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CONTENTS

THE GEOGRAPHY OF THE UPPER ROCK RIVER VALLEY: A STUDY IN CHOROGRAPHY

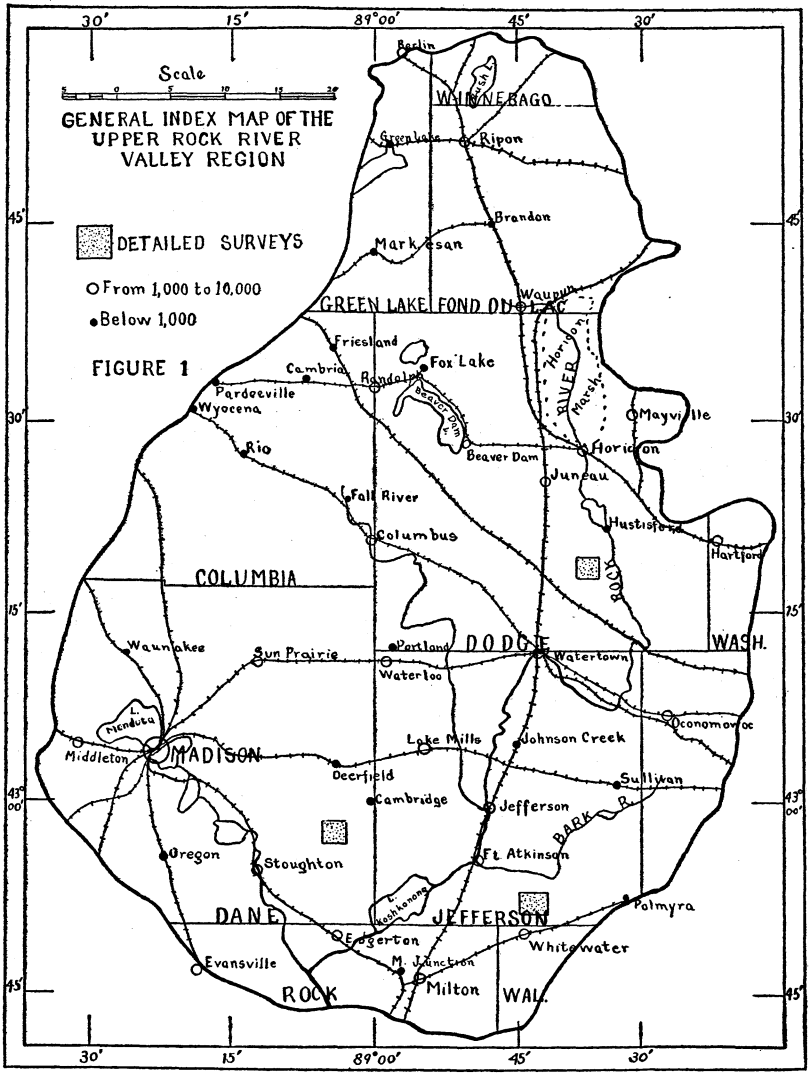
H. O. LATHROP

INTRODUCTION

The Upper Rock River Valley is a region of middle-latitude mixed farming, diversified dairy production, and a multiform small-scale industrial life imposed upon a variety of glacial topographic features left by the late Wisconsin ice sheet. The landscape varies considerably in detail, but there are broad, unifying elements which give it homogeneity and differentiate it from the adjacent regions. The Region under discussion includes part of the area drained by the Rock River and its tributaries, extending south almost to Janesville, and small marginal areas on the west and north lying outside the Rock River drainage system (Fig. 1). The greatest north-south extent of the Region from Janesville to Berlin is approximately 85 miles, and the maximum east-west extent along a line from Middleton to Delafield is about 60 miles, giving an area of about 3500 square miles. The western limits are marked by a transition to rougher land, while to the northwest the Region merges into a sandy country having a less uniform surface with large areas of marshland. To the east and southeast the Niagara Escarpment and the interlobate Kettle Moraine, with its northward extension, mark the beginning of a region of decidedly stronger relief. The southern extent of the Region is delimited by the outer margin of the terminal moraine of the Green Bay Glacier, beyond which the flattish-to-gently-rolling country is in marked contrast to the region to the north, and partakes strikingly of corn belt characteristics.

In this Region the unifying elements of the natural and cultural landscapes serve to set it apart from the adjacent regions. Marginal areas are generally sufficiently different in character so that boundaries can be drawn with considerable accuracy. However, geographic unconformities are the exception rather than the rule and, for the most part, narrow zones transitional in character, mark the limits of the Region.

The broad unifying characteristics of the Region vary sufficiently in detail to make it desirable to divide it into several sub-regions. It is areally differentiated chiefly by man's cultural



GENERAL INDEX MAP OF THE UPPER ROCK RIVER VALLEY REGION

FIGURE 1

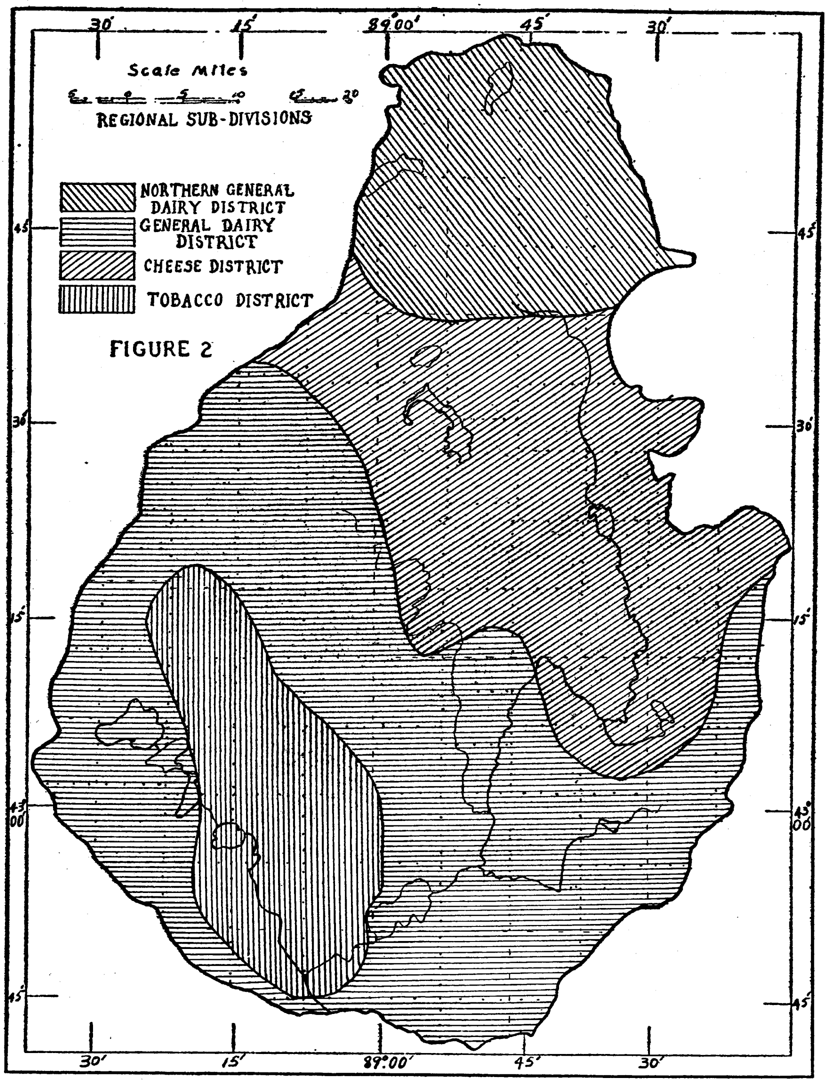
imprint in the various parts. In Dodge County and the margins of adjacent counties, the cheese industry is a conspicuous development which distinguishes this section from the surrounding areas (Fig. 11). A narrow peninsula of the cheese district extends in a westerly direction from the northwest corner of Dodge County to the margin of the Region. In the southwestern part the tobacco industry is areally concentrated in such a fashion as to give a small area individual characteristics and to set it apart (Fig. 5). Lying between these two and extending around the cheese section on two sides is a general dairy district where the milk is marketed at condenseries, creameries, cheese factories, and city markets. Lying to the north of the cheese area and extending to the limits of the Region is a second area where general dairying prevails. Hence, the following agricultural sub-regions may be designated.

I. The Cheese District
II. The Tobacco District
III. The General Dairy District
IV. The Northern General Dairy District

THE CHEESE DISTRICT

The cheese industry of the Region is centered in a striking way in Dodge County (Figs. 1 and 11). The northern boundary of the county is almost coextensive with the limits of the Cheese District in that direction. To the west the shading off of the cheese industry occupies approximately one third of Columbia County, and the southwestern corner of Green Lake County, where the narrow belt referred to above reaches entirely across to the western boundary of the Region. The thinning margins of the industry also extend into the northern border of Dane County, the northeast corner of Jefferson, and the northwest corner of Waukesha counties. In nearly all of these marginal areas cheese making occupies a distinctly secondary position as compared with other dairy interests, and indicates the decreasing importance of the industry outward from Dodge County (Fig. 11). On the south these border areas also represent the retreating margin of cheese production. To the east and northeast thru Washington County the cheese industry joins with the lake-shore cheese area, but the connecting zone shows a relatively lighter cheese production than the centers to the east and west.[1]

[1] Bulletin 90, Wisconsin Department of Agriculture, Madison, Wisconsin, 1928, p. 75.



Types of Relief and their Utilization

Drumlins

Most of the Cheese District has the strongest relief of any part of the Region. The drumlins cover a greater percentage of the surface and are higher than elsewhere, and the individual drumlins have a larger areal extent. They also exert a stronger influence upon man's utilization of the Region than in other parts. The long north-south or northeast-southwest axes are roughly parallel, and the drumlins are located *en echelon* so that transportation across or around them is difficult. In some cases the bases of the adjacent drumlins are almost contiguous, but the higher ones are usually from one to four miles apart with lower drumlin-like ridges, rolling lands of gentle relief, or marshlands lying between. The profound influence of the drumlins upon man's utilization of the Region is evident everywhere. Most of the higher ones have slopes running up to 15 degrees; 5.8 per cent of the area surveyed falls into the classification of "steep" slopes which, by the technique of the survey, runs from 10 to 15 degrees inclusive.[2] The lower gentle slopes are used for all types of agriculture, but the intermediate slopes and summits are generally wooded. The timber is composed of mixed hardwoods of the oak-hickory association. In many cases the smaller timber has been taken out and the underbrush cropped and killed by pasturing so that the woodlands present an open appearance which permits the growth of bluegrass or a mixture of similar grasses, thus providing good permanent pastures. However, in some cases rather heavy stands of timber prevail and the land is little used for pasture because the density of tree growth prevents the development of grasses upon the forest floor.

The production of good agricultural crops upon the steeper slopes and summits of some of the drumlins indicates that the present utilization of such lands is temporary. It is not clear that steepness of slope or sterility or rockiness of soil prohibits agriculture in most cases. The drumlins are composed of a mixture of unconsolidated glacial clays, sands, and gravels, with some boulders intermixed. Such soil texture permits the absorption of large quantities of water so that erosion and soil wash are not serious problems, even upon slopes of 10 to 15 degrees. Due, however, to soil texture and excellent drainage many of such lands are inclined to be droughty in dry spells in summer.

[2] Detailed field surveys were made of three typical areas shown on Figure 1. These surveys covered a total of 13 square miles. Details such as crops, soil, topography, slope, and drainage were observed and mapped. The data thus collected were assembled and totaled and reduced to percentages. These percentages are considered as typical of the areas in which the survey was made and are referred to frequently thruout the paper.

Inter-Drumlin Areas

The land between the higher drumlins consists chiefly of two topographical types, gently-rolling, ridge-like ground moraine and low-lying, flattish lands, some of which are marshy. The former are the best agricultural lands in the Cheese District and comprise about half of the total area. They are well drained and their gently-rolling configuration is almost ideal for plow agriculture. The light-brown loamy soils are fertile and produce abundantly. Originally they were all covered with timber, but there is practically none remaining on such lands because of their high value for agriculture. The glacial influence is again in evidence in the general north-south trend of the low inter-drumlin ridges. Many of them are too low and their configuration is not sufficiently distinct to class them with the other higher and well-formed drumlins, altho they undoubtedly belong to the same class of glacial deposits and have a similar origin.[3] They furnish good locations for many of the roads which in some instances follow the crest of such elevations for miles. As a consequence the highway pattern has a distinctly northeast-southwest to north-south orientation. Because of their good drainage, gentle gradients, and accessibility to roads, these ridges furnish ideal sites for farmsteads and many of the farm homes are located upon them.

The low-lying, flattish, inter-drumlin tracts range all the way from well drained to poorly drained farm lands, thru marsh hay, permanent wet pasture and peat bog, to marshlands covered with cat-tails, coarse grasses, and tamarack and willow thickets. Many of these areas are the beds of former glacial lakes, the well known Horicon Marsh, containing about 60 square miles, being the largest. Considerable areas have been drained by open ditches or tile. The water table is so high that deep ditches of large capacity are necessary to be effective. Where these lands are well drained they make splendid farm lands, the soil survey classifying most of them as various members of the Clyde series. These are black soils, high in humus content, and contain sufficient quantities of silt so that they are fairly easy to work. Their high fertility makes them especially desirable for corn, but their low-lying situation makes them susceptible to unseasonable frosts. It is impossible to drain

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[3] W. C. Alden and his co-workers in the Quarternary Geology of Southeastern Wisconsin classify the low ridges as drumlins.

some areas because the intervening lands separating them from streams is so high as to prohibit the construction of proper drainage ditches.

Large areas of the wet lands are cut for wild or marsh hay. In Dodge County, in 1926 and 1927, the 16,000 acres cut for marsh hay was approximately one and a half times that of alfalfa, and the yield per acre was more than two thirds as great.[4] The acreage of wild hay is about one fourth as great as that of all tame hays with one sixth as large a total yield. Such hay, however, lacks the high nutritious quality of tame hay. The marsh hay lands occupy a little less than three per cent of the total area of the county. After the hay is cut these lands furnish excellent late-summer and fall pastures. They, together with the adjacent permanent wet pastures many of which are too wet even for the cutting of hay in midsummer, occupy an important position in the economy of farm practice. As the late summer rains decrease in frequency and intensity the upland pastures often become short, and in times of extreme drought are entirely inadequate to furnish pasture for the large numbers of livestock. At such times the wet pastures are at their best because the ground water is sufficiently high, even during the most severe droughts, to furnish the grasses with an adequate supply of water.

The Non-Drumlin Area

The part of the Cheese District lying southwest from Waupun about Beaver Dam and to the west and north is outside the drumlin country. In this section the relief is gently rolling; marshlands are smaller in area; there is less timber; and the land, much of which was formerly prairie, is almost ideally situated for agriculture. These differences in the natural environment have a number of consequent responses in man's utilization of the land. A higher percentage of the area is cropped; marsh hay and permanent woodland and wet pasture are almost absent; the roads and fields assume a truly rectangular pattern; and the linear northeast-southwest arrangement of farmsteads gives way to a miscellaneous pattern, influenced by promiscuous elevations in the ground moraine and the road layout.

[4] Bulletin No. 90, Wisconsin Department of Agriculture, 1928, pp. 37-42.

Crop Distribution in Relation to the Natural Environment

The crops produced in the Cheese District are similar to those grown in the remainder of the Region and are typical of dairy

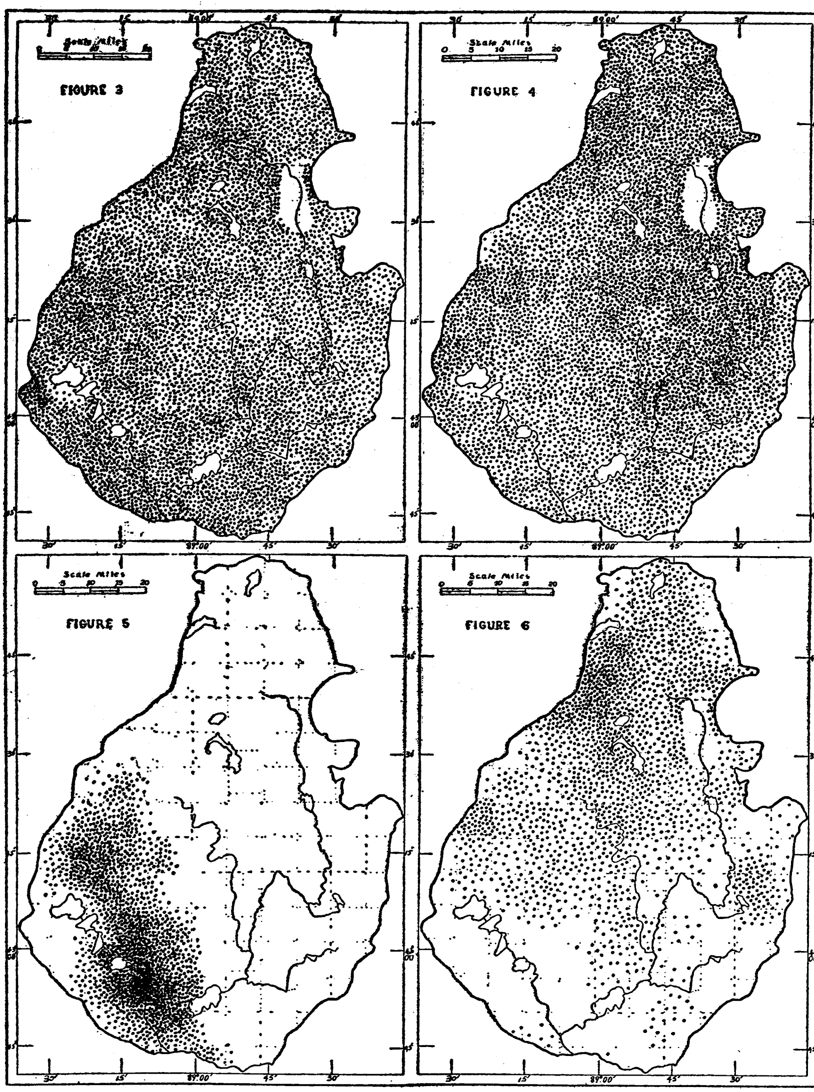

FIG. 3. Corn acreage. One dot equals 50 acres.
FIG. 4. Oat acreage. One dot equals 50 acres.
FIG. 5. Tobacco acreage. One dot equals 10 acres.
FIG. 6. Canning peas acreage. One dot equals 20 acres.

countries in middle latitudes. The grains claim first place and occupy 71 per cent of the area of cropped lands in Dodge County[5] (Figs. 3 and 4). Hay and rotation pasture cover 24 per cent of the cropped area, thus attesting the importance of the dairy industry. The remaining five per cent of cropped lands is given over largely to cash crops, peas for canning being the chief one (Fig. 6). Cash crops are not highly significant because the farmer depends upon the milk check for his cash income. Crops furnish but 13 per cent of the farmer's income compared with 87 per cent from livestock and animal products.[6] Very little hay or grain is sold from the farms. Practically all of it is converted into the various kinds of animal feeds, and in poor crop years the farmer is compelled to buy from outside sources to supplement his own production. However, large purchases over long periods are rare because the dairymen tends to adjust the size of his dairy herd to the food producing capacity of his farm.

Animal Products

The animal population in the Cheese District is large, averaging more than two animal units per acre for the total area of Dodge County, which may be taken as typical of the entire District. The relative importance of the leading animals in 1929 is shown in the following table:[7]

TABLE I

Animals	Number of animals	Number of animal units	Per cent of total
All cattle	91,900	91,900	77.0
Dairy	66,971		
Other	24,929		
Horses, mules, etc.	15,500	15,500	12.0
Swine	50,300	10,060	8.0
Sheep	6,200	885	.7

From the foregoing table the predominance of cattle and cattle products is apparent at once. Milk furnishes more than half of the gross income, to which may be added the returns

[5] Bulletin 90, Wisconsin Department of Agriculture, 1928, p. 15.
[6] Supplement No. 1 to Bulletin 90, Wisconsin Department of Agriculture, 1929, p. 21.
[7] *Ibid*, pp. 16-18. (An animal unit equals one cow, one horse, seven sheep, or five swine.)

from cattle and calves sold off the farm. This gives a total of 64 per cent or almost two thirds of the gross farm income that is obtained from cattle and cattle products. Practically all the cattle in the Cheese District are Holstein. This breed is well

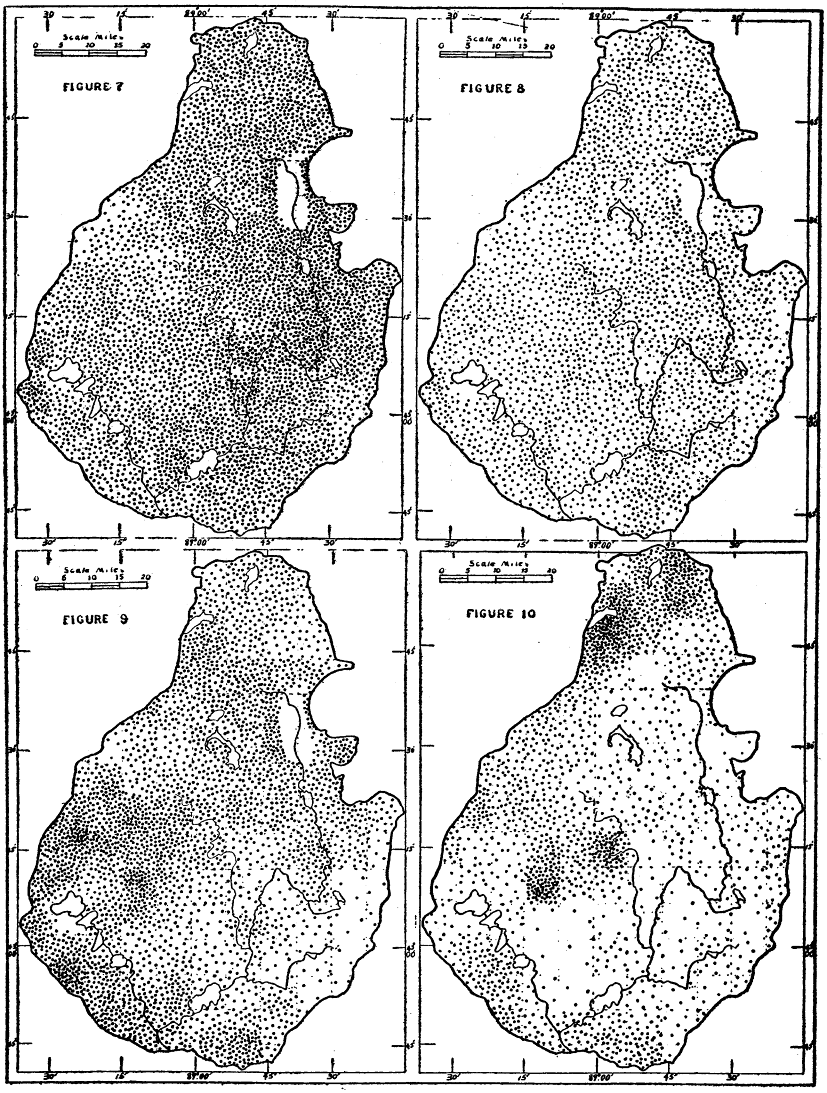

FIG. 7. Milk cows. One dot equals 40 animals.
FIG. 8. Other cattle. One dot equals 40 animals.
FIG. 9. Swine. One dot equals 20 animals.
FIG. 10. Sheep. One dot equals 20 animals.

adapted to the conditions of this District. They give large quantities of milk which is an important consideration in a country where most of the milk is marketed at cheese factories. Holsteins are large animals and heavy feeders which enables them to handle efficiently the bulky and watery grasses from the wet pastures which figure so prominently in the farm economy of the District.

Horses are used in large numbers thruout the District for farm work, altho tractors are also utilized for this purpose. Swine are found on practically every farm and are produced extensively as a by-product of the dairy industry, being fed largely upon skim milk from the creameries or whey from the cheese factories. Their number diminishes markedly in the section where milk is sold to condenseries (Figs. 9 and 13).

THE TOBACCO-DAIRY DISTRICT

DELIMITATION OF THE DISTRICT

The Tobacco-Dairy District is located in the southwestern part of the Rock River Valley Region and occupies portions of Dane and Rock counties. The most intensive cultivation of tobacco centers in the townships of Dunkirk, Pleasant Springs, Albion, and Christiana in Dane County, with a long narrow tongue of heavy production extending northwestward thru the townships of Cottage Grove, Burke, and Windsor (Fig. 5). From this center of heavy production the industry shades off in all directions but with unusual abruptness to the east and west.

In the District thus outlined, tobacco production and dairying are the first interests of the farming population and rural life centers largely about these two activities. In some areas, and with individual farmers over the entire District, tobacco is of prime consideration with dairying holding a secondary place, while in others the reverse is true. In general, the two interests appear to work well together as the number of dairy cows does not diminish appreciably in the Tobacco District. At certain times of the year tobacco makes a heavy demand for labor and attention on the part of the farmer. However, during the cultivating season this is partially met by sharemen and temporary hired help, often women and children. At the time of harvest most of the work in the tobacco fields must be done in the middle of the day when the dairy herd is out on pasture. Thus, it is seen that in many ways tobacco and dairying are supplementary and not competitors for the farmer's time and attention.

General Landscape Characteristics

The topography of the Tobacco District varies considerably in detail. The northeast half lies on the southwest margin of the short-drumlin area. Scattered drumlins of ovoid configuration with patches of timber covering the crests of some of the higher ones characterize the landscape. The long axes of the drumlins extend northeast-southwest, having a maximum length of about a mile, although most of them are less than a quarter of a mile long. The short axes are only a few hundred feet in length in most cases and the maximum elevation is about 100 feet above the surrounding country. However, the slopes break abruptly from the contiguous lands and present small areas of rougher topography. Steep slopes include but 1.4 per cent of the area. Most of the drumlins are farmed and the patches of timber on the summits are small. The soils of the drumlins are coarser than those of lands lying in proximity to them and are classified by the Soil Survey as fine sandy loams or gravelly sandy loams. Such soils are distinctly less productive than adjacent soil types and are especially droughty during dry spells in summer.

The widely separated drumlins occupy only a small percentage of the area and exert a minor influence upon the utilization of the land. The prevailing rolling type of topography is broken by poorly adjusted stream channels, along which are extensive marshlands and peat bogs which serve as permanent pastures. Of the area surveyed 9.2 per cent is used for this purpose. The marshlands gradually become smaller in extent toward the northwest and are almost absent at the northern limit of the Tobacco District. Much of the uplands was originally prairie, which probably occupied half of the total area of the Tobacco District. These are deep, fertile, black soils of high productivity and stand out among the lighter colored Miami soils, which cover most of the original timbered areas. The prairie soils are classified as Carrington loams, and their otherwise nearly level surface is broken by occasional drumlins which become lower and more scattered to the northwest, and are entirely absent in the northern extent of the District.

To the south and southeast the Tobacco District extends across the terminal moraine of the Green Bay Glacier. This area presents a rougher topographic aspect than other parts of the District. Small areas of timber remain on the steeper slopes of the ridges and hills which comprise the moraine. Most of the land is cleared, however, and some of the finer tobaccos are grown upon the well-selected slopes and soils of this type of topography. Edgerton, the chief tobacco market for the District, lies in the morainal lands. The northwest-southeast trending belt of low hills composing the moraine are from one to two miles in width, and their outer margin marks the southwestern limit of the Region. South of them the dominantly prairie lands of the Illinoian Drift present a contrasting type of landscape and mark the beginning of the corn belt type of topography. Tobacco is grown in decreasing quantities south of the moraine which indicates that the newer soils and varied topography to the north are probably factors favoring tobacco production.

Farm Crops in Relation to the Natural Environment

The usual crop association of middle-latitude grains and hays is found in the Tobacco District. In the area surveyed 84 per cent of the land was in crops. The percentage devoted to permanent pasture and timber is correspondingly low, as previously noted. Thus the Tobacco District has a high percentage of cultivated land and a relatively intensive cultivation. Practically all the area except the marshlands is in agricultural crops or rotation pasture.

Tobacco is the only special crop and is the one that gives distinguishing characteristics to the cultural landscape. Seed beds covered with cheese cloth in early spring, heavy manuring of the land in winter, thorough working and preparation of the soil, the unique planting implement with its tank of water for watering the transplanted seedlings, intensive cultivation thruout the summer, the heavy hand labor of suckering, topping, and cutting, and the final stringing of the heavy wilted plants on laths to be transported to the tobacco barn, all give distinction to the cultural landscape of this District. The rough tobacco barn planked up and down with unplaned unpainted boards adds a further distinctive feature. Tobacco requires the attention and interest of the farmer throughout the year and his activities and equipment distinguish the Tobacco District from the adjacent areas.

Most of the tobacco is of special quality and is produced for cigar binders. Thin tough leaves of uniform quality and color are demanded for this purpose, so that special attention is given to the choice of soil and topography, to the curing process, and to the variety of tobacco, in order that the product may enter the market at a high price for this special use. Slight differences in soil change the thickness, color, and flavor of the leaf. Ignorance or carelessness in curing and processing the crop after it is in the shed may mean a difference of ten cents a pound in final receipts. Thus, the tobacco industry requires much attention and forethought on the part of the grower and careful selection of soil and topography. "It can truly be said that tobacco culture is one of the fine arts of agriculture, and patience, perseverance and care are the three graces which lead to success."[8]

The long practice of tobacco culture in this District gives the necessary skill and the newly arrived Norwegian immigrant has supplied much of the unskilled labor. Tobacco culture was important before the Norwegian immigrants entered. As these people with large families and but little money came into the country there was a heavy demand for opportunity to work to secure a livelihood and to buy a farm. Tobacco offered the opportunity. They could become sharemen with the landowner who furnished the experience, land, and capital. As rapidly as possible they bought their own farms but continued to cultivate tobacco. They have been willing to do the heavy exacting labor required by tobacco culture for the large returns to be secured. The Norwegians have thus become the chief tobacco growers and have tended to perpetuate the industry wherever they have gone.[9]

Tobacco from this belt is shipped all over the United States for cigar binders. In order to facilitate marketing and to sta-

[8] Report, Commissioner of Labor Statistics of Wisconsin, 1883-1884, p. 222.

[9] Hibbard, B. H., *History of Agriculture in Dane County*. Bulletin No. 101, University of Wisconsin, Economics and Political Science Series, Vol. 1, No. 2, p. 172.

bilize prices, a pool of tobacco growers has been formed which claims to control about two-thirds of the acreage. Many large growers do not belong because they prefer to do their own dealing and sell when they desire, while others find it difficult to get sharemen who are willing to wait for the pool to sell the tobacco.

Edgerton is the chief marketing center for tobacco. The outstanding feature in the city is the group of tobacco warehouses. The tobacco is purchased by buyers and stored there awaiting shipment elsewhere. This little city is the Mecca for the buyers in this District. Tobacco and the tobacco market are the topics of conversation everywhere and the city's chief importance is due to this product. During the winter hundreds of laborers, chiefly women, are employed in the warehouses. Edgerton's leadership in the tobacco trade appears to be largely historical, as it is not so near the geographical center of the tobacco belt of today as Stoughton. In the early history of the industry it was near the center of the tobacco growing district and its importance has continued because of the momentum of its early start. Good hotel accomodations for the buyers existed, the warehouses were built there, and the marketing phase of the industry appears to be permanently established.

The grains are the largest group of crops in acreage in the Tobacco District. Corn ranks first as a crop and occupies almost 20 per cent of the cropped area, while oats is a close second with almost 17 per cent. These two crops are grown largely in rotation, and occupy the same lands over a period of years. They are grown almost wholly on the flat and rolling lands. Corn, in common with other cultivated crops, suffers at times because so much care and attention are required by the tobacco crop at the season when corn needs cultivation; if tobacco needs attention the other crops are often neglected. Neither corn nor oats is sold off the farms in any considerable quantity, but both are fed in the original form or ground with other grains into mixed dairy feeds.

Wheat and barley are grains of secondary importance in this belt, as elsewhere in the Rock River Valley Region. Together they occupy but 6 per cent of the cropped land, of which 5.4 per cent is devoted to barley, leaving to wheat a negligible percentage. This is an interesting transformation from 60 years ago when wheat occupied the rich prairie lands of this section almost to the exclusion of all other crops.[10] Both crops are fed upon the farms. Wheat, barley, and oats are sometimes intermixed in the same field, and given the rather colorful name of "succotash".

Hay and rotation pasture together occupy 44 per cent of the cropped land. If the area in permanent marsh and woodland pastures be added, a total of 47 per cent of the land is used for hay and the various types of pasture. This utilization of land reflects in a striking way the importance of the dairy industry in the District.

The Dairy Industry

The animal population in the Tobacco District is dense compared to most sections of Wisconsin or of the United States. It is not so high, however, as in the Cheese District, the attention to tobacco reducing the number of animals. A general indifference prevails toward animal products except those related to dairying. Other animals are produced temporarily or for convenience or work on the farm.

The three chief markets for milk in the Tobacco District are creamery, city market, and condensery, their relative importance being in the order named. Figures 12, 13, and 14 show where each use is dominant. Competition for milk is keen among the several markets. In the area surveyed, milk is sold to all three markets although a slight preference is shown the creamery.

The General Dairy District

Lying between the Cheese District and the Tobacco District, extending far around to the east and west of the former, and completely encompassing the latter, is a District devoted to general dairying without any specialty such as characterizes each of the two sub-regions already discussed. The area is lacking in any large urban infiuence, except for the section lying near Madison, altho numerous villages and towns are scattered over it.

The Short-Drumlin Area

Southeast of a line drawn from Columbus thru Sun Prairie to Madison, short drumlins are the dominant characteristic of

[10] Hibbard, B. H., *History of Dane County, op cit,* p. 121.

