull	Generally slight	Generally strong
Interorbital region of skull in cross section	Arched medially	More flattened
Form of gape typically	Semicircular	Longitudinally semioval
Front of mouth	Somewhat truncated	Evenly curved
Width of gape (see table IV)	Greater	Less
Color averaging	Darker, more bicolored	Paler, more uniform
Scale borders in young	Darker	Less distinct
Fins in young	Reddish	Probably less reddish

In addition to these numerous average differences, the two forms *oligolepis* and *pullum* differ also very interestingly in distribution, as the junior author will indicate in a later paper. As already mentioned, the main range of *oligolepis* in Wisconsin is to the north and east of the territory occupied by *pullum*. They were taken together at only seven localities, as follows:

1. Tributary of West Pecatonica River, 3 miles east of Darlington, Lafayette County.

2. Mineral Branch of West Pecatonica River, just west of Mineral Point, Iowa County.

3. Tributary to Dodge Creek, 5½ miles northeast of Blanchardville, Iowa County.

4. Crawfish River, 2 miles northwest of Fall River, Columbia County.

5. South Branch of Turtle Creek, at Allen Grove, Walworth County.

6. Lake Geneva outlet, 3 miles east of Lake Geneva city, Walworth County.

7. Bark River, Merton, Waukesha County.

These localities all lie in the territory largely occupied by *C. a. pullum,* and in each of these collections that subspecies predominates, except in the lot from Lake Geneva outlet where two specimens of each were caught. There is no real evidence of intergradation even in these localities. The scale counts for each form, where the two occur together (Tables II and III), are almost typical, though apparently showing a slight approach toward the mean of the other subspecies (which might reflect some hybridization in the past). Furthermore, the other characters, such as contours of body, shape of head and size of mouth, confirm the separation. These other characters are all of average or usual significance; even when taken together, they do not invariably characterize individuals. Occasionally whole series of either subspecies show the form characters of the other. Within all of the same stream systems listed above, pure stocks of both subspecies were also taken.

TABLE II

Summary of scale counts in Wisconsin specimens of Campostoma anomalum. In each column the median set of counts is for lateral line scales, the upper set for scales around the body and the bottom set for the sum of these two counts; the circumference counts in the column for C. a. pullum, where occurring alone, are given to the left of the lateral line counts.

Species:	Campostoma anomalum oligolepis								Campostoma anomalum pullum								
Occurring	together with *C. a. pullum*							Alone	Alone		Together with *C. a. oligolepis*						
Locality	1	2	3	4	5	6	7	—	Around body	Lat. line	1	2	3	4	5	6	7
29	..	..	..	..	..	..	..	1	....	....	..	..	..	..	..	..	..
30	..	..	..	..	..	..	..	7	....	....	..	..	..	..	..	..	..
31	..	..	..	..	1	..	..	25	....	....	..	..	..	..	..	..	..
32	1	..	..	..	2	..	..	41	....	....	..	..	..	..	..	..	..
33	..	1	..	..	2	..	..	55	....	....	..	..	..	..	..	..	..
34	..	..	..	..	4	..	1	62	....	....	..	..	..	..	..	..	..
35	..	..	..	1	2	2	..	25	....	....	..	..	..	..	..	..	..
36	..	..	1	..	2	..	..	15	....	....	..	..	..	..	..	..	..
37	..	1	..	..	..	..	..	5	....	....	..	..	..	..	..	..	..
38	..	..	..	..	..	..	..	1	7	....	..	1	..	..	..	..	..
39	..	..	..	..	..	..	..	....	15	....	..	1	..	..	1	..	..
40	..	..	..	..	..	..	..	....	22	....	..	1	..	1	2	..	..
41	..	..	..	..	..	..	..	1	25	....	..	1	..	..	2	1	..
42	..	..	..	..	..	..	..	7	23	....	..	1	..	..	4	1	..
43	..	..	..	..	1	..	..	19	27	....	..	..	1	1	4	..	1
44	..	..	..	..	1	1	..	43	12	....	..	4	1	..	4	..	1
45	..	..	..	1	3	..	..	71	20	....	1	1	..	..	2	..	..
46	1	1	..	..	5	..	1	44	10	....	..	1	..	..	2	..	..
47	..	1	..	..	1	1	..	34	3	3	..	1	..	..	1	..	..
48	..	..	1	..	..	..	..	9	2	8	..	1	..	..	2	..	..
49	..	..	..	..	2	..	..	....	1	12	1	1	1	1	3	..	..
50	..	..	..	..	..	..	..	....	1	22	..	2	..	..	9	..	1
51	..	..	..	..	..	..	..	....	....	38	..	3	..	..	2	..	1
52	..	..	..	..	..	..	..	....	....	39	..	3	1	..	3	..	..
53	..	..	..	..	..	..	..	....	....	31	..	1	..	1	1	1	..
54	..	..	..	..	..	..	..	....	....	20	1	1	..	..	1	..	..
55	..	..	..	..	..	..	..	....	....	12	..	..	..	..	..	..	..
56	..	..	..	..	..	..	..	....	....	7	..	..	..	..	..	..	..
57	..	..	..	..	..	..	..	....	....	3	..	..	..	..	..	1	..
58	..	..	..	..	..	..	..	....	....	2	..	..	..	..	..	..	..
72	..	..	..	..	..	..	..	1	....	....	..	..	..	..	..	..	..
73	..	..	..	..	..	..	..	2	....	....	..	..	..	..	..	..	..
74	..	..	..	..	..	..	..	6	....	....	..	..	..	..	..	..	..
75	..	..	..	..	1	..	..	14	....	....	..	..	..	..	..	..	..
76	..	..	..	..	1	..	..	18	....	....	..	..	..	..	..	..	..
77	..	..	..	..	..	..	..	31	....	....	..	..	..	..	..	..	..
78	1	..	..	..	1	..	..	41	....	....	..	..	..	..	..	..	..
79	..	1	..	..	2	1	..	42	....	....	..	..	..	..	..	..	..
80	..	..	..	1	4	..	1	27	....	....	..	..	..	..	..	..	..
81	..	..	..	..	1	..	..	15	....	....	..	..	..	..	..	..	..
82	..	..	..	..	2	1	..	11	....	....	..	..	..	..	..	..	..
83	..	..	..	..	1	..	..	3	....	....	..	..	..	..	..	..	..
84	..	1	1	..	..	..	..	....	....	....	..	..	..	..	..	..	..

85	..	..	..	..	..	..	..	1	....		....	..	..	..	..	..	..	..
86	..	..	..	..	..	..	..	....		2		..	..	..	..	..	..	..
87	..	..	..	..	..	..	..	....		1		..	..	..	..	..	..	..
88	..	..	..	..	..	..	..	....		3		..	1	..	..	..	..	..
89	..	..	..	..	..	..	..	....		7		..	1	..	1	..	..	..
90	..	..	..	..	..	..	..	....		11		..	1	..	..	3	..	..
91	..	..	..	..	..	..	..	....		14		..	2	..	..	2	..	..
92	..	..	..	..	..	..	..	....		19		..	..	..	..	4	..	..
93	..	..	..	..	..	..	..	....		18		..	..	1	..	3	..	..
94	..	..	..	..	..	..	..	....		13		..	..	..	..	2	..	2
95	..	..	..	..	..	..	..	....		13		..	1	1	..	2	1	..
96	..	..	..	..	..	..	..	....		11		..	3	..	1	4	..	..
97	..	..	..	..	..	..	..	....		15		..	1	..	..	..	..	..
98	..	..	..	..	..	..	..	....		15		..	1	..	..	..	1	..
99	..	..	..	..	..	..	..	....		8		1	..	..	..	1	..	..
100	..	..	..	..	..	..	..	....		7		..	1	..	..	..	..	..
101	..	..	..	..	..	..	..	....		3		..	..	..	..	..	..	..
102	..	..	..	..	..	..	..	....		2		..	..	..	..	..	..	..
103	..	..	..	..	..	..	..	....		....		..	..	..	..	..	..	..
104	..	..	..	..	..	..	..	....		1		..	..	..	..	..	..	..
105	..	..	..	..	..	..	..	....		....		..	..	..	..	..	..	..
106	..	..	..	..	..	..	..	....		1		..	..	..	..	..	..	..
107	..	..	..	..	..	..	..	....		1		..	..	..	..	..	..	..

The two Wisconsin forms of *Campostoma* are regarded as subspecies despite the fact that we have been unable to find good evidence that they intergrade. This course is followed because in other localities we find the distinctive features to break down. Thus in the Ohio Valley form, typical *C. a. anomalum,* the scales are intermediate in number. (See Table III).

In fact, the distinction of *C. a. oligolepis* as individuals from *C. a. anomalum* is often difficult, though the average characters are sufficiently different to enable most series to be distinguished rather readily. In addition to having the scales usually somewhat fewer, *oligolepis* usually has the mouth somewhat smaller (Table IV). The form of body, head and mouth is very similar.

C. a. anomalum differs only in average characters from *C. a. pullum*; the distinction of individuals often appears impossible and the identification of series is difficult at times. These differences involve scale size (Table III), mouth size (Table IV) and shape and form of body and head. The characters of form, in which typical *anomalum* resembles *oligolepis* closely, are most subject to variation.

TABLE III

Average of scale counts for different lots of Campostoma anomalum. The number of specimens on which each average is based is indicated in parenthesis.

	Scales around body	Scales in lateral line	Sum of the two counts
C. a. olgolepis where occurring alone in Wisconsin	33.3 (237)	45.1 (228)	78.3 (212)
C. a. oligolepis where occurring with *C. a. pullum* in Wisconsin	34.1 (21)	46.0 (21)	80.1 (21)
C. a. anomalum, Ohio Valley (exclusive of Kanawha, Cumberland and Tennessee systems)	38.1 (51)	47.6 (55)	85.6 (51)
C. a pullum, where occurring with *C. a. oligolepis* in Wisconsin	42.9 (43)	50.9 (43)	93.8 (42)
C. a. pullum where occurring alone in Wisconsin........	42.3 (166)	52.0 (194)	94.4 (163)

Since *C. a. anomalum* appears to be incompletely differentiated from *C. a. oligolepis* on the one hand and from *C. a. pullum* on the other hand, it seems logical to regard both *oligolepis* and *pullum* as subspecies of *C. anomalum*, even though they themselves appear to intergrade very slightly or not at all. When other subspecies of *anomalum* (yet unnamed) are considered, the treatment of *oligolepis* as a subspecies appears to be almost demanded.

Description (based primarily on nuptial male holotype 92 mm. long to caudal, supplemented by measurements in parenthesis of numerous paratypes).—This is usually an elongated by rather thick fish: greatest depth 4.7 (4.3 to 4.7, usually about 4.5) in standard length; least depth of caudal peduncle 2.6 (2.05 to 2.8, usually 2.2 to 2.5) in head, 2.7 (2.0 to 3.0, usually 2.4 to 2.7) in depth of body, measured over curve of side, and 2.4 (2.1 to 2.6) in standard length of caudal peduncle. The anterior dorsal profile is usually rather flattish, less arched than in *pullum*. The head tends toward a squarish form (relatively speaking), flattened above, broad, and rather globose in the muzzle region: length of head 3.8 (to 4.3, usually about 4.0) in standard length; depth of head, from occiput to isthmus, 1.4 (1.35 to 1.6, usually about 1.5); width of head 1.8 (1.5 to 1.8, usually about 1.65) in length of head; least bony interorbital width 3.5 (3.05 to 3.8, usually 3.3 to 3.5); postorbital length 2.1 (2.0 to 2.25); sensory lines in frontal region of skull nearly parallel, not so strongly convergent and approximated anteriorly as in *pullum*; suborbital width 5.0 (5.1 to 7.0); eye (cornea) 5.9 (4.2 to 6.0); snout 2.65 (2.6 to 2.95); length of upper jaw 3.1 (3.0 to 3.8); width of mouth including lips 2.7 (2.7 to 3.35); width of gape, excluding outer lip, 3.6 (3.9 to 5.2, usually 4.3 to 4.8 in non-breeding males and females).

Distance from tip of snout to origin of dorsal 2.05 (2.0 to 2.1) in standard length; snout to pelvic 2.25 (2.05 to 2.2); insertion of pelvic to origin of anal 1.05 (1.05 to 1.35) in distance between insertions of paired fins; longest dorsal ray 1.4 (1.2 to 1.5) in head; length of depressed dorsal 1.3 (1.3 to 1.8) in distance forward to occiput; dorsal base 2.0 (2.0 to 2.65); length of caudal fin 1.15 (0.95 to 1.1) in head; length of depressed anal 1.3 (1.3 to 1.5); anal base 2.15 (2.3 to 2.9 in non-breeding males and females); length of pectoral fin 1.05 (1.1 to 1.5) in interspace between insertions of paired fins; length of pelvic fin 1.2 (1.1 to 1.6) in pelvic-anal interspace.

Dorsal with 8 principal rays (constant); anal 8 in holotype, but normally with 7; caudal 19 (18 to 20) principal rays; pectoral 17 (13 to 17); pelvic 8 (rarely 9).

For scale counts refer to Tables II and III. The scale structure is about the same as in *pullum*. The focus is far basad.

TABLE IV

Width of gape in three subspecies of Campostoma anomalum. measured between angles of gape, not across outer lips; measured into head.

	C. a. anomalum	*C. a. oligolepis*	*C. a. pullum*
Usual variation in half-grown and adults	3.7 to 4.4	4.3 to 4.8	4.6 to 5.5
Extreme variation in half-grown to adults	3.4 to 4.7	3.9 to 5.2	4.4 to 6.2
In large breeding males, about	3.3	3.6	3.8

The lateral field is much reduced by the encroachment of the apical field, which bears numerous radii between which the ridges are curved. An anterolateral angle may be fairly well marked or absent. The lateral radii run obliquely to the scale margin.

Gill-rakers 22 (19 to 24). Pharyngeal teeth 4-4 in all specimens examined, with an obliquely truncated grinding surface and obsolete hook. Intestine coiled around air-bladder as usual in the genus.

The general color and color pattern is similar to that of the other forms, with average differences noted in Table I. The breeding male shows the usual large subbasal blackish markings and orange shades on the fins, possibly more intensely than in *pullum.*

The nuptial tubercles are similar to those of other subspecies. Very large, suberect ones, with swollen bases, occur on top of head and on sides, as shown in the figure. Much smaller soft tubercles or papillae occur on all surfaces of the head, and are enlarged and uniserially arranged along each branchiostegal ray and on adjacent opercular edge. The tubercles on the upper surface of the pectoral rays are moderately large, slightly hooked forward and arranged in one series basally branching one distally. Tubercles are also scattered in one series, along the anterior dorsal rays, strongest on last unbranched ray. At most barest traces of tubercles can be detected on the caudal fin, or on the thickened rays of anal and pelvic fins.

The name *oligolepis* emphasizes the character of low scale number, which reaches its extreme in this subspecies.

2. *Boleosoma nigrum eulepis,* new subspecies

Plate III, Figs. 1, 2, 3.

Holotype.—An adult 45 mm. long to caudal, collected in a tributary of the West Branch of Rock River, 2 miles north of Atwater, Dodge County, Wisconsin; Cat. No. 77225, Museum of Zoology, University of Michigan.

A large number of paratypes from Wisconsin, Minnesota and Iowa, grading in standard length up to 61 mm., are in the collections of the universities of Michigan and Wisconsin.

Forbes and Richardson (1909: 297-298) discovered an extremely interesting trend of variation in *Boleosoma nigrum* in Illinois. We quote their remarks:

> In studying our collections, wide variation was noticed with respect to the scaly covering of the breast and cheeks, ranging from complete nakedness to complete scaliness of both, and also a considerable variation in robustness of build. While, generally speaking, specimens become more scaly northward and more slender southward, it was not possible to make out, even approximately, any line or area of division, either general or local, between the two forms, or to draw any definite dividing

line among the variants themselves. This confusion of conditions may be illustrated by the following analysis of a single collection of forty-six specimens (Accessions No. 28180) obtained from the north fork of the Vermilion River in Vermilion county June 6, 1901.

Variations of *Boleosoma nigrum* (46 specimens)

Scales on cheeks	Scales on breast	Males	Females
None	None	2	5
None	Trace	2	2
None	Two thirds covered	0	1
Trace	None	0	1
One third covered	None	1	0
Half covered	None	1	0
Trace	Trace	1	2
Trace	Half covered	2	1
Trace	Fully covered	5	1
One fifth covered	Fully covered	3	1
One third covered	Fully covered	4	1
Half covered	Fully covered	4	2
Fully covered	Fully covered	4	0
Totals		29	17

It was also impossible to distinguish any correlation, even approximately constant, between robustness of form and scaliness of cheeks and breasts, both stout and slender forms having these parts sometimes naked and sometimes more or less covered with scales. The larger percentage of specimens with scaly breasts and cheeks came from the Rock River basin, from the northwest district, and from the Lake Michigan drainage; but in all these districts scaly and naked specimens were intermingled, the latter preponderating. In collections from the Kaskaskia, the Saline, the Cache, and the lower Wabash Valley, on the other hand, both cheeks and breasts were also invariably naked, while in the upper Wabash streams and in the Illinois basin the two forms were indiscriminately commingled. The larger number of the stouter specimens came from the Rock River system and the northwest area, while those from the Kaskaskia, the Cache, and the Saline were of more slender proportions, with the depth usually nearer six times than five times the length. A similar study of specimens from a wider range would probably show that Illinois is in a region of transition between two varieties of this species—the typical *nigrum*, with slender body and naked breast and cheeks, and some scaly-cheeked variety, probably *olmstedi*, or perhaps identical with it.

Our work has disclosed the form toward which Forbes and Richardson found *Boleosoma nigrum* grading in northern Illinois. This form can not be *B. n. olmstedi* as Forbes and Richardson rather naturally supposed, because it is separated from *olmstedi* by a wide band of ordinary *nigrum* through Ontario, Lake Erie, Ohio and Kentucky.

B. n. eulepis in typical form we find to be limited to the glacial lake districts of Wisconsin (Lake Michigan and Mississippi River drainage basins), Minnesota, Iowa and probably of Illinois. In areas of these states where glacial lakes are numerous, the *Boleosoma* population is almost consistently of the *eulepis* type. The range of the subspecies is discontinuous. Around each of its territories, *eulepis* intergrades extensively, completely and rather regularly with the surrounding and wide-spread *B. n. nigrum.*

B. n. eulepis differs from the Atlantic drainage form *B. n. olmstedi* in having fewer dorsal rays (9 to 14, usually 11 or 12, instead of usually 13 to 15), in having fewer scales on the average (48 instead of about 50 in lateral line to caudal), and the soft dorsal lower and less finely tessellated in breeding males.

From typical *B. n. nigrum,* as represented in the Ohio Valley, and elsewhere, *eulepis* differs in its larger size, decidedly more robust form, darker color, and perhaps in having more dorsal soft rays on the average. Occasionally we encountered such extreme types of *B. n. nigrum* in Wisconsin, notably in a few very isolated colonies within *eulepis* territories. But as a rule, there is virtually no difference between *B. n. nigrum* and *B. n. eulepis* within Wisconsin, in characters other than the degree of completeness of squamation. The number of scales in the lateral line may average very slightly higher, and the soft dorsal fin may average a trifle higher, but the differences are of doubtful statistical significance and are wholly unusable for identification purposes. The data are given in Table V.

TABLE V

Comparison of counts and measures of the two forms of Boleosoma nigrum in Wisconsin. The figures refer to number of specimens showing each count or measurement.

A. Number of scales in lateral line to caudal base

	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
B. n. nigrum	—	1	4	3	14	18	29	34	29	29	20	15	5	1	3	—	—
Intergrades	—	—	—	2	2	3	7	7	6	10	10	2	8	6	1	—	—
B. n. eulepis	2	1	—	4	6	13	12	18	13	21	12	9	7	7	3	1	1

B. Degree of squamation of nape

Degree scaled	Slightly	Moderately	Completely
Grade	1	2	3
B. n. nigrum	2	202	....
Intergrades	....	31	33
B. n. eulepis	1	19	110

C. Degree of squamation of opercle

Degree scaled	Slightly	Moderately	Completely
Grade	1	2	3
B. n. nigrum	59	146	....
Intergrades	14	49	1
B. n. eulepis	15	102	13

D. Degree of squamation of cheek

Degree scaled	Naked	Slightly	Moderately	Completely
Grade	0	1	2	3
B. n. nigrum	205	....	....	....
Intergrades	49	11	4	....
B. n. eulepis	22	31	70	7

E. Degree of squamation of breast

Degree scaled	Naked	Slightly	Moderately	Completely
Grade	0	1	2	3
B. n. nigrum	201	4	....	1
Intergrades	31	17	7	8
B. n. eulepis	4	9	5	112

F. Degree of squamation of all four areas
(Figures obtained by adding "Grade" of squamation for each area in each specimen)

Degree scaled	2	3	4	5	6	7	8	9	10	11	12
B. n. nigrum	2	57	141	4	....	1	....	....	....	....	....
Intergrades	....	5	20	12	14	3	4	2	4	....	....
B. n. eulepis	....	2	6	7	3	4	7	24	65	4	7

G. Number of dorsal soft rays

	9	10	11	12	13	14
B. n. nigrum	....	4	69	122	10	....
Intergrades	....	1	27	29	7	....
B. n. eulepis	1	3	53	59	12	1

H. Highest dorsal soft ray measured into head

	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2
B. n. nigrum	5	13	33	52	36	54	8	3
Intergrades	1	4	7	19	10	22	1	....
B. n. eulepis	3	14	21	27	15	38	8	3

I. Highest dorsal spine measured into head

	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1
B. n. nigrum	1	3	8	45	56	52	25	7	8	1	1	....	....	....	1
Intergrades	4	3	3	21	16	9	7	....	1	....	....	....	....	....	....
B. n. eulepis	2	4	1	38	31	27	18	1	3	....	....	....	....	....	....

J. Length of head measured into standard length

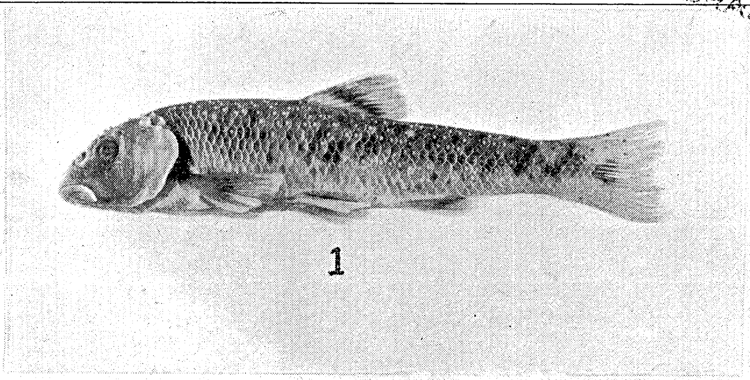
	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5
B. n. nigrum	1	1	19	36	49	45	30	7	11	1	2	3	....	1
Intergrades	....	....	2	14	12	16	11	2	7	....	....	....	....	....
B. n. eulepis	1	....	6	31	37	36	16	2	1	....	....	....	....	....

K. Depth of body measured into standard length

	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3
B. n. nigrum	....	....	....	2	1	4	4	26	39	23	30	28	17	16	4	6	2	....	1
Intergrades	....	....	....	4	2	3	3	8	5	5	11	4	8	3	1	6	....	1	....
B. n. eulepis	1	....	....	1	2	6	7	10	20	13	23	11	11	11	7	6	....	1	....

There is also a very noticeable difference in the roughness of the scales, readily appreciated when one rubs typical examples of the two forms toward the head. The difference is due to the longer marginal ctenii of *B. n. eulepis*, as is easily seen under the microscope. The ctenii in *B. n. eulepis* resemble those of *B. podostemone*[1] as figured by Cockerell and Elder (1913: 157), while the ctenii of *B. n. nigrum* resemble those of *nigrum* or even those of *olmstedi* as figured by the same authors.

The usual variation in *B. n. eulepis* in some additional characters, of little apparent taxonomic significance, are; least depth of caudal peduncle 2.6 to 3.0 in head; head and trunk (to anus) 1.7 to 1.8 in total length; first dorsal base 1.1 to 1.5, second dorsal base 1.1 to 1.4 and anal base 1.75 to 2.1 in head; highest dorsal spine 1.1 to 1.3 in highest dorsal soft ray; pectoral fin 1.0 to 1.1, pelvic fin 1.4 to 1.5 and caudal fin 1.1 to 1.4 in head. Width of head 1.55 to 1.75, snout 3.6 to 4.25, orbit 3.6 to 4.35, eye 3.8 to 5.0, snout and eye 2.0 to 2.3, interorbital 8.2 to 9.5, cheek 3.35 to 3.9, upper jaw 3.4 to 4.4 in head; least distance from lateral line to anterior dorsal contour 2.0 to 2.1 in postorbital. Scales 4 or 5 above and 5 to 7 below lateral line. Dorsal spines usually 8 or 9; pectoral rays 11 or 12; anal I, 7 to I, 10; principal caudal rays 15.



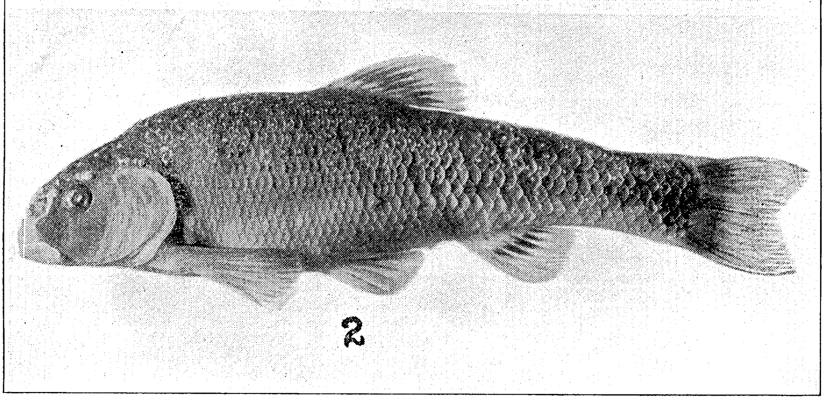


FIG. 1. Holotype of *Campostoma anomalum oligolepis.*

FIG. 2. Nuptial male of *Campostoma anomalum pullum.*

PLATE III

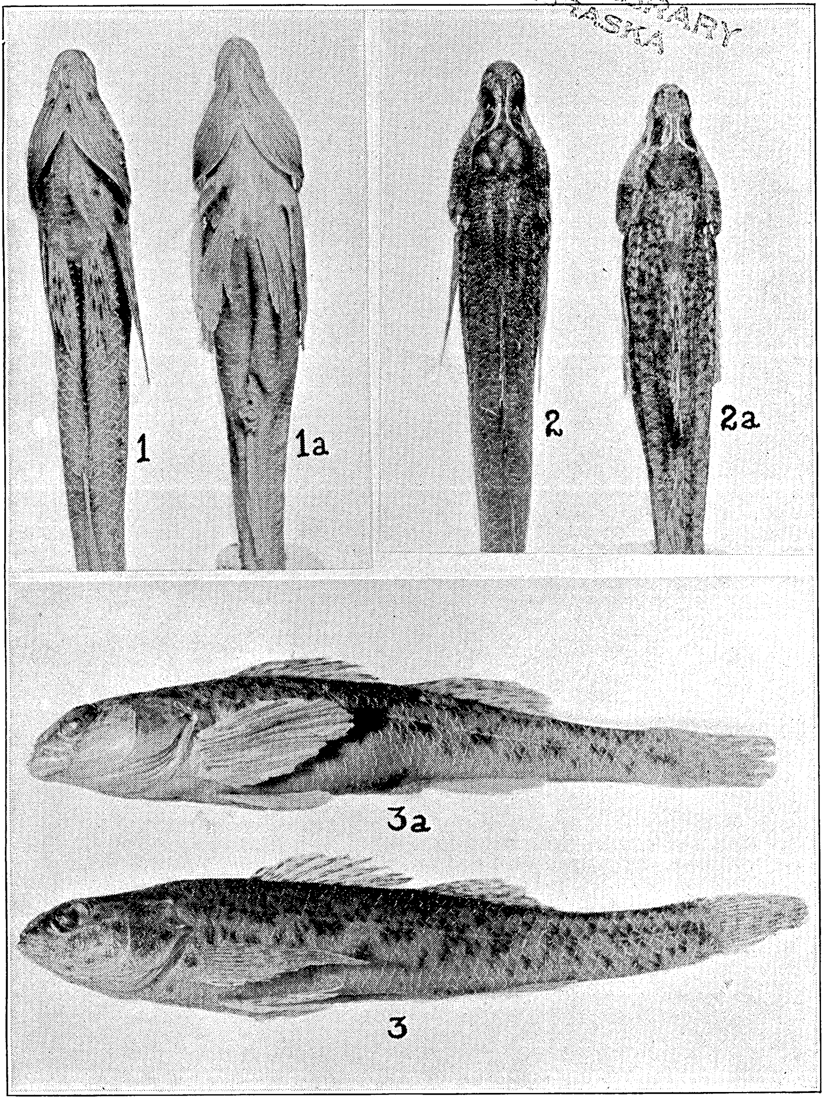


FIG. 1. Ventral view of the holotype of *Boleosoma nigrum eluepis* showing completeness of squamation.

FIG. 1a. Ventral view of specimen of *Boleosoma nigrum nigrum* from Wisconsin.

FIG. 2. Dorsal view of the holotype of *Boleosoma nigrum eulepis.*

FIG. 2a. Dorsal view of a specimen of *Boleosoma nigrum nigrum* from Wisconsin.

FIG. 3. Lateral view of the holotype of *Boleosoma ngrum eluepis.*

FIG. 3a. Lateral view of a specimen of *Boleosoma nigrum nigrum* from Wisconsin.

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GROWTH OF THE YELLOW PERCH (*Perca flavescens* Mitchill) IN NEBISH, SILVER AND WEBER LAKES, VILAS COUNTY, WISCONSIN

EDWARD SCHNEBERGER

From the Limnological Laboratory of the Wisconsin Geological and Natural History Survey.* Notes and reports No. 57.

INTRODUCTION

For nearly a decade the Wisconsin Geological and Natural History Survey has been carrying on limnological investigations on the lakes of the Highland Lake District of Northeastern Wisconsin. These investigations have been extended to over 500 lakes in which there are a variety of environmental conditions. Because of these facts this region is particularly favorable to the study of the growth of fresh water fish in relation to their environmental conditions. With the co-operation of the U. S. Bureau of Fisheries, the Survey began such a study in the summer of 1927, and these studies have been continued to the present time. In 1930, six type lakes were selected, and collecting limited to these lakes. Dr. Ralph Hile of the Bureau of Fisheries is studying the ciscoes, rock bass and bluegills, while the author is studying the perch and gamefish. Recently, Mr. W. A. Spoor has undertaken to investigate the ecology and growth of the common sucker. The present paper deals with the growth of the perch from three of the selected type lakes.

The author takes this opportunity to express his thanks to Dr. E. A. Birge and Dr. Chancey Juday for allowing him to work on the problem while in the employ of the Survey; to his colleague, Dr. Hile, who has been very generous with helpful suggestions, and to Mr. H. J. Deason of the Bureau of Fisheries for the advice and plans for the construction of a microprojection apparatus.

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*This investigation was made in co-operation with the U. S. Bureau of Fisheries and the results are published with the permission of the Commissioner of Fisheries.

METHODS

The fish were caught in gillnets and by hook and line fishing. Some of the smaller sizes were taken with a minnow seine. Records were kept for all gear except the 1928 collections. The fish were taken to the field laboratory to be measured and weighed as soon as possible after having been removed from the nets. The standard length of each fish was taken to the nearest millimeter by means of a steel tape. Weights were taken to the nearest gram by means of a Chatillon spring balance. These data were recorded on standard scale envelopes furnished by the Bureau of Fisheries. Along with these data were also placed the following: Field Number, Species, Locality, Date, Sex, State of Organs, and Gear. A few scales were taken from the left side of the fish near the middle of the body and just above the lateral line, and placed on the inside of the envelope in order to study the scales.

Typical scales were selected from the sample, soaked and cleaned in water and then mounted in glycerine jelly prepared after Van Oosten (1929). Later it was learned that they could be mounted in ordinary white Karo syrup with greater ease and with quite satisfactory results.

The scales were projected upon a piece of ground glass of an apparatus similar to that described by Van Oosten (1923). The 1932 material was studied, however, by means of an apparatus fashioned after that used at present by the Bureau of Fisheries at Ann Arbor, Michigan. The projected scale was measured from the focus outward along the inter-radial space to each annulus and to the outside circulus. Length of previous years of life were calculated by the formula given by Van Oosten (1923).

Due to the fact that additional and valuable material has been collected during the past summer (1933), the validity of the scale method and the ratio between the body and scale are to be considered in a later paper. Space and time do not permit the inclusion of this material in the present report. The calculated lengths of the fish at the end of each year of life previous to capture are given in the tables for the fish from each lake, but wherever comparisons are made, they are based on the average actual standard length of the specimens as much as possible.

Description of the Lakes

The perch for this study were obtained from Nebish, Weber, and Silver Lakes. These three lakes do not have inlets, but Nebish and Silver have outlets which function only during periods of high water.

Table I, taken from the records of the Wisconsin Geological and Natural History Survey, gives a brief description of these lakes. The physical and chemical data cited are the means of a large number of determinations of surface waters. Silver Lake is the largest; its surface area is 2.2 times as large as that of Nebish Lake, and 5.6 times as large as that of Weber Lake. Nebish is almost twice as large as Weber. In volume, Silver is 4.4 times as large as Nebish, and 8.7 times as large as Weber. All three lakes are deep enough for thermal stratification in the summer. Weber Lake has the highest degree of transparency, as the Secchi disc can be seen to an average depth of 7.2 meters. The visibility of the same disc is lost at an average of 6.0 meters in Nebish, and 5.5 meters in Silver. In regard to conductivity and bound CO_2, Silver Lake is the highest and Weber the lowest. Nebish and Weber have an equal amount of organic matter in the centrifuge plankton (0.77 mg/1), while Silver contains somewhat more (0.85 mg/1). On the whole, the conditions for the production of fish food in Silver Lake are more favorable than in the other lakes.

Besides perch these lakes contain other species of fish. Weber contains chiefly perch and small-mouthed bass. Other species have been taken, but as the catches were infrequent and in small numbers these are considered as remnants of bait discarded by fishermen and not as an established species. Nebish Lake contains perch, rock bass, large- and small-mouthed bass, and a few minnows. The following species are found in Silver Lake: perch, rock bass, bluegills, suckers, ciscoes, small-mouthed bass and muskellunge. Minnows and darters are also present. The perch occurs more abundantly in this lake than the other species, and is also more abundant in this lake than in the other two lakes. The rock bass population of Nebish Lake is very large.

Weight Length Relationship

The weight and length of fishes are closely correlated. This relationship is described within reasonable limits of variation

TABLE I

Some physical and chemical characteristics of Nebish, Weber and Silver Lakes.

Lake	Nebish	Weber	Silver
Area in hectares	38.5	15.6	87.3
Maximum depth in meters	15.8	13.5	19.5
Volume in cubic meters	2,015,000	1,133,000	9,884,000
Transparency (meters)	6.0	7.2	5.5
Color	9.0	0.0	4.0
pH	6.8	6.1	7.5
Conductivity (rec. megohms)	19.0	9.4	62.0
Bound CO_2 (mg/1)	4.0	1.2	15.5
Organic matter in centrifuge plankton (mg/1)	0.77	0.77	0.85

by the formula $W = cL^3$; W = weight, L = length, and c is a factor which varies for any species only as the weight fluctuates in proportion to the cube of the length. It is assumed that the specific gravity and form of the species do not change materially. The factor c then is an index to the condition of the specimen and is called the "coefficient of condition".

In order to simplify the formula, another factor, K, is introduced and is equal to 100c. Substituting this in the original formula gives

$$W = \frac{KL^3}{100c}$$

where W is expressed in grams and L in centimeters.

The exactness of the proportion of the weight to the length has been considered by several authors. Crozier and Hecht (1914) and Hecht (1913, 1916) conclude that, as a rule, the weight is proportional to the cube of the length. More recent authors, however, have found that the weight is proportional to a power somewhat higher than the cube of the length.

Keyes (1928) shows that the weight of the herring, Fundulus and sardine increases more rapidly than the cube of the length. The value of the exponent is always greater than 3 and less than 4. This author concludes that the more rapid increase of the weight is due to changes in form rather than in specific gravity. Since fishes are in close hydrostatic equilibrium with their environment, there is little or no chance of a change in specific gravity. Similar differences were found by Clark (1928), Hart (1931), Tester (1931), and others for different species.

The relationship between weight and length for the perch from Nebish and Weber lakes (1932 material) was obtained by plotting the average weights and lengths on double logarithmic paper. A straight line was drawn through the points and the slope determined. It was found that the weight increased at a slightly higher rate than the cube of the length. For Weber Lake the value of the exponent is 3.10 and for Nebish it is 3.19. For the purposes of this paper the approximate formula is sufficiently accurate.

The chief factors that are reported as influencing the weight of fish are sexual maturity and the condition of the individual (fatness). In regard to sex, Heincke (1907), and Crozier and Hecht (1914) found that sex does not influence the constant ratio between weight and length. Heincke's constant, "Ernährungskoeffizient", however, showed seasonal fluctuations.

Hecht (1916) found it unnecessary to use a correction factor for the weight of the contents of the stomach. In the sardine, Clark (1928) found that the undigested food in the alimentary tract had no effect on the weight of the fish. The weight-length factor fluctuated in the same way for the eviscerated fish as it did for the total weight.

As these collections were made during the summer months, the fish were well through their spawning; so it was decided to determine the effect, if any, of the contents of the alimentary tract on the value of K. This factor was computed for fish with different percentages of undigested food in the alimentary tract. The results are shown in the following table:

WEBER LAKE, 1932

Per cent of undigested food	No. fish	Mean K
0 (empty)	47	1.4405±.118
1-24	99	1.4585±.765
25-50	34	1.5118±.140

SILVER LAKE, 1932

Per cent of undigested food	No. fish	Mean K
0 (empty)	129	1.6080±.078
25-50	71	1.7020±.112
All fish	200	1.6470±.077

The probable error of the difference of the means (Edm) for the mean K of the empty fish and the 1-24% is 0.0180 ± 0.14.

When the mean K of the 25-50% full fish is compared with the mean K of the empty fish, the Edm is 0.0713±0.153. In both comparisons the difference of the means is smaller than the corresponding probable error, indicating that the difference is insignificant.

Since the perch in Weber Lake feed largely on insect larvae, it was thought that perhaps the weight-length factor might be influenced by a different type of food. In Silver Lake the perch had been feeding on small perch; therefore, comparisons are made on perch with different percentages of fish in their alimentary tract. The results of these comparisons are as follows: the Edm of K between the empty and 25-50% contents for Silver Lake is 0.094 ± 0.137. A comparison of the mean K for all fish with the 25-50% group shows that the Edm is 0.055 ± 0.136. A similar comparison of the mean K of the empty fish and the mean K of all fish gives an Edm of 0.039 ± 0.110, which shows that there is no significant difference. From these data it can be concluded that the undigested food in the alimentary tract has no appreciable effect on the value of the weight-length factor. It is also true that the type of food present has no direct effect upon this value.

Table II shows the average K for each age-group for the years 1930-1933, inclusive. The table reveals that for the most part there is a general decline in the value of K for Nebish and Weber

TABLE II

Average K of each age-group from each lake.

	Age-group*						
Lake	I	II	III	IV	V	VI	VII
Nebish							
1930	1.77	1.85	1.72	1.78			
1931	1.66	1.73	1.82	1.75	1.75	1.54	
1932	1.64	1.58	1.61	1.50			
Weber							
1930	1.65	1.61	1.64	1.68	1.70	1.65	
1931		1.54	1.67	1.59	1.62	1.25	
1932		1.40	1.49	1.54	1.60	1.56	1.65
Silver							
1930			1.73	1.63	1.67	1.76	1.79
1931		1.53	1.55	1.53	1.46	1.53	1.63
1932			1.63	1.61	1.65	1.65	1.69

* VIII/Weber (1932), 1.54; Silver (1932), 1.58.

lakes. In Silver Lake the average of K declines slightly in 1931, followed by an increase in 1932. The increase is not sufficient, however, to equal the value of K for 1930. It will also be seen that the perch from Nebish are in the best condition while those from Silver Lake are in the poorest condition. Weber Lake forms an intermediate group. The same situation is found in the rate of growth, as will be seen later.

Sex Ratio

In many instances various authors have reported that one of the sexes is more numerous than the other. The variation depends somewhat upon the species; that is, the males are more numerous in some species, while in others the females are more numerous. For the perch of Lake Erie, Jobes (1932) makes no statement regarding sex ratio, but gives a table (II, p. 647) of the males and females of age-groups II and III taken in 1927 and 1928. His data show substantially a 1:1 sex ratio in age-groups II and III in Lake Erie. This table includes 476 perch, of which 240 were females and 236 were males.

In Nebish Lake the males are slightly more numerous than the females. The ratio of females to males is 1:1.26. In Weber and Silver lakes the reverse is true, as there are more females than males. In these two lakes the male to female ratio is 1:1.31 and 1:1.40, respectively. Table III gives the number in each length frequency class for each of the three lakes. In Nebish Lake the sexes are almost equally distributed through all sizes. In Weber Lake the larger groups, 215-245 mm., contain only females; no males larger than the frequency value of 205 were found. There is a sharp decline in the number of males after the 145 mm. group.

In Silver Lake the 115-135 mm. length frequency classes contain 94% of all males. Of the larger males, the 165 and 185 mm. groups contain only one male each. From the data in this table it is seen that the males are more numerous than the females in the smaller sizes, but they are less numerous in the larger sizes. The number of males decreases with increasing size.

TABLE III

Sex compostion of the 1932 catches.

Length* in mm.	Number females	Number males	Total	Per cent females
Nebish Lake				
105	2		2	100
115	5	11	16	31
125	12	13	25	48
135	10	17	27	37
145	13	36	46	28
155	34	36	70	49
165	28	32	60	47
175	25	23	48	52
185	15	16	31	48
195	9	13	22	41
205	3	2	5	60
215		1	1	
225	1	1	2	50
Total	157	198	355	44
Weber Lake				
115	9	25	34	27
125	54	57	111	49
135	58	44	102	58
145	36	18	54	67
155	8	8	16	50
165	21	5	26	81
175	6	3	9	67
185	4	5	9	45
195	2	9	11	18
205	7	2	9	78
215	9		9	100
225	12		12	100
235	4		4	100
245	1		1	100
Total	231	176	407	57
Silver Lake				
105		8	8	
115	11	84	95	12
125	45	38	83	54
135	51	24	75	68
145	56	7	63	89
155	43		43	100
165	17	1	18	95
175				
185	5	1	6	83
195				
205	1		1	100
Total	229	163	392	58

* Mid-points of classes.

Gill Net Selectivity

Since gill nets are known to be highly selective in the size of fish they take, a variety of sizes of mesh was used in the collecting. During the seasons 1931 and 1932 the following sizes of mesh were used: ⅝, ¾, ⅞, 1, 1⅛, 1¼, and 1½ inches. These measurements are bar measure instead of stretched mesh. The ⅝ inch bar measure is equivalent to 1¼ inch stretched mesh, etc. The meshes were made from linen thread and each net was six feet deep and 150 feet long. In each setting the nets were tied together to form a gang in which each mesh size was represented. When the fish were removed from the net they were placed in a container upon which was painted the corresponding net size. The size of the gear was recorded on each of the scale envelopes.

Not only are gill nets known to be selective in the size of fish they take, but they may take only the larger individuals of one age-group and the smaller individuals of the next larger age-group. Sometimes a net will take specimens that are very much above or below the average size of that net. In these cases the fish are not gilled but tangled in the meshes, or, in the case of larger specimens, they are caught by some structure such as the parts of the mouth. These are accidental catches and are not frequent enough to play a part in the selectivity of the net.

TABLE IV

Gill net selectivity. Number of perch per age-group per mesh size. Nebish Lake, 1932.

	Age-group												
Mesh Length													
	⅝	¾	⅝	¾	⅞	1	¾	⅞	1	1⅛	1¼	1	1¼
105	2												
115	13	1	1										
125	13	7	2	2									
135	2	9		16									
145		1	1	20	1		20						
155			1	30	29			6	1				
165				4	39	7	2	8					
175					14	4	3	9	10				
185					6	1		7	11				
195								1	10	5		3	
205									1	3	1		
215													
225										1			1
235													1

Figure 1 and Table IV show the age-groups and lengths of fish taken by the different sizes of gill nets from Nebish Lake. In the graphs in Figure 1 are shown the length frequency curves for each mesh size for each of the age-groups. There is an overlapping of sizes of fish in each of the age-groups. The net-length frequency curves for each of the age-groups show that the maximum length of fish taken by the smaller sizes of mesh is overlapped by the minimum lengths of fish taken by the next larger size. Only two nets, the ⅝ and ¾ inch mesh, took fish belonging to age-group I. The ⅝ mesh took the smaller specimens, and the ¾ inch mesh took the larger specimens of this group. In age-group II, four mesh sizes (⅝, ¾, ⅞, and 1 inch) functioned in taking specimens. Although the ⅝ and 1 inch nets took only a few fish, they took specimens of the two extreme limits of size of the age-group. While the ¾ and ⅞ took the bulk of the age-group, neither would be sufficient alone to take a representative sample of this age-group, because the majority of the fish taken by the ¾ inch mesh fall below the modal length of the age-group, and those taken by the ⅞ inch net fall well above the modal length.

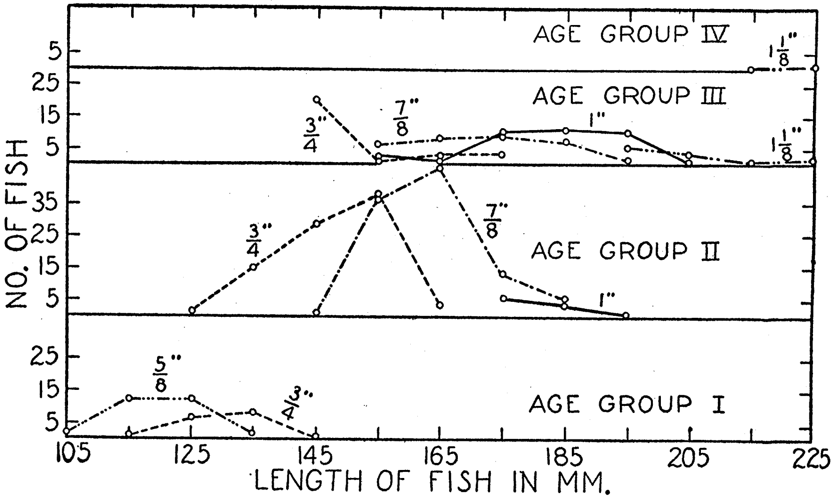

FIG. 1. Catch per net by age-groups. Nebish Lake, 1932.

In age-group III the ¾ and 1⅛ inch meshes took fish of the two extreme lengths, while the ⅞ and 1 inch took most of the fish of this group. Here again the ⅞ inch specimens fall below the mode and the 1 inch fall above. Age-group IV is represented by only five specimens taken by nets. Of these, three were taken by the 1 inch mesh and two by the 1⅛ inch mesh. The 1¼ inch meshes caught but one fish, which belonged to age-group III. No perch were taken by the 1½ inch net.

Table V shows the relation between mesh size and length frequencies of the various age-groups of perch taken from Silver Lake. This table shows that the smaller fish of one age-group are taken by one net size, and that the larger specimens of the same group are taken by the next larger size of mesh.

TABLE V

Gill net selectivity. Number of perch per age-group per mesh size. Silver Lake, 1932

Length Measure	Age-group II		III			IV				V				VI		
	⅝	¾	⅝	¾	⅞	⅝	¾	⅞	1	⅝	¾	⅞	1	⅝	⅞	1
105			3			4										
115	2		8			47				16						
125		1	321	3		22	15			13	1			3		
135	2	1	1	10		16	31			1				3		
145		2		7	2	1	13	6			4				1	
155					8		3	11	1		7	11			1	
165					2						3	8			2	1
175								1				9			1	
185											1		2			

From the foregoing data and discussion it can be concluded that on the whole the sampling of the different age-groups has been adequate. Although the individual nets show a decided selectivity, the difficulty was surmounted by having nets of various sizes. The difference in sizes of mesh was small enough so that no large gaps in ages and sizes occurred.

Not all of the perch collected for this study were taken by gill nets, as hook and line fishing was carried on to some extent. The most extensive collecting by hook and line fishing was carried on in Silver Lake in 1931. Of the 463 perch taken from this lake, 220 were taken by hook and line fishing. The remaining 243 were taken by the gill nets. Table VI shows the length frequencies of each age-group caught by hook and line compared with those taken by gill nets.

All age-groups with the exception of VI and VII are fairly well represented by the hook and line catches. Since there are but 220 specimens represented in seven age-groups, it seems that this hook and line sample is quite representative because it does not show any selectivity. These data indicate that hook and line catches of large numbers of perch will present a representative sample, provided small hooks are used.

TABLE VI

Silver Lake, 1931 collections. Net catches compared with hook and line catches.

Gear Length	Age-group																
	II			III				IV				V			VI		
	H[1]	⅝	¾	H	⅝	¾	⅞	H	⅝	¾	⅞	H	¾	⅞	H	⅞	1¼
45	1			10		2	1	11									
85	2																
95	6																
105	16	6		1	11												
115	15	12		20	68			1	4								
125	22	9	1	28	28			7	9	3							
135	6	2	1	13	8	2		9	3	25							
145	1			10		2	1	11	2	29	3	1	1				
155				3			1	6		6	1	1		1			
165				2				6				6			1		
175								4		1		5		1			
185								3				4					
195												3			1		
205								2				1					
215												1					
225															1	1	1

Rate of Growth

NEBISH LAKE

Collecting was carried on in this lake for three years, 1930, 1931, and 1932. A total of 632 perch was taken during this period. Only 55 were collected in 1930, 232 in 1931, and 245 during the 1932 season.

The sexes were not determined in 1930 and 1931, but were determined in 1932. The females numbered 157, and the remaining 188 were males. Data regarding the growth of males and females are given in Table VII, which shows the average actual length, weight, K, and calculated lengths. In most cases, the females show a slightly higher (2-4 mm.) rate of growth than the males. The males of age-group V, however, are 11 mm.

longer than the females. As there are but two females and four males in this group, the difference loses its significance. The difference between the sexes of the other ages is also considerd not significant, especially when compared with the average of the combined data.

TABLE VII

Nebish Lake, 1932. Averages of weight, K, actual and calculated lengths for each age-group

Age-group	Number of fish	Average weight	Average K	Average actual length	Average calculated lengths per age-group I	II	III	IV
				Females				
I	23	31	1.66	123	80			
II	87	65	1.57	159	51	122		
III	45	90	1.60	173	50	100	152	
IV	2	120	1.64	194	37	86	127	172
Total	157							
				Males				
I	26	31	1.63	118	86			
II	101	64	1.60	157	55	124		
III	57	89	1.63	169	47	90	143	
IV	4	137	1.43	205	44	103	159	190
Total	188							
				Males and Females				
I	49	31	1.64	120	84			
II	188	64	1.58	158	53	124		
III	102	88	1.61	171	48	95	147	
IV	6	131	1.50	201	45	130	144	179
Total	345							

Assuming that the same relation exists between the sexes of other years, the growth of the other years may be compared. Table VIII gives the data regarding each of the other years. The youngest fish belong to age-group I, and the oldest to age-group VI (7th year of life). Since age-group VI contains but one specimen, which is smaller than the average of age-group V of the same year, it is given no further consideration. The curves in Figure 2 are based on the average actual length of each age-group, with the exception of age-group 0. The value of this group is based on the average calculated lengths. It will be noted that the curve for the 1930 collection varies considerably from the other years. Since there are but 55 specimens represented in this curve, a great deal of significance cannot be given to this difference.

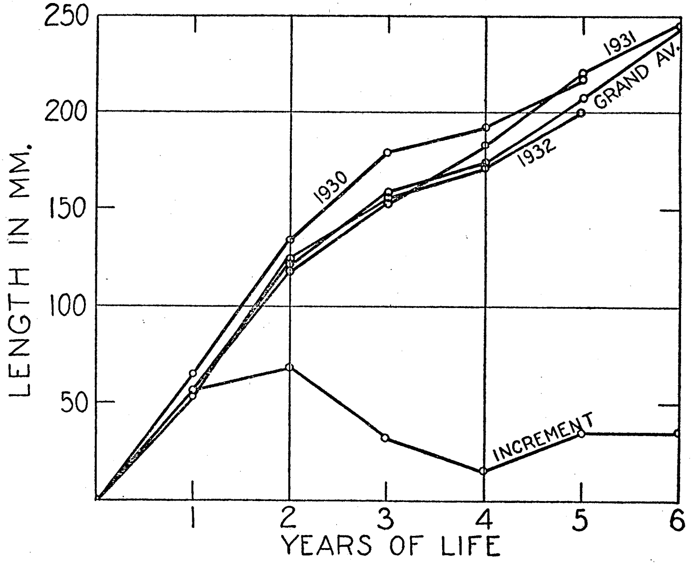

FIG. 2. Growth of perch from Nebish Lake.

When the grand average (Table IX, Fig. 2) is taken, it is seen to fit the 1932 data rather closely. This is to be expected, inasmuch as the 1932 collection comprises over 50% of the total collection. There is a sharp rise in increment the first two years: 56 mm. the first year, and 68 mm. the second year. During the third and fourth years there is a sharp decline in the increment curve. This decline may be correlated with the attainment of sexual maturity. After the fourth year there follows an increase in increment.

Jobes (1932) gives a preliminary report on the growth of perch from Lake Erie. He finds that the growth is very rapid in the first two years, but that there is a decline in growth rate during the third summer. In regard to this decline Jobes says, "The decided decrease in the growth-rate during the third summer may possibly be correlated with the attainment of sexual maturity." Figure 3 shows a comparison of the growth of perch from Nebish Lake with those from Lake Erie. The curves of this diagram show a very close agreement in the type of growth. The Lake Erie perch, however, are consistently larger than the Nebish specimens. The average increments show the same decline during the third summer in Lake Erie and also in the Nebish Lake perch. If this decline is due to the attainment of sexual maturity, it has a greater effect on the Nebish perch during the fourth summer than it does on the Lake Erie specimens. The recovery of the Nebish perch occurs during the fifth summer, while the Lake Erie specimens do not show an increase until a year later.

TABLE VIII

Nebish Lake, 1930 and 1931. Averages of weight, K, actual and calculated lengths for each age-group.

Age-group	Number of fish	Average weight	Average K	Average actual length	Average calculated lengths per age-group I	II	III	IV	V	VI
				1930						
I	23	44	1.77	134	67					
II	12	110	1.85	180	60	130				
III	5	122	1.72	192	56	109	162			
IV	15	190	1.78	219	66	116	167	200		
Total	55									
				1931						
I	87	34	1.66	124	72					
II	106	63	1.73	153	43	101				
III	7	113	1.82	181	46	98	151			
IV	18	192	1.75	222	48	93	156	193		
V	13	260	1.75	245	50	100	166	205	228	
VI	1	164	1.54	220	33	58	112	168	191	212
Total	232									

TABLE IX

Nebish Lake. Summary of average lengths for each year of life.

Year caught	Years of Life 1	2	3	4	5	6	7	Total fish
1930	64*	134(23)[1]	180(12)	192(5)	219(15)			55
1931	55*	124(87)	153(106)	181(7)	222(18)	245(13)	220(1)	232
1932	55*	120(49)	158(188)	171(102)	201(6)			345
Grand average	56*	124(159)	157(306)	173(114)	209(39)	245(13)	......(1)	632
Average increment	56	68	33	16	36	36		

* Calculated lengths, the rest are actual lengths.

[1] Number of specimens in parentheses.

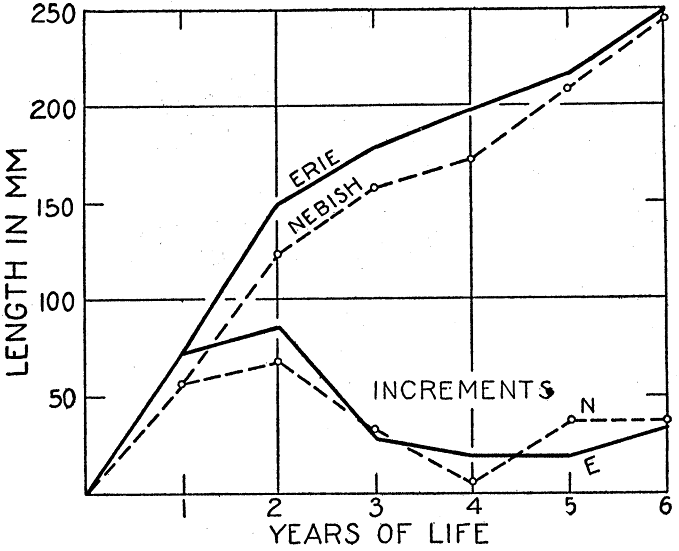

FIG. 3. Average growth of perch from Lake Erie (Jobes) and Nebish Lake.

WEBER LAKE

Collecting was carried on during the summers of 1928, 1930, 1931, and 1932. Table Xa shows the number of fish in each age-group, average length, K, and the average calculated lengths for each of the four collections. Table Xb gives a summary of the average length for each age group.

Two collections were made in 1932, one in the early season during the first part of July, and one in the late season during the latter part of August. The purpose of the two collections was to determine whether or not any significant growth occurred within the limits of the collecting season. Data regarding the early and late seasons are given in Table XI. This table shows that only age-group II contains sufficient numbers for statistical comparisons. When these data are treated statistically, the following means are found:

	Early Season	Late Season	Edm
Females	130.0 ± 0.299	134.16 ± 0.147	4.16 ± 0.347
Male	126.1 ± 0.270	128.17 ± 0.148	2.07 ± 0.308
Edm	3.9 ± 0.403	5.99 ± 0.209	

The increment of the females from July 6 to August 17 was 4 mm., while the males increased 2 mm. during the same period (42 days). The probable error of the difference of the means between the early and late season females is 4.16 ± 0.347, and the same value for the early and late season males is 2.07 ± 0.308. The difference, though slight, is significant. When the sizes of the sexes are compared, it is seen that the difference between the early season females and males is 3.9±0.403, and between the late season females and males is 5.99 ± 0.209. In each of these cases the difference of the means is small but significant. These data indicate that there is a significant difference between the growth of males and females, as well as between the early and late season collections.

TABLE Xa

Weber Lake, 1928, 1930, 1931 and 1932. Averages of weight, K, actual and calculated lengths for each age-group.

Age-group	Number of fish	Average weight	Average K	Average actual length	Average calculated lengths per age-group I	II	III	IV	V	VI	VII	VIII
				1928								
III	4	43	1.47	136	54	88	121					
IV	117	42	1.47	154	43	68	104	131				
V	35	80	1.41	178	42	69	105	137	158			
VI	17	87	1.44	183	41	68	92	115	131	164		
VII	4	85	1.45	183	35	57	74	99	123	148	165	
Total	177											
				1930								
I	2	26	1.65	117	71							
II	7	33	1.61	125	51	93						
III	6	83	1.64	166	56	95	133					
IV	53	107	1.68	185	62	100	137	164				
V	96	109	1.70	186	56	91	119	146	167			
VI	18	134	1.65	201	56	86	118	143	168	185		
Total	182											
				1931								
I	1	9		103	73							
II	97	37	1.54	133	50	112						
III	16	81	1.67	166	43	91	142					
IV	91	114	1.59	192	48	94	135	167				
V	100	126	1.62	198	44	86	121	150	175			
VI	13	136	1.25	203	43	80	115	143	163	182		
Total	318											
				1932								
II	285	33	1.40	130	51	111						
III	55	59	1.49	157	41	96	146					
IV	17	86	1.54	172	41	93	127	142				
V	17	131	1.60	200	52	94	135	159	181			
VI	21	142	1.56	207	49	88	126	153	178	194		
VII	9	184	1.65	223	41	77	114	144	165	186	207	
VIII	3	174	1.54	224	33	66	91	119	147	168	192	206
Total	407											

Table Xb gives the grand average lengths of each age-group based on the actual lengths of these specimens with the exception of age-groups O and I, which are the average of all calculated lengths for these two age-groups. The growth of the fish

TABLE Xb

Weber Lake Summary of average lengths for each year of life.

Year caught	Age-group* O[1]	I[1]	II	III	IV	V	VI	Total fish
1928	44	68	121**	136(4)	154(117)	178(35)	183(17)	177
1930	57	93	125(7)	166(6)	185(53)	186(96)	201(18)	182
1931	50	96	133(97)	166(16)	192(91)	198(100)	203(13)	318
1932	57	104	130(285)	157(55)	172(17)	200(17)	207(21)	407
Gr. Av.	53	95	130(390)	158(81)	174(283)	191(248)	198(64)	1084
Av. Inc.	53	42	35	28	16	17	7	

*VII; 1928, 183(4), 1932, 223(9). VIII; 1932, 224(3). [1] Calculated lengths.
**Calculated, but not included in grand average.
Note: Gr. Av. VII, 210(13); VIII, 224(3). Av. Inc. VII, 12; VIII, 14.

TABLE XI

Weber Lake, 1932. Data on early and late season catches.

Age-group	Number of fish	Average weight	Average K	Average actual length	Average calculated lengths per age-group I	II	III	IV	V	VI	VII	VIII
				Early season females								
II	52	33	1.49	130	52	114						
III	22	57	1.49	156	38	92	145					
IV	9	77	1.51	167	40	92	124	157				
V	3	128	1.47	203	51	94	131	162	187			
VI	3	160	1.43	227	49	82	119	167	195	212		
VII	3	178	1.68	218	42	83	114	143	165	184	209	
Total	92											
				Late season females								
II	99	35	1.26	134	47	110						
III	9	76	1.52	171	41	97	158					
IV	6	104	1.59	184	43	90	135	167				
V	8	147	1.66	206	56	98	141	165	189			
VI	9	167	1.65	216	47	90	137	161	185	202		
VII	5	197	1.61	231	42	81	115	147	163	193	210	
VIII	3	174	1.54	224	33	66	91	119	147	166	192	206
Total	139											
				Early season males								
II	51	33	1.49	126	57	113						
III	21	55	1.47	154	44	99	144					
VI	5	116	1.54	196	56	94	120	143	171	186		
Total	77											
				Late season males								
II	83	31	1.47	128	51	107						
III	3	43	1.47	143	37	82	125					
IV	2	60	1.48	157	38	88	114	127				
V	6	111	1.60	191	46	88	129	150	166			
VI	4	108	1.49	191	44	82	111	135	156	171		
VII	1	132	1.75	198	38	78	108	130	144	160	181	
Total	99											

Note: For combined data on early and late season males and females, see 1932 collection in table 13a.

taken in 1928 is the slowest of all. The growth of the other years agrees quite closely to the grand average. The average increment shows that the greatest growth was made during the first year of life.

SILVER LAKE

A total of 1405 perch from Silver Lake were studied. Table XII shows the data for each year. Of the total number of fish, 187 were collected in 1928, 412 in 1930, 463 in 1931, and 343 in 1932. As with the other lakes, the sexes were not determined until the 1932 season. Table XIII gives the data regarding the

TABLE XII

Silver Lake, 1928, 1930, 1931, 1932. Averages of weight, K, actual and calculated lengths for each age-group.

Age-group	Number of fish	Av'ge weight	Av'ge K	Average actual length	Average calculated lengths per age-group I	II	III	IV	V	VI	VII
				1928							
II	26	15	1.32	104	48	80					
III	79	28	1.44	123	47	79	107				
IV	48	52	1.63	146	45	75	101	128			
V	31	88	1.69	172	43	75	108	130	155		
VI	2	74	1.63	165	34	65	87	110	130	152	
VII	1	74	1.63	196	39	75	99	119	130	150	178
Total	187										
				1930							
II	23	39	1.73	111	57	90					
III	281	31	1.63	122	47	75	102				
IV	56	61	1.67	162	48	80	109	131			
V	37	95	1.76	174	41	69	97	123	159		
VI	14	152	1.79	202	41	70	108	134	158	182	
Total	412										
				1931							
II	99	24	1.53	115	52	91					
III	198	28	1.55	119	38	73	102				
IV	135	46	1.53	142	36	69	101	127			
V	25	81	1.46	175	43	75	103	133	159		
VI	5	146	1.53	210	35	71	99	137	169	192	
VII	1	130	1.63	200	35	64	96	121	142	173	197
Total	463										
				1932							
II	8	38	1.63	131	44	103					
III	73	38	1.61	130	45	76	109				
IV	174	37	1.65	130	35	64	92	114			
V	77	46	1.65	138	34	63	89	109	124		
VI	10	68	1.69	152	34	58	83	104	124	151	
VII	1	100	1.58	185	29	53	82	111	141	156	170
Total	343										

TABLE XIII

Silver Lake, 1932. Averages of weight, K, actual and calculated lengths for each age-group

Age-group	Number of fish	Av'ge weight	Av'ge K	Avg. act'l length	Average calculated lengths per age-group I	II	III	IV	V	VI	VII
				Females							
II	8	38	1.63	131	44	103					
III	61	40	1.62	133	45	77	110				
IV	93	44	1.66	137	35	65	94	119			
V	37	60	1.69	152	35	63	95	118	135		
VI	7	83	1.70	166	36	61	88	109	133	151	
VII	1	100	1.58	185	29	53	82	111	141	156	170
Total	207										
				Males							
III	12	27	1.60	117	41	71	101				
IV	81	29	1.64	120	36	64	90	108			
V	40	34	1.62	126	34	62	84	101	115		
VI	3	33	1.67	125	28	51	72	92	107	116	
Total	136										

See table XII, 1932 collections, for combined data.

growth of the males and females. Of the 343 perch taken in 1932, 207 were females and 136 were males. There seems to be a decided difference between the growth of the two sexes, the females growing at a much higher rate than the males. The average of the combined data of the males and females is also shown in the table. The females seem to have a longer span of life than the males.

The 1932 data are so conflicting that it is not possible to make comparisons with other years, and they are, therefore, omitted from the grand average shown in Table XIV. Such differences may be due to the mixing of two local races. The 1932 collection was made about 200 meters from the station where the previous collections were taken. The possibilities of two local races in this lake are small because of its small size (87.2 hectares) and also because a thorough sounding and mapping of the lake revealed no barriers. If there are local races present here, there must be a sharp localization of the two groups. However, further data are necessary before this point can be settled.

The growth of the three years 1928, 1930, and 1931 (Table XIV) is in close agreement with the other years. In age-group VI the average of those taken in 1928 is low. This is undoubtedly due to the inadequacy of the data, inasmuch as there are only two specimens. These are not included in the grand average. The average increment, obtained from the grand average, shows a sharp decline between the third and fourth years of life, which may perhaps be interpreted as due to sexual maturity occurring at this time.

Comparison of Growth Rates

Table XV and Figure 4 show the rate of growth of perch from each of the three lakes, Nebish, Weber and Silver. The lengths given are the grand averages of the actual lengths of each age-group, with the exception of age-group O from Nebish Lake, and age-groups O and I from Weber and Silver lakes. These values are based on the average of all calculated lengths. The data from Nebish are compiled from the material collected in 1930, 1931, and 1932; Weber, 1928, 1930, 1931, and 1932; and Silver, 1928, 1930, and 1931. Figure 4 shows that the Nebish Lake perch have the most rapid growth; they attain an average length of 245 mm. during six years of life. The average of age-group VIII (9th year of life) of the Weber Lake perch was 224 mm. The growth of the Weber Lake perch was not sufficiently rapid for those specimens to attain a size equal to the largest from Nebish Lake in three years additional time. The early growth of the Silver Lake perch proceeds at a much

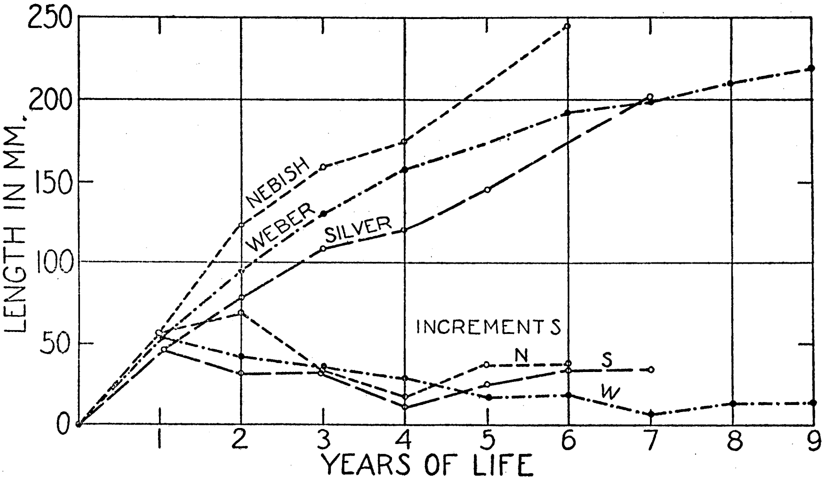

FIG. 4. Average rate of growth of perch from Nebish, Weber, and Silver lakes.

slower rate than that of the other two lakes, until the fourth summer. Following the fourth summer there is an increase in growth rate, so that at the end of the 7th year of life the Silver Lake perch have surpassed those from Weber of the same age by three millimeters. The figure shows that Nebish ranks first in growth rate, Weber second, and Silver third.

Church (1927), studying the effect of crowding on the rate of growth of the tropical fish, *Platypoecilus maculatus rubra*, found that the rate of growth was always greatest when the fewest fish were present. These experiments were later repeated by Shaw (1929) who obtained similar results.

TABLE XIV

Silver Lake. Summary of average lengths for each year of life.

Year caught	Year of life I*	II*	III	IV	V	VI	VII	VIII	Total fish
1928	46	78	104(26)	123(79)	146(48)	172(31)	165(2)	196(1)	187
1930	47	75	111(23)	122(281)	162(56)	174(37)	202(14)		412
1931	40	78	115(99)	119(198)	142(135)	175(25)	210(5)	200(1)	463
Grand average	45	77	109(148)	120(558)	145(239)	173(93)	201(21)	198(2)	1062
Average Increment	45	32	32	11	25	28	28		

* Calculated lengths, the rest are actual lengths.

TABLE XV

Comparison of the growth of perch from Wisconsin lakes with the growth of those from other localities.

Lake	O	I	II	III	IV	V	VI	VII	VIII
Nebish	56	124	157	173	209	245			
Weber	53	95	130	158	174	191	198	210	224
Silver	45	77	109	120	145	173	201		
Erie (Harkness)..	44		144	168	187	217	234	244	
Wawasee (Hile)..	39	86	129	167	198	220	230		
Erie (Jobes	69	150	176	197	316	250			

The existence of two sizes of perch in the same body of water or in closely connected or neighboring bodies of water is a phenomenon that has been observed. In two of the Madison (Wisconsin) lakes, Lake Mendota and Lake Monona, differences in size of perch are very noticeable. Lake Mendota, which is much larger than Monona, and drains into the latter, contains a much larger population of perch, but they are small. In the smaller and shallower body of water, Lake Monona, the perch are almost twice as large, but the population is much smaller. Wagner (1910) assigns this difference to the fact that the conditions for hatching and nourishing the young are better in Mendota than in Monona. Naturally the abundance of young as well as of older perch in Mendota brings on a struggle for food. This competition for food does not have its effect in the elimination of the weaker fish, but manifests itself in a decreased growth rate. In Monona, such a high proportion of the perch does not survive, and the competition for food is not so keen. Wagner also mentions that the pike-perch (*Stizostedion*) might be a possible factor in keeping down the population of perch in this lake.

Birge (1922) states that in 1883 or 1884 there was an epidemic among the perch of Lake Mendota which resulted in an enormous mortality. Those that died were only the larger specimens, and they were decidedly larger than those now found. The removal of these larger specimens which had preyed upon the smaller sizes, made conditions more favorable for the survival of small perch. Insufficient food for this increased number had its effect in that the small fish could not reach the larger size.

Dymond (1926) shows the same correlation between size of fish and population in Lake Nipigon. In the sheltered southern bays of this lake the perch occur in great numbers. With one haul of about forty yards with a fifty foot seine, 1,760 perch were taken. These were all small, the largest measuring less than six and one-half inches. In the northern bays, which presumably have a smaller population, specimens measuring ten and one-half inches are taken regularly.

Although a definite knowledge of the total population in Nebish, Weber and Silver lakes is not available, it is possible to obtain an idea of the relative abundance of perch present in these lakes through the rate of capture in gill nets. This necessitates uniformity in gear and methods. During the 1932 season all perch were taken by gill nets. The same nets were used in each lake and set specifically for perch. The following table is constructed from the 1932 records, and these are very similar to the previous years.

Lake	Hours of Fishing	Total Perch Caught	Perch per Hour
Nebish	224	352	1.57
Weber	44	430	9.78
Silber	24	396	16.50

From the above table it is seen that the perch are most abundant in Silver Lake, and least abundant in Nebish Lake. The relative abundance of perch in Weber Lake lies approximately midway between Nebish and Silver lakes. The ratio of fish caught per hour between Nebish and Silver is 1:11, while the ratio between Nebish and Weber is 1:6; that is, during the period of time necessary to catch one perch in Nebish the same nets would catch 11 and 6 fish from Silver and Weber lakes respectively. When relative abundance of perch is correlated with their rate of growth (Fig. 4), it is seen that an indirect correlation exists. Nebish Lake perch are characterized by the most rapid growth and least abundance. Silver Lake perch have the slowest growth and are the most abundant. Weber forms an intermediate group, both in growth and in abundance. These data give evidence that the density of the population is a contributing factor affecting the rate of growth of fish.

It is interesting at this point to compare the growth of the perch from the lakes of Northeastern Wisconsin with those from different localities. Harkness (1922) and Jobes (1932) report the growth of perch from Lake Erie, while Hile (1930) describes the growth of perch from Lake Wawasee, an inland lake in Indiana. The data given by these workers are included in Table XV, and they are shown graphically in Figure 5. The data for the growth of perch obtained by Harkness and Jobes in Lake Erie are not in agreement, but their collections were made in different localities and at a different time.