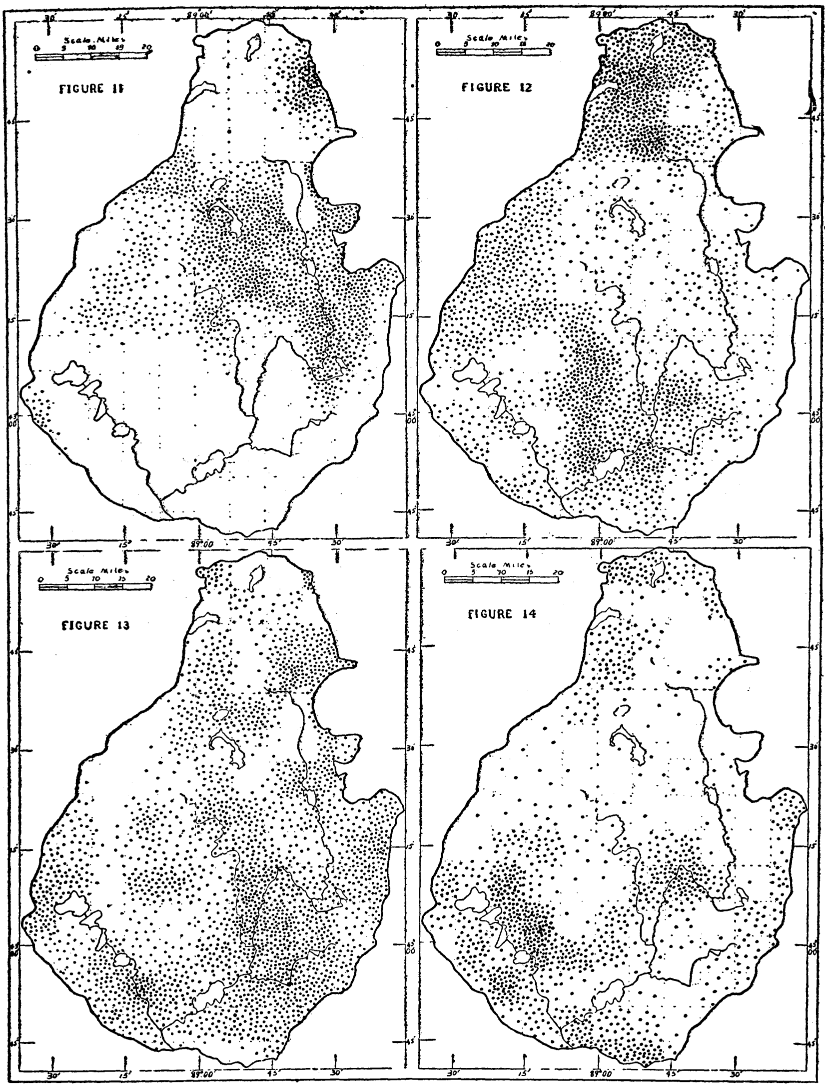

Fig. 11. Cheese. One dot equals 2 farms selling milk to cheese factories.
Fig. 12. Creameries. One dot equals 2 farms selling milk to creameries.
Fig. 13. Condenseries. One dot equals 2 farms selling milk to condenseries.
Fig. 14. City Market. One dot equals 2 farms selling milk to city markets.

the topography, while to the northwest of this line they are almost absent. Since uses of the land are influenced in many ways by this topographic difference, it seems wise to divide the General Dairy District into two divisions for general descriptive purposes, and it is convenient to refer to a similar division in the discussion of certain phases of human occupance. Hereafter, these two divisions will be referred to as the drumlin and the non-drumlin areas. The drumlins are short and are similar to those of the Tobacco District.[11]

Marshes

Drainage is even more poorly developed than in the long-drumlin country and large areas of marshlands and some poorly drained farm lands lie between the drumlins. Many of the lower areas merge into tamarack swamps surrounded by sedges, cat-tails, and other coarse marsh growth that have little value even for pasture.[12] Hence, there are considerable tracts of idle or waste lands in some parts of the District. Large areas are in permanent pasture and others are cut for marsh hay which plays a similar role in the system of farm economy as in the Cheese District.

The soil in most of the marshes is peaty. It has a depth of two to five feet in the smaller, and five to fifteen feet in the larger marshes.[13] The peat soils are widely distributed over the drumlin section and practically every township has some areas of such land. Small tracts have been drained and are now used for agricultural purposes. In general, such soils require considerable cultivation and attention after reclamation before they are highly productive for general agriculture. When properly conditioned, they produce good crops of corn, hay, and similar crops. Only a small percentage of such soils has been reclaimed and many of the others are so located as to make it physically impossible to drain them, while in others drainage is so expensive as to be prohibitive.

The Rolling Lands

Lying in intermediate locations between the flat lands and the scattered drumlins are large areas of rolling ground moraine, similar to such lands already described in the Cheese

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[11] Geib, W. F. and Others, *Soil Survey of Jefferson County,* U. S. Department of Agriculture, 1914, p. 56.

[12] Geib, W. F. and Others, *Soil Survey of Jefferson County,* U. S. Department of Agriculture, 1914, p. 56.

[13] *Ibid,* p. 56.

District. In the parts of the terminal moraine timber covers a large per cent of the area. The moraines are much rougher than the adjacent lands and consist of a miscellaneous collection of hills and valleys having a variety of soils and numerous small lakes scattered thru the depressions. The Lake Mills recessional moraine extending thru Lake Mills, Jefferson, and Hebron is a belt of hills roughly concentric with the terminal moraine and marks a tract of rougher land, extending transverse to the general trend of the drumlins. In this area the characteristic morainal features predominate.

THE NON-DRUMLIN AREA

The northwestern non-drumlin section consists of long stretches of upland having a gently undulating to rolling topography and black prairie soils. The prairie soils are interspersed with tracts of Miami soils which range all the way from silt loams thru the sandy loams and, near Wyocena, merge into the dominantly sandy soils, which mark the northwestern extent of the Rock River Valley Region.[14] The drumlins are absent from the surface profile in this section and much of the topography has an almost monotonous uniformity. The soil maps show the various phases of soil types trending northeast-southwest, corresponding to the movement of the ice.[15] The chief variations in the topography are the rounded rolling hills of the ground moraine and small valleys where shallow streams have cut their channels. Drainage is better developed than in the drumlin section but small tracts of marsh and peat are found along streams, in depressions which have not had time since the glacial period to become drained by natural processes, and in old glacial stream channels like the one extending from Cambria to Pardeeville.[16] However, the areas of marsh and wet lands are small compared to those of the drumlin area.

In some places near the western margin of the Region, ledges of sandstone protruding thru the mantle of glacial till show the character of the bed rock and indicate that the glacial debris is thinning as proximity to the western limit of glaciation is reached. The lowest land values in the Region are found along

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[14] Whitson, A. R., *General Soil Map of Wisconsin,*

[15] Gieb, W. J. and Others, *Soil Surveys of Dane and Columbia Counties,* U. S. Department of Agriculture, 1915 and 1913, Soil Maps.

[16] Gieb, W. J. and Others, *op cit,* Soil Map.

the northwestern margin where contact is made with the infertile sand soils lying to the northwest. The per acre value is only about 40 per cent as great as some of the better lands of the Region.

HUMAN OCCUPANCY

Human occupancy in the General Dairy District has many similarities to that of the Districts already discussed. Crop associations are similar but there is a somewhat greater diversity of crops and they are grown to a greater extent on the flatter lands. The following table shows the percentage of land devoted to the various crops in Jefferson County:[17]

TABLE II

Crop	Per cent of land occupied	Crop	Per cent of land occupied
Corn	30.0	Wheat	2.2
Oats	31.0	Peas	1.3
Tame Hay	23.2	Potatoes	1.0
Barley	3.8	Rye	.6

The general character of the crops, their use, and function are practically the same as in the Cheese and Tobacco Districts. Tame hay is supplemented by large quantities of marsh or wild hay. It has about one fourth the area of tame hay and is used extensively for winter feed.

The following table shows the chief sources of farm income in Jefferson County for 1927, which is typical of the District.[18]

TABLE III

Source of income	Per cent of income	Source of income	Per cent of income
Milk	55	Hay	1
Cattle & Calves	14	Potatoes	1
Hogs	13	Peas	1
Poultry & Eggs	11	Clover Seed	1
Grains	2	Other	1

The outstanding dominance of animal products is apparent at once. The minor importance of farm crops for cash income

[17] Bulletin No. 90, *op cit*, p. 15.
[18] Supplement No. 1 to Bulletin No. 90, *op cit*, p. 21.

emphasizes their utilization as feed for the dairy and farm animals. Milk constitutes a large element in the food of hogs and poultry.

The various markets for milk are shown in the following table, the figures indicating the per cent of milk sold to each type of market in Jefferson county in 1927.[19]

TABLE IV

Market	Per cent of milk sold	Market	Per cent of milk sold
Condensery	46	Cheese Factory	7
Creamery	27	Cream Shipping	3
City Market	13	Other Uses	4

The wide variety of markets for milk gives the basis for the regional classification of this section as the General Dairy District.

The condensery market is limited chiefly to the southeastern half, including Jefferson and the margins of the adjacent counties in the Rock River Valley Region. Six large condenseries draw milk from this part of the District, where almost ideal conditions exist for this phase of the dairy industry. An old well-established dairy industry of great intensity and producing large and dependable quantities of milk insures a regular and continuous milk supply to the expensive condensery plants; adequate railway transportation moves the canned product to the city market or the seaboard if it is to be exported; and the fluid-milk market, which is the only competitor that tends to supplant the condensery is only beginning to make itself felt.

Jefferson County sends 13 per cent of its milk to city markets, a large part of which is shipped out of the state. The receiving stations at Sun Prairie, Oregon, Milton, and Richmond all collect milk for the Chicago market, while trucking service to Milwaukee reaches the Palmyra-Whitewater district.

Creameries are important as a market for milk thruout the General Dairy District. In many ways they form the backbone of the dairy industry and decline only where there is severe competition for the other markets. They have their greatest

[19] Bulletin No. 90, *op cit*, p. 74.

intensity in the western half of Jefferson County and the row of townships along the eastern side of Dane County. This is an extensive rural section away from cities and in which no condensery is located. A similar area exists along the western margin of the Region in central Columbia County and extends southward into northern Dane County, where it joins with the first district in the northeast corner of this county (Fig. 12).

The cheese industry was important at one time over much of the District. Competition of other markets for milk has pushed this industry northward until now it is important only along the northern margin. There is every indication that its retreat will continue as the condensery and fluid milk markets extend their areas.

This District has the same types of 'other cattle' as indicated in the Districts discussed previously. In the southeastern part considerable attention is given to the production of blooded stock because in this section the dairy industry is old and presents more mature aspects. Some beef cattle are produced along the southeast margin because of the proximity to the corn and beef region to the south. Hogs are grown extensively thruout the District but are especially numerous in the creamery sections, in the grain producing areas in northern Dane and southern Columbia counties, and along the southern margin near to the hog region of the corn belt. Sheep are produced to some extent on rougher lands thruout the District but are most important in a small area in northern Dane County.

The Northern Dairy District

The area lying between the Cheese District and the northern boundary of the Rock River Valley Region has general characteristics similar to those of the non-drumlin section of the General Dairy District. The chief reason for separating it from the latter is that the two are not contiguous, being divided by a northwestward projection of the Cheese District. The two General Dairy Districts have similarity, not only in human occupance but their natural characteristics show many resemblances. The northern District is a small area and includes minor parts of Green Lake, Fond du Lac, and Winnebago Counties (Fig. 1).

Much of the western half of the District is an undulating to gently rolling upland. It contains the second largest area of prairie soils in the Upper Rock River Region. This prairie area extends in a rough semi-circle westward from Waupun, curves northeast to the south of Green Lake, and reaches northward past Ripon to the vicinity of Rush Lake, with one prong projecting on either side of this lake. Favorable topography, congenial climate, and the black, fertile, silt loams, 12 to 14 inches deep, make this one of the finest agricultural areas in the Region. This is emphasized by the various crop and animal maps. To the west and northwest of the prairie belt is a strip of timber-land soils lighter in color and having a somewhat rougher topography. These merge at the western boundary of the Region into a country of decidedly stronger relief and dominantly sandy soils.

The eastern half of the Northern Dairy District is made up chiefly of a series of low, roughly concentric, recessional moraines, interspersed with extensive areas of marshlands lying between the low morainal ridges. The morainal areas and the adjacent intermediate slopes are fair agricultural lands where they are not too gravelly and sandy, but in general they are much inferior in their agricultural adaptations to the rich prairie lands lying contiguous to them on the west. The extensive marshlands, which are conspicuously absent in the western half of the District, have been drained only to a limited extent and are used chiefly for permanent pastures and marsh hay as similar lands are in the southeastern part of the Rock River Region. To the north a low moraine, about 50 feet in elevation and a mile wide, extending from northwest to southeast, marks the southward limit of a temporary re-advance of the Green Bay Glacial Lobe and the outer limits of glacial Lake Oshkosh. To the south and west extensive marshlands border the moraine while to the north the nearly flat surface, mantled with red glacial clays, slopes gently to Lake Winnebago. This moraine forms the northern limit of the Rock River Region. From the northeastern extremity of Horicon Marsh, the Niagara Escarpment extending in a broad semi-circle toward the northeast, rises abruptly 50 to 150 feet above the old lake plain lying to the west and marks the beginning of rougher topography to the east. This escarpment forms the eastern boundary of the Region. The recessional moraines noted above die out to the east and the flat plain adjacent to the Niagara Escarpment, representing the old basin of Lake Winnebago, is excellent farm land. There are but small areas of marsh but large areas of the Clyde soils require drainage.[20] The Poygan clays and the Clyde soils, when properly drained, rank high in natural fertility.

Crops

The same major crop associations are found in this northernmost of the Districts as in the remainder of the Region. Climatic conditions and natural factors are essentially the same as elsewhere. Ripon, lying near the center of the District, has a growing season of 158 days which is approximately the same as that for stations situated farther south.[21]

Peas for canning are grown extensively thruout the District and show their greatest intensity of production in Green Lake and Mackford townships in the southeastern part of Green Lake County (Fig. 6). This county derives 7 per cent of its gross farm income from canning peas and ranks first in the state in this respect. Markesan, a small town in the heart of the area of intensive pea cultivation, has three large canning factories handling peas exclusively. In this section the viners, at frequent intervals along the main highways, are a distinguishing feature of the landscape, while in late summer the odor from the numerous stacks of fermenting vines is a noticeable characteristic of the District.

Hemp attained considerable importance in this section of the state during the World War, but with the return of cheaper cotton after the war, hemp prices dropped so low as to make the returns from it unsatisfactory and its production declined. It is still grown to some extent and is marketed at hemp mills located at Waupun, Markesan, and Fairwater. It is used chiefly for making various types of cord and cheap ropes. There is no indication that its production will reach larger proportions than at present.

Animals and Animal Industries

The animal population shows the usual characteristics observed over the major Region. All types of farm animals are

[20] Gieb, W. J. and Others, *Soil Survey of Fond du Lac County,* United States Department of Agriculture, 1913, pp. 32, 37.

[21] United States Weather Bureau, Section 60, Eastern Wisconsin.

grown and, with the exception of sheep, show an almost even distribution over the District. In general they have about the same density and importance as elsewhere.

Cattle and the dairy industry continue to assume a role of first importance. The density of dairy cattle is slightly less than in Dodge and Jefferson Counties but is about the average for the Region. Holsteins are the leading type of cattle produced. The following table shows the various breeds and their relative importance as reported by the Wisconsin Livestock Breeders Association for Green Lake County.[22]

TABLE V

Breed	Relative numbers	Breed	Relative numbers
Holstein breeders	100	Hereford breeders	8
Shorthorn breeders ...	40	Jersey breeders	4
Guernsey breeders	34	Red Polled breeders ..	4
Brown Swiss breeders	20	*Total*	*210*

Milk is sold to all of the four types of market, which justifies the designation, the General Dairy District. The creamery is the most important market but it is confined chiefly to the western two thirds of the District (Fig. 12). This area represents one of the most intensively developed creamery markets of the entire Region, 97 per cent of the milk of Alto township being marketed at creameries. They are unimportant in the eastern part of the District due to the southwestward extension of a cheese area from Lake Winnebago. Over 60 per cent of the farmers in Eldorado township dispose of their milk to cheese factories. South of the cheese area the milk market is dominated by condenseries located at Ripon and Berlin. Fluid milk for cities is the least important of the major milk markets. Marginal areas to the southwest, the southeast, and the northwest patronize this type of market. The localized character of this market is shown on Figure 14.

Considerable attention is given to the production of beef cattle, which are about half as numerous as dairy cattle. Some farmers raise beef cattle while others import steers from the ranges and fatten them for the market. Swine are important in

[22] Soil Survey of Green Lake County, *op cit,* p. 1805.

the creamery and prairie sections because of an abundance of food in the form of grain and skim milk. This District contains the largest and most intensive sheep producing area in the entire Region. Their production is concentrated most strikingly in the vicinity of Green Lake. The utilization of the rough topography for pasture lands and the abundance of pea vines for pen feeding may help to explain this distribution.

TRANSPORTATION

The Region has excellent rail and highway transportation facilities. Its location near to the two important railroad centers of Chicago and Milwaukee cause many railroads to cross the Region as they converge upon these two main centers. The location within the Region of Madison, a railroad center of secondary importance, further increases the network of railways. Railroads, connecting lake shore cities of Wisconsin with the Twin Cities and the West, are crossed by lines linking the industrial Fox-Winnebago Valley and Duluth-Superior and the northwest with Chicago. This crossing of railroad lines gives almost a surplus of railroad transport. All cities and most of the villages are located upon railroads and no part of the Region is handicapped by distance from rail lines.

The highway system of the Region is characterized by the same well-developed network of roads as the railways. The locational factors affecting railway development have had a similar influence upon highways. Many of the concrete roads parallel the railroads. The intensity of dairy development requires adequate transportation. Hence roads are numerous and well kept. Even minor cross roads are usually surfaced with gravel, an abundance of which is found in glacial deposits covering the Region. In many cases the gravel pit is located in the drumlins, eskers, and moraines adjacent to the road being surfaced. Many county highways are oiled and snow plows keep them passable in winter because milk must reach the market daily.

CITIES

Madison is the only large urban center in the Region.[23] Watertown is the only other city reaching a population of 10,000,

[23] Madison is not discussed in this paper. A full treatment is given in a Master's dissertation by Cyril Stout, 1931, University of Wisconsin.

altho Beaver Dam falls but slightly under that figure.[24] All of the other cities except Fort Atkinson are under 5,000. Thus, in general, the Region is characterized by a considerable number of towns and small cities from 1000 to 5000 population and numerous villages and cross-road hamlets. There is little tendency for any of the cities except Madison to show any marked growth. Most of them show a small increase in population during the last census decade. The smaller towns and villages present a static or declining population and are chiefly important as trade centers for groceries and such staples as are required by the immediate rural communities. Even this importance is threatened as better roads and automobile facilities enable farmers to reach larger shopping centers in a few minutes. This influence is also affecting the growth and importance of the larger towns and cities as shoppers can reach the urban centers such as Madison and Milwaukee in one to two hours. Without doubt, this is the most important factor in the slow growth of most of the cities of the Region.

Inland waters have played an important part in the location and development of the cities. Most of them are located on the Rock River and its tributaries or upon lakes. Water navigation has had practically no influence upon the growth of the cities of the Region, altho there is record of a steamboat ascending the Rock River as far as Jefferson. The river is too shallow and has too many rapids and falls to be of value commercially. Early attempts to connect it with Lake Michigan or to canalize it failed. Most of the cities grew up around water power sites. These water powers are all small but they served the early communities for grinding flour and turned sawmills to saw lumber for the farm buildings. Several of them are now used to furnish part of the power for modern factories, but most of them are used to grind feed. This importance should not be minimized in a dairy community which uses large quantities of ground feeds. The streams or lakes have been an important factor in the growth and development of the cities. Water for industrial plants, disposal of sewage and industrial wastes, natural ice supply, bathing beaches, and sites for tourist camps are some of the more important services of inland waters to the people of the Region.

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[24] United States Census Bureau Bulletin, Population of Wisconsin, 1930.

INDUSTRIES

The industrial development within the Region is exceptionally high for a district of dominantly rural characteristics. Many of the industries are the outgrowth of basic raw materials for manufacture or are a response to the demands of the community for specific types of manufactured goods. Because of this quality they will be referred to as "community industries" to distinguish them from those that have no basis in raw materials or markets in the community in which they are located.

COMMUNITY INDUSTRIES

Since dairying is the key agricultural interest of the Region it is natural to find that many of the industries are closely related to it. Cheese factories, creameries, condenseries, and ice cream factories are found throughout the Region, and as indicated above are more or less concentrated in the several Districts of the Region. Many of them are small, but taken as a group they constitute the most significant manufacturing industry of the Region. All of the cities, every village of importance, and almost every cross-road hamlet has one or more milk-using industries. Rarely can one travel more than five to ten miles across the Region in any direction without seeing one or more factories of this type; and in this distance several of the smaller types such as creameries and cheese factories may be observed. Practically all the cities have several milk-using factories. Some of these, as in the case of condenseries, are large, involve the investment of large sums of money, have a large pay-roll, and give a market for milk within a radius of ten to fifteen miles. Practically all of the condensed milk is shipped out of the state, much of it being exported to foreign countries.

Several factories are located in the Region for the purpose of supplying the demands of the dairy industry. The James Manufacturing Company at Fort Atkinson specializes in the manufacture of barn equipment and is said to be the "the largest in the world" producing this type of goods. The factory has two units with 13 acres of floor space and employs 700 to 800 laborers. Their annual business runs into the millions of dollars, of which, about 10 per cent represents exports. The

Creamery Package Company with headquarters in Chicago and with plants at Fort Atkinson and Lake Mills manufactures equipment for the milk-using factories. The heavy bulky character of the product makes it desirable to have the factory located as near the market as possible. Some other small factories manufacturing similar farm and dairy equipment are found in various cities. Large can manufacturing plants at Waupun and Oconomowoc supply condenseries and canning companies with tin cans for their product.

Feed mills are numerous and well distributed thruout the Region. Practically every village and cross-roads community has one and several are found in the larger cities. Many of them have inherited the water power sites from the grist or saw mill of earlier days. In general, the individual plants are small but the total volume of business is large.

The canning industry in the northern two thirds of the Region is second only to the dairy industry. Canning factories are located in practically every hamlet and village in that part of the Region. Wisconsin produces about one half of the canning peas of the United States, and approximately a quarter of Wisconsin's production, or almost one eighth of the total for the United States, is produced in this small Region. Some corn is packed in the factories in the southern half of the Region and small quantities of fresh vegetables are canned in a few of the factories. It is peas, however, that give volume and stability to the canning industry. Small plants supplying canning factories with equipment are located at Columbus.

A few mineral industries based upon local raw material are found. An abandoned iron and steel plant at Mayville was the largest. Plants producing lime and various types of limestone products are located along the Niagara escarpment near Mayville, at Madison, and at various other points in the Region. Brick and tile for local use and based upon glacial clays are produced at Whitewater, Jefferson, and Watertown. Sand and gravel are obtained in many places and the landscape is marred by the ugly scars of the abandoned pits. Core sand for foundries is produced extensively near Berlin.

At several places in the Region small wood-working establishments present relict forms of an earlier industrial adjustment. Such types are the table slide factories at Watertown, the small wood-working establishments at Jefferson and Stoughton, and wagon and carriage factories which have recently closed down. Local timber at one time supplied these or similar parent industries but the raw material is now shipped in.

Commercial Industries

This type of industry ships in the raw material and markets its production largely outside of the Region. Most of them are located in the Region due to the interest of local capital or are units of large factories located outside the near-by urban centers to take advantage of cheaper rents and of lower wages in an unorganized labor market. The group producing iron and steel products is the most important. This includes the farm seeders at Horicon, the Western Malleables Company at Beaver Dam, the Malleable Iron Range Company of the same city, the Otto Biefield Company of Watertown, producers of boilers and concentrators, the Kissel Motor Company at Hartford,[25] and the Highway Trailer Company of Edgerton. Some of these companies employ several hundred men, and have an annual business which reaches into the millions of dollars. The size and variety of this type of product is surprising.

Seven shoe factories and six knitting mills are found in the Region. Some of these plants are large, employing 400 to 500 laborers. Most of them represent units of large industries with headquarters at Milwaukee or Chicago. They are located in the Region to take advantage of cheaper rents and lower labor costs. The proximity of the Region to the large urban centers and the excellent transportation available make the small cities a good location for these units.[26]

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[25] The latest information indicates that this plant is going out of business.

[26] A number of other small factories of a miscellaneous nature are omitted from this survey because space does not permit adequate description.

This paper is an abridgment of a dissertation submitted to the faculty of the University of Wisconsin in candidacy for the degree of Doctor of Philosophy. Abbreviation of the paper has necessitated the omission of much data, many pictures, most of the maps, many footnotes, and the bibliography.

THE TWO CREEKS FOREST BED, MANITOWOC COUNTY, WISCONSIN

L. R. WILSON

INTRODUCTION

After the theory of continental glaciation was accepted, it was not until more extensive study of glacial deposits was made that the theory of multiple glaciation was advanced (see review in Thwaites, 1927). The occurrence of weathered soils, loess, certain lake deposits, and organic remains between glacial tills are evidences of intervals of deglaciation between ice advances.

During the periods of deglaciation, several of which were of considerable length, plants and animals spread northward over the ice-free areas. In many places exposed by the retreat of the glaciers, forests established themselves and thrived until the glaciers again advanced and destroyed them. Many deposits of organic materials buried by till have been found in various parts of the world, and where these remains are of trees some of which are in place, the deposit is spoken of as a "forest bed".

The Two Creeks Forest Bed is such a deposit. It is exposed on the shore of Lake Michigan two miles east of Two Creeks, Manitowoc County, Wisconsin, in Sections 11 and 13, Township 21 North, Range 25 East. Exposures extend along the shore for about a half mile. The same forest bed is also exposed three miles to the north on the lake shore, and in a ravine about a quarter of a mile to the west in Section 35, Township 22 North, Range 24 East, Kewaunee County. Other exposures doubtless exist, but time has not allowed further field work.

The deposit studied in detail by the writer is at the first-named locality. It is several inches thick and approximately one hundred feet long. The forest bed lies between the varved clays deposited during the retreat of the Middle Wisconsin or "Gray ice" and the till of the Late Wisconsin or "Red ice".

Previously no extensive study has been made of the Two Creeks Forest Bed, though a notice was published by Goldthwait (1907) who discovered the exposure. From 1922 to 1930 F. T. Thwaites visited the area several times, but his examinations were brief. In 1922 he submitted some wood to the Forest Products Laboratory at Madison, and one species of tree was identified. In 1926 he sent some mollusks to F. C. Baker at Urbana, who identified three species. Conditions for examination were poor during most of this time on account of the low level of the lake, which checked wave work.

Other forest beds in Wisconsin have been noted in well drillings, and occur most abundantly in the southeastern part of the state (Alden, 1918. pp. 177-179). Lawson (1902) published a preliminary report on the forest beds of the lower Fox River valley in which he described extensive deposits. These apparently contained much valuable material, but the exposures have nearly all been destroyed.

Geology

Descriptive Geology

The clay banks in which the Two Creeks Forest Bed is exposed show the following geological formations:

The lowest layer exposed is till deposited by the Gray ice, presumably of "Middle" Wisconsin age. The drift that is commonly called "Middle" Wisconsin in this state is Leverett's third substage of the Wisconsin Stage of glaciation (Leverett, 1929).

The Gray till is overlain by a glacial lake deposit of poorly varved red and gray clays, interbedded with lenses of sand and silt. The deposit is about twelve feet thick, and the contact of the varved clay and the Gray till is shown in Fig. 2. It was not possible to count the varves because of their imperfect structure and the amount of disturbance of the strata.

The forest bed is found on top of the varved clays, and above that are several inches of silty sediment. Red till, presumably of "Late" Wisconsin age (Leverett's "substage four"), overlies the thin lake sediments. At the forest bed the till is about eight feet thick. On top of the Red till are local varved clays of Lake Algonquin.

In an unpublished report on the glacial geology of part of northeastern Wisconsin, F. T. Thwaites says: "Although large numbers of exposures of Red and Gray tills have been examined, no evidence of interglacial weathering or soil development has been observed except at the forest bed near Two Creeks.

The recent rise of the lake level has shown definitely that the organic deposit at that place rests upon imperfectly varved silty clays, which have been much disturbed by the work of the Red

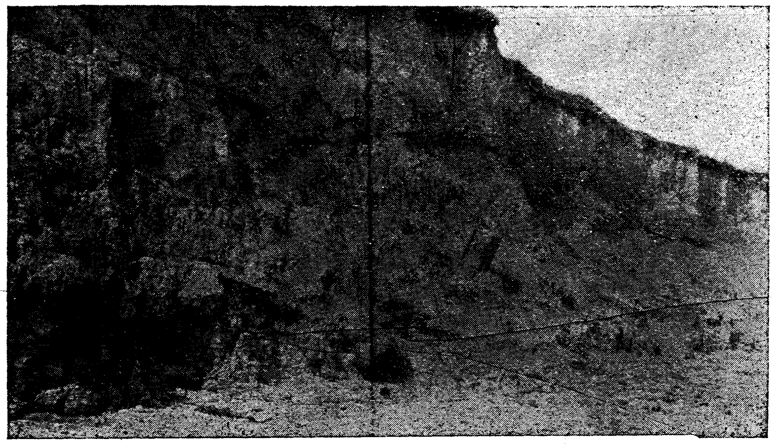

FIG. 1. General view of the Two Creeks Forest Bed exposed on the shore of Lake Michigan. (Photograph by F. T. Thwaites.)

FIG. 2. Contact of the Gray Till and the silty varved clay. (Photograph by F. T. Thwaites.)

ice. These sediments are seven to twenty feet thick and rest upon Gray clayey till, which may be presumed to be of Middle Wisconsin age."

Historical Geology

The oldest formation exposed at the Two Creeks Forest Bed is the till of the Gray ice. This till was probably deposited during the Middle Wisconsin Substage during which the ice extended to the lower end of Lake Michigan.

With the recession of the Gray ice the water in the Lake Michigan basin rose to a height of about sixty feet above the present lake level, forming what is known as the Glenwood Stage of Glacial Lake Chicago (F. T. Thwaites, unpublished). The lake then drained through the Des Plaines River at Chicago; sediments of this lake were assorted into separate layers known as "varves". Of these, the coarser silty material was deposited during the summer and the fine clays, mostly red, were laid down when the lake was frozen over in winter. They are aptly called "the annual rings of the earth". The varves of Lake Chicago occur above the Gray till and are best defined near the bottom of the deposit. Near the top the varves are indistinct and show that the lake was gradually becoming warmer as the ice receded toward the north.

The Gray ice retreated northward until the Straits of Mackinac were freed and there was a fall of the lake to a level lower than the present. How much farther north the margin of the Gray ice retreated is not known. The Two Creeks Forest was developed on the land thus formed.

The interval in which the forest bed developed was at least eighty-two years in length, as shown by the growth rings of the oldest log, and the time necessary for the establishment of the forest would undoubtedly increase this figure several times. The forest bed interval came to a close with the advance of the Red ice.

Before the destruction of the Two Creeks Forest by the Red ice, there was a flooding of the forest floor and a deposition of several inches of sediment on top of the organic remains. The water that flooded the forest came either from the rising lake caused by the Red ice blocking the outlet of Lake Michigan at the Straits of Mackinac or by streams and ponds beside the advancing glacier.

The Red ice overrode the forest bed and moved as far south as Milwaukee, where the outer margin of its drift is found.

The water rose at Chicago to a height about forty feet above the present level of Lake Michigan, and the outlet was again through the Des Plaines River. This condition is known as the Calumet Stage of Lake Chicago.

The striking difference in color between the tills deposited by the two glaciers gave rise to what was long an unsolved problem. Alden (1918. pp. 314-315) suggested that it is due to the ice overriding red clays deposited in Lake Chicago. These clays were colored by waters from the iron regions of northern Michigan. However, the clays deposited during the retreat of the Gray ice are not particularly red. Possibly a more sound suggestion has been advanced recently by F. T. Thwaites, namely, that the Red ice came from a more westerly center than did the Gray. With an advance from this direction several of the iron ranges of northern Michigan were passed over and this gave the red color directly to the till. The ice of the later substage reached the forest bed by crossing the low northern part of Door County, then spreading out to the southwest over the Lake Michigan lowland.

The retreat of the Red ice left the forest bed buried under eight to twelve feet of red clay till, and the exposure of the organic remains has been effected by post glacial cliff formation. The clay banks are rapidly receding whenever the level of Lake Michigan is high enough for effective wave erosion.

Organic Remains

Wood

All the wood thus far examined has been of one, or possibly two, species of spruce *Picea mariana* (Mill.) BSP. and *P. canadensis* (Mill.) BSP. It is interesting to note that all interglacial wood found in Wisconsin to date has proved on critical examination to be either spruce or hemlock. Of the latter species only one record is known; this is a specimen taken from the excavation for the Schroeder Hotel at Milwaukee, and reported to the writer by Mr. D. Costello of Marquette University. The geological formations which overlay this log are not known. Other kinds of trees recorded from the Chicago region (Baker, 1920 p. 5) are extinct species of spruce and oak.

Like much other wood of interglacial age, the Two Creeks Forest Bed material is soft and easily broken. It checks and breaks into short sections on drying. The tissues, however, are not destroyed, and microscopic sections have been made of them.

Where wood and peat have been in contact with the Red till, there is a zone in the clay a few inches wide of greenish gray color due to deoxidation.

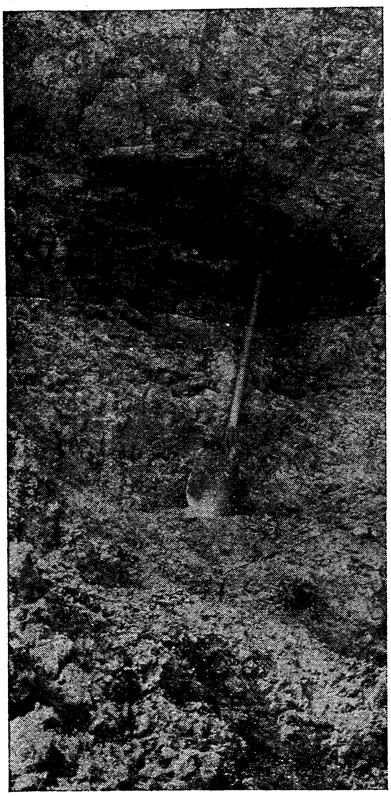

FIG. 3

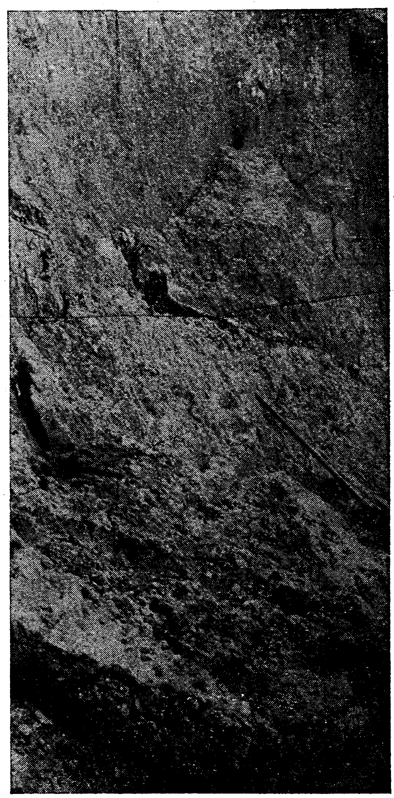

FIG. 4

FIG. 3. Spruce log exposed from sediment layer, showing the usual direction in which the logs are found pointing. (Photograph by F. T. Thwaites.)

FIG. 4. Spruce stump *in situ* with its log exposed on the left, also showing the root on which the fossil bracket fungus was attached. (Photograph by F. T. Thwaites.)

The logs occur most frequently in the layer of sediment above the forest bed, where they evidently fell after being broken from their stumps by the glacial ice. Most of the logs are found pointing toward the southwest (Fig. 3), and it is thought that here the last ice moved in that direction.

One stump was found *in situ* (Fig. 4), with the butt of the broken-off log almost attached. The roots of this stump extend along the forest bed peat and on a portion of the root that had been exposed above the ground during the interglacial period was found a bracket fungus. It is a *Polyporus,* but the species has not been determined. Goldthwait (1907. p. 61) also observed a stump *in situ* when he discovered the Two Creeks Forest Bed.

All the logs that have not been broken by subsequent handling show ragged splintering ends in consequence of glacial action upon the trees. This condition indicates a violent twisting and bending of live trees before they were felled.

The growth rings were studied in sections of six logs. The greatest number of rings shown in one section is eighty-two; the average is about sixty. Five of the logs showed by the width of successive rings a marked decrease in the rate of growth in the last twelve years of the Two Creeks Interval. One log taken from the Red till, which is above the forest bed, showed but little decrease until the last year of its growth. This particular log may be white spruce, *Picea canadensis* (Mill.) BSP. The other logs studied have been taken to represent the growing conditions in the forest bed, whereas the log taken from the till above is considered as having been transported by ice from a different environment farther north. When the log taken from the Red till is compared with the others, an extreme difference in size and growth rate is noticeable. This log is twice the diameter of any of the others, though it has only the average number of growth rings. The width of the rings does not agree with that of the forest bed trees. There is no growth decrease until the last year of the tree's life, which fact alone suggests conditions unlike those at the Two Creeks Forest.

The growth rings cannot be compared exactly with reference to particular years, for it is not known whether all the trees were destroyed in the same year or whether they were all alive at the time of the ice advance; however, it is considered probable that the largest log, having been transported by the ice, was felled several years before the Two Creeks Forest trees. It is not probable that more time elapsed, for in that case the log would probably show more evidence of crushing.

Close study of wood sections has shown that certain small growth rings of the forest bed trees occur at years approximately corresponding to those in which wide growth rings occur in the log from the Red till, and *vice versa.* If excessive moisture (Zon and Averell, 1929) was one of the primary factors for small growth rings in the forest bed trees, as is suggested by the character of the flora and fauna, then trees growing on higher ground would not have been similarly affected and probably throve better in wet years. In dry years the forest bed trees, having more favorable conditions, would grow more rapidly while those on the upland would be adversely affected, and consequently the rings formed in those years would be narrower. Other factors, such as temperature and wind, may also have affected ring growth, but the primary factor here concerned seems to have been moisture.

Mosses

The moss flora of the Forest Bed comprises the most extensive group of plants found in the remains. The moss material was submitted to Mr. L. S. Cheney, who has identified nineteen species. Mr. Cheney (1930) has published a notice of these mosses in which he reports eight species. The additional eleven species that he has since recognized came from other parts of the same exposure.

All the mosses recognized are of existing species, and are in general more northern in their modern distribution than the Two Creeks Forest Bed. Nearly all are found in northern Wisconsin, but the present southern limits of a few are in Canada. The northern limit of all the species is generally in northern Canada and northern Europe. Several species range from the Bering Straits to Spitzbergen and Siberia. One species, *Swartzia montana* (Lamk.) Lindb., is found from the Arctic to the Antarctic, although in lower latitudes it is restricted entirely to alpine regions.

There are two ecological horizons shown by the mosses, and it is interesting to note how well they agree with the other organic remains in these horizons. The problem of succession however, will be considered under the subject of ecological history.

Peat

The peat of the forest bed is poorly formed and at some parts of the exposure is wanting entirely. It is evident from this condition as well as from other organic remains that the Two Creeks Forest Bed was not exactly a lowland forest, but rather a dry forest, at one stage of its existence. There are places along the exposure where the mosses and other plant remains have accumulated as a silty peat, such as can be found in any spruce forest today. It is from this peat that the microfossils were secured, though their number was comparatively small.

The usual technique used by paleo-ecologists was employed in the study of the pollen and spore fossils (Ertman, 1931). Identification of pollen grains and spores was checked by reference to prepared slides of recent material of the same species.

Mollusks

Seven species of mollusks have been recognized from the forest bed by Mr. F. C. Baker, to whom specimens were submitted. These were from three levels in the forest bed, and agree ecologically with other organic remains from their respective horizons. One Pleistocene form was reported; this came from the clay immediately beneath the forest bed. Other individuals found in higher levels represent existing species.

Ecological History

The ecological history of the Two Creeks Forest Bed is remarkably well defined in the thin layer of organic remains exposed.

As already described, the forest bed rests upon a deposit of varved clay, and it is in this clay that the first traces of plant and animal remains are found. Fragments of plants are found in the varved clay to a considerable depth, but none of these can be identified. Near the top of the varved clay deposit three species of mollusks were found. One is identified by Baker as *Fossaria dalli* (Baker); its habit is wet mud above water. Because of its large size, he considers this mollusk a Pleistocene race (*in litt.* to F. T. Thwaites, 1926). The other two species are *Pupilla muscorum* (Linn.) and *Succinea avara* Say., both forest forms might have been common at the edge of a flood plain. These mollusks seem to date the period of the forest bed with the earliest exposure of land above the glacial lake that preceded it. There probably appeared at this time a few grasses and mosses, for the peat fossils suggest such a development. There was probably a brief period when only grasses and mosses covered the clay, but a spruce forest very soon became established, for almost directly on the surface of the clay there occur spruce cones, needles, and forest mosses. Mixed with these mosses are shells of land mollusks *Succinea avara* and *Vertigo ventricosa* (Morse) One moss is peculiarly restricted to the lowest level of the forest bed. This is *Bryum cyclophyllum* (Schwaegr.) B. and S., a forest form, and it seems to have been the first moss to have become established on the Two Creeks Forest floor. Other plants that appear in this horizon are grasses, heaths, birch, jack pine *(Pinus Banksiana* Lamb.) and a species of *Asplenium.* These are represented only by pollen grains and spores. The rare occurrence of the pollen grains of the birch and pine suggest that they were probably blown into the forest bed from a short distance. Fungi were abundant, for the spores are numerous in the peat. Some of these appear to be of lichens; the others are all representative of the dark spored Dematieae.

The spruce forest appears to have thriven for at least sixty-two years before a gradual decrease was observed in the growth rings of the trees. The decrease in growth began roughly twenty years before the forest was destroyed by the advancing ice and water.

Little weathering of the subsoil was accomplished, for it is all calcareous.

Bark beetle excavations have been found, which may belong to the period of forest deterioration. Two genera are represented, as shown by the patterns of the excavations.

The advance of the Red ice upon the Two Creeks Forest must have been gradual. Water flowed into the forest floor, for there is a marked change in the flora and fauna, that would suggest such a condition. If the growth rings of the black spruce are reliable indicators of growing conditions, they show conditions unfavorable to secondary thickening in the Two Creeks Forest during the last twenty years of the interval. An examination of the uppermost plant and animal remains shows them to be entirely wet land and aquatic species. This suggests excess moisture as a reason for the narrow growth rings of the spruce and the beginning of a third period in the ecological history of the interglacial forest.

Apparently the only plants that throve during the last years of this interval were the following aquatic and subaquatic mosses: *Bryum bimum* Schreb., *B. pseudo-triquetrum* (Hedw.) Schwaeg., *Calliergon cordifolium* Kindb., *C. stramineum* (Dicks.) Kindb., *C. turgescens* (Jens.) Kindb., *Camptothecium nitens* Schp., *Campylium stellatum* (Schreb.) Bryhn., *Dicranella* sp., *Ditrichum flexicaule* Hampe, close to var. *brevifolium* Kindb., *Drepanocladus aduncus* Moenkem., var. *typicum* (Hedw.) Ren., *D. aduncus* Moenkem., var. *pseudofluitans* Sanio., *D. revolvens* (Sw.) Warnst., *D. Sendtneri* (Schrp.) Warnst., *D. vernicosus* (Limb.) Warnst., *D. Wilsoni* (Schpr.) Roth., *Scorpidium scorpiodes* (L.) Limpr., *Tortella fragilis* (Drumm.) Limpr.

Mollusks found at the same level as the above named mosses were the following aquatic species: *Gyraulus circumstriatus* (Tryon), *Fossaria parva* (Lea.), *Pisidium* sp.

The mosses show several interesting ecological conditions and furnish also some evidence of the manner in which the forest was destroyed. The uppermost mosses are upright in position and have finely divided sediment infiltrated about their stems. A similar observation was made by Cooper (1923) at Glacier Bay, Alaska. From this fact it seems evident that the forest was flooded with silt bearing water before being overridden by the Red ice. The mosses also show by thin scraggly branches, in the last year of growth, that a losing struggle for existence was under way just before they were buried. Mr. Cheney has pointed out to the writer that some of the leaves of the upper branches contain the remnants of chloroplasts. That chloroplasts should be preserved is remarkable, and it is strong evidence that the mosses were living at the time of burial.

Three or four inches of sediment cover the water mosses and mollusks. In the sediment one noteworthy moss was recorded, namely *Swartzia montana* (Lambk.) Lindb., which grows in an alpine or rocky habitat. As conditions of this type did not occur in the forest bed, it is most probable that this moss was transported from a more northern habitat with the sediment.

The glacial till above the sediment contains fragments of wood and logs, many of which were flattened by the weight of the ice. It was from the Red till that the largest log was taken, and as already noted there is some reason to conclude that this log was transported by the glacier from a more northern and upland forest a possibility which would harmonize with the occurrence of *Swartzia montana.*

Origin of the Two Creeks Forest Bed Life

The study of many Pleistocene organic deposits has revealed new varieties and forms of both plants and animals (Williams, 1930), (Baker, 1930), but from the Two Creeks Forest Bed no new forms with the exception of one Pleistocene molluscan race, has been recognized. This fact may lead us to conclude that the Two Creeks Forest was little different from present forests or habitats in which the recognized species now live, and the forest did not, of course, exist long enough with peculiar conditions to produce new or characteristic forms. The absence of particular Pleistocene forms in the forest bed proper also suggests that the Two Creeks Forest flora and fauna are representative of a general distribution, rather than of an isolated region where local forms and races had been evolved. The forest was evidently in the path of plant and animal distribution, but sources from which the plants and animals arrived can only be suggested at present.

The top thirty-five inches of the clay underlying the forest bed contains miscellaneous tissues. The occurrence of vegetal tissues in the upper varved clays raises a question as to their source, but the writer has not attempted a solution of this geological problem with the present data. It would appear, however, that Glacial Lake Chicago existed long enough to allow plants to establish themselves on nearby land, and that these were then washed into the lake. The plant tissues in the varved clays are too fragmentary to be identified, but may be from the ancestors of the earliest flora of the forest bed. This may explain the origin of some of the Two Creeks Forest Bed plants, but it appears that there must also have been a colonization from the south or west, as indicated by the pollens of jack pine and birch, fern spores, and the great quantity of mollusks. It does not seem probable that such plants and animals could have long survived glacial conditions.

The plants that were not closely associated with the glacier front may have entered the region of the forest bed either from the southeastern or southwestern part of Wisconsin. This is suggested by the many records of interglacial materials in those parts of the state. Several well records west of Baraboo and North Freedom, Sauk County (Alden, 1918. p. 226) show successive layers of vegetable remains separated by aqueous deposits presumably of glacial derivation, and are very suggestive as evidence of the persistence of plants in the Driftless Area of Wisconsin during the Glacial Period. At present only one organic deposit from Baraboo has been examined. The material was secured by F. T. Thwaites and submitted to the writer in March, 1931. It was found under 130 feet of glacial deposits, and according to Mr. Thwaites the deposit may be of Sangamon age. Leaves of several dicotyledonous plants and one species of moss were separated from the sandy material. The leaves are too fragmentary to be identified, except a number which belong to a species of *Vaccinium* resembling most nearly *V. microcarpon* J. D. Hook., a species of northern Europe. The resemblance of the Baraboo specimens is not close enough to consider them as belonging to this species, and it is possible that they represent an extinct species of *Vaccinium.* The moss was identified by Mr. Cheney as *Campylium stellatum* (Schreb.) Bryhn. This deposit will be considered in a later paper.

Baker (1920, pp. 71-73) has described deposits at the southern end of Lake Michigan which appear to be contemporaneous with the Two Creeks Forest Bed, but further correlation of materials has not yet been possible.

The plants and animals may have spread either northward into Manitowoc County along the shore of Lake Michigan, or eastward from the Driftless Area and other, at that time, unglaciated areas that existed outside the limits of the Gray ice. There are many records of other forest beds south and west of Two Creeks (Alden, 1918. p. 179) that probably belong to the same interval, but none of these have been studied. The forest beds of the lower Fox River valley evidently were extensively exposed when Lawson (1902) did his work there, but his records of the plant remains cannot be considered accurate, for as he notes, they were never critically examined. It is doubtful whether logs of pine, cedar, black ash, and tamarack, which he records, could be definitely identified in the field, for only after a microsopic examination of the material is it possible to identify interglacial wood with certainty, and even then to distinguish between closely related species is impossible. The exposures which Lawson visited have nearly all been destroyed, and it has not been possible to secure material from them except one spruce log (*Picea* sp.) from Menasha, Winnebago county. According to Lawson the forest beds of the Fox River valley cover about five hundred square miles and extend into four counties. They probably belong to the same interval as the Two Creeks Forest Bed, and were connected with it. It is evident that the Two Creeks Interval was of long enough duration to allow of the establishment of extensive forests over the eastern part of Wisconsin.

PROBABLE CLIMATE OF THE TWO CREEKS INTERVAL

It is impossible to give any definite statement regarding the climate which prevailed during the Two Creeks Interval because there are two conflicting lines of evidence. These are (a) the present known ranges of the plants, and (b) the present known ranges of the mollusks. Nevertheless, an average range has been computed and taken as an indicator of the probable climatic conditions.

To consider first the ranges of the recognized species of plants, it has been seen that these species are now largely confined to the northern part of North America and northern Eurasia. The greatest abundance of individuals of the species in question seems from a study of literature (Atlas of Canada, 1915; Fernald, 1919; Herzog, 1926) and from the writer's observations, to be in that region somewhat north of Minnesota in Ontario. In that region a flora of a northern type is dominant, and there all the plant species recognized in the forest bed occur, a statement which, so far as their present ranges are known, does not hold for any more southern location.

The mollusks show more southern distributions, which according to Mr. F. C. Baker (*in litt.* 1931) appear to fit into the climatic conditions of northern Wisconsin. The northern distributions of these mollusks are not as well known as are those of the plants, for the reason that they are all small forms and are not as often collected by naturalists.

If an intermediate range is chosen between the general plant range and the general molluscan range, then the climatic conditions of northern Minnesota may be taken as representing approximately the climate of the Two Creeks Interval at the time of the climax forest, which was composed of spruce and other woodland species.

SUMMARY

1. There was an interglacial interval of considerable duration between the Red (Late) and Gray (Middle) Substages of the Wisconsin Stage of glaciation. This is shown by the position of the Two Creeks Forest Bed between tills of characteristic lithological nature.

2. For the Two Creeks Forest Bed to have been established, the Gray ice must have receded north far enough to clear the Straits of Mackinac thus furnishing an outlet to Lake Chicago and allowing its water level to drop to a level near to, or lower than the present.

3. The interval was long enough in duration to allow the growth of a forest whose age was at least eighty-two years.

4. Both plant and animal remains are well preserved and can be definitely identified as present day forms, with the exception of one mollusk *(Fossaria dalli)*, which belongs to a peculiar Pleistocene race differing in size from existing forms.

5. The plants and animals represented in the Two Creeks Forest Bed are today arctic, subarctic, and northern in distribution.

6. There were three periods in the history of the forest bed, characterized: first, by aquatic and semi-aquatic mollusks on top of the varved clay of early Lake Chicago; second, by moist to dry woodland mosses, mollusks, mites, fungi, and trees marking an interval of dry land; and third, by water mosses, water mollusks, and sediment caused by the advance of the Red ice blocking the drainage.

7. The climate of the Two Creeks Interval was probably like that of northern Minnesota, or somewhat colder, as shown by the prevailing northern ranges of the identified plants and animals. The complete deglaciation of Canada is not suggested by the evidence at Two Creeks, Wisconsin.

Specimens of wood, peat, and mollusks are to be found in the Geology Museum of the University of Wisconsin, while the mosses and bracket fungus from the Two Creeks Forest Bed are in the collections of the Herbarium of the same university.

The author wishes to express his appreciation to Dr. N. C. Fassett for his encouragement and suggestions, to Mr. F. T. Thwaites for his geological advice and interest that have made this paper possible, to Mr. L. S. Cheney and Mr. F. C. Baker for identification of specimens, and to Dr. C. E. Allen for his helpful criticism.

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VARVED CLAYS OF WISCONSIN

ELMER W. ELLSWORTH

INTRODUCTION

During 1928-1929 the writer, in conjunction with W. L. Wilgus, made a thorough study of the Waupaca, Wisconsin, varved clay deposit, and presented the results of this work in a printed report.[1] The present study is an extension of this work and covers all of the known varved clay deposits in the state. The writer visited all of the exposures and procured samples for chemical and petrographic analysis. The clays studied represent the basin deposits of at least four known glacial lakes: Glacial Lake Chicago, Glacial Lake Oshkosh, Glacial Lake Wisconsin, and the glacial lake of northwestern Wisconsin.

This study has been made with a definite purpose in view: (1) To determine whether or not samples of varved clay taken from different exposures of the same lake bed possess similar chemical and petrographic properties; (2) To determine to what extent the chemical and mineralogical properties of the varved clays of the different glacial lake beds vary throughout the state; and (3) To determine the value of such analyses in correlating scattered exposures as belonging to one or another former glacial lake basin.

The complete results of the many analyses of the clay samples are included in this report, as well as the conclusions deduced from their interpretation.

The writer wishes to thank Mr. H. R. Aldrich and Mr. J. M. Hansell of the Wisconsin Geological Survey for their cooperation in the work of examining many of the deposits in the field. The work was done in the Sedimentation Laboratory of the University of Wisconsin under the direction of Professor W. H. Twenhofel.

LOCATION OF THE VARVED CLAY DEPOSITS

The geographic areas under consideration are shown upon the accompanying map of the state, Fig. 1. This map also indi-

[1] Ellsworth, E. W., and Wilgus, W. L.: The Varved Clay Deposit at Waupaca, Wisconsin, Trans. Wis. Academy of Science, Arts and Letters, Vol. XXV.

cates the probable position and extent of the several glacial lakes at their maximum extent.

Two Rivers. Along the shore of Lake Michigan, a short distance north of the town of Two Rivers, is an exposure of Pleistocene deposits comprising glacial till, a buried forest bed, and varved clay. The varves of the latter are poorly defined, and are deformed by folding. Representative samples were collected here during the spring of 1929.

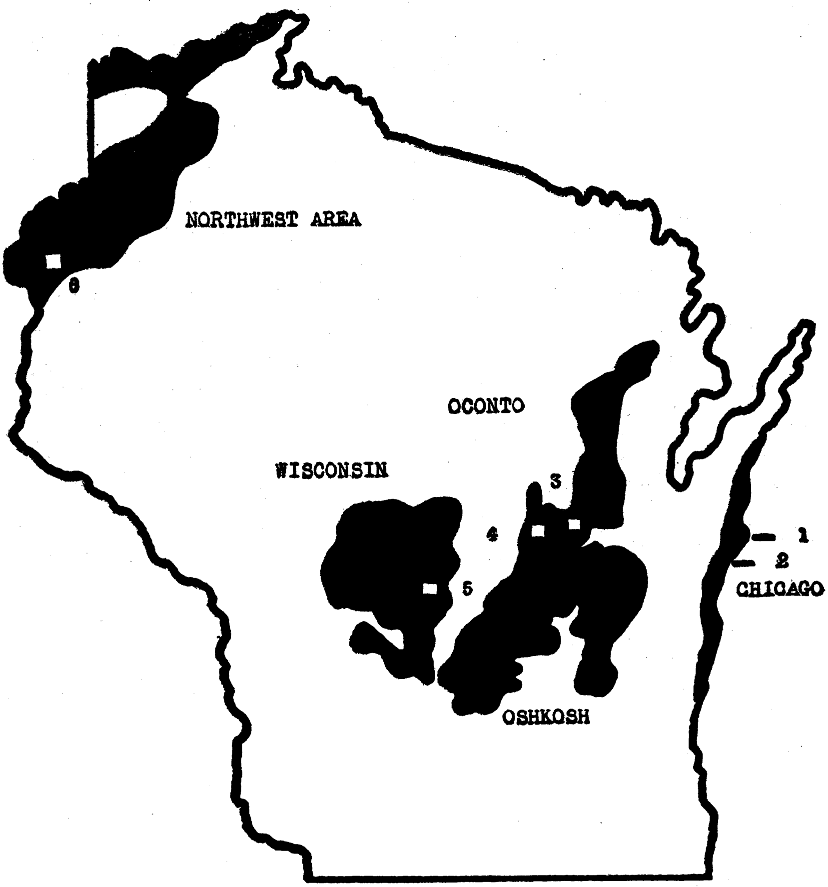

FIG. 1. Key Map. Areas outlined in black indicate the probable position and boundaries (within the state) of the several glacial lakes at their maximum extent. The names on the map are the names of these respective glacial lakes; the numbers denote the locations of the varved clay exposures by geographical units: (1) Two Rivers; (2) Manitowoc; (3) New London; (4) Waupaca; (5) Friendship; (6) Northwest Area.

Manitowoc. Along the southern banks of the Manitowoc River at Manitowoc, varved clay is exposed in the clay pit operated in conjunction with the Leach Company brick yard. The exposed face is fifteen to twenty-five feet high, and the varves are fairly well developed. For the most part they are in a normal horizontal position, though slight folding of some of the beds is noticeable. A large specimen, containing a dozen varves, was brought to Madison during the spring of 1929.

New London. The deposit here has been opened by a local brick concern, and a ten to fifteen foot exposure created. The varves are fairly well defined and appeared to be in a perfectly normal position. Limy concretions, or "clay dogs", were found in the varves at several places. Samples of clay representative of the deposit were taken for analysis.

Friendship. The varved clays here are exposed along the banks of a small stream, and the exposure visited in the fall of 1929 was four to six feet in height. The varves are well defined, but have an average thickness of less than one inch. A small section was cut from the face of the exposure and taken to Madison for examination.

Northwest area. This area includes parts of Burnett and Polk Counties, and contains numerous exposures of varved clay. Those along the Trade, Wood, Clam and St. Croix rivers were examined in the field during the summer of 1929, and representative samples taken from each exposure. The varves are excellently developed in all exposures visited, and are very similar to those studied at Waupaca during the previous year. At three locations the complete sections exposed were measured. From these measurements, which included over five hundred varves, curves showing the variation in varve thickness were constructed, to be later used in the correlation of these deposits.

Samples Analyzed in this Study

In general, at least three complete varves from each exposure were sampled for analysis. Care was taken to select representative varves and to include one from the bottom, middle and top of each exposure. In the laboratory the samples were divided into summer and winter components. The resulting series of samples numbered sixty-five, and the list of these samples and their field locations are presented in Table I.

TABLE I

Sample No.	Winter or Summer Component*	% Fe_2O_3	% Carbonates	% Silicates and Insoluble	General Field Location	Specific Field Location
1	W	14.4	19.6	66.1	Northwest area	Trade River Bridge, Town 36 North, Range 19 West.
2	W	13.4	18.7	67.9		
3	W	13.4	18.8	67.8		
4	S	7.9	†	....		
5	S	7.1	....	....		
6	S	8.3	....	....		
7	S	6.2	8.9	84.9	Northwest Area	Grantsburg clay pit.
8	W	13.5	16.6	69.1	Northwest Area	Benson clay pit.
9	W	14.0	16.5	69.5		
10	S	6.0	9.2	84.8		
11	S	6.4	14.4	79.1		
12	S	6.2	7.8	86.0		
13	S	5.7	13.0	81.3		
14	W	11.0	....	....		
15	W	13.5	15.4	71.1	Northwest Area	Wood River Bridge, NE 21, T. 38N, R. 19W.
16	S	5.6	7.9	86.5		
17	Sa	7.5	11.8	80.7	Northwest Area	Banks of Wood River, 150 paces S., N¼ 20, Town 38 North, Range 19 West
18	Wa	11.5	16.0	72.5		
19	Sb	7.2	11.0	81.8		
20	Wb	13.0	17.7	69.3		
21	Sc	8.0	....	....		
22	Wc	14.2	15.1	70.6		
23	S	7.7	6.6	85.7	Northwest Area	High east banks of St. Croix River, Town 40 North, Range 19 West
24	W	14.8	....	....		
25	S	8.2	....	....		
26	W	14.7	14.2	71.0		
27	S	8.2	5.9	85.9		
28	W	13.2	12.2	74.6		
29	W	14.7	13.4	71.9	Northwest Area	Steep undercut bank of Clam River near its junction with the St. Croix River, Town 40 North, Range 18 West.
30	Sd	5.8	8.3	85.9		
31	Wd	14.0	16.9	69.1		
32	Se	7.1	11.5	81.4		
33	We	12.8	18.2	69.0		
34	Sf	6.5	11.3	82.2		
35	Wf	11.3	16.7	72.0		
36	Sg	5.5	9.6	84.9		
37	Wg	11.2	18.5	70.3		
38	Sh	4.3	26.2	69.5	New London	Clay pit north of New London
39	Wh	5.8	27.5	66.7		
40	S	5.0	30.0	65.0		
41	Si	4.5	30.2	65.3		
42	Wi	8.4	29.9	61.7		
43	Sj	6.7	38.9	54.4	Manitowoc	Leach Company clay pit.
44	Wj	10.0	31.3	58.7		
45	Sk	5.2	39.0	55.8		
46	Wk	6.3	....	....		
47	W	6.5	35.8	57.7		
48	Sl	3.5	40.6	54.7		
49	Wl	6.6	34.1	40.7		
50	S	3.6	38.4	58.0		
51	S	4.5	38.3	57.2		
52	Sm	4.1	38.0	57.9	Two Rivers	Wave-cut banks along shore of Lake Michigan north of Two Rivers.
53	Wm	5.7	39.9	54.4		
54	Wn	6.1	34.3	59.6		
55	Sn	5.2	36.2	58.6		
56	S	5.4	40.0	54.6		
57	S	4.2	45.0	50.8		
58	W	6.8	29.6	63.6	Friendship	Exposure along small stream crossed by highway just south of Friendship
59	S	3.7	24.8	71.5		
60	W	6.8	33.5	59.7		
61	S	3.4	25.0	71.6		
62	S	6.4	5.3	88.3	Northwest Area	Road cut 300 paces South, N. E. 33, Town 39 North, Range 14 West
63	W	9.4	11.5	79.1		
64	S	5.0	4.9	90.1		
65	W	9.5				

*Where the winter and summer components are from the same varve, the letters W and S are followed by a common letter, as Wa and Sa.

†Over one hundred nearly complete carbonate analyses were accidentally destroyed. Samples were replaced wherever possible, and the analyses repeated. The missing percentages represent samples which could not be replaced.

Chemical Analysis of the Clay Samples

In Table I are presented the results of chemical analyses of the clay samples. The Fe_2O_3 content was determined by the permanganate method of titration, and it was found necessary to filter the sample in order to secure a proper end-point. The percentage of CO_2 was determined and this was divided by .459 to secure the approximate total percentage of the common carbonate minerals (assuming the samples contained 50% calcite and 50% dolomite, their total percentage is derived from the percentage of CO_2 by dividing the latter figure by .459). The silicates and insoluble were determined by difference. Duplicate samples were analyzed, and the percentages given below express the average percentages. The average difference between duplicate samples was .3%

From the analyses given in Table I it will be noted that:

(1) In every case the Fe_2O_3 content of the winter components is *higher* than that of the summer components of samples from the same exposure.

(2) In every case the silicate content of the winter components is *lower* than most of the summer components of samples from the Northwest, New London, and Friendship areas.

(3) The silicate content of the varve components from the other geographic areas appears to be about the same.

(4) The carbonate content of the winter components is *higher* than that of the summer components of samples from the Northwest, Friendship and New London (one slight exception) areas.

(5) The carbonate content of the winter components is *lower* than that of the summer components of samples from the Manitowoc exposure.

(6) The carbonate content of the varve components from the Two Rivers exposure is about the same.

It will also be noted that:

(1) The percentage of Fe_2O_3 in the samples of varved clay from the Northwest area is nearly double the percentage of Fe_2O_3 in samples of clay from each of the other areas. Samples of varves from the Northwest area have an average Fe_2O_3 percentage of 9%, whereas this figure for samples from each of the other areas is either 5 or 6%.

(2) The percentage of carbonate in the samples of varved clay from the Northwest area is approximately one-third the percentage of carbonates in samples of clay from each of the other areas. Sample of varves from the Northwest area have an average carbonate percentage of 12%, whereas this figure for samples from each of the other areas varies from 29 to 39%, averaging 33% total carbonates.

Summarizing the above, and interpreting the results in terms of geographic units, it appears that:

(1) Varves of the Northwest area are characterized by:

(a) A silicate content of the winter components which is *lower* than that of the summer components.

(b) A carbonate content of the winter components which is *higher* than that of the summer components.

(c) A percentage of Fe_2O_3 which is nearly double that of varves from each of the other areas. Percentage = 9%.

(d) A percentage of carbonates which is approximately one-third that of varves from each of the other areas. Percentage = 12%.

(e) An Fe_2O_3 content of the winter components which is *higher* than that of the summer components.

(2) Varves of the New London areas are characterized by:

(a) A silicate content of the winter components which is *lower* than that of the summer components.

(b) A carbonate content of the winter components which is *higher* than that of the summer components.

(c) A percentage of Fe_2O_3 which is one half that of varves of the Northwest area. Percentage = 5%.

(d) A percentage of carbonates which is approximately three times that of varves of the Northwest area. Percentage = 29%.

(e) An Fe_2O_3 content of the winter components which is *higher* than that of the summer components.

(3) Varves of the Manitowoc area are characterized by:

(a) A silicate content of the varve components which is approximately the same.

(b) A carbonate content of the winter components which is *lower* than that of the summer components.

(c) A percentage of Fe_2O_3 which is about one half that of varves of the Northwest area. Percentage = 6%.

(d) A percentage of carbonates which is approximately three times that of varves of the Northwest area. Percentage = 37%.

(e) An Fe_2O_3 content of the winter components which is *higher* than that of the summer components.

(4) Varves of the Two Rivers area are characterized by:

(a) A silicate content of the varve components which is approximately the same.

(b) A carbonate content of the winter components which is *higher* than that of the summer components.

(c) A percentage of Fe_2O_3 which is approximately one-half that of varves of the Northwest area. Percentage = 5%.

(d) A percentage of carbonates which is approximately three times that of varves of the Northwest area. Percentage = 39%.

(e) An Fe_2O_3 content of the winter components which is higher than that of the summer components.

(5) Varves of the Friendship area are characterized by:

(a) A silicate content of the winter components which is *lower* than that of the summer components.

(b) A carbonate content of the winter components which is *higher* than that of the summer components.

(c) A percentage of Fe_2O_3 which is one-half that of the varves of the Northwest area. Percentage = 5%.

(d) A percentage of carbonates which is more than twice that of varves of the Northwest area. Percentage = 29%.

(e) An Fe_2O_3 content of the winter components which is *higher* than that of the summer components.

(6) Varves of the Waupaca area[2] are characterized by:

(a) A silicate content of the winter components which is *lower* than that of the summer components.

(b) A carbonate content of the winter components which is *higher* than that of the summer components.

(c) A percentage of Fe_2O_3 which is one half that of varves of the Northwest area. Percentage = 4%.

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[2] Taken from B. A. Thesis, 1929. University of Wisconsin.