Attention has already been called to the striking similarity between the growth of Lake Erie perch (Jobes) and those of Nebish. The curves for these lakes are very similar except that the Erie perch are consistently larger than the Nebish perch. The greatest variation occurs between age-groups I, II and III; after this the Nebish perch have a higher rate of growth, and at age-group V (6th year of life) the Nebish specimens are only 5 mm. shorter than those from Lake Erie. The growth of the perch from Lake Wawasee agrees closely with the data of Harkness for Lake Erie. The first four years of Weber (age-groups O, I, II, and III) agree to a certain extent with Wawasee and Erie (Harkness); after age-group III, the Weber perch have a slower growth than that of the other two lakes. With the exception of age-group O and VI, the Silver Lake specimens are consistently smaller than those from the other lakes.

It will be noticed in Figure 5 that the perch with the highest rate of growth, those from Erie (Jobes) and Nebish, are not as old as those with a lower rate of growth. Wawasee and Erie (Harkness) perch have a lower rate of growth and are older. In Weber Lake specimens as old as age-group VIII (9th year of life) are represented and show slow growth. These data indicate that where the growth rate proceeds at a low rate the fish live longer, and where the growth rate proceeds at a higher rate, the span of life is shortened. In both Nebish and Silver lakes a year older age-group than is shown in the diagram was obtained, but since these groups contained only a few specimens whose average lengths are shorter than the preceding groups, they are not included in the figure. Further evidence is found in the position of the first annulus of the scale. In the younger fish (age-groups II and III) cases are found where the annulus is far from the focus, indicating an extremely rapid growth.

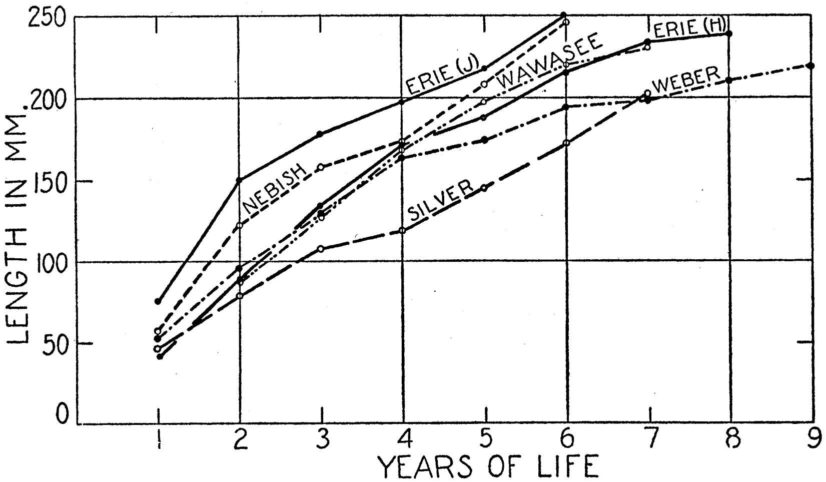

FIG. 5. Growth of perch from Wisconsin compared with those from other localities.

However, this type is rarely found in the older fish, suggesting that the rapid growers are short-lived.

This condition is not limited to perch, as Titcomb (1928) and McCay (1931) have shown by their experiments on trout that those that failed to grow lived longer than those that grew on a similar diet. There is also evidence of this occurring in other animals, particularly mammals. McCay (1933), briefly discussing longevity and optimum growth, points out that those diets that stimulate maximum growth are not conducive to longevity. This author states, "It is possible that longevity and rapid growth are incompatible and that the best chance for an abnormally long life span belongs to the animal that has grown slowly and attained a late maturity."

SUMMARY

1. The growth of perch from Nebish, Weber and Silver lakes in Vilas County, Wisconsin, has been studied.

2. The weight of perch increases at a slightly higher rate than the cube of the length. For the perch from Weber and Silver lakes the value of the exponent is 3.10 and 3.19 respectively.

3. The weight-length relationship in the yellow perch is not affected by the undigested food in the alimentary tract, nor by the type of food present.

4. The sex ratio varies with the different lakes. In Nebish the ratio of females to males is 1:1.26, while the ratio of males to females is 1:1.31 and 1:1.40 in Weber and Silver lakes respectively.

5. Gill nets were selective in that they took only the larger specimens of one age-group and the smaller of the next higher age-group. Adequate sampling was obtained through the use of a series of sizes of meshes, in which the difference between sizes was small.

6. Hook and line samples of perch are adequate if the samples are large and small hooks are used.

7. The males and females from Nebish Lake grow at approximately the same rate.

8. The females in Weber Lake grow faster than the males. Age-group II, 1932, shows significant statistical differences between the growth of the males and females. The growth of age-group II during a period of 42 days, from July 6 to August 17, 1932, is significant.

9. According to the data collected in 1932, the females from Silver Lake grow more rapidly than the males. There is also evidence that there are local races present in Silver Lake.

10. The highest rate of growth occurs in Nebish Lake perch. Silver Lake perch exhibit the slowest growth, while those from Weber Lake form a group intermediate between these two lakes.

11. The rate of growth is in inverse proportion to the relative abundance. The fish caught per hour by gill nets averaged 1.57 in Nebish Lake, 9.78 in Weber Lake, and 16.5 in Silver Lake.

12. Nebish Lake perch have a growth curve that is very similar to that reported by Jobes for the Lake Erie perch, except that the Erie perch are consistently a trifle larger.

13. Weber Lake perch grow at about the same rate as the perch from Wawasee (Hile) and Erie (Harkness) for the first four years, after which the Weber perch grow at a slower rate.

14. The slower growing specimens have a longer span of life. The rapid growing specimens seem to have a shorter span of life.

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FISH FOOD STUDIES OF A NUMBER OF NORTHEASTERN WISCONSIN LAKES

FAYE M. COUEY

Notes from the Limnological Laboratory of the Wisconsin Geological and Natural History Survey*. Notes and reports No. 58.

INTRODUCTION

This paper is based on the results of the examination of the alimentary tracts of 5,767 fish obtained from twenty-four northern Wisconsin lakes during the summers of 1931 and 1932. It was done as part of the program of the Wisconsin Geological and Natural History Survey in the limnological observations which have been carried on since 1925 at the Trout Lake Laboratory, Vilas County. The work has consisted of biological, chemical, and physical observations on the waters of the lakes of this region. The biological aspect includes a qualitative as well as a quantitative study of the plankton and of bottom fauna. For a good discription of the Highland Lake District of Northeastern Wisconsin and the Trout Lake Limnological Laboratory, the reader is referred to Juday and Birge (1930).

In 1927, 1928, and 1930, with the cooperation of the U. S. Bureau of Fisheries, considerable work was done on the age and rate of growth of fish in these lakes. As this afforded a large amount of material, the present work was begun at the suggestion of Professor Chancey Juday.

METHODS

The fish were secured by means of gill nets, fyke nets, seines, and hook and line. The work on age and growth rate was confined principally to six lakes, Trout, Muskellunge, Weber, Nebish, Silver, and Clear, and most of the fish from these lakes were caught with gill nets. In order to obtain a representative group of fish, a string of these nets was used as a unit; a string consisted of seven one hundred-fifty foot nets ranging in size from five-eights inch to one and one half inch bar mesh. This yielded

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*This investigation was made in co-operation with the U. S. Bureau of Fisheries and the results are published with the permission of the Commissioner of Fisheries.

a larger number of fish and a larger number of species than could be caught any other way. The fishing in the remaining lakes was carried on mostly with hook and line and the number of fish from some of them was small. The few small forms that were studied were caught along the shore with a seine.

The fish were brought to the laboratory where they were weighed, measured (standard length), scale samples taken, and these data placed on the outside of the envelope containing the scales. This work on the age and growth rate was done by the fish-catching crew. Each fish was given a serial number which was placed in its mouth so that reference could be made to its data envelope.

Only the stomach contents were examined in the 1931 material, but in 1932 both stomach and intestinal contents were taken into consideration. In the procedure with the 1931 material, the contents of the stomach were removed, placed in a dish, and the amount of each article present estimated in terms of percentage volume. This was done as follows: the amount of the specific food ingestion was estimated as a certain percentage of the amount of food present, and, to get a better idea of the relative importance of the various articles, the degree of fullness of the stomach was estimated, i.e., 100%, 50%, 10%, etc. This was taken into consideration in tabulating the data by arriving at a weighted average between the first percentage volume and the second.

With the 1932 material, the per cent fullness of the intestine was estimated as well as that of the stomach and the two averaged, making allowance for their difference in size. The contents of the whole alimentary tract were placed together and the amount of each article, in terms of the per cent of the total amount of food, was calculated, again making allowance for the percentage fullness of the alimentary tract. These figures were analogous to those arrived at with the 1931 material.

Of the total number of fish studied, 3,015 were caught in 1931 and of these, 2,082 contained food. In 1932, 2,752 fish were studied, and 1,944 of them contained food. Over one-third of those studied during the two years were empty. This seems an unusually large number to be empty and it was thought that possibly complete digestion had taken place in those fish which had remained alive in the nets for some time. Another reason for so many empty fishes might be regurgitation; some of those brought up from deep water had stomaches everted, due possibly to pressure change. Some fish apparently regurgitated their food while trying to escape from the nets.

For those lakes which had sufficient numbers of fish to have some significance, graphs were made. The different foods were condensed to seven chief articles of diet (fish, insects, amphipods, crayfish, entomostracans, molluscs and plants) which are represented by different lines. The original foods from which these were condensed were: fish, Chironomus larvae and pupae, Chaoborus larvae and pupae, Tanypus larvae and pupae, Palpomyia larvae, Hexagenia nymphs, Coenis nymphs, caddis fly larvae, Odonata nymphs, Sialis larvae, ants, corixids, miscellaneous insects, hydrachnids, Mysis, amphipods, crayfish, ostracods, copepods, cladocerans, snails, clams, leeches, algae, plants, Gordius, sponges, rotifers, and miscellaneous materials (débris etc.). This list was also condensed somewhat for the tables.

In order to correlate type of food with rate of growth or change of growth, the fish were graphically arranged in groups with a length frequency of 10 millimeters . These, plotted against the per cent volume of each article of diet, yield a graph from which may be read the different foods of the different sizes of fish. Due to a lack of the smaller fish, a knowledge of the food of the young is wanting.

List of fishes studied

Perca flavescens (Mitchill)—yellow perch.
1931—1,078 examined and 710 contained food.
1932—1,210 examined and 788 contained food.
Ambloplites rupestris (Rafinesque)—rock bass.
1931— 727 examined and 446 contained food.
1932— 718 examined and 546 contained food.
Helioperca macrochira (Cuvier and Valenciennes)—bluegill.
1931— 259 examined and 233 contained food.
1932— 94 examined and 82 contaned food.
Micropterus dolomieu (Lacépède)—small-mouthed black bass.
1931— 286 examined and 212 contaned food.
1932— 141 examined and 81 contained food.
Huro floridana (LeSueur)—large-mouthed black bass.
1931— 27 examined and 20 contained food.
1932— 8 examined and 4 contained food.
Stizostedion vitreum (Mitchill)—wall-eyed pike.
1931— 46 examined and 23 contained food.
1932— 64 examined and 44 contained food.

Cristivomer namaycush (Walbaum)—lake trout.
1931— 15 examined and 7 contained food.
1932— 7 examined and 5 contained food.
Esox masquinongy (Mitchill)—muskellunge.
1931— 4 examined and 2 contained food.
1932— 4 examined and 2 contained food.
Leucichthys artedi (LeSueur)—cisco.
1931— 359 examined and 266 contained food.
1932— 342 examined and 281 contained food.
Coregonis clupeaformis (Mitchill)—whitefish.
1931— 21 examined and 17 contained food.
1932— 31 examined and 14 contained food.
Catostomus commersonii (Lacépède)—common sucker.
1931— 124 examined and 76 contained food.
1932— 133 examined and 97 contained food.

EXPOSITION OF DATA

The fish of each lake and their foods are taken up separately below, but only those percentages that are not obvious from the tables will be mentioned. The various species of Diptera, Ephemerida, Entomostraca, Mollusca, and plants which were found, are also mentioned, as tables could not be made comprehensive enough to include them.

Trout Lake

This is one of the largest and is the deepest of the lakes in the region studied. It is a drainage lake (has an outlet).

Perch. The most common fish in the lakes studied is this species, and more yellow perch were obtained from Trout Lake than any other species.

Tables I and II show that the principal foods of the Trout Lake perch are fish and insects, both of equal importance. In the 1931 material, the total food was made up of 36% fish and 33.5% insects. In the 1932 perch, insects were 43% and fish 39% of the total. Those fish found in the perch diet which were identifiable consisted of small perch, minnows and Johnny darters. The Diptera larvae were Chironomus, Chaoborus (Corethra), Tanypus, and Palpomyia, but the 1932 perch contained just Chironomus. The Ephemerida nymphs were all Hexagenia. The miscellaneous insects, i.e., forms not regularly found, consisted of beetles, beetle larvae, mayflies (adult), leaf hoppers, wasps, katydids, grasshoppers, and unidentifiable remains. In 1931 crayfish were rather important (16%) but were rare in the 1932 specimens. The Entomostraca consisted of Copepoda (Cyclops, Diaptomus, and Canthocamptus) and Cladocera (Daphnia, Holopedium, and Camptocercus). The Mollusca were all snails (Planorbis and Physa). Plants were mostly Potamogetons. The "miscellaneous" column includes leeches, sponges, rotifers, Gordius, unidentifiable food, and bottom débris.

The graphs of the food of the perch were not included because of the varying nature of the data concerned. The fish ranged in size from 60 to 220 mm. and there seemed to be little change of diet, from the smallest to the largest. However, the smallest fish which were caught showed a slightly higher insect content in their food; the larger perch showed a sudden drop in insect food and an increase of fish as food. This seems to indicate that the perch from this lake do not have a gradual change of diet with growth, but that this change is sudden. Perhaps this phenomenon is due to the fact that no fish sufficiently small was caught to indicate the exact time of this sudden change in diet.

Rock Bass. The principal foods of the 1931 rock bass were insects, crayfish and fish, in order of importance. In the 1932 rock bass the principal foods were insects and crayfish. The fish diet consisted of minnows and darters. The Ephemerida were all Hexagenia nymphs. A great difference in this food for the two years was noted (30% of the total food was Hexagenia in 1931; 2% in 1932). This difference may be due to the fact that the 1931 fish were caught in nets in fairly deep water. Those in 1932 were caught with hook and line in 4 to 8 feet of water in the upper part of the lake near an old submerged pier and a weed bed. The miscellaneous insects of the 1931 rock bass were mostly grasshoppers with a few beetle remains. Those of 1932 were Gyrinid beetles, midges, dragon flies, and grasshoppers. The larger percentage of insects here was probably due to the shallow water and the overhanging branches along the shore. The plants found were Potamogetons, with a few algae. The Entomostraca were Daphnia and Leptodora.

The rock bass ranged in length from 60 to 200 mm. and these, as well as the perch, presented an inconsistent and varying set of curves when the lengths were plotted against the foods. The smaller rock bass ate principally insects until they reached about 130 mm., at which time there was a decrease in insects and an increase in crayfish and fish in their diets.

Cisco. The food of the ciscoes consisted almost entirely of plankton. In Trout Lake, they ate a few Chironomus and Chaoborus larvae, but by far the most important element of the food was Entomostraca. In 1931 Copepoda constituted 49% and Cladocera 33% of the food. In 1932 the Copepoda made up 42% and the Cladocera 47.5%. Some fish eggs were found in a few of the 1931 specimens. There was not enough variation in the size of these ciscoes to make any correlation between length and diet.

Whitefish. Whitefish were taken only in Trout Lake. A large percentage of the food came from the bottom and consisted of dipterous larvae and molluscs; a few entomostracans were noted also. The larval Diptera were Chironomus, Chaoborus and Tanypus. Mysis was a favorite food, but it was not found in any other species of fish except in the ciscoes from Black Oak Lake. The molluscs were represented by small specimens of Pisidium. The Entomostraca included Ostracoda, Canthocamptus, Leptodora, Acroperus and Ophryoxis. The large amount of miscellaneous material was mostly bottom débris, pine seeds, fish eggs, and rotifers (Conochilus).

Small-Mouthed Black Bass. Representatives of this species were caught with a minnow seine and hook and line. In 1931 ten small bass were caught along the shore with a seine. They were 30 to 40 mm. in length. The main food was Diptera larvae (Chironomus—11%, Chironomus pupae—5%, Chaoborus pupae —8.5%, Tanypus—3%, and Palpomyia—10%). The Ephemerida were all Hexagenia nymphs. The miscellaneous insects were midges, leaf hoppers, and damsel flies. The Entomostraca were all Sida. The miscellaneous column consisted of land spiders. Insects seem to be the main food of small bass. The one small-mouthed bass caught in 1932 contained a large crayfish.

Wall-Eyed Pike. The wall-eyed pike fed almost entirely on other fish. Of the 52 examined from this lake during both summers, only one had eaten anything besides fish and that one had a stomach full of Hexagenia nymphs. The fish eaten were perch, cisco, and minnows.

Lake Trout. There are only five lakes in Wisconsin where this fish is caught, and of these lakes, three are situated in this region. The only specimens caught during this investigation were from Trout Lake. Some of the trout were caught in gill nets and some with hook and line.

Lake trout inhabit deep water and live on fish. The food of those included in this study consisted mostly of ciscoes, but suckers were found in two of them. One trout measuring 810 mm. in length had eaten a sucker 330 mm. long, which weighed 520 grams.

Sucker. Because the sucker is a bottom feeder, its food varies somewhat, consisting of molluscs, dipterous larvae, entomostracans, bottom ooze and débris. The principal food was molluscs (Amnicola, Planorbis, Bythinia, and Pisidium). Chironomus larvae made up 18% of the food in 1931 and 17.5% in 1932. There was a considerable variety of Entomostraca but they were rather few in number. There were some Ostracoda, but most of the Entomostraca were Copepoda (Canthocamptus and Cyclops) and Cladocera (Bosmina, Camptocercus, Daphnia, and Ophryoxis).

The size of the suckers ranged from 120 to 380 mm., no small ones being caught. The curves for 1931 show a gradual decrease in insect food as the length of the fish increases, and a correspondingly increased mollusc consumption. In 1932 no sucker was caught measuring less than 260 mm. in length. Mollusc food was predominant in those caught. In suckers between 320 and 360 mm., insects replaced the mollusc diet, which again prevailed in the larger fish.

NEBISH LAKE

This is a small lake of medium depth (15.8 m.) with rather clear water. The marshy weed beds found in so many of the other lakes are lacking here. The food of the fish from this lake differs from that of other lakes in the great predominance of insects.

Perch. Insects made up 81% of the food of the 1931 perch and 53% of those caught in 1932. There was a further departure from the usual ephemerid findings in that 28.5% of the 1931 food consisted of Coenis; against 1% Hexagenia in 1931 and entirely Coenis (14.5%) in 1932. This was unusual because Coenis nymphs were found in hardly any of the other lakes as food. The Entomostraca were almost entirely Daphnia with a few Leptodora. In 1931 the Mollusca were Pisidium with a few Planorbis and in 1932, Pisidium with a few Planorbis and Amnicola.

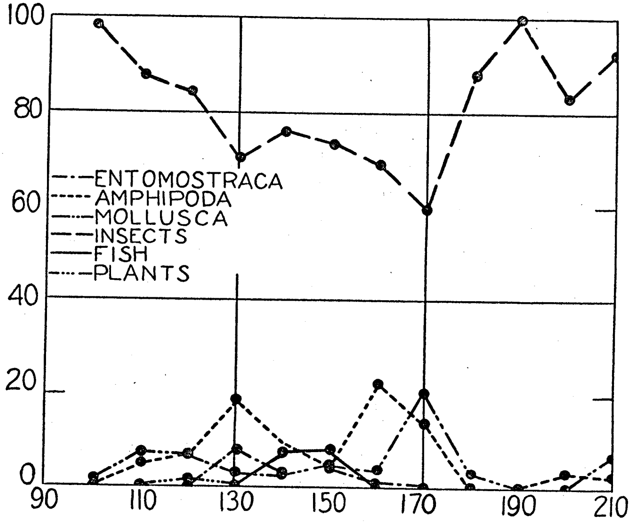

FIG. 1. This diagram shows the percentage composition of the food of different sizes of perch taken in Nebish Lake in 1931. Compare with fig. 2.

Figure 1 represents the type and amount of food eaten by the different sized perch. Here insects predominate; the other foods have little significance. In Figure 2, insects are also the most important food, but there is an increase in Entomostraca in specimens between the lengths of 110 and 150 mm. This increase of Entomostraca during a certain period of growth seems to be characteristic of the perch in all the lakes studied. It occurs as a rule in those perch from 120 to 150 mm. in length.

Rock Bass. The food of this fish is quite similar to that of the food of perch, the main food being insects. Of the Diptera larvae, Chironomus were most important (1931—19.5% of the total food; 1932—42.5%). Of the Ephemerida, Coenis predominated (1931—16.5%; 1932—24.5%). The Entomostraca consisted entirely of Cladocera; in order of their importance, (1931) Holopedium, Leptodora, Daphnia, Sida; (1932) Daphnia, Leptodora, and Holopedium. The molluscs consisted mostly of Pis-

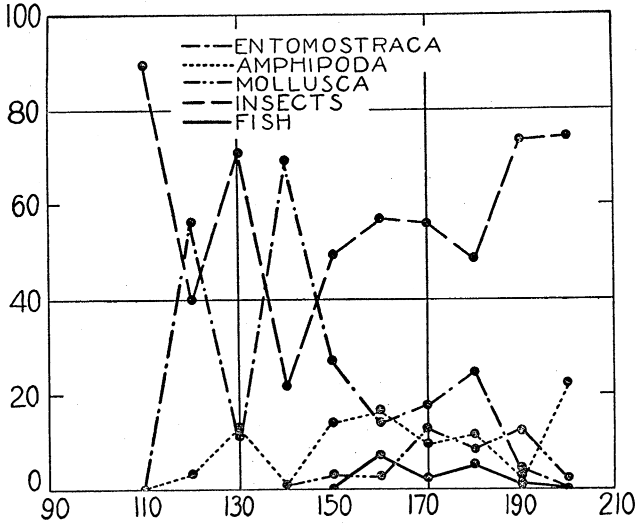

FIG. 2. This diagram shows the percentage composition of the food of different sizes of perch taken in Nebish Lake in 1932. Compare with fig. 1.

idium with a few Planobis in 1931; in 1932 a similar condition existed except that a few Amnicola and Physa were found.

The 1931 rock bass were all so much alike in size that they presented no significant curves. Figure 3 shows the curves for the 1932 rock bass. In these the insect food increases irregularly; fish appears in the stomachs of the 140 mm. group and predominates in the 190 mm. rock bass.

In October of 1932, twenty-seven rock bass were taken from Nebish Lake; Table II shows the marked change of diet that took place with change of season. The main food was Entomostraca, to be followed by insects and molluscs. The entomostracans were all *Daphnia pulex*. They were winter forms, their ephippia containing winter eggs. The molluscs were Planorbis (11% of the total food) and Pisidium (1%). Insecta included no Diptera larvae and, as shown in Table 1, consisted of caddis fly larvae, dragon fly nymphs and Sialis larvae. The miscellaneous insects were mostly the remains of small aquatic beetles. Of note is the fact that no Coenis nymphs were found.

Figure 4 shows the Entomostraca gradually decreasing with increase in the size of the rock bass, and the insect food coming into prominence. In the largest fish, insects are, in their turn, replaced by molluscs.

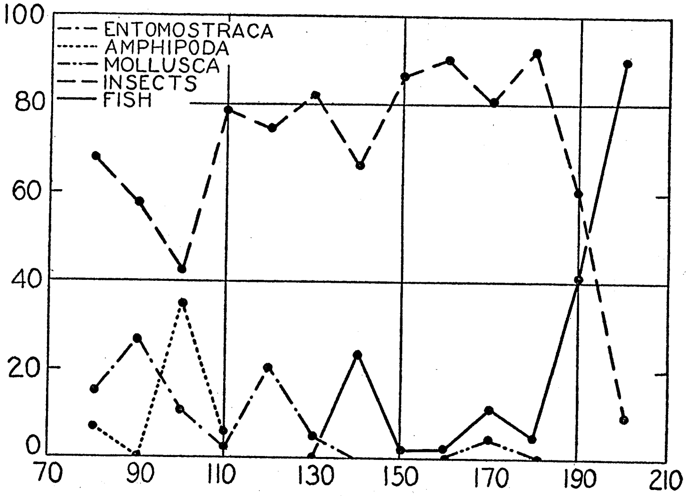

FIG. 3. This diagram shows the percentage composition of the food of different sizes of rock bass taken in Nebish Lake inJuly and August 1932. Compare with fig. 4.

Small-Mouthed Black Bass. The principal food of the large-mouthed bass was insects (1931—61%; 1932—51%), which was followed in order by fish and Entomostraca. The Diptera larvae were mostly Chironomus. The Ephemerida were largely Coenis (1931—12.5%; 1932—5%). The miscellaneous insects were all grasshoppers for both years. Cladocera were the only representatives of the Entomostraca, consisting chiefly of Leptodora, with a few Daphnia and Sida. The Mollusca were represented by Pisidium.

The graphs of these fish were not included, but it is worthy of note that Cladocera were found in the 110 to 160 mm. fish. Insects predominated in fish up to 220 mm., when fish became the main food. However, as the 1932 material contained no fish less than 150 mm. long, the curves were of little significance.

Large-Mouthed Black Bass. One large-mouth bass 118 mm. long was taken from this lake in 1932. It was 50% full and had eaten Hexagenia (60%) and Gyrinid beetles (40%).

WEBER LAKE

This is the clearest and the smallest of the lakes studied. It is a seepage lake with soft water, and has an area of about 38 acres and a maximum depth of 13 m.

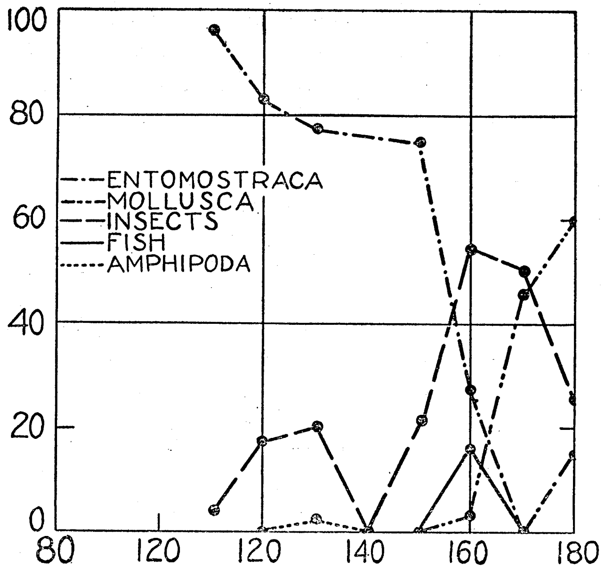

FIG. 4. This diagram shows the percentage composition of the food of different sizes of rock bass taken in Nebish Lake in October 1932. Compare with fig. 3.

Perch. The principal food was insects (1931—84% and 1932—79.5%). Caddis fly larvae were the principal insect food for both years (1931—65.5%; 1932—45.5%). The Diptera larvae for 1931 were Chironomus (35%), Chaoborus (11.5%), and Tanypus (0.5%); for 1932, Chironomus (19%), Chaoborus (8%), and Tanypus (3.5%). Noteworthy is the absence of Ephemerida, especially Hexagenia which was found in most of the lakes. The miscellaneous insects for 1931 were grasshoppers, caterpillars, damsel flies, midges, parnid larvae, and adult dragon flies. For 1932 they were grasshoppers, Hydroporus larvae, beetle remains, and unidentified beetle larvae. The Entomostraca were, for both summers, entirely Cladocera (1931: Ophryoxis, Holopedium, and a few Camptocercus; 1932: Holopedium, Daphnia, Bosmina, Chydorus, Sida, Acantholeberis, and Diaphanosoma). A few molluscs were found; one Planorbis and some specimens of Pisidium were observed.

In 1931 insects predominated in all sizes of perch, the other foods having little significance. In Figure 5 (1932), the young fish subsisted chiefly on Cladocera, changing to insects at 120 to 130 mm. Insects continued to be the principal food throughout the rest of the size range.

Small-Mouthed Black Bass. The 1931 material consisted of five bass with an average length of 230 mm., and twenty-four small ones between 50 and 80 mm. in length. Of the first five, one 110 mm. specimen was 10% full, contained Chaoborus pupae (60%), Holopedium (20%) and Camptocercus (20%). One, 234 mm. in length and 50% full, had eaten two minnows (80%) and plant material (20%). The third fish, 232 mm. long and 10% full, contained fish (90%) and Chironomus (10%). One, 217 mm. in length and 100% full, had eaten one small fish (10%), 10 grasshoppers (60%), and one frog (30%). The fifth one was empty.

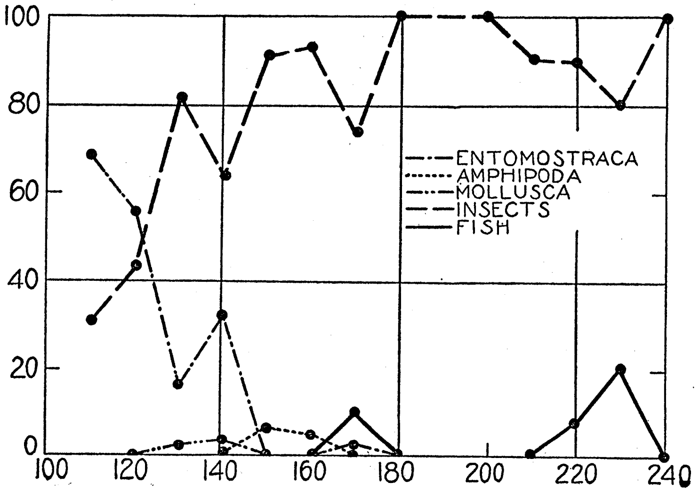

FIG. 5. This diagram shows the percentage composition of the food of different sizes of perch taken in Weber Lake in 1932. Compare with figs. 2 and 6.

The smaller bass ate mostly insects but there was a great variation in their diet. For instance, of four small ones caught on the same day, one was empty, one was 100% full and contained Palpomyia larvae (100%); one, 30% full, had eaten Chironomus larvae (20%), Palpomyia (20%), caddis fly larvae (40%), Daphnia (10%), Sida (5%), and Bosmina (5%); one, 65% full, had eaten Chironomus larvae (5%), Palpomyia (80%), Acantholeberis (5%) and Bosmina (5%). Twenty small ones taken on another day had eaten mostly insects which were, in order of importance: ants, an unidentified fly larva, caterpillar, damsel fly, midge, and Chironomus larvae. One, 25% full, was quite unusual in having eaten 100% Polyphemus. Acantholeberis and Acroperus were found in small amounts in the others.

Only two small-mouthed bass were obtained in 1932. One of these, 15% full, contained a grasshopper; the other, 100% full, had eaten a perch.

MUSKELLUNGE LAKE

This is a rather shallow seepage lake with fairly soft water. Data on fish caught in South Bay were kept separate from those of North Bay during 1931. In 1932 four stations were established and these were designated North Bay, South Bay, West Bay, and Station Four. This was done to see if there was any difference in rate of growth of fish in different parts of the lake. As there was not enough difference in food to warrant a separate treatment of the various stations, the results for the entire lake are grouped together.

Perch. In 1931 fish were the main food of the perch with insects (20%) ranking second and Entomostraca third. The Diptera larvae consisted of Chironomus (5.5% of the the food total) and Chaoborus (0.5%). The Ephemerida were all Hexagenia. The Entomostraca were Copepoda (0.5%) and Cladocera (15.5%). Molluscs were all snails.

In 1932 insects were first in importance in the perch diet (36%), fish second and Entomostraca third. Among the insects, Chironomus made up 12.5% of the food, Chaoborus 6%, Hexagenia 2% and Coenis 1%. The Entomostraca were Ostracoda 1%, a few Copepoda, and Cladocera 14.5%. The molluscs consisted of 4.5% snails and 0.5% bivalves. In 1931 the perch ranged from 90 mm. to 240 mm. in length. The smallest perch ate chiefly insects, but the percentage of insect material showed a marked decline in the 100-130 mm. groups. Correlated with a decrease in insects was a corresponding increase in Entomostraca and fish. Perch that were 150 mm. or more in length subsisted chiefly on small fish. One perch with a length of 190 mm. had a stomach full of plant material.

The 1932 perch from Muskellunge Lake ranged from 80 mm. to 230 mm. in length. Figure 6 shows that the young perch ate Entomostraca chiefly and these organisms continued as an important element of the food up to a length of 160 mm. Insects appeared in the smaller perch and continued to be important even in the larger sizes, where small fish became the chief item of food.

The perch from North Bay in 1931 fed chiefly on fish and Entomostraca. In 1932 the perch from this bay ate insects (Chironomus larvae and Odonata nymphs) and Entomostraca. The perch from South Bay ate mostly fish in 1931, but in 1932 their diet was more varied, consisting of insects and fish, with lesser amounts of snails and amphipods. The perch of Station Four in 1932 ate mostly Cladocera, with some insects and fish, while the West Bay perch fed on Diptera larvae and fish.

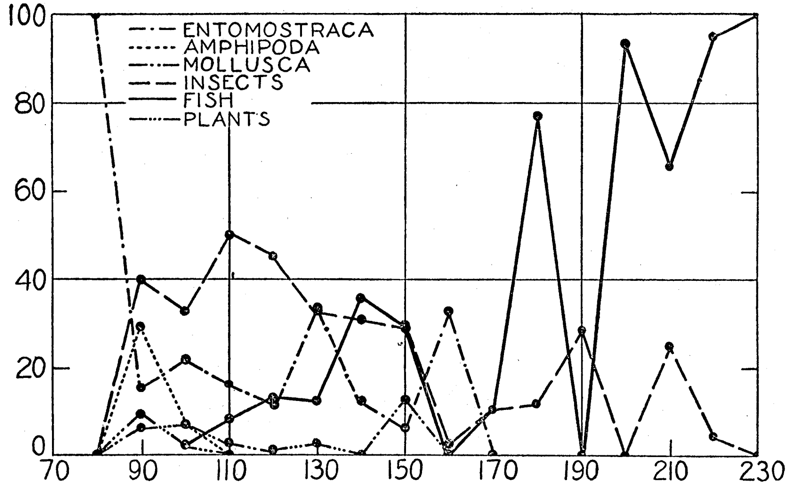

FIG. 6. This diagram shows the percentage composition of the food of different sizes of perch taken in Muskellunge Lake in 1932. Compare with figs. 2 and 5.

Rock Bass. In 1931 insects were the principal food (40.5%) of rock bass. Diptera larvae consisted of Chironomus (1% of the food total) and Chaoborus (3%). Ephemerida were all Hexagenia. The molluscs were all snails.

In 1932 insects were also the main food (58%). The Diptera larvae were Chironomus (2%) and Chaoborus (8.5%). Ephemerida were Hexagenia (17%) and Coenis (2%). Molluscs were represented by snails only.

In 1931 the food of the smaller rock bass consisted chiefly of insects; there was a gradual decrease in insects with increase in the size and a corresponding increase in the amount of fish and crayfish consumed in specimens above 120 mm. in length.

In 1932 (Fig. 7), the food relationship was similar to that of 1931 except that crayfish were not so important and insects were more so.

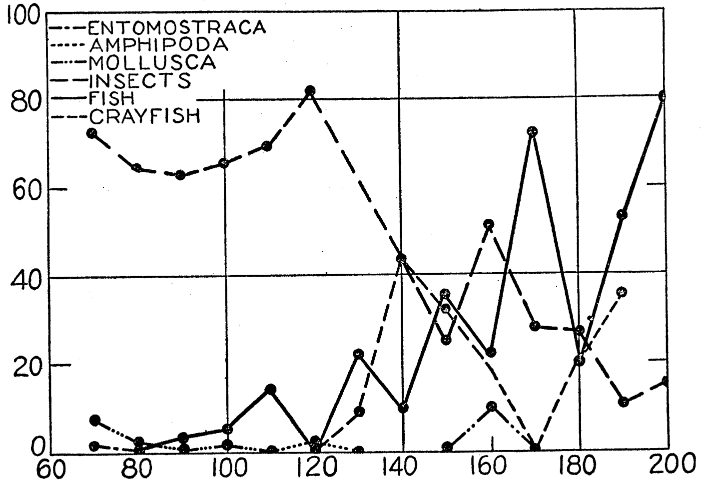

FIG. 7. This diagram shows the percentage composition of the food of different sizes of rock bass taken in Muskellunge Lake in 1932. Compare with figs. 3 and 4.

The rock bass from North Bay in 1931 ate fish and insects with some crayfish. In 1932 insects were the most important food. The rock bass from South Bay ate mostly insect larvae (Odonata nymphs) with some fish and plants. Their food was about the same for the two years. At Station Four insect larvae (Hexagenia and Odonata nymphs) and crayfish were the chief foods. In West Bay the rock bass ate mostly fish and Hexagenia nympmhs.

Bluegill. In 1931 insects were the principal food (49.5%). The Diptera larvae were Chironomus (19.5%), Chaoborus (1%), and Tanypus (0.5%). Ephemerida were all Hexagenia and molluscs were all snails.

In 1932 plants were the main food (34%). (Fig. 8). Seven per cent of the food total were green algae and 27%, large aquatic plants. Insects constituted 29.5% of the food. The Diptera larvae were Chironomus (8.5%), Chaoborus (2%) and

Palpomyia (1.5%). The Ephemerida were Hexagenia (1%) and a few Coenis. Entomostraca were Ostracoda (2.5% of all food present) and a few Cladocera. Molluscs were snails with a few clams.

In 1931 insect food predominated in the small bluegills, decreased and was replaced by plant material in the medium sizes, and again increased in the larger specimens. The pronounced decrease in the amount of insect material in the food of bluegills ranging from 90 to 140 mm. in length seems to be characteristic of this species. Figure 8 shows a similar food distribution in specimens obtained in 1932.

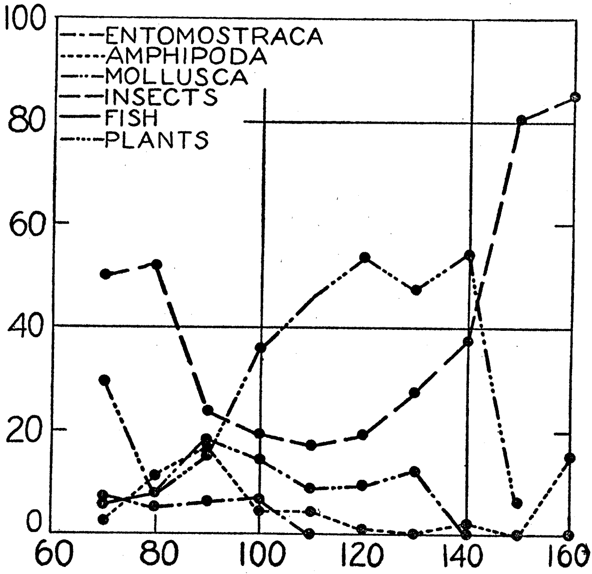

FIG. 8. This diagram shows the percentage composition of the food of different sizes of blue-gills taken in Muskellunge Lake in 1932.

Bluegills were taken from North Bay in 1932 only and they ate mostly insect larvae (Diptera, caddis fly, and Odonata). Those from South Bay in 1931 ate chiefly plants, Diptera larvae, and ants, with some molluscs. In 1932 the bluegills from this bay fed on plants with lesser amounts but greater variation of the other foods. The three bluegills from West Bay had eaten plants and some insect larvae.

Small-Mouthed Black Bass. Fish were the chief food of this species of bass in both years; in 1931 they constituted 75%

of the diet. In the 1932 specimens, insects constituted 48.5% of the food. Fragments of large aquatic plants were found in some cases. Fish constituted an important element of the food of small-mouths ranging from 110 to 140 mm. in length in 1931, but no fish material was found in those ranging from 140 to 160 mm. in length; the percentage of fish material increased in those ranging from 160 to 230 mm. in length. Plant material formed an important item in those between 160 and 190 mm. in length.

In 1932 two small-mouths with lengths of 100 and 110 mm., respectively, had eaten only Entomostraca. The other specimens varied from 140 to 250 mm. in length; fish material was the main article of diet in them, but insects were quite important in the 140-190 mm. group.

The small-mouths from North and South bays in 1931 ate chiefly fish. Plants occurred in the diet to some extent. In 1932 the specimens from North Bay ate chiefly terrestrial insects and fish. No specimens were obtain from South Bay in 1932. The West Bay specimens had eaten only fish and those from Station Four ate mostly fish.

Large-Mouthed Black Bass. The unusual appearance of the food of the large-mouthed bass in Table I is due to the combining of both the small and the large fish of this species from this lake. The large per cent of fish in the diet is due to the large sized fish, and the large amount of Entomostraca can be ascribed to the fact that the small ones fed mostly on Cladocera. The "miscellaneous" insects labeled in the table were all found in the small fish.

In 1932 all specimens caught were rather large and they ate fish entirely. The plant food was probably accidentally ingested.

Large-mouthed bass were caught in South Bay only in 1931 and their food consisted of fish and Entomostraca. The latter were found in the smallest specimens. In 1932 this species was taken from North and West bays and they were found to have fed mostly on fish.

Muskellunge. Four of these fish were caught in 1931 from South Bay and their food consisted entirely of fish (Johnny darters and chubs).

Cisco. Entomostraca were the main food of ciscoes. The Entomostraca in the 1931 speicmens consisted of Cyclops (50%), Cladocera (24%), and a few Ostracoda. The Diptera larvae were Chironomus (1%) and Chaoborus (3%).

The Entomostraca of the 1932 ciscoes were Cladocera (59%), copepods (42%), and a few Ostracoda. The Diptera were Chironomus larvae (1.5%) and Chaoborus (1.5%).

Not much can be said concerning the food of the different sized ciscoes as there was little difference in the size of those caught. Ciscoes were taken from North and West bays only and there was little difference in type of food.

Sucker. In 1931 insects were the main food (26%). The Diptera larvae were Chironomus (13.5% of all food present), Chaoborus (1.5%), Tanypus (6.5%) and Palpomyia (2%). The Ephemerida were all Hexagenia. The Entomostraca were Ostracoda (1%), Copepoda (5%), and Cladocera (9%). Molluscs were snails (8%) and clams (4.5%). Plants were mostly fragments of higher aquatic forms.

In 1932 insects were also the main food (28%). The Diptera larvae consisted of Chironomus (17.5%), Chaoborus (1.5%), Tanypus (0.5%), and Palpomyia (1%). The Ephemerida were Hexagenia (1%) and Coenis (2%). Entomostraca were Ostracoda (1.5%), Copepoda (3.5%), and Cladocera (15.5%). Molluscs were snails (6%) and clams (2.5%).

The 1931 suckers were 110 to 310 mm. in length. Because of lack of numbers, frequencies of 20 mm. were used in the curves in place of 10 mm., but even so the curves did not show much. Cladocera were most important in the small suckers, molluscs increased in importance in those between 170 and 190 mm., and insects predominated from 170 mm. up.

The 1932 suckers were also divided into groups on a 20 mm. basis, extending from 150 to 330 mm. Entomostraca were predominant in the fish up to 210 mm. and then decreased in number as insects increased. Insects continued to be the main food of the larger suckers.

The suckers from North and South bays in 1931 ate foods that were quite alike, consisting of dipterous larvae Entomostraca and small molluscs. The South Bay suckers ate more Entomostraca than those from North Bay. In 1932 suckers were taken from North and West bays and Station Four and their foods were quite similar to those of the previous summer.

SILVER LAKE

This is a small lake that has about the same type of water as Trout Lake and it drains into Trout Lake in times of high water.

Perch. In 1931 insects were the principal food (54.5%) of Silver Lake perch. The Diptera larvae were Chironomus (4%), Chaoborus (0.5%), Tanypus (1%), and Palpomyia (1%). Ephemerida were all Hexagenia. The miscellaneous insects were grasshoppers, gyrinid beetles and tabanid larvae. The Entomostraca consisted of Copepoda (4.5%), and Cladocera (5%). Molluscs were all snails (Physa). Plants consisted of algae (1%) (Aphanocapsa) and large aquatics (Potamogetons).

Figure 9 shows the 1931 food curves for the various sized Silver Lake perch, which ranged from 100 to 230 mm. The young ate mostly Entomostraca, but insects appeared in the 110 mm. specimens and predominated in the larger sizes. The characteristic change in food, previously described, occurs in the 140 to 160 mm. perch, at which time there is an increase in the amount of fish material consumed.

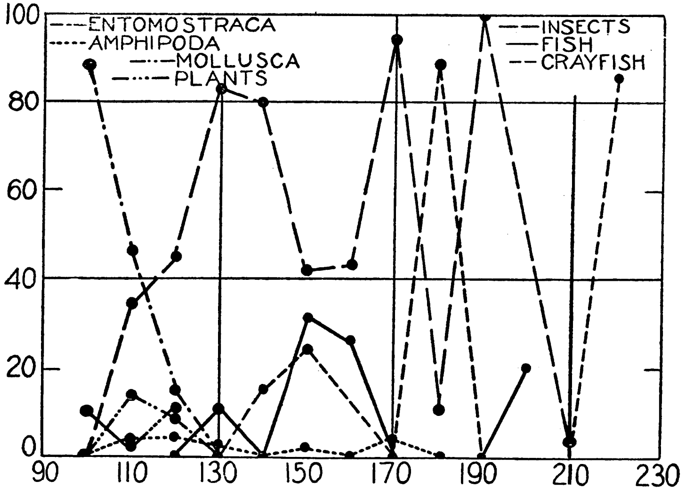

FIG. 9. This diagram shows the percentage composition of the food of different sizes of perch taken in Silver Lake in 1931. Compare with figs, 1, 2, 6 and 8.

In 1932 a considerable change in diet was noted. The main food was fish; this item made up 90% of all food and consisted almost entirely of young perch. Entomostraca were found only in the smallest specimens.

Rock Bass. In 1931 the principal food of rock bass was insects (51.5%). The specimens were 60 to 140 mm. in length. Crayfish were eaten by the smallest rock bass and they increased in importance until they became the main food in the 120 mm. specimens. Only two rock bass containing food were obtained in 1932. One of them (15% full) contained only fish and the other (25% full) had eaten only dragon fly nymphs.

Bluegill. Bluegills were caught only in 1931; they were 70 to 130 mm. in length. The main food was insects (86%). Chironomus larvae (10.5%) were most important and Chaoborus (2%) next. Hexagenia and damsel fly nymphs were found in some numbers, as well as a few Copepoda and Cladocera. Physa represented the mollusc group.

Small-Mouthed Black Bass. In 1931 the small-mouthed black bass from this lake ranged from 70 to 270 mm. in length; the chief constituent of their food consisted of insects, with fish material second in importance. Both of these foods were eaten by all sizes. Five specimens were secured in 1932 ranging from 133 to 200 mm. in length; all of them had eaten small perch.

Cisco. Ciscoes ranging in length from 130 to 210 mm. were taken only in 1931. Their chief food consisted of Copepoda (59%) and Cladocera (30.5%); this was true of all sizes.

Sucker. Insects and molluscs constituted the chief food of the suckers in 1931; the former made up 36.5% and the latter 33.5%. The Entomostraca were represented by 5% Cladocera and 4.5% Copepoda. These suckers varied from 155 to 305 mm. in length, but all of them ate about the same type of food.

CLEAR LAKE

This is a seepage lake with clear, soft water. The fish studies on this lake were concentrated on the ciscoes, so that the other species are not well represented.

Perch. The perch obtained in 1931 were between 115 and 177 mm. in length. Insects constituted the main food item

(86.5%), with Chironomus and Hexagenia as the chief forms. Nostoc was found in some specimens. Only three specimens containing food were obtained in 1932; their food consisted of 65% insects and 35% Leptodora.

Rock Bass. Insects were the chief element in the food of three rock bass taken in 1931, namely 37.5%; the three specimens taken in 1932 contained 97% insects, chiefly Hexagenia (92%).

Small-Mouthed Black Bass. One small-mouthed black bass was taken in 1931. It was 125 mm. long and contained 100% fish.

Wall-Eyed Pike. The 1931 pike measured 220 to 380 mm. in length and fed chiefly on fish (darters and minnows). Insects (19.5%) consisted of Diptera larvae (Chironomus) and Ephemerida (Hexagenia). Entomostraca were Cladocera (Leptodora). Plants were green algae (Coleochaete).

The 1932 pike measured 221 to 390 mm. and fed chiefly on insects (59.5%). One specimen had eaten 84 large Hexagenia nymphs. The fish eaten consisted of darters and minnows.

Cisco. Entomostraca were the chief food of the ciscoes. In 1931 Entomostraca made up 96.5% of the food and consisted of Cyclops (0.5%) and Cladocera (96%); the latter were chiefly Daphnia, with some Leptodora and a few Holopedium. Insects were 3.5% of the total food and consisted of Chironomus 2%, with a few Hexagenia and Tanypus.

In 1932 Entomostraca made up 99.5% of the food, consisting of Cladocera (Daphnia 93% of total food, Leptodora 6.5%, and a few Holopedium). One cisco (no. 963) had eaten 3,052 large Daphnia and nothing else. The only insects found in these ciscoes were Chironomus larvae (0.5%).

VIEUX DESERT

This is the largest lake in this area although it is quite shallow. It has deeply colored water due to vegetable extracts.

Perch. Insects constituted 72% of the food of the perch obtained from this lake in 1931; 41% consisted of Chironomus. While insects predominated in the food of the younger perch, they showed the characteristic decline in percentage in the 110 to 140 mm. groups; insects were replaced by fish in the larger perch. Hyalella was eaten to a considerable extent by perch ranging from 170 to 190 mm. in length.

In the 1932 specimens from this lake, Hyalella was the most important item of food (51%); this crustacean did not form such a large percentage of the food in any other lake although it was present in them. Insects were next in importance (32.5%); molluscs furnished 4.5% of the food and a few Daphnia were found in one specimen. The 1932 perch were caught at two different times (55 in July and 15 in August) and the food was very different for the two periods. The large percentage of Hyalella was found in the July specimens, while most of the snails were noted in the August catch. The youngest perch, beginning at 70 mm., had eaten chieffy insects, but the percentage of insects decreased sharply in the 100-140 mm. perch and was replaced by Hyalella which remained predominant up to 150 mm. Insects, however, continued to be important until supplanted by fish in the larger perch (170-190 mm.)

PALLETTE

This is a small seepage lake with clear soft water.

Perch. Perch were taken from this lake only in 1931. The principal food was fish, consisting of small perch and minnows. Insects amounted to 33% and snails ranked third in importance. Five small specimens, averaging 30 mm. in length, were obtained; their food consisted entirely of Entomostraca (Diaptomus 82%, Cyclops 14% and Chydorus 4%).

Rock Bass. Only five rock bass containing food were taken; insects were the chief article of diet and consisted mainly of unidentifiable remains.

Small-Mouthed Black Bass. The principal food of the 1931 small-mouths consisted of small perch and minnows. The insect material contained an appreciable amount of grasshoppers; one small specimen had eaten Daphnia. Fish was the principal constituent in the food of the 1932 specimens. Chaoborus made up 2% of the food and Chironomus larvae 1%. Leptodora was found in a 169 mm. specimen.

Cisco. Ciscoes were obtained only in 1931. The principal food was Entomostraca (89%), consisting of 36% Cyclops and 53% Cladocera (Daphnia, Chydorus and Bosmina).

Sucker. A 351 mm. sucker was secured; it had eaten chiefly Entomostraca, consisting of 50% Copepoda and 20% Cladocera. Chaoborus larvae made up 10%, other insect remains 10% and plant material 10%.

LONG LAKE

This is a small, shallow lake with fairly clear water. Specimens for food studies were taken from this lake only in 1931.

Perch. Entomostraca were the principal food of these perch; they consisted entirely of Cladocera (Holopedium, Daphnia, Bosmina and Sida). Insects (37.5%) were next in importance, with 5% Chironomus larvae and 2% Chaoborus larvae; the rest were unidentifiable fragments. These perch ranged in size from 100 to 160 mm. The smaller ones ate chiefly entomostracans and those between 130 and 150 mm. chiefly insects. Fish appeared in the food of the 150 mm. group.

Large-Mouthed Black Bass. Three small specimens of large-mouthed black bass were examined. The principal food was fish, but one of them contained remains of a moth.

BLACK OAK LAKE

This lake has an area of 230 ha. and a maximum depth of 26 m. The water is fairly soft.

Ciscoes were obtained from this lake in 1932; they ranged from 170 to 210 mm. in length. Entomostraca formed the principal food, but Mysis and insects played an important rôle also. Ostracoda made up 9% of the total food, while the copepods Cyclops, Canthocamptus and Diaptomus furnished 15.5%, and the cladocerans Daphnia, Leptodora, Chydorus and Bosmina 16.5%. Mysis with 40% was a close second; the results for it are included in the "miscellaneous" column in Table II. This large percentage of Mysis agrees with results reported by other investigators for ciscoes. Some plant material consisting of Nostoc was found in some of the specimens. The smaller ciscoes ate chiefly Entomostraca, but this type of food decreased sharply in the 190 mm. group, with a corresponding increase in Mysis; at 200 mm. then, Mysis decreased and Entomostraca increased. The insect part of the food was consumed chiefly by the larger ciscoes.

OTHER LAKES

Only a few specimens of fish were obtained from several additional lakes, but the numbers were not large enough to give any definite idea of the food relationships of the different sizes. The general type of food material consumed by these specimens is indicated in Table I and no further discussion of them is necessary.

SUMMARY AND DISCUSSION

From the data presented, it is evident that the food of young fish differs considerably from that of the older ones. In some species, notably the perch, rock bass, and black bass, three distinct food periods may be observed. These periods are, first, one when Entomostraca and small insect larvae are eaten, second, when insects are the major food, and third, when fish and crayfish are the chief foods.

Perca flavescens

As the perch were the most numerous and presented the greatest variability of food in the different lakes, two graphs for the two summers were prepared (Figs. 10 and 11). These include all the perch studied from Trout, Muskellunge, Nebish, Silver, Weber, Vieux Desert, and Long lakes; these perch ranged from 60 to 290 mm. in length. These curves are as significant as those for the perch from each lake, for they are modified by the unusual or different foods from certain lakes. One example of this is the 1932 Silver Lake perch which ate 90% fish as compared with 6.5% fish in 1931. A second example is the Nebish Lake perch, which are partly responsible for the high insect curves, due to their eating so predominantly of insects, especially Coenis and Chironomus (1931—81% insects and 1932 —53%). In general, however, insects were the principal food of perch (1931—48%). Those for 1931 consisted of Diptera larvae (13.5%), Ephemerida (14%), caddis fly larvae (7.5%), dragon fly nymphs (9.5%) Sialis larvae (1%), and miscellaneous insects (3%). For 1932, insects were 42% and consisted of Diptera larvae (10%), Ephemerida (4%), caddis fly larvae (11%), dragon fly nymphs (3.5%), ants (1%), and miscellaneous insects (13%). Fish were the next important food, representing about 22% in 1931 and 21% in 1932.

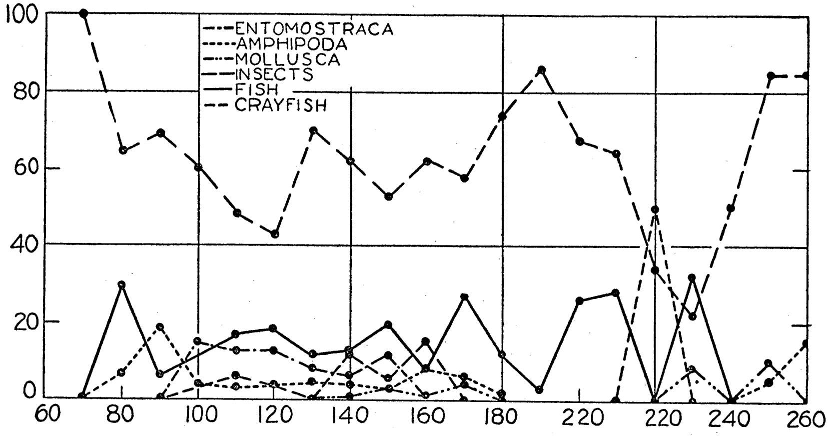

FIG. 10. This diagram shows the percentage composition of the food of different sizes of perch taken in all lakes in 1931. Compare with fig. 11.

Of note is the occurrence of the previously mentioned decline in the percentage of insects (Fig. 11) which is found in the major food curve of perch between 120 and 150 mm. in length. This is a temporary decrease in insects and an increase of fish as food. This raises a question as to why this particular size of perch should suddenly turn cannibalistic.

From a study of the few small perch obtained it can be concluded that the very young fish eat Entomostraca, but quickly change to an insect diet, consisting usually of small dipterous larvae. These, along with other aquatic insect larvae, constitute the principal food until the perch is rather large. The eating of fish as food begins early, but this usually does not become a major food until the perch has reached a length of 180 mm. or more.

As an example of the versatility of perch in feeding habits, the foods of five perch from the same haul in Weber Lake in 1931 are cited. One perch, 185 mm. in length, contained 200 small caddis fly larvae; one, 200 mm., contained a perch 65 mm.

long; one, 196 mm., had eaten 28 large caddis fly larvae; one, 211 mm., had its stomach much distended with 250 Chaoborus larvae; one, 155 mm., had its stomach half full of Ophryoxis.

Forbes and Richardson (1908) state that perch are wholly carnivorous, but differ in their food according to habitat. River perch fed on crayfish, insect larvae, small molluscs and fish, but those from lakes ate entirely fish and crayfish. Reighard (1915) found perch in Douglas Lake eating insects, fish and crayfish but resorting to cannibalism in midsummer. This seems to be true of the 1932 Silver Lake perch also, indicating that the conditions in the lake were not the most favorable for perch during that year. Pearse (1918), in studying the food of shore fish in lakes near Madison, found perch eating mostly insects (38.2%), amphipods (24.5%), and entomostracans (25.8%). In 1920 the same writer found insect larvae and entomostracans as the main food. Clemens *et al* (1924) found in Lake Nipigon that the perch below 4 cm. in length were plankton feeders and that above this size, fish and insects rapidly increased.

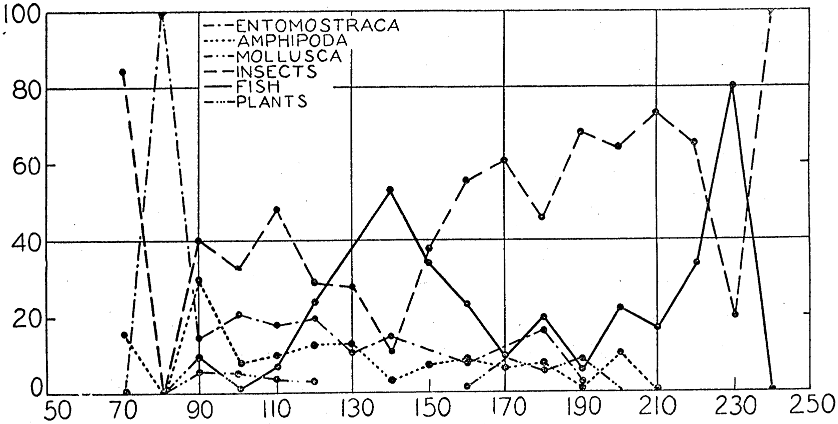

FIG. 11. This diagram shows the percentage composition of the food of different sizes of perch taken in all lakes in 1932. Compare with fig. 10.

Ambloplites rupestris

In 1931 insects were the most important food of the rock bass constituting about 43% and consisting of Diptera larvae (4.5%), ephemerid larvae (6.5%), caddis fly larvae (5%), dragon fly nymphs (11.5%), ants (4.5%), and miscellaneous insects (11%). The Diptera larvae were mostly Chironomus and Chaoborus and the Ephemerida were Hexagenia with some Coenis from Nebish Lake. Crayfish were the next important food, amounting to about 36% of the total. This percentage is rather high due to the fact that a few rock bass from some lakes had eaten largely crayfish. Fish constituted 8% of the total food.

In 1932 insects were also the principal food, making up 54% of the whole. They were similar to the 1932 foods, consisting of Diptera larvae (9%), Ephemerida nymphs (19.5%), caddis fly larvae (4%), dragon fly nymphs (13%), Sialis larvae (1%), ants (0.5%), and miscellaneous insects (7%). Fish were next (9%) with Entomostraca (8%) third in importance. Crayfish (6%) were not so important because fish were not taken from those lakes where crayfish seemed to be so abundant the previous summer.

It is evident from figures 3 and 7 that young rock bass eat largely insects which give way to fish and crayfish in the larger sizes. This change occurs around 140 mm. However, the rock bass caught in October from Nebish Lake (Fig. 4) give a different picture in regard to the type of food eaten, showing that there is a seasonal variation of food. Noteworthy is the large amont of Entomostraca eaten by those from 90 to 150 mm. in length and the increase of molluscs in the larger sizes. Seasonal investigations in other lakes of this district should reveal some interesting results.

Forbes and Richardson (1908) state that rock bass feed on insects and small crustaceans, with a few fish. Hankinson (1908) found that crayfish were the most important food of these fish in Walnut Lake, Michigan. Baker (1916) found crustaceans amounted to 75% of the food, the rest being insects and plants (including algae). Pearse (1915) showed that the food of young rock bass was largely insects and the adults mostly crayfish, although insects were important. Evermann and Clark (1920) examined 260 rock bass and found that those under four inches in length had eaten Entomostraca, a few insect larvae and small fish, while the larger ones ate crayfish and fish. Forbes (1880) mentions three small rock bass under one inch which contained Cladocera, Cyclops, Chironomus and Neuroptera larvae.

The food of the rock bass seems to depend upon the habitat of the fish. If it is in deep water, the foods will be much alike, consisting of bottom fauna. If in shallow water, there will be a greater variety, consisting of more insects (both surface and aquatic), crayfish, fish and other forms which are abundant in weed beds.

Helioperca macrochira

The food of bluegills is what one would expect from fish adapted for life among tall, aquatic plants. In 1931 the food of the bluegills of three lakes consisted of insects principally (65%). They were Diptera larvae (24%), Ephemerida nymphs (22.5%), caddis fly larvae (4%), dragon fly numphs (2%), ants (7%), and miscellaneous insects (5.5%). The diptera were mostly Chironomus and the ephemerids were Hexagenia. Plants constituted 10% of the food of the bluegills, but made up 30% of the food of those taken from Muskellunge lake. They consisted of a small amount of filamentous algae (Spirogyra and Vaucheria) but mostly fragments of leaves and terminal buds of large aquatic plants (Potamogeton and Elodea). The molluscs were all snails (Physa, Planorbis and Amnicola).

The 1932 bluegills were all taken from Muskellunge Lake and, as can be seen from Table II, their diet was about the same as that of the previous summer.

An interesting relationship between the plant and insect foods may be seen in Figure 8. Insects predominate except between 90 and 140 mm., where plants constitute the most important food. This is true only of the Muskellunge Lake bluegills, for those from Silver and Allequash lakes had eaten no plant food. Most of the bluegills from Muskellunge lake were from the South and West bays which were quite shallow, and aquatic plants were in great abundance.

Forbes (1880) found this species eating caddis fly larvae, dragon fly nymphs, amphipods, entomostracans and crayfish. Some fed largely on aquatic plants. Forbes and Richardson (1908) found the bluegill food to be 45% insects, some crustaceans, snails and a few fishes. Reighard (1915) found these fish eating largely plant material with many insects, bryozoans and a few hydrachnids and ostracods. He concluded as did

Forbes, that plants are a regular food and are not taken accidentally. Pearse (1915) found bluegills feeding mostly on insects (46.2%) and entomostracans (24.9%).

The food of the smallest bluegills consisted of small dipterous larvae (mostly Chaoborus and Chironomus) with a few entomostracans. Moore (1920), however, reports the food of fingerlings to consist of Cladocera, Copepoda, Ostracoda, chironomids and nymphs of damsel flies and may flies.

Micropterus dolomieu

In 1931 insects were the chief food of the small-mouthed bass, making up 47% of the diet, and fish were next (35%). The insects consisted of Diptera larvae (5%), Ephemerida (7%), caddis fly larvae (2.5%), dragon fly nymphs (3.5%), ants (10.5%), corixids (3%), and miscellaneous insects (15.5%). Hyalella was present as 3% and crayfish constituted 5% of the total food.

In 1932 fish were the main food (54%). Insects (25.5%) were next, consisting of Diptera larvae (1%), ephemerid nymphs (11.5%), caddis fly larvae (7%), dragon fly nymphs (2%), ants (6%), and miscellaneous insects (8%). Crayfish made up about 16.5% of the food.

In general the food of the small-muothed bass of this region is similar to that described by investigators of other regions. The young are not very well represented in this report but, from the few obtained, it was found that small insect larvae, small surface insects and Entomostraca form the main food. Insects continued to be an important food until the small-mouths were fairly large, at which time they were replaced by fish or crayfish. Crayfish seem to be a favorite food when available. In several lakes where crayfish were plentiful, they were an important item in the diet of the small-mouthed bass. More surface insects were found in this species of bass than in any other species of fish. They consisted of grasshoppers and ants, with lesser amounts of various other terrestrial insects. Although fish were important as food, no cases of cannibalism were noted; the fish eaten, consisted of darters, minnows and small perch. It is of interest to note that Corixidae, which have been reported as quite important as food of small-mouthed bass (Forbes—1880, Lydell 1904, and Pearse—1918 and 1921a) were not found in the specimens of this region although they were found in some of the lakes. One small specimen (60 mm.) from Star Lake had eaten three corixids and a small crayfish. The literature on foods of small-mouthed black bass is well summarized by Tester (1932).

Huro floridana

Adult large-mouthed black bass seem to be quite piscivorous; fish made up about 60% of its food in 1931. The largest ones ate almost entirely fish, but those around 100 mm. in length ate largely insects. The small one (about 50 mm.) ate Cladocera, with a few Cyclops and a few midge larvae.

The 1932 large-mouths were from Muskellunge Lake only and they had eaten almost entirely fish with a few plants; the latter were probably taken accidentally.

Fish and crayfish are reported by Forbes and Richardson (1908), Tracy (1910), Reighard (1915) and Evermann and Clark (1920) as the principal food of this fish. Hankinson (1908) found crayfish to be the most important food in Walnut Lake.

Although there were not sufficient quantities of the various sizes of bass studied to show definitely where the changes in diet occur, still it can be said in general that the food of the smallest sizes consists of entomostracans, changing to insects soon and finally to fish.

Stizostedion vitreum

The wall-eyed pike were all quite large and fed mostly on fish. In 1931 fish made up 85% of the diet, consisting of darters, minnows and perch. The insects were present as Diptera larvae (1%), Ephemerida (6%), Entomostraca (4%) and plant material (1%). In 1932 the food was fish (85%), Ephemerida (4.5%) and some caddis fly larvae, dragon fly nymphs, and crayfish. As can be seen from Tables I and II, fish made up the main food of the wall-eyed pike from all the lakes except Clear Lake. Here insects were an important item of food, even in the largest ones caught.

Forbes (1880) reports small pike eating entomostracans and small fish, and adults eating fish entirely. Forbes and

Richardson (1908) found fish the chief food along with a few crayfish. Pearse (1918 and 1921a) reports fish as the principal food with aquatic insect larvae occasionally found. Clemens *et al* (1924) found small pike (3 to 10 mm.) had eaten mostly Entomostraca, a few Chironomus larvae and a few fish. Those 10 to 40 mm. long had eaten largely Ephemerida nymphs (Hexagenia) and some Trichoptera larvae, with some fish scattered throughout. Those above 40 mm. ate fish entirely. Adamstone (1924) found fish usually as food but occasionally Ephemerida, Trichoptera and Odonata nymphs.

Cristivomer namaycush

The food of the lake trout was entirely fish, mostly ciscoes with a few suckers. No small ones were examined. Clemens *et al* (1924) found about the same food. Although the species of small fish eaten were more varied, ciscoes were the main food.

Esox masquinongy

The food of the muskellunge was found to be entirely fish, consisting of perch, darters, and chubs. No very small ones containing food were taken.

Leucichthys artedi

Ciscoes are preeminently plankton feeders. Tables I and II show that entomostracans were the principal food taken by them. Exception may be taken here to the ciscoes of Black Oak Lake in which Mysis was an important article of diet (40% Mysis and 41% entomostracans). Mysis has been reported by other investigators as a favorite food of ciscoes, but Black Oak Lake is the only one in this region in which this crustacean played an important rôle.

The 1931 ciscoes had eaten about 47.5% Cladocera, 34% Copepoda and small amounts of Diptera larvae. In the 1932 ciscoes, Cladocera made up 54.5%, Copepoda 25%, Ostracoda 2%, Mysis 10%, with small amounts of dipterous larvae.

Clemens *et al* (1924) found ciscoes feeding chiefly on *Mysis relicta* and, in smaller amounts, on *Limnocalanus macrurus*. Those taken in shallow bays fed on Daphnia and other plankton animals. Adamstone (1924) reported that bottom forms were eaten occasionally, especially by the younger specimens; these included mysids, amphipods, cladocerans, copepods, ostracods, chironomids, ephemerids, hydrachnids and molluscs. Rawson (1928) found that the ciscoes were essentially plankton feeders in Lake Simco, but they took some bottom forms also. The latter included emphemerids, chironomids, amphipods and oligochaets.

Coregonus clupeaformis

Whitefish were taken only in Trout Lake; they proved to be chiefly bottom feeders. The principal foods, in order of importance, were Diptera larvae, molluscs and Entomostraca. Included in the "miscellaneous" column of Table I is Mysis (11%). In the same column of Table II is Rotifera (14%) and Mysis (5%). Also there was a considerable amount of bottom débris consisting of ooze, plant fragments, pebbles, and some unidentifiable fish eggs.

Clemens *et al* (1924) state that the food of whitefish, in order of importance, was Pontoporeia, Chironomus larvae, molluscs and Ephemerida nymphs. Hart (1931) found the chief items of food of adults to be amphipods, molluscs and insect larvae. The food of young whitefish is reported to be Entomostraca by Forbes (1883) and Hankinson (1916). Hankinson (1911) records whitefish of Walnut Lake as eating mostly Chironomus larvae and Daphnia and he notes a seasonal variation.

Catostomus commersonii

Of the 1931 suckers, molluscs (39%) were the main food, with Diptera larvae (23%) second and Entomostraca (7%) third. Débris was 19%. In 1932 Diptera were 27%, molluscs 24.5% and Entomostraca 12%. Débris was 30%.

The sucker eats a larger variety of food than any other species examined. It is entirely a bottom feeder, which accounts for so much mud and bottom débris in its food. Pearse says, "the sucker is remarkable for the fineness of the food it is able to select. No other fish shows such a high percentage of protozoans, unicellular algae and rotifers in its food" (1915). Hankinson (1908) found the suckers in Walnut Lake eating caddis fly larvae, midge larvae and other insects, small bivalve molluscs, amphipods and Entomostraca. In Oneida Lake, Baker (1916) found that the suckers had eaten mud, plant remains, molluscs and insects. Bigelow (1924) found that the young suckers from Lake Nipigon were plankton feeders. Clemens *et al* (1924) state that, as the sucker grows, it takes more and more of the larger bottom organisms such as Chironomus larvae and later ephemerid nymphs, caddis fly larvae, molluscs, and amphipods. Algae and diatoms are also reported as being eaten.

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TABLE I

Percentage composition of food of different species of fish taken in various lakes in 1931.

	Number examined	Number containing food	Fish	Diptera larvae	Ephemerid nymphs	Caddis fly larvae	Dragon fly larvae	Sialis larvae	Ants	Corixids	Miscellaneous insects	Hydrachnida	Amphipods	Crayfish	Entomostraca	Mollusca	Plants	Miscellaneous
Trout Lake																		
Perch	160	96	36.0	4.5	9.0	16.0	+			0.5	3.5	+	2.0	16.0	4.0	1.0	2.0	4.5
Rock bass	38	32	13.5	1.	30.	4.5	5.		.5	1.	19.	2.		20.5	+		1.	3.
Cisco	81	69		11.5	+						1.	+	+		82.			5.
Whitefish	21	17		39.5	6.										2.	14.5		37.5
Black bass (s.m.)	10	10		37.5	13.5				.5		29.	.5	8.5		7.			4.5
Wall-eyed pike	30	14	96.		1.													2.5
Lake trout	15	7	100.															
Sucker	49	34		24.5	4.	7.5			+			.5	3.5		11.5	25.	1.5	23.
Nebish																		
Perch	109	94	2.5	25.	29.5	25.5	.5	+			+		8.5		1.5	5.5	+	2.5
Rock bass	184	122	3.5	43.5	17.	13.	1.5	+			3.5		2.5		7.5	5.	+	2.
Black bass (s.m.)	66	58	20.5	3.5	14.	25.	1.	1.5	6.5		9.5		1.		12.	1.5		3.
Weber																		
Perch	178	158	6.5	15.5	,	65.5	1.			+	2.		1.5		2.5	+	.5	5.