SAMPLE NO	LOCATION		HEAVY MINERALS																									
	GENERAL	SPECIFIC	UNKNOWN	OPAQUE	ZOISITE	ZIRCON	TOURMALINE	TOPAZ	TREMOLITE	TITANITE	STAUROLITE	SILLIMANITE	RUTILE	OLIVINE	MONAZITE	MUSCOVITE	KYANITE	HORNBLEND	HYPERSTHENE	GARNET	FLUORITE	EPIDOTE	ENSTATITE	CHLORITE	BIOTITE	ACTINOLITE	ANDALUSITE	APATITE
4	Northwest	Trade River	8	40		8		4					8	4				4		12		4						8
5	Area	Bridge	4	48		2	2						20	2			2	4		4		4	2					6
6	"	"		56		8	6		2				10					10		2		2	2					2
7	"	Grantsburg	4	42	2	2	2		2				7	2			2	8		6		12	2	2	4	2		2
		Clay Pit																										
10	"	Benson	2	26	2	6	4	2	2	2	6						6	10		8		18		2			2	2
11	"	Clay Pit	2	22		10	4	4					10			2	2	18		2		4	6	2	4	4		4
12	"	"	2	30		6	2	6		4		6	3	6			6	16		2	2	2		4		2		2
13	"	"		50		6	4	4			4		2	12				10		2		2			2	2		
16	"	Wood R. Bridge	4	36		8		8									4	20				10		6				4
17	"	Banks of	4	32		8	2	6						4				22		6		10		2		2		2
19	"	Wood River		48		8	4	12			4							12				4		2		4		2
21	"	"	4	44		10	2	2						4				16				6		2	2			8
23	"	St. Croix River	4	66		14	4	2										6										4
25	"	"	4	34	2	4	4	4										12				18	2	6				10
27	"	"	2	58		10	6	6					6					4				4	2					2
30	"	Clam River	4	30		4	6	2				2		4			4	16	2	6		8	6			2		4
32	"	"	4	38		4	2	4				4	4	2		2	2		16			8	2			2		6
34	"	"	2	50		2		10					4				4	10		4		4		2		2		6
36	"	"	4	36		2		2					2				8	10		2		12		2	2			18
38	New London	New London	14	42		10		16										4		2		6						6
40	Area	Clay Pit	4	26		4	4	4					2					24		4		10	2	4				12
41	"	"	4	42		2	2				2		2	2				20				8	2	8		4		2
43	Manitowoc	Leach Co	2	26							2	2	2					26				8		22				10
45	Area	Clay Pit		50			4				6							12		8		10		4		4		2
48	"	"	2	22		4		2	4			2						26		8		12		12				6
50	"	"	4	24		2	4	10										28		6		8		4				10
51	"	"		28	2								4															
52	Two Rivers	Forest Bed		68				4										8		2		14						4
55	Area	"		32		2	14	6	12				2		2				20				8					2
56	"	"	2	26		10	4				2		18					8				12		6		2		10
57	"	"	4	32		4	4					2	2					16		2		26					2	6
59	Friendship	Stream Exposure	4	36			2			2		6		4				14		6		18		6	2			
61	Area	"	2	32		6	2					4						16		8		18		4	2			6
65	Northwest Area	Road Cut		42	4	2	4	2					4					18		4		12			2	2	2	2

FIG. 2. Results of the petrographic analysis.

(d) A percentage of carbonates which is more than double that of varves of the Northwest area. Percentage = 27%.

(e) An Fe_2O_3 content of the winter components which is higher than that of the summer components.

From the above data it is clear that the varved clays from each geographic area possess definite chemical characteristics. The varves of the New London, Waupaca, and Friendship areas are very similar with respect to their chemical composition. The varves of the Northwest, Manitowoc, and Two Rivers areas are not only distinctly different from those of the other areas, but each of these possesses varves which are different in chemical composition from those of each of the other areas.

Petrographic Analysis of the Clay Samples

The same series[3] of samples which was analyzed chemically was made the subject of a petrographic analysis.

The samples were very thoroughly washed and rewashed (by decantation) in an ammoniacal solution, and the heavy mineral grains separated from the light grains by use of tetrabromo-ethane (specific gravity 2.9). The heavy minerals were then mounted on glass slides, with the use of Canada balsam.

A table presenting the results of the petrographic analysis of the heavy minerals is presented in Fig. 2. A study of this

Table II. *The average percentages of the common minerals found in the clays of each area.*

Mineral	(1) Northwest area	(2) New London	(3) Manitowoc	(4) Two Rivers	(5) Friend-ship	(6) Waupaca *
Opaque....	41	37	30	40	32	32
Hornblende	11	16	25	10	16	26
Epidote....	7	8	10	15	18	35
Zircon.....	6	6	1	7	6	1
Topaz.....	4	7	2	4	0	1
Apatite....	4	7	7	5	3	0
Rutile.....	4	1	1	4	0	0
Garnet....	3	3	6	1	8	1
Tourmaline	3	3	2	3	2	0
Kyanite...	2	0	1	0	0	1
Chlorite...	2	4	9	1	4	0
Olivine....	2	1	0	1	0	0

* See Ellsworth, E. W. and Wilgus, W. L. The Varved Clay Deposit at Waupaca, Wisconsin. Trans. Wis. Academy. Vol. XXV. 1929.

[3] The winter components were not analyzed for their mineral content.

table reveals that there are wide differences in the analyses of samples from the same geographic areas, and even from the same field exposure. It is very apparent that if the clays of a single area possess common mineral characteristics, these will be revealed only through the average of many petrographic analyses. Even then the individual differences appear to be so great, in some instances, that the value of such averages is very doubtful.

Table II presents the average mineral composition of clays of each of the areas studied. Only the important (abundant) minerals are included. A careful comparison of these analyses brings to light a grouping of the clays of these areas into two divisions: (1) The clays of the Northwest, Two Rivers, and New London areas, and (2) the clays of the Manitowoc, Waupaca, and Friendship areas. The average mineral composition of the clays of each of the divisions is presented in Table III.

TABLE III. *The average mineral composition of the clays of (1) the Northwest, Two Rivers and London areas; and (2) the Manitowoc, Waupaca and Friendship areas.*

Mineral	(1) Northwest Area Two Rivers Area, New London Area	(2) Manitowoc Area Waupaca Area, Friendship Area
Opaque	40%	32%
Hornblende	12%	22%
Epidote	10%	21%
Zircon	6%	3%
Topaz	5%	1%
Apatite	5%	3%
Garnet	2%	5%

While the table shows that clays of each of these divisions are quite different, the writer is inclined to attach no great importance to this grouping of the clays. If the common source material of the clays is indicated by their common petrographic characteristics, it is difficult to see how the clays of the Northwest, New London, and Two Rivers areas, could be derived from the same terranes, and different from those which were the source terranes for the clays of an overlapping area (division 2).

CORRELATION OF THE VARVED CLAY DEPOSITS

At three localities, Benson, Clam River and Wood River, the complete sections exposed were carefully measured in the field. Over five hundred varves were measured, and curves showing the variations in varve thickness were constructed from the field measurements. Copies of these curves were sent to Baron Gerard De Geer, at Stockholm, for correlation with the solar curve. Regarding the correlation which he made, De Geer states[4]:

"______a close comparison has made it possible to identify almost all of the varves on your diagrams. The similarity is so conclusive that your measurements will afford a valuable contribution to the material which I am collecting for a universal solar curve."

"______ By a detailed comparison you will find that the similarity of the curves does not leave any doubt as to their identification."

This correlation dates the varves of the Northwest area as having been deposited several hundred years after those at Waupaca and Manitowoc.

SUMMARY AND CONCLUSIONS

(1) This study has shown that samples of varved clay taken from different exposures of the same glacial lake bed in Wisconsin present similar chemical characteristics but their petrographic analyses show a wide range in variation.

(2) The chemical properties of the varved clays of the London, Waupaca, and Friendship areas have been shown to be similar, while those of the Northwest, Manitowoc, and Two Rivers areas are different from the three just mentioned. Thus the deposits of glacial lakes Oshkosh and Wisconsin are shown to be similar chemically, and were probably derived from the same source materials. The deposits in Glacial Lake Chicago and the glacial lake of Northwestern Wisconsin are different chemically, and each in turn is quite different from those of glacial lakes Oshkosh and Wisconsin.

(3) This study would tend to indicate that the chemical analysis of varved clays of scattered exposures is of value in

[4] Letter of May 3, 1930.

correlating them with one or another glacial lake basin in Wisconsin. The value of a petrographic analysis in this connection is very doubtful, due to the wide range in the variations of the mineral content of varves of even the same exposure.

(4) De Geer's correlation of the varves of the Northwest area assigns to them an age which is several hundred years younger than those of Glacial Lake Oshkosh exposed at Waupaca.

THE DISTRIBUTION OF CLOUDINESS IN WISCONSIN

ERIC R. MILLER

The six charts of this paper show by isonephs (lines of equal cloudiness) the bimonthly average percentage of sky covered with clouds during the ten years, 1920 to 1929 inclusive.

The most obvious feature of these maps is a region of maximum cloudiness in northwestern and north central Wisconsin, apparently derived from the western end of Lake Superior, or associated with the western front of the northern highlands. Another area of maximum cloudiness hangs over Lake Michigan. A belt of less cloudiness follows the valleys of the Mississippi, lower Wisconsin, Fox and its extension in Green Bay from September to April. From May to August this is obliterated by the union of the two regions of maximum cloudiness.

The annual march of cloudiness shows a single period, with a maximum in November and a minimum in August, differing from the rainfall periodicity with two maxima in Spring and Autumn.

The data from which these charts were prepared are the results of personal, not instrumental, observation. Some interesting statistical and psychological problems arose in working them up for charting.

"Instructions for cooperative Observers, Circulars B and C, Instrument Division, U.S. Weather Bureau, 7th ed." contains the following directions: "Par. 67. Character of the day.—The general character of the day from sunrise to sunset should be recorded as "clear" when the sky averages three-tenths or less obscured; partly cloudy, when from four-tenths to seven-tenths obscured; and cloudy when more than seven-tenths obscured. The average cloudiness from sunrise to sunset may be estimated with considerable accuracy by noting the degree of cloudiness on the scale given, as near sunrise as possible, between noon and 1 p. m. and near sunset; add these and divide by 3; the quotient will be the average cloudiness." The frequency of clear, partly cloudy and cloudy days is the sole form used in printed tables for the cooperative stations. To reduce these three figures to one for use in mapping the average cloudiness at Madison on the clear, partly cloudy and cloudy days was taken out (Table I). From these data conversion tables were prepared for each month. As a check on the use of Madison data throughout the state, the conversion tables were applied

TABLE I. *Average cloudiness at Madison, Wisconsin on clear, partly cloudy and cloudy days.*

Character of day	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Clear	1.3	1.3	1.2	1.6	1.4	1.7	1.8	1.4	1.2	1.0	1.1	1.2	1.4
Partly Cloudy	5.4	5.7	5.5	5.8	5.6	5.4	5.5	5.6	5.5	5.4	5.6	5.9	5.6
Cloudy	9.4	9.6	9.5	9.3	9.2	8.9	8.8	9.0	9.2	9.3	9.5	9.5	9.3

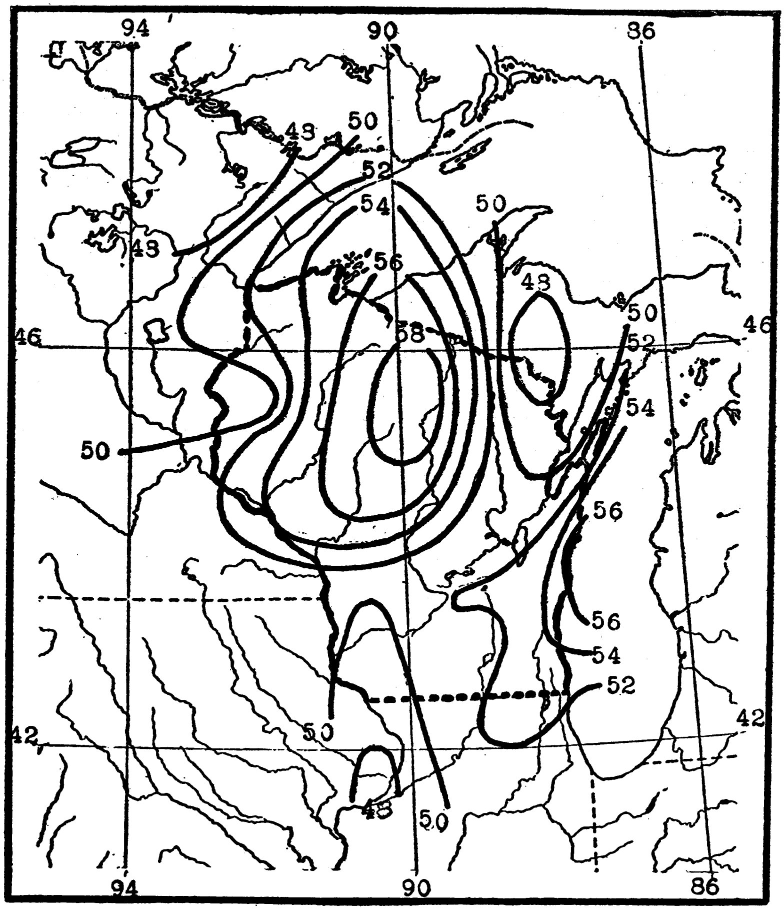


FIG. 1. Cloudiness, January–February, per cent of sky covered with clouds, 10-year average, 1920–1929.

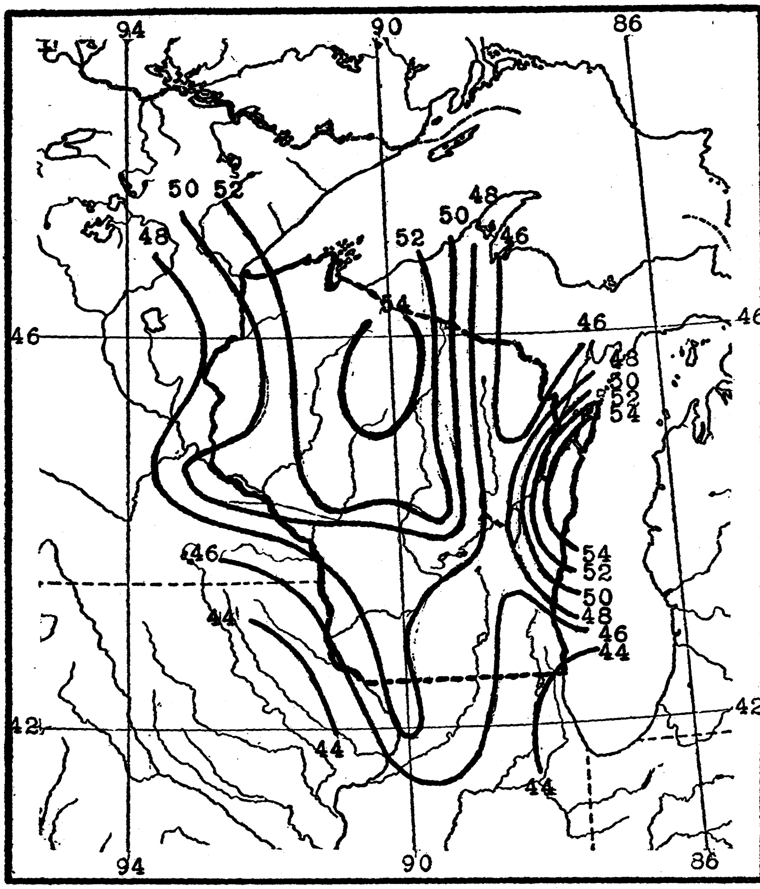


FIG. 2. Cloudiness, March–April, per cent of sky covered with clouds, 10-year average, 1920–1929.

to data on "Character of Day" from the regular Weather Bureau offices, where the average cloudiness is also recorded. The results of these comparisons appear in Table II. The average difference for the whole 60 pairs is -.07 or a little more than one per cent.

The records from the observing stations were first plotted individually, but were so inconsistent that it was necessary to smooth by averaging them five at a time and plotting the results at median points.

The results also averaged lower than the data from the regular observing stations of the Weather Bureau. The regular

TABLE II. *Comparison of monthly cloudiness, estimated from number of clear, partly cloudy and cloudy days, with observed data.*

Place	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Avg. Diff.
Milwaukee:													
estimated	6.1	6.5	6.1	5.6	5.1	5.3	4.7	4.7	5.4	5.7	6.7	6.7	
observed	6.0	6.5	6.5	5.9	5.1	5.2	4.7	4.6	5.3	5.6	7.0	6.9	–.1
Madison:													
estimated	6.1	6.4	6.3	6.2	6.0	6.1	5.1	5.0	5.6	5.4	7.0	6.6	
observed	6.2	6.6	6.4	6.4	5.8	5.9	5.2	5.0	5.4	5.4	7.0	6.9	–.0
Wausau:													
estimated	6.1	6.0	5.7	6.1	5.4	6.0	5.1	5.3	5.6	5.6	7.5	6.8	
observed	6.3	6.0	6.0	5.7	5.4	5.7	5.2	5.3	5.6	5.9	7.7	7.0	–.0
La Crosse:													
estimated	6.2	6.1	6.1	6.1	5.7	5.7	4.8	4.8	5.5	5.4	7.0	6.5	
observed	6.1	6.4	6.2	6.3	5.7	5.8	5.0	4.7	5.6	5.5	7.1	6.6	–.1
Green Bay:													
estimated	6.4	6.5	6.0	6.1	5.7	5.8	5.0	5.2	6.0	6.1	7.2	6.9	
observed	6.4	6.7	6.2	6.0	5.8	5.9	5.3	5.4	6.2	6.3	7.4	7.1	–.1

TABLE III. *Cloudiness at regular and cooperative weather stations.*

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Duluth	5.4	5.4	5.3	5.4	5.0	5.3	4.4	4.4	5.6	5.7	6.8	5.9
12 coop. obsrs.	5.1	5.0	4.8	5.1	4.5	4.7	4.0	4.1	5.3	5.1	6.3	5.7
Difference	.3	.4	.5	.3	.5	.6	.4	.3	.3	.6	.5	.2
Cornucopia, Wis.	6.5	5.6	5.3	5.8	4.5	4.9	4.6	4.6	5.6	5.4	6.7	7.0
Danbury, Wis.	4.6	5.0	5.1	4.9	3.6	3.6	2.8	3.1	5.3	5.0	6.4	5.7
Wausau	6.3	6.0	6.0	5.7	5.4	5.7	5.2	5.3	5.6	5.9	7.7	7.0
20 coop. obsrs.	5.4	5.4	5.1	5.1	4.6	4.7	4.1	4.2	5.1	4.9	6.6	6.1
Difference	.9	.6	.9	.6	.8	1.0	1.1	1.1	.5	1.0	1.1	.9
Prentice	6.1	5.9	6.3	6.6	5.7	5.7	5.2	5.1	6.1	5.9	7.5	7.0
Florence	4.0	4.1	4.1	4.0	3.5	3.2	3.1	3.0	3.7	3.6	5.3	4.5
Green Bay	6.4	6.7	6.2	6.0	5.8	5.9	5.3	5.4	6.2	6.3	7.4	7.1
11 coop. obsrs.	5.1	5.5	5.1	5.2	4.8	4.8	4.3	4.3	5.1	5.0	6.7	6.2
Difference	1.3	1.2	1.1	.8	1.0	1.1	1.0	1.1	1.1	1.3	.7	.9
Marinette	5.7	5.7	5.4	5.7	5.3	5.8	5.3	5.1	5.7	5.4	7.2	6.7
Menasha	3.5	4.3	3.6	4.0	2.9	2.7	2.5	2.4	3.3	3.7	5.4	5.0
Milwaukee	6.0	6.5	6.5	5.9	5.1	5.2	4.7	4.6	5.3	5.6	7.0	6.9
5 coop. obsrs.	5.1	5.5	5.2	4.9	4.1	4.1	3.3	3.6	4.5	4.8	6.3	6.0
Difference	.9	1.0	1.3	1.0	1.0	1.1	1.4	1.0	.8	.8	.7	.9
Plymouth	5.6	6.1	5.7	5.3	4.5	4.7	4.0	4.7	5.3	5.6	6.7	6.3
Fond du Lac	4.4	5.1	4.5	4.4	3.7	3.5	2.7	2.9	4.2	4.2	5.9	5.7
Madison	6.2	6.6	6.4	6.4	5.8	5.9	5.2	5.0	5.4	5.4	7.0	6.9
11 coop. obsrs.	5.0	5.5	5.2	5.1	4.4	4.4	3.8	3.8	4.7	4.8	6.0	5.9
Difference	1.1	1.1	1.3	1.3	1.4	1.5	1.4	1.2	.7	.6	1.0	1.0
Prairie du Sac	5.4	6.1	5.5	5.8	4.9	5.0	4.7	4.4	5.2	5.2	6.5	6.1
Brodhead	4.1	5.0	4.7	4.3	3.3	3.1	2.3	2.9	3.9	4.3	5.7	5.4
La Crosse	6.1	6.4	6.2	6.3	5.7	5.8	5.0	4.7	5.6	5.5	7.1	6.6
11 coop. obsrs.	5.0	5.3	5.1	5.1	4.6	4.6	3.9	3.9	4.8	4.6	6.3	5.7
Difference	1.1	1.1	1.1	1.2	1.1	1.2	1.1	.8	.8	.9	.8	.9
Meadow Valley	5.4	5.9	5.6	5.8	5.4	5.6	5.1	4.9	5.8	5.5	6.9	6.4
Hillsboro	3.9	4.2	4.2	4.3	3.6	3.9	3.5	3.4	4.0	3.8	5.1	4.6
Minneapolis	6.2	6.6	6.2	6.4	5.9	6.0	5.2	4.9	5.8	5.7	6.9	6.5
St. Paul	5.9	6.2	5.6	5.8	5.1	5.1	4.5	4.4	5.5	5.3	6.9	6.6
11 coop. obsrs.	5.3	5.4	5.1	5.2	4.6	4.9	4.1	4.1	5.1	4.9	6.1	5.7
Downing	6.7	6.9	6.0	6.3	5.4	6.6	5.4	5.5	6.4	5.9	7.3	7.5
Mora, Minn.	4.8	4.9	4.3	4.0	3.5	3.5	3.0	2.7	4.3	4.3	5.4	5.3

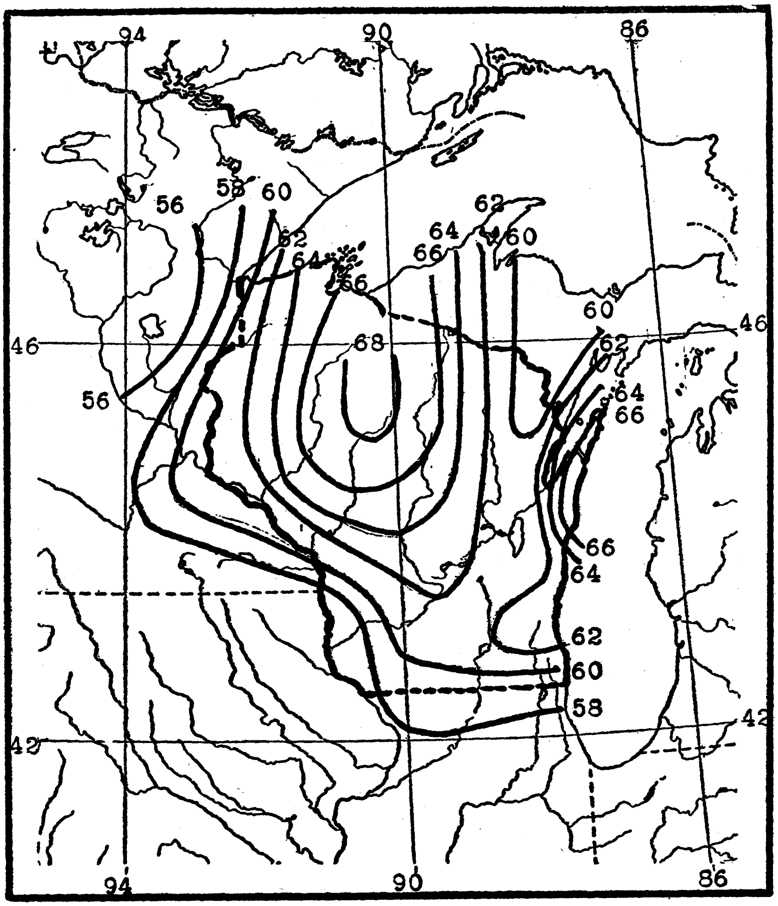


FIG. 3. Cloudiness, May–June, per cent of sky covered with clouds, 10-year average, 1920–1929.

observers are required to take account of all kinds of clouds in estimating cloudiness, so that a day with the sky covered with cirro-stratus cloud would be recorded cloudy although the sun were shining brightly all day, while the cooperative observer would doubtless record it clear. In order to show the characteristic difference between regular and cooperative observers in recording cloudiness, the data from each of the regular weather observing stations in or near the borders of Wisconsin is tabulated in Table III, with the average cloudiness at the cooperative stations in the vicinity, and records from one cooperative

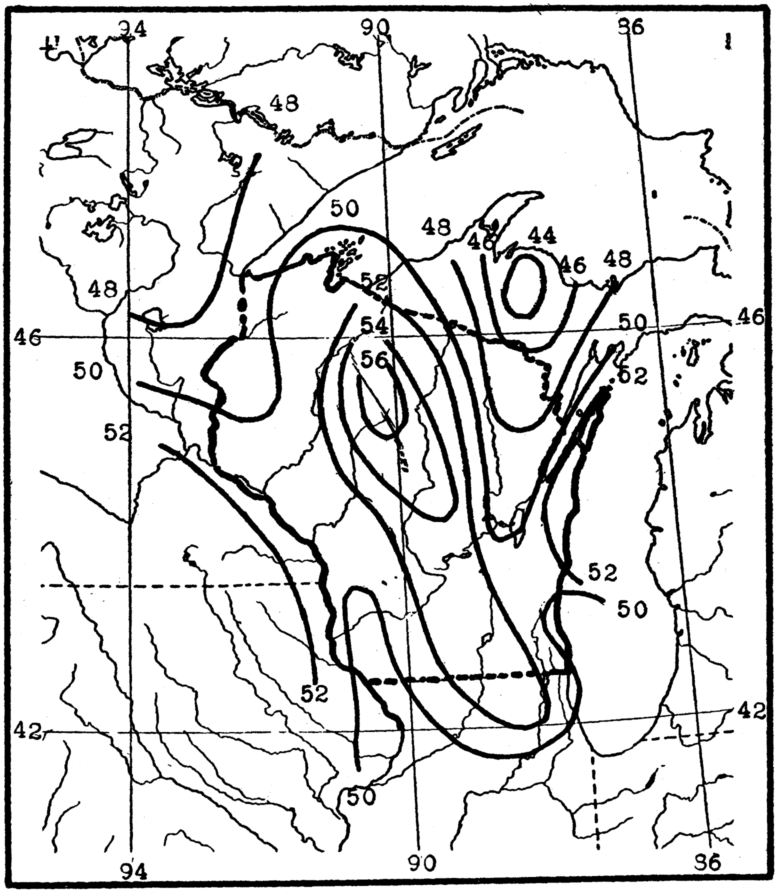


Fig. 4. Cloudiness, July–August, per cent of sky covered with clouds, 10-year average, 1920–1929.

observer with a high average and another with a low average. These data are for the same period, 1920 to 1929 inclusive.

The larger difference between Madison and the surrounding cooperative observers may be due to the pyrheliometric observations at Madison. These make the observer conscious of every faint cloud. Such observations are not made at the other regular stations. The less amount of cloud at St., Paul than at Minneapolis may be due to more smoke, since St. Paul is the easterly of the Twin Cities, and smoke is not included in the count of tenths of sky obscured by cloud.

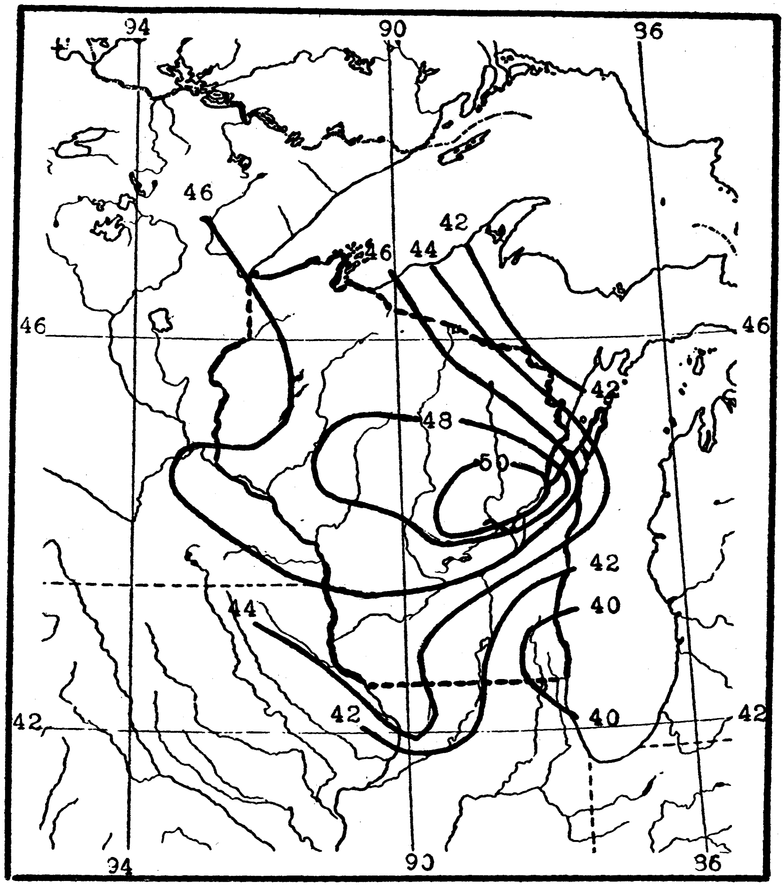


FIG. 5. Cloudiness, September–October, per cent of sky covered with clouds, 10-year average, 1920–1929.

All of the regular Weather Bureau stations, except Duluth, in and around Wisconsin are supplied with the Marvin thermometric sunshine recorder. This instrument nominally records the duration of bright sunshine. Actually its sensitiveness varies with the intensity of sunshine. One difficulty that has not been solved is that it requires readjustment to the intensity of sunlight as the latter varies from season to season. No quantitative method of doing this has been devised, hence the records of the instrument are not comparable one station with another, nor one time with another.

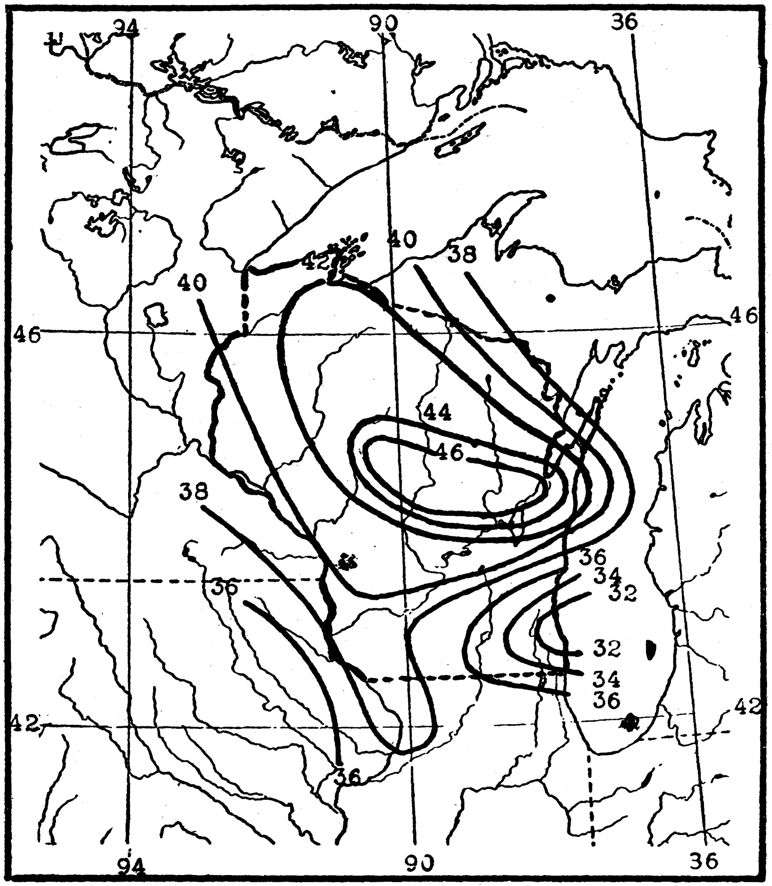


FIG. 6. Cloudiness, November–December, per cent of sky covered with clouds, 10-year average, 1920–1929.

In order to measure the relation of the records from the sunshine recorder to the cloudiness during daylight hours the coefficient of correlation between the cloudiness and the percentage of duration of sunshine in each month for 26 years at Madison, and for January and July at a number of other stations, has been calculated and set down in Table IV.

In the case of Charles City, the sunshine is recorded as varying with the cloudiness, in July, in 9 of the first 13 years of the record. Since then the two elements have varied in the opposite sense 11 years in 13, so that the coefficient would be much larger for the last 13 years.

TABLE IV. *Coefficient of correlation between monthly cloudiness and percentage of sunshine. (26 years.)*

Place	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Madison	-.86	-.82	-.77	-.67	-.51	-.56	-.50	-.50	-.79	-.89	-.85	-.89
Charles City, Iowa	-.71						-.23					
Chicago	-.94						-.78					
Des Moines	-.93						-.88					
Dubuque	-.97						-.77					
Escanaba, Mich.	-.92						-.90					
Green Bay	-.80						-.45					
La Crosse	-.88						-.78					
Milwaukee	-.72						-.64					
St. Paul	-.88						-.81					
S. Ste. Marie	-.94						-.84					
Omaha	-.73						-.72					

The diurnal march of cloudiness at Madison is shown in Table V.

The midday maximum in the warmer months would be accentuated if the convectional types of cloud only were included in

TABLE V. *Average cloudiness from bihourly observations, Madison, Wis. 1920–1929.*

Month	7 a.m.	9 a.m.	11 a.m.	Noon	1 p.m.	3 p.m.	5 p.m.	7 p.m.
January	6.3	6.7	6.3	6.0	5.7	5.8	5.5	5.1
February	6.4	6.8	6.8	6.5	6.6	6.4	6.3	5.7
March	6.0	6.6	6.5	6.3	6.4	6.4	6.2	5.8
April	6.3	6.3	6.4	6.6	6.4	6.6	6.6	5.9
May	5.7	5.6	5.8	6.0	5.9	6.1	5.9	5.8
June	5.6	5.8	6.2	6.3	6.2	6.2	5.8	5.4
July	4.8	5.2	5.7	6.0	5.6	5.4	4.9	4.8
August	4.7	5.0	5.1	5.0	5.1	5.1	4.8	4.6
September	5.3	5.4	5.4	5.5	5.5	5.6	5.3	5.0
October	5.2	5.5	5.6	5.5	5.6	5.5	5.2	4.6
November	6.8	7.1	7.2	7.0	6.9	7.1	6.6	6.0
December	6.6	7.0	7.1	6.8	7.0	6.8	6.2	6.0

the count. For comparison the average cloudiness at 7 a. m., noon and 7 p. m. at a number of cities is given in Table VI.