Black bass (s.m.)	29	24	6.	21.		2.			18.5		34.5				5.		1.	14.
Muskellunge																		
Perch	207	83	48.	6.	2.	5.5	1.5	1.			4.			1.	14.	2.	6.	9.5
Rock bass	338	189	22.5	4.	3.5	3.5	23.5	1.5	1.		3.5		.5	13.5		3.	11.	6.
Bluegill	225	206		21.	2.5		2.		16.5		7.5		2.5		+	8.5	30.	7.5
Cisco	82	80		4.						+		+			74.			20.5
Black bass (s.m.)	57	34	75.		1.5		2.5		.5		7.5					1.	11.	1.
Black bass (l.m.)	19	12	50.5	2.							4.		3.5		32.		1.5	7.5
Wall-eyed pike	1	1	100.															
Muskellunge	4	2	100.															
Sucker	53	34		23.5	1.					.5	1.	3.5	8.5		15.	12.5	8.5	26.
Clear																		
Perch	13	11	11.	2.5	61.5	6.	.5	14.			2.						1.5	
Rock bass	4	3		1.	12.5		24.							58.5				4.
Cisco	131	62		2.5	1.										96.5			
Wall-eyed pike	15	8	60.	3.	16.5										12.		4.5	5.
Black bass (s.m.)	2	1	100.															
Silver																		
Perch	176	103	6.5	6.5	16.5	11.5	15.5	+	.5	.5	3.5	.5	2.	11.	9.5	3.5	2.	8.
Rock bass	124	78	5.	.5	9.5	1.	25.	1.5	6.5	.5	7.	.5		35.5		+	1.	4.5

Bluegill	27	23		12.5	50.	2.5	3.5		5.		2.5	1.	13.5		2.	.5		6.
Cisco	42	39		.5											89.5			10.
Black bass (s.m.)	31	20	35.		9.5		20.		8.5		17.			9.5			1.	
Sucker	21	7		33.			3.5						1.		.5	43.5		28.
Crystal																		
Perch	9	5	56.5	26.5							5.5		1.		2.			8.
Black bass (s.m.)	4	4		15.	8.5				74.								3.5	
Star																		
Rock bass	1	1	20.								20.			30.			30.	
Black bass (s.m.)	1	1								50.				50.				
Rock																		
Perch	23	15	33.5	4.	4.	3.5	34.5	3.	.5	2.					+	.5	12.	3.5
Rock bass	4	4	24.5			8.5	12.		41.								4.	10.
Black bass (s.m.)	6	5	5.						37.		51.5						5.5	1.
Long Lake																		
Perch	98	58	5.	7.		15.	11.				4.5				43.5			15.
Black bass (l.m.)	3	3	50.								4.							46.
Vieux Desert																		
Perch	35	34	13.5	42.5	12.	17.					.5		7.5				4.	2.5
Jute																		

Black bass (s.m.)	28	20	83.5			4.5					8.5							2.
Allequash																		
Perch	3	2		50.									50.					
Rock bass	10	5												93.		2.	1.	3.
Bluegill	6	4		39.	15.	10.					6.5	3.	9.5		.5	9.		7.5
Starrett																		
Perch	4	2					51.5				17.			31.5				
Plum																		
Perch	15	12	31.5	3.5		9.5							.5	50.5		.5		3.
Rock bass	1	1												100.				
Larry																		
Black bass (s.m.)	14	10		2.5	37.5	6.5					15.		33.		2.		1.5	
Bear																		
Rock bass	12	6					37.5				3.			47.		3.5		9.
Black bass (s.m.)	1	1	100.															
Black bass (l.m.)	5	5	80.	10.			10.											
Arbor Vitae																		
Perch	8	8		4.5	5.						2.5		77.5					9.
Spider																		
Perch	32	25	25.	4.	4.						1.	1.5	5.	48.5		3.	4.	5.

Black bass (s.m.)	3	2							4.		23.			15.5				58.
Pallette																		
Perch	8	4	55.			4.	29.									13.5		
Rock bass	11	5				25.					67.					5.		3.
Cisco	23	16		3.5											89.			7.5
Black bass (s.m.)	16	10	58.5				4.5		7.5		28.				1.5			
Sucker	1	1		10.							10.				70.		10.	
Razorback																		
Black bass (s.m.)	18	12	39.5	6.	16.		23.5				7.5				2.			6.

TABLE II

Percentage composition of food of different species of fish taken in various lakes in 1932.

	No. examined	No. with food	Fish	Diptera larvae	Ephemerid nymphs	Caddis fly larvae	Dragon fly nymphs	Sialis larvae	Ants	Corixids	Miscellaneous insects	Hydrachnida	Amphipods	Crayfish	Entomostraca	Mollusca	Plants	Miscellaneous
Trout Lake																		
Perch	106	60	39.0	1.0	1.5	4.0	14.5		5.0		17.0		+	1.0		6.0	1.5	9.0
Rock bass	103	74	4.	.5	2.	+	10.		2.5		30.			36.5	.5			14.
Cisco	100	78		4.											89.5			6.
Whitefish	31	14	.5	28.5								1.		2.5	11.5	18.		39.5
Black bass (s.m.)	1	1												100.				
Lake trout	7	5	100.															
Wall-eyed pike	22	10	100.															
Sucker	40	27		22.		.5		1.5				+	2.		5.	39.5		28.5
Nebish																		
Perch	178	154	2.5	19.5	14.5	14.	4.	+			1.		10.5		21.5	5.		6.
Rock bass	209	170	7.5	46.5	24.5	4.5	1.	+			2.	+	1.		3.5	.5	+	6.
Rock bass (Oct.)	27	26	3.5			8.	6.5	9.			6.5	1.	.5		50.5	12.		2.
Black bass (s.m.)	42	30	41.	3.	5.5	40.	4.		2.5		1.5			+				2.
Weber																		

Perch	184	137	1.	30.5	+	45.5	.				3.	+	1.5		14.	.5		2.
Black bass (s.m.)	2	2	83.								17.							
Muskellunge																		
Perch	375	213	17.5	18.5	3.	4.	9.5	+			1.	1.	2.		15.5	5.	1.	21.
Rock bass	371	269	12.	10.5	19.	7.5	16.	+	.5	+	4.5	+	.5	5.5	+	.5	2.	20.5
Bluegill	94	82	.5	13.	1.	7.	2.5	+	2.5		3.5	1.5	6.		2.5	9.	34.	15.
Cisco	72	60		3.								+			96.5			1.5
Black bass (s.m.)	61	24	42.		5.		7.		11.		25.5				1.5		6.5	2.
Black bass (l.m.)	8	4	94.														6.	
Wall-eyed pike	1	1	100.															
Sucker	85	63		25.	3.	2.						1.	2.		20.5	8.5	.5	38.
Silver																		
Perch	273	144	90.	+	.5	+		+			+			1.5				
Rock bass	3	2	37.5				62.5											
Black bass (s.m.)	5	5	100.															
Sucker	8	7		35.							1.5	5	1.		9.5	25.5		25.
Clear																		
Perch	7	3				55.					10.					3.		
Rock bass	3	3			92.						5.					3.		
Cisco	94	78		.5											99.5			

Wall-eyed pike	23	19	40.5		57.5	1.	1.											.5
Black Oak																		
Cisco	71	65		3.5						1.5					41.		+	54.
Vieux Desert																		
Perch	76	70	6.	9.	3.5	18.5	.5			1.	.5	51.			+	4.5	.5	5.
Rock bass	2	2		4.		8.5						11.5						76.
Pallette																		
Black bass (s.m.)	30	19	58.5	3.		1.5	3.		23.5		4.5				2.5		1.5	2.5
Lost																		
Muskellunge	4	2	100.															
Wall-eyed pike	18	14	99.											1.				
Crane (Vandercook)																		
Perch	11	7	10.5		10.5						75.							4.

PHOTOSYNTHESIS OF ALGAE AT DIFFERENT DEPTHS IN SOME LAKES OF NORTHEASTERN WISCONSIN

I. OBSERVATIONS OF 1933

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From the Limnological Laboratory of the Wisconsin Geological and Natural History Survey. Notes and reports No. 59.

INTRODUCTION

Observations on the penetration of solar radiation into the waters of the inland lakes have been carried on more or less continuously by the Wisconsin Survey since 1900. In the earlier years, these studies were more closely related to the problem of the thermal changes which take place in lake waters and that of the annual heat budget; they also included the problem of the manner in which the heat is distributed to different strata in lakes.

At the same time, the question of the relation of solar radiation to the process of photosynthesis in the various aquatic plants at differen depths was kept in mind. No work was done on this problem, however, until the summer of 1932, when observations were made on the photosynthetic activities of two cultures of green algae and of a few of the large aquatic plants in three of the northeastern lakes. A preliminary report on the results obtained in these experiments has recently been published (Schomer 1934). These studies were continued during the summer of 1933 with the algal cultures and the present report is based upon the results obtained in this investigation.

METHOD

The general plan of the investigation was essentially the same as that of Marshall and Orr (1928). Algal cultures were placed in bottles and suspended at different depths from a buoy for a definite period of time and the quantity of oxygen produced during the interval was determined by a modified Winkler method. In some cases, hydrogen ion readings and carbon dioxide titrations were made.

Apparatus. The glass stoppered bottles had a capacity of about 150 cc and half of them were painted with a water-proof black paint so that they could be used as controls in determining the amount of oxygen used in respiration during the progress of the experiment. While suspended in the lake, these controls were also enclosed in black cloth bags in order to prevent the reflection of light from their surfaces.

The bottles were suspended in coarse mesh galvanized wire baskets which were large enough to hold four of them, two samples and two controls; duplicates were run at each depth. The buoy from which the bottles were suspended, consisted of two floats connected by a half-inch galvanized iron pipe about 3 m. long. The buoy was anchored in a north-south direction so that the shadows of the floats would not fall upon the algal cultures. The surface basket was attached to one of the floats by means of an adjustable supporting wire.

Cultures. Pure cultures of two species of algae were used for the experiments, namely *Coccomyxa simplex* and *Chlorella pyrenoides.* Several nutrient solutions containing carbohydrate compounds were tried, but it was not possible to produce sufficient quantities of the algae in these media under sterile conditions; the cultures became contaminated with fungi. Several mineral nutrient media were then tried and the following one proved to be very satisfactory for the cultivation of these two forms:

KH_2PO_4	2.72 grams
$MgSO_4$	4.93 grams
$Ca(NO_3)_2$	4.72 grams

These salts were dissolved in distilled water and made up to ten liters. A few drops of $FeCl_3$ solution were added to each liter. Abundant growths of these algae were obtained in a few days in this culture medium; the cultures were kept in large glass covered battery jars on an outdoor stand which was shaded by trees.

Procedure. The algae were removed from one liter of the culture medium by means of a centrifuge and they were then added to 4 l. of filtered surface water from Trout Lake; this water contains a good supply of raw materials necessary for photosynthesis. The mean free carbon dioxide content is 1.3 mg/1 and the bound carbon dioxide 18.8 mg/1; the Ca averages 9.6 mg/1, the Mg 6.4 mg/1 and the hydrogen ion pH 7.5.

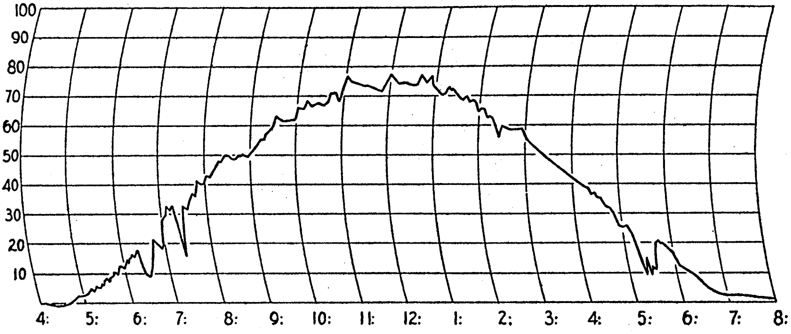
The algal suspension in the filtered lake water was thoroughly stirred and the bottles were filled; care was used in closing the bottles in order to avoid the inclusion of air bubbles. Two clear and two black bottles were then placed in each basket and the baskets were stored in a light-tight box, painted black on the inside, for transportation to the buoy where they were suspended; at the end of three hours, the cultures were taken up and the chemicals were added at once in the boat. In order to obtain the oxygen content of the samples at the beginning of the experiment, two control samples were taken along and the chemicals added to them at the time the cultures were suspended from the buoy.

The exposures were limited to three hours because gas bubbles were noted in some of the bottles when longer periods were used; this was true especially in the strata showing optimum photosynthesis. Samples of the algal suspension were removed at the time the bottles were filled and preserved for the purpose of enumerating the organisms.

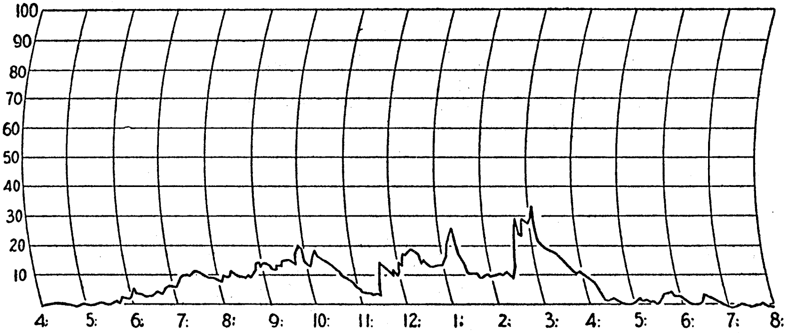
SOLARIMETER READINGS

In 1932, observations were made on the amount of solar and sky radiation delivered to the surface of the lake during the progress of the experiments on photosynthesis; this was done by taking solarimeter readings at regular intervals during each experiment. In 1933 however, a self-registering instrument was used, so that the total quantity of energy reaching the surface of the lakes during the experiments was obtained; this apparatus was also operated for periods of 12 to 24 hours. Some of the records are represented in Figures 1, 2 and 3.

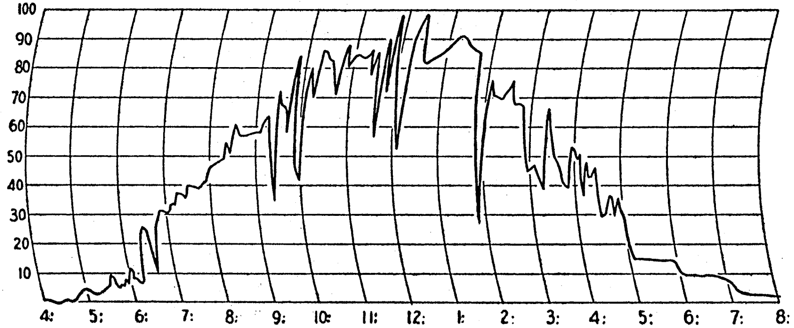
Figure 1 shows the results obtained on July 6, 7 and 9, 1933. On July 6, the sky was only slightly cloudy at times, while July 7 was a cloudy day. There was an alternation of clouds and sunshine on July 9; the highest reading of the summer was obtained about noon on this date. In Figure 2, August 2 was a cloudy day, while August 4 and August 5 had both clouds and sunshine. August 7 in Figure 3 was characterized by clouds and sun. On August 23 (Fig. 3), the sky was fairly clear until about 1:15 p.m., after which there was an alternation of clouds and sunshine; the experiment performed on this date was terminated soon after the clouds appeared.



JULY 6



JULY 7



JULY 9

FIG. 1. The curves in this figure show the amount of solar and sky radiation at Trout Lake on July 6, 7 and 9, 1933, between 4:00 a.m. and 8:00 p.m.

The solarimeter used in making these records was standardized against a Callendar pyrheliometer which has been in continuous use by the Weather Bureau at Madison, Wisconsin, for more than twenty years. This standardization made it possible to determine the quantity of radiation delivered to the

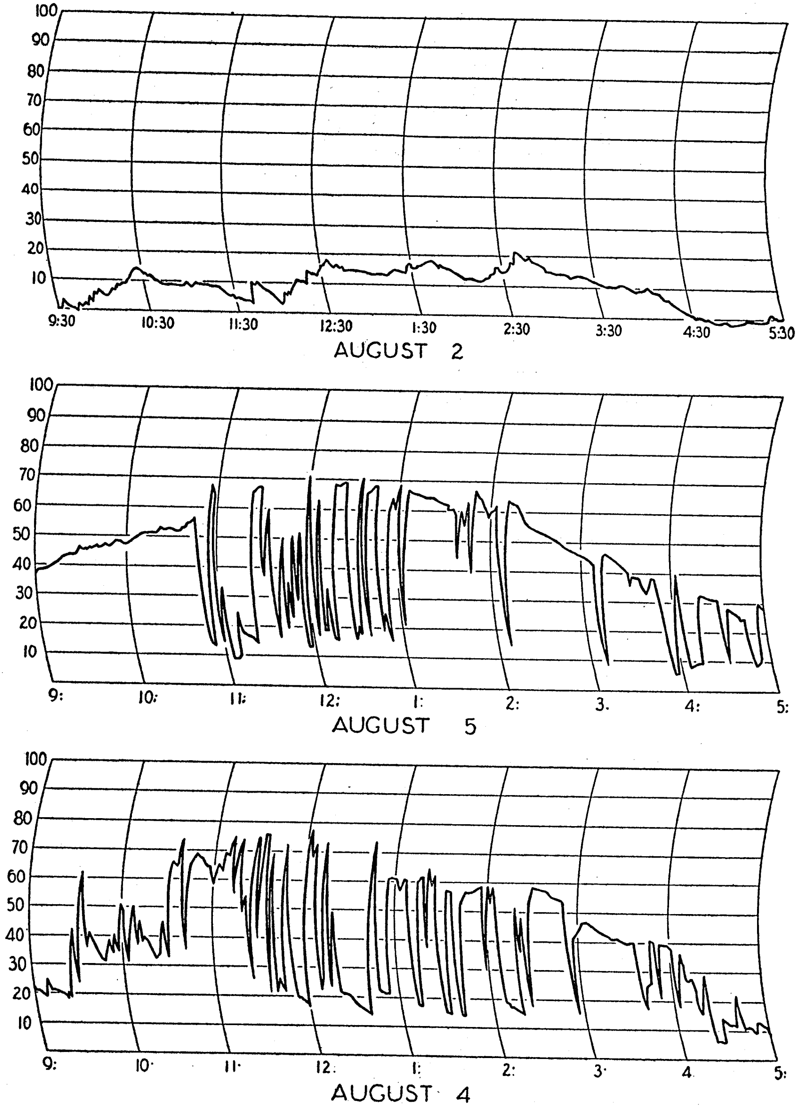
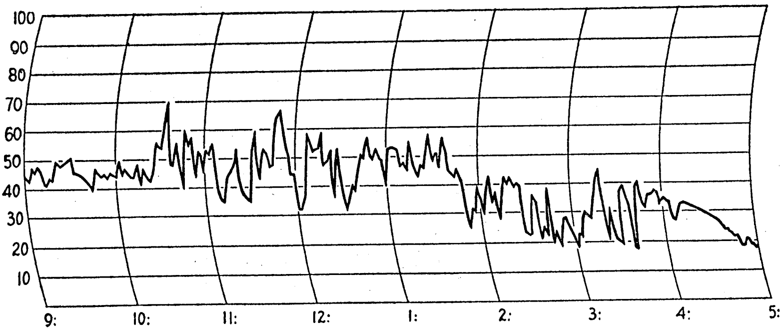


FIG. 2. The curves in this figure show the amount of solar and sky radiation at Trout Lake during a period of eight hours on August 2, 4 and 5, 1933.

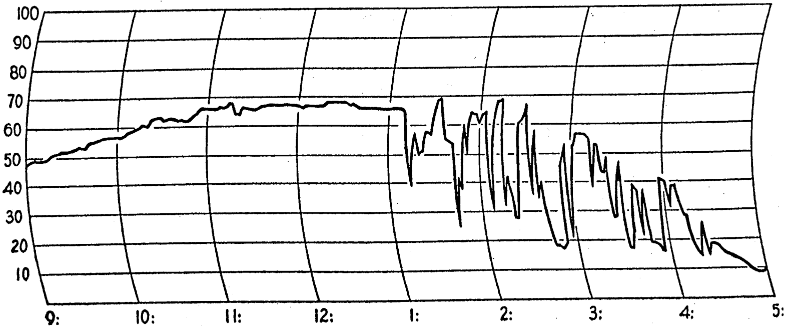
lake surface during any period of the day. The amount of this energy is indicated in terms of the unit employed by the United States Weather Bureau, namely the gram calorie per square centimeter per minute; for the sake of brevity, the word "calorie" is used in the following discussion instead of the complete expression.

Observations were made with a pyrlimnometer to determine the percentage transmission of the radiation to the various strata; from these results, the quantity of energy penetrating to the various depths has been computed.

For these experiments on photosynthesis, four lakes were selected which covered the range from very clear, transparent water, which transmitted the maximum amount of radiation, to that which has a deep brown color due to the presence of vegetable stains derived from peat and bog deposits and which cuts



AUGUST 7



AUGUST 23

FIG. 3. These curves show the amount of solar and sky radiation at Trout Lake on August 7 and 23, 1933.

off the solar energy very rapidly. On the platinum-cobalt scale, the brown color of these lake waters ranged from zero in Crystal Lake to 168 in Helmet Lake.

DATA OBTAINED

Crystal Lake

This lake has an area of 30.2 ha. and a maximum depth of 21 m. It has neither an inlet nor an outlet and the shores consist of sand. The water is very soft and transparent. A maximum disc reading of 13.6 m. has been obtained on this lake and the reading at the time of the experiment was 13.5 m. The water did not have any brown color whatever.

On August 4, 1933, a series of samples of *Coccomyxa simplex* was suspended at various depths down to 15 m. between 11:00 a.m. and 2:00 p.m. On August 5, cultures of *Chlorella pyrenoides* were used between 11:00 a.m. and 2:00 p.m.; this series extended to a depth of 20 m. A second series of Coccomyxa cultures was used on August 7 and it extended to a depth of 20 m. also; the time interval was 10:45 a.m. to 1:45 p.m. The solarimeter records for these three dates are shown in Figures 2 and 3.

The curves in Figure 4 show the results obtained in these three experiments; they are based on the quantity of oxygen produced per million cells of algae at the different depths. They indicate that the solar energy was too great in the upper water for maximum photosynthesis at the time of day and under the weather conditions which prevailed during these experiments. Thus there was a gradual increase in the oxygen production from the surface to a depth of 5 m. in two series and to 6 m. in the third. The maximum yield of oxygen on August 4 was 0.426 mg. per million cells, 0.528 on August 5 and 0.501 on August 7. (Table 1). Below these optimum depths, there was a gradual decline in the oxygen production with increasing depth; at 17 m. it had fallen to the point where the oxygen produced in photosynthesis was just equal to the amount consumed in respiration and decomposition. This depth is known as the compensation point. It is indicated by a plus sign in curves B and C; series A did not go deep enough to show this point. A certain amount of oxygen was produced below this depth, but the quantity was less than that consumed in respiration and decomposition. It may be noted in this connection, however, that three species of moss thrive on the bottom of Crystal Lake at depths of 18 to 20 m. (Juday 1934).

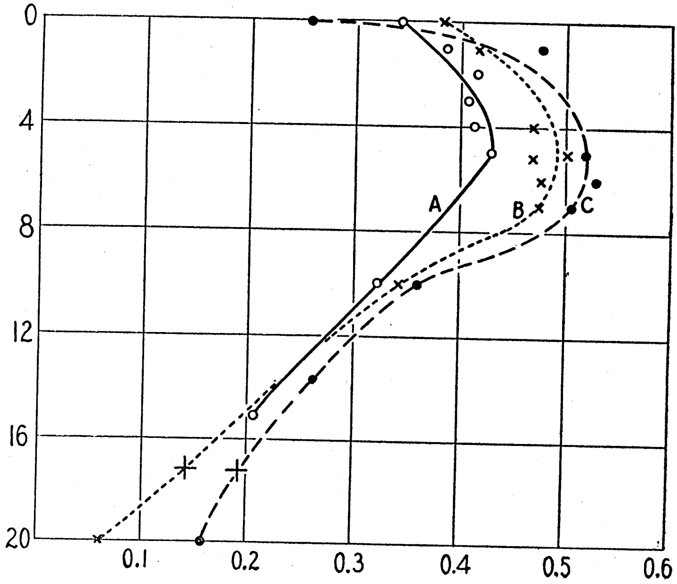


FIG. 4. Photosynthesis of algal cultures at different depths in Crystal Lake during three hour periods on August 4 (A), 5 (C) and 7 (B), 1933. Curves A and B represent *Coccomyxa simplex* and curve C, *Chlorella pyrenoides*. The curves show the amount of oxygen produced per million cells at the different depths.

The total quantity of solar energy delivered to the surface of Crystal Lake during the three hour periods of these experiments was as follows:—August 4, 124.9 cal.; August 5, 134.9 cal.; August 7, 141.4 cal. Pyrlimnometer readings taken on July 29 showed that 0.9 per cent of the solar energy delivered to the surface of the lake penetrated to a depth of 17 m., which was the compensation point. On this basis, 1.12 cal/cm^2 reached 17 m. during the three hour period on August 4, 1.21 cal. on August 5 and 1.27 cal. on August 7. Thus it required an average of 1.20 cal/cm^2 of solar energy during a period of three hours in the middle of the day to produce enough oxygen at 17 m. to balance the amount consumed in respiration and decomposition.

About 14.5 per cent of the solar radiation penetrated to a depth of 5 m. and 12 per cent to 6 m.; these are the two depths at which maximum oxygen production was found. In the 5 m. maxima for Coccomyxa, 18.1 cal/cm^2 reached this depth in three hours on August 4 and 20.5 cal. on August 7. For the Chlorella experiment on August 5, 16.2 cal. reached 6 m., the point of maximum oxygen production, in three hours. The radiation at 5 m. consisted of 16 per cent violet, 20 per cent blue, 27 per cent green, 23 per cent yellow, 10 per cent orange and 4 per cent red; thus 70 per cent of it fell in the blue-green-yellow part of the spectrum.

Table 1 shows that the temperature of Crystal Lake ranged from a maximum of 22.9° C. at the surface to a minimum of 11.3° at the bottom. The temperatures at the depths of optimum oxygen production were substantially the same as those at the surface. The differences in temperature at the different depths apparently had little effect upon respiration, so that the mean of the entire series of black bottles was used in each case in making a correction for the oxygen consumed in this process.

Trout Lake

Trout Lake has an area of 1,583 ha. and a maximum depth of 35 m. The water is usually slightly stained with vegetable extractives brought in by some of the tributary streams. The color of the surface water ranges from zero to 14 on the platinum-cobalt scale; it was 14 on August 29, 1933. The water is much less transparent than that of Crystal Lake; the disc readings in Trout Lake vary from 3.3 to 6.5 m., with a mean of 4.5 m. A reading of 5.9 m. was recorded on August 29, 1933.

Figure 5 shows the results obtained on August 23 and 28, 1933. Chlorella was used on the former date and Coccomyxa on the latter. The cultures were exposed from 10:45 a.m. to 1:45 p.m. on August 23 and from 11:25 a.m. to 2:25 p.m. on August 28. Figure 3 shows the solar energy record for August 23; on this date the sky was clear until about 1:15 p.m., with alternating clouds and sunshine during the remainder of the afternoon. Thus the three hour experimental period extended into the partly cloudy time only about half an hour. There was an unusual drouth during the summer and this was accompanied by many forest fires in the month of August, so that the air contained varing amounts of smoke during this time. This smoke reduced the amount of radiant energy that reached the surface of the lake; on some days, in fact, the smoke was so dense that it caused a very material reduction in the radiation.

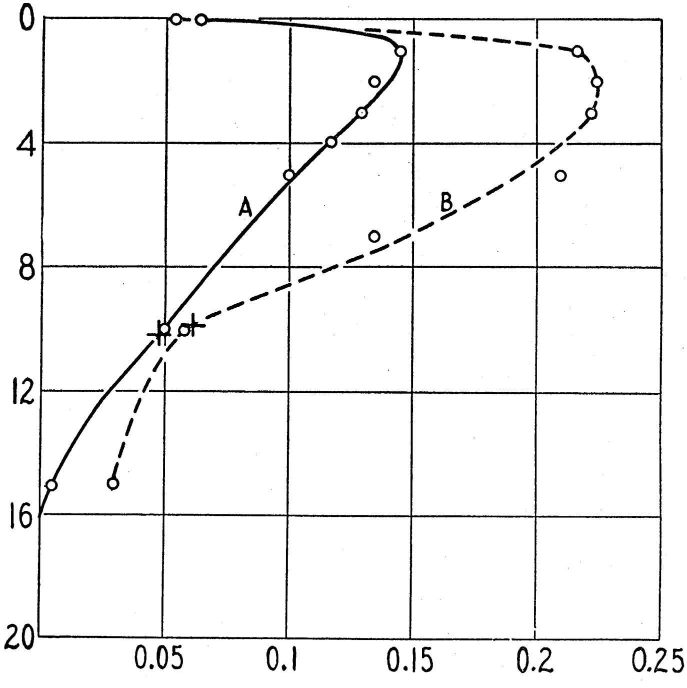


FIG. 5. Photosynthesis of algal cultures at different depths in Trout Lake during three hour periods on August 23 (B) and 28 (A), 1933. Curve A represents *Coccomyxa simplex* and curve B, *Chlorella pyrenoides*. The curves show the amount of oxygen produced per million cells at the different depths.

Curve A of Figure 5 represents the results obtained with Coccomyxa cultures on August 28. The maximum oxygen production was found at 1 m., namely 0.145 mg. per million cells. The compensation point fell at 10. m. Curve B indicates the oxygen yield of Chlorella on August 23. The oxygen production was larger on this date than on August 28; this was accounted for in part, at least, by a larger amount of solar radiation on the former date. A total of 190.4 cal. reached the surface of Trout Lake during the three hour period on August 23 and only 122.1 cal. on August 28.

The maximum production of oxygen was noted at 2 m. on August 23 and it amounted to 0.225 mg. per million cells. Substantially the same quantity of oxygen was produced at 3 m.; in fact, there was very little difference in the yields at 1 m., 2 m. and 3 m. (Table I). The compensation point for both series of algae was found at 10 m.

About 28 per cent of the solar energy incident on the surface of Trout Lake during mid-day penetrates to a depth of 1 m., 17 per cent to 2 m., 11.2 per cent to 3 m. and 1 per cent to 10 m. On this basis, the quantity of solar energy reaching the various depths during the three hour experimental period was as follows: —August 23, 53.3 cal/cm^2 at 1 m., 32.4 at 2 m., 21.3 at 3 m. and 1.9 at 10 m.; August 28, 34.2 at 1 m., 20.7 at 2 m., 13.7 at 3 m. and 1.22 at 10 m.

The maximum oxygen production of Chlorella at 2 m. in Trout Lake on August 23 was correlated with 32.4 cal., while that at 6 m. in Crystal Lake on August 5 was correlated with 16.2 cal., or just half as much solar energy. Furthermore, the oxygen production in Crystal was more than twice as great as that in Trout, namely 0.528 mg. per million cells in the former and 0.225 mg. in the latter. A similar difference was noted in the Coccomyxa cultures. The maximum of 0.145 mg. per million cells at 1 m. in Trout Lake on August 28 was correlated with 20.7 cal., while those at 5 m. in Crystal Lake, 0.426 and 0.501 mg., were correlated with 18.1 and 20.5 cal. on August 4 and 7, respectively.

The total energy delivered to the compensation depths in three hours was not very different, however; it was 1.56 cal. at 10 m. in Trout Lake and 1.20 cal. at 17 m. in Crystal Lake.

At 1 m. in Trout Lake, the percentages of radiation belonging to the different parts of the spectrum were as follows:—violet 9 per cent, blue 17, green 18, yellow 21, orange 20 and red 15.

Three series of experiments were run in the upper 5 m. of Trout Lake on August 24, 1933; they began at 7:30 a.m. and were continued until 4:30 p.m. (Table I). Coccomyxa cultures were used for the three series. A maximum oxygen production of 0.221 mg. per million cells was obtained at 2 m. in the first series in the period from 7:30 to 10:30 a.m. In the mid-day series, 10:30 a.m. to 1:30 p.m., the maximum yield was 0.242 mg. per million cells at 3 m.; in this series, however, there was very little difference in the yield between 1 m. and 4 m. The largest production in the 1:30-4:30 p.m. series was found at 1 m.; it amounted to 0.233 mg. per million cells. None of the series went deep enough to determine the compensation point. It is interesting to note that the yield of the surface samples was smallest in the mid-day series; it was less than half as much as that of the afternoon series.

The amount of solar energy delivered to the surface during each of the experiments was smallest in the forenoon series and largest in the mid-day series; it amounted to 70.9 cal. in the former and 176.8 cal. in the latter series.

Two series were run on August 26; the first one covered the period from 8:45 to 11:45 a.m. and the second from 2:00 to 5:00 p.m. The largest production of oxygen in the forenoon series was 0.300 mg. per million cells at 2 m. and in the afternoon series 0.257 mg. at 3 m.

Mud Lake

This is a small body of water with an area of only 5.48 ha. and a maximum depth of 15.7 m. It has neither an inlet nor an outlet, so that the water is soft; the specific conductance of the surface water averages about 16×10^{-6}. The shores are somewhat boggy in places and the water receives a certain amount of brown vegetable stain from these bog areas; as a result the water has a color of 33 on the platinum-cobalt scale. The transparency is rather low; the disc reading was 1.9 m. on August 14, 1933.

A series of Chlorella cultures was suspended in Mud Lake on August 15, 1933, from 11:45 a.m. to 2:45 p.m. and one of Coccomyxa culture on August 19, from 11:10 a.m. to 2:10 p.m. Both species of algae yielded substantially the same amounts of oxygen in the upper 2 m. as shown in the curves of Figure 6, but Chlorella gave a somewhat larger yield between 2 m. and 10 m. The optimum production was found at 0.5 m.; the amount produced at this depth was 0.329 mg. per milllion cells on August 15 and 0.324 mg. on August 19. (Table I). The compensation point fell at the same depth for both series, namely 4.5 m.

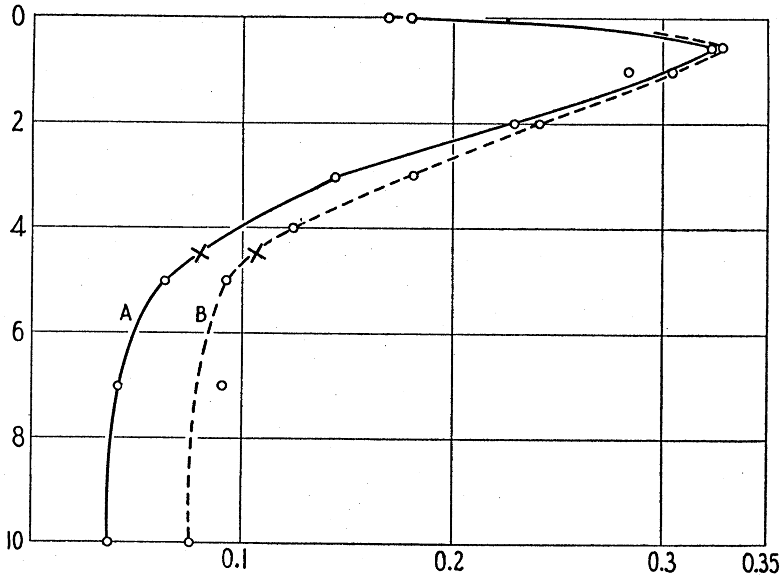


FIG. 6. Photosynthsis of algal cultures at different depths in Mud Lake during three hour periods on August 15 (B) and 19 (A), 1933. Curve A represents *Coccomyxa simplex* and curve B, *Chlorella pyrenoides*. The curves show the amount of oxygen produced per million cells at the different depths.

Pyrlimnometer readings taken on August 14 showed that 22.5 per cent of the radiation incident on the surface of Mud Lake penetrated to a depth of 0.5 m., which was the depth of maximum oxygen production; only 13 per cent of this energy was left at 1 m., 3.7 per cent at 2 m. and 0.4 per cent at 4.5 m. The total radiation incident on the surface during the three hour period on August 15 was 191.0 cal/cm^2 and 207.2 cal. on August 19. On August 15, therefore, about 43.0 cal. of this energy reached a depth 0.5 m. and only 0.76 cal. penetrated to 4.5 m.; on August 19, the respective amounts were 46.6 cal. at 0.5 m. and 0.83 cal. at 4.5 m.

Helmet Lake

This is a typical bog lakelet; it has an area of 3.0 ha. and a maximum depth of 10.4 m. There is no inlet or outlet and the water is soft; the specific conductance was 19×10^{-6} on August 8, 1933. It has boggy shores and the water is deeply stained with vegetable extractives derived from the peat. On August

11, the color of the surface water was 168 on the platinum-cobalt scale. In some years the water is more highly colored; a maximum reading of 268 was obtained in 1930. The transparency is low also; the disc reading on August 8, 1933, was 1.5 m. Readings as low as 0.8 m. have been obtained in other years.

Five series of cultures were used in Helmet Lake and the results for three of them are shown in the curves of Figure 7. On August 10, the Coccomyxa cultures were exposed from 11:25 a.m. to 2:25 p.m. On August 11, Chlorella cultures were used from 10:45 a.m. to 1:45 p.m. and Coccomyxa again from 11:25 a.m. to 2:25 p.m. on August 14. The curves in Figure 7 show that there was a marked difference in the quantity of oxygen produced in these three experiments.

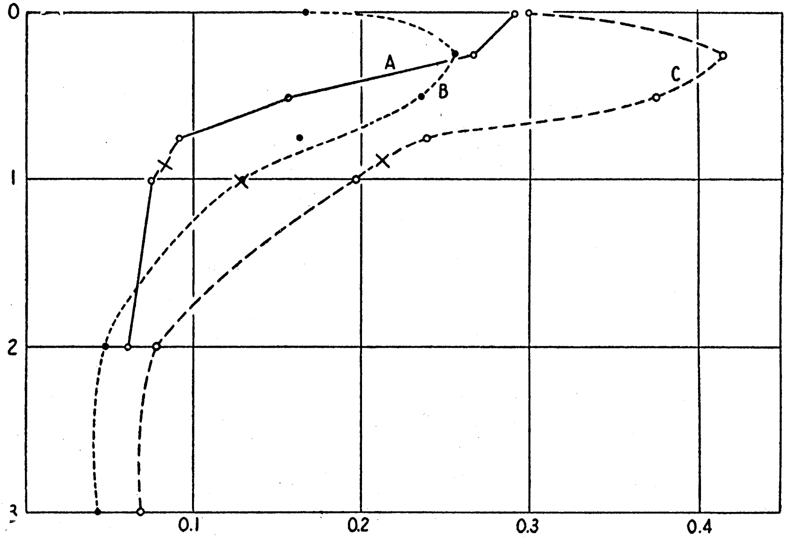


FIG. 7. Photosynthesis of algal cultures in Helmet Lake during three hour periods on August 10 (A), 11 (B) and 14 (C), 1933. Curves A and C represent *Coccomyxa simplex* and curve B *Chlorella pyrenoides*. The curves show the amount of oxygen produced per million cells at the different depths.

On August 10, the sky was overcast and it rained while the experiment was in progress. The results for this series are shown in curve A. As might be expected under these weather conditions, the maximum production of oxygen was found in the surface sample; it amounted to 0.298 mg. per million cells for the three hour period. There was a rapid decline in oxygen production below the surface; by far the greater part of the decrease was noted between 0.25 and 0.75 m. The compensation point was found at 1 m. The solarimeter was not in operation on this day, so that the amount of radiation reaching the surface of the lakelet was not determined.

The Chlorella culture gave a maximum yield of oxygen at a depth of 0.25 m. on August 11; it was 0.254 mg. of oxygen per million cells for the three hour period. (See curve B in Figure 7). Below this depth the production decreased rapidly to the compensation point at 1 m. The radiation delivered to the surface of the lakelet during this experiment amounted to 191.1 cal/cm^2 and 14 per cent penetrated to a depth of 0.25 m., the depth of maximum photosynthesis; this was equivalent to 26.7 cal. in three hours. The maximum oxygen yield in this series was somewhat smaller than that of the surface sample on August 10.

The optimum oxygen production on August 14 was obtained at 0.25 m., but it was larger than in the other two series, namely 0.413 mg. per million cells. (Curve C in Figure 7). The solar energy reaching the surface of Helmet during the experimental period on this day amounted to 236.3 cal. and 33.1 cal. penetrated to 0.25 m. This is approximately 25 per cent more solar energy than reached this depth on August 11; the oxygen yield, on the other hand, was about 60 per cent larger on August 14 than on August 11.

The compensation point was situated at a depth of 1 m. in the three Helmet Lake experiments. The amount of solar energy reaching this depth in three hours was 2.86 cal. on August 11 and 3.54 cal. on August 14. These quantities were considerably larger than those found at the compensation points in the other three lakes; in the latter, the amounts ranged from a minimum of 0.76 cal. in one series of Mud Lake to a maximum of 1.90 cal. in a Trout Lake series. In such highly colored water as that of Helmet Lake, more than 80 per cent of the energy penetrating to a depth of 1 m. falls in the orange-red part of the spectrum and apparently it is not as effective in the process of photosynthesis.

UTILIZATION OF SOLAR RADIATION IN PHOTOSYNTHESIS

The oxygen production gives a basis for the computation of the percentage of energy utilized by the algae in the process of photosynthesis; the oxygen yield per square centimeter of cell surface at the different depths is readily converted into terms of glucose with a combustion value of 3760 calories per gram.

In Crystal Lake, the percentage of energy utilized by the algae gradually increased from about 0.5 per cent at the surface to a maximum of 9.2 per cent of that penetrating to a depth of 10 m. It ranged from 0.05 per cent at the surface in Trout Lake to a maximum of 4.3 per cent at 7 m. in the Chlorella series and from 0.09 per cent at the surface to 6.2 per cent at 10 m. in the Coccomyxa series.

The highest percentage of utilization was found in the highly colored water of Helmet Lake. In the Chlorella series of August 11, it ranged from 0.16 per cent at the surface to 9.5 per cent at 1 m. and in the Coccomyxa series of August 14, from 0.23 per cent at the surface to 11.3 per cent at 1 m. In the Chlorella series, the utilization declined to 4.6 per cent at 2 m. and in the Coccomyxa series of August 14, from 0.23 per cent at the surface to 11.3 per cent at 1 m. In the Chlorella series, the utilization declined to 4.6 per cent at 2 m. and in the Coccomyxa series to 6.3 per cent at 2 m.

RESULTS OF OTHER INVESTIGATORS

Gaarder and Gran (1927) used marine plankton rich in diatoms in some photosynthesis experiments at various depths in the latter part of March; they obtained substantially the same results at 2 m. as at the surface and the 5 m. sample was only 5-10 per cent below the maximum. The compensation point was reached at 10 m.

Marshall and Orr (1928) made a large number of experiments on the photosynthesis of diatom cultures suspended at different depths in the sea at the Millport Marine Station. Since the methods employed in the Wisconsin investigations were substantially the same as those of these investigators, some direct comparisons of results can be made. Marshall and Orr found a maximum oxygen production of 0.393 mg. per million diatom cells at 6 m. on June 10, 1927, from 12:00 to 2:57 p.m. and a maximum of 0.404 mg. was noted at 2 m. on the same date in the 3:00-5:55 p.m. series. A somewhat larger maximum was obtained at 2 m. in a 9:00-12:00 a.m. series on June 28, namely 0.422 mg. per million diatom cells. The light intensity was much greater, however, on June 10 than on June 28; on the former date, 390.4 mg. of oxalic acid were decomposed during the three hours of the experiment and only 119.8 mg. in the experimental period on the latter date.

In comparison with this, a maximum oxygen production of 0.426 mg. per million Coccomymxa cells was obtained at 5 m. in Crystal Lake from 11:00 a.m. to 2:00 p.m. on August 4, 1933 and one of 0.528 mg. per million cells of Chlorella at 6 m. during the same period on August 5. The total quantity of solar energy delivered to the surface of the lake was much the same on the two days, namely 124.9 cal/cm^2 during the three hours of August 4 and 134.9 cal/cm^2 during that of August 5.

Marshall and Orr found maximum oxygen production at the surface on dark days, but at depths of 2 m. to 6 m. on bright days, especially in summer. Similar results were obtained on Crystal and Trout lakes, but the maximum yield was found at 0.5 m. and 0.25 m. in the colored waters of Mud and Helmet lakes. They also found that the light intensity was too great on bright days in winter for maximum oxygen production at the surface. The compensation depths in their experiments fell in the 20-30 m. stratum in mid-summer. In the Wisconsin lakes it ranged from a maximum of 17 m. in Crystal Lake to a minimum of 1 m. in Helmet Lake.

Nielsen (1933) experimented with natural plankton and found that the oxygen production was substantially the same at 0.2 m. and at 2 m. The compensation point was reached at a depth of 7 m. in his experiments. This is not as deep as the compensation points in Crystal and Trout lakes, but deeper than those of Mud and Helmet lakes.

Kurasige (1932) studied the photosynthesis of natural plankton consisting chiefly of Melosira and Synedra; the experiment was performed out of doors in the latter part of March, using a 40 l. aquarium. The diatoms produced 0.515 mg. of oxygen per million cells per day at a temperature of 8-16° C., when the total radiation was about 500 cal/cm^2. He found a linear relation between oxygen production and the amount of solar radiation. The oxygen production decreased between 11:00 a.m. and 3:00 p.m., thus showing that the sunlight was too intense for optimum photosynthesis during this period.

SUMMARY

1. The photosynthesis of two species of algae at different depths in four lakes was determined by measuring the quantity of oxygen produced.

2. Maximum oxygen production was found at the surface on dark, cloudy days, but at a certain distance below the surface on bright, clear days.

3. The depth of the maximum production on clear days depended upon the transparency and color of the water.

4. The depth of the compensation point, where the quantity of oxygen produced by photosynthesis just balanced that consumed in respiration, also varied with the transparency and color of the water.

5. The amount of solar energy penetrating to the various depths was determined.

6. The percentage of utilization of solar radiation by the algae increased with increasing depth, reaching a maximum where the total radiation varied from 1.2 to 8 cal/cm^2 in a three hour period.

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TABLE I

Several series of experiments on photosynthesis are given for 1933. Solar energy is expressed in gram calories per square centimeter for the three hour period in each case and the oxygen is indicated in milligrams per million cells for the three hour interval.

Lake	Date	Hours	Depth in meters	Temper ature °C.	Solar energy	Organ-ism	Oxygen produced
Crystal	Aug. 4	11:00- 2:00	0	22.8	124.9	Coccomyxa	0.342
			1	......	....	“	0.385
			2	......	....	“	0.415
			4	......	....	“	0.411
			5	......	....	“	0.426
			7	22.6	....	“	....
			10	15.9	....	“	0.321
			15	12.0	....	“	0.205
	Aug. 5	11:00- 2:00	0	22.9	134.9	Chlorella	0.256
			1	......	....	“	0.476
			4	......	....	“	0.508
			5	22.7	....	“	0.515
			6	......	....	“	0.528
			7	22.4	....	“	0.504
			10	15.6	....	“	0.359
			20	11.3	....	“	0.158
	Aug. 7	10:45- 1:45	0	......	141.4	Coccomyxa	0.380
			1	......	....	“	0.416
			4	......	....	“	0.467
			5	......	....	“	0.501
			6	......	....	“	0.477
			7	......	....	“	0.475
			10	......	....	“	0.343
			20	......	....	“	0.058
Helmet	Aug. 10	11:25- 2:25	0	24.9	....	Coccomyxa	0.298
			0.25	......	....	“	0.266
			0.50	......	....	“	0.157
			0.75	......	....	“	0.093
			1	23.2	....	“	0.075
			2	20.7	....	“	0.067
	Aug. 14	11:25- 2:25	0	......	236.3	Coccomyxa	0.299
			0.25	......	....	“	0.413
			0.50	......	....	“	0.372
			0.75	......	....	“	0.238
			1	......	....	“	0.196
			2	......	....	“	0.076

(Table I Continued)

Lake	Date	Hours	Depth in meters	Temperature C.	Solar energy	Organism	Oxygen produced
Trout	Aug. 23	10:45 1:45	0	19.5	190.4	Chlorella	0.053
			1	......	....	“	0.216
			2	......	....	“	0.225
			3	......	....	“	0.223
			5	......	....	“	0.210
			7	19.5	....	“	0.135
			10	19.5	....	“	0.051
			15	8.2	....	“	0.031
	Aug. 24	7:30 10:30	0	......	70.9	Coccomyxa	0.116
			1	......	....	“	0.191
			2	......	....	“	0.221
			3	......	....	“	0.174
			4	......	....	“	0.152
			5	......	....	“	0.107
		10:30- 1:30	0	......	176.8	Coccomyxa	0.065
			1	......	....	“	0.238
			2	......	....	“	0.232
			3	......	....	“	0.242
			4	......	....	“	0.234
			5	......	....	“	0.209
		1:30- 4:30	0	......	85.6	Coccomyxa	0.153
			1	......	....	“	0.233
			2	......	....	“	0.174
			4	......	....	“	0.152
			5	......	....	“	0.124
	Aug. 26	8:45 11:45	0	......	86.0	Coccomyxa	0.206
			1	......	....	“	0.296
			2	......	....	“	0.300
			3	......	....	“	0.266
			4	......	....	“	0.238
			5	......	....	“	0.189
			10	......	....	“	0.045
		2:00- 5:00	0	......	127.7	Coccomyxa	0.103
			1	......	....	“	0.230
			2	......	....	“	0.240
			3	......	....	“	0.257
			4	......	....	“	0.219
			5	......	....	“	0.175
			10	......	....	“	0.035
			15	......	....	“	0.029

THE COURSE AND SIGNIFICANCE OF SEXUAL DIFFERENTIATION

CHARLES E. ALLEN

In the most nearly primitive condition that we can now envisage with certainty living matter existed in the form of cells, isolated or temporarily in contact; many organisms still extant are in this respect relatively primitive. Cells increased in number by division—the simplest and doubtless the original method of division being that of a single cell into two similar daughter cells. In case the parent cell was differentiated into cytoplasm and nucleus—as are cells of the great majority of present-day types—its division was necessarily preceded by a division of the nucleus.

Cell division was, therefore, so far as can now be determined, the original method of reproduction. It remains the basic reproductive process in all living organisms. For a cell aggregate or a multicellular organism consists of cells owing their origin ultimately to division of the cells of the parent organism or organisms, and so on indefinitely backward.

In contrast to the increase in number of cells by division, a reverse process is possible—the union of two or more cells into one. As illustrated, for example, in some flagellates and rhizopods, the union of two cells without walls which have come in contact is superficially very like the union of two drops of water when they touch into one drop. Actually, of course, the union of protoplasts must be a much more complex procedure than this; but the similarity is striking and probably not without significance. If the uniting cells are delimited by walls, as is true of the anastomosing cells of some fungi, the additional step is involved of a dissolution of the walls in the region of contact.

The possibility of cell union, manifested in various widely separated groups of organisms, offers a suggestion as to how a new evolutionary departure may have occurred. This departure involved the union not only of two cells but also of their nuclei. Cells which thus united in pairs were *gametes*; the single-nucleate cell formed by their union was a *zygote*. Whether or not the new step first occurred, as it were, by chance, a union of nuclei following upon a casual union of cells, can not now be said. But it is certain that, once brought about, gametic union opened the way to most far-reaching consequences. Its central importance lay in the facts that it brought two distinct and usually different sets of hereditary substances into a new combination, and that it necessitated sooner or later a reshuffling of those substances into still other new and varied groupings. By these means novel possibilities of hereditary variation were introduced, and new raw material was provided for the evolutionary process.

However it first came about, and whether once or, as is most probable, many times in different lines, the union of gametes became an established habit—a habit fixed, it may be imagined, in consequence of the advantages enjoyed by those organisms which had developed the new possibility. It became and remained a definite part of the life cycle, not only of many relatively simple organisms, but of those lines which were to lead to the more complex or "higher" groups of animals and plants. True, gametic union has dropped out of the life cycles of individual species in various of these higher groups; but such union is still of nearly universal occurrence save in a very few lowly assemblages.

Many one-celled and simple colonial plants still living retain what must be considered the original type of gametic union, in which the gametes are, to all appearance, substantially alike. In some instances these like gametes are ordinary vegetative cells that, under particular conditions, assume the gametic function; in other cases they are smaller, having been produced by a division or a series of divisions of a vegetative cell.

But among simple plants are others, often closely related to some of those just mentioned, which produce two sets of visibly different gametes. The differentiation of two kinds of gametes constituted another significant innovation. Like gametic union, gametic differentiation became a habit fixed in the genetic constitution of the species concerned. We may not explain in causal terms the occurrence of this type of differentiation; a possible guess is that it expressed a tendency inherent in the constitution of living matter which, once a certain degree of evolutionary development was reached, found expression. But while the causative explanation escapes us, it is easy to perceive the advantage that a species derived from the differentiation of two classes of gametes. This advantage followed from the fact that, gametic union being an established habit and its periodic occurrence a matter of vital import to the species, the gametes were burdened with two distinct functions: one to come into contact, the other to provide for the zygote the food needed by it for its own activities, including division or "germination," and by the cells to be formed when it divides.

The ancestral lines of most animals and plants converge in the flagellates—organisms which during at least a considerable part of their existence are single motile cells. Therefore, motility was an original property of gametes, if and when gametic union was established at the flagellate level of evolutionary development; or, if at a somewhat higher level, the production of motile gametes involved that of cells representing the persistence of a not very distant ancestral condition. In general, therefore, the coming together of gametes was provided for by their motility—together, of course, with the development of the power of response by movement toward the source of a stimulus emanating from another gamete of the same species. The provision of food to be stored in and carried by the gametes also implied no new development; merely some extension of a process of food-manufacture already in possession and essential to the existence of the species.

But, even at a low level of development, these two functions necessary to the success of gametic union were measurably in conflict. The storage of food within a gamete tended to an increase in size, rendering it less suited to active movement. The difficulty was increased if, as in many algae and fungi, the zygote was to pass into an extended dormant period during which its continued existence would be dependent upon stored food; or if, as in the lines that led to "higher" plants and animals, the germination of the zygote was to be followed by an embryonic phase in the development of a new generation.

Even in many comparatively simple organisms, then, the inconsistency between two duties to be performed by the gametes made itself felt. The inconsistency was avoided, as many difficulties in more familiar stages of development have been avoided, by a division of labor. One gamete, assuming the function of food-carriage, became larger, less motile, and ultimately quite non-motile. It is henceforth distinguished as the *female* gamete. The other, the *male* gamete, remaining small or even becoming smaller, carried only the food supply needed in its own brief existence, and continued motile or even became capable of greater activity.

It was said that gametic union probably became established independently in different lines as a regularly recurrent process. It is certain that gametic differentiation has occurred independently in many diverse lines of animals and plants. If the illustrations here cited of this differentiation are taken from the plant kingdom, it is because many plants, particularly algae, still survive which illustrate steps in the increasing differentiation of the gametes; whereas among animals, even including protozoa, the early chapters of this history are but sparsely represented.

In selecting species illustrative of the sequence in question, a caution necessary in dealing with most evolutionary series must be kept in mind; namely, that a species now living which represents stage *A* is not likely to be directly ancestral to another contemporary species representing stage *B*. Rather, the former species presents, with reference to a particular evolutionary process, a condition essentially similar to one through which, it may reasonably be concluded, passed the ancestors of the second species. The relationship between such living species, if any, is ordinarily collateral, not lineal.

With the progress of sexual differentiation the female and male gametes came to differ both in structure (including size) and in behavior. Only one of these differences may be apparent at a very early stage in differentiation. Thus the gametes of Ectocarpus, a widespread genus of brown seaweeds, are alike in structure and size but different in behavior. In Giffordia, however, a close relative, the gametes have come to differ in size as well as in behavior.

Sex—the occurrence of sexual differentiation—thus arose as an adaptation to needs that resulted from the adoption of the habit of gametic union. Sex is not a primitive characteristic of living matter. It constitutes an adaptation that occurred at periods long subsequent to the first appearance of living matter upon our planet. This adaptation was itself the beginning of a long developmental history, destined to extend far beyond the gametes in which it first appeared, and to affect in different ways and in varying degrees the structures and functions of the organisms producing the gametes.

The appearance of, and the progressive increase in, differences between female and male gametes, may be considered the first chapter of sexual differentiation; the female becoming many times, often thousands of times, as large as the male and quite passive; the male gamete, in most groups, remaining extremely active. In this latter respect, however, some interesting divergences appear; as in the red algae, whose male gametes, while very small, are non-motile; their movement to the neighborhood of the female gametes is effected by currents of the water in which the plants are submerged.

By a second series of steps, there came about a differentiation of the organs in which the gametes are produced. Distinct female and male organs are to be found in many algae; more highly specialized structures of these classes appear in liverworts, mosses, and ferns.

In the third phase of this history, differentiation extended to structures other than the organs in which gametes were formed; particularly, as in mosses, to such structures as leaves in the immediate neighborhood of the gamete-bearing organs, or the branches on which these organs are borne. The extreme of this type of differentiation is found in those species in which female and male gametes are formed by separate organisms (whether plant or animal). This latter degree of sexual separation, also, has been brought about independently in different lines; and it is notable that in various of the larger groups of plants some species retain the power of producing both kinds of gametes on the same plant, whereas in other species, often within the same genus, the possibilities of such production are more or less sharply separated; in the latter species some individual plants are male, others female. In certain cases the female and male plants have become greatly different; the male plant being usually much smaller than the female, as well as more or less divergent in structure. The climax in this direction is illustrated by some species of Oedogonium among the green algae, and by those mosses which have dwarf male plants. Here sexual differentiation, beginning with the gametes, has progressed until it involves the whole organism.

In a fourth series of steps a tendency appears for the gamete-bearing plant to take over in part the particular functions first performed by the gametes. Those functions, as we have seen, were to bring the gametes together, and to provide food for the use of the zygote and for the launching of the new generation which will come from the zygote. As this new generation developed a longer and longer embryonic stage, its need of an initial food supply increased. With this need was connected another, also of increasing importance; that, namely, of shelter for the embryo, originally enclosed only within the wall of the zygote. Liverworts and mosses supply relatively simple illustrations of the ways by which the gametes are in a measure relieved of their duties. The male gamete-bearing organs are so constructed that by the dissolution of some of their cells the male gametes are freed; and water-absorbing substances are secreted whose swelling forces out the gametes. In some liverworts, an explosive discharge throws the male gametes outward to a considerable distance. On the other hand, the female organ provides a pathway through which the male gamete may swim in order to reach the female gamete, and a substance to whose stimulating effect the male gamete responds by a directed movement. The female organ is partly imbedded in tissues of the parent plant, fitted to provide nutrition. The female parent, too, provides special sheltering structures for the embryo. All these devices, assisting in the performance of duties originally incumbent upon the gametes alone, constitute part of the story of sexual differentiation.

Still further developments in the same direction appear in seed plants. The pollen grain, a young male plant, is itself transported by wind or insects to the neighborhood of the female plant. The pollen tube, an outgrowth of the same much-reduced male plant, provides a means by which the male gamete may reach the female. So effective are these means of transport that the male gamete has lost most of its power of motility, formerly its distinctive characteristic. The female plant, likewise reduced, consists (in the gymnosperms) chiefly of tissue destined to nourish the embryo.

But most remarkable among the sexual adaptations of seed plants, constituting the fifth, and thus far the final, chapter of the story, are those by means of which certain functions, incumbent first upon the gametes, then taken over by the parents—that is, the gamete-producing plants—have been in considerable measure assumed by the grandparents. The paternal grandparent assists, by the structure of its stamens, in the distribution of the potential fathers—a distribution in which the assistance of wind or of insects (occasionally of other agencies) has been commandeered. The maternal grandparent provides a place wherein the young father-to-be may land and may complete development; a canal through which the paternal pollen tube may grow; and structures which will surround the mother and its enclosed embryo, supplying to the latter, through periods of growth and dormancy, both nutriment and shelter.

As has been said, a substantially similar story could be told of the course of sexual differentiation in animals, save for the fact that the earlier phases of this process are but poorly represented in surviving species; whereas the story can be reconstructed virtually in its entirety from the observation of plants still living. It does not appear, however, that in any animal species the grandparents have ever become so essential to the production and care of the grandchildren as are grandparents among the seed plants.

The story of sexual differentiation, as here outlined, like most stories of biological import, has been learned backward. First to be observed were sexual differences manifested by the higher animals; later, not clearly recognized until the closing years of the seventeenth century, corresponding differences in the higher plants. Only a few years before had the male gametes of an animal first been seen. Not until the second half of the nineteenth century was the process of gametic union understood in its major outlines; and much of what has been here discussed proceeds from knowledge acquired but yesterday. Such a reversed working out of a problem results inevitably in the persistence of concepts based upon an incomplete knowledge of conditions in more complex organisms, whereas ideally those conditions should be explained in terms of concepts derived from simpler forms. Most emphatically is the latter statement true of any notion with an evolutionary bearing.

One outcome of the growth of knowledge in reverse has been the notion of sex as something fundamentally characteristic of living matter. Really, sex is neither fundamental nor primitive.

It represents an adaptation to certain needs—or a means of solution of certain problems—which appeared at a particular and relatively advanced stage of evolutionary progress.

Another consequence of our having learned the story backward rather than forward is the still frequent and absurd application, particularly in textbooks, of the term "sexual reproduction" to gametic union. For, although in a multicellular organism the union of gametes is a step preparatory to reproduction of that organism, gametic union itself is never reproduction. It is the exact reverse. Yet more absurd is it to call the union of like gametes "sexual reproduction." Since such a union represents a step that preceded in evolution the appearance of sexual differentiation, it is no more "sexual" than it is "reproduction." It is easier for scientific, as well as for some other classes of writers, to use old-established but inaccurate phrases than it is to criticize and make precise their terminology so that they may, within the limitations imposed by a very imperfect language, say just what they mean.

WILD LIFE RESEARCH IN WISCONSIN

ALDO LEOPOLD

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HISTORY

Wisconsin has always been a stronghold for ornithology. In the 1840s, before the state was half settled, the two Kumliens (*1*) at Delavan, and Dr. P. R. Hoy at Racine, had started their painstaking inventories of our avian species.

Then followed the era of "economic ornithology," the inventory not of bird species but of bird foods. In 1873 F. H. King (*2*) started exploring the economic relations of Wisconsin birds, a field which was later developed nationally by Judd, Fisher, Beal, McAtee, and other naturalists of the U. S. Biological Survey. King's undeviating rigor in applying the economic yardstick tells us much, not only about birds, but about the natural philosophy of his generation. With all the circumspection of a cautious radical expecting short shrift from his contemporaries, King suggests "the preservation of animals to *some extent detrimental,* i.e., to some extent at cross purposes with the sacred economy of *Homo sapiens.* Apparently it was dangerous in those days to assert flatly that a beautiful animal is his own justification.

King discovers, evidently with surprise, that an actual count showed more birds per square mile near Ithaca, New York, than in the more recently settled regions of Jefferson County, Wisconsin. He shared in, or at least had to deal with, the then universal assumption that wild life must disappear with the advance of settlement. This should be of special interest to the modern game manager, whose life-work rests squarely on the opposite premise.

At the turn of the century it became fashionable not only to love birds, but publicly to avow the fact. The amateur movement, as expressed in Bird Clubs and Audubon Societies, was strong in this state. Bird-lovers lacked both the botany and the entomology necessary to pursue economic studies, and of course also the dead specimens for study. Their energies turned to expanding the species inventory, to migration records, and latterly to banding. It may not be generally known that one of the pioneers in large-scale banding was Dr. L. J. Cole (*3*) of Wisconsin. Desultory banding had, of course, been practiced since the Middle Ages (*4*).

Wild life research in the modern sense began in this state when Herbert L. Stoddard, an "incorrigible" young naturalist from Sauk City, was retained by the Milwaukee Public Museum as taxidermist and collector in 1921. Sometime during that apprenticeship he must have conceived what is today the foundational theorem of wild life management, namely:

> *A species can be decimated by throwing its environment out of balance. Conversely, it can be restored by restoring the balanced assortment of environmental features required for its welfare.*

Stoddard first applied this theorem to his now famous Georgia quail investigation (*5*). The idea, however, must have been born during his work here. It is significant that its birthplace was in the mind of a man who had never seen the inside of a High School. A whole new profession is now engaged in following down its ramifications.

Stoddard cast his intellectual pebble in Georgia in 1924. By 1928 the outermost ripples had travelled back to the state of his nativity. In that year two projects, patterned after the Georgia model, were started here. Alfred O. Gross began the Wisconsin prairie chicken investigation (*6*), under the auspices of the Research Bureau of the State Conservation Commission. Paul L. Errington, under a grant to the University from the ammunition industry, started the Wisconsin quail investigation (*7*).

THE QUAIL INVESTIGATION

It is now three years since the completion of Errington's work, and perhaps not too early to attempt a summary of his discoveries and an appraisal of their significance. This may seem unbecoming in one who enjoyed daily association with his work, but those who understand the degree to which he was "his own man" may find it not improper.

Errington's most valuable findings relate to predation and its interrelations with food and cover. It has long been known that fitness determines survival, but we have only dimly realized that environment determines fitness. Errington worked out, for

Wisconsin quail, the details of just how and why. He qualified the usual supposition that species have certain inherent aptitudes for capture or escape, by showing that those aptitudes are operative only within certain narrow limits of circumstance. Thus the Cooper's hawk catches quail, but given a suitable variety of food and cover, the covey promptly changes its habits and becomes hawk-proof. On the other hand, if without alternative foods, it is annihilated either by the hawk or by starvation.

A corollary of this is that predation falls heaviest on coveys occupying marginal ranges. These may be wiped out while nearby coveys with good food and cover go unscathed. Predation is never uniformly distributed among population units.

All predation has been considered as selective of the unfit. Errington discovered wide variations in selectivity. Certain predators catch quail by chance, i.e., non-selectively; others catch only misfits, and are highly selective. The predators of high "economic" value, such as the Buteo hawks, are the most selective.

To get the data which yielded these conclusions, Errington invented new technique for field studies, supplementing the techniques previously devised by Stoddard. For example, by tethering young hawks and owls and forcing them to regurgitate the food brought them by parents, he obtained their daily menu without recourse to killing, and secured a continuity impossible under older methods. By feeding captive raptors various animals and then collecting their pellets, he found the rate of pellet formation and the degree to which the smaller bones are digested, thus allowing more and sounder conclusions to be drawn from the pellets of wild birds.

Stoddard and Errington jointly are probably responsible for the discovery of the food sequence, a concept unknown to the economic ornithologists with their composite cross-sections of stomachs gathered at diverse times and places. The daily menu of quail in winter was found to follow a sequence representing a descending scale of palatability. Winter survival was found to be a question of how low on the scale the last blizzard came. That low-scale foods do not sustain weight and fitness was experimentally verified.

Errington now promulgates, for Wisconsin quail, the general theorem (*8*) that predation varies with the degree to which a population falls below or rises above carrying capacity. A range when over-stocked loses heavily, apparently regardless of the number or kind of predators or buffers. The same range when under-stocked loses lightly, regardless of the number or kind of predators or buffers. That is to say, quail populations on any given range fluctuate about a norm representing carrying capacity. It follows that enhanced carrying capacity, i.e., food and cover improvements, is the only effective predator-control, also that surplus over capacity had as well be used by hunters as by natural enemies.

In general, Errington created a coherent, though necessarily tentative, theory of predation which so far applies only to Wisconsin quail, but which may ultimately have far-flung consequences to ecological science. It is a timely contribution, because predation continues to be the prime cause of dissension between gunpowder and field glass hunters.

RESEARCH SEQUENCE

Wild life management research projects are so far of several types, which occur in a rather definite sequence. By projecting this sequence a little into the future, we can gain a rough idea of the volume and kind of work which lies ahead. For any one species the sequence is:

1. Survey of the species, to find the most important chances for improving its environment and thus raising population levels.
2. Tests of the findings on actual range, to see if the higher levels are obtained.
3. Ecological exploration of key plants.
4. Physiological and pathological studies.
5. Economic vehicles for encouraging management.

Species surveys have been made by Errington of Wisconsin quail and by Gross and Schmidt of prairie chickens. Deer, waterfowl, shorebirds, fur animals, and cottontails remain virgin fields as yet untouched. Michigan surveys of pheasants by Wight (*9*) and of Hungarian partridge by Yeatter (*9a*) will probably suffice for this state; likewise Minnesota's survey of ruffed grouse by King.

Errington's findings on quail are now being tested on the Coon Valley Erosion Control Project by Holt. The findings of Schmidt and Gross on prairie chickens are being tested on the central Wisconsin Game Area. Some less thorough tests of Wight's, Yeatter's, and Errington's findings are being conducted, in cooperation with the University, by volunteer farm groups at Faville Grove in Jefferson County, Monroe Center in Adams County, and Riley in Dane County.

Tests nearly always disclose deficient knowledge of some key plant, but this type of research is as yet lacking in Wisconsin. For example, we need to learn how, by ecological manipulation, to control the supply of wild rice, wild celery, trefoil, ragweed, and false climbing buckwheat. Stoddard induces a growth of legumes in Georgia by plowing furrows in sod, or by controlled burning. In Scotland the grouse crop—some 2 million birds per year—rests squarely on the ecological manipulation of heather (*10*).

Physiological and pathological studies have begun. A cycle study was recently inaugurated by Grange (*10a*) and Wing (*10b*) under a grant of funds to the University by a group of sportsmen. Wisconsin also enjoys close cooperative relations with Dr. R. G. Green's study of cyclic diseases at the University of Minnesota. There is crying need for a study of vitamin and mineral nutrition as affecting disease and reproduction in game birds.

To accomplish conservation, game research must not stop with its "layette" of biological facts. There remains the problem of economic adjustments to encourage their use by landowners. Some current aspects of conservation economics have been treated in a separate paper(*11*).

OPPORTUNITIES

Wild life research offers a new field for service, not only to the larger universities and agricultural colleges, but also to colleges, agricultural high school teachers, county agents, forest officers, game officials, and private naturalists throughout the state. The first criterion of vitality in such a program is its degree of dispersion among many investigators of diverse points of view. There are so far ten times more challenging problems than investigators to attack them.

It may also be proper to ask why any scientific institution in this state, confronted by so many unanswered questions of vital import to our future, should have to seek outlets for its brains and energy in expeditions to foreign lands. The era of geographical exploration of the earth is about over, but the era of ecological exploration of our own dooryards has just begun. Wild life research is one of many virgin fields of inquiry in which any persistent investigator may contribute not only to science, but to the permanence of the organic resources on which civilization is dependent.

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MAPLE SUGAR: A BIBLIOGRAPHY OF EARLY RECORDS

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University of Wisconsin, Madison, and Kellogg Public Library, Green Bay

This bibliography of references to maple sap and its products is presented as part of a program of research on the history of foods. In this instance interest centers around two typically American foods obtainable from the "wounded maple" and in the past referred to as Canada, American or Indian sugar and American "melasses" or "syrrup" of maple, respectively. Its first item, an excerpt from the journal of a Jesuit missionary, marks it as beginning with a period (1634) which is coincident with the coming of the first white man to Wisconsin.

It is not a bibliography in the sense that it is an exhaustive compilation of all the titles or relevant comments and observations which have appeared on this subject during the two-and-a-quarter century span which opened with a significant date in the history of the Northwest Territory and closed, approximately, during Civil War days. In this respect it falls short of that measure of completeness. Except for a few items, it is the result of a search of a selected group of books of travel and natural history, diaries, journals, narratives and miscellaneous communications in periodicals, many of them long out of print, in the collection of the State Historical Society of Wisconsin. It is deemed to be sufficiently comprehensive to supply the student of this field of history with source material which is not only instructive and interesting, but, at times, even amusing.

1. Le Juene, Paul 1634

   Jesuit Relations and Allied Documents. Travels and Explorations of the Jesuit Missionaries in New France. 1610-1791. R. G. Thwaites, Editor. The Burrows Brothers Company, Cleveland, 1901, Vol. VI, p. 273.

   (The sugar maple a source of food for the Indian)

   "When they are pressed by famine, they eat the shavings or bark of a certain tree, which they call *Michtan*, which they split in the Spring to get from it a juice, sweet as honey or as sugar; I have been told of this by several, but they do not enjoy much of it, so scanty is the flow."

2. Denys, Nicolas 1672

Histoire naturelle des Peuples, des Animaux, des Arbres & Plantes de l'Amerique Septentrionale, & de ses divers Climats. Paris, 1672, Vol. II. Chap. XX. W. F. Ganong, The Description and Natural History of the Coasts of North America (Acadia). Toronto, 1908, p. 380-1.

(Description of the tapping of maple trees whose sap is a favorite drink of both Indians and French)

"That tree has sap different from that of all others. There is made from it a beverage very pleasing to drink, of the colour of Spanish wine but not so good. It has a sweetness which renders it of very good taste; it does not inconvenience the stomach. It passes as promptly as the waters of Pouque. I believe that it would be good for those who have the stone. To obtain it in the spring and autumn, when the tree is in sap, a gash is made about half a foot deep, a little hollowed in the middle to receive the water. This gash has a height of about a foot, and almost the same breadth. Below the gash, five or six inches, there is made a hole with a drill or gimlet which penetrates to the middle of the gash where the water collects. There is inserted a quill, or two end to end if one is not long enough, of which the lower extremity leads to some vessel to receive the water. In two or three hours it will yield three or fours pots of the liquid. This is the drink of the Indians, and even of the French, who are fond of it."

3. Nouvel, Henri 1673

Jesuit Relations. Vol. LVI, p. 101.

(Sap is called "maple water.")

"About the same time, I made various excursions on the ice in quest of stray sheep,—finding five children, to Baptize, and a sick young man, for whose salvation Providence was more watchful than I. For, having inadvertently baptized him, not with natural water, but with a certain liquor that runs from the trees toward the end of Winter, and which is known as "Maplewater", which I took for natural water, I discovered my mistake when, wishing to give this patient a dose of Theriac, I asked for some maple-water,—which, being naturally sweet, is more suitable for such a purpose. I was given some of the same liquor that I had used in baptizing him, and was thus obliged to repair that error,—happily a little before his death."

4. Dalmas, Antoine 1674
Ibid., Vol. LVIII, p. 121.
(Red maples)

This is a report to the superior Dablon, of an expedition of observation around Isle Jesus, near Montreal made in September, 1674.

"We visited the country; the land is very stony, but has many walnut-trees, beeches, aspens, and red maples, which are numerous along these Shores."

5. Nouvel, Henri 1675
Ibid., Vol. LX, p. 217.
(Comment on lofty oaks and maples)
Pertinent to the region near Lake Erie.

6. Thornton, ------ 1684
Phil. Mag., 1, 322-3 (1798).

Of an Attempt to make the Maple Sugar above an hundred Years ago. Dr. Robinson to Mr. Ray.