Observations are made at Minneapolis at noon and night only, at St. Paul morning and noon only, and as we have seen that there is a systematic difference it will be interesting to compare the data for the hour when records are made at both places (see bottom of Table VI.)

The average percentage of possible sunshine for each hour, at Madison for the 20 years 1911-1930, in Table VII, when compared with the preceding tables, shows the essentially dif-

TABLE VI. *Average cloudiness at 7 am, noon and 7 pm, 1920–1929 inc.*

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Duluth													
7 a.m. ...	5.3	6.1	5.2	5.2	4.4	4.1	3.7	4.4	5.1	5.3	6.5	5.8	5.1
Noon	5.3	5.4	5.2	5.2	4.7	5.4	4.8	4.4	5.6	5.5	6.5	5.7	5.3
7 p.m. ..	4.3	4.8	5.1	5.2	4.7	4.9	3.9	3.9	4.7	5.0	5.9	5.4	4.8
Wausau													
7 a.m. ...	6.6	6.9	5.9	5.6	5.3	5.6	4.7	5.0	5.4	5.9	7.1	7.1	5.9
Noon	5.6	5.7	5.8	5.7	5.7	5.8	5.4	5.0	5.3	5.2	7.3	6.5	5.8
Green Bay													
7 a.m. ...	6.3	6.9	6.0	5.9	5.3	5.4	4.6	5.0	5.4	6.1	7.2	7.1	6.0
Noon	6.0	6.6	5.9	5.8	5.5	5.9	5.3	5.1	5.9	5.8	7.2	6.9	6.0
7 p.m. ..	5.0	5.8	5.6	5.7	5.5	5.6	4.8	4.8	5.4	4.6	6.8	6.3	5.5
Milwaukee													
7 a.m. ...	6.2	6.6	6.0	5.5	4.8	5.0	4.4	4.5	4.8	5.4	6.5	6.7	5.5
Noon	6.1	6.4	6.3	6.0	5.2	5.4	4.9	4.7	5.4	5.6	7.0	6.8	5.8
7 p.m. ..	5.4	5.8	6.0	5.5	5.0	4.9	4.3	4.2	4.7	4.8	6.6	6.1	5.3
Dubuque													
7 a.m. ...	6.0	6.3	6.2	5.9	5.6	5.3	4.8	4.8	5.2	5.1	6.5	6.3	5.7
Noon	5.7	6.4	6.3	6.2	6.2	6.3	5.9	5.0	5.3	5.6	6.5	6.8	6.0
7 p.m. ..	5.4	5.8	6.0	5.9	6.2	5.0	4.7	4.7	4.9	4.7	6.1	5.6	5.4
La Crosse													
7 a.m. ...	6.2	6.3	6.1	5.9	5.4	5.6	4.8	4.7	5.1	5.4	6.8	6.8	5.8
Noon	6.0	6.0	6.1	6.2	5.8	5.8	5.2	4.7	5.5	5.8	7.1	6.5	5.9
7 p.m. ..	5.2	6.0	5.8	5.7	5.8	5.1	4.4	4.1	5.3	4.5	6.4	6.0	5.4
St. Paul													
7 a.m. ...	5.4	6.0	5.8	5.7	5.1	5.1	4.6	4.5	5.6	5.3	6.5	6.1	5.5
Noon	6.2	6.7	5.9	6.2	5.6	5.8	5.3	4.5	5.5	5.6	6.8	6.4	5.9
Minneapolis													
Noon	6.4	6.9	6.2	6.5	5.9	6.4	5.9	5.2	5.9	5.7	6.9	6.5	6.2
7 p.m. ..	5.5	5.7	5.9	6.5	6.1	5.8	4.5	4.3	5.3	5.4	6.4	5.9	5.6

ferent character of the records from the thermometric sunshine recorder. The high percentages in the middle of the day in summer directly contradict the observations of cloudiness. The November maximum of cloudiness does not appear.

In closing, it may be remarked that the chief cloud-making process, the cyclonic storm, has been eliminated by the method

TABLE VII. *Percentage of possible sunshine at Madison, Wis., 1911–1930, in the different hours of the day.*

Mo.	Percentage of possible sunshine in the hour ending:																Mean
	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	
Jan.				31	33	39	48	54	55	53	48	40	37	33			44
Feb.			35	34	37	46	54	59	59	54	45	40	37				48
Mar.		35	38	41	48	55	60	63	63	62	58	50	43	38	33		51
Apr.	39	42	42	46	54	60	64	65	66	64	60	54	44	38	34		53
May	47	47	49	54	61	67	69	70	69	68	65	58	51	45	41	37	57
Jun.	51	52	54	59	66	71	74	78	79	78	73	69	59	51	46	43	63
Jul.	54	55	57	62	71	77	80	81	82	82	78	72	65	58	51	47	68
Aug.	46	50	51	56	63	70	75	77	78	75	72	67	59	51	47	43	64
Sep.		46	47	49	56	63	67	69	68	67	64	56	50	47	42		58
Oct.		41	42	44	48	54	57	59	58	56	51	45	43	43			51
Nov.			34	31	34	39	45	47	47	45	40	36	35				40
Dec.				27	30	36	40	44	44	41	36	34	32				37

of tabulating the data. The maps of average distribution show the influence of the Great Lakes as nearby sources of moist air, the tables bring out the annual and daily cycles. It has been necessary to devote much space to the discussion of methods of observation because the observations are personal estimates, which could be better standardized only at an impossible expense.

THE DEVELOPMENT OF THE ICE CREAM FREEZER

H. A. SCHUETTE AND FRANCIS J. ROBINSON

Contribution from the Laboratory of Foods and Sanitation, Department of Chemistry, University of Wisconsin

The ice cream industry was one of the laggards in the mechanization process of the industrial revolution for reasons which are probably twofold. On the one hand it was slow to attain a full measure of growth—the first wholesale ice cream manufacturing plant was established by Jacob Fussel as late as 1851—and on the other the vicissitudes in the demand for the product had made an extensive early localization in factories economically infeasible. Not until the latter part of the past century did ice cream-making, firmly intrenched as it was, leave the small shop of the confectioner and the kitchen of the housewife for the factory of commerce. This move brought notable results for ice cream became the product of a vast and well regulated manufacturing industry, a standard article of commerce within the reach of every one, a food as well as a confection. Such changes cannot rightly be accounted for by any single factor; yet without the development of the modern freezer, which has enforced the advantages of large scale production, few of these changes would have occurred and ice cream might still be the simple "cream ice", the frozen cream of past years. It should prove worth while, therefore, to look into the history of ice cream freezers and thus gain an appreciation of an important phase in the development of the science of ice cream making.

Parkinson *(1)*, a "practical confectioner of Chestnut Street, Philadelphia" in 1849 prepared a statement of what was probably the typical equipment of American ice cream makers until the middle of the nineteenth century. The utensils requisite in that period for making this food, and descriptive comments thereon, are reproduced in his own words, to wit:

> "1. Pewter pots of various sizes suitable to the quantity of mixture intended to be frozen. Tin or zinc will not answer the purpose as it congeals the mixture too quickly without al-

lowing it a sufficient time to become properly incorporated, and forms it in lumps like hailstones.

2. Moulds.

3. Ice pails.

4. The spatula. This is an instrument somewhat resembling a gardener's spade; it should be made of stout copper and tinned, the blade being about four inches long by three in width, round at the end, and having a socket to receive a wooden handle; this is for scraping the ice cream, etc., from the sides of the pot as it freezes and for mixing it.

5. Either a large mortar or pestle, or a strong box and mallet for pounding the ice.

6. A spade wherewith to mix the ice and salt together, fixing your pails, etc.

7. A tin case or box—for keeping the ices in form of fruits after they are finished."

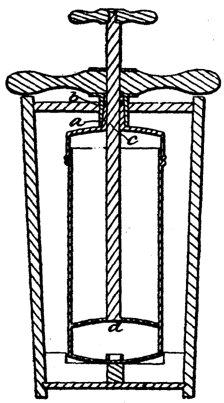
It has been reported *(2)* that a Nancy Johnson, the wife of a young naval officer, invented the ice cream freezer shortly after Dolly Madison had "officially" introduced this confection to Washington society. Be that as it may, however, letters patent on a similar piece of apparatus which was a combination of revolving freezer and beater were granted for the first time in the United States in 1848 *(3)*. The patentee, Young, before proceeding to describe his invention says in part,

> "Many devices have been resorted to for expeditiously freezing ice cream, but all have been found to be defective. The best now in use is that known as 'Johnson's', which is, like the ordinary freezer, with a revolving shaft inside it, on which are two curved wings that move round and cause the cream to revolve in the freezer and be thrown to the outside. I find that the operation is greatly facilitated by causing the freezer itself to move rapidly as well as the cream inside."

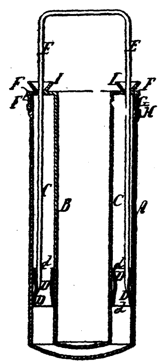
Describing his invention he says,

> "— there is a beater, full of holes, for the purpose of moving the cream inside, while by turning the freezer in the ice the ice is brought into close contact with it, and the cream is so put in motion as to bring all of it rapidly into contact with the cold sides of the freezer, which cannot be done by stirring alone, while, by the aid of the beater, the cream is lightened and the air allowed to come between the particles as effectually as by any other mode of stirring, and by their united operation the cream is more perfectly and speedily frozen and well beaten than by either of the modes now used."

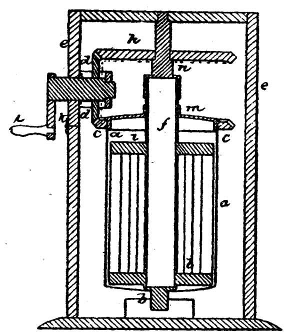
Two other patents on freezers were issued that same year. One of these *(4)* was for a device for congealing the cream in the annular space between two concentric cylinders when the smaller one was filled with ice and salt and the larger one was



W. G. Young
Patent No. 6501
May 30, 1848



A. H. Austin
Patent No. 5775
Sept. 19, 1848



H. B. Masser
Patent No. 5960
Dec. 12, 1848

surrounded by this refrigerant. The cream was agitated with a specially constructed plunger which served also to scrape the frozen product from the walls. The other *(5)* covered a contrivance which suggests in a sense the modern household freezer. In describing his invention, the patentee explains,

> "My invention consists in constructing a freezer so as to revolve the dasher within it and also at the same time to turn the freezer in an opposite direction within the ice box, and I form the spindle in the dasher large and hollow for the purpose of containing ice."

During the next year two more freezers were invented. The first *(6)* one embodied a minor structural feature for making more convenient the use of a central freezing core, but the second *(7)* one apparently did not suffer from a lack of novelty. The inventor proposed to freeze the cream by forcing through it a current of cold air for he says,

> "The nature of my invention consists in causing a blast of chilled air to permeate, be diffused through and disturb the liquids and materials of which ice cream is made. I chill the

> blast by drawing it from the atmosphere into a receptacle which is made to surround the sides and bottom of the vessel containing the ice or refrigerating mass. Within this vessel the can containing the liquids and materials of which the ice cream is to be formed is placed, and the interval between the two packed with ice or the freezing compound. The air may be drawn off at a central opening in the bottom of the air chamber. A section of elastic hose is fastened in any usual way to the opening and similarly attached at its other end to an ordinary double bellows, mounted on a suitable frame. . . . To the nozzle of this bellows I append a tube which passes down through the middle of the ice cream tub and separates into four or more horizontal branches open at their ends at the bottom of the same. . . The chilled air blast being forced through the horizontal branch tubes, bubbles up through out the whole body of the liquids and materials intended for ice cream and besides abstracting caloric from them by its own immensely extended contact therewith, it thoroughly disturbs them and brings every portion of the same into continually repeated contact with the refrigerating surfaces . . .".

Coffeen, the inventor of this device, was perhaps ahead of the times and public taste with his air bubbling freezer that would turn out ice cream with a scandalously high over-run—providing, of course, that the contrivance would function as claimed. And granting that it did work, the product made with it would probably not have enjoyed any large measure of popularity. Until almost the end of that century people generally had looked upon ice cream as a luxury rather than as a readily ingested food, as an out-of-the-ordinary dessert whose sweetness should remain upon the palate as long as possible. The turn of the century still found a popular preference for a "heavy" ice cream as the following comment *(8)*, which incidentally gives us a hint of the then accepted and genteel mode of eating this dessert, testifies:

> "Ice cream made from cream containing but 16 or 20 per cent of fat will lack body or character; when put into the mouth it immediately vanishes which is disappointing to the lover of good ice cream."

France, already rich in ice cream lore, is also in a position to claim the distinction of having granted early patents, for it is recorded that such were issued to Garnier (1829), to Koymans (1833), and to Columbin (1837) *(9)* for various types of freezers. Such early inventive activity was no doubt stimulated by the perfection and popularity which ice cream had attained in its capital for the Parisians of that day were already well acquainted with this dish through the ice cream "parlors" operated by the Italians Velloni and Tortoni.[1] From Paris, too, comes what is probably one of our earliest *printed* recipes (1768) for making this confection *(10)*.

Like the simplicity-loving Yankees, the British did not develop the niceties in manufacturing this table delicacy until some years later yet they did anticipate American invention in this field by letters patent granted a Thomas Masters in 1843 *(11)* for a device whose name suggests that the uses to which it was adapted were many. It consisted essentially of a pewter can containing a three-bladed revolving "spatula" and surrounded by a "frigorific material" such as ice, new-fallen snow, or mixtures of the two and common salt, sal ammoniac, salt petre, ammonium nitrate, or calcium chloride. Lacking any of the latter the operator might also use, *mirabile dictu,* diluted sulphuric, concentrated muriatic or sulphurous acids in conjunction with the snow! The inventor summarized his claims in the following words:

> "Firstly, freezing, cooling, churning, and ice-preserving may be conjointly and simultaneously effected.
>
> Secondly, the solution of which ice creams and water ices are made may be beaten up while in the act of freezing.
>
> Thirdly, the apparatus may be applied occasionally to some of the said purposes only and occasionally to others, and
>
> Fourthly, each of the several parts of the apparatus may be used with advantage either in combination or separately."

Master's invention of a freezer, or "churn", was soon followed by the publication of his "Ice Book" (1844) which was "a compendious and concise history of everything connected with ice from its first introduction into Europe as an article of luxury" up to the time of the appearance of this treatise. Besides which it was "a valuable collection of the most approved recipes for making superior water ices and ice creams at a few minutes

[1] In 1798 Velloni established a magnificent place, outfitted with lounges, mirrors and marble top tables, for the serving of ice creams, etc., at 10 Boulevard des Italiens and similar branches throughout the city. He failed in this enterprise and turned it over to Tortoni, an employee, who made a success of the business while poor Velloni committed suicide. Tortoni retired in 1825 with an annual income of 100,000 francs.

notice." The publication of this book, which is deemed to be the first one devoted exclusively to water ices and ice cream, was marked by the simultaneous appearance of newspaper advertisements circulated in the hope of educating the public in the use of his freezers.

Since the evolution of the modern ice cream freezer is due in a large measure to improvements in refrigeration processes, a brief history of the latter will reveal some of the paths of that evolution. In 1755 *(12)* a Dr. William Cullen is reported to have developed an apparatus for freezing water by evaporation in a partial vacuum. It was not until the middle of the following century, however, that mechanical refrigeration began to assume any practical value for then Perkins (1834), Twining (1850) and Harrison (1857) devised refrigerators that employed the principle of evaporating a highly volatile liquid under diminished pressure. Certain inherent defects in the construction of the machinery necessary in operating with the liquids in question apparently led to the development of the ammonia refrigerator by Carre (1859). His apparatus consisted of two strong vessels, a boiler containing a concentrated ammonia solution and an evaporating chamber, joined together with a tube. In appearance and operation it was not unlike the small domestic refrigeration unit which was developed several years ago for use in those communities where electricity is not available. To operate this machine, one raised the temperature of the saturated ammonia solution solution in the boiler to 130-150°C. whereupon the liberated ammonia, driven over under high pressure into the water-cooled refrigerator, condensed to a liquid. The boiler was then placed in cold water, the effect of which was a fall in temperature which was accompanied by a reduction of the pressure in the apparatus, a rapid vaporization of the liquid ammonia in the refrigerator and the production of an intense cold. Reece (1869) improved upon this machine in that he used brine flowing through a coil within the refrigerator.

German brewers are said to have employed artificial refrigeration as early as 1867. Its use in sugar refineries, meat-curing houses and for cold storage also began at a rather early date, but the only really extensive application which these machines found was in the manufacture of artificial ice. And in this connection it may not be untimely to add the thought that it requires no stretch of the imagination to picture a union of the ice cream and artificial ice industries in that the latter found in the former a convenient outlet for its surplus or unsaleable ice.

Until the beginning of the twentieth century freezing an ice cream mix with manually operated equipment was still a common procedure as witness the following reminiscence *(13)* of the "good old days" by F. D. Hutchinson, one of Iowa's pioneer manufacturers: "I remember on the Fourth of July of 1890 we shipped out three hundred gallons all frozen by hand power." The advent of commercial electricity made it possible, of course, to utilize a cheaper form of energy in turning the freezer crank.

The precursor of the modern brine freezer and storage tank is probably of the type said to have been operated by Edward Walker in 1902 *(14)*. During the same year the Miller brine freezer was developed and this was soon followed by the Miller-Tyson machine. The reception accorded this type of freezer by industry is reflected rather well in the following conservative prediction, *(15)* "It may safely be assumed that the brine freezer will never put the ordinary ice and salt freezers out of business. It bids fair to play an important part in the development of the industry from this time on." Commenting further on this subject the author says, "There are some manufacturers who still pin their faith to the steam engine regardless of cost of installation and operation, the complicated nature of the plant required and the necessity of employing a licensed engineer, who, in all likehood, will ever be found too busy to do more than look after his engine. This is difficult to understand for surely economy is as necessary in the ice cream business as elsewhere."

During the first decade of the present century there were in use *(16)* several types of commercial freezers. Among them were the vertical-batch ice freezer, a very common type which at that time had already been in use for many years; a similar one cooled with brine; a horizontal brine machine which seems to have been much preferred because excellent results were obtainable with it and little trouble experienced in getting "swell" *(17)*; and an open horizontal continuous brine freezer which was said to possess advantages not shared by the closed machines, especially in affording the operator an opportunity

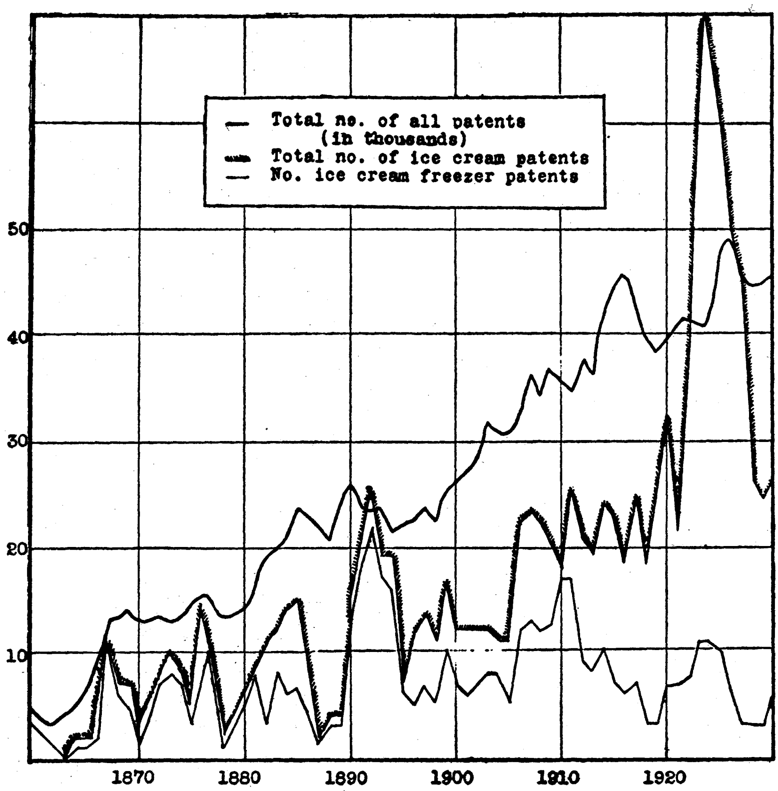


FIG. 2. Patents annually granted in the United States during the period 1860–1930.

for a more frequent use of the thermometer. Within the past fifteen years the temperature of the refrigerants of the batch type of freezers has been lowered by five to ten degrees, a change in technic which has resulted in an improved texture of the product and an increased output per unit of freezer capacity.

A direct expansion or ammonia type of freezer was brought out in the year 1914 but it was not well received until, some eleven years later, it had undergone numerous modifications and improvements. The new machine immediately became popular. It has certain advantages over the brine type of freezer for, among other reasons, refrigeration losses were materially reduced.

One more freezer requires mention for it enjoys a wide popularity. The machine in question is the so-called horizontal con-

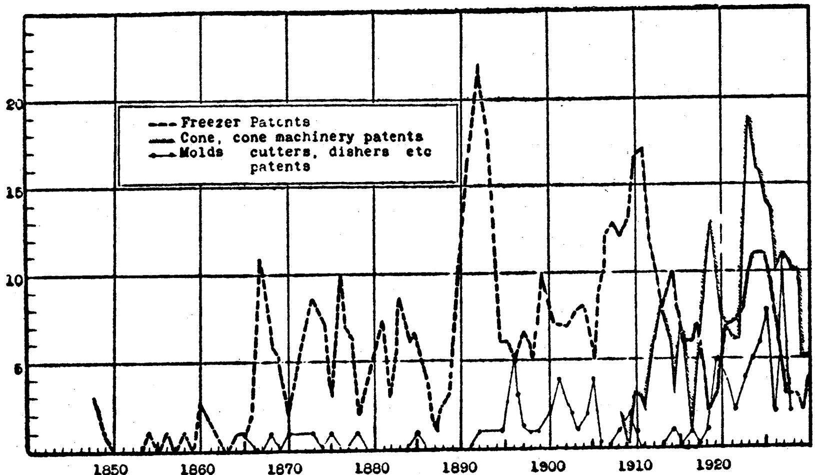


FIG. 3. Number of certain types of patents pertaining to ice cream issued in the United States 1848–1930.

tinuous disc freezer which was introduced in 1928 as an improvement over early machines of this type which were not entirely satisfactory, although the theory of their operation was attractive. The ice cream made in them invariably was coarse and fluffy. Not so, however, the present machines with

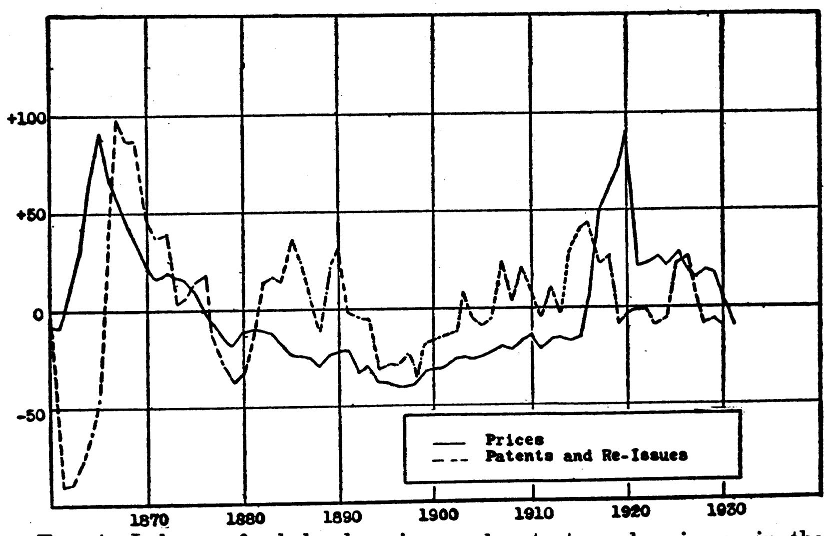


FIG. 4. Indexes of wholesale prices and patents and re-issues in the United States 1860–1930. (Expressed as percentage deviations from the trend in multiples of the standard deviation.)

which the manufacturer is able to turn out a uniform product of a fine texture because of a more rapid freezing at a low temperature.

The degree of perfection which freezers have attained is reflected in the general high state of development of ice cream manufacturing processes. A glance at Figure 2 shows that the annual number of ice cream freezer patents has not exhibited any appreciable upward long time trend within the past twenty years, perhaps because the need and the possibility for the improvement of freezers was not as large as for the improvement of other ice cream equipment. If we look into this more closely, we find, indeed, that during the same period the number of patents for equipment and apparatus designed primarily to facilitate the distribution and consumption of ice cream has shown a large increase. From this one is led to believe that ice cream manufacturers have pursued the general course of others in shifting the main emphasis from improvements in the methods of production to improvements in the methods of distribution.

Inventive activity, as exemplified by the number of patents granted, in the ice cream field seems to follow the course of general inventive activity except that the amplitude of the cycli-

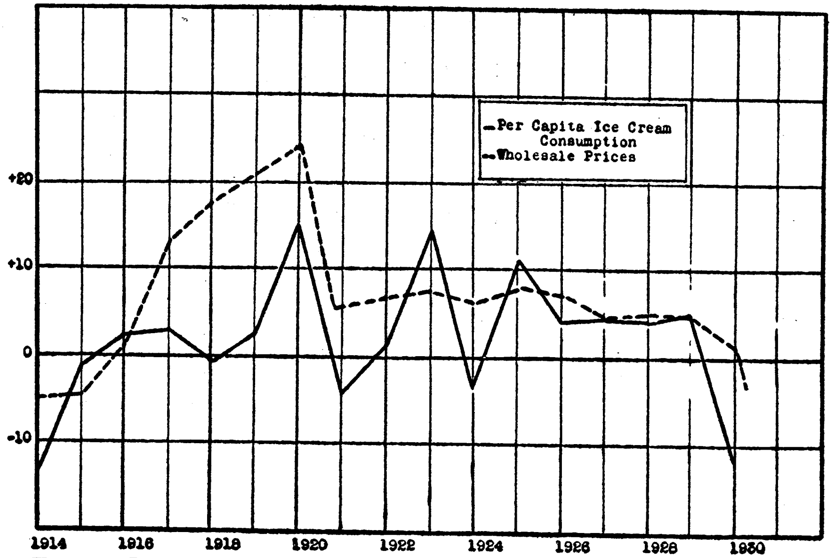


FIG. 5. Indexes of per capita ice cream consumption and wholesale prices in the United States 1914–1930.

cal fluctuations in the ice cream patent curve is larger (Figure 3). This latter circumstance may be attributed in part to the small numbers which we are considering—less than fifty—but a more definite meaning is suggested when we consider the large positive degree of correlation existing between the percentage deviation from the trend of patents and of wholesale commodity prices (Figure 4). Ice cream is a food yet not an essential one, hence its consumption (Table I) is dependent at least to some extent upon the purchasing power of the consumer.

TABLE I. *Annual per capita consumption of ice cream in the United States for the period 1914-1930.*

Year	Gals. per capita	Year	Gals. per capita
1914*	1.68	1922	2.43
1915	1.88†	1923	2.68
1916	2.08	1924	2.50
1917	2.07	1925	2.80
1918	2.14	1926	2.77
1919	2.49	1927‡	2.85
1920	2.46	1928	2.92
1921	2.28	1929	3.02
		1930§	2.80

*Data for the period 1914–1926 from Pirtle: A Handbook of Dairy Statistics, Bur. Agric. Economics, U. S. Dept. Agric., 1928, p. 5.

†Interpolated. Data for the period 1927–1929 from Bur. Agric. Economics, U. S. Dept. Agric.

‡Yearbook of Agriculture, U. S. Dept. Agric.

§Based on estimate made by Bureau of Service and Statistics of the International Association of Ice Cream Manufacturers. *Ice Cream Trade J.*, 27, No. 4, 56 (1931).

While other commodities show a more ready adjustment to changes in the price level, the retail price and the composition of ice cream as fixed by statute, definition or public taste remain nearly constant over long periods of time. Thus it becomes apparent that ice cream consumption should be doubly "sensitive" to changes in general prices or economic conditions. Figure 5 bears out this assumption.[2] Minor fluctuations in ice cream production could perhaps be attributed to weather conditions; but the diversity of climate over the United States furnishes us with a fairly reliable statistical sample. Thus it is to be noted that while the weather conditions in 1930 were "good"

[2] It must be borne in mind that the manufacture of ice cream was partially restricted during the period of the World War which accounts for the low level of production for the years 1916-1919.

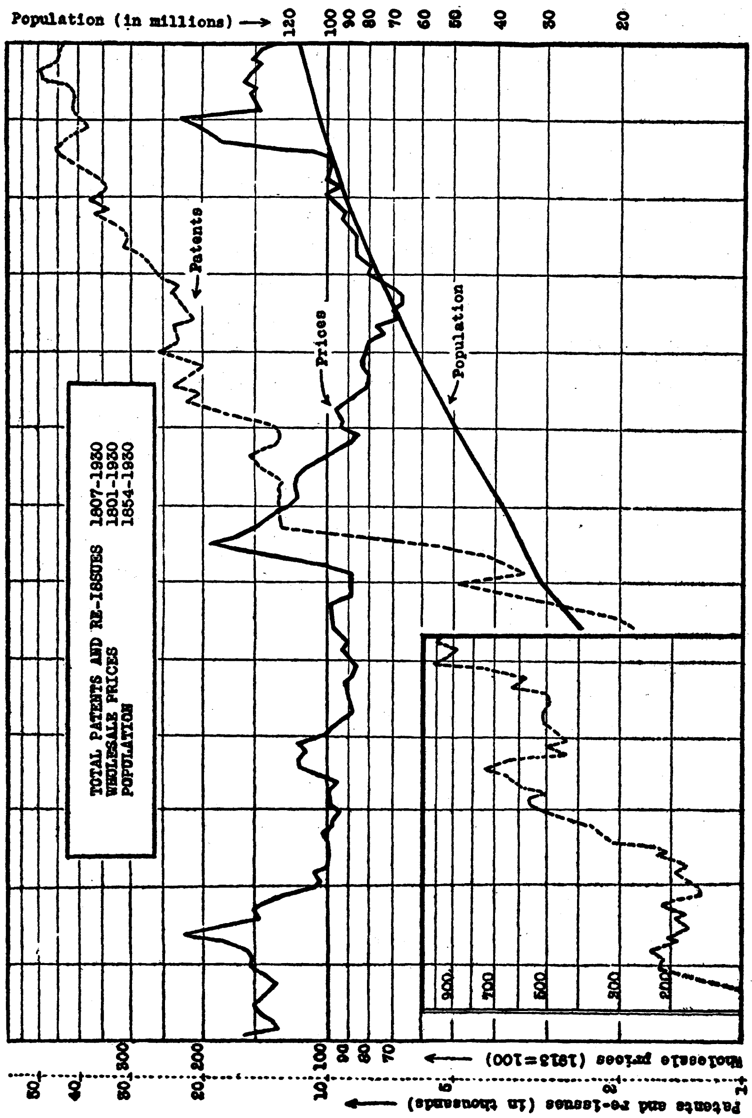


FIG. 6. Patents, population and wholesale prices of ice cream in the United States.

from the manufacturers' point of view, a sharp decline in production occurred during that year *(18)*.

Turning again to a comparison of the number of patents granted annually and wholesale commodity prices (Figure 6), we may conclude that there is a definite relation between variations in these two factors. Yet the question of which is the forerunner or the cause in initiating the movements of the cycles can not be answered as readily as would appear at first sight; for the simplest view that high prices and a high general level of business activity should result in a larger demand for inventions does not explain the sharp drop in the number of patents granted in 1919 and 1928, years just preceding the "depressions". As a possible explanation of this it may be suggested that during the height of a business cycle there is a diminished incentive for seeking better methods of production; businesses almost run themselves and everyone runs a business. The smaller annual variations in the number of patents granted probably are an indication of the intimate connection between the forces operating in the patent market and the forces operating in other markets. As a fruitful source for speculation we can see in these curves a relation between invention and money; a graphic illustration of Dean Hoover's view on the utility of wars in stimulating inventive activity (but certainly not ice cream inventions); and a hint of the extent of future ice cream freezer development.

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SHAKESPEARE'S USE OF ENGLISH AND FOREIGN ELEMENTS IN THE SETTING OF *THE TWO GENTLEMEN OF VERONA*

JULIA GRACE WALES

I

INTRODUCTION

Professor O. J. Campbell has given us an enlightening study of the influence of Italian comedy in *The Two Gentlemen of Verona*.[1]

"A search for time-worn commonplaces of Italian comedy in this drama," he says, ". . . has convinced me that practically all its important structural elements are patterned after recurrent features of 'Italian comedy'." Among the features having prototypes in Italian plays or scenarios he discusses the conflict of love and friendship, the rescue of the faithless friend by the faithful, the repentance of the former, the double wedding at the end; the balcony scene, the lady disguised as a page, attached to one of the *amorosi*; the pathetic irony of scenes in which the supposed page talks with or of her master, an errant lover; the Petrarchan conceits, discourses on love, etc., the intermezzi of clowns and "the contrast between the quick-witted rogue and the slow-witted rustic", the appearance of the dog on the stage.

Professor Campbell finds "Shakespeare's contribution to the growth of romantic comedy, not in new forms of dramatic ingenuity, but in the emotional deepening of elements taken bodily from a drama which was at once comedy of intrigue and highly complicated farce".

The present study of *The Two Gentlemen of Verona* may be said to deal with this "emotional deepening", and especially with one of the factors through which it seems to come about —namely, Shakespeare's treatment of the setting.

[1] "The Two Gentlemen of Verona and Italian Comedy", in *Studies in Shakespeare, Milton, and Donne,* by members of the English Department of the University of Michigan. New York, 1925.