"It appears, by the following correspondence between Dr. Robinson and Mr. Ray, that the property of the American maple of yielding a saccharin juice was known above a century ago, and that attempts were even made to produce sugar from it:

London, March 10, 1684.

"Dear Sir,

"I have enclosed you some sugar of the first boiling got from the juice of the wounded maple: Mr. Ashton, Secretary to The Royal Society, presented it to me. 'Twas sent from Canada, where the natives prepare it from the said juice; eight pints yielding commonly a pound of sugar. The Indians have practiced it time out of mind; the French begin to refine it; and to turn it to much advantage. If you have any of these trees by you, could you not make the trial proceeding as with the sugar cane?

Answer to Dr. Robinson:

Black Notley, April 1, 1684.

"Yours of the 10th instant I received, and therein an enclosed specimen of the Canada sugar, a thing to me strange and before unheard of. It were well worth the experiment you mention. I therefore engaged a friend and neighbour of mine, an ingenious apothecary, whom I employed yesterday to boil the juice of the greater maple, a tree which grows freely half a mile off from my residence. Having made an extract, he found a whitish substance, like to brown sugar, and tasting very sweet, immersed in a substance of the color and consistency of molasses. Upon curing, I have no doubt it will make perfect sugar. When it is cured, I will give you a farther account of it."

7. -------- 1685

Phil. Trans., 15, 988.

(An account of a sort of Sugar made of the Juice of the Maple, In Canada)

"The Savages of *Canada,* in the time that the Sap rises, in the *Maple,* make an Incision in the *Tree,* by which it runs out; and after they have evaporated 8 pounds of the liquor, there remains one pound as sweet, and as much *Sugar,* as that which is got out of the Canes; Part of the same Sugar, is sent to be refined at Roven.

"The Savages have practiced this Art, longer than any now living among them can remember.

"There is made with this *Sugar* a very good Syrup of Maiden Hair, and other Capillary Plants, which is used in *France.*"

8. Joutel, Henri 1688

Journal historique du dernier Voyage que feu M. de la Sale fit dans la Golfe de Mexique pour trouver l'embouchure, & le cours de la Riviere de Missicipi. Paris, 1713, p. 352; in translation, A Journal of the Last Voyage perform'd by Monsr. de la Sale, to the Gulph of Mexico to find out the Mouth of the Missisipi River, London, 1714, p. 179. See also Pierre Margry, Découvertes et Établissements des Français dans l'ouest et dans le sud du l'Amérique Septentrionale (1614-1754). Paris, 1878, Pt. III, p. 510.

(Sweet water from a tree)

"The bad Weather oblig'd us to stay in that Place, till *April.* That Time of Rest was advantageous for the Healing my Foot; and there being but very little Game in that Place, we had Nothing but our Meal or *Indian* Wheat to feed on; yet we discover'd a Kind of *Manna,* which was a great help to us. It was a Sort of Trees, resembling our Maple, in which we made Incisions, whence flow'd a sweet Liquor, and in it we boil'd our *Indian* wheat which made it delicious, sweet and of a very agreeable *Relish.*

"There being no Sugar-Canes in that Country, those Trees supply'd that Liquor, which being boil'd up and evaporated, turn'd into a Kind of Sugar somewhat brownish, but very good."

9. LeClerq, Chrestien 1691

Nouvelle relation de la Gaspesie, qui contient les Moeurs & la Religion des Sauvages Gaspesiens Porte-Croix, adorateurs du Soleil, & d'autres Peuples de l'Amerique Septentrionale, dite la Canada. Paris. 1691, p. 124; W. F. Ganong, New Relation of Gaspesia with the Customs and religion of the Gaspesian Indians. Toronto, 1910, p. 122-3.

(Water of the maple)

"As to the water of the maple, which is the sap of that same tree, it is equally delicious to French and Indians, who take their fill of it in spring. It is true also that it is very pleasing and abundant in Gaspesia, for through a very little opening which is made with an axe in a maple, ten to a dozen half-gallons may run out. A thing which has seemed to me very remarkable in the maple water is this, that if, by virtue of boiling, it is reduced to a third, it becomes a real syrup, which hardens to something like sugar, and takes on a reddish colour. It is formed into little loaves which are sent to France as a curiosity, and which in actual use serve very often as a substitute for French sugar. I have several times mixed it with brandy, cloves & cinnamon, and this makes a kind of very agreeable rossolis. The observation is worthy of note that there must be snow at foot of the tree in order that it shall let its sweet water run; and it refuses to yield this liquid when the snow appears no more upon the ground."

10. de Lahontan, Louis baron 1703

New Voyages to North-America. London, 1703, Vol. I, (a) p. 106, (b) p. 249; Vol. II, (c) p. 15.

a. (Maple syrrup at Green Bay)

"For Drink they gave me a very pleasant Liquor, which was nothing but a Syrrup of Maple beat up with water; . . . ."

b. (The mapple-tree)

"It yields a Sap, which has a much pleasanter taste than the best Limonade or Cherry-water, and makes the wholsomest drink in the World. This Liquor is drawn by cutting the Tree two Inches deep in the Wood, the cut being run sloping to length of ten or twelve Inches. . . Of this Sap they make Sugar and Syrup, which is so valuable, that there can't be a better remedy for fortifying the Stomach. 'Tis but few of the Inhabitants that have the patience to make Mapple-Water, for as common and used things are always slighted, so there's scarce any body but Children that give themselves the trouble of gashing these Trees. . . ."

c. (Mapletree-Water)

"I remember one Day in a Village of the Outaouas at *Missilimakinac* a Slave brought into the Cottage where I was, a sort of Vessel made of a thick piece of soft wood, which he had borrowed on purpose, in which he pretended to preserve Mapletree-Water."

11. Dudley, Paul 1720

Phil. Trans., 31, 27-8.

An Account of the Method of making Sugar from the Juice of the Maple Tree in New England

Directions are given for making maple sugar of the juice of the upland maple that is maple trees that grow upon the highlands.

"Some put in a little Beef Sewet, as big as a Walnut, when they take it off the Fire, to make it turn the better to Sugar, and to prevent its candying, but it will do without. . . . . our Physicians look upon it not only to be as good for common use as the *West India* sugar, but to exceed all other for its Medicinal Virtue."

12. Charlevoix, P. F. X., de 1721

Journal d'un Voyage fait par ordre du Roi dans l'Amérique Septentrionale. Paris, 1744, Vol. III, p. 121; Anon., Journal of a voyage to North-America, London, 1761, Vol. I, p. 191-4; Louise Phelps Kellogg edition, Chicago, 1923, Vol. I, 176-9.

(Juice of the Maple)

"I was regaled here with the juice of the maple; this is the season of its flowing. It is extremely delicious, has a most pleasing coolness, and is exceedingly wholesome; the manner of its extracting it is very simple."

13. Rasles, Sébastien 1722

Jesuit Relations, Vol. LXVII. p. 93.

Lettre du Père Sébastien Rasles, Missionnaire de la Campagnie de Jésus dans la nouvelle France, à M. son neveu

Father Rasles is among the Abnakis Indians in Lower Canada and writes on October 15 from Nanrantsouak as follows:

". . . . my only nourishment is pounded Indian corn, of which I make every day a sort of broth; that I cook in water. The only improvement that I can supply for it is, to mix with it a little sugar, to relieve its insipidity. There is no lack of sugar in these forests. In the spring the maple-trees contain a fluid resembling that which the canes of the islands contain. The women busy themselves in receiving it into vessels of bark, when it trickles from these trees; they boil it, and obtain from it a fairly good sugar. The first which is obtained is always the best."

14. Beverley, Robert 1722

The History of Virginia. London, 2 ed. 1722, p. 118.

(The natural Product, and Conveniences of Virginia)

"The Honey and Sugar-Trees are likewise spontaneous, near the Heads of the Rivers. The Honey-Tree bears a thick swelling Pod, full of Honey, appearing at a Distance like the bending Pod of a Bean or Pea; it is very like the Carob Tree in the Herbals. The Sugar-Tree yields a kind of Sap or Juice, which by boiling is made into Sugar. This juice is drawn out, by wounding the Trunk of the Tree, and placing a Receiver under the Wound. It is said, that the

Indians made on Pound of Sugar, out of eight Pounds of the Liquor. Some of this Sugar I examined very carefully. It was bright and moist, with a large full Grain; the Sweetness of it being like that of good Muscovada.

"Though this Discovery has not been made by the *English* above 28 or 30 Years; yet it has been known among the *Indians* before the English settled there. It was found out by the *English* after this Manner. The soldiers which were kept on the Land Frontiers, to clear them of the Indians, taking their Range through a Piece of low Ground, about forty Miles above the then inhabited Parts of *Patowmeck* River, and resting themselves in the Woods of those low Grounds, observed an inspissate Juice, like Molasses, distilling from the Tree. The Heat of the Sun had candied some of this Juice, which gave the Men a Curiosity to taste it. They found it sweet, and by this Process of Nature, learn'd to improve it into Sugar. But the Christian Inhabitants are now settled where many of these Trees grow, but it hath not yet been tried, whether for Quantity, or Quality it may be worth while to cultivate this Discovery.

"Thus the *Canada Indians* made Sugar of the Sap of a Tree. And *Peter Martyr* mentions a Tree that yields the like Sap, but without any Description. The *Eleomeli* of the Ancients, a sweet Juice like Honey, is said to be got by wounding the Olive Tree: and the *East-Indians* extract a Sort of Sugar, they call *Jagra*, from the Juice or potable Liquor, that flows from the Coco-Tree: The whole Process of Boiling, Graining and Refining of which, is accurately set down by the Authors of *Hortus Malabaricus*."

15. Lafitau, Jos. F. 1724

Moeurs des sauvages Ameriquains, comparees aux meours des premiers temps. Paris, 1724, Vol. II, p. 154.

(Maple syrup)

"Au mois de Mars, lorsque le Soleil a pris un peu de force, & que les Arbres commencent à entrer en seve, elles font des incisions transversales avec la hache sur le tronc de ces arbres, d'ou il coule en abondance une eau, qu'elles reçoivent dans de grands vaisseaux d'écorce; elles sont ensuite bouillir cette eau sur le feu, qui en consume tout le phlegme, & qui épaissit le reste en consistence de syrop, ou meme de pain de sucre, selon le degré & la quantité de châleur qu'ils veulent lui donner. Il n'y a point à cela d'autre mystere. Ce sucre est très pectoral, admirable pour les médicamens; mais quoqu'il soit plus sain que celui des Cannes, il n'en a point l'agrément, ni la délicatesse, & a presque toûjours un petit goût de brûle. Les François le travaillent mieux que les Sauvagesses de qui ils ont appris à le faire; mais ils n'ont pû encore venir à bout de la blanchir, & de la raffiner."

16\. Lemery, L. 1745

A Treatise of All Sorts of Foods, Both Animal and Vegetable: also of Drinkables. Translated by D. Hay, London, 3 ed. 1745, p. 351.

(The sap of the maple)

"The Body, Branches, and Root of the Maple, yields a sweet and pleasant Sap; this Liquor, Mr. *Ray* says, is more abounding in cold and rainy Weather, than in any other, While the Birch, on the contrary, yield more in hot and dry Weather."

17\. Kalm, Peter 1748

Travels into North America. J. R. Forster trans. London, 1772, Vol. I, 2 ed., p. 132.

(Treacle and Sugar)

"When the tree is felled early in spring, a sweet juice runs out of it, like that which runs out of our birches. This juice they do not make any use of here; but in *Canada* they make both treacle and sugar of it."

18\. -------- 1765

Gentlemen's Mag., 35, 439.

(An American discovery)

"The *Americans* have discovered a method of making sugar from a liquor procured by boring the maple tree. They say that more than 30 gallons have been procured from one tree, which being manufactured after the manner of the syrup proceeding from the sugar canes, produces a sugar equal in goodness to that of *Jamaica;* and that the molasses extracted from the pressure of the liquor, is very little inferior to our *West India* molasses".

19. Bossu, N. 1771

Travels through that Part of North America formerly called Louisiana. Translated from the French by J. R. London, 1771, Vol. I, 188-9.

(Sagamité sweetened with syrup of the maple tree)

"After the first ceremonies were over, they brought me a calebash full of the vegetable juice of the maple tree. The Indians extract it in January, make a hole at the bottom of it, and apply a little tube to that. At the first thaw, they get a little barrel full of this juice, which they boil to a syrup; and being boiled over again, it changes into a reddish sugar, looking like *Calabrian manna*; the apothecaries justly prefer it to the sugar which is made of sugar canes. The French who are settled at the Illinois have learnt from the Indians to make this syrup, which is an exceeding good remedy for colds, and rheumatisms . . . they likewise brought a dish of boiled gruel, of maize flour, called *Sagamité,* sweetened with syrup of the maple tree; it is an Indian dish which is tolerably good and refreshing."

20. Adair, James 1775

The History of the American Indians. London, 1775. p. 416.

(Indians make sugar.)

"Several of the Indians produce sugar out of the sweet maple-tree, by making an incision, draining the juice, and boiling it to a proper consistence."

21. Carver, Jonathan 1778

Travels through the Interior Parts of North-America in the Years 1766, 1767, and 1768. London, 1778, (a) p. 262, (b) p. 282, (c) p. 496.

a. (Sugar not a sweetening agent)

"And even when they consume the sugar which they have extracted from the maple tree, they use it not to render some other food palatable, but generally eat it by itself."

b. (Present of sugar)

"In the morning before I continued my route, several of their wives brought me a present of some sugar, for whom I found a few ribands."

c. (Two sorts of maple trees)

"Of this tree there are two sorts, the hard and the soft, both of which yield a luscious juice, from which the Indians by boiling make very good sugar. The sap of the former is much richer and sweeter than the latter, but the soft produces the greater quantity. . . ."

22. Bliss, Eugene F. 1782

Diary of David Zeisberger, a Moravian Missionary among the Indians of Ohio. Trans. and ed. Cincinnati, 1885, Vol. I, p. 63, 66, 137, 186, 224, 324; Vol. II, p. 95, 305, 311, 347, 384.

(Sugar making in Ohio)

Sugar making was practiced by the Indians of Ohio in the period 1782-1797.

23. Belknap, Jeremy 1784

Coll. Mass. Hist. Soc., [5] 3, 181 (1877).

(White Mountain Tour)

"Great quantities of maple sugar are made here. Mr. W. has a set of vats to contain the sap, and a boiling house. They commonly make enough for a year's store. ---- Our bill of fare this day was ham, tongues, dried beef, trouts, and a sauce composed of raspberries, cream, and maple sugar."

24. Hollingsworth, S. 1786

An account of the Present State of Nova Scotia. Edinburgh, 1786, p. 21-2.

(Natural Productions)

"------ none is more useful to the inhabitants, than a species of maple, distinguished by the name of the sugar tree, as affording a considerable quantity of that ingredient; ------ the juice flows fast into a vessel placed below to receive it, and decreases in quantity as the sun declines toward evening.

"The sugar, when cold, is of a reddish brown colour, somewhat transparent, and very pleasant to the taste. It can only, however, be considered as of use to the inhabitants within in the province; and they have not failed to ascribe to it several virtues, either real or imaginary, as a medicine."

25. -------- 1788

Amer. Museum Univ. Mag., 4, 349-50.

(Advantages of the culture of the sugar maple-tree)

Directions are given for making maple sugar, maple molasses, maple beer, maple wine and maple vinegar.

26. Schöpf, Johann David 1788

Reise durch einige der mittlern und südlichen vereinigten nordamerikanischen Staaten, nach Ost-Florida und den Bahama-Inseln unternommen in den Jahren 1783 und 1784. Erlangen, 1788, Vol. I, p. 417; Alfred J. Morrison, Travels in the Confederation (1783-1784). Philadelphia, 1911, Vol. I, 271-3.

(Maple sugar is cheaper than ordinary sugar.)

"The sugar-maple is largely used by the people of these parts, because the carriage makes the customary sugar too dear for them. . . . It is brown, to be sure, and somewhat dirty and viscous, but by repeated refinings can be made good and agreeable."

27. Loskiel, George Heinrich 1789

Geschichte der Mission der evangelischen Brüder unter den Indianern in Nordamerika. Barby and Leipzig, 1789, p. 92-4; C. I. LaTrobe, History of the Mission of the United Brethren. London, 1794, Pt. I, p. 72-3.

(Maple tree is much esteemed.)

". . . near the Muskingum, sugar is boiled both in spring, autumn, and winter, in case of need. . . . This is used by the Indians either to sweeten their victuals, or in the place of bread: and it is thought more wholesome, and sweeter than our common brown sugar."

28. -------- 1789

Amer. Museum Univ. Mag., 6, 98-101.

Observations on manufacturing sugar from the sap of the maple tree

Directions for making include use of wooden vessels that "will not give the liquor a bad taste". Too small a grain is due to (1) makers have not used "lime or lye, or anything else, to make it granulate; (2) sugar boiled too much. Author suggests "a heaped spoonful of slacked lime—for about six gallons of sap". If quantity of lime too small, "the sugar will not be sufficiently grained; if too much, it will give the sugar a reddish cast."

29. -------- 1790

Ibid., 7, 303-4

On maple sugar

"The manufactory of maple sugar opens a wide prospect of wealth to the united states. . . . Hence 250,336 acres of maple land will be sufficient to supply the whole united states."

30. A Society of Gentlemen 1790

Univ. Asylum Columbian Mag., 5, 106-9, 153-6; *Nova Scotia Mag.*, 3, 249-54; *Annual Register 1791*, 33 (Useful Projects), 93.

Remarks on the Manufacturing of Maple Sugar

"A communication of such observations and directions *on manufacturing the Maple-Sugar* as will be most useful to those who, from situation, interest or patriotism, may be induced to engage in and carry on this business."

The States of New York and Pennsylvania have "a sufficient number of this kind of tree . . . to supply the whole of the United States, with this article."

31. -------- 1790

Ibid., 133.

Maple-sugar. Extract of a letter from Mr. William Cooper, at Cooper's-Town, Pennsylvania

"Those who think it more profit to clear them off the ground, to make way for wheat or pasture, will please to attend to the following receipt, taken from a farmer who had saved four acres, exposed to the North-West, and then recollect what employment is more profitable.

'Received, Coopers' town, April 30, 1790, of William Cooper, sixteen pounds, for six hundred and forty pounds of sugar, at six pence per pound; made every pound with my own hands, without any assistance, in less than four weeks; besides attending to the other business of my farm, as providing firewood, taking care of cattle, etc.

John Nicholls

'Witness,
'Richard R. Smith'

32. -------- 1790

Ibid., 5, 203.

Shipment of Maple-Sugar

. . . "It has moreover other things in its favour, to recommend it in preference to the sugar which is imported from the West-India Islands. It is made by the hands of freemen, and at a season of the year when not a single insect exists to mix with and pollute it; whereas the West-India sugar is the product of the unwilling labour of negro slaves, and made in a climate and in a season of the year, in which insects of all kinds abound, all of whom feed upon and mix with the sugar, so that the best India sugar may be looked upon as a composition consisting of the juice of the cane—and of the juices or excretions of ants, pismires, cockroaches, borers, fleas, mosquitoes, spiders, bugs, grasshoppers, flies, lizards; and twenty other West India insects. To these ingredients is added, the sweat of the negroes, and when they are angry, nobody knows what else."

33. Lincklaen, John 1791

Travels in the Years 1791 and 1792 in Pennsylvania, New York and Vermont, Journals of John Lincklaen, Agent of the Holland Land Company. Helen Lincklaen Fairchild. New York and London, 1897, p. 88-9.

(Vermont Journal—September 1791)

"There is in the whole State a considerable number of Mapple Trees, but the people do not seem to be persuaded of advantages they might gain from this tree. ---- Finally the chief reason for not making sugar is that they have no home market, and that the price of transportation by land is too dear ----."

34. Belknap, Jeremy 1792

The History of New-Hampshire. Boston, 1792, Vol. III, 2 ed., p. 113-6.

Forest-trees and other Vegetable productions

Descriptive of manufacture of maple sugar.

35. Imlay, Gilbert 1792

A Topographical Description of the Western Territory of North America. London, 1792, p. 117-8.

(Maple tree is productive of the finest sugars under care and management.)

"The perfection to which we have brought our sugars has induced many people in the upper parts of the States of New York and Pennsylvania to make a business of it during the season of the juice running; and considerable quantities have been sent to the markets of Philadelphia and York, not inferior to the best clayed, French, and Spanish sugars."

36. Rush, Benjamin 1793

Trans. Amer. Phil. Soc., 3, (a) 69, (b) 74.

An account of the Sugar Maple-tree of the United States, and of the methods of obtaining Sugar from it, together with observations upon the advantages both public and private of this Sugar.

a. (Concentration of sap by freezing)

By freezing the sap, "one-half of a given quantity of sap reduced in this way, is better than one third of the same quantity reduced by boiling."

b. (Maple sugar and corn mixture)

"They mix a certain quantity of maple sugar, with an equal quantity of Indian corn, dried and powdered, in its milky state. This mixture is packed in little baskets, which are frequently wetted in travelling, without injuring the sugar. A few spoonfulls of it mixed with half a pint of spring water, afford them a pleasant and strengthening meal".

37. Wansey, Henry 1794

The Journal of an Excursion to the United States of of North America in the Summer of 1794. Salisbury, 1796, p. 63.

(Journey from Boston to New York)

"After passing Middleton, I saw the first maple sugar tree; ----many afterwards that had been tapped. There are many other kinds of maple trees; the black, the white, and the red do not produce the saccharine liquor".

38. Graham, J. A. 1797

A Descriptive Sketch of the Present State of Vermont. London, 1797, (a) p. 57, (b) 156-7.

a. (Maple sugar at Sandgate)

"The making of sugar from the sap of the maple tree, and of pot and pearl ashes, has afforded them great assistance, ...".

b. (Indian method of concentrating sap)

"The method pursued by the *Aborigines* in making this article was as follows: Large troughs were made of the Pine Tree, sufficient to contain a thousand gallons or upwards; the young Indians collected the sap into these troughs, the women in the mean time (for the men consider every thing but war and hunting as beneath their dignity) made large fires for heating the stones necessary for the process; when these were fit for their purpose, they plunged them into the sap in the troughs, and continued the operation till they had boiled the sugar down to the consistence they wished."

39. -------- 1797

Amer. Univ. Mag., 2, 221-4.

An Account of the Sugar-Maple Tree

"There are three modes of reducing the sap to sugar: by evaporation, by freezing, and by boiling; of which the latter is most general, as being the most expeditious. . . . . It affords a most agreeable melasses, and an excellent vinegar."

40. Allen, Ira 1798

Natural and Political History of the State of Vermont. London, 1798, (a) p. 9, (b) p. 277; *Coll. Vt. Hist. Soc.*, 1, (a) 335, (b) 484 (1870).

a. Sugar Maple

". . . other species of useful timber, amongst which is the sugar maple, from which the farmers often make more sugar than serves for the usual consumption of their families, by the use of their kitchen utensils; . . .".

b. Maple sugar much used

"Maple sugar forms a great article of domestic consumption, the material is plenty, the preparation easy, the taste agreeable, it seldom cloys the stomach, it is an excellent antiscorbutic, and so innocent, that it may be taken in almost any quantity by infants."

41. Rush, Benjamin 1798

Phil. Mag., 1, 182-91.

An Account of the Sugar Maple of the United States

Descriptive, with a plea for use of this sugar in place of that made by slave labor.

42. Drake, Samuel G. 1799

Tragedies of the Wilderness; or True and Authentic Narratives of Captives. Boston, 1841, (a) p. 197, (b) p. 215.

(Sugar tubs of elm bark)

"In this month we began to make sugar. As some of the elm bark will strip at this season, the squaws, after finding a tree that would do, cut it down, and with a crooked stick, broad and sharp at the end, took the bark off the tree, and of this bark made vessels in a curious manner, that would hold about two gallons each: they made above one hundred of these kind of vessels. In the sugar tree they cut a notch, sloping down, and at the end of the notch stuck in a tomahawk; in the place where they stuck the tomahawk they drove a long chip, in order to carry the water out from the tree, and under this they set their vessel to receive it. As sugar trees were plenty and large here, they seldom or never notched a tree that was not two or three feet over. They also made bark vessels for carrying the water, that would hold about four gallons each. They had two brass kettles, that held about fifteen gallons each, and other smaller kettles in which they boiled the water, but as they could not at times boil away the water as fast as it was collected, they made vessels of bark, that would hold about one hundred gallons each for retaining the water; and though the sugar trees did not run every day, they had always a sufficient quantity to keep them boiling during the whole sugar season.

"The way we commonly used our sugar while encamped was by putting it in bear's fat until the fat was almost as sweet as the sugar itself, and in this we dipped our roasted venison".

(Concentration of maple sap by freezing)

"Shortly after we came to this pace the squaws began to make sugar. We had no large kettles with us this year, and they made the frost, in some measure, supply the place of fire in making sugar. Their large bark vessels, for holding the stock water, they made broad and shallow; and as the weather is very cold here, it frequently freezes at night in sugar time; and the ice they break and cast out of the vessels. I asked them if they were not throwing away the sugar. They said no; it was water they were casting away; sugar did not freeze, and there was scarcely any in that ice. They said I might try the experiment, and boil some of it, and see what I would get. I never did try it; but I observed that, after several times freezing, the water that remained in the vessel changed its color, and became very sweet."

43. Williams, Samuel 1809

Natural and Civil History of Vermont. Burlington, Vt., 1809, Vol. II, 2 ed., p. 363-4.

(Manufactures in Vermont)

"The manufacture of maple sugar is also an article of great importance to the state. Perhaps two thirds of the families are engaged in this business in the spring, and they make more sugar than is used among the people. Considerable quantities are carried to the shop keepers; which always find a ready sale, and good pay. The business is now carried on, under the greatest disadvantages: Without proper conveniences, instruments, or works; solely by the exertions of private families, in the woods, and without any other conveniences than one or two iron kettles, the largest of which will not hold more than four or five pailfulls. . . . This manufacture is capable of great improvements. . . . And it might become an article of much importance, in the commerce of the country."

44. Henry, Alexander 1809

Travels and Adventures in Canada and the Indian Territories between the Years 1760 and 1776. New York, 1809, (a) p. 69, (b) p. 70, (c) p. 143.

a. (Sap flow)

"When, in the morning, there is a clear sun, and the night has left ice of the thickness of a dollar, the greatest quantity is produced."

b. (Sugar diet of the Ojibwas)

"... we hunted and fished, yet sugar was our principal food during the whole month of April. I have known Indians to live wholly upon the same and become fat".

c. (Squaws make the sugar.)

"... we turned our attention to sugar making, the management of which—belong to the women, the men cutting wood for the fires, and hunting and fishing".

45. -------- 1814

Coll. Mass. Hist. Soc., [2] 3, 114 (1846).

Note on New Holderness, N. H.

"The prevailing wood is oak, but there is a good deal of other wood, particularly of pine, beach, and maple. From the sap of the black, or sugar maple, (acer saccharinum) a considerable quantity of sugar is made."

46. Dwight, Timothy 1821

Travels in New-England and New-York. New-Haven, 1821, Vol. 1, p. 40.

(Descriptive)

"The sap of this tree is a very pleasant drink; and the sirup is by many persons preferred to honey."

47. Hunter, John D. 1823

Manners and Customs of Several Indian Tribes Located West of the Mississippi. Philadelphia, 1823, p. 315.

(The sugar month of the Indians)

"... and the thirteenth month is the sugar month because in it they manufacture their sugar, from the maple and box elder trees."

48. Hunter, John D. 1824

Memoirs of a Captivity among the Indians of North America, from Childhood to the Age of Nineteen. London. 1824, 3 ed. p. 290.

(Indian's fondness for maple sugar)

"In districts of country where the sugar maple abounds, the Indians prepare considerable quantities of sugar by simply concentrating the juices of the tree by boiling, till it acquires a sufficient consistency to crystallize on cooling. But, as the are extravagently fond of it, very little is preserved beyond the sugar-making season. The men tap the

the trees, attach spigots to them, make the sap troughs; and sometimes, at this frolicking season, assist the squaws in collecting sap."

49. Keating, William H. 1824

Narrative of an Expedition to the Source of St. Peter's River, Lake Winnepeek, Lake of the Woods, &c. Philadelphia. 1824. Vol. 1, p. 114.

(Description of rude process practiced by Indians)

"We are informed, that they profess to have been well acquainted with the art of making maple sugar previous to their intercourse with white men. Our interpreter states that having once expressed his doubts on the subject in the presence of José Renard, a Kickapoo chief, the latter answered him immediately with a smile, 'Can it be that thou art so simple as to ask me such a question, seeing that the Master of Life has imparted to us an instinct which enables us to substitute stone hatchets and knives for those made of steel by the whites; wherefore should we not have known as well as they how to manufacture sugar? He has made us all, that we should enjoy life; he has placed before us all the requisites for the support of existence, food, water, fire, trees. etc.; wherefore then should he have withheld from us the art of excavating the trees in order to make troughs of them, of placing sap in these, of heating the stones and throwing them into the sap so as to cause it to boil, and by by this means reducing it into sugar.' "

50. James, Edwin 1830

A Narrative of the Captivity and Adventures of John Tanner. New York, 1830, (a) p. 294, (b) p. 321.

a. (Objibwa names for the sugar maple and the river maple trees)

Nin-au-tik = sugar maple (our own tree). She-she-gum-maw-wis = river maple (sap flows fast).

b. (Menominee name for sugar moon)

Sho-bo-maw-kun ka-zho = sugar moon.

51. Bouchette, Joseph 1832

The British Dominions in North America. London, 1832, Vol. 1, p. 371-2.

Manufactures—Maple Sugar

"Maple sugar will nevertheless ever continue a favourite luxury, if not a necessity, with the Canadian peasant, who has not unaptly been considered as having for it the same sort of natural predilection that an Englishman has for his beer, a Scotchman for his scones, and a Mexican for his pulque."

52. Evans, Francis A. 1833

The Emigrant's Guide to Canada. Dublin, 1833, p. 105-7.

On Making Maple Sugar

Descriptive.

53. -------- 1837

Graham J., 1, 87

Maple Sugar

Farmers owning "sugar lots" are urged to give attention to the subject of making sugar at home, for there are many who would purchase maple sugar if it were brought into market in a suitable state for common use. It would make the best of loaf sugar, and the molasses made from it would be of a superior quality. Those who are opposed to the use of "free labor produce" should be interested in this phase of the subject.

54. Jameson, Anna B. 1838

Winter Studies and Summer Rambles in Canada, London, 1838, Vol. III, p. 217.

(Manufacture of sugar by the daughter of Waub Ojeeg)

"A large tract of Sugar Island is her property; and this year she manufactured herself three thousand five hundred weight of sugar of excellent quality."

55. Ducatel, ---- 1846

Catholic Mag., 5, 92.

A Fortnight among the Chippewas of Lake Superior

"The birchbark is made into troughs (pisketahnahgun) in which the maple sugar (sinzibuckwud) is gathered in March and April. ---- With the birch bark is also manufactured the sugar basket (mukkuk) ------."

56. Sparks, Jared 1848

The Library of American Biography. Boston, 1848, [2] Vol. VII. p. 189.

Life of Sebastien Rale

"His constant food was Indian corn, of which, pounded in a mortar and boiled, he made hominy. The only condiment he could have was supplied by maple sugar, prepared in the spring by the women, who collected the sap of the trees in vessels of bark, and boiled it down."

57. Gesner, Abraham 1849

The Industrial Resources of Nova Scotia. Halifax, 1849, p. 213.

Manufactories—Maple Sugar

"This sugar may be made as white and as lively as any from the tropical climates. The kind usually made is sold in small brown cakes. The sap also affords a delicious syrup, and the 'last run' makes excellent vinegar."

58. Morgan, Lewis H. 1851

League of the Ho-de-no-sau-nee, or Iroquois. Rochester, 1851, p. 369.

(Sugar from the maple)

"Our Indian population have been long in the habit of manufacturing sugar from the maple. Whether they learned the art from us, or we received it from them, is uncertain. One evidence, at least, of its antiquity, is to be found in one of their ancient religious festivals, instituted to the maple, and called the Maple dance."

59. Schoolcraft, Henry R. 1852

History Condition and Prospects of the Indian Tribes of the United States. Philadelphia. 1852. Vol. II, p. 55.

Sugar-Making

"It forms a sort of Indian carnival. The article is profusely eaten by all of every age, and a quantity is put up for sale in a species of boxes made from the white birch bark, which are called mococks, or mokuks. These sugar-boxes are in the shape of the lower section of a quadrangular pramid. . . . . miniature mokuks are ornamented with dyed porcupine quills, skilfully wrought in the shape of flowers and boxes.

"The heydey scenes of the Seensibaukwut, or sugar-making, crown the labors of the spring. The pelt of animals is now out of season, winter has ended with all its vigors, and the introduction of warm weather prepares the Indian mind for a season of hilarity and feasting, for which the sale of his 'golden mokuks' gives him some means."

60. Jones, Electa F. 1854

Stockbridge, Past and Present. Springfield, 1854, (a) p. 23, (b) p. 26-7.

(Maple sugar made by Stockbridge Indians)

"The Muh-he-con-ne-ak . . . manufactured large quantities of Maple Sugar. And indeed we seem to be chiefly indebted to them for the knowledge of this luxury, for as late as 1749, Mr. Hopkins, in writing of Stockbridge and its Indians, not only describes its taste, and the manner in which it is *made*, but tells *what it is*, as if very little known."

b. (Legend of the origin of maple sap)

"They had a rare acquaintance with heavenly bodies; even the children could tell their names; and it is an interesting fact, that not only Muh-hu-con-ne-ok, but other New England Indians, gave the name of "The Bear" and *"Great Bear"* to the same constellation which is so called by European nations. Their mythological account was this: — that these stars were so many men engaged in a bear hunt. They commenced the hunt in the spring, and by autumn had wounded the animal, so that his blood was falling upon the forests, and dyeing them with those beautiful hues of the season. In the winter they slew him, and the snow was but his dripping oil. ---- This melted in the spring, and furnished the trees with sap."

61. Kohl, Johann G. 1860

Kitchi-Gami. Wanderings around Lake Superior. London, 1860. p. 318.

(Maple sugar as preservative and condiment)

"The Indians dry it ('pagessaneg' des prunes sauvages —wild plum) at times, but more usually boil it with maple sugar, and make it into a sort of cake, or dough. They boil and stir the plums in the kettle, until the mass becomes thick; they spread it out on a piece of skin or birch bark for the thickness of an inch, and let it dry in the sun. It supplies a tough, leathery substance, which they roll up and pack in their 'makaks' (birch-bark boxes). These are then placed in holes in the ground, like so many other things of their housekeeping, and covered with earth. It keeps sweet a long time and in winter they cut off pieces, which they boil with dried meat. 'C'est bon-bon, monsieur—tout à fait'.

"Whether the art of preserving fruit with sugar is an old invention of the Indians I am unable to say, but I believe so, for it has been ascertained that the manufacture of sugar was pre-European among the Indians. Besides, the use of sugar as the universal and almost only condiment in Indian cookery is most extended. Sugar serves them, too, instead of salt, which even those who live among Europeans use very little or not at all. They are fond of mixing their meat with sweets, and even sprinkle sugar or maple syrup over fish boiled in water. They have a perfect aversion for salt. ---- That great cookery symbol, the salt-box, which is regarded among many salt-consuming nations with a species of superstitious reverence, is hence hardly ever found in an Indian lodge. But the larger sugar makak may be always seen there, and when the children are impatient, the mother gives them some of the contents, and they will sit at the door and eat sugar by handfuls."

62. -------- 1860

Canadian Settlers' Guide. 1860, p. 66; Chamberlain, *Am. Anthropol.*, 4, 39 (1891).

(Flavor due to bark vessels)

"The Indian sugar (maple), which looks dry and yellow and is not sold in cakes but in birch boxes, *mowkowks,* as they call them, I have been told owes its peculiar taste to the bark vessels that the sap is gathered in, and its grain to being kept constantly stirred while boiling".

63. Hind, Henry Youle 1860

Narrative of the Canadian Red River Exploring Expedition of 1857 and of the Assinniboine and Saskatchewan Exploring Expedition of 1858. London, 1860, Vol. I, p. 127-8.

(Sap of ash-leaved maple used for sugar making)

"The maple, which at one time grew in considerable quantities near Sugar Point, is not the true sugar maple

(Acer saccharinum) so common in western Canada, but another species, generally known as the ash-leaved maple *(Negundo fraxinifolium)*, also furnishing an abundance of juice from which sugar is made as far north as the Saskatchewan."

64. Poore, Ben Perley 1866

Report of the Commissioner of Agriculture for the Year 1866. Washington, 1867, p. 500.

(An Indian festival dish)

"From the sap of the maple tree they made a coarse-grained sugar, which, when mixed with freshly pounded '*suppaun*' and seasoned with fried whortleberries, was baked into a dainty dish for high festivals."

65. Wheeler, Timothy 1869

New England Farmer, Boston, Oct. 9, 1869.

(Indian rule for predicting the character of the sugar season)

"If the maple leaves ripen and turn yellow, and the buds perfect themselves so that the leaves fall off naturally, without a frost, then there will be a good flow of sap the following spring; but if there is a hard frost that kills the leaves and they fall off prematurely, before the bud is perfected, then we may look out for a poor yield of sap. In other words, the flow of sap will be more or less abundant in proportion to the ripeness of the tree before the frost of the previous autumn".

66. Leland, Charles G. 1884

Algonquin Legends of New England. Boston, 1881, p. 121.

(A Penobscot legend)

"Now Wasis was the Baby. And he sat on the floor sucking a piece of maple sugar, greatly contented, troubling no one."

67. Brinton, Daniel G. 1885

The Lenape and Their Legends. Philadelphia, 1885, p. 255.

(Algonkin Indians prefer maple sugar.)

The general name applied by the Iroquois to the Algonkins is given as *Ratirontaks*, from *karonta*, tree, and *ikeks*, to eat, "Tree-eaters". They were probably so called from their love of the product of the sugar maple.

68. Blackbird, Andrew J. 1887

History of the Ottawa and Chippewa Indians of Michigan. Ypsilanti, 1887, p. 72.

(Indian legend of sugar trees)

"The legends say, that once upon a time the sugar trees did produce sap at certain seasons of the year which was almost like a pure syrup; but when this mischievous Ne-naw-bo-zhoo had tasted it, he said to himself, 'Ah, that is too cheap. It will not do. My nephews will obtain this sugar too easily in the future time and the sugar will be worthless'. And therefore he diluted the sap until he could not taste any sweetness therein. Then he said, 'Now my nephews will have to labor hard to make the sugar out of this sap, and the sugar will be much more valuable to them in the future time.' "

69. Henshaw, H. W. 1890

Amer. Anthropol., **3**, 341-51.

Indian Origin of Maple Sugar

"Considering the great familiarity of the Indians with the natural edible products of America, and the general ignorance of the European on this subject, it is fairly to be inferred that the *a priori* likehood of the discovery of the properties of the maple sap is all in favor of the Indian."

70. Chamberlain, A. J. 1891

Ibid., 4, 39-43.

The Maple Amongst the Algonkian Tribes

The legend of the Menomine Indians on the origin of maple sugar making runs as follows: "One day Nokomis, the grandmother of Manabush, was in the forest and accidently cut the bark of a tree. Seeing that a thick syrup exuded from the cut, she put her finger to the substance, and upon tasting it found it to be very sweet and agreeable. She then gave some of it to her grandson, Manabush, who liked it very much, but thought that if the syrup ran from the trees in such a state it would cause idleness among the women. He then told Nakomis that in order to give his aunts employment and keep them from idleness he would dilute the thick sap whereupon he took up a vessel of water and poured it over the tops of the trees, and thus reduced the sap to its present consistency. This is why the women have to boil down the sap to make syrup."

71. Chamberlain, A. F. 1891
Ibid., 381-3.

Maple Sugar and the Indians

Evidence is presented in support of the claim that the American Indian first made maple sugar.

72. Carr, Lucien 1895
Proc. Amer. Antiq. Soc., [ns] 10, 155-90.

The Food of Certain American Indians and Their Methods of Preparing it

"It was made wherever the tree grew, and it found special favor as an ingredient in their preparation of parched cornmeal or as we call it, nocake or rockahominy. They also cooked corn in the syrup 'after the fashion of parlines,' which was a favorite dish with them, as a similar preparation is today with us; and in more recent times they also made a preserve of plums which is said to have been good. Among some tribes, and in recent times, this sugar may be said to have taken the place of salt, though this latter article was known from the earliest times."

INDEX

THE GEOGRAPHY OF THE CENTRAL SAND PLAIN OF WISCONSIN*

J. RILEY STAATS

THE LANDSCAPE

The Central Sand Plain of Wisconsin (Figure 1) is a region in which the physical and cultural elements of its landscape sharply delimit it from surrounding more highly developed regions. (Figures 3 and 4) This sandy area, whose flattish surface is interrupted locally by numerous sandstone knobs rising from 100 to 300 feet above the surrounding plain by terraces along the Wisconsin River, by ridges extending from the Franconia escarpment, which forms the southern and western boundaries of the region, and locally by low sand dunes, presents a stage upon which a succession of cultural landscapes has been imposed.

The development of the Central Sand Plain landscape may be divided into: (1) Landscape in the Period of French and Indian Occupance, which was dominant previous to 1830; (2) Landscape in the Lumbering and Pioneer Stage, 1830 to 1880; (3) Landscape in the Transitional Stage, 1880 to 1920; and (4) the Present Landscape.[1]

THE PRESENT LANDSCAPE

The present scene is distinguished by features of cultural decadence in the rural areas, and by specialized manufactural and commercial urban centers along the chief waterways. Variations in one or more of its physical forms is locally reflected in cultural responses. Areas of better soils, in scattered locations, contain a higher than the average per cent of cultivated land and better kept farmsteads. Such sections stand as islands of higher utilization surrounded by or intermingled with areas of sand which are decidedly less developed. On the other hand, in some portions of the plain, the development is below the av-

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* This study, which was prosecuted largely on the basis of field work of a reconnaissance nature, on detailed statistical studies, and on a study of the literature, is an abridgement of a dissertation. Abbreviation of the paper has necessitated the omission of much data, most of the pictures and maps, many footnotes, and the bibliography.

[1] On account of a limited space a description and interpretation of the present scene only is attempted.

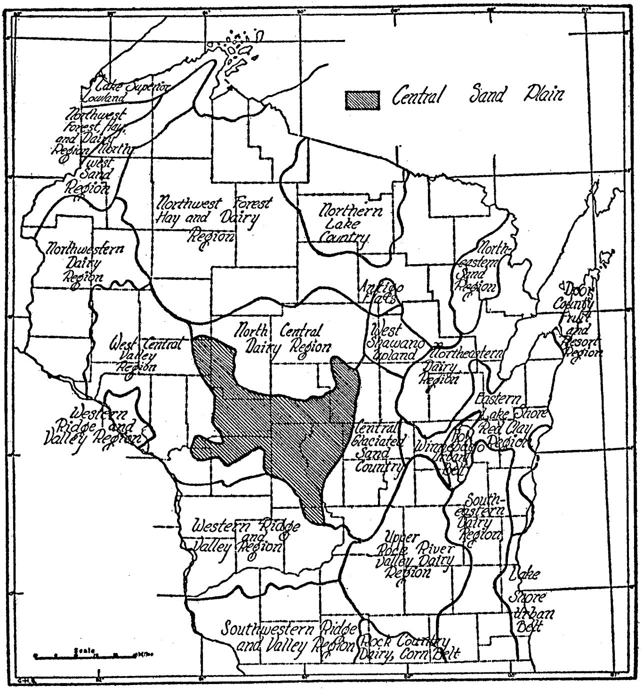

Fig. 1.—Geographic Regions of Wisconsin.*

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* Ph.D. thesis of Loyal Durand, Jr., University of Wisconsin, 1930.

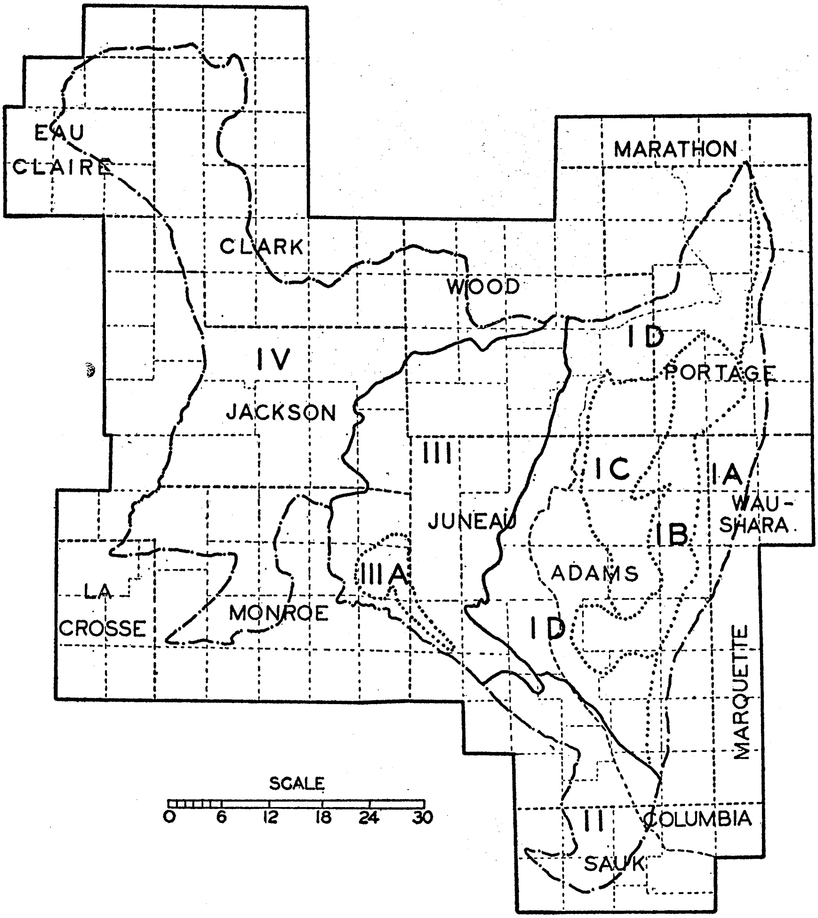


Fig. 2.—Central Sand Plain

I. Eastern farming and dairying area
  a. Outwash plain
  b. Marshland and associated sandy strips
  c. Sand dunes and brush section
  d. Flood plains, terraces, and areas of better soil

II. Southeastern farming and dairying area

III. Central marsh area
  a. Island of higher utilization

IV. Western brush and dairying area

——.——.——.—— regional boundary

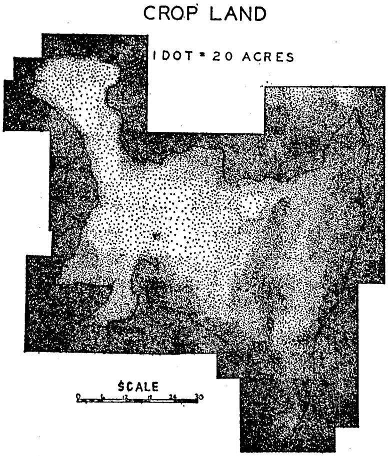


FIG. 3

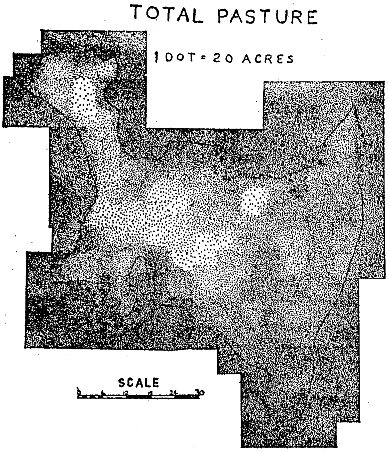
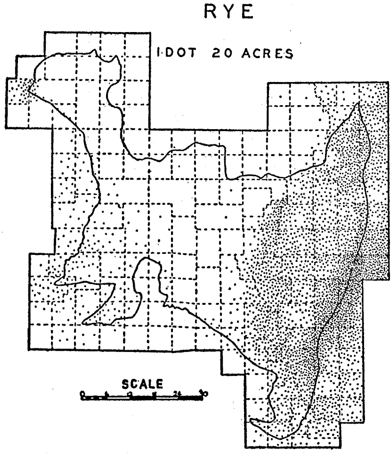


FIG. 4.



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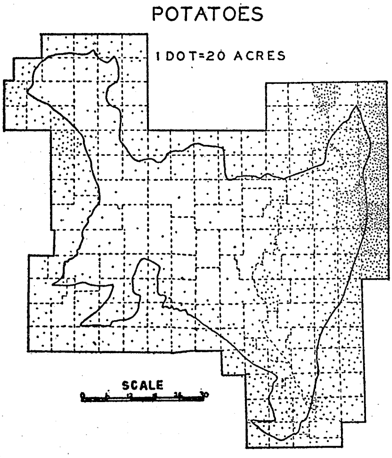

FIG. 6.

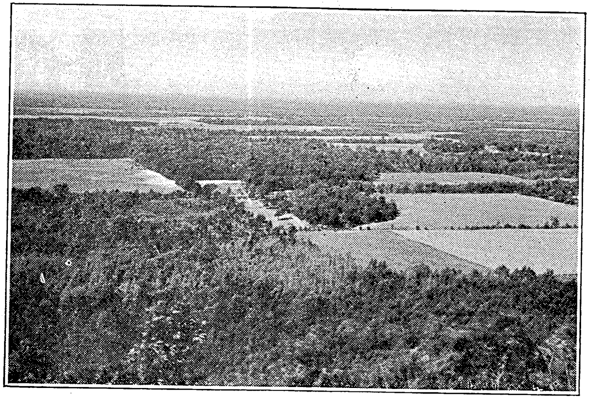

FIG. 1.—A typical scene in an area of sandy loams

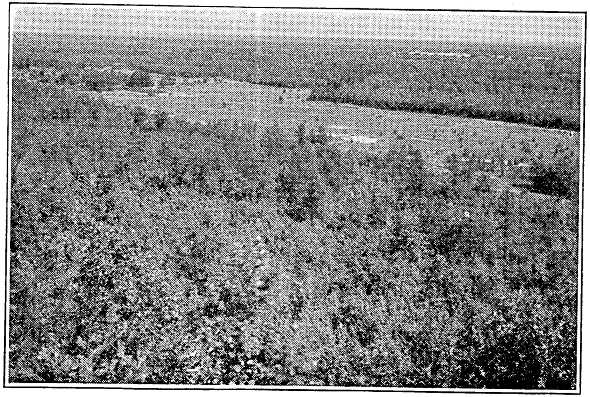

FIG. 2.—A view of the wooded portion of the Central Sand Plain

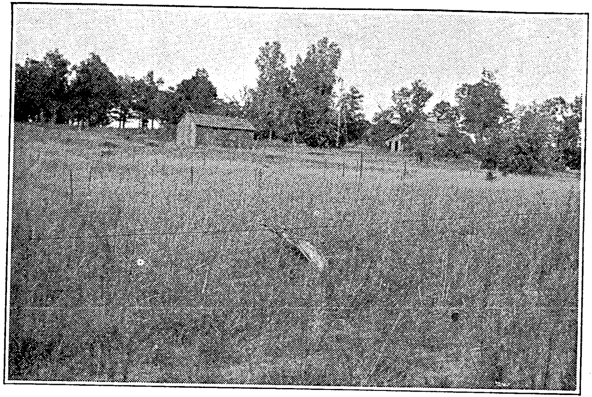

FIG. 3.—An abandoned farmstead, one of the many evidences of decadence

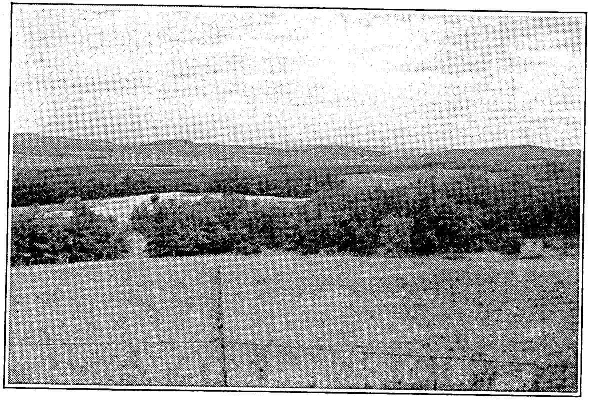

FIG. 4.—A typical view in the Southeastern Farming and Dairying Area

erage for the region as a whole. These parts contain little in the way of cultural imprint other than evidences of past forest exploitation as shown by many stumps among the brush.

Fluvio-glacial sediments, alluvium, residual materials, and loess, individually or in combination, have given rise to a variety of soils that may be classified under the general term of pine sands.[2] Of the soil types, including sands, sandy loams, and peat, sand is by far the most widespread, and it is to this soil in its various phases more than to any other element of the physical complex that the economic aspects of the region are closely related. In addition to its low plant food content, the coarse soil imposes a severe restriction upon general agriculture because of its droughty nature.

A high percentage of the Central Sand Plain is cut-over and brush lands (Plate 4, Figure 2) in which jack pine (Pinus Banksiana) and scrub oak (Quercus nan, Quercus marilandica, and Quercus coccinea) predominate. Only remnants of the former cover of white (Pinus strobus) and Norway (Pinus resinosa) pines, which extended over a considerable portion of the region, are found scattered over the area. These remnants stand as lone sentinels or in small, widely-scattered patches of a few acres in extent. In some localities, instead of pure stands of jack pine and scrub oak, one finds variations in the natural cover, including other species such as aspen (Populus tremuloides), willow (Salix Viminalis and Salix Purpurea), and tamarack (Lerx laricina). The aspen, willow, and tamarack are generally found in areas of poorly drained soils, such as the Dunning series which surround the marshes, and in the marshes themselves. Where scrub oak is in pure stands or is mixed with jack pine, hazel (Corylus Americana) and sweet fern (Comptonia aspenifolia) undergrowth are common; in other parts of the region where jack pine is found in pure stands the ground cover is generally a sparse growth of grass which incompletely mantles the underlying sand.

Not all of the untilled areas are covered with brush and scrub timber, since marsh occupies large tracts of the Central Sand Plain. In these sections the dominant soil is peat. The utility of such land is low, since it is limited to the production of marsh hay, cranberries, blueberries, and moss, unless it is

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[2] The term "pine sands" is used to include several varieties of quartz sand which is very low in plant food and in which pines and scrub oak are practically the only trees that thrive.

drained. If drained, a general type of farming is carried on with varying results.

The climatic conditions of the Central Sand Plain are those peculiar to middle latitudes in continental locations. This region, according to Köppen's classification, lies in the Dfb climate. A growing season of 125 to 146 days, too short for corn to mature properly, constitutes another phase of the restrictions imposed upon the use of the area for general agriculture. An annual precipitation of 30 to 35 inches, with the maximum coming in the growing season, is usually sufficient for the kind of crops that are commonly grown in an environment of sandy soils, short growing season, and mean summer temperatures not exceeding 71 degrees. It frequently happens, however, that during the latter part of summer of some years crops suffer from a lack of moisture, since a small decrease of precipitation during this period of the year is critical in sandy soils that are characteristically droughty.

Of the region as a whole, only 43.9 per cent is in farms, and of this amount 38.7 per cent is in crop land and 40.1 per cent in pasture.[3] The latter percentage represents all types of pasture, the greater part of which is wooded. These figures reveal the main uses of the farm land, yet they are somewhat misleading, since neither the quality of the pasture nor the crop yields are comparable to those of surrounding regions. Dairying is the chief occupation, but here again, in comparison with contiguous areas its development is meager indeed. (Figure 7) In most parts of the Central Sand Plain the money derived from the sale of milk and cream is the chief farm income. The silo, which is characteristic of adjacent dairying areas, is generally absent from the region except in areas of better soils where it is found in connection with nearly every barn.

Crops of the Central Sand Plain include small grains (rye, oats, buckwheat, and some barley); corn, tame hay (including clover and timothy, alfalfa, soya beans, and German millet) as feed and forage crops for the dairy industry; potatoes, cranberries, and vegetables, all three as cash crops. The sandy plain does not, however, have a large acreage of any of the above crops. Furthermore their acreages are unevenly distributed be-

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[3] All percentages, unless otherwise stated, were compiled from data obtained at the Crop and Livestock Reporting Service of Wisconsin, and from the United States Census, both giving figures for civil towns.

cause of the variations in the fertility of the soils in the different parts of the region. In comparison with surrounding areas no crop, with the exception of rye, is very important. (Figures 3 and 5)

The cropped fields in portions of the plain are rectangular following the pattern of the land survey of the Northwest Territory, (Plate 4, Figure 1) while in other sections their shapes are adjustments to the local physical conditions. In the gently rolling areas where the land between the the ridges is cleared and the ridges are generally wooded (Plate 4, Figure 4), the shapes of the cleared and cropped fields tend to conform to the trend of the ridges and dunes. Thus it is that the cleared areas break the monotonous continuity of brush and marsh lands, which are so characteristic of the Central Sand Plain.

The farms of this region average 160.4 acres in size, an acreage exceeded in Wisconsin only by that in the Western Ridge and Valley Region wherein the farms average 161.7 acres. Of the farm land of the region, 21.3 per cent is waste, used neither for crop land, farmsteads, nor pasture, a percentage of waste and unused land that is exceeded only by that of the farms in the northern part of the state.[4]

Small farmsteads, situated in small clearings or on the edges of marshes, are characteristic landscape features. A few farmsteads are found widely scattered in the drained portions of the marshes adjacent to the drained ditches or along the highways in those parts of the marsh lands which have been brought wholly under cultivation. A three to four room house, often unpainted, a small barn, and a few sheds and small outbuildings comprise the structures of the typical farmstead—the sand country cannot support a larger capital investment in improvements.

The Central Sand Plain of Wisconsin is sparsely settled, and for the region as a whole, rural in character. The density of population is 24.4 per square mile, and 34 per cent of the people live on farms, giving a density of farm population of 8.3 per square mile.[5] Country stores, small cross-road hamlets, and villages of a few hundred inhabitants are more characteristic than larger villages and cities. Moreover, the cities that are closely related to the Central Sand Plain have two general types of lo-

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[4] Ebeling, Walter, H., et. al., Wisconsin Agriculture, Bulletin 140, p. 42, 1932.
[5] Ibid, p. 40.

cations, namely: (1) along the Wisconsin River, and (2) nearby in other regions.

The cities and many of the villages have in their brief histories passed through a series of functional changes. Generally they started in connection with the lumbering industry as sites for saw-mills, as outfitting centers for the lumber camps or both. If they were able to adapt themselves to changed conditions at the close of the lumbering operations, they declined but temporarily, and then took on new activity in commercial or industrial functions. If, on the other hand, their sites offered no special advantage for industry or their locations no opportunity for commerce they passed into decadence—the Central Sand Plain, without some special advantages other than those contained in its general upland, cannot support a city of much magnitude.

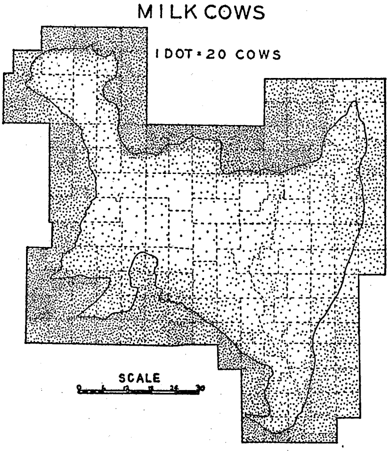

FIG. 7.

The small hamlets and the villages in the Central Sand Plain are, for the most part, located either on branch railroad lines or improved trunk highways. These small and widely scattered units are tied by lines of transportation to the cities along the Wisconsin River and to the near-by cities of the surrounding regions.

REGIONAL SUBDIVISIONS

As previously stated, the Central Sand Plain of Wisconsin is delimited by sharp changes in both the cultural and physical elements of the landscape. (Figures 3, 4 and 7) Passing from the plain into contiguous regions, an observer passes from a region of sandy soils, low percentage of improved land, small farmsteads, and a high percentage of wooded and waste lands to regions of heavier soils, (except in the Glaciated Sand Region), a higher percentage of cleared and improved land, and larger and better kept farmsteads. Thus, the human imprint is far more conspicuous in the surrounding regions than in the Central Sand Plain itself. Moreover in the region as a whole there is a high degree of unity in soils, topography, natural vegetation, and cultural forms, but by a more detailed survey sufficient differences were discovered to warrant subdividing the region, for the purpose of description and interpretation into: (Figure 2)

(1) An Eastern Farming and Dairying Area (1240 sq. mi.)

(2) A Southeastern Farming and Dairying Area (250 sq. mi.)

(3) A Central Marsh Area (610 sq. mi.), and

(4) A Western Brush and Dairying Area (1110 sq. mi.

THE EASTERN FARMING AND DAIRYING AREA

Similar to the region as a whole, a general view of the Eastern Farming and Dairying Area presents a wooded terrain (Plate 4, Fig. 2) whose general flatness is broken locally by minor surface configurations. From the crest of one of the sandstone knobs an observer can look over a monotonously flat surface that fades into obscurity in the distance. A closer examination, however, reveals irregularities that result from sandstone outliers, areas of sand dunes, and terraces along the rivers and their larger tributaries. In the localities of sand dunes the terrain becomes gently undulating; and adjacent to the Wisconsin River, in many places, the rise from one terrace to another appears, from a distance, as a low range of hills.

Varying degrees in intensity of utilization, and often a lack of proper methods to maintain soil fertility characterize the agricultural use of the Eastern Farming and Dairying Area. It is not uncommon to find a farm that has been properly managed having its buildings in good repair while a farm near-by, which has not been properly cared for, has been abandoned (Plate 4, Figure 3). Where the better soils prevail, due to the silt content or the proximity of the underlying clays laid down in Glacial Lake Wisconsin, well developed farms are prevalent. Between such areas of better soils, however, wood expanses prevail in which small clearings are found which may or may not contain a small farmstead. The percentage of land in farms in this subdivision varies from approximately 20 per cent in the western part to over 80 per cent in the eastern as compared with approximately 43 per cent for the region as a whole. From 20 to 40 per cent is in crops and plowable pasture, which is a higher percentage than that of the other subdivisions save the Southeastern Farming and Dairying Area. In fact, in some parts of the western portion of the Central Sand Plain less than 2 per cent of the total area is in crop land and plowable pasture.

The Eastern Farming and Dairying Area is one of mixed farming and dairying with a tendency towards specialization in one or more crops. In the northeastern portion of the area potatoes are the chief cash crop (Figure 6), and in the southeastern part rye becomes the chief cash crop (Figure 5). In both of the above sections, however, dairying is important, and landscape features associated with dairying are conspicuous. The chief crops are rye, oats, and corn, occupying 18.3, 11.2, and 12.3 per cent of the crop land respectively. These are raised primarily for feed and forage crops, although some rye is sold.

In its detailed features the Eastern Farming and Dairying Area may be divided on the basis of these differences into: (1) an outwash plain, (2) a marsh and associated sandy strip, (3) a sand dune and brush land section, and (4) flood plains, terraces, and islands of better soils. (Figure 2)

The Outwash Plain—An outwash plain, varying in width from two to four miles, lies adjacent to the western base of the moraine which forms the eastern boundary of the Central Sand Plain. This seemingly flat land is highly developed in comparison with other parts of the region. A substratum of finer soil and the incorporation of minerals leached from the moraine give to the soil in this strip a higher quality than that generally found elsewhere in the sandy area. It is this quality of soil which accounts for the higher development, a development in which over 40 per cent of the total area is in crops.

In the northern half of the outwash plain one finds a tendency towards specialization in the cropping practices in which potatoes are generally the chief source of farm income. In this section fields of potatoes varying from 5 to 15 acres in size are found on nearly every farm. The loose, friable soil of the outwash plain is a favorable environment for a tuber crop.

Even though potatoes are extensively grown, the importance of dairying is also apparent. Barns are much larger than those on the average farm of the Eastern Farming and Dairying Area, most of them have gambrel-roofs instead of inverted "V" types, and for the most part the barns have one or two silos in connection.

Towards the southern part of the outwash plain, a change in the landscape becomes apparent. The crop associations are slightly different. While potatoes are still raised on a commercial scale they are less important in the farm economy. This is due to the droughtier condition of the soil, a condition that results from a substratum of gravel rather than one of fine materials such as characteristically underly the soil in the northern part of the plain. Fields of rye largely replace the potato fields, and rye becomes the chief cash crop in the southern section. (Figures 5 and 6)

The Marsh Lands and Associated Sandy Strips—The outwash plain merges, along its western border, into a strip of flattish marsh and associated sandy islands and ridges. In the northern portion of this marshy area, artificial drainage ditches carry away excess water, and as a result, the flat area is used for pasture, tame hay, and to some extent for general farming. The southern part of the strip, on the other hand, is undrained, and largely given over to marsh hay, waste land, and occasional small patches of farm land.

The fields of the drained portion of the marsh are large and the buildings of the widely spaced farmsteads are more pretentious and in better repair than those in the undrained part. In the undrained portion of the marshy strip the farm buildings of the widely spaced farms are generally small, in poor condition, and located on some sandy island or ridge within the marsh or on its border. Surrounding the barns of the latter farmsteads are found a number of stacks of marsh hay which add to the meager supply of forage crops for dairying.

The Sand Dunes and Brush Land Section—The area of undulating sand dune topography is largely a section of cut-over brush composed of jack pine and scrub oak in which small scattered farmsteads are found along the roads at widely spaced intervals, or in isolated locations. In the latter instances the farms are accessible only by means of winding trails—merely two ruts in the sand. Less than 10 per cent of the section is cleared, and only a portion of this amount is farmed. The cleared fields are generally fenced to protect the crops from being grazed over by cattle that roam at will through the brushy area in search of the small amount of forage that such vegetation affords. In the cleared plots, corn, rye, and potatoes are the chief crops raised, and, due to the excessive drainage and low fertility of the soil, these crops often produce meager yields.

The farm income from this section is derived primarily from two sources, namely: (1) from a small amount of cream, the end product of the meager dairy industry on most of the farms of the section, and (2) from pine bolts which are hauled to the paper mills at Nekoosa, Port Edwards, or Wisconsin Rapids. Conspicuous features associated with the latter source are the many piles of bolts that one may observe along the roads, and in small clearings which may be reached by winding trails through the brush.

Another conspicuous feature connected with the pulp wood industry is the acreage of reforested lands which the paper companies are enlarging at the rate of approximately 3,000 acres per year. These forested plots, with their rows of trees of uniform heights and of the same species, stand in marked contrast to the heterogeneous expanses of cut-over lands that characterize the general wooded landscape. Beginning in 1950 the Nepco Paper Company hopes to have available a sufficient supply of pine bolts of its own in the Central Sand Plain.

Flood Plains, Terraces, and Islands of Better Soils—The present flood plain of the Wisconsin River is wooded and its use is limited to a scanty amount of grazing together with a patchy development of summer cottages. On either side of the present flood plain of the river the surface rises through a series of terraces which are more pronounced in the northern than in the southern portion of the plain. These terraces contain fragmentary patches of sandy loams interspersed with small areas of sand. Such a distribution of soils is reflected in the cultural pattern of the section. The better soils show a high percentage of improved land while sandy areas are either largely wooded, or having been cleared, they are now mostly abandoned. The patchy character of the areal scene is further epitomized by the types of homesteads; the prosperous appearance of those on the loams stand out in contrast to the smaller homesteads, often in disrepair or even abandoned, that are found in the sandy portion of the terraces.

Islands of better soils, varying in size from less than 5 to over 10 square miles, are found beyond the terraces on the eastern side of the Wisconsin River. Here again, such islands in comparison with surrounding localities are centers of intensive farming and dairying.

URBAN LANDSCAPE

As previously stated, the Central Sand Plain, generally is rural. However, 42 per cent of the people live in cities of over 1,000 inhabitants. These urban centers have a distinct pattern in their arrangement. The cities of the region, save Wisconsin Dells, are in the Eastern Farming and Dairying Area, located on the Wisconsin River, a stream with which they are intimately related. The greater number of the villages are, likewise, located in this eastern subdivision, the largest and one of the best developed areas of the plain. Classified according to their functions, the urban centers may be divided into: (1) villages whose functions are primarily commercial, (2) urban centers, dominantly manufactural, and (3) urban centers, commercial and manufactural.

Commercial Villages—The small commercial villages, ranging from less than fifty to several hundred inhabitants, serve local trade areas, and each is connected by rail or by improved highways to cities within the area or with those on the periphery. Some of these centers contain creameries where butter is made while others are merely centers for collecting cream to be sent to larger towns and cities.

Plainfield, a village of 537 inhabitants, is representative of the small urban centers of the Eastern Farming and Dairying Area. The whole village complex reflects its functions. It is dominantly a commercial center, containing feed stores, lumber and coal yards, potato warehouses, gasoline storage tanks, and a small stockyard, in addition to the usual array of merchandising and service establishments that characterize a commercial village of comparable size.

Urban Centers, Dominantly Manufactural—Nekoosa, Port Edwards, and Biron, urban centers which are dominantly manufactural, started as saw mill towns making use of the available water power at rapids in the Wisconsin River where the stream had cut its channel to the underlying crystalline rocks. With the passing of the timber, the saw mills were replaced by paper and pulp mills, the industries upon which the cities are now dependent for their existence. The trade areas which these neuclei serve are practically confined to their corporate limits; and the residential sections are occupied almost exclusively by people connected either directly or indirectly with the paper industry.

As previously stated, the paper mills, located at these centers were established at sites of former saw mills where both water power and an adequate water supply were available, factors which have located the paper mills in the Central Sand Plain. In relation to raw materials and markets, location in this region is disadvantageous, since most of the raw materials come from, and the finished products must be sent to outside regions. The pulp wood comes largely from northern Wisconsin, Minnesota, and Canada; the sulphur from Louisiana, and the limestone from northeastern Wisconsin and Michigan. The markets are more widespread, since they include central and eastern United States.

A distant view of Nekoosa, a representative of the manufactural group, includes lofty smokestacks of the paper mill, located on the west bank of the Wisconsin River, and the city's water tower rising above what appears to be a grove. Approaching the city, down the terraced descent to the river, the outlines of the mill and the city's structure come into view beyond the artificial lake that has been formed by a dam across the river at this point. The paper manufacturing plant and its associated storage yard and railroad tracks are the most distinctive features of this urban landscape, since the residences and the commercial establishments are, in the main, like those features of other cities of comparable size. The rail lines leading northward from the mill separate into a series of spur lines which penetrate the various parts of the storage yard, an area of approximately 30 acres, in which are the long ricks of bolts and the coal sheds.

Urban Centers, Commercial and Manufactural—Stevens Point (13,000) and Wisconsin Rapids (8,000) are the urban centers in this classification. They differ from the preceding class in: (1) their functions, which include both commercial and manufactural activities, (2) their size, and (3) their relation to the Central Sand Plain in which they are located. As in the preceding class of urban centers, paper mills are important, but in Stevens Point and Wisconsin Rapids other establishments such as furniture factories which had their beginning during the lumbering stage, feed mills which supply dairy feeds to the Central Sand Plain and contiguous areas, and milk products plants are included in the manufactural aspects of these cities as well. Due to the range of functions found in these cities, they have become considerably larger than the manufactural centers previously discussed.

The commercial functions are more closely related to the Central Sand Plain than are the manufactural. The trade areas of these cities include the northern part of the plain as well as parts of contiguous regions. Their manufactural functions, while related in part to the region in which they are located, are dominantly related to more remote regions, even to the extent of the whole United States and a part of Canada.

In the general structure of Stevens Point and Wisconsin Rapids, the manufactural and commercial sections are adjacent to the Wisconsin River where power facilities and transportation lines are concentrated. The manufactural plants are usually next to the stream, and these in turn are flanked by storage and wholesaling establishments, which are succeeded by retailing centers. The retailing establishments are concentrated along one or more of the principal streets, both paralleling the storage and warehousing facilities and at right angles to them. Residential aspects of these cities are not unusual for cities of comparable size.

THE SOUTHEASTERN FARMING AND DAIRYING AREA

The Southeastern Farming and Dairying Area, embracing the southern portion of Adams and parts of Juneau, Columbia and Sauk Counties, has greater relief than any of the other subdivisions of the Central Sand Plain. Differences of 200 to 300 feet between the ridge tops and the intervening valleys, within short distances, are not uncommon. (Plate 2) The sandstone ridges and knobs become more numerous towards the southern, western, and northwestern borders of the region, where portions of the strata that formerly continued into the West Central Valley Region and the Western Ridge and Valley Region (Figure 1) have been cut off from the main body by erosion.

The soil of the Southeastern Farming and Dairying Area, while varied, is, for the area as a whole, more suitable for farming than that of the other subdivisions of the Central Sand Plain. An exception to this quality of soil, however, is found in the central portion of the area where there is a predominance of sandy soil of relatively low utility. In this particular section "blowouts" are not uncommon; jack pine is dominant in the tree cover; and fallow and waste land occupy a high percentage of the cleared portion of the section. Leaving the central part of the area and going towards the borders, jack pine is largely replaced by oak and sandy loams become the dominant soils. The sandstone knobs and ridges in these parts are generally capped with Lower Magnesian dolomite rather than Dresbach sandstone, and as a result of the weathering of the dolomite, the soils have higher silt content which gives to them a higher quality.

Soil and topographic differences within the area give a distinctive pattern to the cleared and wooded sections. The crests and upper slopes of the ridges and mounds are wooded, while the lower slopes and intervening valleys are either farmed or devoted to cleared pasture. (Plate 4). A second Characteristic location of wooded lands is along the streams, where narrow ribbons of brush wind about, in conforming to the stream courses.

This subdivision differs from the Eastern Farming and Dairying Area, moreover, in having a better quality of soils, a higher degree of development, and a generally better quality of homes. For the area as a whole there is a higher percentage of improved land.[6] In this subdivision the average farm contains from 8 to 15 dairy cattle; the figure for the Central Sand Plain as a whole is 7.8.[7]

The homesteads are tied to each other and to the surrounding areas by a net of highways, whose rectangular pattern corresponds in general to section lines, a pattern that is interrupted in parts of the Central Sand Plain by marshes and brushy waste lands. The surfaced roads are thus spaced sufficiently close to give accessibility to all the farms within the subdivision, an important factor in an area where the inhabitants must make frequent use of the highways in transporting milk and cream to the condensaries and creameries.

The urban development of this subdivision is limited, since most of the urban centers serving the area have a peripheral location in relation to it. An exception is the city of Wisconsin Dells, which is well within its borders. This center is predominantly a resort city. It owes its importance as a resort center to its proximity to the scenic features of the Dells of the Wisconsin River, which is a part of the gorge of the glacially-diverted Wisconsin River. The most conspicuous features of this city are many hotels and amusement establishments connected with the resort business. In addition, summer cottages along the west bank of the river, boat houses, boats anchored at the piers, parking spaces, and booths with souvenirs and tourists' needs add to the unique character of Wisconsin Dells and cause it to be distinctly different from other cities of the Central Sand Plain.

by fallow and the stubble of small grains. Most of the wood-

Minor manufactural features in addition to its resort aspect are found within the city, such as a small creamery and a dairy fixtures plant. The creamery draws practically all of its cream, amounting to 7,000 pounds per day,[8] from the Central Sand Plain; the dairy fixtures plant might easily be missed by the casual observer passing through the city.

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[6] Subdivision	Per Cent of Total Area in Farms	Per Cent of Total Area in Crops
Eastern Farming and Dairying Area	60	27.0
Southeastern Farming and Dairying Area	71	32.0
Central Marsh Area	26	5.6
Western Brush and Dairying Area	34	9.5

Statistics from Crop Reporting Service of Wisconsin for 1929 and United States Census of 1930 (Figures for 1929).

[7] Ebeling, Walter, H., et. al., Wisconsin Agriculture, Bulletin 140 (1932), pp. 36-43.

[8] Personal interview with the manager.

THE CENTRAL MARSH AREA

The Central Marsh Area, comprising 610 square miles, is the least developed of the subdivisions of the Central Sand Plain (p. 17). It is a level featureless plain except for a few sandstone crags that rise abruptly from its surface, and numerous low sand islands. The islands are but a few feet above the general level, and therefore do not produce marked topographic features. In the marsh localities jack pine, aspen, willow, and tamarack, with an undergrowth of sedge and blueberries, comprise the natural cover; on the sand islands scrub oak with an undergrowth of hazel and sweet fern, and scattered jack pine make up the vegetation complex; while the tops of the sandstone knobs are either devoid of vegetation or have a sparse growth of pine. In fact, the change in vegetation is so sharp that the sandy islands may be located by noting the vegetation of the area.

The small amount of general farming that is carried on in the Central Marsh Area is confined primarily to the northern border, adjacent to the North Central Dairy Region of Wisconsin, (Figure 1) a region intensively developed, and to an island of approximately 60 square miles of higher utilization in the southeastern portion of the area (Figure 2). The well kept farmsteads, with comfortable homes, large red dairy barns and their accompanying silos found in this island, are comparable to like features in the West Central Valley Region to the south. The remainder of the general farming is found scattered over the subdivision, generally along the drainage ditches. In this portion of the Central Sand Plain there is a large drainage project that hindered rather than helped to adjust the use of the area to its natural conditions.

The chief importance of the Central Marsh Area for farming lies in its specialized crops, such as cranberries, sphagnum moss, and blueberries. Wisconsin ranks third among the states of the United States in the production of cranberries, having 1,150 acres in producing marshes, of which the Central Marsh Area contains 1,090 acres,[9] or approximately 95 per cent of the state's acreage. The present production lies mainly in two separate areas: (1) southern Wood County, for which the commercial outlet is Wisconsin Rapids, and (2) southeastern Jack-

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[9] 15th Census of United States.

son, northeastern Monroe, and west central Juneau Counties, for which the outlet is Mather.

The natural environment in these two districts is very favorable for cranberry production. The summers are fairly cool (p. 4), which is a normal requisite; the necessary acidic peat soils are at hand; when sand is used in the marshes it can be obtained near-by at the margin of the marsh; and the flat terrain can easily be converted into wide reservoirs to supply the necessary water, by building low dams at right angles to the natural drainage.

Sphagnum moss, which requires an abundance of ground water, is found in the same general areas in which cranberries are produced. Artificial drainage has almost restricted this plant, formerly far more widespread, to the northern and western fringes of the Central Marsh Area where the water table is higher. Over 80,000 bales, each weighing approximately 20 pounds, are shipped yearly from Wisconsin Rapids. This is estimated to be from one-half to two-thirds of Wisconsin's output, a state which produces from two-thirds to three-fourths of the commercial crop of the United States.[10]

THE WESTERN BRUSH AND DAIRYING AREA

As the name implies, the Western Brush and Dairying Area is largely brush covered. In it small clearings are found where feed and forage crops are raised for a limited dairy industry. Similar to the Central Marsh Area, large portions of this subdivision are waste land (Figures 3 and 4) in which there are practically no inhabitants. In such areas one may drive for miles and see no cultural imprint save the two ruts in the sand that suffice for roads. In some localities, however, as near some of the sandstone outliers, and in isolated patches, the ubitiquous sand is replaced by sandy loams, and as a result the expanses of waste and isolated farmsteads are replaced by limited areas of intensive agriculture. It often occurs that these well developed areas encircle the outliers in bands varying in width from a half mile to over a mile.

On the average farm the greater part of the land is covered with brush and cut-over timber, but most of the timbered portion of the farm is pastured even though such types of pasture

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[10] Data supplied by the Wisconsin Moss Company of Wisconsin Rapids

furnish but scanty forage. Woodland pasture is supplemented by fallow and the stubble of small grains. Most of the woodland is unfenced, and whether privately, state, or county owned, it is grazed over indiscriminately by cattle from near-by farmsteads.

The three chief crops, clover and timothy hay, oats, and corn occupy 76 per cent of the cropped land. To supplement the forage produced by clover and timothy and that supplied by corn fodder, soya beans are raised, and wild hay is cut from the scattered areas of marsh. The importance of marsh hay is emphasized by stacks of it about the barns throughout the area.

The urban development in both the Western Brush and Dairying Area and the Central Marsh Area is meager. With respect to both of these subdivisions the cities are peripheral, and only cross-road villages are found within the areas. These small centers serve as foci for collection of the small amount of produce, and for distribution of commercial products to their limited and relatively barren trade areas.

URBAN DEVELOPMENT OF THE ENTIRE REGION

The limited agricultural development and the sparse population of the Central Sand Plain are not sufficient for extensive urbanization. Most of the Central Sand Plain is included in the trade areas of peripheral cities, whose chief sources of produce are the better-developed regions in which they are located. The low fertility and the droughty condition of the sandy soils, which are so widespread in the Central Sand Plain, restrict the agricultural development of the region. Furthermore, these adverse environmental conditions augment the decadence of the rural areas so that more and more land is either abandoned or reforested. It is only where special features exist, such as sites for water power with their associated paper mills, and scenic features such as the Dells of the Wisconsin River, that urban centers within the Central Sand Plain seem to be stable.

INSOLUBLE RESIDUES FROM WISCONSIN SEDIMENTARY ROCKS*

PART 1. INSOLUBLE RESIDUES AS AN AID IN THE STUDY OF SEDIMENTARY ROCKS

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Introduction.—It is a well known fact that almost every sedimentary rock leaves some *insoluble residue* when digested in hydrochloric acid. The amount of this material may range from less than 1% (as in very pure limestones and dolomites) to more than 99% (as in very pure sandstones). While percentages of insoluble material have been recorded from chemical analyses for many years, little attention has been paid to that material until very recently. It is the purpose of this brief discussion to call attention to the uses that may be made of insoluble residues in the study of sedimentary rocks.

POSSIBLE USES OF INSOLUBLE RESIDUES

1. All students of sedimentary rocks are aware of the uses which have been made of diagnostic fossils (both macroscopic and microscopic), heavy detrital minerals, and insoluble residues for purposes of correlation. Work now in progress on Wisconsin Silurian dolomites has shown that certain residues appear to mark definite horizons in wells and exposures. Many problems of a similar nature, involving the determination of the amount, character and possible stratigraphic significance of insoluble residues in both well cuttings and exposures are awaiting investigation in Wisconsin as well as elsewhere.

2. Paleontologists are following with interest the rapid increase in number and variety of micro-fossils (foraminifera, conodonts, scolecodonts, etc.), which are being recovered from calcareous rocks by acid digestion (See Plate V, Figs. 4, 6-8,

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* Part 1 is written specifically to acquaint thesis students in Geology with the methods and potentialities of insoluble residue analysis, and to suggest problems for future investigation. It represents one of the research projects made possible by a grant from the Wisconsin Alumni Research Foundation to the writer for the fall semester, 1933-34. Part 2 gives in abstract form the results of four thesis projects, investigated in the Sedimentation Laboratory of the Department of Geology at the University of Wisconsin, under the direction of Drs. W. H. Twenhofel and R. R. Shrock. Laboratory materials for these projects were furnished by the Milwaukee Public Museum.

13). Not only are these of value for correlation but they also help to picture life conditions and relations at the time they lived. Investigation, by insoluble residue analysis, of Pre-Cambrian calcareous rocks might produce significant results concerning the amount and character of the life of that time. Much may be learned about the very early growth stages of certain organisms if their youthful shells can be found. Such shells have been recovered from certain Wisconsin dolomites, and further investigations along these lines may produce interesting results.

3. Many investigators have found that insoluble residues aid in reconstructing conditions of sedimentation. The basal beds of the Black River limestone in Indiana, Illinois and Wisconsin frequently contain a high percentage of detrital quartz. When released from the calcareous matrix, the grains are found to be well rounded and frosted (See Plate V, Figs. 5, 9). These conditions obviously suggest affinities with the underlying St. Peter sandstone. The basal beds of the St. Lawrence dolomite, the Oneota dolomite, the Black River limestone and the Devonian of Wisconsin need to be studied for their detrital content. Original chert nodules, siliceous oölites, and other insoluble substances often furnish information of value (See Plate V, Figs. 1-3). Dolocastic chert has been reported frequently and chert masses containing impressions of crystals other than those of dolomite should be looked for. Small chert nodules in the Mayville dolomite of Wisconsin contain calcitic crinoid fragments and brachiopod shells, both of which are suggestive of the origin of the chert. The detailed study of these nodules, both as to faunal content and time of origin, promises some interesting results. Much has been written concerning the significance of glauconite in sedimentary rocks. Most of the Wisconsin dolomites contain some glauconite, and investigations of this material will be aided by insoluble residue analysis.

4. It is widely recognized that almost all sedimentary rocks have undergone certain changes since deposition as sediments. Most of these are so well known that they need not be mentioned. A few, however, are cleared up considerably by light thrown on them from studies of insoluble residues. European geologists, and very recently Americans also, have reported a number of authigenic minerals from sedimentary rocks. Quartz

and feldspar are the chief ones, and both have been found in abundance in Wisconsin dolomites. Microcline from the Silurian dolomites occurs as prismatic crystals with well developed brachy- and macropinacoidal faces. The crystals are composed of a shell of authigenic origin built around, and in crystallographic continuity with, a nuclear detrital grain of microcline (See Plate V, Figs. 11-12). Other kinds of authigenic feldspar have been found in insoluble residues from Wisconsin rocks (*e.g.* the Mendota dolomite), but they have not yet been definitely identified. Their thorough study constitutes an important problem. The recovery and accurate identification of all authigenic minerals in sedimentary rocks are needed to understand adequately one of the important changes that takes place in a sedimentary rock after deposition (See Plate 5, Fig. 10).

Recent work by the writer on certain Wisconsin dolomites shows that, when these rocks are treated for a short time with a weak solution of hydrochloric acid, the crystals are not only separated from each other but are also broken up into cleavage fragments. This fragmentation is due to the fact that solution proceeds most rapidly along the cleavage planes of the mineral. Small rhombs of carbonate carried by certain spring waters may have originated by the solution action just described. Investigations of the way various minerals behave during solution might produce significant results.

5. Students of sedimentary rocks are familiar with the way English, Scotch and French petrologists have utilized heavy detrital minerals in determining provenances of sediments. Similar work has been initiated in America recently, and many problems have been outlined and suggested. The presence of detrital minerals in certain of the limestones on Anticosti island suggests that it might be very much worth while to recover the insoluble residues of all calcareous rocks lying on the periphery, or upon the main mass, of the Canadian Shield, and study them along with the heavy detrital minerals from the clastic rocks to determine the relations between the sediments and the crystalline terrane from which they presumably were derived. By utilizing exposures and well cuttings studies of the calcareous formations, as well as of the clastic ones, which lie around buried or partly exhumed Wisconsin Pre-Cambrian hills might be pursued with significant results.

6. Geologists have been able, by using chemical and stratigraphic data, to estimate roughly the relative percentages of sandstone, shale and limestone in the world's sedimentary column. Insoluble residue analysis, extended to include all types of sedimentary rocks, might well alter those estimates somewhat. In order to carry out such a program, however, it would be necessary to sample all rocks in some uniform manner.

7. Many field geologists occasionally find themselves at a loss to describe satisfactorily and accurately some sedimentary rock. A chemical analysis showing soluble material, sand, silt and clay would make this much easier and more definite. The entire Wisconsin sedimentary column needs to be studied with this in mind.

PART 2. STUDIES OF WISCONSIN SEDIMENTARY ROCKS

1. *INSOLUBLE RESIDUES FROM WISCONSIN SILURIAN DOLOMITES*

*George B. Burpee**

Purpose.—This investigation was initiated to determine whether the lithologic units of the Wisconsin Silurian possessed characteristic insoluble residues which might be of assistance in correlating exposed formations with those encountered in wells down the dip from the outcrop.

Procedure.—The samples used in this study were collected by Dr. R. R. Shrock in eastern Wisconsin during the summers of 1930 and 1931. They were analyzed in the Sedimentation Laboratory at the University of Wisconsin with laboratory materials furnished by the Milwaukee Public Museum.

A 20-40 gram sample was crushed into fragments about one-half inch in greatest dimension, and then dissolved in a 50% solution of hydrochloric acid at a temperature slightly below boiling. It was necessary in some cases to wash the sample and treat it with fresh acid several times before all of the soluble matter was dissolved. When all possible reaction had ceased the acid was decanted and the residue washed clean of acid and

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* Submitted as a thesis for the degree of Master of Arts (Geology) at the University of Wisconsin, 1932. Abstracted by R. R. Shrock.

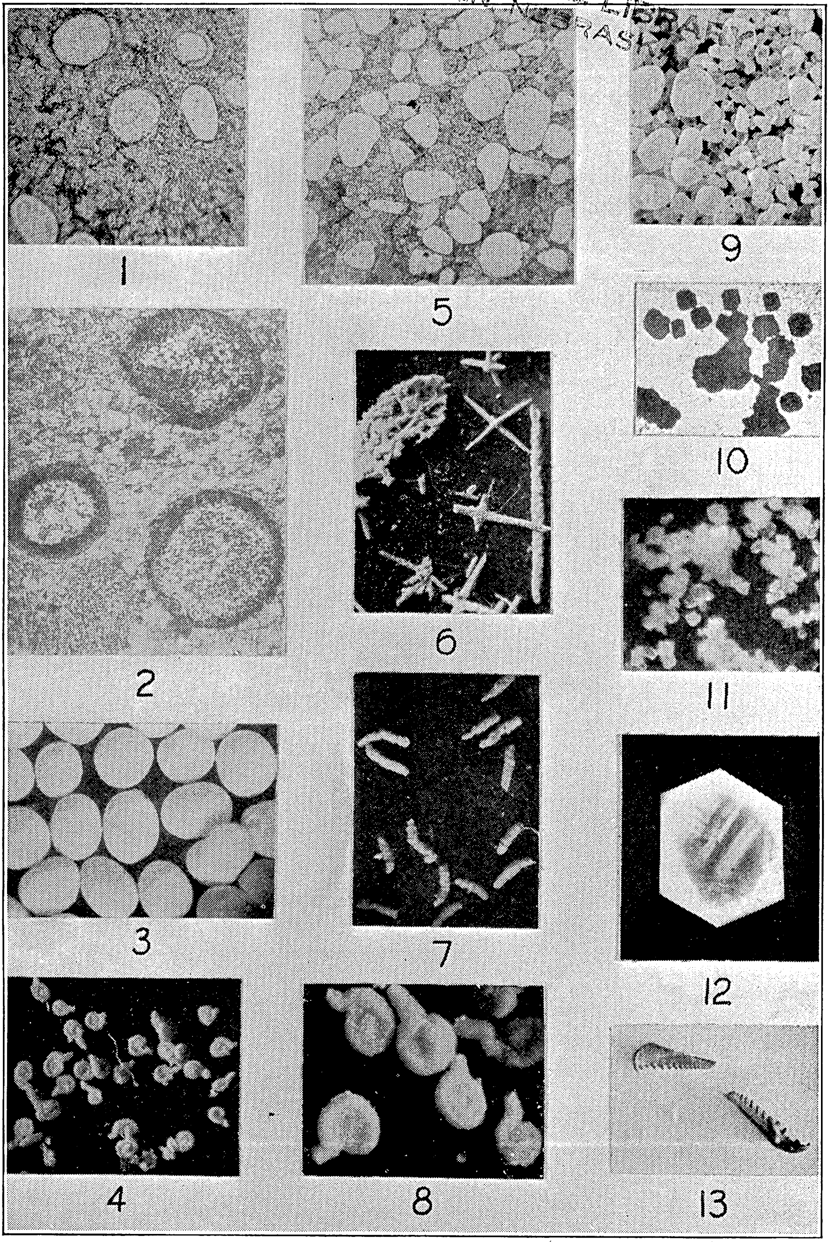

PLATE V. *1.* Thin section showing siliceous oölites in a calcareous matrix (x10). *2.* Same as *1,* enlarged (x25), showing several siliceous oölites under crossed nicols. Note the central core of quartz. *3.* Residue of siliceous oölites from same rock as *1* and *2* (x15). *4.* Siliceous foraminifera (x8). *5.* Detrital quartz grains in a clacareous matrix, shown in a thin section (x15). *6.* Siliceous sponge spicules (x4). *7.* Siliceous foraminifera (x8). *8.* Several enlarged (x20) specimens of *4.* *9.* Residue of detrital quartz grains from same rock as *5* (x10). Note rounding and frosting. *10.* Authigenic pyrite crystals (x10). *11.* Authigenic microcline crystals (x25). *12.* An authigenic microcline crystal, greatly magnified (x200) and with crossed nicols, showing the nuclear detrital grain around which the later authigenic shell grew (Photograph by W. L. Wilgus). *13.* Chitinous jaws (x10).

clay material. From this procedure only a granular residue remained. This was then carefully washed onto a tared watch glass, dried and weighed. It was then filed for future microscopic study. No attempt was made to determine the amount of clayey matter in the residues.

Results.—Three general types of insoluble residues were found. First, almost all of the samples analyzed contained a small percentage (0.5%—3%) of very fine to fine authigenic quartz, and a second mineral then unidentified and thought also to be quartz with a peculiar crystal habit, but now known to be authigenic feldspar (microcline). The quartz consists of clear, anhedral or euhedral prismatic crystals with rhombohedral terminations. The feldspar usually occurs as euhedral prismatic crystals with well developed brachy- and macropinacoidal faces. They sometimes have a nucleus consisting of a detrital grain of microcline. In these cases the authigenic shell of the crystal is developed in crystallographic continuity with the nuclear grain. Second, silicified fossils although far less abundant than the authigenic minerals just described comprise the diagnostic fraction of the residues. In order of abundance these fossils are sponge spicules, silicified foraminifera, fragments of brachiopod shells, internal casts of ostracods and bryozoans, fragments of crinoids and corals, and minute silicified gastropods or glauconitic casts of such shells. The foraminifera, and possibly the ostracods, have stratigraphic significance. It might be added that a residue composed chiefly of rounded detrital grains of quartz was found in the basal beds of the Devonian, which immediately overlie the Silurian at Cedarburg.

The *Mayville* dolomite is characterized by residues of chert and hexactinellid sponge spicules. The amount of the residue ranges from less than 1% to as much as 15%, but these percentages do not include the chert nodules which are abundant at certain horizons throughout the formation. The *Byron* dolomite rarely contains more than 2% of insoluble material, but has a distinctive foraminiferal-ostracod fauna which has been found at Burlington, Waukesha (in what may be the so-called *Waukesha* beds), and in well cuttings from a deep well near Racine. The *Coral* beds as exposed in the vicinity of Valders contain from 3%—26% of insoluble material, consisting largely of small crystals of quartz and feldspar (Burpee, without optical study, called all of the crystals quartz). The *Racine* beds, as developed in the vicinity of Racine, contain only a very small residue (seldom over 1%), consisting of a little chert, some very fine anhedral crystals of either quartz or feldspar and a few masses of marcasite (?). A reef facies of the Racine ("Guelph") at Cedarburg contains no appreciable amount of insoluble material, but is overlaid unconformably by Devonian strata which carry a distinctive residue of rounded detrital quartz grains. The *Waubakee* dolomite, youngest of the Silurian formations of Wisconsin and known only from a few scattered exposures in the vicinity of Milwaukee, contains no appreciable residue.

In summary it may be stated that the Silurian dolomites of Wisconsin carry a diversity of insoluble material, usually in small amount; but that with the exception of certain silicified fossils, the residues so far obtained and studied do not have stratigraphic significance. The foraminifera, and possibly the ostracods, seem to be limited to a narrow stratigraphic range in the Byron formation, and may with further investigations become a useful horizon marker.

2. *THE INSOLUBLE RESIDUES OF THE ONEOTA DOLOMITE OF WESTERN WISCONSIN.*

*Joseph J. Drindak**

Purpose.—This study was undertaken to ascertain the amount and character of the insoluble material in the Oneota dolomite, and in the immediately underlying arenaceous strata, in western Wisconsin; and to determine whether that insoluble material might be of stratigraphic or economic importance.

Procedure.—Samples were collected in the summer of 1932 with the aid of E. H. Powell and R. R. Shrock. They were taken in vertical sections about five feet apart unless there was a distinct change in lithology, in which case a sample was taken where the change occurred, and then the same procedure as before was followed. In one section samples were taken every six inches in the lower part and every foot in the upper part. The analytical work was carried on in the Sedimentation Labora-

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* Submitted as a thesis for the degree of Bachelor of Philosophy (Geology) at the University of Wisconsin, 1933. Abstracted by R. R. Shrock.

tory at the University of Wisconsin, with laboratory materials furnished by the Milwaukee Public Museum.

About a 20-gram sample was crushed into small fragments averaging about one-half inch in greatest dimension, wetted with distilled water and then dissolved in a 50% solution of hydrochloric acid. In some instances the sample had to be washed and treated with new acid several times before all of the soluble rock was dissolved. After solution had ceased completely the acid was decanted, and the remaining insoluble residue was washed until all of the finely divided silt and clay had been removed and only a granular residue remained. This was then washed onto a tared watch glass, dried, weighed, and studied.

Results.—The insoluble constituents of the Oneota dolomite show considerable diversity. (1) Silicified corals and sponge spicules, mainly monaxons, are present throughout the formation in the sections studied, but do not seem to have stratigraphic significance. (2) Quartz is abundantly represented in the lower part of the formation by rounded and frosted detrital grains, and throughout the formation by minute crystals and clusters of crystals. (3) Siliceous oölites are usually present in the oölitic beds of the formation, and may show concentric structure. (4) Glauconite is abundant in certain beds ("Green speckled beds")* and is common throughout the formation in small amount. Dolocastic chert was encountered in some beds and mica flakes are not uncommon in the arenaceous strata immediately underlying the base of the formation.

On the basis of lithology and field relations, and to a very limited extent on the basis of insoluble residue content, it is possible to subdivide the Oneota dolomite into several fairly distinct zones, as shown in Fig. 1. These have interesting, though rarely distinctive, residues.

Zone 1 belongs below the Oneota dolomite and is probably to be correlated with the *Madison* sandstone of the central and eastern parts of Wisconsin. It bears such a close relation to the basal part of the Oneota, however, that it was thought advisable to study its insoluble content along with that of the over-

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* The basal part of the Oneota dolomite is characterized by thin beds of bluish-gray dolomite speckled or spotted with roughly spheroidal masses of greenish, or when weathered yellowish or slightly bluish, clay-like matter composed in large part of glauconite. These beds are specially designated in the sections of Fig. 1.

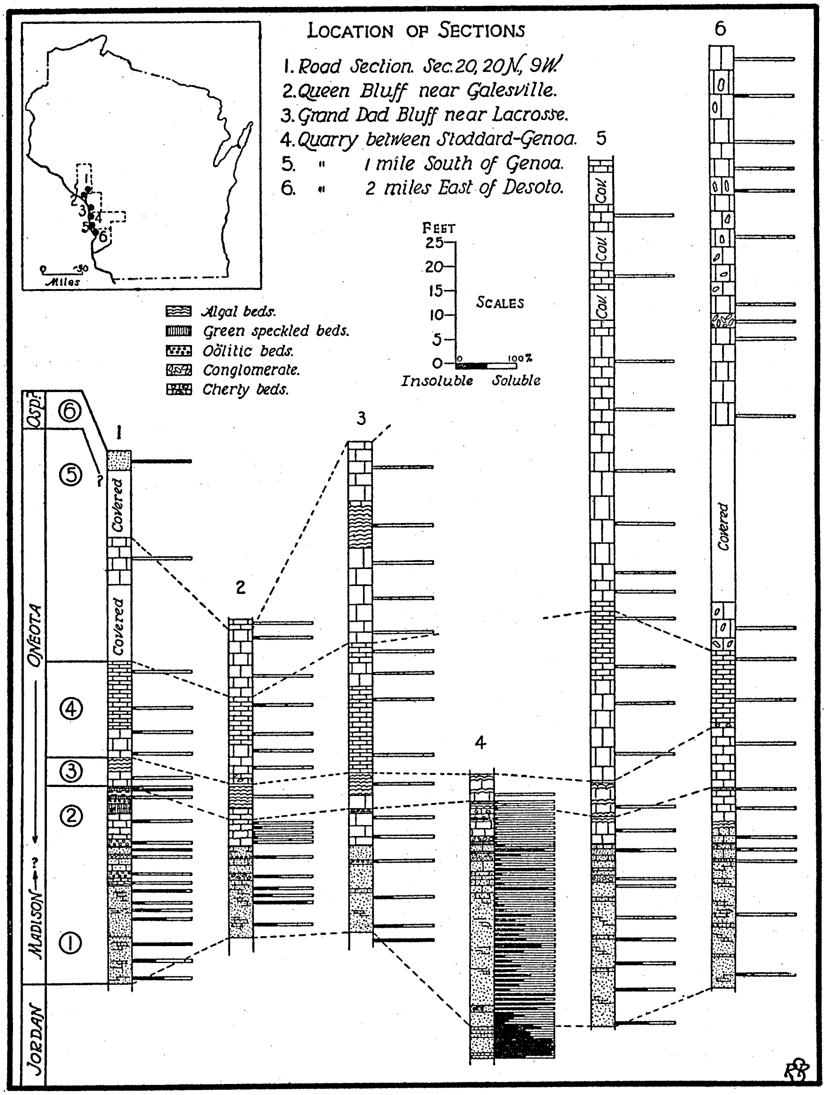

Fig. 1. Chart of stratigraphic sections showing the relative amounts of soluble and insoluble material at various horizons in the Oneota dolomite of western Wisconsin. The Madison-Oneota boundary is uncertain in some sections, hence it is not indicated.

lying formation. The base of zone 1 was taken at the top of the *Jordan* sandstone where the first strong dolomite influence appeared. The top of the zone, which has been reported as an unconformity, could not always be determined, hence no definite contact between the top of the Madison and the base of the Oneota is indicated in the sections in Fig. 1. Sand lenses and layers, dolomitically-cemented arenaceous beds, shale layers and conglomerates characterize the zone, but neither their presence nor number is consistent. The residues are composed mainly of rounded and frosted detrital grains of quartz in the sandstone layers, and both detrital and authigenic quartz in the dolomitic beds. Chert, glauconite and mica flakes were also obtained from some of the residues, but usually in small amount. The insoluble material tends to decrease upward in the zone.

Zone 2 comprises the basal part of the Oneota dolomite and is characterized by a diversity of lithology. The "green speckled beds" are always prominent, but there are also oölitic beds, shale layers, algal layers and conglomerates, all of which vary in thickness and number. All are highly dolomitic and contain small percentages of insoluble material. The detrital quartz of zone 1 gives way upward to authigenic quartz pretty largely, which occurs in the form of single crystals or crystal clusters. Chert is found in the algal layers, while the oölitic beds yield siliceous oölites. Glauconite is found especially abundant in the "green speckled beds" and may make up as much as 30% of the residues. Sponge spicules and casts of cup corals occur sparsely throughout the zone.

Zone 3 is characterized by a well developed algal biostrome. The insoluble material is present in small amount, and consists of authigenic quartz, chert masses, siliceous oölites and rare sponge spicules. Large chert masses may be seen in this zone in the field but they are not considered in percentages of insoluble material, for in the collection of samples every effort was made to obtain dolomite free of visible chert.

Zone 4 is an interval of thin-bedded dolomites, designated as "punky beds"* in the field, alternating with thicker strata of the same general lithology. The insoluble content is quite small, and is composed mainly of fine authigenic quartz, small chert masses,

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* These fine-grained, thin-bedded dolomites have been designated in the field as the "punky beds", because when struck with a hammer they give a thud.

siliceous oölites, dolocastic chert, sponge spicules and glauconite grains.

Zone 5 is characterized by thick, massive beds of dolomite, somewhat cherty in places and often containing a discontinuous algal biostrome or a conglomerate horizon. Authigenic quartz crystals, both singly and in clusters, are common in this zone along with spongy chert. Chert and siliceous cement increase upward in some sections. The large masses of chert are not included in the residue percentages.

Zone 6 represents a sequence of arenaceous strata above the Oneota dolomite and probably correlates with either the *New Richmond* or *St. Peter* sandstone. The insoluble residue which comprises nearly the entire rock consists of siliceous cementing material, detrital quartz grains and a few siliceous oölites.

In summary it may be said that this study of the Oneota dolomite has shown that underlying and overlying formations (Madison sandstone below and New Richmond or St. Peter sandstone above) can be sharply differentiated from the Oneota on the basis of the amount and character of the residues; but that it is not possible to identify definite zones or horizons within the dolomite formation with any degree of success.

3. *A SEDIMENTATIONAL STUDY OF A PART OF THE TREMPEALEAU FORMATION IN SOUTHERN WISCONSIN.*

*Bernhard O. Hougen.**

Purpose.—This study was made to determine: (1) the percentages of soluble (calcareous) and insoluble (sand, silt and clay) materials in selected exposures of the Trempealeau formation in southern Wisconsin; and (2) whether the insoluble constituents possessed characteristics which might be used either for interpreting conditions of sedimentation at the time of deposition or for correlation purposes.

Procedure.—Samples were collected, with the aid of G. O. Raasch, from four exposures near Avoca, Muscoda, Gotham and Kingston, along or near the Wisconsin river valley (See Fig. 1).

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* Submitted as a thesis for the degree of Bachelor of Philosophy (Geology) at the University of Wisconsin, 1933. Abstracted by R. R. Shrock.

Hand speciments (about 2″x3″x3″) were taken every three feet throughout the section unless individual strata were under that figure in thickness, in which case several small fragments were taken from each of the thin beds in the three-foot zone.

After a microscopic examination of the sample was made (both before and after crushing), about 20 grams of the crushed rock (fragments about ½ inch in greatest dimension) were digested in a 50% solution of hydrochloric acid at a temperature slightly below boiling for twenty four hours. The sample was then washed and treated with new acid. This was continued until all solution action ceased. The acid was then decanted and the residue washed free from acid with distilled water. The residue was then dried and weighed, after which it was moistened and poured into a specially devised water classifier, where the clay content was separated from the sand-silt fraction.* The latter fraction, saved in the process of separation, was then dried and weighed. Percentages of soluble material, sand-silt material and clay were then computed. It must be emphasized that while the methods used did not give highly accurate results, nevertheless, they are quite satisfactory for the purposes intended because of the variation of the formation both vertically and horizontally.

Results.—The insoluble residues from the Trempealeau formation in the four sections studied consist mainly of clay; silt; rounded and angular quartz grains; authigenic quartz, and possibly feldspar, crystals; and glauconite. The soluble material is almost entirely calcite and dolomite (relative percentages were not determined), with a very small amount of iron oxide.

The results of the analyses are shown on Fig. 1. The *St. Lawrence* dolomite always is impure carrying as much as 30% of insoluble material. The *Lodi* shale carries a surprising amount of soluble matter, in some cases well over 50%. It is also apparent that the clay and sand-silt material may or may not be fairly evenly balanced. The *Jordan* sandstone was found to contain a considerable amount of calcareous material in most of the sampes. This situation is not always apparent in outcrops. The main importance of the insoluble residue data is to give a more accu-

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*Considerable experimentation was necessary before the proper procedure and apparatus were discovered. Finally, however, it was possible to remove the *clay* (particles less than 1/256 mm. in largest dimension) rather successfully.

rate picture of rock composition than has been available before. In themselves the residues do not possess characteristics which are distinctive, and hence are of little value for correlation purposes.

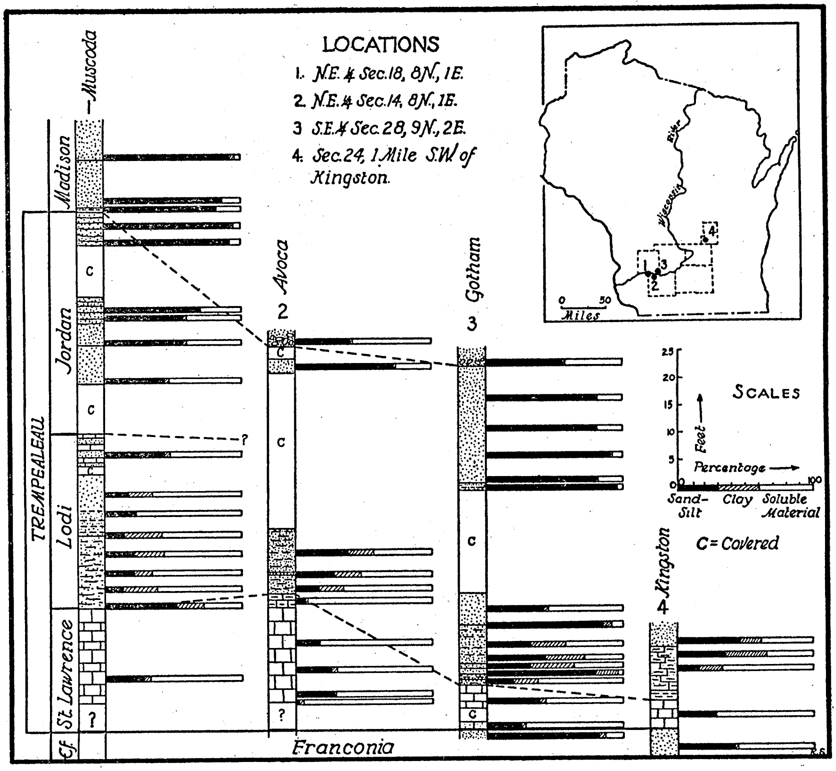

Fig. 1. Chart of stratigraphic sections showing the relative amounts of soluble matter, sand and silt, and clay at various horizons of the Trempealeau formation in southern Wisconsin. Sections were measured by G. O. Raasch.

4. *INSOLUBLE RESIDUES OF THE MENDOTA (ST. LAWRENCE) DOLOMITE.*

Ray E. Wilcox.[*]

Purpose.—This investigation was undertaken to find the amount, character and possible uses of any insoluble materials that might be present in the Mendota dolomite of the Madison

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[*] Submitted as a thesis for the degree of Bachelor of Philosophy (Geology) at the University of Wisconsin, 1933. Abstracted by R. R. Shrock.

vicinity. Correlation of the Mendota with the St. Lawrence dolomite follows the practice of Wisconsin geologists.

Procedure.—Samples were collected with the aid of Mr. F. T. Thwaites. Some well cuttings were also obtained from him. The analyses were made in the Sedimentation at the University of Wisconsin, with laboratory materials furnished by the Milwaukee Public Museum.

From 25 to 50 grams of the sample were crushed to fragments averaging about 0.3 cms. in greatest dimension, placed in a beaker and wetted with distilled water, and then dissolved in a 50% solution of hydrochloric acid at a temperature slightly below boiling. It was in some cases necessary to wash the samples and then add new acid several times before all of the soluble matter was dissolved. After all action had ceased the acid was decanted and the residue washed free of acid. Care was taken not to pour off any of the residue. It was then washed onto a tared watch glass, dried, and weighed. It was then returned to a beaker, wetted and the fine clayey material removed by careful decantation. The result was a clean, granular residue whose particles were above clay dimensions. This residue was then washed onto a tared watch glass, dried and weighed. The method just outlined gave a reasonably satisfactory separation of the sand-silt and clay fractions of the original residue.

Results.—The results of the investigation are tabulated on Fig. 1. The insoluble residues consisted of the following: (1) white, green or brown clay of about the same amount in most of the samples; (2) rounded and frosted detrital grains of quartz, scattered throughout the formation, and showing incipient secondary enlargement; (3) authigenic feldspar crystals consisting of a shell of feldspar of authigenic origin around a nuclear detrital grain of microcline; (4) fairly large flakes of detrital muscovite; (5) fine to coarse, dark to light green, rounded and polished grains of glauconite; and (6) irregular masses of soft, argillaceous, cinder-like material containing ferruginous matter.

Three significant facts are apparent from the data tabulated on Fig. 1. (1) The basal part of the Mendota dolomite is marked by a thin conglomerate, which is composed of sand and clay, and dolomite. The analyses show that the insoluble material is high (25% to over 50%). It consists of rounded and frosted grains of quartz, some of which show secondary enlargement; polished glauconite grains; mica flakes; and some silt and clay. (2) The algal layers or biostromes are conspicuous by their very low insoluble content. Obviously the water in which the algae grew must have been free of muddy matter. (3) The strata in the Pheasant Branch section, and the upper beds of the Farwells Point section, carry considerable insoluble material, but it is to be noted that algal layers are absent. Perhaps the high residues furnish the explanation for the absence of the algae.

While the amount and character of the insoluble residues of the Mendota formation are distinctly different from those of the underlying *Franconia* or of the overlying *Lodi* shale, it will be necessary to obtain much more information on all of the residues before they can be used successfully for correlation purposes. The best procedure will be to use the residues in conjunction with the lithologic data and field relations.

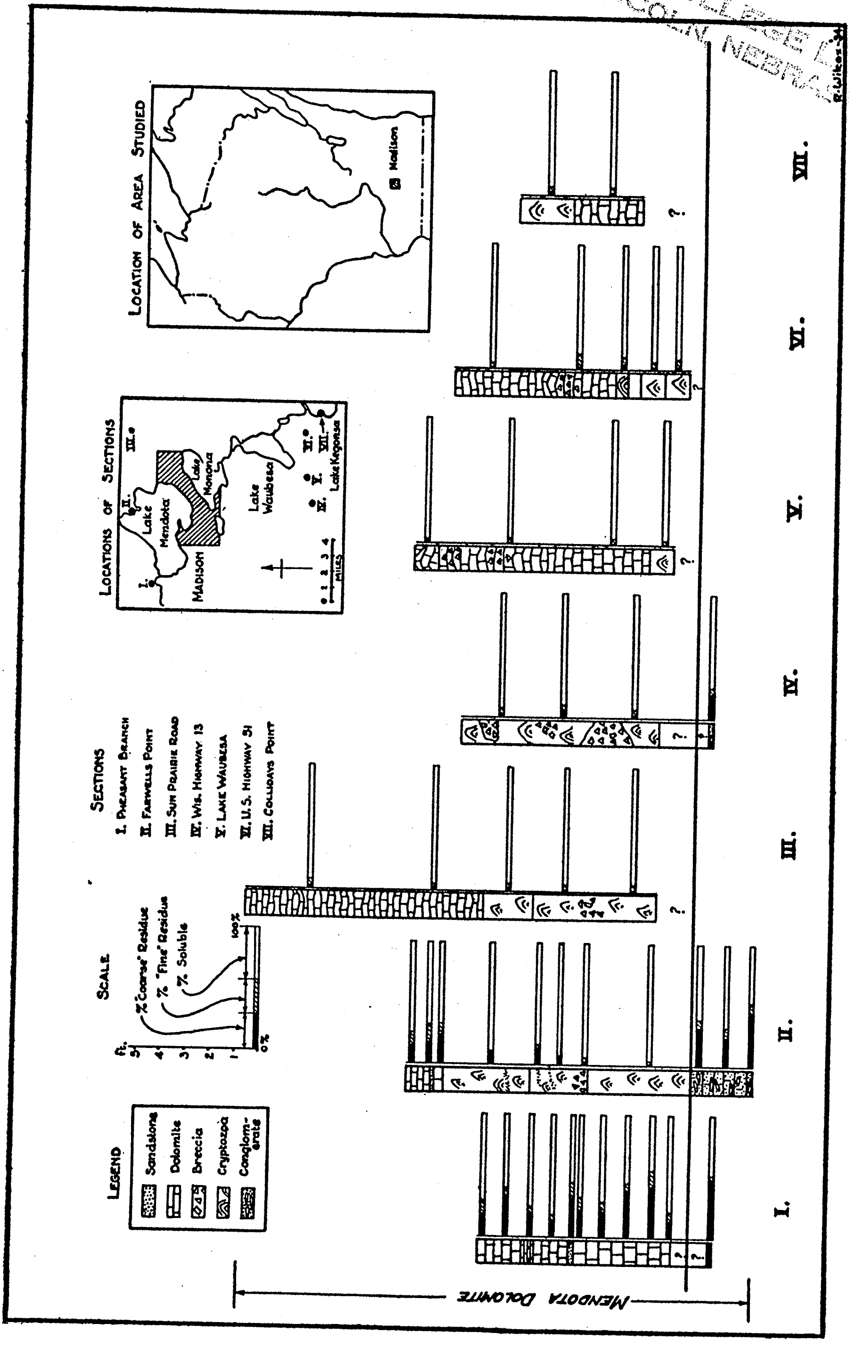

Fig. 1. Chart of stratigraphic sections showing the amount and character of the insoluble residues of the Mendota dolomite. The heavy horizontal line marks the top of the conglomerate which characterizes the base of the dolomite.

PRELIMINARY LIST OF THE HYDRACARINA OF WISCONSIN

PART IV

RUTH MARSHALL

Parts I, II and III of the *Preliminary List of the Hydracarina of Wisconsin* recorded fifty-three species belonging to eighteen genera. The present paper adds fourteen species representing four genera of the family *Hygrobatidae.* None of these are new but additional data are given for several of them. As in the preceding Parts, drawings and some of the outstanding characters of each species are given, together with distribution data as far as known. For complete descriptions of the species, the student of the group is referred to the titles in the bibliography.

The preparation of this work has been greatly aided by a grant from the Society of Sigma Xi. For most of the material the author is indebted to the Wisconsin Natural History Survey.

Following the system of Viets, the Koenikeas are included with the Unionicolas and the Neumanias in the subfamily *Unionicolinae;* superficially they resemble the Mideopsinae. The genus *Koenikea* was set up by Wolcott (1900) with one species, *K. concava*; in reality, two species were here included, as was noted by other investigators and pointed out by Koenike and Lundblad. Dr. Wolcott also erected another genus, *Tanaognathus,* with one species, *T. spinipes,* now regarded as a Koenikea. It was evident that other species were also present and this led to further confusion in identifications, of which the present author was also guilty. Viets (1930), after the examination of a small amount of North American material, reviewed the literature and established three new species and more clearly defined the original two. These five species are all present in Wisconsin; the present paper adds data on the differentiation of the sexes. The Koenikeas are small mites, usually less than one millimeter in length; the body is greatly compressed and concave dorsally; the skin is heavily chitinized and pierced with fine pores and the dorsal exoskeleton shows a furrow near the margin which thus encloses a large circular area. The genus appears to be most abundant in the New World.

The Pionas form one of the largest genera of the water mites, both in numbers of species and in individuals. They are soft bodied, with striated skin, often brightly colored, usually elliptical in form and of medium size, although a few attain a length of two millimeters. The shape of the large fourth spimera, each with a prominent posterior angle, together with the presence of two or more hair papillae on the fourth segment of the palpus, will usually serve to identify the genus. The genital openings lie close to the epimera; sexual dimorphism is marked, shown especially in the peculiarities of the third and fourth legs in the male, the latter always showing a large concavity in the fourth segment. This paper lists only six of the several species of Pionas in the state; it is hoped to include the remainder in the next Part.

The Forelias, a small group, closely resemble the Pionas from which they are readily distinguished by the shape of the fourth epimera; in this plate the anterior and posterior margins meet in the median line to form an acute angle. The Huitfeldtias are rare; they resemble the female Pionas in the form of the epimera but lack the other distinctive features of that genus.

Koenike concava Wol.

Pl. VI, fig. 3-5

The original account of the species (Wolcott, 1900) gave the male and female; both forms described, however, were obviously females. Dr. Wolcott deposited co-types in the National Museum and these have been examined by the author. Little can be determined from them, since the preservation is poor, but it is evident that two species are present. Dr. Viets (1930) designated Wolcott's male (in reality a female) as *K. concava* and called the other female *K. wolcotti* n. nom. The true male is now known and here described. The body is nearly circular in the male and measures from 0.60 to 0.69 mm. in length. The females are more elongated and vary in length from 0.70 to 0.93 mm, depending upon the age. A lyre-shaped dark marking is seen on the dorsal side, over which is a broadly U-shaped red mass. (The mark shown in Wolcott's fig. 15 was not observed.) The epimera are united in one plate, their places of union marked by heavy lines, The genital plates are large and close to the fourth epimera; their small and scattered acetabula, set into the body wall, form indistinct wing-shaped areas, narrow in the male. The legs are weak. The rostrum of the maxillary organ is a little prolonged and is seen as a rounded body in ventral view. In the palpus the second segment is nearly as wide as the first leg; the fourth segment is distinguished by the presence of a hair-bearing papilla near the distal end.

Specimens have been found in Michigan, Indiana, Illinois, Iowa, Florida and Louisiana. In Wisconsin they have been found in ponds in Adams county and in lakes Wingra and Green, in the latter to a depth of six meters.

Koenikea haldemani Viets

Pl. VI, fig. 1, 2

A species closely related to *K. concava,* with which it has been confused, the female was recognized and separated from it by Viets (1930). The male is now known. The body in both sexes is nearly circular. Males measure from 0.525 to 0.575 mm. in length; females, 0.62 to 0.72 mm. The center of the body shows a large magenta or violet blotch. The epimera are fused, the divisions between them shown by heavy lines; the fourth pair are wider than in *K. concava.* The genital regions are at some distance from the epimera; the genital cleft and plates are large in the female, much smaller in the male. The scattered and indistinct acetabula cover a narrow and widely extended area. The second segment of the palpus is wider than the legs, which are weak; the fourth segment lacks a papilla. The rostrum is but little projected.

Specimens have been found in ponds in Adams county, in Green lake and lakes in Iowa.

Koenikea wolcotti Viets

Pl. VI, fig. 6, 7

First described by Wolcott (1900) as the female of *K. concava,* it was separated as a distinct species by Viets (1930), the male of which is still unknown. The body of the female is nearly circular, 0.75 to 0.90 mm. in length. The body covering is very heavy; blotches of red show anteriorly and posteriorly. The epimeral plates join except for a considerable space between the third and fourth of either side; the first pair have projecting rounded anterior ends. A distinctive feature of this species is the large curved snout or rostral spine, with two long curved bristles near its base. The palpi are more slender than the legs and resemble those of *K. haldemani.* The fourth pair of legs bear several scattered pectinated spines. Genital acetabula are few, scattered and indistinct; they lie in the body wall in a narrow area extending outward from the large genital plates.

Individuals were collected in lake Wingra; they have also been found in Michigan, Indiana and Illinois.

Koenikea marshallae Viets

Pl. VII, fig. 8-11

The male is from 0.55 to 0.65 mm. in length, the width being only slightly less; the anterior region projects conspicuously and there is a protuberance over each eye. The female is from 0.675 to 0.775 mm. in length, relatively slimmer than the male, with anterior projections not so large. Blue green and red blotches are conspicuous on both surfaces. The epimeral groups are separated, with a wide space between the third and fourth of each side in the female; the first pair have projecting rounded anterior ends. The genital clefts are long and near the last epimera; the plates are very large in the female. The genital acetabula are irregular and indistinct and form broad wing-shaped areas. The rostrum of the maxillary organ is greatly drawn out and prolonged into a very conspicuous slim sickle-shaped spine; this bears two large hairs at its base. The palpi bear numerous hairs but no papillae. The legs are weak, scarcely wider than the palpi.

Material has been found in Ontario, Michigan, Illinois and Louisiana; in Wisconsin in ponds in Adams county, in Spooner, Allequash, Twin and Green lakes, in the latter to a depth of six meters.

Koenikea spinipes (Wol.)

Pl. VII, fig. 12-15

Originally described and set aside in a new genus, *Tanaognathus*, by Wolcott (1900) from the study of one specimen, a male, this species was placed with the Koenikeas by Viets (1930).

While this is probably its place, nevertheless the peculiarities of the palpi and legs set it apart from other described species. In the character of the rostral snout it resembles *K. wolcotti.* The female is now known. The male is from 0.625 to 0.70 mm. in length; the female, 0.90 to 1.10 mm. The body is nearly circular in form with an anterior projection, or slightly wider than long in the male. The skin is very thick and blue blotches show on this in life. The epimera in the male come close together except for a space in the center of the field; in the female the third and fourth of each side are separated from the others by a small space. The genital areas lie close to the last epimera; in the female the cleft is long and the plates are large, while in the male the reverse is true. The genital acetabula lie in the body wall in an area which is broad but not laterally extensive. The rostrum of the maxillary organ is drawn out to form a heavy greatly curved snout, broad at the base, with a conical tip; dorsal to this are two long heavy curved hairs. The palpus is very small; the basal segment is the broadest, while the second is longer than succeeding ones; the fourth segment has a large projection on its distal end projecting parallel to the fifth. The legs are rather stout and bear pectinate hairs; the fifth segment in each is enlarged in the center, while the sixth is slightly curved. The first leg ends in an expanded tip which bears a pair of large sickle-shaped claws.

Specimens were collected in lakes Wingra and Allequash. They have also been found in Michigan and Illinois.

Huitfeldtia rectipes Thor

Pl. VIII, fig. 16-18

An uncommon species, the only one in the genus, a few specimens, all males, have been found in northern lakes. The body is oval, thin-skinned, with brown blotches. Males measure up to 1.25 mm. in length; females are a little longer. The epimera resemble those of the female Pionas but are smaller and the groups are well separated. The genital areas are removed from the epimera and have lunate plates, united at the ends in the male, which bear a small number of conspicuous acetabula. Palpi are slender; the third segment bears a long hair and the fourth exceeds the others in length.

The species has been reported from northern Europe and Germany. It has been found in Ontario, Saskatchewan and in four lakes in Vilas county. In two collections individuals were found at a depth of about fourteen meters.

Forelia liliacea (Müll.)

Pl. VIII, fig. 22-25

This cosmopolitan species measures in the largest males nearly 0.70 mm., and in the females up to 0.80 mm. The posterior end of the body is elongated, especially in the male; the general color is brown. The epimeral groups are close together in the male, well separated in the female; the genital area lies almost entirely within the bay formed by the large triangular last pair. In the female the genital plates, well removed from the long aperature, are broad and bear from fifteen to thirty acetabula each; in the male the plates are narrower, joined at either end of the short aperature, and lie close to the last epimera, scarcely extending beyond their sharp posterior angles. The palpi are stouter than the first pair of legs. The fourth pair of legs are a little longer than the body; in the male the sixth segment is bent strongly dorsally and bears ten or more blunt spines on the inner surface.

The species is found throughout Europe and is reported for Africa. It has been found in Ontario, Wyoming, Washington and Michigan. In Wisconsin collections have been made in Spooner and Bass (Waupaca) lakes and in several lakes in Vilas county, in one case to a depth of eight meters.

Forelia ovalis Mar.

Pl. VIII, fig. 19-21

Closely related to *F. liliacea,* this species is a little larger with stouter legs and shows a red trident-shaped dorsal mark. The genital plates extend laterally beyond the posterior blunter angles of the fourth epimera and bear many small acetabula; in the male the plates meet for a short space below the short genital opening. The fourth leg in the male is a little shorter than the body and all of the segments are stout; the sixth segment, lying nearly in the same plane as the fifth, has a broad proximal part which is extended into a finger-shaped process bearing a row of short blade-like bristles.

Collections have been made in Ontario and Illinois. In Wisconsin the species has been found in the Madison and Jordan lake regions, in Green lake and in eight lakes in Vilas county, in one case to a depth of thirteen meters.

Piona crassa (Wol.)

Pl. X, fig. 37-42

This is an unusual Piona, being heavily built and chitinized. The entire dorsal surface of the male is thinly chitinized and somewhat flattened, while the female has a small anterior dorsal plate, characters not given in the original description of the species. The remainder of the cuticula is thick, with heavy ridges. Living specimens show the usual brown blotches on the dorsal side; a faint pink shows in the center of these, while the edges of the ventral plates are tinged with red and the appendages are deep blue. Males are about 0.65 mm. in length; females, from 0.80 to 1.00 mm. The posterior angle of the fourth epimera is especially sharp; all of the plates are united in the male. The conspicuous genital tongue-shaped plates, bearing a large number of acetabula, are strongly curved and extend far out beyond the lateral boundaries of the epimera. In the male these plates meet medially below the small opening to form an oblong area devoid of acetabula to which the anal plate is fused. The short stout flattened palpi are very unusual in that the fourth segment has eight small papillae arranged in two rows on the projecting distal margin. The author has not observed any marked difference in the palpi in the two sexes; Wolcott (1902, fig. 60) in a description based upon a single individual gives a much slimmer palpus for the female. The legs are stout, with short terminal segments in the first three pairs. The third leg has a truncated sixth segment, while the long fifth segment bears distally several heavy spines and one very long hair, the last character not given in the original description. The fourth leg has unusually stout proximal segments with the characteristic concavity on the fourth.

Specimens have been found in Montana, Michigan, Illinois and in Wisconsin in lake Wingra and in three regions in Adams and Vilas counties.

Piona rotunda (Kram.)

Pl. IX, fig. 26-31

A cosmopolitan species and widely distributed, its variability and the lack of very distinctive characters make the identification of *P. rotunda* difficult, especially in the case of the female. Confusion in this matter is evident in some of the older literature. The body is broadly elliptical and shows brown blotches under a finely ridged surface. Largest males measure about 0.80 mm., females, 1.10 mm. The genital areas in both sexes extend laterally hardly beyond the posterior angles of the moderately concave borders of the fourth epimera. The fused genital plates of the male show a broad concavity on the posterior border; there are from fifteen to thirty acetabula on either side, with a large shallow free area under the genital opening. The anal plate lies well back of the genital plates. In the female there are about the same number of acetabula placed on a sickle-shaped plate on either side, arranged in an irregular crowded row, with a few others embedded in the wall on the concave side. The palpi are wider than the first pair of legs, with a slim fourth segment bearing two small papillae. The sixth segment of the third leg is about half of the length of the fifth, a little expanded at the end; one of its claws bears a long straight tip.

This species has been found all over Europe and in parts of Asia and Africa. It has been collected in Alaska, British Columbia, Ontario, Montana, Michigan and Nebraska. In Wisconsin there are records for lakes Wingra, Coma, Mason, ponds near Cable, Wisconsin Dells, Green Bay and waters of Adams and Vilas counties.

Piona reighardi (Wol.)

Pl. IX, fig. 32-36

The females of this species closely resemble *P. rotunda,* from which it is separated with difficulty, since both species show great variability in the genital plates. Co-types of both species, deposited in the National Museum by Dr. Wolcott, and examined by the author, are not well preserved; there appears, however, to have been some confusion of the two forms. Living material, believed by the author to be the true *P. reighardi,* usually shows a bright red spot ventrally at the meeting of the epimeral groups; dorsally there is a yellowish or white T-shaped mark surrounded by dark brown blotches; the eyes are dark red and the appendages deep blue. Ventral plates are rather heavy, often blue tinged. The body is broadly oval with little or no indentation anteriorly; the average length is about 0.90 mm. The fourth epimera show a greater concavity on the posterior border than in the related species, and the sickle-shaped genital plates (rarely broken) are more elongated and may extend a little farther laterally than the posterior angle of the epimera. The genital acetabula are highly variable in number; they are usually larger and more irregularly arranged than in the related species, and bunched at both ends of the plates, while in the body wall are from two to four more on either side. The palpi are much like those of *P. rotunda,* but the second segment is a little stouter.

The original description of the species (Wolcott, 1902, p. 235) gave an incomplete and inaccurate description of the male, since only one specimen, poorly preserved, was known. Males in the present collection are abundant; they are often much smaller than the females, averaging about 0.63 mm. in length, and showing the same coloration. Small spaces separate the epimeral groups, which cover the greater part of the ventral surface. The united genital plates are much like those of *P. rotunda,* but they extend laterally beyond the angle of the fourth epimera (rather than "about even with the tip of the process in the posterior margin"), and the genital opening extends through about half of the length of the plate (instead of "throughout the entire length of this genital area"). There are from twenty to twenty-five acetabula on each side. The posterior concavity of the united plates is deeper than in the related species, with the anal plate well within it. The third leg has a shorter terminal segment, with a shorter claw, and the fourth segment of the last leg is likewise shorter and stouter bristles than in *P. rotunda.*

Dr. Wolcott in the same paper (p. 240) identified as *P. obturbans* (Piers.) two females in a collection from Louisiana. In the author's opinion these were probably *P. reighardi,* since the females of the two species are much alike and the specimens were believed to have shown some red color when alive.

This species appears to be the most abundant Piona in central North America. It has been found in Ontario, Michigan, Minnesota, Montana, Indiana, Illinois, Iowa, Louisiana and

Georgia. In Wisconsin it has been collected in nearly all regions visited, often in large numbers, from the surface to a depth of 12 M. The author's record for Alaska is probably wrong; in a re-examination the specimens (females) appear to be *P. rotunda.* Likewise the record of the Canadian Arctic Expedition (1913-18, v. III: 13H) is in doubt; some of the specimens, deposited in Ottowa, have been examined by the author.

Piona media (Wol.)

Pl. XI, fig. 49-53

Described originally from one preserved female, this species, including the male, can now be fully characterized. The body is broadly oval; the dorsal side shows a yellowish T-shaped figure surrounded by brown blotches on a pale yellow or bluish background, while the plates and appendages are blue. The eyes are very large and the antenniform bristles are small. Males average about 0.57 mm. in length, females nearly 1.00 mm. Plates and legs are heavy. The posterior margin of the fourth epimera shows only a moderate concavity. The genital areas resemble those of *P. rotunda* and *P. reighardi* but they are of greater extent and carry more acetabula. In the female the broadly sickle-shaped plates extend laterally beyond the posterior angle of the fourth epimera and carry each some thirty-five or more acetabula arranged in two irregular rows with some bunching, together with a few more embedded in the wall. In the male the tongue-shaped plates reach laterally to the margin of the body and bear each about thirty-five acetabula; the genital opening is large and the margin of the united genital plates below it shows a deep concavity in which lies the anal plate. The palpi are unusually large, especially in the male; the second segment is nearly twice the width of the first leg and the fourth segment bears two large slim papillae nearly opposite each other. The pectination on the spines of the palpi described by Wolcott was not observed by the author. The third and fourth legs of the male resemble those of *P. reighardi.*

Specimens have been found in Ontario, Michigan, Illinois and Indiana. In Wisconsin collections have been made in lakes Winnebago, Starr, Wingra, Twin, Little John, in ponds near Burlington and in five bodies of water in Adams county.

Dr. Walter* has described a single female found in a Swiss lake which bears a close resemblance to *P. media;* its identification is in doubt.

Piona inconstans (Wol.)

Pl. XI, fig. 54-57

The body is elliptical, covered with fine wavey lines, often showing a faint red T-shaped dorsal mark in the center of the dark brown blotches. Females are from 0.75 to 1.10 mm. in length, males a little smaller. The females closely resemble *P. rotunda* and *P. reighardi,* from which they are distinguished by peculiarities of the genital plate. Here the ten to twenty acetabula of each side lie on a broken sickle-shaped plate, a small anterior piece with a few acetabula and hairs and a posterior piece (sometimes again broken) carrying the others in an irregular row, while two or more lie free in the body wall or on small plates. Great variability is seen in this matter; even the two sides of the same individuals are unlike. The genital plates do not extend laterally farther than the posterior angles of the last epimera. The palpi are slim, much like those of the related species.

The male, not included in the original description of the species, is now known. It is relatively large, measuring about 0.90 mm. The epimeral groups are separated by unusually wide spaces for males of this group of Pionas, and they occupy only about two-thirds of the ventral surface. The genital plates are small, in form like those of *P. rotunda,* with a small and variable number of acetabula, about fifteen on each side, and they do not extend laterally quite as far as the posterior angle of the last epimera. The sixth segment of the third leg is broadened near the proximal end and again distally where it ends in two curved claws, one of them very long. The fourth segment of the fourth leg has a large concavity and the proximal border bears a bunch of long slim bristles.

Specimens have been found in Alaska, Ontario, Maine, Massachusetts, Michigan, Illinois, Missouri, Nebraska, Louisiana and Florida. In Wisconsin they have been collected in lakes Winnebago, Mendota, Mason and Twin and in ponds near Wisconsin Dells.

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* Die Hydracarinen der Schweiz. Rev. Suis de Zool., v. 15, 1907, p. 533-5, fig. 40, 41.

Piona conglobata (Koch)

Pl. X, fig. 43-47

This cosmopolitan species has already been reported from Wisconsin. The females collected conform closely to identified material; unfortunately the author has no specimens with which to compare the one male so far found and published accounts are not in agreement as to certain details of the genital plates. However, as the palpi and details of other parts of both sexes conform, it is believed that these individuals represent the true *P. conglobata.* The body is oval, the surface coarsely ridged. Antenniform bristles are long. The dorsal surface shows brown blotches on a dull yellow background with sometimes faint red showing in the center. Largest females measure 0.90 mm. in length, the single male, 0.45 mm. The epimera are well separated in the female, closely approximated in the male; the fourth pair show a moderate posterior medial concavity. The genital areas in both sexes are extensive and extend laterally beyond the posterior angle of the last epimera. Acetabula are few, scattered and very irregularly placed; in the female these are embedded directly in the body wall except for a few on two small plates near either end of the long genital opening. In the male the united genital plates are not very clearly outlined; there is a deep concavity where they meet and the anal plate does not join them. The genital opening is small and the markings near it are complex and difficult to make out. The palpi are large, a little stouter in the male than in the female; the fourth segment bears three large hair papillae in the center of the flexor surface. In the male the first two pairs of legs have the terminal segment much thickened distally; the last segment of the third leg is moderately long and has a reduced claw, while the fourth leg has a very large concavity on the fourth segment.

The species is found over all of Europe and there are records for Turkestan and Mongolia. In Wisconsin material has been found in a mill pond at Oxford and in lakes Spooner and Little John.

Rockford College,
Sept. 1, 1933

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* Since the completion of this manuscript the author has received identified specimens from Germany through the kindness of Dr. K. Viets. It is now clear that the American form is not identical with the European; consequently it will be designated as *P. conglobata wisconsinensis* nov. var. It is distinguished from the parent species chiefly by the presence of a greater number of genital acetabula and by the form of the male genital plates; the latter show an upturned margin where they meet the posterior angle of the fourth epimera.