Recent historical studies of Shakespeare, Professor Campbell's and others, serve to reawaken in our minds a number of related questions. How are the near and the distant, the native and the foreign, the particular and the universal related in Shakespeare's art? How far did the audience imagine a foreign scene, how far an English scene? And whether the scene was in fancy English or foreign, how did Shakespeare combine and utilize the elements of concrete reality out of which he fashioned it? What imaginative end did these elements serve? And wherein does a study of them deepen and vivify our sense of the action as a whole? These are general and more or less speculative questions, to which precise answers can perhaps never be given, since it is only in flashes that we can hope to get back imaginatively into the mind of Elizabethan playwright or audience. Yet it may be worth while to bring together again the data we have, in the hope that brooding over them may here and there give some new insight.

In his edition of 1921, Sir Arthur Quiller-Couch thus summarizes the facts about the play:

> So far as we know, this play first achieved print in the folio of 1623, where it follows *The Tempest*. But it stands first on the list of six comedies mentioned by Meres in 1598, and all internal tests, of craftsmanship and versification, point to a date considerably earlier yet. It is indeed, by general consent, a youthful production: and we may safely place it somewhere near the threshold of Shakespeare's dramatic career.

Yet in this play Shakespeare was already combining English and foreign elements in a shot fabric of dazzling weave. Here where the workmanship is comparatively obvious, it is worth while to seek hints of his later process.

II

Elements of the Setting

The Travel Motif. In the first scene of *The Two Gentlemen of Verona* Valentine's defense of travel, though it looks toward Italy, is obviously English color. Valentine is going far away "to see the wonders of the world abroad". Though, as far as we know, Shakespeare never left England, it is clear that he knew well the feelings, the reactions and counter-reactions, of going from the inner to the outer world, from country to town, and back to country and back again to town. Now he may in his mind have linked these transitions with the greater ones of going from one's own land to foreign ones and coming home again. Hence it may not be too fanciful to seek references in the plays to transitions from country to town as throwing light on the wider experiences of his imaginary travellers.

"Home-keeping youths have ever homely wits".[2] It is interesting to find the words in a play which intervenes between *Love's Labour's Lost* and *As You Like It.* The former play may very well be an outcome of the surface fascination of town and court life for the country boy and his first reaction against their shallowness. A student of *Love's Labour's Lost* has commented on a "certain tiredness in the tone"[3] of the play, but it is the healthy tiredness of energetic youth, which will throw off a momentary obsession. In *The Two Gentlemen of Verona,* a spirit of energy and adventure predominates. In *As You Like It,* later on, Shakespeare has a rollicking holiday in the country and comes back to town ready for the year's work.

T. F. Ordish shows that such a holiday was an easy matter:

> A young man from a provincial town, used to rural sights and sounds, endowed with the love of nature, would not pine for the green fields at home; he would take a walk into the country. He would find a forest of Arden on the heights of Hampstead and Highgate; he could take part in a sheep-shearing celebration at even less distance. As he walked through the city on business bent, a flock of wild duck or teal might wing over his head with outstretched neck, taking flight from the marshes on the north of the city, to the river or the marshes on the south between Paris Garden and Lambeth.[4]

The link between *The Two Gentlemen of Verona* and *As You Like It* is found again in Valentine's soliloquy in the forest, which foreshadows the meditations of the banished Duke:

> How use doth breed a habit in a man!
> This shadowy desert, unfrequented woods,
> I better brook than flourishing people'd towns:
> Here can I sit alone, unseen of any,
> And to the nightingale's complaining notes
> Tune my distresses and record my woes.[5]

[2] *The Two Gentlemen of Verona.* I. i. 2.
[3] A Girton student, in a class discussion.
[4] T. F. Ordish, *Shakespeare's London,* 1897, pp. 7-8.
[5] *The Two Gentlemen of Verona.* V. 4. 1-6.

Thus Valentine, making a virtue of necessity, finds charm and wholesomeness in the simple life. Of the simple and conventional life much has been written in connection with *As You Like It.* Yet in re-reading the play with the present question in mind—Do Shakespeare's English journeys throw light on the continental journeys of his characters?—one is struck afresh by the number of passages dealing with town and country, life at home, and life abroad. It will serve our purpose to turn aside and examine these for a moment.

In the first scene of *As You Like It,* Orlando is chafing because, while his brother is kept at school,[6] he himself is "kept rustically at home",[7] must "feed with hinds",[8] is trained like a peasant,[9] and is not allowed "such exercises as become a gentleman".[10] He wishes to go disguised to the place of wrestling[11] and "try the strength of" his "youth".[12]

Among the older men who are associated with Orlando's youthful adventures, are three who have seen life, each in his own way: (1) Adam, (2) the banished Duke, and (3) Jaques, who, whatever his years, is constitutionally an "old gentleman",[13] as Audrey calls him. Old Adam's age is "as a lusty winter, frosty but kindly",[14] because he has disciplined himself by the standards of "the antique world",

> When service sweat for duty, not for meed,[15]

not according to "the fashion of these times,"

> Where none will sweat but for promotion;
> And, having that, do choke their service up
> Even with the having.[16]

He offers Orlando what he has saved for his own time of need,[17] for the old and poor the height of sacrifice. To change his place is for Adam a painful uprooting:

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[6] *As You Like It.* I. 1. 5.
[7] *As You Like It.* I. 1. 7.
[8] *Ibid.* I. 1. 20.
[9] *Ibid.* I. l. 71.
[10] *Ibid.* I. l. 75.
[11] *Ibid.* I. l. 131
[12] *Ibid.* I. ii. 182.
[13] *As You Like It.* V. 1. 4.
[14] *Ibid.* II. iii. 52, 53.
[15] *Ibid.* II. iii. 57, 58.
[16] *Ibid.* II. iii. 60-62.
[17] *Ibid.* II. iii. 30-45.

From seventeen years till now almost fourscore
Here lived I, but now live here no more.
At seventeen years many their fortune seek;
But at fourscore it is too late a week.[18]

He has never grown reconciled to the condition of the world

Where what is comely
Envenoms him that bears it.[19]

"To most men," says Einstein, "the court spelled misery and disappointment. . . . The poetic tradition of satire against court life revived from Alexandrian example was in part conventional, in part caused by disappointment".[20] We may compare the similar comment of E. K. Chambers: "It is precisely this discontent of the finer spirits with the condition of the court life that gives its burden to the pastoral comedy of *As You Like It*".[21]

The conclusions of the banished Duke are similar. Whatever his inward regrets, he has found the woods "more free from peril than the envious court",[22] and "the churlish chiding of the winter's wind"[23] a better counsellor than the flatterers of prosperous days.[24] As for Jaques, he has carried into the wilderness a "complex" of resentment against the world. The song sung by the courtly foresters as they lay the cloth[25] for a picnic dinner voices the optimism of the Duke's view of the simple life:

Who doth ambition shun
And loves to sit in the sun,
Seeking the food he eats
And pleas'd with what he gets,
Come hither, come hither, come hither.
Here shall he see
No enemy
But winter and rough weather.[26]

Jaques' addition is more cynical,[27] and the song of Amiens gives the key of their melancholy:

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[18] *Ibid.* II. iii. 71-74.
[19] *Ibid.* II. iii. 14-15.
[20] Lewis Einstein, *Tudor Ideals,* New York, 1921, p. 45-7.
[21] E. K. Chambers, *Shakespeare's England,* 1916, I. iii, p. 82.
[22] *As You Like It.* II. i. 4.
[23] *Ibid.* II. i. 7.
[24] *Ibid.* II. i. 10-11.
[25] *Ibid.* II. v. 31.
[26] *Ibid.* II. v. 40-47.
[27] *Ibid.* II. v. 52-59.

Blow, blow, thou winter wind,
Thou art not so unkind
As man's ingratitude . . . . .

Most friendship is feigning, most loving mere folly:
Then, heigh-ho, the holly!
This life is most jolly.

Freeze, freeze, thou bitter sky,
Thou dost not bite so nigh
As benefits forgot:
Though thou the waters warp,
Thy sting is not so sharp
As friend remembered not.[28]

Orlando has been touched with the same infection, though his disposition has escaped remarkably well.

Why should this a desert be?
For it is unpeople'd? No:
Tongues I'll hang on every tree
That shall civil sayings show.
Some how brief the life of man
Runs his erring pilgrimage,
That the stretching of a span
Buckles in his sum of age;
Some of violated vows
'Twixt the souls of friend and friend.[29]

The country atmosphere of *As You Like It* is of course romanticized, partly conformed to the conventions of the pastoral; yet there are flashes of realism. Orlando who is "inland bred",[30] having made the city man's little mistake about the country, hastens to apologize:

Pardon me, I pray you:
I thought that all things had been savage here;
And therefore I put on the countenance
Of stern commandment.[31]

Touchstone gets into similar difficulties, but Rosalind is more tactful:

Touchstone. Holla, you clown!
Rosalind. Peace, fool: he's not thy kinsman.
Corin. Who calls?
Touchstone. Your betters, sir.

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[28] *As You Like It.* II. vii. 174-6, 181-189.
[29] *Ibid.* III. ii. 133-143.
[30] *Ibid.* II. vii. 106-109.
[31] *Ibid.* II. vii. 96

Corin. Else are they very wretched.
Rosalind. Peace, I say.—Good even to you, friend.
Corin. And to you, gentle sir, and to you all.[32]

Later in the play, Corin and Touchstone discuss the manners of shepherds and courtiers for some seventy-five lines.[33] Corin, though literal-minded, is no fool. He has the wit to point out that "those that are good manners at the court are as ridiculous in the country as the behaviour of the country is mockable at the court." And Touchstone, while pretending to mock at Corin's rusticity, helps him to prove further that rustic manners can be intrinsically at least as good as courtly manners, that the latter are often artificial and not as fastidious as they seem.

The conclusion of the whole matter — country versus town, the simple life versus the court, home versus the great world — is left somewhat obscure. Several pairs of our foresters wrangle over some side of it. Jaques easily talks down the optimism of the Duke and is as easily worsted by the common sense of Rosalind.

Jaques . . . . but it is a melancholy of mine own, compounded of many simples, extracted from many objects, and indeed the sundry contemplation of my travels, which, by often rumination, wraps me in a most humorous sadness.
Rosalind. A traveller! By my faith, you have great reason to be sad. I fear you have sold your own lands to see other men's; then, to have seen much and to have nothing, is to have rich eyes and poor hands.
Jaques. Yes, I have gained my experience.
Rosalind. And your experience makes you sad. I had rather have a fool to make me merry than experience to make me sad; and to travel for it too! [34]

In the end all hie themselves cheerfully back to public life — with two exceptions. The comic, impulsive, suspicious, worried, highly suggestible little tyrant, Frederick, has, quite in character,

put on religious life,
And thrown into neglect the pompous court.[35]

[32] *As You Like It.* II. iv. 66-70.
[33] *Ibid.* III. ii. 11-90.
[34] *As You Like It.* IV. i. 15-29.
[35] *Ibid.* V. iv, 187-188.

And Jaques, his intellectual curiosity piqued by this conversion, will stay to consider matters further at the Duke's abandoned cave.

These ideas are of course commonplaces of the pastoral.[36] But commonplaces themselves reveal contemporary reality, and may betray the mind of a man whose nature it was to assimilate the imaginative elements of his age. Einstein's comment on this point is interesting:

> English country life became established on its modern basis during the Sixteenth Century. The novel conditions of stability and order, the diffusion of luxury and the rise of a new propertied class, were all circumstances which made for its appreciation and which in turn were to be productive of a domesticated idea of nature. Another cause contributing to this result was entirely intellectual. The revival of classical antiquity and its lesson both direct and indirect, through text, translation, and continental influence, added to this feeling, and by an odd paradox, dusty manuscripts helped to arouse the sense of nature. Men loved the country more after they had read Theocritus and Virgil, while so artificial a growth as the pastoral comedy could by devious paths throw back to nature.[37]

Let us return now to the play which deals directly with travel. Valentine feels that a love affair is the only excuse for not setting forth to see "the wonders of the world abroad".[38] Proteus also takes seriously the privilege of seeing "rare and noteworthy objects"[39] in travel, and in his soliloquy commends his friend's course rather than his own:

> He after honour hunts; I after love:
> He leaves his friends to dignify them more;
> . . . .
> Thou, Julia, thou has metamorphosed me—
> Made me neglect my studies, lose my time,
> War with good counsel, set the world at nought.[40]

Similarly in a later scene, the father of Proteus is reproached for suffering his son to spend his youth at home:

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[36] For the vogue of the pastoral in England see E. K. Chambers, *English Pastorals*, London, 1906; A. H. Thorndike, "The Pastoral Element in the English Drama before 1605", *Mod. Lang. Notes*, XIV (1899), 4, p. 227; W. W. Greg, *Pastoral Poetry and Pastoral Drama*, London, 1906; C. F. Tucker Brooke, *The Tudor Drama*, 1911, Ch. viii & Bibliography.

[37] Einstein, *Tudor Ideals*, New York, 1921, p. 269.

[38] *The Two Gentlemen of Verona*, I. i. 6.

[39] *Ibid.* I. i. 13. Cf. Bacon: *Of Travel.*

[40] *Ibid.* I. i. 64-65, 67-69.

While other men of slender reputation,
Put forth their sons to seek preferment out;
Some to the wars to try their fortunes there;
Some to discover islands far away;
Some to the studious universities.
For any or for all these exercises
He said that Proteus your son was meet,
And did request me to importune you
To let him spend his time no more at home,
Which would be great impeachment to his age
In having known no travel in his youth.[41]

W. J. Rolfe's note on this passage is illuminating. He quotes Gifford, *Memoirs of Ben Jonson:*

> The nobility, who had been nursed in domestic turbulence, for which there was now no place, and the more active spirits among the gentry, for whom entertainment could no longer be found in feudal grandeur and hospitality, took advantage of the diversity of employment happily opened, and spread themselves in every direction.

Rolfe also quotes Knight:

> Here in three lines we have a recital of the great principles that whether separately, or more frequently in combination, gave their impulses to the ambition of an Essex, a Sidney, a Raleigh, and a Drake.[42]

Antonio has already been hammering on the same notion:

I have considered well his loss of time
And how he cannot be a perfect man,
Not being tried and tutored in the world;
Experience is by industry achieved,
Then, tell me, whither were I best to send him?[43]

In these two passages there is an interesting fusion of two appeals to the English imagination — that of the New World and that of the Italian Renaissance, the appeal on the one hand of the undiscovered and untried, and on the other of a mature and traditional civilization. I do not here mean to imply that the effect of the Italian Renaissance in England was conservative — it was, of course, in the main, far other — but only that Englishmen turning to the continent of Europe, came under sophisticated, not primitive, influences. Part of the apparently

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[41] *Ibid.* I. iii. 6-16
[42] See pages 130-32 and page 11.
[43] The Two Gentlemen of Verona. I. iii. 19-24.

magical power of the sixteenth century in literature is due to the fusion of these two forms of appeal. Neither alone could be such a source of power. Emphasis upon the old, emphasis upon the new, will lead equally to decadence. It is the impact of new upon old that is the creative force. In our own period of conscious intellectualization, conservative and radical tendencies too often eye each other across a gulf of controversy. The more intuitive Elizabethan instinctively combined the two.

There is a certain contrast between the wholehearted belief in the value of travel as expressed in these passages and the Puritan fear of the evil influences abroad expressed by Ascham and others.[44] Yet in both there is the same tendency, perennially English, to consider practical and ethical values. The traveller went forth to improve himself, to study and report systematically, and to do a service for his nation.

To quote a contemporary writer on travel:

> Wherefore both in these days and in all ages heretofore the best and wisest, the chiefe and noblest men, have alwaie travelled, as by example might be proved, were it not tedious to entreat of a matter so presumptuous . . . so to profite, and inrich themselves with experience and true wisdom, and especially to benefite their owne proper and natural countrie, they traversed over and travelled into other countries.[45]

The young man is warned against pleasure-seeking and admonished to take his opportunities seriously.

In *The Traveiler of Jerome Turler* we find similar sentiments: Travel should help a man

> to discern what is good and bad in his owne countrey . . . He shall also have more skyll how to entertain strangers, and understand the maners of men more perfectly, and according to his affayres and dealinges with them, applie himself unto them according as the circumstances of time and place shall require.[46]

No less striking than this motive of the conscientious tourist is that of the adventurous pioneer. In the sixteenth century

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[44] See Einstein, *The Italian Renaissance in England*, New York, 1902, Chapter IV, "The Italian Danger". Einstein quotes Ascham, Sandys, Dallington, Nashe, Gascoigne, Harrison, Mulcaster, and others. Cf. Clare Howard, *English Travellers of the Renaissance*, London and New York, 1914, Chapter III, "Some Cynical Aspersions upon the Benefits of Travel", pp. 50-70.

[45] *A Direction for Travellers.* Taken out of Justus Lipsius and enlarged for the behoofe of the right honourable Lord, the young Earle of Bedford, being now ready to travell. London, 1592. (Brit. Mus. 10024. Acc. 5) p. 3.

[46] *The Traveiler of Jerome Turler*, London, 1575. See also, W. B. Rye, *England As Seen by Foreigners*, London, 1865, pp. xix-xxviii, quotations from several early English works in praise and censure of foreign travel.

the pioneer was still discoverer rather than "settler". And yet even at this time are discernible the two qualities which have together made the "settler"—the love of home mixed with the love of adventure, the home basis of contentment itself giving depth and vitality to the wandering spirit—the tendency to go and return, or if return is not feasible, to build stable New Englands overseas. This double quality is remarked by a nineteenth century student of English life.

> That Englishmen are such hardy explorers, such persistent settlers of the waste places of the earth, attests their love of home. They go, not because they wish to go, but because they hope to return with enough to establish a home in England. . . . . To have a house and bit of garden of one's own, an Englishman or woman will submit to the utmost economy of expenditure, and the most rigorously accurate system of accounts. It may be a social prejudice or an ingrained habit of the British stamp of mind, but whatever it is, there can be no doubt, that the Englishman's ideal of life is to be a free man and master of the castle of his own house.[47]

The quality is of course not merely English but a characteristic contribution of the Northern races to human development.

The Elizabethan attested his belief in the value of travel by willingness to face the dangers it entailed.

> If dangers do environ thee,

says Proteus,

> Commend thy grievance to my holy prayers,
> For I will be thy beadsman, Valentine.

These dangers were considerable in England.

> Travellers were exposed to a variety of risks . . . . Apart from the dangers incident to the state of the roads and bridges, there was the possibility of encountering highway robbers . . . . Organized gangs infested exposed places . . . . Travellers who carried no great valuables were as liable to attack as the richly-laden. But highwaymen were commonly credited with merciful treatment of the very poor.[48]

The dangers were at least as great in Italy.

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[47] Price Collier, *England and the English,* 1909, p. 173.

[48] *Shakespeare's England,* London, 1916, Vol. I, Chap. vii, "Land Travel", by Charles Hughes, pp. 207-8. See also bibliography for the chapter—Harrison, Moryson, etc.

> The long series of invasions rendered many parts of Italy almost impassable to women, and since the larger and better policed states of the sixteenth century still bestowed their *mauvais sujets* on their neighbours, who no longer welcomed the exiles with open arms, the banished men either hired themselves as secret agents to do murder that could not now be openly contrived, or took to the hills and preyed on the wayfarer.[49]

Perhaps even greater dangers were encountered in journeying from England to Italy. On the dangers to travellers Clare Howard in *English Travellers of the Renaissance*[50] cites many contemporary references showing that travellers meet with dangers not a few by sea and land, from highwaymen and other robbers, to disease and exposure. Which of these kinds of journeys had Shakespeare uppermost in mind when he thought of the dangers of travel? We can perhaps safely conjecture that in his imagination there was a mixture of all three. But is there any evidence within the play that, whatever the casual suggestions from which his picture of travel was made, he tried to imagine and meant his audience to imagine not a journey up to London from Stratford, nor a voyage from England to Italy, but a journey literally from Verona to Milan?

That to all intents and purposes Valentine sailed from London and landed at some Italian port, seems at first glance, to find support in allusions to distance,[51] dangers,[52] letters,[53] absent friends,[54] remittances of money,[55] and especially in the fact that the journey is by water.[56] This last, however, is less significant than it seems. For Sullivan, in his researches on the waterways of Northern Italy in the sixteenth century[57] has shown that the facts do not contradict anything that Shakespeare has implied as to a possible river route from Verona to Milan. The Adige was the main highway from Verona to

[49] Wm. Boulting, *Women in Italy,* London, 1910, p. 209.

[50] 1914, p. 47.

[51] *The Two Gentlemen of Verona,* I. iii. Proteus is to travel in company.

[52] *Ibid.* I. i. 16.

[53] *Ibid.* I. i. 57.

[54] *Ibid.* II. iv. 59.

[55] *Ibid.* I. iii. 58-59.

[56] *The Two Gentlemen of Verona,* II. iii.

[57] See Edward Sullivan, "Shakespeare and the Waterways of Northern Italy," the *Nineteenth Century,* 1908, August, 64, p. 215. Sullivan cites numerous passages from Italian works of the fifteenth and sixteenth centuries and from the works of travellers regarding these river routes. See also M. P. Tilly, "Shakespeare and Italian Geography," *Jour. Eng. and Germ. Phil.,* 1916, p. 454. Tilly quotes *The Pilgrimage of Sir R. Guylforde, Knight to the Holy Land,* A. D. 1506, which describes just such a journey by river and canal.

many Italian cities. Similarly Sarrazin finds realistic allusions in Saint Gregory's Well, the forest near Milan, "the rising of the mountain foot that leads toward Mantua."[58] While these allusions are perhaps not definite and precise enough to justify the conclusion that Shakespeare had at this time much detailed knowledge of Italy, they are at least convincing evidence that he meant to give a degree of local color to the play.

Thus, however we came here, we are, as we enter into the action of the play, to feel ourselves in Italy; and it has not been stage scenery, nor even any considerable mass of detailed allusions,[59] such as Shakespeare uses in later plays, but chiefly the general talk of journeys by sea and land, that has wrought the magical transition and wafted us hither. This, then, for the purposes of the play itself, is the significance of so marked an emphasis on the glamor of foreign scenes. It has none the less a wider significance: it reflects an ever present element in the Elizabethan consciousness and in Shakespeare's own imagination, — the absorbing and many-sided interest, individual and national, materialistic, romantic, and cultural, of travel and adventure in the New World and the Old. Nor is this spirit inconsistent with homelier passages in *As You Like It* and other plays. Shakespeare's imagination found everywhere more than enough to keep it busy, and it is easy to believe that he was well content to spend his days in his own country. But had circumstances favored his going abroad no man would have enjoyed seeing the world more than he. And no doubt it delighted him to pick up knowledge of distant places and to imagine the scenes of his plays in foreign lands.

Minor Romantic Machinery. A Shakespearean scholar has casually expressed the opinion that Shakespeare uses Italian color chiefly as romantic background,[60] much as the Balkan states have been used in popular English novels, as a region

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[58] G. Sarrazin, "Neue Italienische Skizzen zu Shakespeare," *D. S. G. Jahrbuch*, Vol. XXXIX (1903), pp. 62-68. See also E. Koeppel, Jahrbuch, XLIII, p. 247. Koeppel attempts to demolish Sarrazin's theory of St. Gregory's Well as an indication that Shakespeare knew Italy. He points out that in passages cited by Sarrazin there is no actual mention of a well, and that as the hospital was for the plague, there probably would not be a famous spring in such a dangerous neighborhood. See also a full note on this passage in the Arden Edition, p. 81.

[59] See Sir Edward Sullivan's discussion of the names in the play—not all Italian. He notes that almost no Italian words or phrases occur. See "Shakespeare in Italy", *Nineteenth Century*, LXXXIII, p. 146.

[60] Miss Janet Spens in conversation. I quote with permission.

far away, not too precisely known, favorable to all kinds of adventure. The present play, especially, lends color to this theory through the large proportion of details of purely romantic machinery as compared with more realistic furnishing: a disguise for a lady,[61] including doublet and jerkin,[62] her hair to be knit up with silken strings,[63] a chamber window,[64] a lady's picture,[65] two rings,[66] a sealed sonnet,[67] banishment,[68] a serenade,[69] a thicket where a nightingale sings,[70] a lost glove,[71] a corded ladder provided with anchoring hooks,[72] an upper tower under lock and key,[73]

> And built so shelving that one cannot climb it
> Without apparent hazard of his life,[74]

a long cloak,[75] a friar's cell,[76] an abbey, a postern by the abbey wall,[77] an emperor's court,[78] an out-law infested forest,[79] a robber's cave.[80]

These may seem homogeneous elements, but they have a certain variety. They include many of the stock properties of the romantic drama. In the unscalable tower and the dungeon we have further accessories of mediaeval romance. It is to do the same romantic service that the monastic elements come in. These, like the "corded stair", are suggested by Brooke's *Romeus and Juliet.*[81] Silvia goes to Friar Patrick's cell as Juliet to Friar Laurence's. But the Friar Laurence of this play, wandering through the forest in the garb of his order, muttering his penitential prayers, is more alert and effectual than the

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61 *The Two Gentlemen of Verona.* II. vii. 39
62 *Ibid.* II. vii. 49.
63 *Ibid.* II. vii. 45.
64 *Ibid.* IV. ii.
65 *Ibid.* Also IV. iv. 122.
66 *Ibid.* IV. iv. 137 ; V. iv. 96.
67 *Ibid.* III. i. 140-150.
68 *Ibid.* IV. i. 170-187.
69 *Ibid.* IV. ii.
70 *Ibid.* V. iv. 1-6.
71 *Ibid.* II. i. 3, 4.
72 *Ibid.* III. i. 117-118.
73 *Ibid.* II. i. 36.
74 *The Two Gentlemen of Verona.* III. i. 115-116.
75 *Ibid.* III. i. 131.
76 *Ibid.* V. ii. 42.
77 *Ibid.* V. ii. 9.
78 *Ibid.* I. iii. 27.
79 Act IV. Scene i.
80 Act IV. iii. 12.
81 Arthur Brooke, *Romeus and Juliet,* Ed. J. J. Munro, London, 1908, 11.813-816.

benevolent priest of the later play. No doubt he was none the less suggested by Brooke's Franciscan Friar Laurence.

> This barefoot friar girt with cord his grayish weed,
> For he of Francis' order was, a friar, as I rede.[82]

Brooke has no mention of the abbey. We possibly have the hint for that in Montemayor's *Diana:* "My brother and I were brought up in a nunnerie, where an aunt of ours was abbesse."[83] "The postern by the abbey wall" no doubt suggested the parallel phrase "behind the abbey wall" in *Romeo and Juliet.* Ordish says: " 'Out at the postern, by the abbey wall' was a line in all probability suggested by a London locality."[84] Eglamour has been associated with these ecclesiastics because of his vow of chastity and because his helping Silvia to escape is a remote parallel to Laurence's intended aid to Juliet. But he is really a very different element and an interesting one. Quiller-Couch and Wilson[85] believe the "adapter", not Shakespeare, to be responsible for his disappearance from the play.

Now these romantic elements themselves, especially window scenes and disguises, were, as Professor Campbell has so fully established, material of Italian plays and stories, and were associated in the English mind with an Italian background. Also the window, and in some cases the disguise,[86] actually played an important part in the life of the Italian woman of the sixteenth century. Boulting speaks of the balcony as a means of flirting.[87] Similarly the opportunity that her religious duties gave the young girl to get away from the imprisonment of her father's home into the thrill of the outer world,[88] was a privilege dearly cherished and often abused. And, of course, in a general sense, Roman Catholic color is proper to Italy. Thus on the whole, it is safe to say that in this play, at least to some extent, Shakespeare uses romantic machinery for Italy as well as Italy for romance.

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[82] *Ibid.* 11.565-6.

[83] Hazlitt's *Shakespeare's Library,* Vol. I. p. 278.

[84] *Op. cit.,* p. 172.

[85] See p. 115-6, below. Cf. *Op. cit.,* p. xvi-xvii.

[86] See Victor Owen Freeburg, *Disguise Plots in Elizabethan Drama,* New York, 1915.

[87] Boulting, *Woman in Italy,* pp. 117-118.

[88] See Boulting, p. 119. "Church was the accepted covert for a woman to wait in ambush, make eyes and display her charms."

The Emperor's Court. But two elements of the romantic machinery are less certain in their geographical suggestion: the Emperor's Court, and the Wood.

Before we turn to these let us pause to note a view put forward by T. F. Ordish in *Shakespeare's London:*

> The fact that Shakespeare took his plots and stories from foreign sources, retaining the names and *locales* of the originals, has proved a more effective disguise to posterity than it was to the Elizabethans. With them the device was taken for granted—it was the mode of the time. It constituted part of the "play," with the audience, to detect the reality beneath the mask, the actual beneath the fictitious.[89]

Thus Ordish would perhaps say of the Emperor's Court that it is in reality only the court of Elizabeth, where the would-be courtier

> shall practice tilts and tournaments,
> Hear sweet discourse, converse with noblemen,
> And be in eye of every exercise
> Worthy his youth and nobleness of birth.

Tilts and tournaments are mentioned in *Diana.*

> When he had, therefore, by sundrie signes, as by Tylt and Tourneyes, and by prauncing up and down upon his proude jennet before my windowes, made it manifest that he was in love with me (for at the first I did not so well perceive it) he determined in the end to write a letter unto me.[90]

Shakespeare no doubt gathered most of his knowledge of courts and courtiers from his chance acquaintance with men of the world. There was a literature of the subject open to him, however. That Shakespeare knew Castiglione's *Book of the Courtier* finds evidence in *Much Ado.*[91] T. F. Crane in *Italian Social Customs of the Sixteenth Century* gives us an idea of the extensive influence of *The Book of the Courtier* in Europe. He comments on Johnson's high opinion of *The Courtier,* and adds a quotation which might well be a commentary on the general situation in the present play:

> "I observed" says Boswell, "that at some courts in Germany, there were academies for the pages, who are the sons of gentle-

[89] T. Fairman Ordish, *Shakespeare's London,* 1897, p. 140.

[90] *Shakespeare's Library,* 1875, I, p. 279.

[91] See M. A. Scott, "The Book of the Courtier: a possible Benedick and Beatrice." *P. M. L. A.,* V. 16 (1901), pp. 475-502.

men, and receive their education without any expense to their parents." Dr. Johnson said, that manners were best learned at these courts. "You are admitted with great facility to the prince's company, and yet must treat him with respect. At a great court, you are at such a distance that you get no good." [92]

Einstein says:

> Halfway between the learning of the scholar, and the practice in sport and arms of the knight, was the new Renaissance idea of a gentleman's education. Borrowed largely from the Italian and French writers, though also from Spanish and even Polish, a body of opinion grew up for the training of those who aimed to fit themselves to be of service to their country. They were advised to study laws and treaties, civil policy and moral sciences. .... For the rich, travel became the approved method, and even those of small means like Sidney went from country to country in search of experience. The system was at best haphazard.[93]

He goes on to speak of Humphrey Gilbert's plan of an academy.

> The programme of studies embraced civil government and finances, martial exercises, and surgery. This was the real humanist ideal applied to life with its vision of a New England venturing into distant lands. Gilbert had realized the promise of what the colonies were to mean for British expansion, but his suggestion met with no response from the most parsimonious of rulers.[94]

In our play other gentlemen of good estimation have journeyed to the court to salute the sovereign. Quiller-Couch and Wilson quote Stevens:[95]

> Shakespeare has been guilty of no mistake in placing the emperor's court at Milan. Several of the German emperors held their courts there occasionally.

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[92] T. F. Crane, *Italian Social Customs of the Sixteenth Century* (1920), Chap. IV, pp. 205-7. See also (referred to by Crane, p. 205) Sir Walter Raleigh's introduction to Hoby's translation of Castiglione, London, 1900, *passim*. See also M. A. Scott, *Elizabethan Translations from the Italian*, Boston and New York, 1916, descriptions of some twenty-one books on manners and morals, translated from the Italian into English and published in England between the years 1561 and 1607.

[93] Einstein, *Tudor Ideals*, 1921, pp. 54-5. A footnote refers us to Grimaldus Goslicius: *The Counsellor*.

[94] *Tudor Ideals*, p. 166. On the education of a gentleman see also for example, Sir Philip Sidney's letters to his brother Robert, (*The Miscellaneous Works of Sir Philip Sidney*, London, 1893, pp. 328-339) for advice on travel, horsemanship, fencing, etc.

[95] See their edition of *The Two Gentlemen of Verona*, 1921, p. 88.

They think "emperor" was the Shakespearean style and "Duke" that of the theater and the abridger. Professor Young says, however,[96]

> We need not infer that Shakespeare had in mind the occasional sojourn of Charles V (Emperor 1519–1556) at Milan. 'Emperor' here probably refers only to the Duke of Milan.

The court is a place of set love-making, fanciful compliments, artificially witty conversation. There is an extensive literature not only of worthy ideals and accomplishments in general but of conversation in particular. In reading Crane's chapter on Parlor Games in Italy,[97] we realize how highly conventionalized the give and take of social intercourse had become abroad. In the England of Shakespeare's plays (springing out of the ordinary life of cruder people) the talk is of course more democratic and less patterned than in the Italian books of social usage, but we are not surprised to find behind any pun, riddle, question, or debate something harking back to Italy. When Valentine says, "I have dined," he is far from original. Compare a dialogue from Lyly:[98]

> *Manes* . . . which I have not done these three days.
> *Pyllus.* What is that?
> *Manes.* Dined . . . .
> *Pyllus* . . . . How many have so fed their eyes with their mistress picture that they never desired to take food, being glutted with the delight in their favours.[99]

In a delightful chapter on "The High Purpose of the Elizabethan Traveller," Clare Howard summarizes the directions of the manuals for travellers:

> They have in common the tendency to rationalize the activities of man which was so marked a feature of the Renaissance. The simple errant impulse that Chaucer noted as belonging with the

[96] K. Young, *The Two Gentlemen of Verona,* New Haven, 1924, p. 85.

[97] See Crane, *Italian Social Customs in the Sixteenth Century* (1920) *passim,* especially Chapter VI.

[98] *Alexander and Campaspe,* I. ii. 14, 65-7. Ed. R. Warwick Bond, V. II. p. 320.

[99] Compare Geoffrey Fenton, *Certain Tragical Discourses of Bandello* (1567), Discourse XIII, pp. 248-9: "And in place to performe the expectation of his hostess in tasting the sondrie delicate meates she prepared for hym, he fed only upon the dishes of love; and contenting hymselfe with the dyot of his eyes, who . . . imparted their norriture to the hearte" etc. I do not know whether any one else has remarked these rather obvious and very insignificant parallels. For a discussion of this general type of indebtedness, see R. Warwick Bond, The Complete Works of John Lyly, 1902, Vol. II. pp. 473-86: "Note on Italian Influence."

> songs of birds and coming of spring, is dignified into a philosophy of travel . . . .[100]
> In short, the perils and discomforts of travel made a mild prelude to the real life into which a young man must presently fight his way. Only experience could teach him how to be cunning, wary, and bold; how he might hold his own, at court or at sea, among Elizabeth's adventurers.[101]

In another passage the same writer says:

> Underneath worldly ambition was the old curiosity to see the world and know all sorts of men—to be tried and tested. More powerful than any theory of education was the yearning for far-off, foreign things, and the magic of the sea.[102]

We may compare with this a passage from *Shakespeare's England:*[103]

> Thus the court was a place where high prizes were to be won. To the lads of England it offered in anticipation a romantic adventure and in retrospect too often a memory of sordid intrigue. So confesses Sir John Harrington, a godson of the Queen, who fluttered in the wake of Essex, and just escaped being entangled in his fall.
>
> 'I have spente my time, my fortune, and almost my honestie, to buy false hopes, false friends, and shallow praise;—and be it remembered that he who casteth up this reckoning of a courtlie minion, will sette his summe like a foole at the ende, for not beinge a knave at the beginninge.'

At the court, we find in our play, one meets foreign visitors with commendations from great potentates, tyrannical fathers, caddish rivals, ladies versed in the ways of the world—all new to Valentine. Silvia is a great lady, not a little spoiled, used to having her own way, an accomplished flirt. Her admirers are her slaves, and she means to keep them all in an obedient humor. When Valentine's temper and bluntness get the better of him, she welcomes interruptions, murmuring sweetly,

> No more, no more, gentlemen—Here comes my father.[104]

When Proteus arrives at the court, she instantly enrolls him

[100] Howard, *English Travellers of the Renaissance,* London and New York, 1894. Chapter II, p. 29.
[101] Howard, *English Travellers of the Renaissance,* London and New York, 1894, p. 30. See also the bibliography.
[102] *Ibid.* p. 19.
[103] *Shakespeare's England,* 1916, I. iii. pp. 81-82.
[104] II. iv. 47.

among her servitors, tossing down challenges which he knows only too well how to take up.[105]

Such details, it is true, serve equally well to fill in a picture of court life far away or near at hand. Yet, as Professor Pyre has pointed out[106], we can say that the court itself, that a sophisticated society itself, was associated in the popular mind with continental and above all Italian cities, that the English little Italy of the sixteenth century was found in the higher circles of London life. The cosmopolite of the sixteenth century was Italianate. W. B. Rye quotes from Cardan (1585) :[107]

> In dress they are like Italians . . . . I wondered much especially when I was in England and rode about on horseback in the neighborhood of London, for I seemed to be in Italy. When I looked among those groups of English sitting together, I completely thought myself to be among Italians; they were like, as I saw, in figure, manners, dress, gesture, colour; but when they opened their mouths I could not understand so much as a word, and wondered at them as if they were my countrymen gone mad and raving.

An Elizabethan traveller says:[108]

> . . . it is growen into a proverbe amonge the Italians, *Thedesco Italianato, Diabolo incarnato:* that is to saye, a Dutchman become in maners lyke an Italian putteth on the nature of the Devill, and is apt unto all kinds of wickednesse.

The Wood. The wood presents a similar problem. Ordish says of it: "The scene in the forest of the frontiers of Mantua could also be realized without the aid of scenic art. All playgoers, all Londoners, knew the forest which almost encompassed London on the Middlesex side".[109] Sarrazin, though he admits discrepancies, finds a real forest "upon the rising of the mountain foot that leads toward Mantua".[110] Miss Spens emphasizes the romantic and traditional element and finds that the wood, like the forest of Arden and like Sherwood in Munday's *Robert*

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105 II. iv. 102-115.

106 In lecturing at the University of Wisconsin.

107 W. B. Rye, *England as Seen by Foreigners,* London, 1865, p. 7.

108 Turler, *The Traveiler of Jerome Turler,* London, 1575, p. 66.

109 Ordish, *Shakespeare's London,* 1897, pp. 112-3.

110 The researches of Sir Edward Sullivan make it further possible to realize the mountain foot in the realm of the actual. "I now find there were two highways between Milan and Mantua, and that the N. E. road passes 'the mountain-foot' when nearing Palazzolo—(See Schotti *Itinerarium Italiae,* De Brixia)" "Shakespeare and Italy", the *Nineteenth Century,* LXXXIII, p. 339.

Earl of Huntington is the woodland scene of the Robin Hood stories, and that the outlaws are our ancient playfellows, the Merry Men of English oral tradition:

> Robin Hood seems to have been something of an obsession with Munday, and it may therefore not be without significance that Shakespeare twice uses the outlaw motive in his comedies: in *The Two Gentlemen of Verona* (which we have seen is probably otherwise indebted to Munday) and in *As You Like It.* The name of Robin Hood is mentioned, however, merely in passing. What Shakespeare gets is the free life of the forest. The effect of this natural background in *The Two Gentlemen of Verona* is almost magical.[111]

Certain it is that the outlaws "practice an honorable kind of thieving",[112] like a manly fight, are chivalrous "to silly women and poor passengers",[113] welcome a brave leader, are capable of being reformed, "civil, full of good, and fit for great employment".[114]

Though Robin Hood is English, the pastoral romance is of wide continental connections. Sidney's Arcadia, itself a region where anything can happen, tells of far, far away and draws on continental sources. *As You Like It,* moreover, comes as much from Lodge's *Rosalynd* as from oral traditions of Robin Hood; and a striking analogue of Rosalynd (and possibly a source) is to be found in *Certain Tragical Discourses of Bandello.*[115] Here we find — located in Spain some of the flora and fauna of Arden, much of its free spirit, a young man and his servant making themselves at home with Crusoe-like ingenuity in the wilderness,[115] the young man disguised as a pilgrim and relieving his feelings in an unfortunate love affair by carving verses on rocks and trees. In our effort to locate "the rising of the mountain foot" it may be worth pausing to note that three or four days' and nights' wandering on the part of Bandello's

[111] Janet Spens, *Shakespeare and Tradition,* Oxford, 1916, p. 33.

[112] IV. i. 40.

[113] IV. i. 72.

[114] V. iv. 156-7.

[115] There his man made provision accordynge to the condicion of their state and necessity of the place, dyggynge for his firste indevor certeine soddes and lomppes of claye, wherewith he entrenched and rampierd their felden shopp, to defende theym aganste the furye of wilde beastes, who other wayes myghte oppresse theym in the nyghte. He made, also, two beddes, or lytle couches, of softe mosse, wyth a testure and sides of wodde, which he hewde in no less fyne proporcion then yf the skill of the carpenter had assisted the worke."—*Certain Tragical Discourses of Bandello,* translated by Geoffrey Fenton, Discourse XIII, pp. 273-4. (*Tudor Translations,* Vol. XX.)

travellers "broughte them at last to the foot of a large mountaine, inhabited only with savage beasts and creatures unreasonable".[116] Truly if we are Elizabethans we have been in this wood before, but not necessarily near London; just as often in our dreams of parts unknown.

But it is not necessary to turn to pure romance in order to find outlaws some of whom in the tyranny of petty governments and municipal feuds, may have been of noble descent and even kept some noble qualities. As we have seen, the regions between the Italian cities were infested by adventurers and exiles of various classes.

English Elements of the Setting. We have considered as elements in the background the motive of travel, the obviously Italian allusions, the non-geographical romantic elements. It remains to discuss the more definitely English elements. In these we find not a little support for Ordish's theory. Country and every-day life are suggested through allusions chiefly supplied by the low-comedy characters: the life of the shepherd and the ways of sheep, fodder, wages, pasture, pound and pinfold;[117] the robin redbreast singing on the branch, the cock in the barnyard,[118] the alehouse,[119] the weather-cock on the steeple,[120] the melancholy gait of lions in the tower,[121] the country housewife who can milk, brew, sew, knit, wash and scour and spin.[122] And Speed gives us a series of pictures, struck out boldly in a line apiece, of familiar types in characteristic action: "to walk alone, like one that hath the pestilence; to sigh, like a school-boy that hath lost his ABC; to weep like a young wench that hath buried her grandam; to fast, like one that takes diet; to watch, like one that fears robbery; to speak puling, like a beggar at Hallowmas."[123] We have a hint or two of a northern

[116] *Certain Tragical Discourses of Bandello,* translated by Geoffrey Fenton. Discourse XIII, p. 272.

[117] I. i. 72-99.

[118] II. i. 21, 28.

[119] II. v. 54.

[120] II. i. 142.

[121] II. i. 29.

[122] III. i.

[123] II. vii. 19

Rolfe in his edition of *The Two Gentlemen of Verona,* 1905, p. 138, quotes Knight on this passage: "The beggar not only spake 'puling' at Hallowmas, but his importunities or his threats were heard at all seasons. The disease of the country was vagrancy; and to this deep-rooted evil there were only applied the surface remedies to which Launce alludes, 'the stocks' and 'the pillory'."

climate; the folly of trying to kindle fire with snow,[124] "the uncertain glory of an April day".[125] And the passage on the brook need not take us far from home:

> The current that with gentle murmur glides,
> Thou knowest, being stopped, impatiently doth rage;
> But when his fair course is not hindered,
> He makes sweet music on the enamelled stones,
> Giving a gentle kiss to every sedge
> He overtaketh in his pilgrimage;
> And so by many winding nooks he strays
> With willing sport to the wild ocean.[126]

These elements for the most part, however, English in origin though they undoubtedly are, are not such as definitely to break an Italian illusion. There were shepherds, housewives, school boys, beggars, in Italy as well as England; and untravelled spectators could think of these details in other lands as well as their own.

Such is the background of the play. Exceedingly little of this concrete detail can be traced to the sources.[127] We have already quoted a few suggestive passages from *Diana Enamorada.* To these may be added a few others as calling up fairly vivid scenes.

Don Felix is sent by his father to the Princess Augusta Caesarina's court. Felismena follows him disguised as a man. The journey takes twenty days.

> "I took up mine Inne in a street less frequented with concurse of people . . . . . But midnight being a little past, mine host called at my chamber doore, and tolde me if I was desirious to heare some braue musicke, I should arise quickly, and open a window towards the street."

She hears Don Felix say to Fabius, the page,

(The rest of the note is also of interest.) Cf. *Shakespeare's England,* Oxford, 1916, II, Chapter XXVIII, "Rogues and Vagabonds," by Charles Whibley. The problem of poverty had been aggravated by the dissolution of the monasteries (p. 486)—"The three-fold object of Elizabeth's poor-laws was to feed the hungry, to punish the evildoer, and to exact payment from the unwilling rich." (p. 490) —"The severest punishments meted out to the scoundrel, the heaviest toles levied upon the wealthy, neither cured nor discouraged the crime of vagabondage." (p. 491.)

[124] II. vii. 19.

[125] I. iii. 85.

[126] II. vii. 25-32.

[127] As far as we know what these are. Here as elsewhere there is, of course, the possibility of an intervening play.

"'Now it is time, my masters, bicause the Lady is in her gallerie ouer her garden taking the fresh aire of the coole night.' He had no sooner saide so, but they began to winde three Cornets and a Sackbot, with such skill and sweetnesse, that it seemed celestiall musicke . . . .

"After they had first, with a concert of musicke, sung this song, two plaied, the one upon a Lute, the other upon a siluer sounding Harpe, being accompanied with the sweete voice of my Don Felix . . . .

"The sonnet being ended, they paused awhile, playing on fower Lutes togither, and on a paire of Virginals, with such heauenly melodie, that the whole worlde (I thinke) could not affoord sweeter musick to the eare . . . .

"About dawning of the day the musicke ended, and I did what I could to espie out my Don Felix, but the darknes of the night was mine enimie therein."

The next day she goes to the palace.

"Comminge therefore to a faire broad court before the pallace gate, I viewed the windowe and galleries, where I sawe such store of blazing beauties, and gallant Ladies, that I am not able now to recount, nor then to do any more but wonder at their graces, their gorgeous attyre, their jewels, their brauve fashions of apparell, and ornaments wherewith they were so richly set up. Up and downe this place, before the windowes roade many lords and braue gentlemen in rich and sumptuous habits, and mounted upon proud Jennets, euery one casting his eie to that part where his thoughts were secretly placed."

As she stands at the palace gate, she sees Don Felix. A highly detailed passage follows:

. . . . . I sawe him comming along with a great traine of followers attending on his person, all of them being brauely apparelled in a liuerie of watchet silke, garded with yellow veluet, and stitched on either side with threedes of twisted siluer, wearing likewise blew, yellow, and white feathers in their hats. But my Lorde Don Felix had on a paire of ash colour hose, embrodered and drawen foorth with watchet tissue; his dublet was of white saten, embrodered with knots of golde, and likewise an embrodered jerkin of the same coloured veluet; and his short cape cloke was of blacke veluet, edged with gold lace, and hung full of buttons of pearle and gold, and lined with razed watchet satten: by his side he ware, at a paire of embrodered hangers, a rapier and dagger, with engrauen hilts and pommell of beaten golde. On his head, a hat beset full of golden stars, in the mids of euerie which a rich orient pearle was enchased, and his feather was likewise blew, yellow, and white. Mounted he came upon a faire dapple graie Jennet, with a rich furniture of blew, embrodered with golde and seede pearle.[128]

Don Felix dismounts and goes up "a paire of staires into the chamber of presence".

Felismena learns from Fabius that Don Felix serves Celia "and therefore weares and giues for his liuerie an azure blew, which is the colour of the skie, and white and yellow, which are the colours of his Lady and mistresse".

With the exception of the above passages the background of the story is vague and conventional.

Munday's *Two Italian Gentlemen,* which presents some resemblances to *The Two Gentlemen of Verona* in situation, has street scene, window, lute, and letter. But, as is true of *Diana,* the detailed passages have little in common with our play, though Medusa's box of enchantments — an egg of a black hen, a quill plucked from a crow, the heart of a black cat, the blood of a bat, a goat's brain, the liver of a purple dove, a cock's eye, capon's spur, the left leg of a quail, goose's bill, gander's tongue, mounting eagle's tail, etc.—bring to mind the ingredients of the witches' caldron in *Macbeth.* Riche's *Apolonius and Silla,* in which the resemblances of situation are stronger, has very little concrete detail of setting. It does present, however, a general background of Mediterranean travel.

In our survey of the elements of the setting of *The Two Gentlemen of Verona,* we have glanced at several theories: that of Sarrazin, that Shakespeare is using Italian detail to fill in a realistic Italian background, that suggested by Miss Spens, that he uses Italy for an effect, not of realism, but of indefinite distance and romance, that of Ordish, that the Italian setting is a thin disguise for pictures of English life.[129] The various theories may be less conflicting than they seem. At all events, degrees and distinctions are to be observed, from play to play, in the nature and use of the foreign scene. Before attempting to draw further conclusions, however, let us turn to the characters and setting of the present play, which the background is intended to throw into relief.

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[128] Hazlitt, Shakespeare's library. Vol. I, p. 290.

[129] Ordish, *Shakespeare's London,* p. 161. "Ephesus, perhaps, stood for London, and Syracuse for Antwerp." Quiller-Couch and Wilson apparently tend to Ordish's view. Op. cit. 1921, pp. ix, x. Cf. the similar view stated by Jacobs, in the introduction to Painter's *Palace of Pleasure,* 1890.

III

Characters and Action

The story seems to be Spanish and Italian in origin. Among the possible sources are Montemayor's *Diana Enamorda,* Riche's *History of Apolonius and Silla,*[130] Brooke's *Romeus and Juliet,* and Munday's *The Two Italian Gentlemen.*

Two points are brought out by the study of the sources: (a) the stock nature of many of the incidents,[131] (b) the relation of the play to later plays, and especially to *Romeo and Juliet* and to *Twelfth Night.* The resemblance to later plays,[132] again, is chiefly interesting as bringing out the difference in treatment, the *Two Gentlemen of Verona* having less depth of realism, less clearness of characterization, and less unity of effect.

To judge by the relation of the play to its possible sources and to the later plays similar in source, the elements that chiefly interested Shakespeare were (a) the adventures of travel,[133] (b) the story of intrigue, disguise,[134] and escape, (c) the pathos of Julia's situation, a close parallel to Viola's, (d) a friendship

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[130] For an admirable summary of the parallels between *Two Gentlemen of Verona* and these sources see Introduction to the edition of the play in the Arden Shakespeare, ed. R. Warwick Bond, London, 1906.

[131] Cornelia C. Coulter, "The Plautine Tradition in Shakespeare," *Journal of English and German Philology,* v. xix, p. 78.

"The *pater familias* of a Latin comedy was useful chiefly because he furnished (albeit unwillingly) the necessary funds for his son's romance. Sometimes the memory of his own wild oats made him tolerant of the young man's misdemeanors; more often he took an uncompromising stand as a censor of morals and *laudator temporis acti.* In four plays of Plautus (*Asinaria, Bacchides, Casina, Mercator*) the old men cast lustful eyes at their sons' mistresses; in the *Aulularia,* the rich old bachelor Megadorus makes an honorable request for the hand of the miser's daughter, without dowry. Italian dramatists took over these figures, and, by exaggerating their ridiculous aspects, developed the Pantaloon and the Pedant or Doctor, the former, as a rule, the father of hero or heroine, and the latter often a suitor for the lady's hand. Both were unattractive figures, stupid, avaricious, amorous, and easily duped by the young people in the play. Shakespeare's treatment is much more kindly, but we can still recognize the traits of the classical *senex* in the stern decrees of Antonio (*The Two Gentlemen of Verona,* I. 3.) and Baptista (*Taming of the Shrew* I. 1.), in Capulet's reminiscences of by-gone days (*Romeo and Juliet* I. 5.), and in the 'wise saws' of Polonius to Laertes (*Hamlet* I. 3.). Silvia's father traps Valentine by the story of a coy lady whom his 'aged eloquence' had failed to move (*Two Gentlemen of Verona* III. 1. 76-136), and 'old Signior Gremio' offers plate and gold, Tyrian tapestry and arras counterpoints as dower for the fair Bianca (*Taming of the Shrew* II. i. 347-364)."

[132] For a summary of resemblances to later plays see Furnivall's introduction to "The Two Gentlemen of Verona" in *The Century Shakespeare,* 1908. See also the Edition of Quiller-Couch and Wilson, 1921, pp. ix-xv.

[133] Cf. *Merchant of Venice.*

[134] See Freeburg, *Disguise Plots in Elizabethan Drama,* New York, 1915.

complicated by differences of temperament,[135] (e) an enchanted place and a happy ending.

Professor Campbell has shown, however, that even these are so essentially stock appeals to popular interest that we cannot assume anything more than that Shakespeare knew how to use them as such. Yet if, in the comedies, as Professor Stoll contends,[136] a swift theatrical appeal, without deeper dramatic implications, is the norm, Shakespeare often departs widely from it. Given a story of a certain degree of remoteness from real life, he sometimes gets a detail out of focus, brings it too close to the camera, over-realizes it. Shakespeare is stronger in his sense both of tragic unity and of romantic unity than in his sense of comic unity. In *Love's Labour's Lost,* in *The Comedy of Errors* he encounters this difficulty.

In *Love's Labour's Lost* the scene suddenly "begins to cloud". The players doff their fantastic disguises, their artificial speech, and their courtly self-deception, and step forth human beings who feel pain as we do.

> Honest plain words best pierce the ear of grief.[137]

The bubble of the comic illusion has broken when the King is told to

> go with speed
> To some forlorn and naked hermitage
> Remote from all the pleasures of the world,[138]

and Biron to

> Visit the speechless sick and still converse
> With groaning wretches.[139]

Biron replies

> To move wild laughter in the throat of death?
> It cannot be; it is impossible;
> Mirth cannot move a soul in agony.[140]

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[135] See Quiller-Couch's introduction, *The Two Gentlemen of Verona,* New York, 1921.

[136] Cf. on this point the general position of "the skeptics". See Karl Young, "The Shakespeare Skeptics", *North American Review,* March, 1922. Also Mr. Young's review of Schücking, *Philological Quarterly,* I, 3, July 1922, pp. 228-234. See especially note 5, page 229 (bibliography).

[137] V. ii, 763.

[138] *Love's Labour's Lost,* V. ii, 804-6.

[139] Ibid. 861-2.

[140] Ibid. 865-7.

Yet because the play must end as a comedy, there is an attempt at the end, not altogether unsuccessful, to persuade us that the grief of the princess—natural and expected rather than tragic —is not one of the storms of life, but slips over the grass of the park like the shadow of a drifting cloud on a summer afternoon. Nevertheless we have been strangely reminded that there are such things as storms and winter.

In *The Comedy of Errors,* similar realities break through, out of keeping with what Miss Spens has called "the hard, unlovely type" of the Latin comedy.[141] The grief of Aegeon acquires a certain vitality, likewise the romance of Antipholus and Luciana, the religious atmosphere of the abbey, the reunion of the family. In the *Merchant of Venice* and *Much Ado About Nothing* tragedy comes through in a way disastrous to the comic unity.[142]

In *The Two Gentlemen of Verona* are there any characters or situations which tend to emerge into stronger reality than the general plane of the action leads us to expect?[143]

The character of Julia changes somewhat and becomes more real as the story goes on. In the first act she is coy, self-centered, unreasonable, and unrefined. The scene has a fairly close parallel in Yonge. One has only to compare it cursorily with a later parallel, Portia's discussion of her suitors with Nerissa, to see how inferior to the latter it is in dignity. In Act II, Scene vii, there is more liveliness and sincerity as well as more lyric beauty in Julia's speeches. In Act IV, Scene ii, Shakespeare has grown much more interested in Julia, and her situation. Her lines are brief and strong; and in the poignant note of "I would always have one play but one thing,"[144] it is almost the voice of Viola that we hear. In Act IV, Scene ii, Julia's experience is still further developed. Silvia's character is externally presented; we know little of her experience from the inside; but Julia, like Viola, utters words that in their double meaning have an aspect of soliloquy.[145]

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[141] *Shakespeare and Tradition,* Oxford, 1916, p. 7.

[142] Commented on by many critics. See, for example, Heinrich Bulhaupt, Variorum edition of *Much Ado About Nothing,* p. 379.

[143] Quiller-Couch and Wilson account for discrepancies by the interesting theory that the play does not stand as Shakespeare wrote it but has been "tightened" and revised for acting purposes by another hand. See pp. 115-6 below.

[144] IV. ii. 72.

[145] IV. iv.

In the course of the play there is some attempt to show the mind of Proteus, also, from the inside. There are some soliloquies — one on his love affair with Julia — in which he expresses contempt for himself for wasting his time;[146] one explaining the lack of courage which results in his going abroad;[147] one in which he reveals his infatuation for Silvia and tries to account for the complete change in his own state of mind:

She's fair, and so is Julia that I love,—
That I did love, for now my love is thawed,
Which, like a waxen image 'gainst a fire,
Bears no impression of the thing it was.
Methinks my love to Valentine is cold,
And that I love him not as I was wont:
O, but I love his lady too too much
And that's the reason I love him so little.[148]

There is a fourth soliloquy of about forty lines, which is apparently meant to display some degree of moral struggle. It sounds like a forlorn effort on Shakespeare's part to make a case for Proteus. Proteus realizes the ignominy of what he is doing:

To leave my Julia, shall I be forsworn;
To love fair Silvia, shall I be forsworn;
To wrong my friend, I shall be much forsworn.[149]

But he defends his course by a two-fold argument: (1) love is all-powerful:

At first I did adore a twinkling star,
But now I worship a celestial sun,

the celestial sun being Silvia the great lady, (2) self-realization is the first law of life:

Julia I lose, and Valentine I lose:
If I keep them, I needs must lose myself;
If I lose them, thus find I, by their loss,
For Valentine, myself; for Julia, Silvia.
I to myself am dearer than a friend,
For love is still most precious in itself;

[146] I. i. 63-69.
[147] I. iii. 78-87.
[148] II. iv. 191-214.
[149] II. vi. 1-3.

I cannot now prove constant to myself,
Without some treachery used to Valentine.[150]

Proteus then carries out his plot with the relentlessness of a man hypnotized by a motive that he never again stops to survey, since he knows that it is evil.

Except in a passage at the opening of Act IV, intended chiefly for description and atmosphere, there is no such attempt to present directly the working of Valentine's mind. Yet he seems much more alive. Indeed it is because he is more real that he needs less explanation. He is reflective,[151] something of an idler in his way,[152] yet with plenty of energy, lacking the alertness and finesse of a man of the world, engagingly slow to understand what is to his advantage,[153] blunt of speech, impetuous of temper, capable of vigorous action but incapable of successful intrigue,[154] without experience of treachery and easily duped by it, of resourceful imagination, adventurous, yet demanding little of life, and adaptable to adverse circumstances.[155]

His praise of Proteus shows what he thinks, with more or less injustice to himself, to be his own defects:

I know him as myself; for from our infancy
We have conversed and spent our hours together;
And though myself have been an idle truant,
Omitting the sweet benefit of time
To clothe mine age with angel-like perfection,
Yet hath Sir Proteus, for that's his name,
Made use and fair advantage of his days;
His years but young, but his experience old;
His head unmellow'd, but his judgment ripe:
And, in a word (for far behind his worth
Come all the praises that I now bestow),
He is complete in feature and in mind,
With all good grace to grace a gentleman.[156]

Because of this comparatively clear characterization of Valentine, we, as we read the play, stand in his shoes in the last

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[150] This long soliloquy seems to me to be an attempt at psychology. The earlier soliloquies are no doubt, as Professor Stoll would hold, chiefly external explanation to the audience.

[151] V. iv. 1.

[152] II. iv. 64.

[153] II. iv.

[154] III. i.

[155] V. iv.

[156] II. iv. 62-74.

act. Through his eyes we are staring at Proteus, trying vainly to understand what manner of man this false friend can be. In the final scene, however, the dramatic situation is abandoned as a whole. Silvia to all intents and purposes is forgotten. If we take the play seriously as it stands, the conclusion of the whole matter seems to be: "I forgive you; I take you back — but I don't understand." Proteus is put to a final test, "Here, take the girl if you want her." But how he responds to this test we do not know, since Julia at this point re-enters the action. If we think of this scene as falling below what we are to expect, instead of thinking of the rest of the play as rising above it, the dénouement is puzzling.

Professor Stoll, and other skeptical critics,[157] maintain that Shakespeare, like his audience, cared more for story than for drama in the true sense, and easily threw aside the problem of character in favor of a mechanically happy ending. It would be absurd to deny that there is truth in this view. Shakespeare knew this ending to be theatrically acceptable to his audience, and was satisfied to give it to them. It would be easier to take this as the whole truth, if it were not that again and again in the plays, — in almost any scene of every play — Shakespeare shows that, whatever the professional necessities under which he worked, his own spontaneous interest is easily captivated by character as character and by the genuine dramatic values of a situation. Thus the real puzzle of *The Two Gentlemen of Verona* is not alone in the unmotivated happy ending but in the combination of this with more strongly motivated earlier passages. We must accept the simple explanation as far as it goes; but in Shakespeare we are dealing with a personality as well as a condition, and it is well to remember that beneath and beyond the simple fact are more complex possibilities. Speculation about these may be harmless, may even be wholesome, as protecting us from any temptation to dogmatism and rigidity, provided and only provided we never forget that it is speculation merely.

And here the theory of Quiller-Couch and Wilson may help us out. "It may be then that Shakespeare invented a solution which at the first performance was found to be ineffective; that the final scene was partly rewritten — not by Shakespeare

[157] See footnote 136, p. 111 above.

— and given its crude and conventional *coup de theâtre;* that in this mutilated form it remained on the play-copy; and that so it reached the printer.[158] But it will be asked, if we omit

All that was mine in Silvia I give thee

how do we account for Julia's swoon? Our own answer is that we do not try to account for it; our hypothesis being that the swoon and the couplet together are 'other man's work'; and that Shakespeare had another dénouement which possibly proved ineffective on the stage, and that the one we have is a stage-adapter's substitute."[159]

Sir Arthur Quiller-Couch wisely refrains from telling us what Shakespeare's other dénouement was. Our guess would be (a guess, pure and simple) — an effort by Valentine to probe the mind of Proteus, resulting in a dialogue more interesting to the dramatist himself than to the Elizabethan play-goer.

Before we leave the subject let us turn once more to the relation between the present play and *Twelfth Night.* A curious episode in the latter play is that of Antonio and Sebastian. Antonio is an older man who bears to Sebastian something the relation of Adam to Orlando, and of the Antonio of the *Merchant of Venice* to Bassanio. In *As You Like It* and *The Merchant of Venice,* the younger man proves worthy of the fidelity of the elder. In *Twelfth Night,* likewise, he proves worthy. But there is a scene of almost tragic vividness,[160] in which Antonio, thinking himself deceived, takes an attitude much more mature than Valentine's:

Will you deny me now?
Is't possible that my deserts to you
Can lack persuasion? Do not tempt my misery,
Lest that it make me so unsound a man
As to upbraid you with those kindnesses
That I have done for you..................
....
But O how vile an idol proves this god!
Thou hast, Sebastian, done good feature shame.
In nature there's no blemish but the mind;
None can be call'd deformed but the unkind.
Virtue is beauty. . . . .

[158] See introduction to *Two Gentlemen of Verona,* edited by Quiller-Couch and Wilson, New York, 1921, p. xvi.

[159] *Ibid.* p. xviii.

[160] Miss Margaret Ashdown of Westfield College, the University of London, commented to me (I think in this connection) on the poignancy of this scene.

And again when he has had time to digest his wrongs, Antonio utters words very unlike Valentine's too easy re-instatement of the wrong-doer.

A witchcraft drew me hither:
That most ungrateful boy, there by your side,
From the rude sea's enrag'd and foamy mouth
Did I redeem; a wreck past hope he was.
His life I gave him, and did thereto add
My love, without retention or restraint,
All his in dedication..................
..........His false cunning
Not meaning to partake with me in danger,
Taught him to face me out of his acquaintance,
And grew a twenty years removed thing
While one could wink.

Matters are cleared up for Antonio. There are two Sebastians.

Antonio. How have you made division of yourself?
An apple cleft in two is not more twain
Than these two creatures. Which is Sebastian?
....
Sebastian ..... A spirit I am indeed
But am in that dimension grossly clad
Which from the womb I did participate.

All is resolved by the simple device of mistaken identity. In a figure, perhaps, Valentine gets out of his difficulty in somewhat the same way. Who has not succeeded in reinstating his friend by reflecting on the notion of man's Protean double nature? He did wrong, we say to ourselves, through yielding to the hypnosis of an evil idea; his real self, thoroughly aroused, will repudiate his action, and will learn from the bitterness of repentance not to lapse from its own integrity again. In *The Two Gentlemen of Verona,* as it stands, the injured man's resentment, and his forgiveness, are more hastily presented than any dramatic condensation allows — so hastily, indeed, as to seem ironical. But in the later play where the situation of the betrayed friend is only an incident, and an illusion at that, Shakespeare shows his power to make it almost tragically real.[161]

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[161] Cf. on the subject of friendship vs. love, Max Förster, (reviewing Hans Kliem, on *Sentimentale Freundschaft in der Shakespeare-Epoche,* Jena, 1915), S. G. *Jahrbuch,* LI (1915), p. 261.

"Dieser schwärmerische Freundschaftkultus stammt natürlich aus der Antike, wobei auch diesmal wieder, wie bei sonstiger Renaissancekultur, Frankreich (namentlich Montaigne) eine gewichtige Vermittlerrolle zufallen mag. Antik sind vor allem die oft in der damaligen englischen Literatur wiederkehrenden

Thus, however they account for it, the critics feel that the dénouement is below the level of Shakespeare's usual treatment, below the level, even, of this play as a whole. Yet there may be an advantage in treating the weakest point as our point of departure, in approaching the dramatic problem of the play as it were from the direction of its lower level. From this standpoint what we have to try to understand is not the weak points of the play but its strong points. Wherein lie the outstanding differences between this play and its cruder prototypes?

One conspicuous difference lies in the greater variety of its scene and background. Professor Campbell stresses the point that "the scene of the action in an Italian comedy, both learned and professional, was a public place". In our play both forest and court scenes are directly presented. Then there is a strengthening in our sense of the persons, though, as we have seen, this gain is uneven and varies from incident to incident. There is great strengthening of the spirit of romance and no less of the sense of reality; and through these there is a deepening of the whole dramatic and poetic appeal.

IV

The Setting and the Total Effect

Now does this examination help us at all in framing a theory of Shakespeare's use of background in this play? How is the story related to the background, and does the background help us to interpret the story?

Before answering this question, let us again turn for a moment to that very different type of play, *The Comedy of Errors.* It is, of course, not a romantic comedy, but a farce of the Latin type; the situations are too wildly absurd to admit of being made probable by any artistic device whatsoever. It is meant that we should confine ourselves to the realm of farce, and not ask why or how such things could happen. We must not reflect upon their strangeness; we must only laugh at their

Anschauungen, dasz Männerfreundschaft Höher stünde als Frauenliebe und alle Bande der Familie (Bacon, Spenser, Th. Browne), dasz der Freund ein anderes Selbst (another himself) sei und dasz echte Freundschaft 'eine Seele in zwei Körpern' bedeute . . . Dasz dabei manche psychologische Unmöglichkeit mit unterläuft, verschlug dem damaligen Leser wenig . . . Für ein Stück, wie 'Die beiden Edelleute von Verona' gewinnt man erst das richtige Verständnis, wenn man es in Lichte dieses Freundschaftkultus betrachtet".

absurdity. Yet oddly enough, reflection upon their strangeness is exactly what Shakespeare demands of us repeatedly in the following expressions:

They say this town is full of cozenage;
As, nimble jugglers that deceive the eye,
Dark-working sorcerers that change the mind,
Soul-killing witches that deform the body.
. . . .
This is the fairy land. O spite of spites!
We talk with goblins, owls, and elvish sprites:
If we obey them not, this will ensue,
They'll suck our breath, or pinch us black and blue.
. . . .
Against my soul's pure truth, why labour you
To make it wander in an unknown field?
. . . .
I'll stop my ears against the mermaid's song.
. . . .
Sure, these are but imaginary wiles,
And Lapland sorcerers do inhabit here.
. . . . .Witness
That he is borne about invisible.
. . . .
I think you all have drunk of Circe's cup.
. . . .
Why this is strange—Go call the abbess hither.
I think you all are mated or stark mad.