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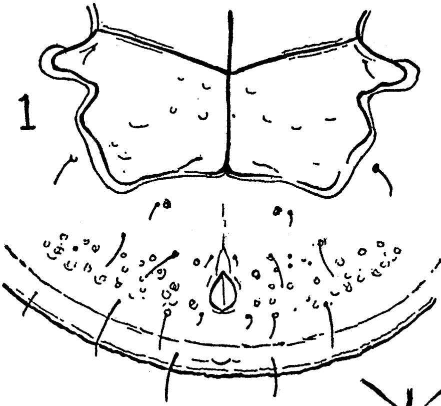
EXPLANATION OF THE PLATES

VI

1. *Koenikea haldemani*, genital area, male
2. *Koenikea haldemani*, ventral side, female
3. *Koenikea concava*, genital area, male
4. *Koenikea concava*, right palpus, female, inner side
5. *Koenikea concava*, ventral side, female
6. *Koenikea wolcotti*, rostral spine and palpi, female
7. *Koenikea wolcotti*, ventral side, female



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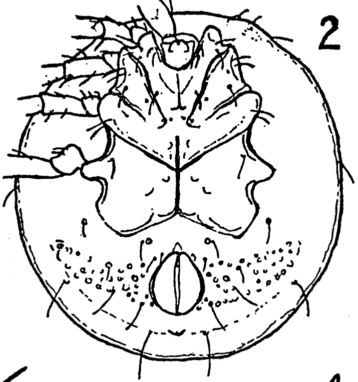

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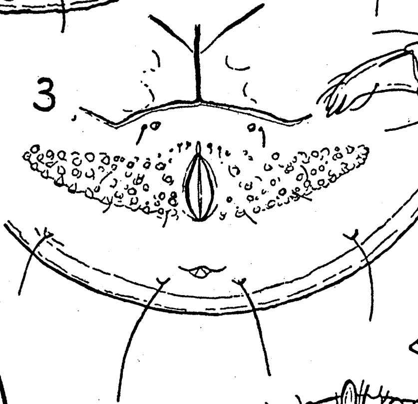

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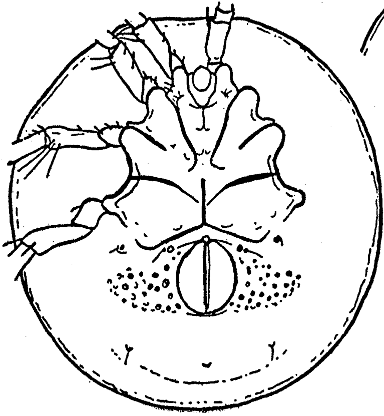

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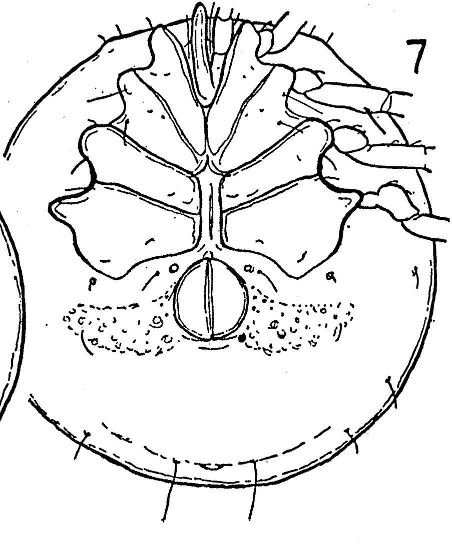

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VII

8. *Koenikea marshallae*, dorsal side, female
9. *Koenikea marshallae*, genital region, male
10. *Koenikea marshallae*, ventral side, female
11. *Koenikea marshallae*, rostrum and right palpus, female
12. *Koenikea spinipes*, ventral side, male
13. *Koenikea spinipes*, rostrum and right palpus, female
14. *Koenikea spinipes*, end of leg I, male (one claw omitted)
15. *Koenikea spinipes*, genital region, female

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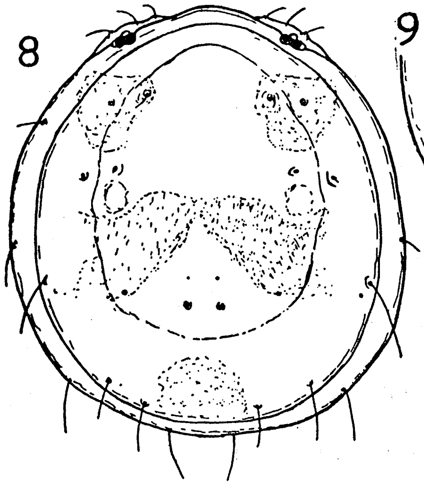

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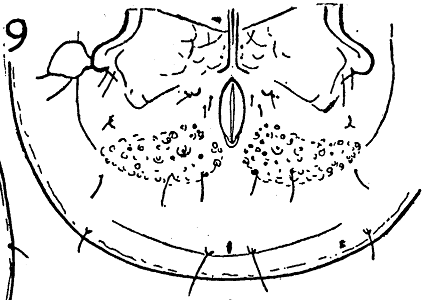

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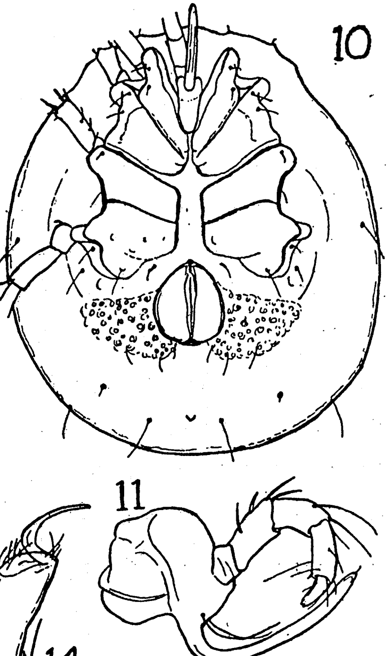

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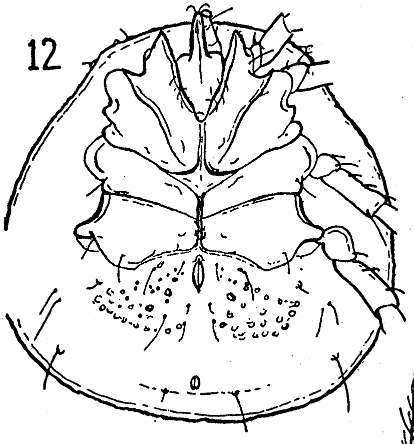

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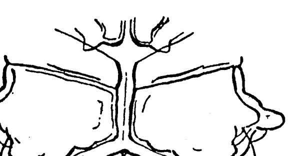

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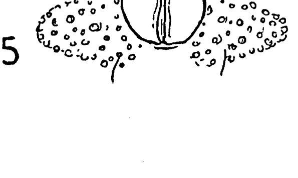
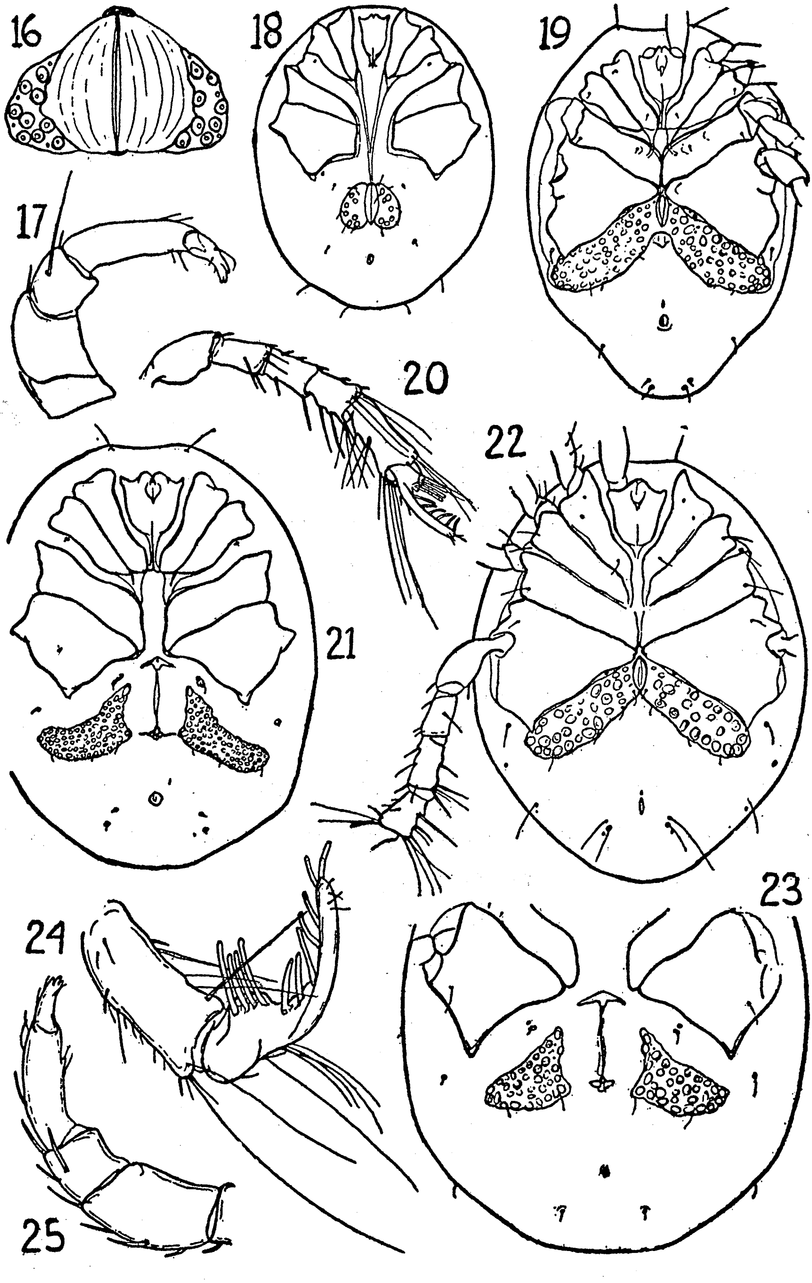


VIII

16. *Huitfeldtia rectipes*, genital plates, female (after Thor)
17. *Huitfeldtia rectipes*, right palpus
18. *Huitfeldtia rectipes*, ventral side, male
19. *Forelia ovalis*, ventral side, male
20. *Forelia ovalis*, leg IV, male
21. *Forelia ovalis*, ventral side, female
22. *Forelia liliacea*, ventral side, male
23. *Forelia liliacea*, genital area, female
24. *Forelia liliacea*, 5th and 6th segments, leg IV, male (foreshortened)
25. *Forelia liliacea*, right palpus, female, outer side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IX

26. *Piona rotunda*, genital area, male
27. *Piona rotunda*, end of leg III, male
28. *Piona rotunda*, right palpus, male, outer side
29. *Piona rotunda*, genital area, female
30. *Piona rotunda*, 4th segment, leg IV, male
31. *Piona rotunda*, 6th segment, leg II, male
32. *Piona reighardi*, 5th and 6th segments, leg III, male
33. *Piona reighardi*, 4th segment, leg IV, male
34. *Piona reighardi*, right palpus, male, inner side
35. *Piona reighardi*, female, genital area
36. *Piona reighardi*, ventral side, male

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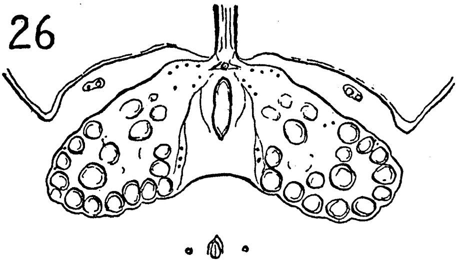

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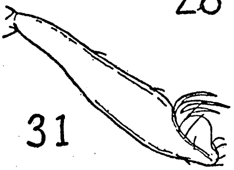

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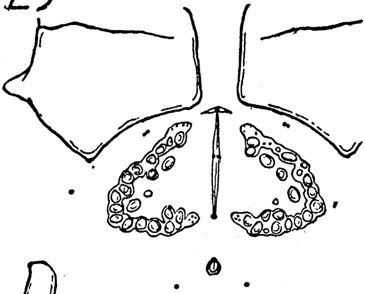

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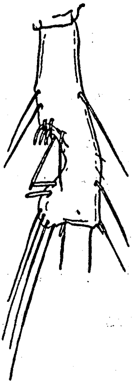

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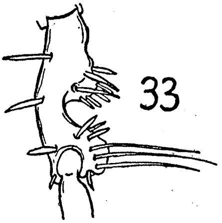

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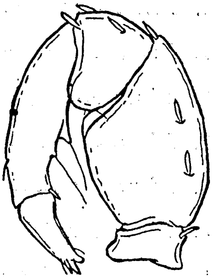

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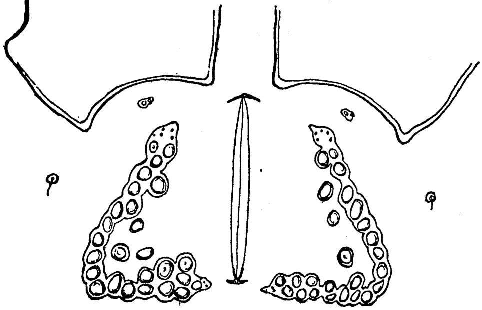

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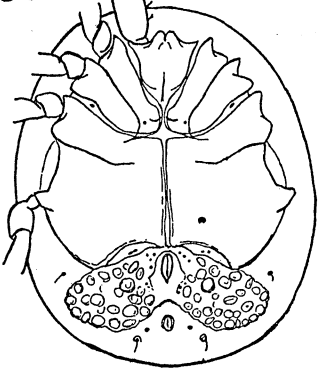

X

37. *Piona crassa,* ventral side, male
38. *Piona crassa,* genital area, female
39. *Piona crassa,* right palpus, female, outer side
40. *Piona crassa,* dorsal side, female
41. *Piona crassa,* leg IV, male
42. *Piona crassa,* 5th and 6th segments, leg III, male
43. *Piona conglobata,* genital area, male
44. *Piona conglobata,* 6th segment, leg II, male
45. *Piona conglobata,* genital area, female
46. *Piona conglobata,* 6th segment, leg III, male
47. *Piona conglobata,* right palpus, male, outer side

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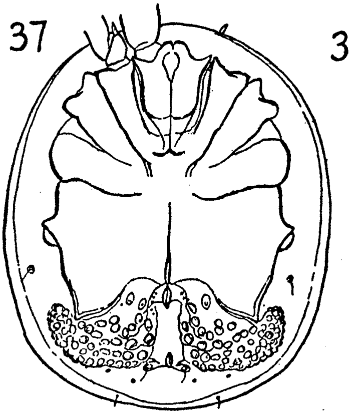

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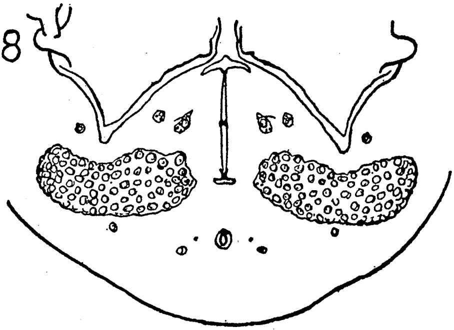

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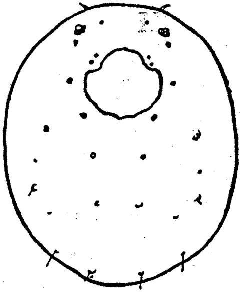

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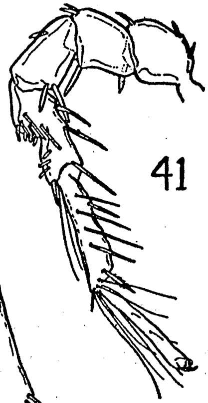

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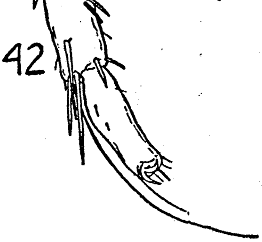

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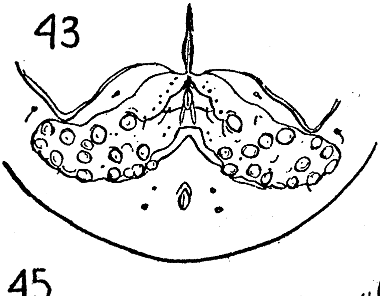

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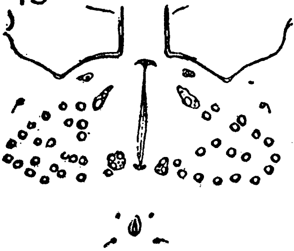

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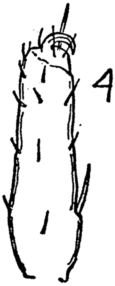

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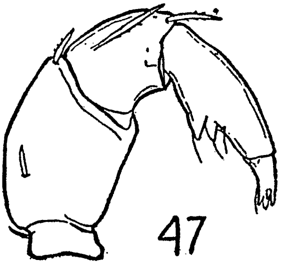
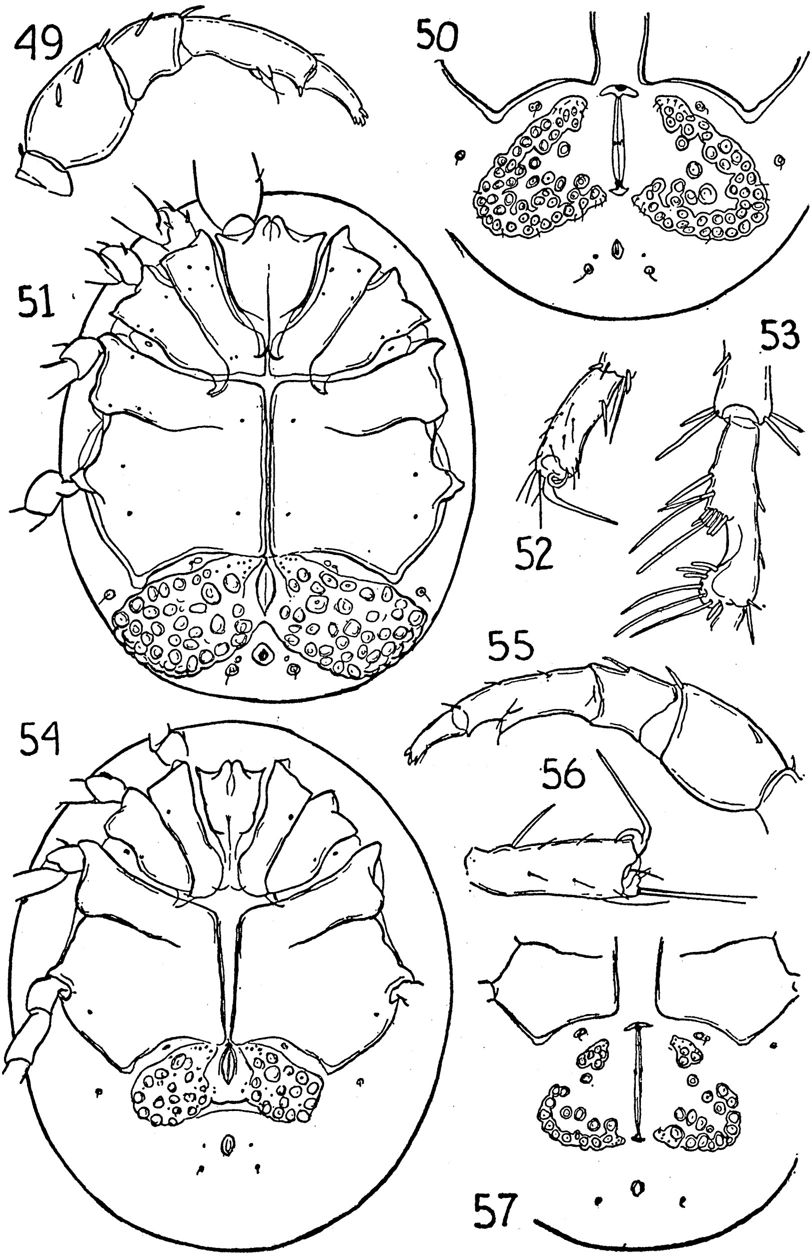


XI

49. *Piona media*, left palpus, male, inner side
50. *Piona media*, genital area, female
51. *Piona media*, ventral side, male
52. *Piona media*, 6th segment, leg III, male
53. *Piona media*, 4th segment, leg IV, male
54. *Piona inconstans*, ventral side, male
55. *Piona inconstans*, left palpus, female, outer side
56. *Piona inconstans*, 6th segment, leg III, male
57. *Piona inconstans*, genital area, female

PLATE XI



PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN. XXLV. SALICACEAE

DAVID F. COSTELLO

The maps in this report are based on specimens in the following herbaria: University of Wisconsin, Milwaukee Public Museum, Mr. S. C. Wadmond, of Delavan, Wis., and Iowa State College, Ames, Iowa. The writer is grateful for the courtesies extended by the curators of these herberia. The Wisconsin willows in the Gray Herbariumwere listed by Dr. Norman C. Fassett. Ranges of the poplars as noted by Mr. L. S. Cheney have been used in compiling the maps for that genus. Many of the willows in the author's herbarium have been examined and the identifications checked by Dr. Carleton R. Ball of the University of California. His kindly criticism and his many useful notes and suggestions have been a source of inspiration.

1. POPULUS

Localities based on unpublished studies by Mr. Cheney are here represented by small dots. Additions to the ranges shown by Cheney, represented by herbarium specimens, are shown by large dots.

The following key is based on mature leaves.

Costello: Prelim. Rept. Flora Wis. XXIV Salicaceae

a. Leaves serrate or toothed; glabrous beneath
  b. Petioles flattened laterally
    c. Leaf blades ovate to orbicular in outline
      d. Blades 3 - 6 cm. long, margins finely serrate ------------------*P. tremuloides*
      dd. Bladies 5 - 10 cm. long, margins coarsely toothed ------------------------*P. grandidentata*
    cc. Leaf blades triangular to rhombic ovate in outline
      d. Blades broader than long, abruptly acuminate; marginal teeth slightly incurved; tree with col-

umnar habit ---------------*P. nigra* var. *italica*

dd. Blades longer than broad.

e. Blades distinctly triangular, truncate or broadly cordate at base; marginal teeth distinctly incurved; tree with broad rounded crown ---------------------*P. deltoides*

ee. Blades rhombic ovate, broadly rounded at base; margin crenate serrate; tree with pyramidal habit ---------------------------X *P. Eugenei*

bb. Petioles round in cross section

c. Blades ovate lanceolate, broadly rounded at the base --------------------------------*P. balsamifera*

cc. Blades broadly ovate, cordate at the base; veins pubescent below -----------------------*P. candicans*

aa. Leaves lobed or coarsely sinute-crenate; petioles and lower sides of leaves densely white tomentose ------*P. alba*

1. *P. alba* L. White Poplar, Silver Leaf Poplar. (Fig. 1). Introduced from Europe. Extensively cultivated and freely spreading by root. Two forms are commonly cultivated in the state: *P. alba* var. *nivea* (Willd.) Wesm., characterized by its maple like leaves which are densely white tomentose beneath; and *P. alba* var. *pyramidalis* Bunge [*P. alba* var. *Bolleana* (Lauche) Wesm.], characterized by its columnar habit, and smooth green bark. Herbarium specimens of *P. alba* and its varieties are much needed.

2. *P. tremuloides* Michx. American Aspen, Trembling Poplar, Quaking Aspen. (Fig. 2). Occurs in every county in the state. The habitat varies from sandy shores of lakes, tamarack swamps, and dry barrens to limestone ridges and the summits of wooded bluffs.

The foliage of this tree is exceedingly variable. *P. tremuloides* f. *reniformis* Tidestrom[1] is, "distinguished by its kidney-shaped leaves, which are ordinarily about 5 - 6 cm. in length and 7 - 8 cm. in width." *P. tremuloides* var. *intermedia* Victorin[2] has heart shaped leaves which are relatively large by the

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[1] Rhodora 16:206. 1914

[2] Contrib. Lab. Bot. Univ. Montreal. No. 16. 1930

time the fruits have matured. I have collected a form near West Allis and also near Newburg which is characterized by cordate leaves which retain their dark shining green color for a period of two or three weeks after the leaves of typical *P. tremuloides* have become pale lemon yellow in the autumn. This form, however, does not appear to be identical with *P. tremuloides* f. *reniformis* Tidst., which was described from Maryland, nor does it resemble *P. tremuloides* var. *intermedia* Victorin, described from Quebec, which has much larger leaves. Further study will be necessary to determine its exact status.

Leaves from vigorous shoots or sprouts frequently are cordate at the base and much larger than typical leaves in this species. They are frequently misidentified in herbaria.

3. *P. grandidentata* Michx. Large Toothed Aspen. (Fig. 3). Like *P. tremuloides* this tree occurs in every county. Common along river banks, in rich woods, swamps and on moist uplands. Variations from the typical leaf form are not uncommon. Rotund leaves or leaves with cordate bases and typical leaves are frequently found on the same branch. Occasionally leaves with entire margins, or with two or three lobes may be seen. Leaves of sucker sprouts are large, cordate at base, and covered with a fine pubescence.

4. *P. balsamifera* L. (*P. tacamahacca* Mill.). Balsam Poplar, Tacamahac. (Fig. 4). Particularly abundant in the northeastern one fourth of the state and in the Lake Superior region. Common along river banks and borders of swamps.

5. *P. deltoides* Marsh. (*P. monilifera* Ait.; *P. virginiana* Fourg.; *P. balsamifera* L., in part). Cottonwood. (Fig. 5). This tree reaches its northern limits in Wisconsin, occupying the southern two thirds of the state. It is especially abundant along the Mississippi, Wisconsin, Kickapoo, Chippewa, Red Cedar, Embarass, Fox and Sugar River bottoms.

6. *P. candicans* Ait. (*P. balsamifera* var. *candicans* Gray). Balm or Gilead. Introduced. Occasionally found as an escape from cultivation. Cheney's maps show that it has been planted over approximately the same range as the following.

7. *P. nigra* L. var. *italica* Du Roi. Lombardy Poplar. (Fig. 6). Introduced from Europe. Frequently spreading from cultivation. Only staminate trees are known.

8. X *P. Eugenei* Simon-Louis. Catal. ex Schneider, Ill. Handb. Laubholzk. 1:9. 1904. Norway Poplar, Sudden Sawlog. Planted in the northwestern part of the state. A rapid growing tree with rhombic-ovate leaves, rounded at the base, acuminate at the tip, coriaceous, with rounded teeth. This tree is not well understood. Some have held it to be a hybrid, *P. deltoides* X *P. nigra* var. *italica*; others believe it to be a form of the *P. deltoides* complex. Good specimens for comparison are needed.

2. SALIX

Since willows are dioecious, and since they hybridize freely and show great variation in response to environmental conditions, they are a difficult group to identify. The only satisfactory way to study them is to tag individual shrubs or trees with metal labels and to collect material from these individuals throughout the seasons. Only in this way can one be certain as to which flowers go with which leaves. Material of this kind is much needed in herbaria.

The leaves or individuals vary from season to season as does the condition of hairiness on leaves and twigs. Twigs exposed to the sun may be pubescent while shaded twigs on the same plant are glabrous. Second growth, following grazing, cutting by mowing machines, or defoliation by insects almost invariably results in the production of pubescent leaves. Hybrids may usually be expected to show characteristics intermediate between the species of the cross. Monstrosities, particularly of the flowers, are not uncommon.

In spite of the multitudinous variations of willows, it is hoped that the three following keys may be of use.

KEY TO MATURE LEAVES

a. Leaves glabrous or glabrate beneath
  b. Leaves green on both sides
    c. Leaves linear to linear lanceolate
      d. Leaves linear, short acuminate; margins remotely denticulate ------------------ *S. interior*
      dd. Leaves lanceolate, long attenuate from near the base; margins closely serrate ---------*S. nigra*

cc. Leaves oblong lanceolate, to broadly lanceolate or ovate
  - d. Leaves short acuminate
    - e. Leaves leathery, bright green and shining above (cultivated tree) --------*S. pentandra*
    - ee. Leaves thin, not shining, usually paler beneath, cordate at base on vigorous shoots --------------------------*S. cordata*
  - dd. Leaves with long acuminate curved tips, shining on both sides ----------------------*S. lucida*

bb. Leaves glaucous or whitish beneath
  - c. Margins entire or irregularly crenate-serrate
    - d. Margins entire, revolute; blades linear-oblong to elliptic-obovate, slightly coriaceous, 2 - 6 cm. long, veiny above -------------*S. pedicellaris* var. *hypoglauca*
    - dd. Margins irregularly crenate-serrate; blades lanceolate to elliptic, 5 - 12 cm. long --*S. discolor*
  - cc. Margins distinctly and uniformly serrate
    - d. Leaves broadly rounded to cordate at base
      - e. Leaves dull above, paler beneath --*S. cordata*
      - ee. Leaves glossy above, glaucous beneath
        - f. Petioles short, leaves blackening in drying; stipules large ---*S. glaucophylla*
        - ff. Petioles long and slender, leaves prominently reticulate veined beneath; stipules obsolete or minute ---*S. pyrifolia*
    - dd. Leaves acute at base
      - e. Petioles glandular at apex.
        - f. Tall shrub; leaves short acuminate, coriaceous, elliptical --------*S. serissima*
        - ff. Large trees; leaves long acuminate, lanceolate

- g. 7 - 10 teeth per cm. of margin; branches slightly brittle at base ------------*S. alba*
- gg. 4 - 6 teeth per cm. of margin; branches very brittle at base --------------*S. fragilis*
- ee. Petioles not glandular.
  - f. Leaves ovate lanceolate, long attenuate; petioles 1 - 3 cm. long; large tree ------------------*S. amygdaloides*
  - ff. Leaves narrowly lanceolate; petioles 1 cm. or less; shrub -------*S. petiolaris*
- aa. Leaves pubescent beneath
  - b. Margin entire or nearly so
    - c. Blades densely white tomentose below, dark green above, with sunken veins; branchlets sometimes densely white tomentose ---------------*S. candida*
    - cc. Blades grayish tomentose to somewhat glaucous below
      - d. Leaves 4 - 10 cm. long, petioles distinct; shrub 1 - 3 m. high ----------------------*S. humilis*
      - dd. Leaves 1 - 5 cm. long, petioles very short; shrub 0.5 m. high ------------------*S. tristis*
  - bb. Margin finely serrate to crenate serrate.
    - c. Leaves ovate or obovate to broadly lanceolate
      - d. Leaves serrate-crenate, thin, mostly acute at base, usually finely pubescent and rugose beneath -------------------------*S. bebbiana*
      - dd. Leaves closely glandular serrate, thick and leathery, cordate or rounded at base, frequently permanently silky lanate above --*S. adenophylla*
    - cc. Leaves linear or narrowly lanceolate.
      - d. Leaves linear to oblong-lanceolate, margins remotely denticulate; nearly sessile --*S. interior*

dd. Leaves lanceolate, evenly serrate; petioles distinct.
  - e. Petioles glandular; trees ----------- *S. alba*
  - ee. Petioles not glandular; shrubs
    - f. Leaves slightly silky beneath, sometimes drying black --------------- *S. petiolaris*
    - ff. Leaves densely silvery pubescent beneath, black in drying -------------- *S. sericea*

KEY TO STAMINATE FLOWERS, TWIGS, AND YOUNG LEAVES

a. Flower scales yellowish
- **b.** Stamens 3 - 5 or more
  - c. Aments elongated, slender-cylindrical; scales crisp villous on the inside
    - d. Stipules large, semi-cordate and pointed, or small and ovate, persistent or deciduous ------ *S. nigra*
    - dd. Stipules reniform, minute or none -------------------- *S. amygdaloides*
  - cc. Aments thick, short-cylindrical or ellipsoid-ovoid, densely flowered.
    - d. Aments appearing with the leaves.
      - e. Young leaves glabrous from the first ------------------- *S. pentandra*
      - ee. Young leaves pubescent with crisp rufescent or sordid caducous hairs ---------- *S. lucida*
    - dd. Aments appearing after the leaves (in early summer) ------------------------ *S. serissima*
- **bb.** Stamens 2
  - c. Aments appearing after the leaves, frequently in clusters of 2 or 3 ---------------------- *S. interior*
  - cc. Aments appearing with the leaves
    - d. Aments 1.5 - 2.5 cm. long; leaves sparsely pubescent when young; twigs long and slender, drooping ---------------------- *S. babylonica*

dd. Aments 3 - 5 cm. long; twigs not drooping

  e. Young leaves glabrous from the first ------------------------ *S. fragilis*

  ee. Young leaves silky pubescent on both sides

    f. Twigs green to olive-brown ------ *S. abla*

    ff. Twigs yellow or reddish ------------- *S. alba* var. *vitellina*

aa. Scales brown to black or colored at tip (stamens 2)

b. Flowers appearing before the leaves.

  c. Anthers reddish

    d. Filaments hairy; anthers often united so as to appear as one; buds sub-opposite on the twig ---------------------------- *S. purpurea*

    dd. Filaments smooth; anthers not united; buds alternate; low shrub of cold bogs ---- *S. candida*

  cc. Anthers yellowish

    d. Aments 2.5 - 5 cm. long

      e. Flower scales brown or black, with long silky hairs

        f. Branchlets dark brown to black or purple ---------------------- *S. discolor*

        ff. Branchlets stout, mostly yellow to chestnut brown ---------- *S. glaucophylla*

      ee. Flower scales rose tipped, thinly villous; branching divaricate; bud scars numerous ----------------------- *S. bebbiana*

    dd. Aments 0.5 - 2.5 cm. long

      e. Aments narrowly cylindrical, 2 cm. long, sometimes leafy bracted at base; young leaves very silky when they appear -*S. sericea*

      ee. Aments globular, ovoid, or ellipsoid; young leaves downy but not silky when they appear

        f. Aments ovoid or ellipsoid, 1 - 2 cm. long, often recurved -------------- *S. humilis* ff. Aments globular or ovoid, 0.5 - 1 cm. long ------------------------*S. tristis*

bb. Flowers appearing with the leaves

c. Young leaves silvery silky

d. Young leaves densely lanate, ovate or broadly lanceolate; aments 1.5 - 3 cm. long; twigs stout, frequently yellowish ------------*S. adenophylla*

dd. Young leaves thinly silky pubescent, narrowly lanceolate; aments 1 - 2 cm. long; twigs slender, usually purplish ------------------*S. petiolaris*

cc. Young leaves not silvery silky

d. Young leaves glabrous from the first

e. Scales glabrous or glabrate, greenish yellow; twigs slender; aments 1.5 - 2 cm. long ------------*S. pedicellaris* var. *hypoglauca*

ee. Scales pubescent or silky villous; twigs medium to stout; aments 2 - 3 cm. long ---------------------------*S. pyrifolia*

dd. Young leaves puberulent or pubescent

e. Aments 1 - 2 cm. long, narrowed at base; twigs slender, divaricate, usually full of bud scars -------------------------*S. bebbiana*

ee. Aments 2 - 4 cm. long, slender; twigs medium, not divaricate ----------*S. cordata*

KEY TO PISTILLATE FLOWERS, TWIGS, AND YOUNG LEAVES

a. Mature capsules glabrous (except sometimes in *S. interior*)

b. Scales yellow, falling before the catkins are ripe

c. Flowers appearing after the leaves; tall shrubs

d. Leaves linear lanceolate, remotely denticulate; capsules blunt; fruiting in late spring or early summer -------------------------*S. interior*

dd. Leaves ovate lanceolate, shining above; capsules awl shaped; fruiting in July and August ----------------------*S. serissima*

cc. Flowers appearing with the leaves
  d. Twigs slender, sometimes drooping; catkins slender and loose (except in *S. babylonica*); trees
    e. Fruiting aments 3 - 11 cm. long; capsules distinctly pedicelled, 3 - 6 cm. long.
      f. Stipules minute, very early deciduous; aments becoming very loose in fruit; capsules globose-conical, long pedicelled ---------------*S. amygdaloides*
      ff. Stipules large, semi-cordate, pointed and persistent, or small, ovate and deciduous; aments more or less dense; capsules ovoid-conical, short pedicelled ---*S. nigra*
    ee. Fruiting aments 1.5 - 2 cm. long; capsules sessile, 1 - 1.5 mm. long ------*S. babylonica*
  dd. Twigs medium or stout, not drooping
    e. Catkins thicks, short and dense; shrubs or small trees
      f. Capsule conic-subulate; pedicel twice exceeding the gland; young leaves glabrous from the first (cult. shrub or small tree) ---------------*S. pentandra*
      ff. Capsules conic-ovoid (long beaked); pedicels 3 or 4 times exceeding the gland; young leaves sparingly rusty pubescent -------------------------*S. lucida*
    ee. Catkins slender, loosely flowered, 4 - 8 cm. long in fruit; large trees
      f. Capsules sessile or nearly so, ovoid conical (short ovoid); young leaves silky pubescent -----------------------*S. alba*
      ff. Capsules short pedicelled, subulate-conical (long conic lanceolate); leaves glabrous from the first ---------------*S. fragilis*
bb. Scales brownish to black, persistent (except *S. bebbiana*)

c. Aments usually appearing before the leaves; young leaves glabrous from the first; scales gray pubescent with long, matted or twisted hairs
--------------------*S. glaucophylla*

cc. Aments appearing with the leaves

d. Capsules reddish or reddish green, 5 - 8 mm. long

e. Young leaves and twigs glabrous throughout; leaf margins entire; pedicels 2 - 4 mm. long
--------*S. pedicellaris* var. *hypoglauca*

ee. Young leaves densely lanate pubescent; margins serrate; twigs pubescent; pedicels 0.5 - 1 mm. long ------------*S. adenophylla*

dd. Capsules greenish

e. Capsules 8 - 10 mm. long; pedicels 2.5 - 3.5 mm. long; twigs shining, reddish-castaneous or olive; stipules obsolete or minute
-------------------*S. pyrifolia*

ee. Capsules 4.5 - 6 mm. long; pedicels 1 - 1.5 mm. long; twigs yellowish to dark brown, puberulent to pubescent; stipules persistent, usually conspicuous; young leaves lanceolate
---------------------*S. cordata*

aa. Mature capsules pubescent

b. Aments appearing before the leaves

c. Buds alternate on the twig; capsules distinctly pedicelled

d. Flower scales brown or black, at least at the tip

e. Capsules densely white woolly; twigs sometimes white woolly; styles dark red
--------------------*S. candida*

ee. Capsules not white woolly; twigs brown or black

f. Twigs black or purple; mature capsules 7 - 12 mm. long; aments 2.5 - 7 cm. long; scales copiously clothed with long glossy hairs --------------------*S. discolor* ff. Twigs brown; mature capsules 6 - 9 mm. long; aments 1 - 4 cm. long in fruit.

g. Catkins 1.5 - 4 cm. long in fruit; tall shrub (1 - 2 m. high) -----*S. humilis*

gg. Catkins 1 - 1.5 cm. long in fruit; low shrub (0.5 m. high) -------*S. tristis*

dd. Flower scales yellow, rose tipped, elongate (aments sometimes appearing with the leaves) ------------------*S. bebbiana*

cc. Buds sub-opposite on the twig; capsules sessile (cultivated shrub or small tree) ------*S. purpurea*

bb. Aments appearing with the leaves

c. Capsules 3 - 5 mm. long, ovoid-oblong (blunt); fruiting aments dense, sessile or subsessile ----------------------*S. sericea*

cc. Capsules 6 - 8 mm. long, lanceolate-conic; fruiting aments lax, leafy bracteate; twigs frequently drying purplish black ----------------------*S. petiolaris*

1. *S. nigra* Marsh. Black Willow. (Fig. 7). Banks of streams and moist places in rich soil. Although widely distributed in the state it is nowhere abundant. Most abundant in southern two thirds of the state.

2. *S. amygdaloides* Anders. Peach Leaved Willow. (Fig. 8). Common in moist rich soil throughout southern two thirds of the state. Cheney states that the range is, "a little south of the range of *S. nigra*." Herbarium specimens of this tree are few and of poor quality.

3. *S. pentandra* L. Bay Leaved Willow. A cultivated species introduced from Europe. Seldom escapes.

4. *S. lucida* Muhl. Shining Willow. (Fig. 9). Widely distributed excepting in the southwest corner of the state. Common on low ground, in ponds and along streams. I have collected, in a pond near Cedarburg, a form of elongated capsules as in *S. lucida*; leaves somewhat resembling *S. fragilis*, but silky beneath and with 9 - 11 serrations per cm. of margin as in *S. alba*. Dr. Ball has examined my specimens and leaves

them as *S. lucida X S. alba* (?). I have not seen material from Wisconsin that appears to be *S. lucida* var. *intonsa* Fernald.

5. *S. serissima* (Bailey) Fernald. Autumn Willow. (Fig. 10). Apparently confined to the northwestern and southeastern portions of the state. Found in mossy swamps with *Betula pumila* var. *glandulifera, Larix laricina* and *Rhus Vernix*. Especially abundant about bogs in the southeastern counties.

6. *S. fragilis* L. Crack Willow. Naturalized from Europe. One of our commonest willows along roadsides and streams in the southern part of the state. I have collected branched staminate catkins from a number of willows of this species near Thiensville for three successive years[3]. It seems probable that this is an inherited characteristic.

7. *S. alba* L. White Willow. Introduced from Europe. Widely planted and freely escaping. Leaves often permanently silky beneath; twigs greenish. Var. *vitellina* L. Koch has more Koch has more glabrate leaves; twigs yellow or orange.

8. *S. babylonica* L. Weeping Willow. Naturalized from Europe. Occasionally found along streams. Cultivated varieties are numerous.

9. *S. interior* Rowlee. *S. longifolia* Muhl. *S. fluviatilis* of many authors. Sandbar Willow. (Fig. 11). Common throughout the state. This willow frequently flowers a second time. I have collected flowers as early as April 25 and as late as July 20. When the leaves of this species are eaten by larvae, the new leaves which are then produced are always more or less silvery pubescent.

What appears to be *S. interior* var. *pedicellata* (Andersson) Ball has been collected in Grant County (Fig. 11, cross). The very narrow and finely denticulate leaves agree with typical specimens collected along the Missouri River in southeastern Nebraska where it is common.

10. *S. cordata* Muhl. Heart Leaved Willow. (Fig. 12). Frequent throughout the state. In wet places, around ponds and on the banks of streams. The leaves of this willow are variable. Narrow leaved forms are common, while the leaves

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[3] Costello, Jour. Heredity 23:238. 1932.

of vigorous shoots and water sprouts are broadly oblong lanceolate with cordate bases.

11. *S. glaucophylla* Bebb. Glaucous Leaved Willow, Blueleaf Willow, Broadleaf Willow. (Fig. 13). Follows the western shore of Lake Michigan closely. Characteristic of sandy shores of lakes. A very small leaved form grows on the dry clay banks of the ravines near Lake Michigan in Milwaukee and Racine Counties. It is doubtfully var. *angustifolia* Bebb. Wadmond[4], in his Flora of Racine and Kenosha Counties, states that he finds *S. glaucophylla*, "inland on low prairies more abundantly than near the Lake, and even when found near the Lake, it seems to affect wet clayey soils, rather than sand."

12. *S. pyrifolia* Anders. *S. balsamifera* Barratt, Gray's Man., ed. 7. Balsam Willow. (Fig. 14). Mostly in the northern half of the state. Low ground and in spruce swamps. Infrequent.

13. *S. adenophylla* Hooker. *S. syrticola* Fernald, of Gray's Man., ed. 7. Gland Leaved Willow. (Fig. 15, dot). The rarest willow in the state. Has been collected only at Two Rivers, Manitowoc Co., on the sand dunes. In Indiana it is fairly common in the dune region bordering the lake. Usually found growing with *S. glaucophylla* in the dunes at the south end of Lake Michigan.

14. *S. pedicellaris* Pursh.[5] Bog Willow. (Fig. 16, cross). A single specimen, collected by A. M. Fuller on Washington Island, Door County, seems to belong here. The sub-coriaceous leaves are green on both surfaces as contrasted with the pale glaucous under surfaces of the leaves of the following variety.

S. pedicellaris var. *hypoglauca* Fernald.[6] (Fig. 16). Most of our material seems to belong here. Common in bogs and springy meadows.

15. *S. discolor* Muhl. Glaucous Willow, Pussy Willow. (Fig. 17). Probably found in every county in the state. Very common in swamps and wet places.

S. discolor var. *eriocephala* (Michx.) Anders. (*S. eriocephala* Michx.). This variety is characterized by pubescent twigs

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[4] Wadmond, Trans. Wis. Acad. Sci., Arts and Let. 16:826. 1909

[5] Fernald, Rhodora 11:157-162. 1909

[6] Fernald, l.c.

and by leaves more or less pubescent below. Frequently the aments are more densely pubescent than in the species. Range the same as the species.

16. *S. petiolaris* J. E. Smith. Slender Willow. (Fig. 18). Common in meadows, along banks of streams and in ponds. Forms with pubescent leaves are frequently collected. The second crop of leaves, following defoliation, is always more or less pubescent.

17. *S. humilis* Marsh. Prairie Willow, Upland Willow. (Fig. 19). Throughout the state, but nowhere abundant. Dry prairies and sandy areas.

18. *S. tristis* Ait. Dwarf Gray Willow, Dwarf Pussy Willow. (Fig. 20). Dry sandy places, borders of woods and clearings. Similar to above but smaller in every respect. Russel[7] states that this species was reported from Milwaukee County by J. A. Brandon in 1900. I have seen no herbarium specimens from that locality.

19. *S. sericea* Marsh. Silky Willow. (Fig. 15, squares). In moist places. Should be sought for in the Driftless Area. The station noted as Beloit, Rock Co. is doubtful. This sheet, containing two species, no date, collected by Dr. Lathrop, possibly has New York as its locality.

20. *S. bebbiana* Sargent[8] (*S. rostrata* Richards., Grays Man., ed. 7). Bebb Willow, Beak Willow. (Fig. 21). Common in moist or swampy areas throughout the state. A large shrub with leaves finely pubescent above and densely pubescent beneath. The glabrate leaved variety, *S. bebbiana* var. *perrostrata* (Hydb.) Schn., grows with the species but is not common.

21. *S. candida* Flugge. Sage Willow, Hoary Willow. (Fig. 22). Found mostly in cold bogs at the margin of tamarack spruce swamps.

S. candida var. *denudata* Anders. (Fig. 22, cross). First collected by A. M. Fuller, No. 2371, in the Cedarburg Bog, Ozaukee Co., 1928. As in the Indiana specimens collected by Chas. C. Deam[9], the capsules are entirely glabrous. The ma-

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[7] Russel, Bull. Wis. Nat. Hist. Soc., 5:186. 1907

[8] Rhodora, 26:122-123. 1924

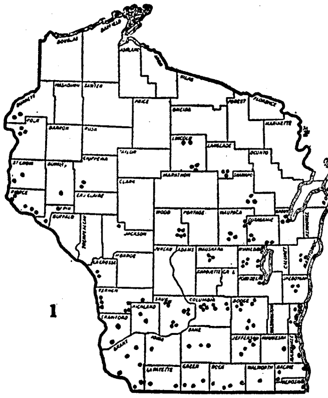
[9] Deam, Shrubs of Indiana p. 58. 1924.

tured capsules are short pedicelled, and similar in shape to typical *candida*. The lower fourth of the narrow leaves is inrolled to such an extent as to give to the leaf the appearance of being long petioled. The leaves are green on both sides, rugose above and strongly veined below. I have recently collected specimens of this variety in the same place.

S. candida X *S. petiolaris*. Cedarburg Bog, Ozaukee Co. For two successive years I have found this cross growing on the quaking bog in company with *S. candida* and *S. petiolaris*. Leaves are intermediate between the two species, like *S. petiolaris* in shape and mostly like *S. candida* in pubescence. Intermediates resembling one species or the other more closely than the cross have also been collected. Carleton R. Ball has seen my specimen No. 928, July 8, 1932, and states in a letter that although the thinly tomentose to glabrate undersurfaces of the leaves might indicate variety *denudata* Anders., "the leaves are broader than *denudata* as seen by me." He also mentions the, "sparsely denticulate and scarcely revolute margins, which would be expected in hybrids with *petiolaris*."

22. *S. viminalis* L. Osier. Introduced from Europe and cultivated in parks as an ornamental. No evidence that is has escaped anywhere in the state.

23. *S. purpurea* L. Purple Willow, Basket Willow. Naturalized from Europe. A common escape along roadsides and in waste places. The subopposite leaves are a distinguishing characteristic.



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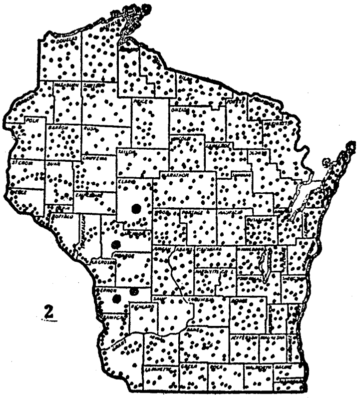
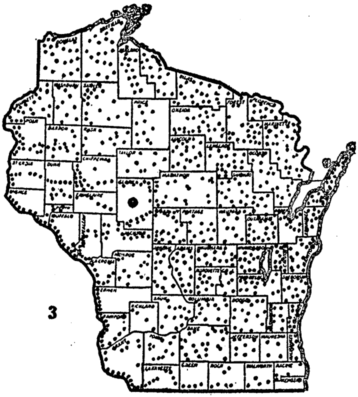
Populus alba



2

Populus tremuloides



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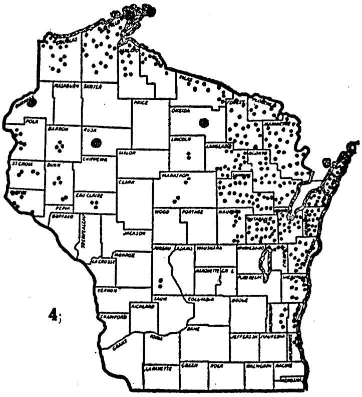
Populus grandidentata



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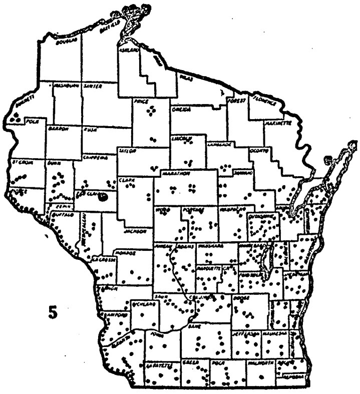
Populus balsamifera



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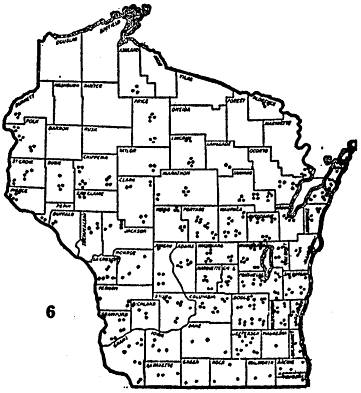
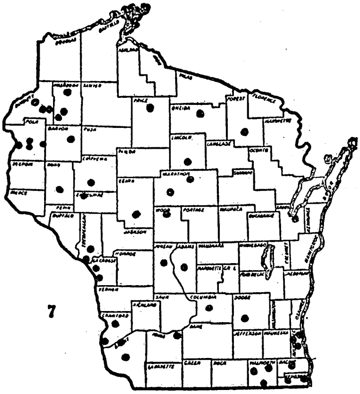
Populus deltoides



6

P. nigra var. italica



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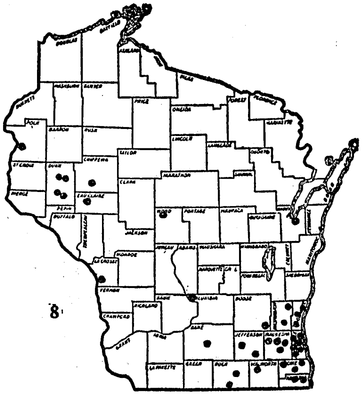
Salix nigra



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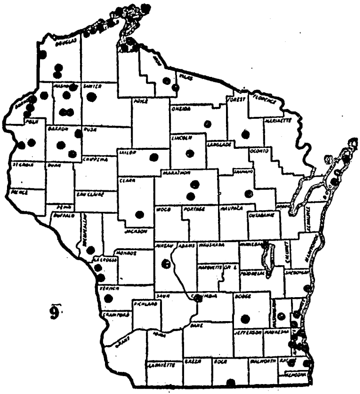
Salix amygdaloides



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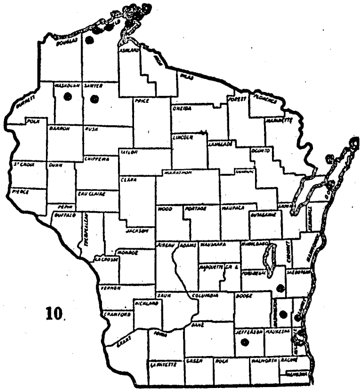
Salix lucida



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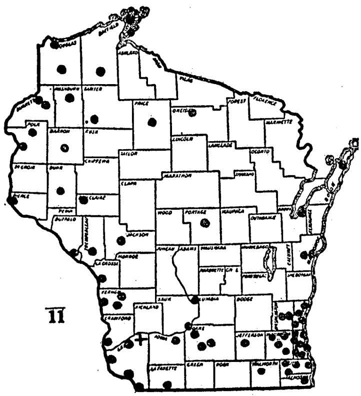
Salix serissima



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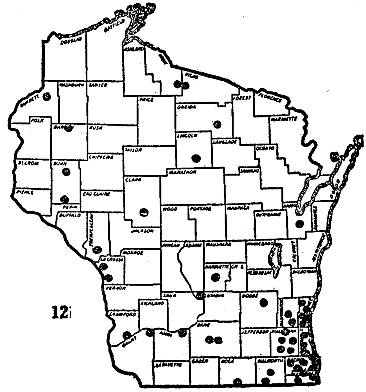
Salix interior



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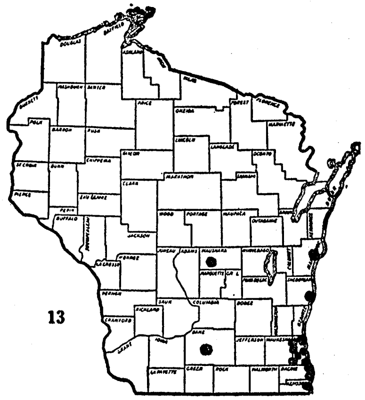
Salix cordata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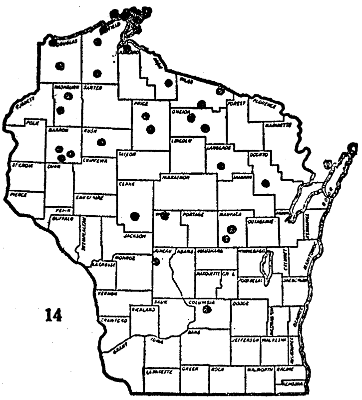
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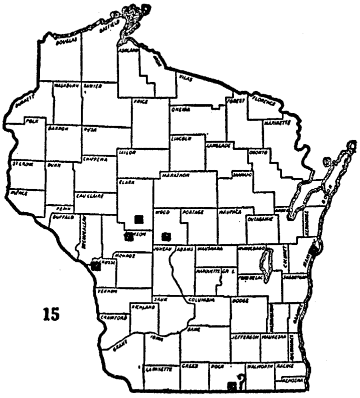
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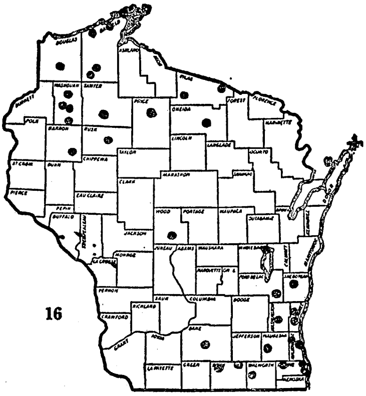
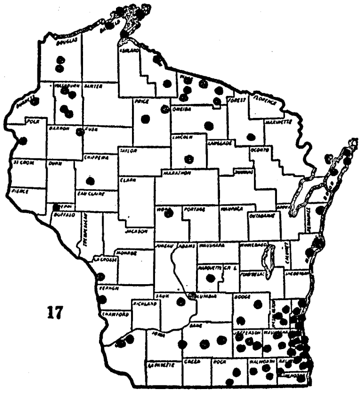
● Salix adenophylla
■ Salix sericea


16

+ Salix pedicellaris
● S. pedicellaris var. hypoglauca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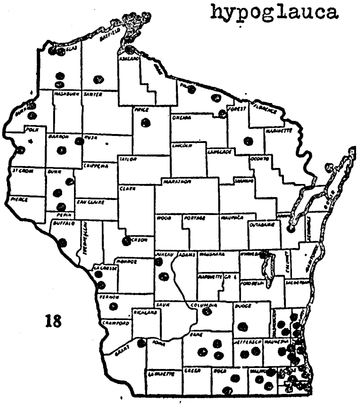
Salix discolor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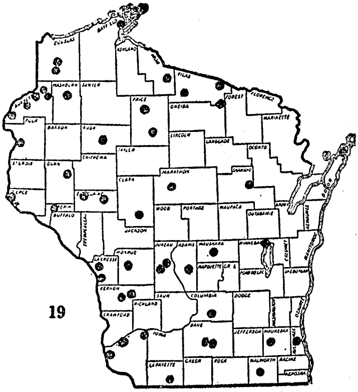
Salix petiolaris



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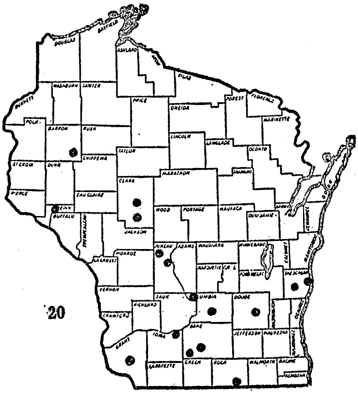
Salix humilis



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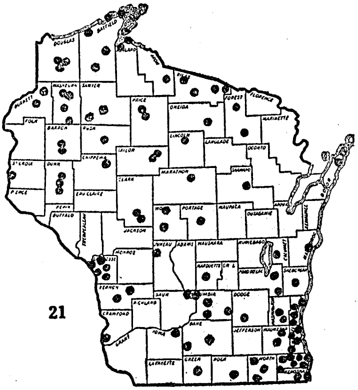
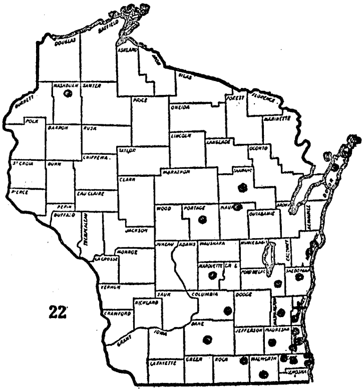
Salix tristis



21

Salix bebbiana



22

● Salix candida
+ S. candida var. denudata

ELABORATION OF SETTING IN *OTHELLO* AND THE EMPHASIS OF THE TRAGEDY

JULIA GRACE WALES

I

THE SETTING

The Significance of the Study of Place for this Play

The sense of place is one of the major factors in Shakespeare's imaginative appeal, though not place, necessarily, in any scientific, geographical signification. That he is no realist interested in facts for themselves, must not be allowed to obscure the complementary truth that he is no classicist either, but a romantic. There is nothing abstract about his scene. It is individualized through homely detail. His airy nothing is always given name and habitation; and largely from these obtains its interpretation and emphasis.

In a study of *Othello* from this point of view it would be instructive, did space permit, to bring together all the concrete detail of the play, whether English, foreign, or neutral, and to examine and classify it for its significance in creating atmosphere and building up a sense of locality. The cumulative effect of this detail would be greatly enhanced could we gather and place beside it all the notes and illustrations, collected by editors[1] of the play or scattered through learned articles,[2] which

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[1] We can only refer the reader to the various annotated editions of the play and cite a few significant passages that have not yet found their way into these editions.

See, for example, *Variorum*, p. 5 for C. A. Brown's comment, and p. 8 for Staunton's, on the mercantile associations of Florence; p. 46 for Knight's note on *Luccicos*; pp. 30-32, a long note on "as double as the duke's" (I. ii. 11-17), with quotations from Contareno and Thomas on the power of the Duke in relation to the rest of the Council. Again, see *Variorum*, pp. 28, 29, for a long and interesting note, including Malone's famous illustration from Lewkenor on Venetian officers especially charged with protecting the city by night.

See also Hart's note on *nettles* (I. iii. 325-7), *Arden Edition* (1903), p. 53; that on *chrysolite* (V. ii. 143), p. 240; that on *coloquintida* (I. iii. 355), p. 57.

See a good note in the *Yale Edition* (1918), p. 134, on the historical background of the war.

[2] One passage must be quoted from the researches of Sir Edward Sullivan, "Shakespeare in Italy," *The Nineteenth Century* (1908), pp. 329-330. "The word Veronessa shows an intimacy with Italy in two distinct directions; first, it is a correctly formed feminine adjective, meaning 'of, or belonging to Verona'; and secondly, it implies an acquaintance with the fact that Verona (which was in the Venetian State) furnished war galleys to Venice, or that the Venetians kept a portion of their own fleet at or near Verona. . . . The importance from a naval point of view of the Adige, which flows through Verona, may be appreciated by reading in pre-Shakespearian Italian histories the account given of the fleet of ships sent by the Venetians up the river to the Lago di Garda to assist their army in that district against Filippo Visconte, Duke of Milan. The distance was about two hundred miles, and the flotilla consisted of twenty-five barks and six galleys under the command of Zeno."

He refers in a foot note to Alberti, F. Leandro, *Descriptione di Tutta Italia*, Venice, 1586, p. 397, "who cites Biondo and other writers. See also Hazlitt's *History of the Venetian Republic* (1860), where a full account is given of this remarkable expedition."

have extended its temporal and local significance and deepened its imaginative connotation. To do this, however, would entail too much repetition of accessible material.

The valuable researches of Mr. J. W. Draper,[3] too recently before us and too extended to be reviewed here, are evidence enough that the subject of Italian local color in *Othello* had been by no means exhausted by earlier writers and that useful material is still coming in.[4]

The more general works on the sixteenth and early seventeenth centuries are constantly throwing new light on the subject;[5] and continued search into the materials of history, such

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[3] J. W. Draper: "Captain General Othello," *Anglia*, XLIII (1931), 296; " 'This Poor Trash of Venice'," *Jour. of Eng. and Germ. Philology*, XXX (1931), 508; " 'Honest Iago'," *Pub. Mod. Lang. Assoc.* XLVI (1931), 724; "Shakespeare's Othello and Elizabethan Army Life," *Rev. Ang.-Am.*, IX (1932), 319; "Some Details of Italian Local Color in Othello," *Sh. Jb.*, 1932, pp. 125-7; "Desdemona, a Compound of Two Cultures," *Rev. Litt. Comp.*, XIII (1933), pp. 337-351.

Especially interesting is the wealth of new illustration, given in these articles, of army life in England and on the Continent and of conditions in England and Italy having to do with the freedom of women.

[4] See "Shakespeare's Venice" by Violet M. Jeffrey, *Mod. Lang. Rev.*, vol. 27 (1932), pp. 24-35, in which the problem of the identity of "the Sagittary" is reopened.

[5] Perhaps it is sheer coincidence that a passage in Hazlitt's *Venetian Republic* seems to illuminate Iago's figure of speech (I. i. 75-77):

I'll call aloud.
Do; with like timorous accent and dire yell
As when, by night and negligence, the fire
Is spied in populous cities.

The dread of fire like that of plague was common to all the countries of Europe. Hazlitt gives an account of a great fire in Venice in 1577: "The damage was incalculable, and speculative reports were soon spread over Europe of the amount of the losses." (*The Venetian Republic*, 1860. Ed. 1915. Vol. II, p. 133.) Disastrous fires occurred in 1479, 1483, 1574, 1577. (*Ibid.*, pp. 496-497.)

In *Shakespeare's England* (Oxford, 1916, I. Ch. VI. pp. 170-171) we find, on the general background, a passage of the utmost interest:

"For the characters and events of old-time plays, Shakespeare's Europe is concentrated upon Athens and Rome, but is extended to the easternmost recesses of the Mediterranean. In the Tudor period the Turks had pushed this frontier of Europe westward: Rhodes (1522) and Cyprus (1571) had fallen; Greece and its islands had already become Asiatic; and there was a redistribution of forces. Accordingly, in the modern-Mediterranean plays of Shakespeare—*All's Well, Much Ado, Two Gentlemen, The Winter's Tale, Twelfth Night, Othello, Romeo and Juliet*, and *The Merchant of Venice*—Athens is not named, and Rome is named only twice (*Tam. Sh.* IV. ii. 75, *Merch. of V.* IV. i. 153); and the scenes are laid in Verona, which is misdescribed as a tidal port (*Two Gent. of Verona*, II. iii. 40), Venice, Padua, Milan, Mantua, Florence, Marseilles, Illyria, Sicily, or Messina; and of these only the last two figure in the old-Mediterranean plays. The eastern Mediterranean is only once to the fore. In *Othello*, Rhodes and Cyprus are physical and political storm centers, where the Turks and Venetians would have fought had not all the Turks been drowned; at Cyprus the Furies which watch over family life overwhelm all the leading characters in the play. With this exception—if it is an exception—the modern plays shun the eastern Mediterranean, Greece, Middle Italy, and all the principal places in the old-Mediterranean plays. The sea is the same sea as of old, and swarms with pirates (*Merch. of V.* I. iii. 24), like those of which Pompey wanted to rid it (*Ant. & Cleop.* II. vi. 36); and Italy is still the place where Spaniards, Neopolitans, Frenchmen, Englishmen, Scotchmen, Germans, and Polish Counts Palatine meet (*Merch. of V.* I. ii); and an occasional 'Moor' (Mohammedan) lends an Asiatic or an African tinge. Italy is still cosmopolitan and dominates the Mediterranean, but the center of political gravity has shifted, and for Shakespeare, whose instincts draw him to places where life is rich and full, Italy and the Mediterranean mean different things in ancient and modern times."

See also an interesting note on "guards of the ever-fixed pole," I, p. 453; also a note on "carrack," I. p. 153, which should be compared with the note on "lawful prize" in *Variorum*, p. 37—these comments affording an excellent illustration of Shakespeare's method of piecing out foreign information with English detail for the general purpose of realism in the sense of substantiality. The present writer has endeavored to examine this composite process in two studies: "Shakespeare's Use of English and Foreign elements in the Setting of *The Two Gentlemen of Verona*," *Wisconsin Academy of Sciences, Arts, and Letters*, vol. 27 (1932), pp. 85-126, and "Shakespeare's Use of English and Foreign Elements in *Much Ado about Nothing*," *Ibid.*, vol. 28

as the travel books of the period and of slightly earlier and later decades, is still rewarded with new and pertinent matter.[6]

Point by point these researches may seem merely curious. But they have a cumulative and critical value. They prove beyond a doubt that in *Othello* Shakespeare is building up a sense of place, and that deliberately, for an artistic purpose. What that purpose is becomes evident when we realize that the local color of the play is not homogeneous but consists of two elements in sharp contrast with each other, and that this contrast is in vital relation to the tension of the tragedy.

The Italian background and the world of Othello's memories may to our imagination have come to be merged romantically in the general impression of the play. Yet in trying to get the tragedy before us as a whole, it is of first importance to distinguish the two and to keep the contrast between them vividly in mind.

Venetian Color

The detail of Venetian color used in this play is less opulent than that used in the *Merchant of Venice,* more economical, yet adequate. We are left in no doubt how to visualize these backgrounds. To see how richly they are filled in, we have only to

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(1933), pp. 363-398. Mr. J. W. Draper stresses the process as a conscious method in his "Desdemona, a Compound of two Cultures." (See note 3 above.)

Shakespeare's England also affords information on the sword of Spain (I. p. 132): "In *Othello* (V. ii. 252) we have 'It is a sword of Spain, the ice brook's temper.' So the modern version, but in the earliest printed edition, 1622, it was 'The Ise Brokkes temper.' Isebrook was the English name for Innsbruck in the Tyrol, whence some of the best steel was imported into England from the early part of the sixteenth century until the Civil War. This steel was used for the manufacture of armour in England, and 'Isebrook' and other variants of spelling can be found in documents quoted in the Calendars of State Papers from April 1517 to April 1595. Moreover warm water of various degrees of heat was used here, as in Japan, by the famous swordsmith Musamane, for tempering the blades. Othello's expression merely means a Spanish blade of the best Innsbruck temper." If, by this interpretation, the passage loses one element of poetry, it has, on the other hand, gained slightly in exotic suggestion.

[6] James Howell in his *Survey of the Signorie of Venice,* London, 1651, gives an elaborate account of the government of the Republic. Though not available to Shakespeare, the following passage is of interest:

"The Generall in warr upon the Continent is commonly som forren Prince; He is not chosen either of the Senatorian or patrician order: he hath an ample salarie, viz. ten captaines pay, and 4000 crownes a yer: ther goes along with him two Legats or Proveditores, who are Gentlemen of Venice, and of the Senatorian order, and without the concurrence of their advice he neither acts nor decrees anything himself without their intervention. These Proveditores are perpetually assistants to the Generall and they pay the Soldiers Salaries, and their main care is that nothing be done rashly to the detriment or dishonor of the Republic."

I regret that I have not this page reference; nor have I been able to check the passage. Howell also mentions (p. 17) the "Provosts of the night." Cf. *Variorum,* p. 47, for more immediately pertinent illustrations: Malone's statement supported from Contareno (trans. by Lewkenor, 1599) that it was against the policy of the Venetian State to entrust the command of the army to a native; also a passage cited by Reed from Thomas's *History of Italy* to the same effect.

For an account of the travel books of the time, see Clare Howard, *English Travellers of the Renaissance* (1914), with bibliography.

Fynes Moryson, writing in 1611, says after speaking of Italian love of revenge and skill in making poisons (*Shakespeare's Europe,* Glasgow, 1907, pp. 405-406): "For which treasons the Italians are so warye, espetially hauing a quarrell, as they will not goe abroade nor yet open their doores to any knocking by night, or somuch as putt their head out of a windowe to speake with him that knockes."

look at the meager setting of Cinthio's story, of which the following passages are the most significant as bringing out the contrast:

> The Venetians resolving to change the garrison which they maintain in Cyprus, elected the Moor to the command of the troops which they destined for that island . . . he was extremely pleased with the honour proposed to him (as it is a dignity conferred only on those who are noble, brave, trusty, and of approved courage).
>
> He had in his company an ensign of a very aimiable outward appearance, but whose character was extremely treacherous and base. . . .
>
> Had he not feared the strict and impartial justice of the Venetians he would have put him openly to death. . . .
>
> The Venetian magistrates, hearing that one of their fellow-citizens had been treated with so much cruelty by a barbarian, had the Moor arrested in Cyprus and brought to Venice, where, by means of the torture, they endeavored to find out the truth. But the Moor possessed force and constancy of mind sufficient to undergo the torture without confessing anything.[7]

In the play, on the other hand, we have in the first scene the chiaroscuro of a street by night, the taper at the window, flaring torches and gleaming swords; in the second, the stateliness of the Council Chamber and the gravity of the discussions going on there, the stir of arriving messengers, and the background of war and critical action. And it is worth noting that the theatrical interest of the two scenes, the suspense which gives to each a focus and unity of its own, its own rise and fall of intensity, is largely dependent upon the skillful use of setting. Similarly in Act II the suspense arises out of the realization of place—the seaport and citadel, the storm—"than which a fuller blast ne'er shook our battlements,"—the relief and serenity of a safe landing; the merry-making passing into carousal "in night and on the court and guard of safety", " in a town of war, yet wild, the people's hearts brimful of fear," "the clink and fall of swords," voices "high in oath," the clanging of a dreadful bell.

When the main action in finally under way in the third act, the sense of place is less immediate than indirect. It is the background of Venice of which we are again made conscious—and not now of its justice and dignity, of power worthily held, but rather of palaces where "foul things" "intrude", of hypocrisies

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[7] Shakespeare's Library, II, pp. 286, 306, 307. Cf. the comment of Violet Jeffrey (see note 3 above), "Giraldi Cinthio, in his version of the tale, supplies no details whatsoever of the town: yet the scenes of the play set in Venice are packed with local color."

too subtle to be divined save by one versed in the ways of the world, who "knows all qualities with a learned spirit of human dealings."[8] In the end we return to the earlier impression and feel that the honor of Venice has remained inviolate.

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[8] H. N. Maugham (*The Book of Italian Travel, London,* 1903) pronounces Shakespeare's Italy uniformly that of the Italian novelists as far as local color is concerned, but adds in a footnote "except in the character of Iago, who is a typical Renaissance Italian".

The fact is that Shakespeare, as we should expect, reflects in his plays both contemporary attitudes, the romantic lure and educational advantages of Italian travel and the patriotic and to some extent even the protestant and puritan condemnation of its evil influences.

But although he reflects the two aspects of Italy, Shakespeare does not of course subject them to any sort of scientific historical study. In fact he cheerfully combines and mixes them. In this respect it is worth while to contrast *Othello* with the *Duchess of Malfi.* In Webster's play there is a more fully developed Italian atmosphere, as Italy was thought of in England—for instance, in the corruption of the church, of government, the preponderance of evil, the misuse of the law, wholesale bribery, the tendency to use crime freely as a means to an end and to make little of it. Of course, for theatrical purposes, Webster uses also many trappings, conventionally associated with Italy, but no more realistic than romantic—such as the control of marriage by the family, the emphasis on banishment, on poison and the dagger, the easy isolation of the palace, superstitions about drugs and charms, the ancient abbey and the echo, etc. Also he brings in natural references to place and time, the new fortifications at Naples, "I knew him in Padua", "the Cardinal hath made more bad faces by his oppression than ever Michael Angelo made good ones"; the baths at Lucca, the shrine at Loretto, the citadel of St. Benet, etc. But chiefly Webster seeks to get an Italian effect by emphasizing the intellectual attitude of the Italian renaissance, the will, force, intellect of his villains, the intellectual doubt of Antonio and the Duchess.

Dost thou think we shall know one another
In th'other world? . . . .
O that 'twere possible we might
But hold some two days' conference with the dead!
From them I should learn somewhat, I am sure,
I never shall know here. I'll tell thee a miracle:
I am not mad yet, to my cause of sorrow.

This is the miracle. She does not go mad—nor does Antonio—nor Bosola. They have strong heads—these skeptics. Julia the "great woman of pleasure" is likewise typical. She too dies like an intellectualist:

'Tis weakness
Too much to think what should have been done: I go
I know not whither.

In his intellectual attitude Bosola is unlike Iago, less convincing, though in some ways more interesting. He knows doubt of his own philosophy. The growth of his doubt is gradual; however, because of over-condensation, far too swift for us to follow satisfactorily. Throughout the play, evil is the norm of action and atmosphere. The good is rare and stands alone. The characters struggle with evil as an intellectual problem, not a single issue. At the end it is not so much the active triumph of good that we feel as *the proved futility of evil. Nothing is gained by wrong; hence you may dare to be good if you prefer it.*

Shakespeare gives us no such sense of general human depravity. Even in *Othello,* good appears as the norm; the evil, though real and unconquered, is presented as monstrous.

Fynes Moryson in *Shakespeare's Europe* (1617, p. 408), expresses the popular view of the Italian character: "Thus the Italyans being by nature false dissemblers in their owne actions, are also most distrustfull of others with whome they deale or converse, thincking that no man is so foolish as to deale playnly, and to meane as he speakes." For earlier comments cf. Maugham, p. 14: "Young Englishmen did not always come back entirely improved by this southern experience. Ascham, the gentle master of Lady Jane Grey, was only nine days in Italy, but he tells us that he saw 'in that time, in one city, more liberty to sin, than ever I heard tell of in our noble city of London in nine years.' Robert Greene, the dramatist, admits that he 'saw and practised on his Italian travels such villainy as it is abomination to describe.' Sir Philip Sidney has admitted the dangers of Italy, but remarks that he is acquainted with 'divers noble personages . . . whom all the sirens of Italy could never untwine from the mast of God's word'."

See Einstein's account of *The Subtlety of the Italian,* by F. G. B. A., 1591, a book which argues that the Italians ought "to be shut up from all access or entrance into other countries. If such means were adopted, 'we no more shall be exposed to the lamentable miseries into which they were wont to bring us headlong at their own lust and pleasure'."—Einstein, *The Italian Renaissance in England,* pp. 170-172. See also *Ibid.,* p. 160—a quotation from Gascoigne: "George Gascoigne, in his lines to a friend about travel in Italy, advised him to beware of poison when invited to dinners, never to drink before another had tasted the beverage, to be on the lookout for poisoned soap, and take care lest the tailor stuff his doublet with what might bring on a a deadly sweat. The Italian art of poisoning impressed itself on the Elizabethan imagination and furnished endless material to the dramatists." He also quotes Nash, *Piers Penniless* (p. 38): "O Italy academy of manslaughter, the sporting place of murder, the apothecary shop of all nations! How many weapons hast thou invented for malice."

On the subject of infidelity and private vengeance, Fynes Moryson says:

"Adulteries (as all furyes of Jelousy, or signes of making loue, to wiues, daughters, and sisters)

The elements of Venetian setting which receive the most emphasis thus group themselves about four aspects of the story: the romantic elopement,[9] Othello's official relation to Venice, the

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are commonly prosecuted by priuate reuenge, and by murther, and the Princes and Judges, measuring their just reuenge by their owne passions proper to that nation, make no great inquiry after such murthers besides that the reuenging party is wise inough to doe them secretly, or at least in disguised habitts."—*Shakespeare's Europe,* p. 160.

Einstein says (*Tudor Ideals,* 1921, p. 123):

"The frequency of vengeance on the stage suggests that this motive as an incentive to crime was readily understood, but it was associated more with Italy where the absence of central authority and the inadequacy of the law, favored the wronged individual taking the remedy into his own hands. . . . Perhaps one reason why the Elizabethan drama save in the greater Shakespearian masterpieces remains so dead to us, is the lack of contact between modern life and private vengeance. The Englishman of the Sixteenth Century had still enough associations with former recollections of violence to make the crimes of Italy appear not altogether remote."

Similarly, Boulting says (*Tasso and his Times,* 1907, pp. 182-3):

"The Italian gentleman of the sixteenth century felt certain stains as keenly as wounds; and the growing respect for female relatives and family pride had this consequence, that any unfaithfulness on the part of a wife or any unchastity on the part of a sister were visited by the speedy removal of the suspected lover, and in time it became *de rigeur* that she also should pay for her fault with death. The restriction of the power of the nobles to their own domestic circle and the growth of honor provided the world with a terrible series of family tragedies which struck the imagination of our English dramatists and gave us 'Othello' and the 'The White Devil,' and 'The Duchess of Malfi'."

Mr. J. W. Draper (cf. note 3 above) finds a similar attitude among English army officers of the period.

[9] On the subject of Othello's marriage, some passages from Boulting's *Woman in Italy* (1910, pp. 72, 74) are worth quoting:

"In the middle of the sixteenth century, the Council of Trent published the decision *De Sacramenti Matrimonii,* which insisted on ecclesiastical marriage and the prior publication of banns. . . . . Not merely was marriage subjected to family interests, but the State also had a word to say. . . . By reason of the peculiar patrician government of Venice a noble marrying a plebian woman was excluded from the Venetian Council, until the contract was submitted to the Government and allowed."

That Desdemona's difficulties were not unparalleled is seen in the story (given by Boulting, *Woman in Italy,* pp. 77-79) of Giulietta Spinola (Genoa, 1545), who somewhat independently married the man of her choice. An official inquiry was instituted as to whether she had been forced into wedlock. She declared that she wished to return to her husband. "The Vicar vainly endeavored to get her uncles and trustees to accept the marriage, and the question of its validity was referred to the Archbishop, who decided that it was valid, and, therefore, a sacrament. The trustees, not to be balked, then appealed to Pope Paul III himself. . . . Meantime Giulietta was removed, first to another convent, where it was deemed impossible for her husband to hold any communication with her, and then to the house of a lady of the Spinola family, where she was again interrogated by the Vicar. . . . But the spirited girl, determined not to be thwarted, contrived to make her escape, gained her spouse's castle and resumed the interrupted honeymoon."

Mr. J. W. Draper (cf. note 3 above) says of Desdemona:

"Her hybrid origin is surely a secret we are not intended to explore; and so may future critics continue as heretofore to find her only 'angelic' and 'innocent' and 'shy' and forget, as Shakespeare wished us to forget, that she wooed a husband for herself, deceived a father and made him die of bitterness, and then stepped back into child-like innocence at the dramatic behest of four acts of mighty tragedy." We are inclined to wonder, however, whether it is not the shy and innocent girl who might do with simplicity what Desdemona does. Is it not because she is simple and acts "all of a piece" that she can do it and so sincerely? A more complex woman would have thought twice. Even Juliet is more complex by nature—though younger.

A distant parallel to Desdemona's story is found in the story of Bianca Cappello, given by W. C. Hazlitt, *The Venetian Republic* (1915), Vol. II. pp. 139-140. "Bianca, sole child and heiress of Bartolommeo Cappello, a noble Venetian" yielded "to the advances of Pietro Bonaventura, a young Florentine of good but poor family, employed as a book-keeper at the Salviati bank, who resided in a house near the Casa Cappello at S. Apollinare, adjoining the Ponte Storto. Love letters were exchanged; and Bonaventura, allured by the beauty of the girl and her probable fortune, . . . persuaded her to elope with him on the night of the 28th November 1563. The fugitives had engaged the services of a gondolier named Girolamo, and had taken into their confidence the uncle of Bonaventura and three or four others, whose silence or aid they deemed imperative. . . . They crossed the frontier and reached Florence in safety. Bianca carried with her all her jewellery.

"The amazing news was spread over the city the next morning. The Council of Ten and the Avogadors took immediate proceedings; prices were set on the heads of the principals. . . . The afflicted parent added a reward of 6,000 lire to that of the government for the recovery of his misguided child, who was only sixteen years of age at this time." The rest of Bianca's story differs widely from Desdemona's. The warning "she has deceived her father and may thee", unjust in Desdemona's case, would have been just in Bianca's.

corrupt side of Venetian life, and on the other hand, the dignity and integrity of the Venetian State.[10]

Othello's Memories

As already indicated, Venetian color is, however, not the only significant element of the setting; another kind of detail is used in profusion in building up a remoter background to be seen in the mind's eye only—a world of memory and imagination.

We would fain hear Othello "run through" the continuous story of his pilgrimage, the "distressful strokes" that his youth suffered, the "disastrous chances" of his later years. But (like Desdemona as she went about her house-affairs) we have only snatches—besieged cities, capture, slavery, and redemption; his mother receiving the enchanted handkerchief from the ancient sybil who devined her thoughts;[11] the pomp of war, the Pontic sea and its icy current;[12] the encounter with the turbaned Turk at Aleppo;[13] curious peoples in their own lands, caves, deserts,

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[10] For an account of the official machinery of Venice in the sixteenth century, cf. W. C. Hazlitt, *The Venetian Republic,* Vol. II, Chapter XLVIII: "The provision for the public service was at once exhaustively comprehensive and jealously minute. No labor, ingenuity or cost was spared in rendering all the departments of the state, spending and administrative, efficient and adequate to current wants. A brief survey of the offices and magistratures engaged in the management of affairs suffices to impress on us the magnitude of the responsibility and charge, which gradual conquest and aggrandizement had laid on Venice, as well as the corresponding genius, which manifested itself for the control and protection of a dominion so extensive and so scattered, no less than of a territory at home beyond everything precious." (pp. 448-9.)

Cf. *Variorum,* p. 43. Lloyd: "Central in the First Act is the scene in the Council Chamber; and the consideration, by the Duke and Senators, of the news from Cyprus is no mere surplusage; it strikes a tone of dispassionate appreciation of evidence and opinion that dominates all the succeeding scenes of agitation and disorders. From inconsistent intelligence, the main point of agreement is carefully adopted for further examination, notwithstanding predisposition to underrate it; intelligence, otherwise of good authority, is condemned as fallacious from collateral indications; and lastly, thus prepared for, the last courier has full credence, and the critical circumstances once understood, action follows at once. Othello is dispatched that very night. The same solid perspicacity distinguishes the reception of the complaint of Brabantio."

[11] In *Shakespeare's England* (II, 485-6) we have an account of the gypsies in England in Shakespeare's day:

"It was in the beginning of the sixteenth century that they made their first appearance, and the mystery of their coming and going was still unsolved. Though they were called Egyptians, or in derision, Moon-men, there were few who believed in their eastern origin. 'Ptolomy, I warrant,' says Dekker, 'never called them his subjects, no, nor Pharao before him.' And the same writer, declaring that their complexion is filthier than the tawney face of a red-ochre man, is sure, in defiance of the truth, that it is not their own. 'Yet are they not borne so,' says he, 'neither has the Sunne burnt them so, but they are painted so' . . . . They lightly deceived the common people, 'wholly addicted and given to novelties, toyes and new fangles;' whom they delighted with the strangeness of their headgear, and of whose credulity they took an easy advantage. Wherever they went they practiced legerdemain, or fast and loose, they professed a knowledge of physiognomy, palmistry, and other abused sciences, and by foretelling in the hand destinies, deaths, and fortunes, they robbed poor country girls of money and linen."

Shakespeare may have had in mind the gypsies of his own country; but in Othello's words he characteristically utilized their Oriental suggestions to contribute to an Oriental atmosphere.

[12] See *Variorum,* pp. 210, 211, for the passage in Holland's Pliny on which this is based; also Swinburne's eloquent comment.

[13] These regions made a strong and familiar appeal to the English mind.

The malignant and turbaned Turk was a real person to the Englishman as well as to the Venetian. We have for example an account of the escape of John Fox from the captivity of the Turks in Alexandria. See C. R. Beazley, *Voyages and Travels mainly during the sixteenth and seventeenth centuries* (Arber's *English Garner*), 1903, I. 139-149. Even Englishmen knew what it meant to be taken captive and "sold to slavery." See also Ascham's account (1552) of ex-and mountain passes, with rocks sharp against the sky.

Though the lines beginning

> Wherein of antres vast and deserts idle

are among the most familiar in literature, they never lose their power to take us by surprise. Shakespeare never saw these things or anything like them. Whence is the peculiar quality and coloration of this landscape? The most satisfactory answer is that given by Professor H. B. Lathrop,[14] who quotes a striking passage from a sixteenth-century translation into English of de Changy's summary of Pliny's Natural History:

> Towards the west there is a people called *Arimaspi*, that hath but one eye in their foreheads, they are in the desert and wilde Countrey. The people called *Agriphagi*, liue with the flesh of Panthers and Lyons: and the people called *Anthropomphagi* which we call *Canibals*, liue with humaine fleshe. *The Cinamolgi*, their heades are almost lyke to the heades of Dogges. *Affrica* aunciently called *Libia*, doeth containe the *Moores*, and the pillers of *Hercules*, (among the floudes) there is *Onylus* that doth ingender Cocodrils. There are goodlye Forrests with vnknowen trees, some of the which trees beare threades, of the which is made clothing of cotton. Cyrenes and Syrtes, make their houses of salt stones cut out of the mountaines, there is the mountaine of *Ciry*, the which doth ingender and bring forth many precious stones. In *Libie*, which is at the end of the *Ethiopes*, there are people, differing from the common order of others, they haue among them no names, and they curse the Sunne for his great heate, by the which they are all black sauing their teeth, and a little the palme of their handes, and they neuer dreame. The others called *Troglodites* haue caues and holes in the grounde, & haue no other houses. Others called *Gramantes*, they make no mariages, but all women are common. *Gamphasantes* they go all naked. *Blemmyis* is a people so called, they haue no heades, but haue their mouth and their eyes in their breastes.

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changes of Turkish and Christian atrocities: *The English Works of Roger Ascham,* Cambridge, 1904, pp. 130, ff.

For interesting passages on these regions, including Aleppo, see the narration of John Eldred, "the first Englishman who reached India, overland, 1583-1589." (See Beazley I, 295-303). See also *Shakespeare's England,* I, Chapter VI, *passim*; also the bibliography of this chapter. See also H. C. Hart's introduction to the *Arden Edition* of the play (1903, 1928) for the parallels in Holland's *Pliny.*

Among the many books listed in the bibliography of Clare Howard, *English Travellers of the Renaissance* (1914) is that by George Sandys' published in London in 1615, entitled *A relation of a journey begun An. Dom. 1610. Four Bookes. Containing a description of the Turkish Empire, of AEgypt, of the Holy Land, of the Remote Parts of Italy and Islands adjoyning.* This book is too late of course to be a source of any of the allusions in Othello. But it testifies to the popular interest in the regions which were the obscure background of Othello's adventures. Sandys describes the Euxine Sea (pp. 39-40) and tells how the Bosphorus "setteth with a strong current into Propontis." He describes the habits and dress of the "turban'd Turks." He tells of the slave markets. Their slaves "are Christians taken in the warres, or purchased with their money. Of these there are weekly markets in the Citie, where they are to be sold as horses in Faires; the men being rated according their faculties, or personal abilities, as the women for their youths and beauties." He says (p. 69) that "with their aspects of pity and affection" they "endevour to allure the Christians to buy them, as expecting from them a more easie servitude and continuance of their religion. . . . But gally-slaves are seldome released, in regard of their small number, and much employment which they have for them."

[14] Henry Burrowes Lathrop, *Translations from the Classics into English, from Caxton to Chapman. University of Wisconsin Studies in Language and Literature,* no. 35 (1933), pp. 219-20.

"Here," says Professor Lathrop, "within the spaces of two pages, is everything whereof it was Othello's 'hint to speak'."[15] Everything, we answer as we read, except the perspective of the picture. Could it have been from the flat surface of these pages that Shakespeare lifted up his eyes to its depths and distances? Mr. Lathrop promptly answers our question: "Nothing is omitted but the loftiness of the hills, 'whose heads touch heaven.' And even this omission is but natural. The region named—though the geography extends further—is Africa, which 'doth contain the Moors'—Othello's own country, and the hills whose heads touch heaven, as Shakespeare's Ovid would suggest, are the summits of Mount Atlas itself, bearer of the skies, the loftiest mountain in the land of the Moor, Othello."

Let us not forget, however, that the scope of the pilgrimage includes not only strange and shadowy lands, but a world more tangible, if no less romantic: one familiar to Venetian traders, travellers, and warriors. And so in the final allusion to Aleppo[16] the two main elements of the setting come suddenly and sharply into relation, and the sweep of memory is indissolubly linked with Othello's loyalty to Venice.

II

THE EMPHASIS

Two Noble-Barbarian Theories

It is usually best to appeal first to the structure of a play for light on its emphasis.

Professor Bradley says

> Of all Shakespeare's tragedies, . . . Othello is the most painfully exciting and the most terrible. . . . Othello is not only the most masterly of the tragedies in point of construction, but its method of construction is unusual. And this method, by which the conflict begins late, and advances without appreciable pauses and with accelerating speed to the catastrophe is a main cause of the painful tension just described.[17]

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[15] See also his earlier article: "Shakespeare's Anthropophagi. The Source of the Travel's History of Othello." *The Nation.* 100. Ja. 21, 1915. 76-77.

The scattered parallels with Holland's Pliny noted by Hart, *Arden Edition,* 1903, pp. 26, 39, etc., though in themselves significant, are much less convincing than this massing of the material within two pages. For the well-known passage from Sir Walter Raleigh (*The Discoverie of Guiana,* 1596; p. 85, Ed. Hakluyt Soc.) usually associated with the lines, see *Variorum,* p. 56.

[16] And here we must recall to the reader's mind a note provided by Professor Parrott in the *Tudor Edition* of the play (1928, p. 168):

"The Venetians had special trading privileges in this town. If the Turkish law that the Christian who struck a Turk must either turn Turk or lose his right arm prevailed there, Othello risked his life to uphold the honor of Venice."

[17] *Shakespearian Tragedy,* pp. 176, 177. Cf. *Ibid.,* pp. 64-7.

Professor Bradley lays a very considerable stress on Othello's jealousy; at the same time he does not overlook the importance of disillusionment as a primary factor in the tragedy; and he makes much of the point[18] that Othello is

> not easily jealous, but, being wrought,
> Perplexed in the extreme.

Professor Bradley vigorously dissents from the theory that the play is "primarily a study of a noble barbarian, who has become a Christian and has imbibed some of the civilization of his employers," and that the last acts "depict the outburst" of his Moorish passions "through the thin crust of Venetian culture". Moreover, while admitting that Othello's race has its importance in the play, he says,

> But in regard to the essentials of his character, it is not important; and if anyone had told Shakespeare that no Englishman would have acted like the Moor, and had congratulated him on the accuracy of his racial psychology, I am sure he would have laughed.[19]

In the next paragraph, however, he goes on to say,

> He [Othello] does not belong to our world, and he seems to enter it we know not whence—almost as if from wonderland. There is something mysterious in his descent from men of noble siege; in his wanderings in vast deserts and among marvellous peoples. . . . And he is not merely a romantic figure; his own nature is romantic. . . . He has watched with a poet's eye the Arabian trees dropping their med'cinable gum, and the Indian throwing away his chance-found pearl; . . . So he comes before us dark and grand, with a light upon him from the sun where he was born . . . grave, self-controlled, . . . at once simple and stately in bearing and in speech, a great man naturally modest but fully conscious of his worth, proud of his services to the state, unawed by dignitaries and unelated by honours, secure, it would seem, against all dangers from without and all rebellion from within.[20]

But do not these glowing phrases of Professor Bradley put before us again the idea of the noble barbarian which we were bidden to discard?[21] We cannot of course accept any view which

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[18] *Op. cit.*, p. 186, p. 194. Cf. Sir Walter Raleigh, *Shakespeare (English Men of Letters Series)* 1907, p. 204: "Jealousy and suspicion, as Desdemona knows, are foreign to his nature; he credits others freely with his own noblest qualities."

[19] pp. 186, 187.

[20] pp. 187-189.

[21] The words

> Like the base Indian cast a pearl aside
> Richer than all his tribe

may be of considerable significance. For a discussion on which reading *Indian* or *Judean* is right, see *Variorum*, pp. 327-331. See also a note in the *Yale Edition*, p. 143, and a note in the *Tudor Edition*, p. 167. Obviously the view presented in the present paper accords best with the reading *Indian.*

would make Venetian civilization responsible, broadly speaking, for the good in Othello, and his Moorish blood responsible for the evil. May it not be possible, however, to make the idea of a noble barbarian the basis of an almost opposite theory,—namely, *that the good in Othello is a native good, and that his temporary overthrow comes from the failure of a mistakenly idealized civilization?*

The conception of the noble barbarian as in some ways superior to the more civilized and less natural man was current to some extent in the Renaissance, and is found in explicit form in Montaigne's essay on *Cannibals*—an essay with which we have other reason to believe Shakespeare was familiar.

"There is nothing in that nation," writes Montaigne, "that is either barbarous or savage, unlesse men call that barbarisme which is not common to them. . . . Those nations seeme therefore so barbarous unto me, because they have received very little fashion from humane wit, and yet are neere their originale naturalitie. . . . The very words that import lying, falsehood, treason, dissimulation, covetousness, envie, detraction, and pardon, were never heard amongst them," etc.[22]

Thos. Palmer has an interesting passage bringing in the idea of "the noble barbarian":

> So also is it to be understood, that no nation in the world, how Courtlike soever, but hath the dregs and lees of barbarous incivility; and that many heathen people, by the light of nature meerly inscribed in their hearts, rest for ensamples and reproofes to many civill nations governed by a diviner knowledge, in points of civil actions & conversation.[23]

Montaigne's essay expresses the appeal of New World discovery to the Renaissance imagination. The most striking product of this appeal in Shakespeare is *The Tempest.* Yet is it not possible that we find it in another and in some ways a more vital aspect, in *Othello*? As we have elsewhere[24] emphasized, the Englishman of Shakespeare's day was reacting to two diverse influences, the stimulus that came from Italy, of a riper

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[22] *Essay of Cannibals,* Florio's Translation.

Mr. George Coffin Taylor (*Shakespeare's Debt to Montaigne,* 1925, p. 32) makes this significant observation: "In *Othello,* written in 1604, when one would naturally expect to find Montaigne's influence at its height, it is scarcely discernible. . . . The scant influence on Othello is more easily accounted for by the nature of the particular play, in which Shakespeare seldom introduces matter not germane to the plot or situation."

[23] Thos. Palmer, *An Essay of the Meanes how to make our travailes into forraine Countries, the more profitable and honourable.* London 1606, p. 62.

[24] "Shakespeare's Use of English and Foreign Elements in the Setting of *The Two Gentlemen of Verona,*" in *Transactions of the Wisconsin Academy of Sciences, Arts and Letters,* Vol. 27 (1932), pp. 93-4.

culture and a more self-conscious society, and that which came from the unknown world beyond the Atlantic, and perhaps the most curious and thought-provoking aspect of these two influences is that of the impact of one on the other.[25] Do we perhaps discern something of this aspect in the tragedy of Othello?

It is not necessary of course to assume any direct connection between Montaigne's essay and Shakespeare's play, nor by any means to insinuate that Othello was after all neither a Moor nor a Blackamoor, but a North American Indian. So far as any special barbarian race is concerned, we must agree with Professor Bradley that Shakespeare had no idea of attempting a study of racial psychology. Yet is it not possible that Montaigne's essay, together with the plot of Cinthio's novel, may have suggested to Shakespeare the character of Othello, the general conception of a noble barbarian, the type of a strong and in some ways mature man, who was, nevertheless, in the presence of the complex and more or less corrupt civilization of sixteenth century Europe, a child and a stranger?

While he says that "we must not call the play a tragedy of intrigue as distinguished from a tragedy of character," Professor Bradley is struck by the fact that "Iago's intrigue occupies a position in the drama for which no parallel can be found in other tragedies . . . ."[26] "The part played by accident in this catastrophe," he says again, "accentuates the feeling of fate." And again, "It confounds us with a feeling . . . . that . . . . there is no escape from fate, and even with a feeling . . . . that fate has taken sides with villainy."[27]

For further light on these impressions let us turn back to Professor Bradley's lecture on the substance of tragedy.

"How is it," he asks, "that Othello comes to be the companion of the one man in the world who is at once able enough, brave enough, and vile enough to enslave him? By what strange fatality does it happen that Lear has such daughters, and Cordelia such sisters? Even character itself contributes to these feelings of fatality. How could men escape, we cry, such vehement propensites as drive Romeo, Anthony, Coriolanus, to their doom?

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[25] Cf. for interest in the New World, Rachel M. Kelsey, "Indian Dances in the Tempest", *Journal of English and Germanic Philology,* XIII (1914), pp. 98-103.

See also, Robert Ralston Cawley, "Shakespeare's Use of the Voyagers in *The Tempest.*" PMLA, XLI (1926), pp. 688-726.

[26] *Shakespearian Tragedy,* p. 179.

[27] pp. 181, 182.

And why is it that a man's virtues help to destroy him, and that his weakness or defect is so intertwined with everything that is admirable in him that we can hardly separate them even in imagination?"[28] If these questions indeed have a rational answer at all it would seem to be: Because the world is so constructed that all men must learn; it is not enough to say—as Professor Bradley himself does say[29]—that the vital principle of growth is destructive of all that is evil; it is destructive of all that is incomplete, or rather, of all incompleteness. Therefore it is artistically true to place beside Othello that being who—for the purpose of dramatic condensation—is best fitted to destroy Othello's ideal. Professor Bradley touches this concept, though with a difference.

> These defects or imperfections are certainly, in the wide sense of the word, evil, and they contribute decisively to the conflict and catastrophe. And the inference is again obvious. The ultimate power which shows itself disturbed by this evil and reacts against it, must have a nature alien to it. Indeed its reaction is so vehement and "relentless" that it would seem to be bent on nothing short of good in perfection, and to be ruthless in its demand for it.[30]

Whether the imperfections are to be called good or evil would seem to depend, however, on the direction from which they are approached—whether from an inferior or a superior plane. An identical act or attitude may represent either ethical progress or ethical retrogression.

The moral nature of a man grows by the process of the failure of inadequate desires or ideals and the construction of larger ones. The collapse of an ideal is sometimes attended by moral prostration. Each of Shakespeare's tragedies presents the failure of an ideal or attitude to life and the attendant moral prostration—these being expressed through the dramatic medium of crime or error and outward calamity. To many minds some at least of Shakespeare's tragedies imply also a sense of moral triumph or the foreshadowing of the reconstruction of the individual ideal.

"Nor . . . . are the facts ever so presented," says Professor Bradley, in speaking of the sense of fate in Shakespeare's plays,

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[28] p. 29.

[29] "Yet it appears to engender this evil within itself, and in its effort to overcome and expel it it is agonized with pain, and driven to mutilate its own substance and to lose not only evil but priceless good."—p. 38.

[30] p. 35.

"that it seems to us as if the supreme power . . . . had a special spite against a family or an individual."[31]

No; on the contrary it would seem that the supreme power finds it worth while to complete the individual—never to let him off without putting him through the painful process of the destruction of his illusions. In the various tragedies of Shakespeare we feel varying degrees of sympathy for the central figure and of blame for his mistakes. The essential point is this: that Shakespeare—like natural law—does not seem to distinguish in his catastrophes between sins of ignorance and more deliberate crimes. Othello merely stands as Shakespeare's extreme instance of disaster which must sometimes come upon even those who have acted in accordance with the dictates of a perfect—though limited—soul.[32]

Granted this general view of the play, it is obviously no accident that the construction is peculiar—that is, that the tragedy begins late—or that the action and catastrophe depend upon intrigue. Since this is a tragedy of character, since it not what Othello does that is his ruin, but what he *is*, it is all-important that we be made to grasp his normal character. Hence the long exposition. As for the intrigue, it is a dramatic concentration of forces that are bound to act sooner or later for Othello's enlightment. The enlightment may come suddenly or by degrees,—through the untruth of one man, or of many. In any case, and this is the point to be borne in mind, it must be, as far as Othello is concerned, in a sense *accidental,*—not due to his deliberate fault, but in the nature of the universe, inevitable. Hence the tragedy of Othello has quite as much universal truth as the other tragedies, since it is an example of well-intentioned human nature adjusting itself to the knowledge of good and evil. It is preëminently the tragedy of disillusionment—the disillusionment of a noble barbarian with a somewhat decadent civilization which he had simple-mindedly venerated. If Montaigne's noble barbarian were transferred to civilization, what would become of him? At what terrible price would his adjustment be made? He would believe in the world too much at first; he would be bitterly disappointed, losing all faith; then he would find that after all what he had loved best was true. Confidence in himself

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[31] p. 29.

[32] Cf. Raleigh, *Op. cit.* p. 198: "Othello, like Hamlet, suffers for his very virtues, and the noblest qualities of his mind are made the instruments of his crucifixion."

and the world; disillusionment; reconstruction: that is the tragedy of Othello.

The Second Theory and the Action

Let us briefly review the action from this standpoint. With his usual theatrical wisdom Shakespeare opens the play with a scene tending by every method of suggestion to prejudice us against Othello at the outset. We are expecting him to be a barbarian; we are prepared not to apply to him the standards of civilization. When the real Othello comes upon the scene, we at once become his advocates and tend to be over-lenient with his faults. So far from having to make allowances for him we feel that he is superior to his European surroundings. Othello's first words " 'Tis better as it is"—referring to Iago's boasted wish to punish Roderigo—present him to us as a person of authority, just but generous. In answer to Iago's further insinuations, irritating as they are meant to be, he speaks calmly:

> Let him do his spite:
> My services which I have done the signiory
> Shall out-tongue his complaints. 'Tis yet to
> know,
> Which when I know that boasting is an honour
> I shall promulgate, I fetch my life and being
> From men of royal siege, and my demerits
> May speak unbonneted to as proud a fortune
> As this that I have reached.

On the lines

> Good signior, you shall more command with words
> Than with your weapons

Sir Walter Raleigh makes this comment:

> Fearlessness and the habit of command, pride that would be disgraced by a street brawl, respect for law and humanity, reverence for age, laconic speech and a touch of contempt for the folly that would pit itself, with a rabble of menials, against the General of the Republic and his body-guard—all this is expressed in two lines.[33]

To Brabantio's insulting charge he replies reasonably as to a fractious child,

> What if I do obey?
> How may the duke be therewith satisfied,
> Whose messengers are here about my side,
> Upon some present business of the state,
> To bring me to him?

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[33] *Shakespeare* (*English Men of Letters Series*), 1907, p. 141.

His ceremonious words to the Senate—far from being a mere form—express genuine confidence and veneration. No forms are mere forms to Othello. He takes the civilized world seriously, regards its institutions with reverence, and expects of it a sincerity equal to his own. His respect for himself, his respect for others, and his modesty are all essentially related; it is of the essence of his pride to admit readily his little knowledge of the world.

> Rude am I in my speech
> And little blessed with the soft phrase of
> peace. . . .
> And little of this great world can I speak,
> More than pertains to feats of broil and battle.

Yet the consciousness of his ignorance causes him no doubt of his own perfect soul. Moreover while he has the restraining sense of fitness which we noticed before, he loves the sound of his own words. His vivid imagination—a supposedly child-like and barbarian quality—takes fire the moment he begins to speak of "antres vast and deserts idle." He is satisfied with the part he has played in these adventures. To reflect upon them gives him pleasure—a pleasure of which he does not think of being ashamed. The speech makes a favorable, even a delightful impression upon the Duke. Othello succeeds in justifying his marriage in the eyes of Venice. In the first act he comes off victorious, having behaved with tact, wisdom, decision, courage, unfailing courtesy, unruffled generosity. He has satisfied others, and in no respect disappointed himself.

By the beginning of Act II, we have advanced far in our acquaintance with Othello, having seen him face to face with circumstances which—though far from tragically serious—were fairly critical, testing his resource and self-control. His premonition of evil, early in the second act, is no misgiving of failure in himself or his world—only a superstitious dread of the irony of fate, a passing thought, natural enough to one who is happy and who has imagination enough to think of himself as bereft of his happiness. He looks forward with frank pleasure to renewing old acquaintanceships in Cyprus, but remembering his standard of good manners, checks his too enthusiastic speech and turns to give orders to his attendants, punctiliously considerate of every one, and generous and glad in his recognition of every good quality. Professor Bradley points out that in the third scene of Act II Othello's self-control is emphasized and that here "occur ominous words which make us feel how necessary was the self-control and make us admire it the more."[34]

> Now, by heaven,
> My blood begins my safer guides to rule,
> And passion, having my best judgment collied,
> Assays to lead the way.

They indicate not only Othello's self-control, however, but also his clearly defined *theory* of self-control, the fact that it is a part of his deliberate ideal.

> Good Michael, look you to the guard tonight:
> Let's teach ourselves that honourable stop,
> Not to outsport discretion.

And later in the scene he shows again his veneration for Christian institutions, and his single-minded horror of whatever is barbaric and below the ideal of civilized life.

> Are we turn'd Turks, and to ourselves do that
> Which heaven hath forbid the Ottomites?
> For Christian shame put by this barbarous brawl. . . .
> How comes it, Michael, you are thus forgot?

Cassio is abashed by this reproof and can find no words. Othello's reproof of Montano is also characteristic.

> Worthy Montano, you were wont be civil;
> The gravity and stillness of your youth
> The world hath noted, and your name is great
> In mouths of wisest censure: what's the matter,
> That you unlace your reputation thus
> And spend your rich opinion for the name
> Of a night-brawler? Give me answer to it.

Othello's personal sense of the enormity of the offense—the want of consideration of the public peace—shows that he is still unaccustomed to evil, especially in civilized men, and discerns it with surprise and pain. He feels it not only his military but his moral duty to be very severe.

> Give me to know
> How this foul rout began, who set it on.

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[34] p. 190.

In the early part of Act III we have little new light on the character of Othello. In the first scene he does not appear. In the brief second scene we have a glimpse of him in his post of authority, occupied with his official duties. Not until the middle of the act does the tragedy itself begin.

Iago's first task is to cause Othello to distrust human nature. He sows first a distrust of Cassio, a general suspicion that he is not truthful, that he is given to drink and brawling, then that his whole relation to his chief has been one of darkest duplicity. Next Iago skillfully opens Othello's eyes to the true nature of life in Venice and the capacities for evil hidden in the bosoms of super-subtle Venetians. And after this it is easy to sow a greater doubt in the Moor's trusting soul. He has been deceived in much, why not in more? The general fact of his ignorance of human nature, especially feminine and Venetian human nature, having once been thoroughly brought home to him, he abandons himself to Iago's superior knowledge.

> This fellow's of exceeding honesty,
> And knows all qualities, with a learned spirit,
> Of human dealings.

The mingling in Othello of credulity with susceptibility to doubt is psychologically true to life.[35] His intense imagination once at work, Othello's suspicion becomes a part of him. The devastation is complete, not only of his recent self but of his past self as well.

> O! now, for ever
> Farewell the tranquil mind; farewell content!
> Farewell the plumed troop and the big wars. . . .
> . . . .Othello's occupation's gone!

Yet nothing is actually proved. The struggle begins again, to end quickly in despair.

In the fourth act Othello reaches the lowest point in his humiliation. He loses all sense of personal dignity and of respect for others. He betrays his jealousy and strikes his wife in the presence of incredulous spectators. Professor Bradley cannot reconcile himself to the blow. Yet if the theory here put forward be correct, not only the blow, but the fact (noted by Pro-

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[35] Cf. Raleigh: *Op. cit.* p. 204. "If he were less credulous, more cautious and alert and observant, he would be a lesser man than he is and less worthy of our love." P. 205: "There is a horrible kind of reason on Othello's side when he permits Iago to speak. He knew Iago, or so he believed; Desdemona was a fascinating stranger. Her unlikeness to himself was a part of her attraction: his only tie to her was the tie of instinct and faith."

fessor Bradley) that it occurs in the presence of the Venetian representative is absolutely central in the interpretation of the tragedy. Its dramatic necessity can be appreciated only by reference to the situation in the first act: Othello's confidence in himself in the presence of the Senators, his faith in his own worth and dignity as their loyal servant, his chivalry for his wife, his simple-minded emphasis on good manners. Again and again in the play we are made to realize that Othello has a simple and noble ideal of good manners as a genuine indication of high-mindedness. This is part of his worship of civilization. When he loses his faith in civilization, he loses his manners. To him manners were not merely outward accessories or matters of empty, mechanical habit. They were deliberate actions depending on a conscious state of mind. That is why he could fail in them. The civilized man receiving his conventions ready-made from tradition controls himself automatically, and a degree of outward self-control does not necessarily mean a proportionate security from inward collapse. Othello was a genuine gentleman, but not a mechanical one. Hence the blow and hence its tragedy. Jealousy and violence are mere indications of the crash of his universe. He is overthrown to the extent of failing in his consciously strongest points. In these strong points, he has placed a confidence which, even in the best of men, argues incomplete experience. Yet in one sense we are less in despair of Othello than if he had been capable of saving his personal dignity and keeping his reproaches for a private moment. Reputation and honor, hitherto his ruling passion, are forgotten in a frenzy of anguish.

In the third scene of Act IV Othello has partly recovered himself and displays the calm of definite resolution. He treats Lodovico with courtesy and speaks less harshly, perhaps even kindly, to Desdemona. Emilia observes that "he looks gentler than he did." Although in the scene of the blow he has temporarily ceased to care about his personal dignity, it is clear that one thing remains to him—a sense of abstract justice, the need to avenge that personal honor in which he still believes, to punish the wrong-doers and to vindicate the right. Though bitterly disappointed in others he still has faith in his duty and his power to perform it. Othello's belief as to what his duty was must simply be taken for granted,[36] although it is one that we cannot understand at the present day. When he knows Desdemona's guilt, no question enters his mind as to what is to be done next. And before we blame him for his want of reflection, we must remember that he is not, like Hamlet, amply supplied with the materials of thought.[37] From his point of view there is nothing more to consider. Nowhere has Shakespeare entered more completely into an experience and at the same time wholly shut off from his consciousness those elements which could not enter into a mind infinitely simpler than his own. Othello's quickness of action is the inevitable result of his limited knowledge and his perfect simplicity, sincerity, and certainty of himself. Relentlessly conquering his grief and pity, he murders his wife from a conviction of right, without a qualm as to the justice and necessity of the deed.

Then comes his appalling enlightenment.

At this crisis he is not even able to avenge himself upon his destroyer. He runs at Iago, who evades the stroke. Montano, fearing that the Moor may do himself harm, wrenches his weapon from him.

> I am not valiant neither,
> But every puny whipster gets my sword.
> But why should honour outlive honesty?
> *Let it go all.*

As far as Othello's estimate of himself is concerned, these words mark the lowest point of his moral prostration. They are also the beginning of his triumph. He knows the world now and himself. In Iago he has had an overwhelming revelation of evil. He himself is no wise and moderate man, but one who "like the base Indian threw a pearl away, richer than all his tribe." Yet in Desdemona he has recovered all, so that he can even be just to himself. He has done naught in haste, but all in honor, and one way to vindicate that honor still remains.

> Set you down this;
> And say besides, that in Aleppo once,
> Where a malignant and a turban'd Turk
> Beat a Venetian and traduced the State,
> I took by the throat the circumcised dog,
> And smote him, thus.

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[36] Cf. note 8 above—material from Moryson, Einstein, Boulting, and Draper.

[37] Cf. Raleigh: Op. cit. p. 17. "A measure of the subtle speculative power of Hamlet might have saved Othello from being a murderer; it could not have increased Shakespeare's love for him." Compare the delineation of Hotspur and Coriolanus—also simple-minded warriors and men of action.

He will prove himself still loyal to Venice and the trust she has reposed in him, to his conception of the State and civilization,—that which is noblest in him ready to do swift execution upon whatever has betrayed the ideal. So dies Othello, the Moor, triumphant in Desdemona's truth and in the sincerity of his own perfect soul.

The Setting and the Total Effect

The elaboration of the setting has thus served a definite end, since against its delicate and colorful network, as against the stained fragments of a mosaic background, has been projected in boldest relief the large and simple figure of the Moor. The use of detail of place has done much to present the characters with solidity to the spectator and to create the dramatic situa- in which they move. It has contributed to their inner life also.

Some modern critics see Shakespeare's treatment of Othello (and of many other characters) as for the most part plastic and external, and contrast this method with what they consider to be the modern method of conscious psychological analysis. And yet we wonder whether contemporary and older dramatists alike do not at their best employ a method which is neither of these. Coleridge says, "One of Shakespeare's modes of creating characters is to conceive any one intellectual or moral faculty in morbid excess, and then to place himself, Shakespeare, thus mutilated or diseased, under given circumstances." The process is not deliberate or self-conscious, however, but instinctive and imaginative. Most persons who have tried to write dramatic dialogue know a little of it by experience. If all personalities are latent in any personality, can be, as it were, realized from something in oneself, and if, in order to produce a single one of these, one can check off all in oneself that is foreign to its consciousness, let down shutters on the rest of one's mind, then what remains for use and development is not a constructed, inorganic thing, but something almost as organic as the dramatist's own mind, though on a different scale. And hence in great drama, out of the issues of the heart the mouth speaketh.

The essentials of character may, as Professor Bradley implies, be independent of specific time and place. Yet, however transferable, they are most easily realizable to us in a vivid setting. Shakespeare has in Othello realized an alien personality in an alien place and has somehow assimilated to Othello's inner experience the outer details of his environment and made these symbolic to us of his inner conflict.

Thus Italy in this play serves not merely to represent romance, nor primarily a realistic contemporary background. It is the sophisticated world, rather, in its complexity, at first idealized, then found to have abysmal possibilities of evil, finally restored to its human proportions. Othello's memories, too, stuff of poetry as they are, serve dramatic ends, being images that express to us the Moor's simplicity and the gamut of his experiences, his sense of being equal with his world, his perplexed sense of being unequal to it, and finally, even in his humiliation and tragic remorse, his sense of repudiating its evil and being at one with its good.

Othello is a barbarian in a general rather than a specific sense. Romantically he is the Moor; but if we try to locate him more realistically, we shall find him in many lands and under many disguises. The suggestion for the type came, no doubt, from innumerable sources: indirectly, through the incidents, from Cinthio; perhaps (and if so, more directly) from Montaigne; and at once more generally and more vitally, from any honest soul trying to adjust a simple ideal to a complex environment,—Valentine at the Emperor's court, the Englishman in Italy, Shakespeare himself going up to London.

THE LITERARY GERMAN LANGUAGE AND ITS RELATION TO THE GERMAN DIALECTS

ALFRED SENN

By the term "Literary German Language" we understand that standard form of literary German which is used as a common means of expression and communication in written or printed form by all German speaking people whether they live in Germany proper, in Austria, Czechoslovakia, Switzerland, Alsace-Lorraine, or wherever else. This is the form of the German language that is taught in German schools. It is the only connecting link that unites all the members of the German speaking world.

This standard form of the German language is also that German language which is being learned by foreign students. Foreign students who have never been in a German country are sometimes inclined to regard this form of German as the only one. This error is especially likely to appear in countries having a more or less unified colloquial language, e.g., in the United States. Here English is spoken everywhere in almost entirely the same way, and those who speak of the existence of various American English dialects seem to overemphasize the differences. This is at least inevitably the impression gained by a person familiar with the German dialects. By this I certainly do not want to minimize the dialectal differentiations in American English. I only want to show that the differences existing between the German dialects are by far more important. These differences are so enormous that speakers of the extreme parts of the German territory, if they come in contact, are not able to understand each other if they have not been trained in the use of the standard form of German. That could be easily illustrated here in Madison by confronting two Germans both born in America and not educated in German schools, but one of Low German and the other of Swiss, i.e. High German, especially Upper German, origin. Even if both of them speak their mother tongue to perfection they will not be able to understand each other and will be forced to resort to the use of English.

This little excursion shows clearly that standard German or literary German has to be acquired even by German people. This acquisition is a permanent struggle against the local form of speech, the so-called dialect. Some succeed in overcoming the immense difficulties, but others do not. The question has been raised again and again which part of the linguistic German territory uses the best form of German, in other words, which local form of speech could be regarded as a model and therefore imitated. The answer to this question has varied according to the time and the political or geographical unit in which the litigant parties lived. These linguistic debates were especially vehemently waged at the time of the German Sprachgesellschaften in the 17th century. In more recent times, however, this question seemed to lose importance. It seems as if the German people have become more tolerant toward local expressions. So we find not only single dialectal expressions but also entire sentences and even long drawn-out dialogue in dialectal form in the works of such outstanding writers as Auerbach, Anzengruber, Sudermann, Maria von Ebner-Eschenbach, and Gerhard Hauptmann. This tolerance shown with regard to idiomatical expressions of limited spread is to be explained as a reaction against the classical standard language. At the same time it proves that the unification of the literary German language has been accomplished. The German writers feel so sure of this accomplishment that they see no danger in cultivating local forms. This reaction needs an explanation. The explanation is easy to find if we realize that this linguistic step backwards accompanied a new literary wave, the so-called realism. The realistic writers felt the wide gulf that existed between the written or printed form of standard literary German and that which was used in colloquial everyday speech. They realized that the modern literary German language is scarcely more than a mere fiction. It is merely a written language not actually being spoken anywhere. Therefore realistic writers wishing to depict real life began to use such forms and expressions that were truer to the standards of living of their characters.

I have just stated that the modern literary German language is not actually spoken anywhere. What is actually spoken by most of the cultivated German people is a form of speech that stands between the literary standard form and the dialect. In some parts of Germany this elevated form of colloquial speech is closer to the literary standard, in other parts, especially in the South, it comprises more local dialectal elements. In Swabia and Austria, e.g., the colloquial speech of the higher social stratum is rather more a unified Swabian or Austrian dialect than an adapted form of the standard language. The extreme in this direction is represented by the Swiss. Even today there exists nothing that could be called "common colloquial Swiss". And when in 1921 a Swiss scholar, namely Karl Stucki, undertook to write for practical use a grammar of the German Swiss language,[1] he was compelled to confess that the title of his book was misleading. In his introductory remarks he admits the impossibility of writing a practical grammar embracing the whole German Swiss territory, because even the most cultivated inhabitants of such cities as Zurich, Basel, Bern, and St. Gallen, represent four entirely different linguistic types. Stucki's Swiss grammar may be regarded as a first attempt toward leveling out the dialectal differences on the basis of the dialect of Zurich.

Now to come back to the question of correctness we see that there are two sides to it: (1) the correctness of the written language and (2) the correctness of pronunciation. As to the first one, it is clear and has already been stated above that we possess now a strict common norm for written expression, which only in rare cases permits a choice between two equally recognized forms.[2] In regard to the second side, there exists still great variety.

Standard literary German is however not the only form of language used for literary purposes. In all periods of literary production we find writers who refused to use the generally adopted standard language. A large dialect literature was developed especially during the last century and particularly during the last few decades. It must however be duly emphasized that not all of the so-called dialect literature represents pure dialectal forms. We distinguish three types:[3]

(1) The literature which is mainly based on the standard literary form, but abundantly interspersed with dialectal forms and idiomatical expressions of dialectal character. The best known author of this type is the Swiss Jeremias Gotthelf. In

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[1] Schweizerdeutsch. Abriss einer Grammatik mit Laut- und Formenlehre. Zürich 1921.

[2] Cf. Paul, Deutsche Grammatik I 129 f.

[3] Cf. Hans Reis, Die deutsche Mundartdichtung, 1915. Sammlung Göschen. p. 10 f.

the same category I would also place some of the most prominent Austrian writers: Ludwig Anzengruber, Peter Rosegger, Paula Groger, etc.

(2) The great bulk of dialect literature belongs to the second group which pretends to represent real dialects but actually is an ennobled form of dialect and even a new kind of literary language based on local dialects but frequently abandoning the most striking characteristics of the own dialect and using instead a synonymous form or expression from a neighboring dialect. For an illustration of this statement may I refer to just one author, namely Alfred Huggenberger, one of the prominent Swiss writers of today. He lives in the eastern part of Switzerland, in the canton Thurgau, and the grammatical forms in his popular comedies and farcical plays are essentially those of his dialect. But there are also elements, which for some reason of predilection were taken from other dialects. This is true especially for the expression *mira* meaning "meinetwegen"; e.g. *Verheimleched's mira vor de Lüte, ihr zwoo, wenn I säb recht tunkt* "Verheimlicht es meinetwegen vor den Leuten, ihr zwei, wenn euch das recht dünkt". This sentence is taken from Huggenberger's most important poular comedy *Dem Bollme si bös Wuche*[4] (a Swiss *Malade imaginaire*) p. 61. The word *mira* is characteristic of the Bernese dialect. This type of dialect literature is developing a great multitude of new literary dialects which differ from the spoken dialects in the same way as standard High German differs from colloquial High German. As I have just shown, this is to a certain extent true even of the Swiss dialect literature of which we possess an excellent survey written by Otto von Greyerz, the competent representative of Swiss literature at the University of Berne.[5]

(3) A third group comprises that literary production in dialect form which is a faithful copy of the spoken dialect. The student of dialects is particularly interested in this type of literature, and because he does not trust the professional writers of dialect too much, he is often compelled to write literature himself by collecting texts. He accomplishes that work by writing down fairy tales or stories directly from the lips of some imag-

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[4] Verlag Huber und Co., Frauenfeld, 1914.

[5] Otto von Greyerz, Die Mundartdichtung der deutschen Schweiz. Geschichtlich dargestellt. H. Haessel Verlag, Leipzig, 1924; cf. also the article "Schweizerische Dichtung" in Merker and Stammler's Reallexikon der deutschen Literaturgeschichte III 213-233 written by the same author.

inative country-man or country-woman who is supposed to speak the dialect correctly. Of course, this type of dialect literature is only used for the purposes of scientific investigation.

The question may arise: why did the dialect literature grow up so rapidly just at the time when the unification of the standard literary language had been accomplished? We have already partly answered this question above when we saw that the realistic authors refused to use the sublime forms of standard High German in the speech of personages not belonging to the cultivated class. Thus dialect expressions were used as a means of characterization. In other cases a certain local patriotism was the motive force for the use of the dialect. It is at the same time interesting and important to know that not even one of the German dialect authors wrote dialect because he could not write otherwise. All of them are people of high cultural standard, thoroughly educated, and most of them wrote also in standard High German form at the same time. As examples it may suffice to mention the names of three, namely Johann Peter Hebel, Alfred Huggenberger, and Otto von Greyerz.

In my opinion the best justification for the existence of a dialect literature has been given by Behaghel in the introduction to his edition of Johann Peter Hebel's works.[6] p. XV - XVI. Behaghel states justly that only those things or happenings for which the language already possesses adequate means of expression can be easily described. But only those words which are used again and again are active parts of the language. Therefore a language is capable to express with ease only those things which have already often been expressed in that language. This statement is corroborated by the fact that all those languages which as a result of the world war obtained the role of official languages (e.g. Lithuanian and Lettish) where obliged to create first the necessary terminology before they could be successfully used in the state administration, in the courts, in the schools, etc. The range of possible expressions in a language varies from period to period and from nation to nation. Generally this range of expression must be as large as the field of interest. In a standard literary language, i.e. a language of the higher social stratum, the range of interest diminishes in

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[6] O. Behaghel, Hebels Werke. Erster Teil. Allemannische Gedichte. Deutsche National-Litteratur. 142. Band, Erste Abteilung.

the same proportion as a thing approaches the simple life of the lower classes. This was especially the case in the superidealistic German literature of the 17th and 18th centuries. Therefore, still today, there are a great number of objects, especially numerous plants and animals, meals, household-effects, etc., for which the standard literary language lacks names generally recognized and understood.[7] I have some experience of my own in this field from my work on the Lithuanian-German Dictionary, where it became necessary to add to the German translation the corresponding Latin names in order to avoid misunderstandings. For the same reason the literature proper is unable to grasp and to describe the petty everyday manifestations of emotion that appear as expressions of anger and irritation or in the form of abusive terms and imprecations or as interjections of pain and joy or as innumerable fond and tender words. The standard literary language stands aloof from the speech of the common people. And as a result of this aloofness we find a certain poverty in the speech of the educated class. Therefore, Behaghel regards the creation of the dialect literature as an enlargement of poetry in general.

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[7] Cf. Paul Kretschmer, Wortgeographie der hochdeutschen Unmgangsprache. Göttingen 1918.

THE WINNEBAGO VISIT TO WASHINGTON IN 1828

LOUISE PHELPS KELLOGG

Governor Lewis Cass of Michigan Territory was a man of ideas and resource. Moreover he was profoundly interested in the Indian race and sympathetic with the troubles caused by encroaching frontiersmen. In 1827 had occurred the so-called Winnebago war, which might have proved disastrous for the Northwest frontier had not Cass by rapid movements and wise councils prevented serious bloodshed. The occasion of the outbreak was a false rumor that two Winnebago prisoners had been done to death by the garrison at Fort Snelling on the upper Mississippi. The real cause was the invasion of Winnebago lands between the Mississippi and Rock rivers by lead miners, who overran their territory, drove off the game, and made free with all the Indians considered their own. An even deeper cause was the hatred of the tribe for Americans, to whose occupation of the region they had never become reconciled.

The Winnebago were an eastern offshoot of the Siouan race, which in the dawn of history occupied most of the southern portion of what we now call Wisconsin. During the wars of the French régime, they became weakened in numbers, but not less proud, intractable, and aloof in spirit. They were among the most active associates of Tecumseh and the Shawnee Prophet in their rebellion against the might of the United States. They fiercely resented the coming of American troops in 1816 and were subdued only by fear of the cannon that were placed upon the forts, and the bayonets of the soldiers that mounted guard. When Fort Howard was built at one end of the Fox-Wisconsin waterway and Fort Crawford at the other, they withdrew to their villages on the upper Rock and upper Fox and in sullen silence watched suspiciously the movements of the white men.

After Red Bird, their guilty chief, had surrendered in 1827 at the Portage, and Governor Cass and General Atkinson had put down the incipient rebellion, Cass, in the summer of 1828, called the Winnebago chiefs to a council at Green Bay. Before the council met he wrote to the commissioner of Indian Affairs recommending that a party of their chiefs "be permitted to visit our cities to impress them with our power; it may tend to quiet their restlessness and tame their ferocity." The Commissioner favored the plan as a manner of conquering more merciful than with cannon and bayonets. The War Department approved, and gave orders that fifteen chiefs be invited to visit Washington and that John H. Kinzie accompany them.[1]

Meanwhile their beloved chief Red Bird had died in prison at Prairie du Chien; the government had ordered a fort built at the Portage—in the heart of Winnebago land—and Cass and Pierre Ménard of Illinois had met the chiefs in council at Green Bay. At that conference Cass invited the chiefs to pay a visit to their Great Father, the President of the United States.[2] There was much discussion at the council concerning the personnel of the delegation. The two principal families among the tribe were the Decorah and the Caramaunee, rivals for the headship. The leaders of the Washington delegation were the Caramaunee. Their village was first on Green Lake of Fox River, but after this visit to Washington and the treaty of 1829, the Caramaunee removed to the Baraboo River. The elder Caramaunee, known as Naw-kaw or Wood was at this time the principal chief of the nation. He had been Tecumseh's adviser and was present at his death at the Battle of the Thames. Mrs. Kinzie describes him in 1830 as "a stalwart Indian, with a broad, pleasant countenance, the great peculiarity of which was an immense under lip, hanging nearly to his chin.[3]

Caramaunee's kinsman, Hoo-wau-nee-kah or Little Elk was the orator of the group. When Henry Clay visited the Winnebago in Washington "after carefully looking at the countenances and bearing of all the members of the deputation, [he] had indicated him [Little Elk] as the one possessing the greatest talent; and he was greatly pleased when informed that he was the principal orator of the nation, and decidedly superior in abilities to any other individual of the tribe."[4]

The Decorah family had a tincture of white blood, being descendants of the famous chieftess, Glory-of-the-Morning and her French consort, Sabrevoir de Caris. The head chief of this family was the White War Eagle or Konokah Decorah, grand-

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[1] Indian Office Files, Jan. 24, 1828.

[2] *Ibid.* Proceedings of Council, Aug. 17-20, 1828.

[3] Juliette A. Kinzie, *Wau-Bun,* (edition of 1930), 63.

[4] *Ibid.,* 65.

son of the chieftess. Mrs. Kinzie says of him, he was "the most noble, dignified, and venerable of his own or any other tribe. His fine Roman countenance, rendered still more striking by his bald head, with one solitary tuft of long silvery hair neatly tied and falling back on his shoulders; his perfectly neat, appropriate dress, almost without ornament, and his courteous demeanor, never laid aside under any circumstances, all combined to give him the highest place in the consideration of all who knew him."[5] This fine old chief did not go with the party on this journey as his age forbade. His son, Spoon Decorah, was a somewhat inconspicuous member of the deputation.

The more prominent Decorah that took the journey was a nephew of the old chief, whose village was on the upper Mississippi near La Crosse. His Indian name was Wau-kon-haw-kaw, or Snake Skin, and he usually wore the skin of a rattlesnake woven about his head as a turban. After this journey he was universally known as Washington Decorah. He was a large, handsome man six feet three inches tall and quite an orator, spokesman for his tribe at the Treaty of 1829 at Prairie du Chien. At that treaty he said: "Fifteen of us went last year to see our Great Father; when we shook hands with our Great Father we did not think him a man like ourselves; we thought him the Great Spirit—his house was so grand and everything around him so splendid; but when we heard him speak we found him a man."[6]

The chief who guarded the entrance to Lake Winnebago, with a village on what was later Doty's Island, was Hootschope or Four Legs (really Four who Stand). He was a wise old chief whose wife was a Fox woman. She had been in her youth as far as New York, and knowing the power of the whites she had during the Winnebago War pled successfully with her band not to attack the whites.[7] This family was represented by the nephew of the old chief, whom the whites called Dandy, because of his fondness for dress.[8] He was also called the Little Soldier on the trip, because he bore the hardships well.

The Rock River band was represented by Kaw-ray-kaw-saw, or White Crow, whose village was on Lake Koshkonong. White

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[5] *Ibid.*, 63.

[6] Indian Office Files, Proceedings of the Treaty, Aug. 1829.

[7] I. O. F. Jan. 24, 1828.

[8] Mrs. Kinzie, *Wau-Bun*, 65-66.

Crow was accompanied by his young daughter, eighteen years old and said to be beautiful. She married, soon after her return, another member of the party, Yellow Thunder. She was always called the Washington Woman by her people and Mrs. Kinzie describes the airs she assumed. "She had a pleasant, old-acquaintance sort of air in greeting me, as much as to say, 'You and I have seen the world.' "[9]

Other members of the delegation were "Talk English, a remarkably handsome, powerful young Indian," who received his name on the trip, because of his reiteration of that expression;[10] Tshi-zun-haw-kaw, "who united the characters of a conjurer or medicine man, with that of a brave,"[11] had a most pleasing countenance and was accounted the most intelligent and progressive observer of the party. We have not the names of the other six members of the deputation, but all the chief bands were represented. Their conductors were Robert Forsyth, secretary of Governor Cass, and John H. Kinzie, recently appointed Indian agent at Fort Winnebago. The interpreter was Pierre Pauquette, the half breed Winnebago who had charge of the transfers at the Portage and was much beloved by all the tribe. Moreover he was the only really competent interpreter of the Winnebago language and spoke also both French and English, although he could neither read nor write.

The deputation of fifteen Indian chiefs, one woman, and three conductors left Green Bay with Governor Cass, after he had finished the council negotiations. The steamboat *Henry Clay* conveyed them to Detroit where they arrived about the first of September.[12] They remained a month at Detroit, waiting Governor Cass's convenience and left there Oct. 6 on the *Niagara* for Buffalo. At Buffalo they were conveyed by stage across New York state while Governor Cass traveled on to Washington by a shorter route. The Indians passed through Utica, Schenectady, and Albany, and thence took a river steamer to New York City where they arrived on October 19.[13]

If only some of the chiefs could have kept diaries how amusing and interesting their impressions would have been. They

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[9] *Ibid.,* 75-77.

[10] *Ibid.,* 64-65.

[11] McKenney and Hall, *Indian Tribes* (Phila. 1854), 1, 215.

[12] Detroit *Gazette,* Sept. 4, 1828.

[13] Expense account in Congressional Documents, Serial 186, No. 129.

hitherto had believed themselves braver and more virtuous than the whites and equal in number to them.[14] What must have been their amazement at the numbers of "children of the Great Father," whom they met on their journey. Agent Kinzie tells of their shrewdness when passing by stagecoach through the country. The driver connived with the tavern keepers to sound the horn just as the Indians were seated at table for a meal.

"Do you pay for all these provisions that are set before us at the hotels?" one asked their conductor.

"Yes. Why do you ask."

"Nothing. I thought you paid for just what we ate."

At the next stopping place a fine breakfast was set upon the table of which they partook plentifully. As the horn sounded for the stagecoach, each chief sprang to his feet. One seized the plate of biscuits and poured them into the corner of his blanket; another the remains of a pair of chickens; a third emptied the sugar bowls; each laid hold of what was nearest him, and in a trice nothing was left upon the table but empty plates and dishes. The landlord and waiters, meanwhile, stood laughing and enjoying the trick.[15]

In New York the Winnebago created a sensation. None of their people had ever been seen there, and their barbarous costumes, their singular manners attracted much attention. Proprietors of theatres sent them complimentary tickets and then advertised that the Indians would be present, and their houses were thronged. At the Bowery theatre one of the chiefs was so pleased with the singing of the cantatrice, that he stripped an eagle's feather from his costume and sent it by the boxkeeper to the "singing squaw." October 27 they visited Peale's Museum and enjoyed the experiments, such as the air pump. Nawkaw gravely thanked Mr. Peale with the remark that he could not understand what was done, it must come from the Great Spirit.[16] The next day they went to a balloon ascension at the Battery, and even Kinzie expected they would be impressed with the daring of the aeronauts; but the leading chief thought them unwise to trifle with their lives in that way. "What good does it do?" he asked.[17] Another chief said when asked what he

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[14] *Niles Register*, xxxv, 101.

[15] Mrs. Kinzie, *Wau-Bun*, 78.

[16] *National Intelligencer*, Oct. 28, 1828.

[17] McKenney & Hall, *Indian Tribes*, i, 317.

thought of it, "Think nothing of it. Americans foolish."[18] Nor could the chiefs be made to express their wonder at so many people. Naw-kaw boasted when his attention was called to a great crowd, "We have more in our smallest villages."

New York's enthusiastic adulation was rebuked by Washington journalists to whom Indian visitors were less of a novelty. Indians are intelligent men and should be so treated, wrote a correspondent.[19] Philadelphia however showed an interested curiosity in the chiefs' visit. Arriving there the last of October they made an unexpected appearance at the French opera and excited a lively sensation as they filed into the stage box, in all their savage finery. They stayed at Mr. Wade's hotel on North Third Street,[20] but soon passed on to Washington where they arrived the last day of October and were domiciled at Tennison's Hotel.

Their stay in Washington lasted for six weeks for which the innkeeper charged $1,700.00 including $250.00 for "damages done the house." For the entertainment of the citizens the Winnebago staged a war dance on the common between the White House and the river, for which a dollar's admission was charged. Postponed because of bad weather it finally took place the last of November. The Marine Band played and the chiefs gave the Discovery Dance, a mock battle, and the Rejoice Dance. "The movements of the Indians would not offend the most rigid and fastidious delicacy," wrote an attendant journalist.[21]

One of the amusements then claiming the patronage of Washingtonians was an exhibition at Carusi's Assembly Rooms of trained animals—birds and dogs. When the Winnebago chiefs visited this entertainment they were much delighted. A canary named "Fairy" was supposed to play dominoes and one of the dogs was similarly accomplished. Two of the chiefs challenged these learned animals to a contest. This created a considerable excitement in Washington, all the newspapers carrying an account of the "Challenge Extraordinary." The result of the play was not reported. One day the local militia company, known as the Washington Guards marched in a body to Tennison's Hotel

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[18] Washington *Telegraph,* Oct. 29, 1828.

[19] *Ibid.,* Oct. 26, 1828.

[20] Detroit *Gazette,* Nov. 13, 1828.

[21] Washington *National Journal,* Dec. 1, 1828.

and their band serenaded the chiefs, after which their orator gave thanks in a grandiloquent speech.[22]

The principal purpose of the trip, however, was for the chiefs to have an interview with the President, their Great Father. The President at this time was John Quincy Adams, who was more familiar with deputations from Europe than from the Indian tribes. He received the Winnebago with considerable pomp, surrounded by members of his cabinet and certain invited diplomats. Naw-kaw presented him with a peace pipe and Little Elk declaimed a sonorous oration, translated by Pauquette, in which he assured the Great Father that the tribe would maintain perpetual peace.[23] On December 2 the President received the delegation once more, and gave them a document as follows:

This certifies that Tshi-zhunk-kau-kaw, a Winnebago Chief, in company with fourteen other chiefs and Warriors of that nation, has visited the seat of Government of the United States, and held friendly councils and smoked the pipe of peace with me in my house. Having full confidence in the declarations freely and solemnly made by him and his associates, of their determination to maintain perpetual peace and friendship with the United States, I recommend him to the favorable notice and consideration of all my white and red children. [Signed] John Quincy Adams, President of the United States.[24]

The visit, however delightful, must come to an end. Kinzie prepared for their return journey and had the tribesmen fitted out with clothes by a fashionable tailor, who made them fifteen blue frock coats, as many pair of leggings to match, sixteen blue cloth caps (perhaps one for Pauquette), cloth and ribbon for the squaw, three dozen pair of stockings and twelve pairs of shoes. They traveled across country by stage to Detroit, where they arrived the last of the year. Horses, saddles, and bridles were there bought for them, and they journeyed homeward to their separate Wisconsin villages, with many gifts to testify to the welcome they had received.

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[22] Washington *Chronicle,* Nov. 22, 1828; *National Intelligencer,* Nov. 20, 1828.

[23] Naw-kaw's portrait was painted in the act of presenting the pipe. A reproduction is in McKenney & Hall, *Indian Tribes,* 1, 72. For Little Elk see *Ibid.,* ii, 289. McKenney requested an appropriation for the portraits of all the chiefs at $20 apiece. The originals are not now in Washington.

[24] The original of this document was presented in 1930 to the Museum of Luther College, Decorah, Iowa. It had been preserved by a missionary at Wittenberg, Wis. to whom it had been given by a Winnebago many years ago.

The visit of the chiefs was justified by its results. The expense of $10,272.05 to the government was less than a war would have been. The Winnebago never again attempted a revolt against government authority, and four years later, when the Sauk under Black Hawk went on the warpath, the Winnebago were restrained from joining them by the knowledge that their chiefs had of the might and power of the United States. Especially friendly to the whites were the chiefs of the delegation. White Crow rescued the captive girls from Black Hawk, acted as guide to General Dodge and served with the whites in the battle of Wisconsin Heights. Little Elk kept Kinzie informed of the movements of the hostiles, and a brother of Washington Decorah brought the defeated Black Hawk as prisoner to Prairie du Chien. Certainly the trip to Washington of the Winnebago chiefs proved a good investment for the future welfare of Wisconsin.

THE DETERMINATION OF ORGANIC NITROGEN: PAST AND PRESENT*

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It is the purpose of this review to present a picture, sufficiently comprehensive yet not too detailed, of the development of one of the most fruitful and important fields of organic analysis, the determination of nitrogen, as it has evolved from its crude inceptions down to the numerous specialized techniques of the present day. The plethora of available material and the fact that oxidized nitrogen occurs but rarely in organic materials as compared to the abundance of this element in its reduced condition, necessitates a sharp curtailment of the field. The bulk of the emphasis, therefore, has been placed upon the latter problem.

By way of background for what shall be a century of progress in this field, brief reference to the contributions of the old masters of analytical chemistry to the beginnings of ultimate organic analysis may not be out of order. Taking as a point of departure the pioneering investigations of Lavoisier of about 1784 (*1*) on the determination of the elementary composition of organic substances containing only carbon, hydrogen and oxygen—not accurate, it is true, by present-day standards yet none the less most significant because he exploited a method of analysis which was soon to be improved by others—we come to the contributions of Berthollet (*2*) with respect to nitrogen. In a sense, he applied to this determination the principle of dry distillation. The virtue of his method seemed to lie chiefly in the fact that a large sample was required, a fortuitous situation since the experimental error was large, doubtless no greater than was considered permissible in those days.

Following a brief desultory period of experimentation with gaseous oxygen under atmospheric pressure, attention turned to the use of solid oxidizing agents. Sometime near the beginning of the nineteenth century, Abildgaard had suggested (*3*) and

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later Berzelius (*4*) used this type of reagent; the one manganese dioxide, the other lead peroxide. The first satisfactory values were obtained several years later by Gay-Lussac and Thénard (*5*) who introduced the sample and oxidizing agent, potassium chlorate, in pellet form into the combustion tube fixed in a vertical position. The gaseous reaction products were then analyzed. The presence of nitrogen in the sample made necessary close control of the quality of chlorate added in order to prevent its oxidation to the nitrate form. Although the results which these investigaors obtained were better than others before them had been able to get, the accuracy of their procedure was still far from satisfactory.

It was at this time that Berzelius introduced the horizontal combustion tube with movable burners, thus obviating the difficulty of having particles of substance spatter into a cold portion of the tube and so escape decomposition. Others subsequently clung to the vertical tube; nevertheless the idea proved superior and has remained in use to the present.

A suitable oxidizing agent was the next goal for it was apparent that herein lay one of the limiting factors in the successful determination of the ultimate composition of a compound. Various metallic oxides and oxy-salts had been used up to this time, though rather unsuccessfully except in the case of potassium chlorate. By 1815 this search appears to have ended for then Gay-Lussac (*6*) introduced the now familiar use of cupric oxide as oxidizing agent, together with copper turnings for the decomposition of oxides of nitrogen. Döbereiner (*7*) announced the same discovery almost simultaneously and apparently independently.

THE DUMAS METHOD

We now pass over a series of methods and modifications to the work of a great coordinating genius, Justus von Liebig, and his brilliant contemporary, Jean Baptiste André Dumas. It became increasingly and painfully evident that no simple, accurate method for organic elementary analysis was available, and that this lack greatly crippled investigators in the field, for they had no ultimate foundation upon which to rest their work. To Liebig, in particular, already on the threshold of fundamental discoveries in organic chemistry, this exigency became so great that he devoted a number of years to work on the problem, and was rewarded by a method which, though burdened with certain inescapable errors, nevertheless was reliable and accurate. His apparatus was characterized by extreme simplicity and was little more than a combination of parts well known at the time. In fact, Liebig said of it(*8*), "This apparatus involves nothing new, save its simplicity and the complete dependability which it affords." The first thing which he did was definitely to separate the nitrogen determination from those of carbon, hydrogen and oxygen. Almost like the search for the fabled philosopher's stone had been the quest after a universal method of embracing all organic compounds as well as all elements therein, and Liebig was the first to realize that, since each element has its own peculiarities, much more is gained by attacking them individually rather than collectively. It is true that methods of simultaneous analysis for several elements have been proposed from time to time, but even though very good results were claimed they have enjoyed only passing comment (*9, 10*). At this time, also, Liebig introduced his famous "Kaliapparat," for the purpose of absorbing the carbon dioxide evolved in the combustion of the sample. It was small enough to be weighed conveniently upon the analytical balance and is apparently the precursor of all later models.

Once the way was shown to a reliable method capable of reproducible results, and the limitations of this method clearly recognized, modifications and improvements were not slow of appearance. Of the mushroom crop which sprang forth, one in particular was accepted less reluctantly than the original; in fact, even the name by which the procedure was eventually known was that of modifier rather than originator. We refer to the contribution of Dumas(*11*).

Dumas' improvements were twofold: the substitution of an inert but readily absorbable gas for air in the combustion tube and the use of potassium hydroxide solution, rather than mercury, as the confining liquid. The first modification eliminated an error inherent in Liebig's method but introduced not only the necessity of working with air-free carbon dioxide but also of expelling air from all parts of the apparatus before beginning a combustion. The second modification seems to have withstood best the test of time for it has suffered less by way of change than perhaps any other feature of the procedure.

Dumas produced carbon dioxide by heating lead carbonate in an extended portion of the combustion tube, a practice which was superseded later by the introduction of the separate gas generator (*12*). The Kipp apparatus has been found especially suited for this task if precautions are taken to produce air-free carbon dioxide, such as the procedure of Bernthsen (*13*) whereby one evacuates the water-covered marble chips, or that of Kreusler (*14*) who recommended the use of fused sodium carbonate and sulfuric acid. Numerous other procedures also are available (*15, 16*). More recently Pregl (*17*) recommended a preliminary etching of the marble chips with hydrochloric acid, followed by a careful rinsing with water.

As much effort has been spent upon the preparation of suitable reduced copper for the purpose of decomposing the oxides or nitrogen as securing pure carbon dioxide. Dumas reduced his copper with hydrogen, an unsatisfactory practice as subsequently became evident when it was observed (*18*) that copper thus prepared emitted, upon strong heating, a gas not absorbed by the potassium hydroxide solution. An explanation for this circumstance was eventually found in the fact that a copper hydride is formed during reduction (*19*) under these conditions. Further investigation (*20, 21*) showed that this difficulty could be corrected by igniting the copper strongly and then cooling it, all in a current of pure carbon dioxide. An entirely different approach to a solution of this problem is seen in the suggestion that a silver spiral be substituted for the copper because of the claim that it need be neither reduced nor dried, is more efficient than the latter in decomposing oxides of nitrogen, and serves to hold back halogens, if present (*22, 23*).

Finally, the technique of measuring the nitrogen evolved in the combustion, like all the other features of this determination, has undergone many changes, although the attainment of that development has not, apparently, been so difficult. The history of the convenient azotometer of Schiff (*24*) traces its course from the inverted bell jars of Lavoisier and of Gay-Lussac and Thénard, through the graduated cylinders of Liebig and Dumas, respectively. The whole picture of the development of ultimate organic analysis reflects a fine example of the scientific evolution of a group of procedures brought about by careful, tireless workers, over a period of many decades, by means of which the crude seed, sown with prophetic vision, brings forth an hundredfold of perfect fruit.

THE KJELDAHL METHOD

In a discussion of the wet oxidation method for the determination of nitrogen one again finds material for ample development of the central theme of this review, progress and evolution, for the rise of this procedure embraces fully three-quarters of a century before, as well as the half-century after, the publication of Kjeldahl's original communication. Originally developed to meet the needs of the chemist in the brewing industry, yet it was not to be exclusively his tool for very soon it found entrée into other fields of technical, as well as scientific, analysis.

Essentially, the Kjeldahl method consists in decomposing the material under examination with strong sulfuric acid in the presence of oxidizing agents, accelerators or catalysts, used either singly or in combination. Following complete decomposition, the digestion mixture is made strongly alkaline, whereupon the ammonia is distilled off and subsequently determined by some suitable means.

The technique of effecting decomposition of an organic substance with a sulfuric acid-catalyst mixture as outlined above, appears to have been first employed by Berzelius (*4*) when he investigated the decomposition products from various animal and vegetable substances after digestion with a sulfuric acid-lead peroxide mixture. He, however, concerned himself only with the products of distillation from acid solution.

Sulfuric acid-digestion, followed by precipitation of the resulting ammonia as the chloroplatinate, first enters the picture in 1845 as a method for the determination of urea (*25, 26*). Inasmuch as it was applied to the examination of urine and employed no catalyst, this work of Heintz and Ragsky presages, in a sense, the important modern researches of Folin and coworkers. And in this connection it may be timely, too, to recall that Grete in 1878 (*27*) offered the suggestion that the decomposition of hair, wool, leather and similar substances by the now obsolete Will-Varrentrup soda-lime method (*28*) could be expedited by giving the material under examination a preliminary treatment with sulfuric acid.

It may also be of interest to make mention of the fact that Kjeldahl had apparently received the inspiration to try an acid medium from the researches of Wanklyn and associates (*29*) on the use of strongly alkaline permanganate solutions for the liberation of so-called "albuminoid ammonia". Reasoning that the tendency to split off ammonia would be much greater in acid than in alkaline medium, he tried first dilute and finally concentrated sulfuric acid and was rewarded in the second instance by a yield of ammonia which compared favorably with that obtained by the soda-lime method (*28*). For a series of pure compounds the results were found to agree well with the calculated values, a fact which gave the new procedure further weight. Because of its extreme simplicity and rapidity, together with the high degree of accuracy obtainable in the analysis of protein and related materials, Kjeldahl's method was not long in receiving recognition. Indeed, the germ of an idea suggested by the original communication exactly fifty years ago has brought forth reports of an unprecedented number of investigations, extensions, and modifications. Obviously, the only rational method of reviewing them is by classification, selection of typical examples, and drawing of summarized conclusions. To this end, the subject will be considered with as much brevity as is consistent with clarity of presentation under the topic headings of *Digestion, Distillation of Ammonia, Determination of Ammonia,* and, finally, *Scope of Application of the Method.*

Digestion.—A Kjeldahl digestion mixture consists, in general, of representatives of two classes of substances: (1) strong mineral acids, and (2) catalysts or accelerators. There may also be added a third kind of substance, inert in itself, which dissolves in the acid and serves to raise the boiling point of the mixture, thus increasing the reaction velocity. Potassium sulfate, first employed by Gunning (*31*), or the less expensive sodium salt (*32*), is the most familiar example of this group. Its indiscriminate use, however, may lead, it is said (*33, 34*), to losses of ammonia during digestion when the composition of the residue approximates that of the acid salt. Kjeldahl himself suggested phosphorus pentoxide, an ingredient which has since been used by others either as such (*35-37*) or in the form of the acid as a substitute, wholly or in part (*38-41*), for the sulfuric acid. The desirability of using phosphoric acid has not, however, gone unchallenged (*42*).

Rapid digestion methods involving phosphoric-sulfuric acid mixtures containing hydrogen peroxide as oxidizing agent have been investigated by Wieninger and Lindemann (*43*) who found that these methods, although quite satisfactory, nevertheless yield results appreciably lower than those obtained by the older, slower Kjeldahl method. They offer the further objections that these new methods are very hard on glassware and require comparatively expensive reagents, so that the great saving in time of digestion (10 to 20 minutes as against 55 to 60 minutes) is still of problematic value at present. These discrepancies may well be due to the extremely drastic treatment, rather than spefically to the presence of phosphoric acid. Finally, a proposal which suggests a page from the days when Carius fusions were popular merits mention. It is to the effect that the Kjeldahl digestion of substances not readily attacked be carried out at 330° C. with fuming sulfuric acid in a sealed tube (*44*). Although this interesting suggestion is probably worthy of development, yet the experimental technique and hazards involved would preclude its use except under unusual circumstances.

Passing now to a discussion of catalysts, accelerators, and oxidizing agents used to increase the reaction velocity we find than an unusually large number of substances has been tried for this purpose. The accompanying table lists there, together with significant references and remarks on their efficacy.

TABLE I

Selected List of Catalysts and
Accelerators Available for Use in a Kjeldahl Digestion

Compound	*Author*	*Remarks*
$KMnO_4$	Kjeldahl (*30*)	Added as a final step to insure oxidation.
	Salkowski (*45*)	Ordinarily unnecessary, and objectionable in the presence of substances of high halogen content.
	Phelps (*46*)	May cause loss of nitrogen.
	Dowell and Friedemann (*47*)	Use discontinued.

Compound	*Author*	*Remarks*
$PtCl_4$	Ulsch (*48*)	Use satisfactory except in excessive amounts.
	Anderson (*49*)	Yields low results with partly hydrolyzed proteins.
Pt	Sivan and Raju (*50*)	Effective in the form of a spiral.
HgO	Wilfarth (*51*)	Action is fast but ammonia is held back.
	Phelps and Daudt (*52*)	Superior to $CuSO_4$, alum, $ZnCl_2$, $MnCl_2$, MnO_2, WO_3, MoO_3, TiO_2, or V_2O_5
CuO	Wilfarth (*51*)	Not as efficient as Hg.
Fe_2O_3	Wilfarth (*51*)	Not recommended
Bi_2O_3	Wilfarth (*51*)	Not recommended
	Brill and Agcaoili (*53*)	Not satisfactory for pyridine.
SnO_2	Wilfarth (*51*)	Not recommended
Pb (PbO_2, Pb_3O_4)	Wilfarth (*51*)	Not recommended
P_2O_5, Hg	Argutinsky (*54*)	Good results reported
$CuSO_4$, Hg, K_2SO_4	Trescott (*55*)	Efficiency of mixture confirmed
	Emmett (*56*)	Adoption by A. O. A. C. recommended
$CuSO_4$, HgO	Arnold and Wedemeyer (*57*)	Time of digestion is shortened.
	Bredig and Brown (*58*)	Mixture is more effective than either ingredient alone.
$K_2S_2O_8$	Dakin (*59*)	By its decomposition enhances the effect of the H_2SO_4.
	Milbauer (*60*)	Efficiency confirmed.
	Pittarelli (*61*)	Suitable in clinical analyses.
	Wong (*62*)	Material saving in time.
V_2O_5	Oefele (*63*)	Recommended as "oxygen carrier."
	Marino and Gonnelli (*64*)	Shortens digestion period.

Compound	*Author*	*Remarks*
	Margosches and Lang (*65*)	Efficiency doubtful.
	Brill and Agcaoili (*53*)	Not satisfactory for piperidine.
S_2O_3	Eckert (*66*)	Sulfur is added to fuming H_2SO_4 in analysis of nitro-compounds.
SO_2	Nolte (*90*)	Aids in the decomposition of alkaloids.
$Na_2S_2O_3$	Dhommée (*67*)	Applied to urine analysis
WO_3	Margosches and Lang (*65*)	Yields good results in conjunction with CuO.
CeO_2	Margosches and Lang (*65*)	Moderately successful results obtained.
MoO_3	Phelps and Daudt (*52*)	Not recommended
TiO_2	Phelps and Daudt (*52*)	Not recommended
H_2O_2	Kleeman (*70*)	Combined with K_2SO_4 and Hg, it shortens digestion time and causes no loss of NH_3
	Skutil (*71*)	Procedure highly recommended.
	Huess (*72*)	Well adapted to brewery chemistry.
	Saccardi (*73*)	Satisfactory for leather, flour and cheese.
	Wieninger and Lindemann (*43*)	Recommended, with reservations.
Hg_2I_2	Sborowsky and Sborowsky (*76*)	Superior to Hg.
	Hässig (*77*)	Superiority over Hg denied.
	Richards (*78*)	Saving of time effected.
Fe, CuO	Kürschner (*79*)	Good results obtained with very resistant compounds.
BaO_2	Provvedi (*80*)	Less efficient than H_2O_2 on flour.
Cd	Saiko-Pittner (*81*)	Very efficient action on pyramidone.
Se	Lauro (*82*)	Satisfactory for flour analysis.

Compound	*Author*	*Remarks*
	Tennant, Harrell, and Stull (*83*)	Material reduction in time required for digestion.
	Sandstedt (*84*)	Advantage over Hg in that precipitant unnecessary.
	Messman (*87*)	Mixture of Na_2SO_4, $HgSO_4$, $CuSO_4$ and Se recommended.
	Crossley (*86*)	Time of digestion shortened by substituting Se for Hg.
	Osborn and Krasnitz (*89*)	A Se-HgO mixture is best.
	Saiko-Pittner (*81*)	A K_2SO_4-Se-alcohol mixture is efficient for pyramidone in micro-analysis.
$SeOCl_2$	Rich (*85*)	A mixture of $SeOCl_2$, Cu, and Na_2SO_4 is very effective.
	West and Brandon (*88*)	A H_2SO_4-$SeOCl_2$ mixture is suitable for micro-analyses.
	Osborn and Krasnitz (*89*)	Precipitated Se is more suitable than $SeOCl_2$.
$KClO_4$	Frey, Jenkins and Joslin (*93*)	About equal to HgO and $CuSO_4$ in leather analysis.
$HClO_4$	Mears and Hussy (*68*)	Shortens time of digestion.
	Parker (*69*)	Well adapted to leather analysis.
MnO_2	Stock (*94*)	Suitable for carbonization of all substances.
	Thuau and de Korsak (*95*)	Applied successfully after preliminary treatment with H_2SO_4 alone.
$K_2Cr_2O_7$	Krüger (*96*)	Used in decomposition of organic substances.
Cl_3CCOOH	Grigaut and Thiery (*74*)	Aids in the decomposition of urine samples.
	Lublin (*75*)	Used in conjunction with H_2O_2.
$(COOH)_2$	Nolte (*90*)	Oxalic acid is an aid in the decomposition of alkaloids.
	Bouyer (*91*)	An aid in the decomposition of flour.
$C_{12}H_{22}O_{11}$	Nolte (*92*)	Value of sucrose depends largely upon nature of sample.

That the liberation of the resulting ammonia may be quantitative, it becomes necessary in some cases to destroy heavy metal-ammonium complexes formed during digestion. This is particularly true when mercury compounds have been used in this operation. Potassium sulfide, the precipitant most used today, was introduced by Wilfarth (*51*). Following this came sodium thiosulfate (*98*), now recommended in the current edition of "Methods of Analysis" of the Association of Official Agricultural Chemists as an alternate to sodium sulfide, then monosodium phosphate (*99*), potassium xanthogenate (*100*), and finally potassium arsenate (*101*), because its sponsor had found reason to criticize the action of sodium phosphate. Be that as it may, the first two of this list have been found to be satisfactory, provided a slight excess of the sulfide or a generous excess of the thiosulfate is used (*102*).

Distillation of Ammonia.—Distillation and absorption problems have received their measure of attention, too, the attack upon them being more from the mechanical rather than the chemical standpoint. Space does not permit a description of the many spray traps that have been devised to correct the tendency, because of violent ebullition or foaming, of alkali to be carried over into the condensing system, nor yet a discussion of the evolution of the distillation apparatus from that in vogue in Kjeldahl's time to the highly efficient, multiple-unit commercial type of the present day. Suffice it to state, however, that these difficulties may be practically eliminated by the use of suitable block tin condensers and distilling traps, and such remedial measures for bumping and foaming as zinc, or graphite (*102*), or even, as is still the practice of some, to follow the Biblical admonition of pouring oil—in this case paraffin—upon troubled waters (*175*).

It was not long after the appearance of the Kjeldahl method that the suggestion was made that steam distillation (*103*) be used for the recovery of the ammonia. This practice has met with a certain measure of success (*104-106*) although some investigators (*40*) have reported that it causes small amounts of alkali to be entrained and carried over by the spray. In microanalysis, especially, has this technique been widely used (*17, 40, 107-111*).

Aeration methods have found not a little favor among analysts, particularly in physiological and biological fields (*112, 113*). A comparison of results (*104*) obtained on the one hand by aeration and on the other by distillation has shown, in several instances, that at least as much as one per cent of the nitrogen obtainable by the latter mode of recovery was not carried over by the former. It was found, however, that steam distillation served to bring these low results up to the values obtained by heat distillation, and that a large excess of strong alkali materially aided in increasing the yields by aeration.

Determination of Ammonia.—There now remains the analytical determination of the ammonia. Here again many procedures are available and all of them have found a measure, but by no means the same measure, of success. Of antiquarian interest only is the extravagant precipitation as the double platinum salt (*26*). If not wholly obsolete, the iodometric determination of excess acid proposed by Kjeldahl has enjoyed a very limited use not only because of its cost, but also because of the extreme simplicity of the competitive acidimetric procedure which came into use soon after Kjeldahl's original communication appeared.

References to indicators pertinent to this titration are indeed numerous. A discussion of them has been omitted in order to make room for less common means of attaining the same end. A variant of the acid-base procedure, proposed by Sors (*114*), consists in carefully neutralizing the digestion mixture, adding a measured excess of standard alkali solution, boiling to expel ammonia, and determining by titration the decrease in alkalinity of the solution because of this evolved gas. Satisfactory results are claimed, distillation is avoided, but still the method has not been much used. The thought suggests itself, although it has not been verified experimentally, that the presence of such large quantities of salts in solution would make for a sluggish end-point.

A happy union of two old neighbors, so to speak, was brought about when Nessler's reagent was applied to Kjeldahl distillates, for the history of this reagent can be traced back nearly as far as that of the Kjeldahl digestion. As early as 1839 the fact was announced (*115*) that a dark brown precipitate is formed when mercuric iodide is treated with ammonium hydroxide, but no analytical use was made of this reaction until

Nessler described it (*116*) as an invaluable one for characterizing ammonia. Following this, it was widely accepted as a delicate qualitative and quantitative reagent for extremely small amounts of ammonia (*117, 118*). Eventually it was applied to biological materials (*112*), and to micro-analysis in general (*40, 119*).

The reaction between formaldehyde and ammonium salts, studied extensively by Schiff (*120*), has given rise to still another important method for the determination of ammonia. If we treat a neutral ammonium salt with an excess of strong, neutralized formaldehyde solution, the products of reaction are the free acid and, probably, hexamethylenetetramine. Since one equivalent of acid combines with one of ammonia, the titration of this liberated acid is equivalent to the amount of ammonia in the original salt. This fact was first utilized by Ronchése (*121*), and was subsequently employed by others for the determination of ammonia in urine (*122*), as well as quarternary ammonium bases and ammoniacal solutions (*123*). Its first application to the analysis of a Kjeldahl distillate was apparently in 1910. Its use has spread widely since then (*124-129*).

Closely related to the above work is that of Sörensen (*130*). the so-called formol titration of amino acids. This method depends upon the fact that amino acids in general are neutral substances because of a mutual compensation of the amino and carboxyl groups. Upon treatment with formaldehyde, however, the amino group is changed to a neutral methylene imino group as shown below, causing the acidity of the carboxyl group to become available by titration.

$$RCHNH_2COOH + HCHO = RCHN{:}CH_2.COOH + H_2O$$

Since the reaction is reversible, an excess of formaldehyde is employed to drive imine formation far towards completion. Very wide application has been given this method, as for example in urine analysis (*131*), in studies on the proteolysis of brewery products (*132*), in nitrogen metabolism investigations (*133*), in determining the nitrogen content of bacteriological media, and as an index of the falsification of honey (*134-136*).

The formol titration method is rapid and convenient, the distillation involved in most determinations of basic nitrogen is eliminated, yet it is not a precision method. Difficulties (*136*) hinging around concentration of solutions, concentration of indicators, and the small but unavoidable excess of alkali in the neutralized formaldehyde make duplication of results difficult. Very recently Levy (*137*) in a physical-chemical study of the equilibria involved has observed that two types of reaction, in which either one or two mols of formaldehyde per mol of amino acid are involved, may occur. Then, too, the fact that certain amino acids have a basic reaction is mentioned also as an additional complication. In short, for almost every variation in experimental conditions or nature of amino acids, there is a change in pH of the end point. Moreover, each acid in a mixture—they nearly always occur in mixtures—exhibits a different end-point when titrated under these conditions. The formol titration is thus the concurrence of many separate and complex phenomena and can hardly be regarded as a single definite operation.

As we have seen, the Kjeldahl method attained early popularity as a commercial analytical procedure because of its simplicity and adaptability to routine work. That it should become the subject of constant investigation with a view to further simplification, in the hope of effecting even small economies of time or materials, could hardly have been otherwise. In particular, the need for two standard solutions as in the ordinary acidimetric procedure has been circumvented in a number of ways. One of these, the formol titration, has already been discussed. Another, proposed by Neumann (*138*), is based on the observation (*139*) that, given a properly cooled water condenser, and a sufficiently large volume of liquid in the receiver, no ammonia is lost, even though an insufficient quantity of standard acid be present. All that is necessary is to measure out a slightly insufficient amount of standard acid solution, perform the distillation, and finish the titration in the presence of a suitable indicator. It seems a bit strange that no references pertinent to this method, other than the two cited, appear in the literature.

In contradistinction to this lukewarm reception stands that given the boric acid absorption method of Winkler (*140*). Its principle may best be given in the author's own words, "Boric acid is indeed such a weak acid, that its solution does not noticeably cause color changes of certain indicators. Ammonia is, however, completely fixed by it, provided that a suitable excess of the acid be present." Distillation is carried to completion, whereupon the ammonia is titrated directly in the presence of congo red (*141*), bromphenol blue (*142*) or methyl red indicators (*143*). The method has been successfully applied to a large variety of subjects.

The iodometric titration of the excess of standard acid takes place according to the following equations:

$$5\ KI + KIO_3 + 3\ H_2SO_4 = 6\ I + 3\ K_2SO_4 + 3\ H_2O$$
$$I_2 + 2\ Na_2S_2O_3 = Na_2S_2O_6 + 2\ NaI$$

This reaction, described in most of the older books on analytical chemistry, is not much used today for the reason that it is extremely sensitive towards carbon dioxide (*144*).

Less than three decades ago there appeared a second iodometric procedure (*145, 146*) for the determination of ammonia which has received a fair measure of recent recognition. It depends upon the fact that ammonia is oxidized quantitatively to nitrogen by an alkaline solution of hypobromite according to the following reaction:

$$2\ NH_3 + 3\ NaBrO = 3\ NaBr + N_2 + 3\ H_2O$$

A measured excess of the latter is added, the unused portion being subsequently determined iodometrically. Willard and Cake (*147*) were the first to apply this procedure to the Kjeldahl determination. A number of others have done likewise since (*148-151*). In a sense, oxidation of ammonia by hybobromite is a reaction with a dual role, for, besides carrying out the iodometric procedure as described, the nitrogen which is evolved may be determined gasometrically. This was done some time ago, in principle at least, on urea (*152*). The reaction has been widely utilized since (*101, 151-154*).

Scope of Application of the Method—The great bulk of those natural products, cereals, meat, milk, glue, tankage, or any of their manufactured derivatives, in which the nitrogen content is of vital significance, have a common fundamental characteristic, to wit: nitrogen is present there in the basic condition for the determination of which the Kjeldahl method is universally applicable.

But there exists a second large class of substances, prominent among which are nitro-, nitroso-, and azo-bodies, hydrazine, quinoline and pyridine derivatives, and inorganic nitrites and nitrates which are characterized by a very refractory behavior toward a Kjeldahl decomposition. To the numerous attempts made to subjugate these and so to universalize the method, some attention must be paid. It has been pointed out that the Kjeldahl treatment involves strenuous oxidation. It is quite logical to expect that little could be accomplished with substances unsatisfactorily decomposed merely by increasing the severity of treatment. A search of the literature reveals, indeed, that no such attempts were successful and that whatever has been done by way of extending the method has been accomplished by means of a preliminary reduction before oxidation.

At first rather mild reagents were used, for von Asboth (*155*) claimed to have obtained satisfactory results in the analysis of nitro- and cyano- compounds by adding to the mixture, to provide the necessary reducing environment, either sucrose or benzoic acid. Arnold, however, found that the claims for this mode of procedure were overstated (*156*).

In the same year Jodlbauer (*157*) introduced an important fundamental principle which is still in use today for the determination of nitrates by the Kjeldahl method, viz: the addition of easily nitrated phenols to the sulfuric acid which fixes the nitrogen in a form lending itself to ready and complete reduction. The value of this modification is especially significant in view of the wide occurrence and application of nitrates in fertilizers, etc. The reducing agent used here consisted of several grams of zinc dust with a small amount of platinum chloride solution as catalyst.

Several years later Förster (*97*) employed a phenol-sulfuric acid mixture of five to six per cent phenol content, with sodium thiosulfate. Following this, after a lapse of twenty-seven years, came the use of salicylic acid (*158*) in sulfuric acid solution as the nitrate-fixing agent. This reagent now enjoys an "official" status. A suggestion (*159*) that resorcinol or phloroglucinol be used instead of phenol itself has apparently received little notice.

Zinc in acid solution is by far the most widely used reductant for the resulting nitro-group. In addition, zinc and iron filings

(*160*), stannous chloride in the presence of metallic tin (*161*), iron powder (*162*), elementary sulfur alone (*66*), and sodium hydrosulfite (*163, 164*) have found application.

Reduction methods of an entirely similar nature also serve to bring within range of the Kjeldahl decomposition aromatic nitro-, nitroso-, hydrazine, and azo-substances, although low results have often been recorded in recalcitrant cases (*35, 106, 158, 160, 161, 163, 165,*). Very recently Friedrich (*166*) developed a micro method of universal applicability, involving concentrated hydriodic acid (*d.* 1.7) as reducing agent, followed by a Kjeldahl digestion. With volatile substances, the reaction is carried out in a sealed tube under pressure.

Although it had been established that molecular structure, as well as position and nature of substituents, plays a significant role in determining the susceptibility of aromatic nitrogen compounds to a Kjeldahl decomposition, whether plain or modified, nevertheless, attempt at generalization have proved futile. This is also true of the sugar osazones (*167*).

It has been stated that accurate generalizations are futile; still, the mention of one such attempt by Fleury and Levaltier (*168*) may be helpful in giving a concise, if crude, picture of the situation as it stands. By the application of their procedure they find that most substances are completely decomposed by one-hour's digestion. Difficultly attacked substances, such as creatin, skatol, isatine, quinine, piperazine, morphine, betaine, choline, atropine, tyrosine, and pyridine, require not more than one and one-half hours. The addition of benzoic acid makes analysis of the following possible: sodium nitrate, benzonitrile, the oxime of acetophenone, and piperidine. Reduction with zinc extends the method to picric acid, *m*-dinitrobenzene, phenylhydrazine, mannose hydrazine, and glucosazine. A combination of benzoic acid and zinc opens the way to semicarbazids and semicarbazones. No good decomposition procedure was found for either antipyrine or pyramidone.

With this discussion of the extension of application of the Kjeldahl method there is concluded the historical sketch of the evolution of this great analytical tool. There remain a few words about micro-analytical and biological methods.

Microchemical Methods Applied to Nitrogen Analysis. It has become a matter of common knowledge that Fritz Pregl was the originator of the new branch of analytical chemistry called micro-analysis. His contribution to combustion analysis was far greater than mere reduction of the scale of operations and time involved, as many suppose, for through his painstaking research he succeeded in a fuller refinement of the method and a more complete approach to theoretical accuracy than had previously been achieved. This two-fold advance has been of particularly great benefit to workers in biological chemistry, since the tedious necessity of collecting workable samples of vital materials is greatly lessened thereby. Historically, it is interesting to remember that the inception of micro-methods was due to just this difficulty encountered by Pregl in 1910. While engaged in his physiological researches at Innsbruck he was faced with the choice of spending many weary months purifying quantities if material, or devising analytical methods to fit the samples available. Inasmuch as he was a fine laboratory technician, he chose the latter expedient, continuing work after his transfer to Gratz, until, in 1914, he gave the first demonstration lecture in microanalysis before the Vienna Academy. But still the method did not suit him for it was not until 1917 that the first edition of his now famous book, "Die quantitative organische Mikroanalyse", appeared. Even here progress did not stop, as the book was twice revised and enlarged, the third edition being released in 1929, only one year before his passing. Because he realized that successful micro-analyses are possible only through meticulous attention to details, Pregl took great pains to avoid being misunderstood. To this end he published no articles on the subject in the scientific journals, and made his book almost trivial in its attention to detail, so that those who sought information had of necessity to go to the source and delve deeply.

Not only is a small sample of advantage in biochemical investigations, but it also offers great possibilities in another and less explored field, namely the study of side reactions occuring in conjunction with a given main reaction. It has been said that side reactions are the curse and the hope of organic chemistry. The curse, because they lower the yield of desired product and make it difficult to obtain it pure; the hope, because suitable modification of conditions can make the erstwhile side reaction attain predominance, thus increasing the scope of every synthesis and beating back yet farther the frontiers of synthetic organic chemistry. Obviously, a systematic, accurate method of characterizing small quantities of materials must be the foundation stone of any such investigation.

Concerning application of the principles of the Kjeldahl procedure to micro-analysis, much has been written, though little can be said in a review of this nature. The general tendencies in this application have been first, the use of all-glass apparatus for digestion and distillation in order to minimize the errors of transfer or those occasioned by leaching of rubber connections; second, the use of colorimetric methods for determining the evolved ammonia. Since each of these phases has been adequately treated in previous pages, they will not be discussed again.

One may well question, from the standpoint of sampling, the advisability of applying micro-analysis to agricultural products in general where fine pulverization is so often impossible. Always a difficult problem in this field, it becomes more acute when one considers the responsibility involved in selecting three or four grains of wheat as representative of a carload or a tiny fragment of tankage as a true average of the heterogeneous substances composing that product. Furthermore, in semi-solid materials, the difficulty of representative moisture content would be almost insurmountable. To conclude, then, micro-analysis is probably more valuable than macro-analysis where one is dealing with chemically pure compounds of unquestioned homogeneity because of economies of sample, reagents, apparatus, and time. But agricultural products as they ordinarily occur present the very antithesis of an ideal sample for this work, and, hence, the procedure must be applied with extreme caution, if at all.

Nitrogen Determination in Relation to Biochemistry. Because of the vital relationship that obtains between the nitrogen content of living cells, their products, and life itself, as exemplified by the familiar nitrogen cycle it is most natural and inevitable that biochemists and physiologists should have seized upon the analysis for nitrogen as a research method of the most profound significance and universal application. It is natural, also, that they should have developed their own methods for this purpose. They are accurate enough to indicate the trends in which they were interested, but more convenient than the time-consuming precision methods referred to above. The formol titration of Sörensen is one such method; it has been discussed elsewhere. Again, the contributions of Folin and co-workers, appearing in the *Journal of Biological Chemistry* from about 1910 to date, have done much to further the practical estimation of ammonia, amines, amino acids, etc., in biological materials. These last cannot be discussed here, however, for we would lose the ocean for the water in the attempt.

The name of D. D. Van Slyke is another one well known among workers in this field, for to him goes the credit for devising the gasometric determination of amino nitrogen based on the familiar reaction of primary amines with nitrous acid

$$RNH_2 + HNO_2 = ROH + H_2O + N_2$$

in which a molecular equivalent of gaseous nitrogen is liberated for every mol of amine present. This was first introduced (*169*) in 1910 and has been widely used since in the study of proteins, urea, and enzymes. Since nitrous acid also reacts with urea, it is necessary that this material be carefully removed before analysis (*170*).

Urea is a particularly important substance because it is the chief end-product of nitrogen metabolism in the animal body. A method for its determination proposed by Marshall (*171*) in 1913 depends upon the fact that it is hydrolyzed quantitatively to ammonium carbonate by the enzyme urease. The ammonia may then be distilled off and determined iodometrically or in any of various other ways. Apparently the selection (*172*) of an active urease preparation is a matter of some concern for not all such extracts are of equal quality. Attention must also be given to the concentration of extract, since it has an effect upon the amount of hydrolysis obtained (*173*). All in all, the procedure is one of typical clinical accuracy, but serves very well for comparative purposes.

The determination of nitrogen in water and sewage is properly included here, again because of its animal origin and its relation to the history of the water under examination. Ordinarily a sample of water is examined quantitatively for so-called "albuminoid ammonia", free ammonia, nitrite, and nitrate nitrogen. Of these, the last two involve color reactions with organic dyes which need not be taken up here. Ammonia is determined by Nesslerization, with or without distillation, depending on the amount present. The first-named, or "albuminoid nitrogen", is defined as that nitrogen which is liberated as ammonia by digestion with alkaline permanganate solution after expulsion of any ammonia originally present. Its determination was first proposed by Wanklyn (*174*) in 1867 and, although only of qualitative significance, and incapable of precise definition, has nevertheless persisted these sixty-odd years as a measure of the loosely combined organic nitrogen content of waters and sewage.

CONCLUSION

And now we have indeed reached the end of this review of a century or more of progress of the analytical aspect of nitrogen in organic combination. From the pioneer flights of "pure" chemistry to the practical routine of technology, scientists are rendered invaluable aid by the practice of organic nitrogen analysis. The chemistry of nitrogen is inseparable from the clothes we wear and the food we eat. The chemistry of organic nitrogen is the chemistry of life, and he who understands it has gone a long way towards fathoming the mysteries of bodily economy. The analytical or research chemist who has in his mind some picture of the century-and-a-quarter panorama of evolution preceding even our present limited knowledge cannot but have a deeper appreciation for those who have gone before and for his own humble work in consequence. It is the hope of the authors that this review will prove a contribution to such a picture.

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THE CUPRO-ALKALI METAL CARBONATE SOLUTION IN THE DETERMINATION OF REDUCING SUGARS.

II. A MODIFICATION OF PELLET'S SOLUTION*

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Some sixty years ago the suggestion[1] was made that a solution of a lesser degree of alkalinity than that characteristic of Fehling's solution[2] be used for the determination of reducing sugars in the presence of sucrose because of the hydrolytic action of this reagent upon the latter. This end was to be met by the use of both sodium hydroxide and sodium bicarbonate in such proportions that the former fall short of the stoichiometrical relationship which exists between these two compounds. Pellet,[3] unable to verify the claims made by the sponsor of this solution for a passivity towards sucrose and a satisfactory stability after a six months' aging period, then proposed a modification thereof. The novel features of his reagent were the use of sodium carbonate and a stabilizing agent, ammonium chloride, whose presence was briefly dismissed with a statement of the purpose of adding it to the mixture.

Except for the attention given the first of these proposals by Pellet, both, it seems, passed unnoticed and were soon forgotten. This situation seemed to warrant an investigation of these forgotten techniques, and particularly so because of the comparatively recent revival of interest in this type of sugar-oxidizing solution. As the result of such a study in this Laboratory there has come a modification of Pellet's solution in turn. This new reagent is one which, unlike that of the current form of Fehling's solution, does not in the course of time give any evidences of having undergone auto-reduction nor does it exert a hydrolytic action upon sucrose under the experimental conditions set up in the investigation. Furthermore, it is somewhat more sensitive than the latter towards the common reducing sugars.

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* Condensed from a thesis submitted by Chang Y. Chang to the faculty of the Graduate School of the University of Wisconsin in partial fulfillment of the requirements for the degree Doctor of Philosophy, 1933.

The data relevant to the experimental development of this reagent and a record of its copper-sugar equivalents are presented in this communication.

EXPERIMENTAL

Stability of Pellet's Solution.—Pellet's original directions[3b] for the preparation of his solution were followed, viz:— $CuSO_4.5H_2O$ 68.7 g., Rochelle salts 200 g., Na_2CO_3 100 g., NH_4Cl 6.87 g., water, q.s. 1000 ml. It was early apparent that a finely divided precipitate, its quantity increasing with age, will form in this solution irrespective of the method employed in making the latter. The reaction which is responsible for its formation is not a reversible one for the precipitate in question is stable at elevated temperatures. It availed nothing to heat the freshly prepared solution in the hope of hastening equilibrium inasmuch as the formation of the precipitate continued after the filtered reagent has been set aside. That it is obviously formed at the expense of the strength of the reagent became apparent (Table I) when, from time to time, the filtered reagent (20 ml. plus 30 ml. water) was treated for 45 min. at 65° with a dextrose solution containing 80 mg. of this sugar in 50 ml.

TABLE I

Effect of Age upon the Dextrose-Copper Equivalent of Pellet's Solution

Time hrs.	Cu mgs.	Loss per cent	Time hrs.	Cu mgs.	Loss per cent
0	33.5	..	204	31.2	6.8
24	32.4	3.2	330	...	..
62	32.0	4.4	515	27.7	17.3

Tentative Modification.—The objectionable characteristics of the foregoing reagent were corrected in a measure by following the course of procedure prescribed by Soxhlet[4] in his modification of Fehling's solution,[2] that is preparing it in two parts to be mixed just before use[5] in this instance in the proportion of one volume of the copper solution to four of the alkaline tartrate mixture. Solution A consisted of 343.5 g. $CuSO_4.5H_2O$ and 34.35 g. NH_4Cl in water q.s. one liter, whereas solution B, similarly, contained 250 g. Rochelle salts and 125 g. Na_2CO_3. After letting the latter stand for some time at room temperature, or overnight at 60-70°, to permit the separation of impurities, mainly calcium carbonate, it was ready for use. Equilibrium apparently had been reached in this time for after removal of the precipitate the solution no longer deposited a sediment.

On putting this reagent to use, an unexpected situation arose in that it was found impossible to duplicate satisfactorily the sugar equivalents of this reagent when prepared exactly under the same conditions but at different times, unless one chose to disregard four to ten-mg. discrepancies as inconsequential, the inevitable experimental error chargeable to the "personal equation" of the operator.

The causes for this erratic behavior of the reagent apparently lay in some fault in its composition and, perhaps too, in experimental conditions incapable of bringing out the maximum efficiency of the reaction. Further refinements, such as might be suggested by a study of the effects of shifting some of the factors governing the reduction of the copper solution, were obviously necessary. A resumé of the results of such a course of procedure follows.

Temperature Factor:—The optimum temperature conditions for reduction were studied with two solutions of different alkalinity. By reducing the tartrate content of solution B to 216.25 g. per liter, a concentration exactly comparable to that of the Soxhlet Fehling solution (yet less than that recommended by Pellet by 27 g.) it was possible, because of solubility considerations affecting all of the ingredients, to increase its sodium carbonate content to 238.5 g. and still higher as was done in a later phase of the whole study.

Working at thermostatically controlled temperatures (± 0.1°) and using dextrose (Bureau of Standards sample 41) as the experimental sugar under the conditions noted in preceding paragraphs, it was found (Figure 1) that the rate at which the copper solution is reduced is a function of the degree of its alkalinity and, of course, the temperature at which the reaction is carried out. The solution of greater alkalinity was found to be preferable to the lesser because under these conditions reduction is apparently completed at a lower temperature, or 90°. This point was, therefore, selected as the best working temperature for the studies which followed.

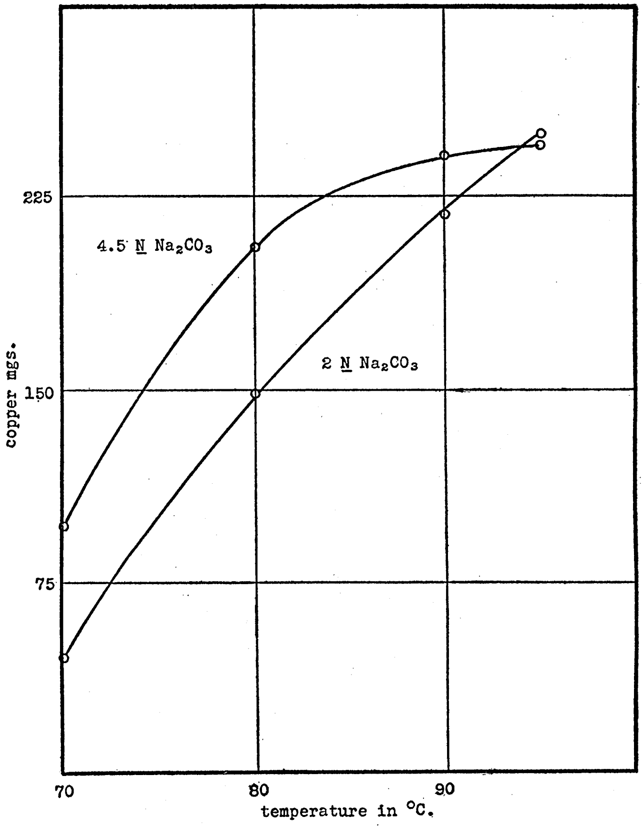

FIG. 1.—Effect of temperature upon the reducing power of dextrose

Time Factor.—Without changing the conditions set up in the preceding experiments with respect to concentration of reactants and nature of reducing agent, and using the copper solution of higher alkalinity, the time required to reach equilibrium, or substantially so, was determined. Observations were made at the end of a 20-minute reaction period and at stated intervals thereafter up to 50 min. inclusive. From the data so obtained it was apparent (Table 2) that the reaction practically reaches equilibrium within 40 min. and that the 45-min. time interval previously adopted was well chosen.

TABLE II

Effect of Time upon the Dextrose-Copper Equivalent of Pellet's Solution

Time min.	Dextrose mgs.	Copper mgs.
20	80	196.1
30	80	233.6
40	80	240.5
45	80	241.0
50	80	241.7

Influence of the Concentration of Carbonate.—It is well known[6] that the concentration of hydroxyl ion influences the rate and amount of oxidation of the sugars. In spite of the fact that a carbonate content equivalent to 4.5 *N* had already been found to make for a satisfactory performance of the reagent, yet it remained to determine whether this concentration of sodium carbonate actually represented the most effective alkalinity. To that end the whole gamut from 1 *N* to 7 *N* carbonate content was studied with respect not only to the oxidation of dextrose, but levulose, maltose and lactose* as well, besides a fifty-fifty mixture of the first-named pair (Figure 2).

It was found in this instance, too, as is the case with Fehling's solution, that the amount of copper reduced increases with increasing concentration of hydroxyl ions up to a point where oxidation of the sugar molecule appears to have reached its maximum. For levulose this condition apparently lies in the use of a reagent whose carbonate content is 2 *N*, yet at the 4.5 *N* point of alkalinity the curve begins to straighten itself out. This situation is significant, for not only does this concentration seem to represent the effective alkalinity for the oxidation of all the other sugars in this group but it is also at this point that dextrose, levulose and an equal mixture of the two exhibit practically the same reducing action when present in the reaction mixture to the extent of 80 mg.

Pellet's Solution in its Modified Form.—The relative concentrations of copper sulfate and ammonium chloride with respect to the whole reagent have been retained, but the desirability of increasing the carbonate content made necessary the use of less

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* These three sugars were of the highest degree of purity obtainable and conformed, on analysis, to the specific rotation characteristic of each. They were dried at 56° in *vacuo* before use.

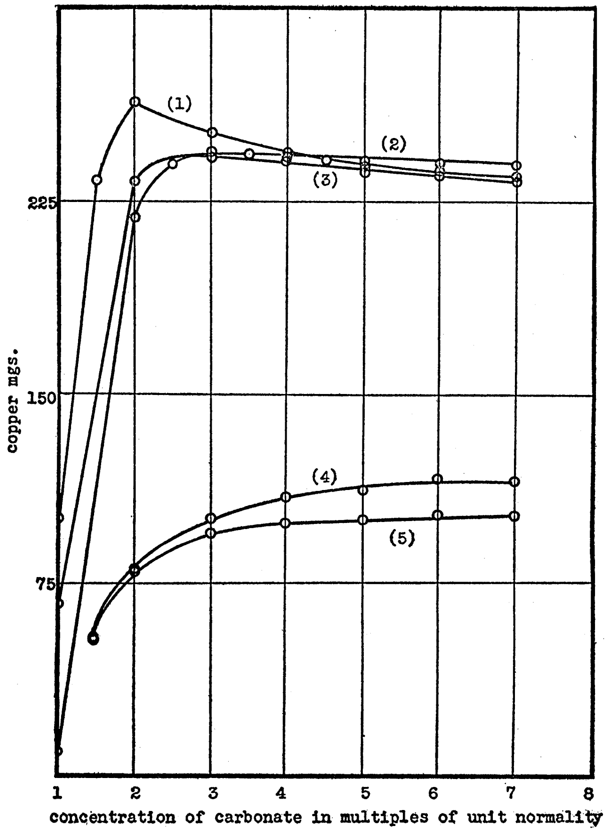

FIG. 2.—The influence of concentration of sodium carbonate upon the reducing powers of various sugars
(1) Levulose (2) Dextrose (3) Levulose-Dextrose
(4) Lactose hydrate (5) Maltose hydrate

Rochelle salts than once suggested.[3b] By preparing the reagent in two parts, as described in preceding paragraphs, the instability of the original form[1] and its tendency to erratic behavior have been overcome. That portion containing the copper is not photo-sensitive—solutions left standing on the shelf twelve months or more with no protection from the sun-light have shown no signs of decomposition—and hence is not susceptible to the forces of auto-reduction because of the presence of the ammonium chloride which dissolves the cuprous oxide as fast as it is formed. The practical significance of this is that no "blank" determination on the reagent is necessary.

The optimum conditions for its use are: (1) time and temperature of reaction, 45 min. and 90°, respectively; (2) 20 ml. of reagent mixed just before use in the proportion of one volume of copper solution to four of tratrate; (3) a sugar solution containing not more than 4 mg. of reducing sugar per cc.; and (4) the reaction mixture diluted with water, if need be, to 80 ml. Finally, the reduction should preferably be carried out in stoppered flasks in order that the original volume of the reaction mixture be maintained and temperature fluctuations at the surface be eliminated.

Sucrose shows no reducing action towards this reagent under the experimental conditions herein set up. This fact was discovered when no cuprous oxide was formed in an 80-ml. reaction mixture containing in one instance 80 mg. of sucrose and 2 g. in another, nor was any significant increase in the copper equivalent of dextrose, levulose, and an equal mixture of the two noted when this sugar was admixed with each to the extent of five per cent. in one series of experiments and fifty per cent. in another. Similarly, the reducing power of maltose was not affected by the addition of an equal weight of sucrose, yet lactose gained slightly in its ability to reduce the copper solution under the same conditions and when it constituted only 17 per cent, of such a mixture. In view of the passivity of sucrose towards this solution, it is difficult to explain this phenomenon except, perhaps, on the basis of promoter action of the former.

Sugar-Copper Equivalents.—The relationship existing between four of the common reducing sugars and the amount of cuprous oxide, in terms of copper, precipitated by them from this reagent under the conditions described above is a straight line function. The relevant mathematical expressions are:

TABLE III

Reducing Sugar Equivalents of the Modified Pellet Solution

Sugar	Range of sugar concen. (x) in 20 ml.	Equation for calculating Cu equiv. (y)	Mean deviation Cu-Cu obs. calcd. mg.
Dextrose	20-100	$2.9846x$-3.660	±0.31
Levulose	20-100	$2.9846x$-3.660	±0.92
Lactose hydrate	20-220	$1.3803x$-2.046	±0.36
Maltose hydrate	20-240	$1.2757x$-2.634	±1.08

The copper equivalent per unit weight of sugar was found to be 2.9 for dextrose or levulose and, similarly, 1.3 and 1.2 for lactose and maltose, respectively. That these equivalents point to a greater degree of sensitiveness of the modified Pellet solution than that shown by the same sugars towards Fehling's solution is shown by the following comparable data: in the order named above they are 2.08, 1.88, 1.23 and 1.01. The practical significance of this lies in the fact, for example, that discrepancies in duplicate determinations of dextrose of 2.9 mgs. are inconsequential inasmuch as the analyses will still agree within one mg. of sugar equivalent.

SUMMARY

The experimental development of a sugar-oxidizing reagent from the forgotten foundations laid by others[1],[3] many years ago has been described with such attention to detail as seemed desirable to point out the fact that the inherent faults in the composition of the latter and the technique of using it have been corrected. The reagent in its present form consists of two parts one of which contains in one liter of solution 343.5 g. $CuSO_4.5H_2O$ and 34.35 g. NH_4Cl, the other, similarly, of 216.52 g. sodium-potassium tartrate and 283.5 g. Na_2CO_3. The copper equivalents of four reducing sugars have been determined by a mode of procedure which involves an 80-ml. reaction mixture 20 ml. of which is reagent (one volume of copper solution mixed immediately before use with four of tartrate solution), and the remainder reducing sugar solution containing not more than 100 mgs. of dextrose or levulose or 220 mgs. of lactose or maltose, the reduction being carried out in a stoppered flask immersed for 45 min. in a 90° bath. What is deemed to be a unique characteristic of this reagent is its passivity towards sucrose under the experimental conditions herein set down.

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A STUDY OF LIGNEOUS SUBSTANCES IN LACUSTRINE MATERIALS

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In past years limnologists in their study of the environments of plant and animal forms in inland lake and sea waters have analyzed waters for dissolved solids and gases and have attempted to determine the composition of lake and sea bottoms as well as that of the existing biological forms. Until recently these analyses were confined largely to inorganic constituents, little attention being paid to the organic material. Although Schuette (*16*) studied the ether extract of Daphnia as early as 1918, it was not until recently that Birge and Juday and Krogh, studying inland lakes, and Waksman studying sea water (*20*) made investigations designed to obtain more information concerning the types of organic compounds made available for further plant and animal consumption by decomposition of already existing dead plants and animals in the water and in bottom muds.

Birge and Juday (*3*) in "Particulate and Dissolved Organic Matter in Inland Lakes" discuss the suspended and dissolved organic matter in inland lake waters. They describe a system of analysis in which the organic material is divided into proteins, fats and carbohydrates. It may be well to summarize the method here.

A determination is made of the total organic nitrogen, total organic carbon (A) and ether extract in the residues under examination. Nitrogen is calculated to protein (B) by means of the factor 6.25, its carbon content being taken as 53 per cent. The carbon content of the fat fraction (C), or ether extract, is taken to be 75 per cent. Calculation of the carbon due to carbohydrate (D) which is 45[2] per cent of the total carbohydrate is then made with the aid of the following formula:

$$D = A - 0.53\,B - 0.75\,C$$

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[1] This study was supported in part by a grant from the Wisconsin Alumni Research Foundation. The analytical results contributed by Lester Brillman and Leslie Gerlach were made possible by CWA funds.

[2] In view of results more recently obtained, 50 per cent has been used as the carbon content of the carbohydrate.

More recent work on ligneous materials indicates that in the above mentioned carbohydrate fraction is included the less easily decomposable ligneous materials. It therefore seemed desirable to determine whether or not the ligneous materials constitute a significant portion of the organic material in the original samples. The limitations of the above procedure are apparent since at least part of the calculation is dependent on the use of average values. It seems unlikely that a better method will be obtained until a more accurate characterization of the organic constituents is made available.

In 1933 Ohle (*11*) reported stratification of the sediment in the Ukleisee near Plön by determining the methoxyl and ligneous content of different strata. For our present investigation the corrected residue isolated from various samples by the sulfuric acid method of Scherrard and Harris (*18*) has been used as a measure of ligneous material. Methoxyl determinations were made on the original samples and on the lignin fractions isolated by the acid treatment. They are presented for purpose of comparison.

CONDITION OF SAMPLES

Samples of bottom mud from the deep parts of six Wisconsin lakes; a sample of mud from Lake O'Malley, an Alaskan fresh water lake; flora and fauna from Wisconsin lakes including Isoetes, Gloeotrichia, Lobelia, and Moss, and several catches each of net plankton and nannoplankton from the waters of Lake Mendota were supplied by the Wisconsin Geological and Natural History Survey for this study. The classification net and nannoplankton is that used in Bulletin 64 published by the Survey.

All mud samples were air dried at the time they were obtained and have been preserved in stoppered bottles. Such a treatment is necessary to prevent fermentation of the organic matter in the moist sediment. Samples of net and nannoplankton were dried in a Hearson* oven at 60°C. Before analysis the samples were dried further in a vacuum desiccator at 60°C until no loss of weight could be observed. All results reported are on the dry weight basis.

Mud samples were obtained with an Ekman dredge and represent only the upper 15 cm. of the deposit.

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* In the Hearson oven outside air is passed over the samples by means of a motor driven fan.

METHODS OF ANALYSIS

Total nitrogen in original samples and special fractions was determined by the micro-Kjeldahl procedure described by Kemmerer and Hallett.[8]

We were primarily interested in the examination of organic matter in the original residues and in the so-called ligneous fraction. The presence of carbonates and hydrous silicates interferes with the estimation of total organic matter in the original muds by loss on ignition. Hence total carbon was determined by the micro-combustion method of Kemmerer and Hallett[7] and the carbonate carbon by a micro carbonate method described by the same authors.[9] The carbonate carbon was subtracted from the total carbon leaving the organic carbon. It should be noted that a survey of many determinations of organic carbon and total organic matter has shown that a reasonably constant ratio exists between total organic matter and organic carbon, namely, organic carbon $\times$ 2 = organic matter. Limnologists commonly use this method in order to obtain a close approximation of the total organic matter. A slightly different factor has been proposed by Waksman for use on marine deposits, this value being 1.887.

In the case of ligneous fractions isolated by the sulfuric acid method to be described later it was possible to determine the total organic matter (lignin and insoluble protein) by ignition. The acid treatment decomposed all carbonates and most of the hydrous clays, the constituents which interfere with the direct determination of organic matter in the original sample by ignition.

Ignitions were made in a muffle furnace at about 700°C, the sample being heated to constant weight.

THE LIGNIN CONTENT OF LACUSTRINE SUBSTANCES

Previous researches have indicated that lignin is the most abundant organic identity present in bottom deposits. Such a condition exists because of all the organic types present lignin is the least decomposable by either ærobic or anærobic bacterial action and lignin does not readily serve as a food substance for macroscopic animal or plant life.

The acid extraction method recommended by Sherrard and Harris for the isolation of lignin seemed well adapted to the sort of material under investigation. According to them cold concentrated sulfuric acid dissolves practically all oxygenous and nitrogenous compounds from naturally occurring organic mixtures, leaving lignin mixed with a relatively small amount of crude protein. The residual nitrogen is probably present in a ligno-protein complex. Temperature and concentration of the sulfuric acid must be such as to remove the whole cellulosic part without causing caramelizing. Acid which is too strong or too warm may also sulfonate some lignin.

Method:

Add a dry two gram sample of algal or other plant material, or a dry ten gram sample of bottom mud, to 16 times its weight of cold 72 per cent sulfuric acid (10°C). A large vessel is required to retain mud samples high in carbonate; a four hundred cc. beaker is large enough for a ten gram sample of mud from Lake Mendota. Although the carbon dioxide liberated upon addition to the acid causes considerable foaming it is possible to keep the material in the beaker. Maintain the acid wet sample at 10°C for sixteen hours, shaking occasionally. Then pour the mixture quantitatively into twenty five times its volume of water in a 3 to 5 liter round bottom flask rotating the vessel meanwhile in order to prevent local overheating. Boil the resulting solution and residue for from 4 to 5 hours under a reflux condenser to hydrolyse any carbohydrate which might have been precipitated by dilution. Upon cooling the solution should be quite clearly wine or red brown, the color being deeper in organic rich mud. Filter through a small hard paper filter disk by aid of suction. Wash the residue until free of sulfate. Carefully remove the residue from the filter paper after it has become caked, transferring it to a tared watch glass. Dry in the same manner as the original sample was dried (vacuum desiccator at 60° C) and weigh. A sample of this dry residue which contains lignin, together with small amounts of nitrogenous substance and varying quantities of silica and other inorganic materials, is then ignited in a muffle furnace at about 700°C for thirty to forty minutes. The loss in weight represents the total organic matter in the residue.

After the prescribed acid extraction no samples showed any evidence of charring or caramelizing. A second extraction with concentrated sulfuric acid did not remove any additional organic matter; hence a single treatment may be considered complete. The final product is dark brown yielding a pure white ash on ignition. No sulfur trioxide fumes were detected during the ignition; indicating that little or no sulfonation of the lignin occurred, and that inorganic sulfate had been completely removed.

The sulfuric acid digestion, besides removing all carbohydrate and a large part of the protein, effected the solution of most of the mineral constituents except silica. Analyses of the ash remaining from the ignition of ligneous residues are given in the following table:

Analysis of Ash from Ligneous Residues

Source of Ash	SiO_2 per cent	Fe_2O_3 per cent	CaO per cent	MgO per cent
Tomahawk	97.30	1.59	0.0	trace
Mendota	93.74	3.20	1.16	trace

In lake bottom detritus the polysaccharides and hemi-celluloses have been almost completely removed by bacterial and possibly hydrolytic action. Such a condition of the sample obviates a preceding acid hydrolysis for removal of pentosans or similar carbohydrates which are alleged to contribute a polymerization product to the lignin residue.*

RESULTS

Analyses of the ligneous residues obtained by the sulfuric acid extraction are reported in Table I. As previously noted the organic fraction of this residue was determined by loss upon ignition. At first glance it might appear that this value is irrelevant. It must be noted, however, that it is necessary to know the organic fraction in the ligneous residue before it is possible to calculate the corrected lignin. In the calculations represented in Table I nitrogen was determined on the ligneous residue and this was converted to an approximate crude protein value by the use of the factor 6.25 × N. The crude protein subtracted from the total organic matter in the ligneous residue gave the so-called corrected lignin. The carbon in the crude

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* Norman (*10*) and others have advised a dilute acid hydrolysis preceding the 72 per cent sulphuric acid digestion in the process of isolating lignin from plant material and composts in order to remove xylan and any other pentosans present which are converted in part by strong sulphuric acid into so-called *apparent* lignin.

TABLE I
COMPOSITION OF ORGANIC MATTER IN RESIDUES FROM SULFURIC ACID EXTRACTION

Source	Loss upon Ignition*	Total C	N	Percentages Crude Protein	Corrected Lignin	C due to Crude Protein	C due to Lignin	$\frac{\text{C due to L}}{\text{Lignin}}$ = C in Lignin
Bottom Deposits								
Mendota	16.27	8.74	0.86	5.38	10.89	2.85	5.89	54.3
Tomahawk	26.83	14.53	1.09	6.81	20.02	3.60	10.93	54.6
Mary	52.60	32.47	1.69	10.56	42.04	5.60	26.87	63.9
Trout	22.20	11.17	0.69	4.31	17.89	2.28	8.89	49.7
Crystal	42.91	25.46	1.55	9.69	33.21	5.15	15.77	47.5
Weber	43.26	26.10	1.08	6.75	36.55	3.58	22.52	61.6
O'Malley	16.20	6.77	0.71	4.44	11.76	2.36	4.62	40.2
Net plankton								
328	52.67	31.52	2.41	15.06	37.61	8.04	23.48	62.5
368	42.02	25.03	2.26	14.13	27.89	7.49	17.54	62.9
5104	32.70	19.93	1.75	10.94	21.76	5.80	14.13	63.5
5105	38.49	24.27	1.83	11.44	27.85	6.06	18.21	65.4
Nannoplankton								
610	21.36	12.22	0.96	6.00	15.36	3.18	9.04	58.7
5156	30.62	17.70	2.03	12.69	17.93	6.73	11.44	63.8
5162	27.45	16.80	1.67	10.44	17.01	5.53	11.27	64.7
Lobelia	38.01	22.69	1.57	9.81	29.19	5.21	17.48	61.3
Gloeotrichia	71.45	43.19	3.00	18.75	52.75	9.94	33.25	63.0
Isoetes	97.31	56.80	5.89	36.81	60.49	19.52	37.28	61.6
Moss (Weber Lake)	60.61	34.28	2.07	12.94	47.66	6.86	27.42	57.5

* Org. Content of Residue after 72% H_2SO_4 Extraction

protein was calculated by the use of the average value of 53 per cent. This carbon subtracted from the total organic carbon in the ligneous residue gave the carbon due to lignin. Finally, the carbon due to lignin divided by lignin gave the percentage of carbon in lignin.

From the nature of the isolation of the ligneous residue and from the method of calculation described it must be obvious that the values given must be considered approximations. However, if the values reported in this and following tables give the general order of magnitude of the carbon in lignin and the order of magnitude of the lignin in the organic part of the original samples, their purpose will be served.

From an examination of the organic content of the ligneous residue in Table I it is obvious that the acid extraction produces a ligneous residue which is strongly contaminated with inorganic constituents, principally silica. The percentage of carbon in lignin of many woods has been found to be somewhat below 65 per cent. In fresh water lake muds the carbon in the lignin as determined by the technique already described ranged from 40.2 per cent for the mud samples from Lake O'Malley to 63.9 per cent for the mud from Lake Mary. Greater agreement is noted for the carbon in the lignin for other samples, the values from net plankton and nannoplankton being 63.6 per cent and 62.4 per cent, respectively. Four other samples, Lobelia, Gloeotrichia, Isoetes, and Moss gave an average carbon in lignin of 60.9 per cent. The relatively great divergence of results for carbon in lignin in the lake muds might suggest that the sulfuric acid treatment outlined, while suited for undecomposed woods, was unsuited for the quantitative isolation of lignin in the heterogeneous bottom muds. At the same time it must be remembered that in the list of lakes is represented both drainage and seepage lakes as well as hard and soft waters, high and low color, and high and low dissolved and suspended organic material. It must also be noted that the organic matter in lake muds represents material which has resulted from the decomposition of plant and animal forms. Most investigators who have reported more regular results have worked with original materials such as wood. Although there was this wide divergence in carbon in lignin between the various lake mud samples from different lakes, no difficulty was experienced in checking the results obtained on an individual sample.

Perhaps of more interest to the limnologist is the ratio of lignin to total organic matter in these inland lake samples or since according to the calculation already described the lignin was formally included in the carbohydrate fraction of the organic matter in lake residues it should be important to make some estimation of the ratio of lignin to carbohydrate.

In Table II the weight of the original samples and the weight of the sulfuric acid residues are given to illustrate the size of the residues handled. With the exception of two columns the remainder of the data is given in percentages. Although percentage lignin in the original material is given this value has less importance than the calculated lignin organic matter ratio since the different samples contain different amounts of inorganic residue. The ratio between lignin and organic matter in the samples is calculated by dividing the corrected lignin in the original material by the total organic matter in the original material, the total organic matter being obtained by multiplying the total organic carbon by 2.00.

The highest lignin content of the muds examined was 29.67 per cent in Lake Mary mud; the lowest, 4.5 per cent in Lake Mendota mud. The highest lignin to organic matter ratio occurs in Lake Mary mud where 47.76 per cent of the organic matter was found to consist of lignin; the lowest ratio was 29.75 per cent in Lake Mendota mud. The other materials examined which are the precursors to the organic substance of the mud were all relatively lower in lignin, the average lignin content of all being 17.5 per cent. These are results which might be anticipated from a consideration of the course of decomposition to which organic matter is subject after it reaches the bottom.

METHOXYL CONTENT OF LACUSTRINE LIGNIN

In order to obtain additional information regarding the nature of lacustrine lignin and if possible to find a shorter means of measuring the relative amounts of lignin in the original samples, the methoxyl content of the original materials previously studied was determined and compared with the methoxyl content of the lignins obtained from them. It was hoped that the

TABLE II
LIGNIN CONTENT OF SOME LACUSTRINE SUBSTANCES

	Sample	Residue after H_2SO_4 Extraction grams	Residue after H_2SO_4 Extraction per cent	Lignin Con. Residue corr. per cent	Lignin in orig. Mat. per cent	Total Org. in original Material (Org. C x 2) per cent	Lig. to Organic Ratio
Mendota Mud	20.00	8.40	42.00	10.89	4.57	15.36	29.75
Tomahawk Mud	20.00	11.15	55.75	20.02	11.16		
Mary Mud	13.02	9.19	70.59	42.04	29.67	62.12	47.76
Trout Mud	9.70	5.72	58.97	17.89	10.55	29.08	36.28
Crystal Mud	9.96	6.00	60.24	33.21	20.01	55.60	36.00
Weber Mud	5.89	3.49	59.25	36.55	21.66	56.18	38.55
O'Malley Mud	8.28	6.03	72.83	11.76	8.56	20.50	41.76
Net plankton							
" 328	1.27	0.49	38.58	37.61	14.51		
" 368	7.20	2.16	30.00	27.89	8.37		
" 5104	2.10	1.05	50.00	21.76	10.88	61.38	17.72
" 5105	4.61	1.36	29.50	27.85	8.24		
Nannoplankton							
" 610	2.77	0.55	19.86	15.36	3.05	28.16	10.83
" 712	4.89	2.34		16.08		38.04	
" 5156	4.85	1.70	35.05	17.93	6.29	38.46	16.35
" 5162	3.25	1.48	45.54	17.01	7.75	39.96	19.39
Lobelia	7.78	2.70	34.70	29.19	10.13	86.12	11.76
Gloeotrichia	5.40	1.39	25.74	52.75	13.58	94.70	14.34
Isoetes	8.55	2.84	33.22	60.49	20.09	77.02	26.08
Moss (Weber)	8.34	3.39	40.65	47.66	19.37	81.64	23.73

TABLE III

THE METHOXYL CONTENT OF SOME LACUSTRINE SUBSTANCES AND OF THE LIGNIN ISOLATED THEREFROM

Substance	CH_3O in Original Material per cent	CH_3O in Lignin Res. per cent	Corr. Lignin in Extracted Residue per cent	CH_3O in Corr. Lignin per cent	Corr. Lignin Content of Orig. Sub. per cent	CH_3O in Orig. Substance due to Lig. per cent	Ratio $\frac{CH_3O \text{ due to Lig.}}{CH_3O \text{ in Original}}$ per cent
Mendota Mud	0.21	0.26	10.89	2.39	4.57	0.11	0.52
Tomahawk Mud	0.37	0.44	20.02	2.20	11.16	0.25	0.68
Mary Mud	1.10	0.92	42.04	2.19	29.67	0.65	0.59
Trout Mud	0.38	0.26	17.89	1.45	10.55	0.15	0.40
Crystal Mud	0.28	0.18	33.21	0.54	20.01	0.11	0.39
Weber Mud	0.39	0.24	36.55	0.66	21.66	0.14	0.36
O'Malley Mud	0.34	0.56	11.76	0.48	8.74	0.04	0.15
Net plankton							
" 328	0.74	0.21	37.61	0.56	14.51	0.08	0.11
" 368	0.56	0.18	27.89	0.65	8.37	0.05	0.09
" 5104	0.65	0.11	21.76	0.51	10.88	0.06	0.09
" 5105	0.60	0.12	27.85	0.43	8.24	0.04	0.07
Nannoplankton							
" 610	0.47	0.14	15.36	0.98	3.05	0.03	0.06
" 5156	0.70	0.15	17.93	0.84	6.29	0.05	0.07
" 5162	0.71	0.17	17.01	1.00	7.75	0.08	0.12
Lobelia	1.47	1.03	29.19	3.53	10.13	0.35	0.23
Gloeotrichia	0.60	0.31	52.75	0.59	13.58	0.08	0.13
Isoetes	0.77	0.35	60.49	0.58	20.09	0.12	0.16
Moss (Weber)	0.47	0.25	47.66	0.52	19.37	0.10	0.21

methoxyl content of the original material might be an index of the lignin in the sample. Clark's modification of the Vieboch and Schwappach method for methoxyl was used for the samples in question. The results obtained are recorded in Table III. The ratio of the percentage of methoxyl in the sulfuric acid residue to percentage of lignin in this residue gives the percentage of methoxyl in lignin, i.e. the methoxyl in the ligneous residue from Lake Mendota mud was 0.26 per cent and the percentage of lignin in the residue was 10.89 per cent; hence, $0.26/10.89 \times 100 = 2.39$ per cent or the methoxyl in lignin for this particular sample. The assumption is made in these calculations that all of the methoxyl in the sulfuric acid ligneous residue is due to lignin; that the crude protein left in the lignin fraction contributes no methoxyl. In examining the percentages of methoxyl in lignin and comparing these values to those reported in the literature note that wood lignin is reported to contain 17 per cent to 26 per cent methoxyl while some straws are reported to contain lignin with as little as 5 per cent methoxyl. In the lignin recovered from lake muds the percentage of methoxyl in lignin was considerably less than 5 per cent. The original wood examined by Sherrard and Harris contained 5.3 per cent methoxyl while isolated lignin contained 82.4 per cent of this. An examination of the data in Table III shows that no such recovery was experienced in the investigation of sub-aquatic types. Not only was there little regularity in the ratio of the methoxyl in lignin to that in the original sample for the bottom muds; there was also considerable variation in the methoxyl content of the lignin recovered from the bottom muds. The methoxyl due to lignin constitutes only one third to two thirds of the total methoxyl in the muds from Wisconsin lakes. In Lake O'Mallley (Alaskan) mud, in which the decomposition of proteins, carbohydrates, fats and other organic types is presumably slower than in the warmer Wisconsin lakes, the lignin portion of the organic part of the sample is smaller and the proportion of methoxyl due to lignin is correspondingly smaller. Only 0.04 per cent of the Lake O'Malley mud was methoxyl due to lignin and this was only 0.15 of the total methoxyl in the mud. The results for the net and nannoplankton show slightly greater uniformity than do those for the lake muds. For the net plankton 7 to 11 per cent of the total methoxyl was in the ligneous residue. However, the corrected lignin content for the same samples was 8 to 14 per cent. In the case of the three nannoplankton samples the methoxyl in the ligneous fraction was 6 to 12 per cent of the total in the sample.

An examination of the column, per cent CH_3O in corrected lignin, reveals that the lignin recovered by the acid process described contained a comparatively small amount of CH_3O. The question arises, is this small methoxyl content due to a too drastic treatment or is it due to the nature of the samples? Although the recovery of methoxyl is not high, i.e., the CH_3O found in the ligneous residue compared to total CH_3O in the original sample is low (column 7), it must also be noted that the CH_3O in the original sample is unusually low.

CONCLUSIONS

If one may assume that the sulfuric acid method for the isolation of lignin from sawdust may be applied with a reasonable degree of success to samples of lake muds and miscellaneous lake types, the data in this report give a fair approximation of the relative amounts of lignin in lake muds, net and nannoplankton, and a few additional lacustrine types. Of more importance, data are given to show what portion of the total organic matter of the samples is ligneous material. For lake muds 30 to 48 per cent of the total organic matter is lignin, for net plankton 18 per cent of the organic matter is lignin, and for the nannoplankton 10 to 20 per cent of the organic matter is lignin. This information is of interest to the limnologist since the ligneous fraction represents material which is not readily available for plant and animal food.

Regarding the ligneous fraction isolated, it is of some significance that the percentage of carbon in the corrected lignin (column 8, Table I) for samples which have undergone the least decomposition approach the high value of 64 per cent, i.e., the carbon content of lignin from lake muds is low for the lake muds and relatively high for the net and nannoplankton and special samples. In considering the low methoxyl content of the lignin from the lake muds, one may explain this in part by the histories of the various samples. Particularly for the bottom muds, the organic matter has been exposed to extreme chemical conditions. If the lignin undergoes gradual decomposition, the most labile functional groups might reasonably be expected to be attacked first; hence, a slow hydrolysis or other change may have caused the alteration in the nature of lignin which has remained for years on the lake bottom.

From the relatively small number of samples examined it does not seem likely that the methoxyl content of the samples is any index of the amount of lignin present. As previously noted, this may be due to the method of isolating the lignin or to the previous history of the samples.

The above material is presented as a preliminary report. It does not seem that conclusive results can be obtained until a greater variety of samples is examined and a more satisfactory technique perfected.

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PROCEEDINGS OF THE ACADEMY

SIXTY-THIRD ANNUAL MEETING

The sixty-third annual meeting of the Wisconsin Academy of Sciences, Arts and Letters was held in joint session with the Wisconsin Archeological Society and the Midwest Museums Conference, at the University of Wisconsin, April 7 and 8, 1933. The following program of papers, special lectures and demonstrations was presented:

Friday morning, Section A.—Duane H. Kipp, Systematizing Wisconsin place names; Albert O. Barton, The ransom of the Hall sisters; F. W. Harris, The queriosites of coins; Joseph Schafer, The Stockbridge Indians; Herman Kerst, Postage stamp printing; Louise P. Kellogg, A Wisconsin Indian agent, Nicolas Boilvin; Kermit Freckman, Pleasant Lake Indian mounds; Vivian Morgan, Old time "memory wreaths"; Harold A. Engle, The "On Wisconsin" broadcasts; Donald Newton, An adult hobby show.

Friday morning, Section B.—V. C. Finch, Characteristics of occupance on the Mississippi delta fringe; E. F. Bean and A. R. Ostrander, Hamilton Mounds quartzite in Adams County; Joseph Wanenmacher, W. H. Twenhofel and Gilbert O. Raasch, Some new facts on the palaeozoic rocks of the Baraboo region; Glenn T. Trewartha, Sequent occupance on the Prairie du Chien terrace: a study in historical geography; Eric R. Miller, Fluctuations of rainfall in Wisconsin, 1836-1932; L. R. Wilson, Historical and climatic correlation of a Madison white oak log; O. A. Mortensen, The cerebrospinal fluid and the cervical lymph nodes; H. W. Mossman, Implantation, fetal membranes and placentation in the squirrels (Sciuridae); L. H. Rubnitz and A. M. Katz, Changes in the testes and accessory glands of the gray and fox squirrels during their seasonal reproductive cycle; R. C. Mullenix, Neuro-histological preparations: organ of corti of monkey, retina of monkey, purkinje cells with pericellular baskets, etc.; W. E. Tottingham and R. Nagy, Chemical changes associated with discoloration of cooked potatoes.

Friday afternoon, Section A.—Theo. T. Brown, A fish-head effigy pipe; Marguerite F. Stiles, Engraved catlinite tablets; John J. Knudsen, An Indian flint implements file; Alice I. Vinje, Norwegian childhood tales; E. Ralph Guentzel, Large native copper knives; Chas. L Emerson, Lieut. James Gorrell, diplomat and strategist; W. F. Bauchle, The mound-builders; Charles E. Brown, Two Wisconsin animal pipes; Gilbert O. Raasch and Fred Wilhelm, A new and inexpensive type of museum display; Wm. W. Bartlett, The Cornell University lands in the Chippewa valley; Lindley V. Sprague, Medicine among the North American Indians.

Friday afternoon, Section B.—Margaret B. Siler, Development of spore walls in *Sphaerocarpos*; Frank H. Smith, Chromosome associations in *Brodiaea*; Fred W. Tinney, Structure and behavior of chromosomes in *Sphaerocarpos*; Jeanette Jones, Ordovician starfishes of Wisconsin; Norman Schmeichel, Sex differentiation in the lined snake, *Tropidoclonion* *lineatum* (Hallowell); Olga A. Smith, The effect of salt on *Bacillus megatherium*; A. H. Maslow, Psychoanalysis and mental hygiene as social philosophies; Alfred Senn, The literary German language and its relation to the German dialects; Ernest Voss, German Bible translations originating in the territory of the Order of the German Knights about the middle of the fourteenth century (by title).

Special lecture on Friday. M. E. Diemer, Wisconsin wild flower photography.

Saturday morning, Section A.—Edgar P. Doudna, The banking problem and the constitution of Wisconsin; Lewis Severson, The gold standard; Edward Bennett, A plan for the restoration of employment.

Saturday morning, Section B.—N. C. Fassett, One day's botanizing near Madison; H. A. Schomer, Photosynthesis of algae at various depths in the lakes of northeastern Wisconsin; L. R. Wilson, Lake development and its effect on the quantity and quality of aquatic plant life; John Steenis, Planting of walleyed pike in northern Wisconsin lakes; Edward Schneberger, Age and growth of gamefish in Wisconsin waters; S. X Gross, Studies on the parasites of northern Wisconsin fish.

Special lectures on Saturday. J. H. Mathews, Scientific methods of crime detection; R. G. Mullenix, Evolution and progress.

The annual business meeting of the Academy was held immediately following the general session, April 8. The secretary presented the following report on membership as of April 7, 1933: honorary members, 3; life members, 12; corresponding members, 16; active members, 307; total, 339. Membership losses during the year: deceased, 5; resigned, 28; dropped for non-payment of dues, 24; dropped for loss of address, 3. Applications for membership from forty-two individuals being presented, the secretary was unanimously instructed to cast the ballot of the Academy in their favor. The list follows: Lawrence J. Berner, West DePere; Paul Carroll, Milwaukee; Francis H. Clabots, West DePere; George Claridge, West DePere; Hilary J. Deason, Ann Arbor, Mich.; L. A. Dobbelsteen, Luxemburg; Sears P. Doolittle, Washington, D. C.; A. A. Drescher, Fennimore; F. J. B. Duchateau, Green Bay; Wm. R. Duden, Ann Arbor, Mich.; Paul L. Errington, Ames, Ia.; L. H. Halverson, Marquette, Mich.; Hance F. Haney, Madison; Carl Hoffman, Appleton; V. K. Kapingen, Milwaukee; Cornelius J. Kirkfleet, Somonauk, Ill.; T M. Langley, Superior; Jos. B. Layde, West DePere; Harold LeMahieu, West Allis; Jos. McCaffrey, West DePere; David J. Mack, Madison; S. L. Mains, Milwaukee; Sister M. Cassiana Marie, Green Bay; Jos. A. Marx, Green Bay; H. J. Mellum, Kenosha; Mrs. A. C. Neville, Green Bay; Peter P. Pritzl, West DePere; Paul P. Rhode, Green Bay; R. K. Richardson, Beloit; Gregory R. Rybrook, West DePere; W. B. Sarles, Madison; Paul L. Savageau, West DePere; J. P. Schumacher, Green Bay; Lewis E. Severson, Beloit; Olga A. Smith, Appleton; Mary E. Storer, Beloit; H. L. Traeger, West DePere; M. J. Vanden Elsen, Brussels; R. P. Wagner, West De Pere; E. J. Westenburger, Green Bay; P. W. Wilson, Madison; M. J. Windt, West DePere. The nominating committee, consisting of E. B.

Skinner, Arthur Beatty and E. M. Gilbert, reported nominations for the various offices, and on motion the nominees were unanimously elected for a term of three years: *President,* Rufus M. Bagg, Appleton; *Vice-President in the Sciences,* Storrs B. Barrett, Williams Bay; *Vice-President in the Arts,* A. M. Keefe, West DePere; *Vice-President in Letters,* A. R. Hohlfeld, Madison; *Secretary-Treasurer,* H. A. Schuette, Madison; *Librarian,* Walter M. Smith; *Curator,* Charles E. Brown, Madison. The treasurer's report, as of March 31, 1933, was presented as follows:

Receipts

Balance in State Treasury, March 31, 1932	$1478.39
State appropriation for 1932-33	1000.00
Dues received from members	526.00
Wis. Geol. & Nat. Hist. Survey for printing	230.00
Annual allowance from A. A. A. S.	100.00
Endowment fund income	116.43
University of Wisconsin for printing	60.00
Academy publications sold	40.45
Reprints sold to authors	42.85
Miscellaneous	1.52
Total	$3595.64

Disbursements

Printing of Vol. 27 of *Transactions*	$1426.54
Etchings and half-tones	104.05
Reprints for Vol. 27 of *Transactions*	373.66
Other printing (programs, announcements, etc.)	31.39
Secretary's salary for the year	200.00
Postage	45.00
Express	15.81
Total disbursements	$2196.45
Balance on deposit, March 31, 1934	1399.19
Total	$3595.64

Endowment Fund

Trust agreement, Central Wis. Trust Co.	$1000.00
City of Madison bond	500.00
Rock County Highway bond	500.00
Chapman Block bonds	400.00
Commonwealth Telephone Company bonds	400.00
Wisconsin Power and Light Company bonds	200.00
Capitol Square Realty Company bonds	200.00
Certificates of deposit	48.50
Cash on hand	12.16
Total	$3260.66

The auditing committee, consisting of Arthur N. Bragg and N. C. Fassett, reported that it had examined the accounts of the treasurer and had found them correct.

The annual dinner was held at the University Club on Friday evening with approximately fifty people in attendance. After the dinner Prof. Charles E. Allen, retiring president of the Academy, presented an address entitled "The Course and Significance of Sexual Differentiation".

The following members of the Academy died during the past year:

W. B. Cairns, Aug. 2, 1932.

Carl Russell Fish, July 10, 1932.

C. Dwight Marsh, April 23, 1932.

Dana C. Munro, Jan. 13, 1933.

Huron H. Smith, Feb. 25, 1933.

LOWELL E. NOLAND
Secretary-Treasurer

SIXTY-FOURTH ANNUAL MEETING

The sixty-fourth annual meeting of the Wisconsin Academy of Sciences, Arts and Letters was held, in joint session with the Wisconsin Archeological Society and Midwest Museums Conference, at Lawrence College, Appleton, April 6 and 7, 1934. The meeting was formally opened by an address of welcome by Dr. Henry M. Wriston, president of Lawrence College, after which the following program of forty-two papers and lectures was presented:

Friday morning, Section A.—H. R. Holand, Mogachutes, a village of the Stone Age; C. E. Brown, A large stone adze; W. A. Titus, Early Wisconsin tribes; Louise P. Kellogg, The Winnebago visit to Washington in 1828.

Friday morning, Section B.—L. F. Graber, The white grub menace in Wisconsin; L. F. Graber, Leaf-hopper (*Empoasca fabae*) populations as related to cutting treatments of alfalfa; H. A. Schuette, A medieval honey law.

Friday morning, general session.—Aldo Leopold, Wild life research in Wisconsin.

Friday afternoon, Section A.—H. R. Holand, Michingan, the haven of refuge; L. S. Buttles, The destruction of mounds in certain southern states; John B. MacHarg, Stereoptican and bulletin board in museum work; Wm. F. Raney, The Grignon family; Geo. Overton, Indian cooking stones; J. O. Frank, Superstitions of the Fox River valley; Nile J. Behncke, Two Indian legends; C. H. Hocking, Ridgeway ghost tales; Gene Sturtevant, The dream dance of Keshena; Lorraine C. Brown, Mounds of the University of Wisconsin arboretum; A. L. Kastner, Recent contribution to the origin and history of siphilis.

Friday afternoon, Section B.—Louis Kahlenberg, Neal Johnson and A. W. Downes, On the activation of gases by metals; Eric R. Miller, Dustfall of November 12, 1933, in Southern Wisconsin; G. W. Woolley, (introduced by L. J. Cole), Early introduction of cattle into Wisconsin (before 1800); N. C. Fassett, Niagara limestone and its flora; L. E. Casida (introduced by L. J. Cole), Endocrine stimulation of ovarian development in farm animals; J. P. von Grueningen, Goethe in American periodicals 1860-1900; Arthur H. Weston (introduced by R. M. Bagg), The date of Christmas; V. W. Meloche, The polarograph, a new tool in analytical chemistry; Ernest Voss, Goethe monuments in America (by title).

Saturday morning, Section A.—A. H. Griffith, Abraham Lincoln; Susan B. Davis, The Wisconsin tercentennary celebration; Francis S. Dayton, Indian fishing camps of the Wolf River; H. E. Mansfield, Drama and the folk spirit of Wisconsin; R. N. Buckstaff, Meteorological display for museum purposes.

Saturday morning, Section B.—B. W. Roland (introduced by J. H. Mathews), The application of colloid chemistry to industrial problems; H. F. Lewis, The chemical behavior of the various components of wood fiber; Loyal Durand, Jr., (introduced by V. C. Finch), The geographic regions of Wisconsin; K. Bertrand (introduced by V. C. Finch), A regional interpretation of woodland and forest land of Wisconsin; J. Riley Staats, The geography of the central sand plain of Wisconsin; L. P. Coonen (introduced by A. M. Keefe), Seasonal variations in *Sargassum filipendula*; J. C. McCaffrey (introduced by A. M. Keefe), Some observations on the true use of antiseptics; J. J. Davis, Notes on parasitic fungi in Wisconsin. XX. (by title).

The Saturday morning sessions were preceded by a tour of inspection of the buildings of the Institute of Paper Chemistry.

The annual business meeting of the Academy was held Friday, April 6, at 4:30 P.M. The secretary presented the following report on membership: honorary members, 3; life members, 12; corresponding members, 14; active members, 353; total, 382. Membership losses during the year: deceased, 2; resigned, 7; dropped for non-payment of dues, 20. Applications for membership from eighteen individuals being presented, the secretary was unanimously instructed to cast the ballot of the Academy in their favor. The list of newly elected members, which includes four elected on Nov. 18, 1933, by council action, follows: Donald Cameron, Racine; Orville Carey, Appleton; Ethel Carter, Appleton; George H. Conant, Ripon; Milford A. Cowley, La Crosse; John T. Curtis, Waukesha; John P. von Grueningen, Madison; Norris F. Hall, Madison; Erma N. Henry, Appleton; Loren C. Hurd, Madison; M. R. Irwin, Madison; Hilda C. Jorgensen, Appleton; Clement D. Ketchum, Appleton; Aldo Leopold, Madison; Harry F. Lewis, Appleton; Ralph S. Nanz, Waukesha; Wm. F. Raney, Appleton; E. Margaret Ritchie, Appleton; Isabel Schilling, Green Bay; George F. Sieker, Madison; J. Riley Staats, Madison; John Voss, Peoria. The status of both George C. Comstock, Beloit, and John R. Commons, Madison, was changed from that of active to corresponding members. Committee appointments were announced as follows: *Publication,* the president and the secretary, ex officio, Arthur Beatty, Madison; *Library,* the librarian, ex officio, A. W. Schorger, Madison, Mrs. A. C. Neville, Green Bay, W. S. Marshall, Madison, A. L Barker, Ripon; *Membership,* the secretary, ex officio, R. C. Mullenix, Appleton, J. O. Carbys, Milwaukee, P. W. Boutwell, Beloit, G. W. Keitt, Madison.

The secretary-treasurer reported informally on the present condition of the Academy's finances and suggested, inasmuch as a final appeal for a printing subsidy from the State had not yet been acted upon, that a formal report be made at a later date. V. W. Meloche and L. E. Noland were appointed to audit the treasurer's books. The question of the place of meeting for next year was left to the Council for decision. A vote of thanks was tendered the authorities of Lawrence College for placing the facilities of the College at the disposal of the Academy.

RECEIPTS

Balance of receipts from State Treasurer	$ 308.31
Dues received from members	557.64
Annual allowance from A. A. A. S.	94.50
Academy publications sold	61.20
Reprints sold to authors	65.15
Interest on investments	222.59
Wisconsin Archeological Society	3.05
Certificates of deposit	89.66
Securities matured	1500.00
Total	$2902.10

DISBURSEMENTS

Secretary's allowance for the year	$200.00
Expenses of Appleton meeting	33.40
Miscellaneous expenses	25.28
Printing of programs, etc.	33.25
Securities purchased	1545.00
Total	$1836.93
Balance in treasury	1065.17

ENDOWMENT FUND

Home Owners Loan Corporation bonds	$1050.00
Rock County Highway bond	500.00
U. S. Treasury bond	500.00
Commonwealth Telephone Company bonds	400.00
Chapman Block bonds (in default)	400.00
Wisconsin Power and Light Company bonds	200.00
Capitol Square Realty Company bonds	200.00
Cash	259.87
Total	$3509.87

July 31, 1934.

The annual dinner was held in Ormsby Hall with seventy-five in attendance. President Bagg spoke informally on the history of the Academy. Following this the assembled guests adjourned to Lawrence Memorial Chapel to listen to a public lecture by Prof. Laurence M. Gould of Carleton College on the subject "Adventures in Antarctic Geology".

The following deaths were reported:

Frank P. Hixon, Oct. 24, 1931.

A. R. Braun, June 21, 1933.

H. A. SCHUETTE
Secretary-Treasurer