These phrases and others indicate that reality has begun to break through the farcical unity so that we are in danger of testing events by probability; hence the illusion must be recaptured in some other way — in fact by the method of poetry. In other words, Shakespeare has even here begun an experiment in romantic unity.[162] The same method seems to be carried further, though not to a wholly successful issue, in *The Two Gentlemen of Verona.*

There may thus be a relation between the wood, with its effect of enchantment, commented on by Miss Spens, and the

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[162] The *Menechmi* supplies a faint suggestion of the method:

Either she is a witch, or else she hath dwelt there and knew ye there.
Fie, awake Menechmus, awake; ye oversleepe yourselfe.
They vex me with strange speeches.
They try to persuade Menechmus that he is mad.
They say I am mad.
This same is either some notable cousening Jugler, or else it is your brother whom we seeke.

improbability of the story which has to be rendered dramatically credible. Shakespeare is employing what we may call *the device of the enchanted place.* This device has, of course, been recognized, at least in implication, by commentators on *A Midsummer Night's Dream, The Tempest,* and other plays; it is not confined to Shakespeare, and comes indeed from a universal artistic law governing the relation of any event to the atmosphere in which it is represented as taking place. None the less it is with Shakespeare perhaps even more elaborate than has been recognized. The mechanism of the device is best studied in *A Midsummer Night's Dream.*[163] Suffice it for the present to say that in *A Midsummer Night's Dream,* by the use of the atmosphere of a place, a highly complex action, of heterogeneous elements, is removed from life, set back, brought into focus, simplified in motivation, and given an illusory credibility such as could have been obtained in no other way. In *The Two Gentlemen of Verona,* Valentine's forgiveness of Proteus as it stands[164] remains a difficulty which even this magic chemical fails to dissolve. But it does succeed for the disentanglements of the love complications and the regeneration of the outlaws.

Now does this device of the enchanted place subserve the Italian setting, or vice versa? Shall we accept the theory of Sarrazin, that Shakespeare is aiming at a picture of Italy, or that of Miss Spens, that he is aiming chiefly at romantic distance? The dramatic needs of this play seem to throw the emphasis with the latter idea. Yet each element contributes to the other; we have a distant and romantic scene but one distinctly Italian.

What, now, is the artistic relation of the English detail to this Italian romantic background?

Miss Spens has an illuminating passage on Lyly's influence on Shakespeare:

> Now Lyly's plays are essentially masques; that is to say, they are representative of actual incidents of the time at which they were performed, translated by the language of allegory and symbolism into a more radiant plane of existence.................
> ....
>
> It was not the business of the poet to create, but to flood the given facts with a golden light of poetry, which should show all

[163] Of which I hope soon to complete a study.

[164] But see p. 116 above and footnotes.

> the fairer connections. The masque is, in fact, the direct antithesis of satire. Now the great comedy of all other literature belongs to the satirical family—it exaggerates whatever is ugly in human action in order to make it ridiculous, and Ben Jonson's comedy shows that without Lyly and Shakespeare English comedy would probably have followed the same lines. The scene of Shakespeare's comedy is laid in a golden world, and the suggestion of that ethereal atmosphere came from Lyly. Lyly failed because he does not at the bottom of his heart believe in this golden world. Shakespeare's task was to give it truth.[165]

Taking this sentence of Miss Spens', "Shakespeare's task was to give it truth", as a text, let us see what are the factors of Shakespeare's method as we are able to discern it already in *The Two Gentlemen of Verona.*

And even when we use the phrase "Shakespeare's method", we must give ourselves a warning. It is characteristic of Shakespeare that he never carried any particular mode far. The moment we begin to define his method we meet trouble; for he was too wholly a creator to have method in a deliberate sense. His conscious intellectual process was too far merged in something more unconscious and vital. Professor Baskerville says of Ben Jonson: "It was the life of the man to be in the midst of things. Let a type of the drama like the masque become popular and he is almost certain to adopt it and exert all his powers to excel in it".[166] Now Shakespeare was also "in the midst of things", — and he too adopted popular types.[167] But he was probably not chiefly concerned with excelling in any particular type, for he was concerned with something more important, with using the type as a means to the end — to delight his audience, and to find outlet for his own peculiar power of holding the mirror up to nature. So when we talk of his method, we mean only the way he did things, and not the way he meant to or self-consciously set out to do things. Shakespeare has in mind not so much the author's point of view as (a) the point of view of the actor or group of actors, (b) the point of view of the spectators. He did not think of personal fame, apparently, or of showing off learning or cleverness.

Shakespeare's method, then, if we use the word in the sense of a partly unconscious process, was to furnish his golden

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[165] *Shakespeare and Tradition*, Oxford, 1916, p. 8.

[166] C. R. Baskerville, *English Elements in Jonson's Early Comedy*, 1911, p. 4.

[167] Cf. A. H. Thorndike, *The Influences of Beaumont and Fletcher on Shakespeare*, Worcester, Mass., 1901.

world with the detail of every-day life, not in order to create an illusion of every-day life, but in order to give reality to the golden world. We have seen in the present play how thriftily he uses the circumstantial bits of romantic machinery. Already the scene has far more substance than a scene as Lyly presents it. Yet the detail of the play is thin and scanty compared with that of any other play of Shakespeare. How elaborately furnished is the forest of Arden, the wood near Athens, the Island of the Tempest! The fairy life of the *Midsummer Night's Dream* is real because made of the stuff of our humdrum routine, and not only is a place or situation given substance in this way, but the mind of a character is similarly realized. Oberon, the Ghost, Caliban, are alive to us because they incidentally reveal two elements in their consciousness: (a) the little objects in the foreground of their attention, (b) the deposit of concrete recollection of the past. A modern poet has deliberately made this method characteristically his own. Fra Lippo Lippi, in a way convincingly incidental to the play of ideas going on in the area of his immediate consciousness, reveals sharply detailed pictures from his memories of street and cloister. Bishop Blougram, conscious of every trivial thing in his surroundings, even of Gigadibs the literary man,

> Who played with spoons, explored his plate's design,
> And ranged the olive stones about its edge,

pours out the riches of a long-stored mind. And in *Andrea del Sarto,* "that cartoon, the second from the door", is only a modern and self-conscious version of "the picture that is hanging in your chamber",[168] of which Proteus, from his place among the trees, is evidently able to get a glimpse in the candle-light behind Silvia's head. In this play Shakespeare's most striking use of detail for characterization is in the treatment of Launce. He knows all the odds and ends that Launce would happen to have in his mind: cats and dogs and geese, puddings and trenchers, Jews, and shoes, and pebble stones, the market-place and the pillory.

Ordish in his valuable book on *Shakespeare's London,* discusses the vast amount of English concrete detail which occurs in those plays whose scene is nominally outside England.[169]

[168] Two Gentlemen of Verona: Act IV, Sc. ii.
[169] Ordish, *Shakespeare's London,* 1897. See especially Chapter IV.

We have already quoted a passage in which he states the belief that "beneath the masquerade of foreign manners lay tacitly the familiar scenes of England and of London". He speaks of this as a "device"[170] taken for granted, a "disguise" to be penetrated, an "illusion" which "gave zest to the satire",[171] a "masquerade of the remote".[172] In this view there is much truth that it would be folly to dispute. Yet it is doubtful whether either Shakespeare or his audience recognized anything twofold in the method. Probably the audience did not sharply distinguish English and foreign elements. They probably did not think of parallel situations, one standing for the other. Local hits amused and delighted them; but these were, to a great extent, extraneous, inserted just as they are by travelling players to-day, and not of the essence of the play itself. The story as story, the people as people, were, in general, the first consideration of playwright, actor, and spectator.

But while the topical allusions were not essential to the play, the local details were essential. They are present not primarily for a satirical purpose — though sometimes Shakespeare is satirical — but for a higher creative purpose — namely, to make the ideal, or in other words, the foreign, the distant, the romantic element, *become real.* When Shakespeare laid the scene of a play in Italy, he meant the audience to think of Italy. He himself imagined Italy as far as his knowledge of Italy enabled him to do so. When his knowledge of Italy gave out, he supplied English detail, not because it was English but because it was real. He put his Italian story into an Italian setting so far as his mind happened to have the materials of such a setting. Possibly when he found something not clear to his imagination, something that for purposes of realizing the action to himself he needed to get clear, he may have looked up or enquired about points of Italian geography, history, or contemporary manners. But if he did this at all, it was merely for the purpose of realization, and not for the purpose of accuracy in the abstract. Thus we are concerned in the plays with Shakespeare's imaginative Italian equipment, not his scientific Italian knowledge. Probably his imaginative equipment in Italian knowledge was greater than that of his audience, for

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170 *Ibid.* p. 140.
171 *Ibid.* p. 211.
172 *Ibid.* p. 212.

he was a man that knowledge (of any human interest, that is) had a tendency to stick to. Ben Jonson liked to show more knowledge than his audience possessed. Shakespeare was too sensitive to the spectator's point of view to do that if he could help it. As a rule the color Shakespeare uses is that familiar not only to himself but to his spectators, part of their imaginative equipment. Hence a great proportion of detail necessary in realizing a situation will have to be English. And his method of using it implied three factors, none of them exactly deliberate: (1) spontaneous observation, (2) subconscious memory, (3) spontaneous selection.

Now at the bottom of every very good mind there is a little machine — something like a dictagraph — automatic, accurate, that goes on noting down every sort of impression and talking to itself in a subterraneous way about these impressions, — very steadily (even when one is not watching it) sorting, arranging, interpreting, storing away. Has one not heard it say, as it made some unusual and unintelligible record, "Now what was that? What was that?" like an automatic "line's busy" machine? Something turns out, let us say, as we did not expect it to turn out. Perhaps a personality proves quite other than the theory we had made of it. And yet we find — to our surprise — that we are not surprised. Why? Because our memory has disclosed its subconscious records. We remember now the points at which we were puzzled, the snag that set the little mechanism purring, "Now what was that? What was that?" The creator — the literary creator more especially — has a superlatively good subconscious recorder. He may be rather absent-minded on the conscious side; for practical purposes he perhaps does not notice things as he ought to do; but sometime after an experience, when he is ready to use it for a creative purpose, he finds his material available, every detail sharpening under the gaze of recollection, like (to change the figure) a photograph developing in the dark room of the subconscious mind.

Shakespeare was accurate also in his selection of the records of memory for artistic use. One more illustration: some years ago there was a popular kind of exhibition in America called a cylorama. One entered a circular building, climbed a winding stair and found oneself in a tower apparently overlooking the circle of a vast plain. The mind knew, of course, that a brick wall was somewhere within a few feet of the handrail — that the far horizon was an impossibility; yet it seemed real. How was it done? By a combination of painted canvas in the background, actual objects near at hand. Here is a well sweep; the rope and bucket are a real rope and bucket; the well, perhaps, is painted. To any ordinary uncritical eye the illusion was perfect and unbreakable. A childish spectator was acutely irritated by its perfection, wanted, quite desperately, to hurl a pebble into that deceptive distance, see it strike against a canvas wall, disclose where the painted scene began. Just so has Shakespeare baffled our senses, by his distant horizons and his details of every-day life, his magical combination of the actual and the imaginary. This is not to say, of course, that Shakespeare invented the method, only that he was its supreme master. All artists have used it in one degree or another in all periods. We find it already in the miracle plays — where in the story of the first Christmas, the shepherds bring to the Child gifts of toys and mittens, real woollen mittens worn on English hills.

We perhaps do not realize how far our sense of the persons depends on this concreteness of setting. In the details of their surroundings lies much of the substantiality of their experiences to themselves and much of their own substantiality to the reader. As we have seen, the sense of romance is very largely a matter of an atmosphere subtly created through the manipulation of detail. And this romance is itself vitalized, made more powerfully romantic by vividness, individualization, color, and perspective. Similarly the illusion of reality has been at critical moments protected by the veil of romance, by a skillfully woven place enchantment that has tended to deepen the dramatic and poetic appeal of the whole.

COWLEY AS A MAN OF LETTERS

Ruth Wallerstein

Every thoughtful reader who goes even a little way into Cowley will become increasingly aware of two dominant impressions forming in his own mind. He will feel a massiveness and intensity of poetry, latent almost everywhere, but not often realized by Cowley in actual word and image and design. Though Cowley rarely wrote poetry as great as the *Ode* on Hervey, there is an equally high spirit latent in much of his poetry, as Milton felt, and as Wordsworth was to feel. The reader will perceive in the second place, as many critics since Gosse have pointed out, how far he is moving into the world of Dryden and Pope. What I have to say, taking its start from these two points of massiveness and rhetoric, should perhaps be called a footnote to previous work on Cowley. In the light of them, I want to stress a new emphasis in the interpretation of his work and to point out certain aspects of his influence which deserve special attention. For Cowley is not only a poet but even more a man of letters. Studied from this side he illustrates both the type and its function to a remarkable degree. Moreover, the study of his influence as a man of letters on later poetry gives us significant material for the study of aesthetics and the laws of the literary imagination.

A cursory glance at his types of work indicates at once the range of interests and hospitality of taste that should characterize a man of letters. To remind the reader briefly, there is the enormous sweep from the childhood poems and schoolboy play, which look back to the earlier Elizabethan world, to the *Anacreontics;* from these to the love lyrics of *The Mistress,* and again to the *Pindarics,* which open up a type of reflective lyric new to England. There are the exuberant boyish Latin play, and the half satiric *Cutter of Coleman Street,* written in college and revised years later, and the long Latin *Libri Planatorum,* written after he had studied medicine in his middle years, and amazing for the virtuosity and fluency of their elegiacs and lyric measures. Then there are the familiar essays, the project for an agricultural college and experimental laboratory, and finally the notes to *Davideis* and the *Pindarics,* which are remarkable for their considered theory and definitions, as well as for their appreciations.[1]

If we look at Cowley's themes, we find the same catholicity and enterprise. Let me only note in passing that he added two new themes to the then traditional and current subjects of lyric poetry, — namely, critical theory and the new science and philosophy. In style, he began with Spenser and Fletcher, wrought under Donne and again under Ben Jonson, garnered much from the classics. Here too he innovated; he both enlarged the scope of irregular verse and set the English pattern for it; he built up the couplet and gave currency to the Alexandrine.

His experimentation is in extraordinary proportion to his actual accomplishment. Other poets of robust nature try a number of modes of poetry and a number of styles before they find their own; but we feel through all the shifts of their work the gradual emergence of one poetic personality, of one poetic vision, and of one style able to hold the impress of that vision. Cowley's various endeavors, on the other hand, though we feel one intelligence behind them, have no such continuity of poetic personality and do not merge into one whole. Cowley never found himself. He brought none of his endeavors to sustained excellence, except the *Anacreontics,* and they are the simplest and most obvious of his poems, as well as the ones most readily translatable from the classics. He almost never has steadily at his command a style as adequate as that of a hundred much lesser poets though he has moments of greater style than they. Even the play of ingenuity which pervades all the surface of his writing, and which is really so characteristic of the man's temper, is not an integral style. Why was this? In truth, intelligence more than poetic fury possesses his work. His intelligence, which coolly used his poetic feeling as a tool, rather than becoming itself the instrument of that feeling, turned to one and to another experiment; and his energy went successively into exploring the theory of these new modes, so that he never subdued and absorbed them into creative feeling. Cowley lived in a poetic age, and he is caught up in its spirit, but

[1] Mr. Nethercot has gathered these notes together in an article called *Abraham Cowley's Discourse on Style,* published in *The Review of English Studies,* October 1926, Vol. II, pp. 385-404.

in him intelligence was more active than primary poetic or philosophic imagination. That was one reason indeed why he accomplished so much.

To explain more fully, Cowley himself felt that he was too much hindered by circumstance and by the attendant dissipation of spirit to drive his work through to its full promise. But in the same disturbed age Marvell, working in a completed tradition, and Davenant, as a transitional poet reaching out to the new feeling and the French influence, are poets equally hindered who brought their vision and style to completion. Cowley attempted more and had something deeper to say than Davenant, and hence his material was far more difficult to assimilate and create into new poetic life; this, however, does not fully explain his incompleteness. In detail he does not show the quickening, the assurance, the high clear light of the Seventeenth Century. Dryden is an example of the accomplishment in the absorbing and perfecting of new modes which can be achieved by the great man of letters who has also a very great artistic gift. In truth, Cowley's gift, as this comparison shows more clearly, was primarily intellectual, and only secondarily poetic. I do not mean by this that Cowley had not a deep and fine imagination, and a sensitive personality. But the range and scope of one's thought, and its sympathetic participation in life, do not necessarily become an immediate part of one's efficient poetic and philosophical creative power unless there be special creative gift. Lacking this, Cowley can only say mediately and in terms of analysis, sometimes dry, what the poet says immediately. His *Ode on the Death of Mr. William Hervey,* in its later stanzas, is an example of this limitation. True, the spacious and poignant opening stanzas, under the whip of perhaps the strongest emotion Cowley ever sought to express, concentrate thought and feeling in imagery that is immediate and splendid:

It was a dismal, and a fearful night,
Scarce could the Morn drive on th' unwilling Light,
When *Sleep, Death's Image,* left my troubled brest,
        By something *liker Death* possest.
My eyes with Tears did uncommanded flow,
        And on my Soul hung the dull weight
        Of some *Intolerable Fate.*
What bell was that? Ah me! Too much I know.

This tide of feeling moves onward into the great traditional elegiac reflection upon the emptiness of the world and the barrenness of a friend left desolate by the death of a noble man. The traditional imagery and thought, with all their glow, are recast into terms of Cowley's and Hervey's actual experience; and in piercing simplicity the realization of grief transcends *Lycidas*.

> My dearest *Friend*, would I had dy'd for thee!
> *Life* and this *World* will henceforth tedious bee.
> Nor shall I know hereafter what to do
>   If once my *Griefs* prove *tedious* too.
> Silent and sad I walk about all day,
>   As sullen *Ghosts* stalk speechless by
>   Where their hid *Treasures* ly;
> Alas, my *Treasure's gone, why do I stay?*
>   . . . .
>
> Ye fields of *Cambridge*, our dear *Cambridge*, say,
> Have ye not seen us walking every day?
> Was there a *Tree* about which did not know
>   The *Love* betwixt us two?
> Henceforth, ye gentle *Trees*, for ever fade;
>   Or your sad branches thicker joyn,
>   And into darksome shades combine,
> Dark as the Grove wherein my Friend is laid.

But as the reflection grows more actual, the movement slows up, and even though it does not lose its nobility, it passes into the step by step analysis of prose:

> His *mirth* was the pure *Spirits* of various Wit,
> Yet never did his *God* or *Friends* forget.
> And when deep talk and wisdom came in view,
>   Retir'd and gave to them their due.
> For the rich help of *Books* he always took,
>   Though his own searching mind before
>   Was so with *Notions* written ore
> As if wise *Nature* had made that her *Book*.

The effect of the close of this ode is due in part to the nature of the world Cowley was experimenting in, the world of Hobbes, Harvey, and the Royal Society. But on the whole, it may be ascribed to the fact that reason rather than poetic imagination is at work in a poetic stream.

Cowley's intelligence is an interesting one. Curiosity, a vigorous intellectual grasp of the external world as fact, and the free play of interest in this fact and in theories of all sorts are basic in it. To compare it with Donne's will define it and will show how really different Cowley is from Donne, and how the pupil changed what he took. Donne's is the far greater and more intense intellect. Raymond Alden noted in the love lyrics of Donne a profound intellectual seriousness not found in Cowley's.[2] All the drive of Donne's character and imagination are behind his intellect. All parts of Donne's life and perception bear on each part. Sheer restless intelligence and curiosity are strong in him; but what gives his thought its special quality is that there is nothing he observes or studies but he strives to make it at once a part of his philosophy and thence a part of his actual belief and will and feeling. Donne's is that "concentration of reason in feeling" which can lead to mysticism. Cowley's intellect, on the other hand, is not philosophical. It has not the Baconian sheer dry weight and depth, nor has it, as I have said, the imaginative drive of Donne's. Yet Cowley has a keen interest in scientific ideas, and he is a leader in giving them currency in the cultivated world as the *Proposition for the Advancement of Learning, To the Royal Society,* and the influence of his poems show.

A brief glance at the method of reading of Cowley and Donne reiterates the same truth. Mediaeval thought and logic had a deep influence in shaping Donne's imagination, as Courthope has shown.[3] But it found its opportunity in the character of Donne's mind and his way of reading. One can imagine him plunging into every book he reads as a matter of life and death. Cowley is far more detached from his intellectual game. He reads as a scholar and critic. One remembers in all this that Cowley is forty-five years younger than Donne, and that Hobbes and other reading of Cowley's maturer years dealt with ideas less imperatively applicable to the individual consciousness than was Donne's reading. But even where Cowley handles the mediaeval reading, in the notes to *Davideis,* he handles it as he handles Hobbes, with shrewd critical insight rather than passion. His temper of a man of letters, if it deny him certain other gifts, is fortunately suited to the material of the

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[2] Raymond M. Alden, *The Lyrical Conceits of the "Metaphysical Poets", Studies in Philology,* Vol. XVII. pp. 183-197.

[3] W. J. Courthope, *A History of English Poetry,* Vol. III, Chapter VI, pp. 103 ff.

time and to making it current in the literary traffic of the day. Johnson's word on Cowley's mind is final: "A mind capacious by nature and replenished by study . . . always either ingenious or learned, either acute or profound."

With these differences in the two minds, as I have suggested, Donne's perception finds its characteristic and inevitable expression first in the love lyrics and the religious lyrics, poems in which the whole content of thought is absorbed in the flash of feeling; and then in the gusto and irony and passionate anger of question which characterize the *Satires* and *Epistles*. Cowley's genius is not suited to the love lyric. True, *The Mistress* is specifically in the school of Donne, and Cowley, sensitive as he is, has caught the vision of Donne, wondering at the complex of personality impinging on the outer world, just as he caught the sweep of Pindar. But that imaginative intensity is not the chief note of even *The Mistress*, as I shall show when I speak of imagery.

Samuel Johnson could see no ground for what Clarendon said of the influence of Ben Jonson on Cowley. Yet the objective definition of his condition and feeling in the ode on Hervey is in the spirit of Ben Jonson's amplest verse, just as his grasp of the traditional imagery is in the spirit of Jonson's epitaphs, and of Jonson's general "judgement" and "eloquence" and "masculine expression", to use Clarendon's phrases.[4] Though Cowley has no note of sublimity and though in detail he has a grotesque literalness which pushes into an arabesque of style, he has a deep sense for noble and comprehensive thought, for the details of the visible world as material and as instrument of thought, and for the glow of emotion that spring from such thought. A splendor of this sort hovers in the *Pindarics*, in much of the *Davideis*, in the bold conception and rapid imagery of the *Hymn to Light*. It was these things that Milton must have felt when he ranked Cowley as a favorite. The final poetic fusion of this material wanting in the actual words of Cowley, Milton could himself make, and must have made even as he read. The range of life and reflection, the sweep of human experience, he appreciated. And these, tempered by Cowley's personality, give everywhere the sense of a great implicit poetry so much larger than the actual accomplishment.

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[4] Edward Hyde, Earl of Clarendon: *His Life by Himself*, Oxford 1857, Vol. I, p. 28.

It was another side of this intellectual quality which worked upon Dryden and Pope, — namely, its power of definition and generalization. Where Donne contributed amply to the general spirit of Dryden's rhetoric in the *Satires,* Cowley gave much to the detail of its reflection and to its technique and even more to Dryden in the *Odes* and to Pope. Consider the *Pindarics,* for example, and the moral and sentimental reflections of Pope's *Homer.* The same drawing out of moral reflection and sentiment as we find in Pope is clearly present, for example, in Cowley's *Second Olympic of Pindar:*

> They [Theron's forefathers] through rough ways, o're many stops they past,
> Till on the fatal bank at last
> They *Agrigentum* built, the beauteous *Eye*
> Of *fair-fac'd Sicilie,*
> Which does it self I' th' *River* by
> With *Pride* and *Joy* espy.
> Then chearful *Notes* their *Painted Years* did sing,
> And *Wealth* was one, and *Honour* th' other *Wing.*
> Their genuine *Virtues* did more sweet and clear,
> In *Fortunes* graceful dress appear.
> To which great *Son* of *Rhea,* say
> The *Firm Word* which forbids things to *Decay.* ....
> For the past sufferings of this noble Race
> (Since things once *past,* and fled out of thine hand,
> Hearken no more to thy command)
> Let *present joys* fill up their place,
> And with *Oblivions* silent stroke deface
> Of foregone Ills the very *trace.* ....
> But *Death* did them from future dangers free,
> What God (alas) will Caution be
> For *Living* Mans securitie,
> Or will *ensure* our *Vessel* in this faithless *Sea?* [5]

Again, for very specific sentiment and definition we may look at the lines on Virgil in *The Motto:*

[5] For the reader's convenience, to make the point even more clear, I give here Ernest Myers' prose translation of the passages cited above:

"They after long toils bravely borne took by a river's side a sacred dwelling place, and became the eye of Sicily, and a life of good luck clave to them, bringing them wealth and Honour to crown their inborn worth.

O son of Kronos and of Rhea . . . guard ever graciously their native fields for their sons that shall come after them.

Now of deeds done whether they be right or wrong not even Time the father of all can make undone the accomplishment, yet with happy fortune forgetfulness may come. For by high delights an alien pain is quelled and dieth, when the decree of God sendeth happiness to grow aloft and widely. . . .

Ay but to mortals the day of death is certain never . . ."

Virgil the *Wise*
Whose verse *walks highest*, but not flies.
Who brought green *Poesie* to her perfect Age;
And made that *Art* which was a *Rage*.

The definitions in the poems *Of Wit* and *Of Reason* have the same quality, as also do epigrammatic elements in *Davideis*, or, to take a final example, the last stanza in the *Pindaric to Dr. Scarborough*, ending with the line, "When all's done, *Life is an Incurable Disease*." The spirit of the sweep of the Renaissance is in him, but in the chop of the two tides, his temper answers more readily to the new mode of analytical definition and reflection. Cowley's own phrase of syllogisms and enthymemes might be taken as a figure of it, when he says of Pindar and Isaiah, "They wrote in enthymemes, we write in syllogisms." The age was no longer ready to drop a premiss and flash to its conclusion, but was beginning to think and to speak in the step by step movement of the syllogism, and Cowley led the way.

In what I have said above and in what I shall say, I am aware that it was Pope who asked, "Who now reads Cowley?" Pope, however, was exaggerating for a special point; moreover, to continue the quotation, "the language of his heart" which Pope praises means much more than the essays suggested by Courthope; and it is to be noted, too, that "his moral pleases" Pope. Further, Pope's dismissal, such as it is, must not be taken at its face value. This becomes even clearer if we give brief consideration to the detail of Cowley's style.

Pope and Dryden consciously studied Denham and Waller as the models of their technique — Dryden especially as he matured. But as their work shows, and as they indicate in various passages, they read and absorbed Cowley in the years when their imaginations were taking shape.[6] That silent formative influence must have been immense. As Thompson has shown, it was from Cowley that Dryden and Pope learned the breadth and spirit — the substance we may say — of the couplet which they finished on the models of Waller and Denham.[7] His influence on the rhetoric of their couplet was no less great. Not

[6] In Pope's case the influence of Crashaw too was strong, and in part in the same direction.

[7] A Hamilton Thompson, *Abraham Cowley*. *Cambridge History of English Literature*, Vol. VII, Chapter III, pp. 70-79.

only is the type of rhetoric indicated in the paragraphs above present in Cowley, but it finds in him its characteristic succinct, general, definitive language, even in descriptive or narrative passages. It permeates *Davideis,* as one example from the wooing of David and Michel will show:

> She weighed all this as well as we may conceive,
> *When those strong thoughts attacked her doubtful breast;*
> His beauty no less active than the rest.

But the shaping quality of Cowley's reasoning temper is equally manifest in the more obvious pervasive element of his style, in its wit and so called "metaphysical" quality. "Metaphysical" style is a very different thing in Donne and Cowley. The stuff, the manner, the imaginative effect of the imagery is very different, although they have in common the intellectual form of statement and the logical extension of image. Donne's images most often represent the truth of the world of inner experience, their outer curiousness being a simple truth in that world, their logic the logic of philosophical imagination seeking to pierce through objects in their casual temporal juxtaposition, to spiritual and emotional reality; and in the satires, his figures make appeal from worldly values to human. Cowley's imagery, if we define it by this comparison, represents not inner life, but sentiment, wit, fancy. Whereas Donne has imagination in the Coleridgean sense, handling and shifting objects to get at what lies behind them, Cowley's is fancy musing upon objects and playing with them, indeed, to see all their facets, but still focusing upon them as fixed objects.

To analyse several of Donne's characteristic images and approach Cowley's figures through them will explain my meaning. In Donne's song "Sweetest love, I do not go", the whole theme, as in many others, is the significance, to a lover, of personal experience as against the outer mechanical fact of life. The images recreate this personal reality, following boldly and directly the psychological flow of the emotion. "When thou sigh'st, thou sigh'st not wind" (He will return as surely as the sun, he has said. Now the mind articulates a fact of nature in another sphere, the fact of her physical life, and the emotion, catching hold of the fact by its symbol, the word, and pivoting on that, pulls the fact back into its own reality of the spirit.) "When thou sigh'st, thou sigh'st not wind, But sigh'st my soul away". The great figure in one of the sonnets on death,

> At the round earth's imagined corners blow
> Your trumpets, Angels,—

is not literally reasonable on the face of it. But reason may deal with it profoundly if its full thought is looked at, if the enthymeme be expanded. It does not matter, says Donne, if the traditional pictures with which we figure the universe be scientifically false; they are but symbols, and the reality is not circumscribed by them, either in itself or for us. This truth he gives us in one flash. The compass figure in the *Valediction,* again, takes us step by step deeper into the perception of the ideal thought on which the emotion rests, and the emotion intensifies and expands as the concept clarifies. What does this teach us of Cowley?

Cowley's imagery develops in a quite different spirit. Like his thought, it is many things in many types of poem. The *Anacreontics* have little essentially in common with the *Pindarics.* But certainly the trick of image elaborated in detail becomes a habit on the surface of his whole style. And he is set going by the extension of figures in earlier poets, particularly Donne's figures. It is this "witty" or "metaphysical" imagery that we now want especially to look at. Some of the poems of *The Mistress* are little allegories of love play, written in the manner of the Elizabethans or Herrick's songs for music, but with the figure of wit and fact caught from Donne taking the place of a myth. *Written in Juice of Lemon* illustrates this. Again, *The Change* begins with courtly Petrarchean play:

> *Love* in her Sunny Eyes does basking play;
> *Love* walks the pleasant Mazes of her Hair;
> *Love* does on both her Lips forever stray;—

But this shifts to analysis:

> With me alas, quite contrary it fares;
> *Darkness* and *Death* lies in my weeping eyes,
> Despair and Paleness in my face appears,
> And Grief, and Fear, Love's greatest Enemies;
> But like the *Persian-Tyrant, Love* within
> Keeps his proud *Court,* and ne're is seen.

The analysis itself, however, becomes not the analysis of emotion or ideal situation, but rather the analysis of the figure itself and hence draws out to its logical conclusion, the epigram:

Oh take *my Heart*, and by that means you'll prove
Within, too stor'd enough of Love:
Give me but Yours, I'll by that change so thrive,
    That *Love* in all my parts shall live.
So powerful is this change, it render can,
My *outside Woman*, and your inside Man.

Poems which suggest specific comparison with Donne define Cowley very clearly. The lyric *My Heart Discovered*, in its search of heart and soul through body, evokes a close comparison with Donne, and in particular the whole conception of the opening lines,

Her body is so gently bright,
Clear and transparent to the sight,
. . . .
That through her flesh, methinks, is seen
The brighter soul that dwells within;

carries us back to Donne's description of Elizabeth Drury,

Her pure and innocent blood
Spoke in her cheeks and so distinctly wrought,
That one might almost say her body thought.

In this poem, one of Cowley's most delightful, the turn of wit answers deeply to the theme of the poem. Skipping a few lines:

I through her *Breast* her Heart espy,
As *Souls* in *hearts* do *Souls* descry,
I see't with gentle *Motions* beat;
I see *Light* in't, but find no *Heat*. . . . .
But, oh, what other *Heart* is there,
Which sighs and crouds to hers so neer, ...
The wounds are many in't and deep;
Still does it bleed, and still does weep.
Whose ever wretched heart it be,
I cannot chuse but grieve to see;
What *pity* in my Breast does raign,
Methinks I *feel* too all its pain.
So torn, and so defac'd it lies,
That it could ne're be known by th' eyes;
But, oh, at last I heard it grone,
And knew by th' voice that 'twas *mine own*.

> So poor Alcione .... [Here he tells briefly how she unknowing weeps the body of her husband.]
> What should the wretched Widow do?
> Grief chang'd her straight; away she flew,
> Turn'd to a Bird: and so at last shall I,
> Both from my *Murther'd Heart,* and *Murth'rer* fly.

The theme is not as in Donne the yearning of personal feeling, or imagination trying to transcend fact. It is objective reflection, half pathetic, half comic, and the temper in which it views its subject might well be called that of social comedy. And again it works up to the epigram. Another lyric, *Silence,* which suggests comparison with *The Triple Fool,* is, in theme, the Donnian passionate analysis of passion, but in expression, the logic moves, like the Hervey ode, with the slow definition of prose, and ends not in the deeper focus of emotion into which Donne takes us, but in the sententious phrase. *The given Heart,* which is frankly and wholly the extended epigram, is on the other hand, rapid, gay, integrated. We see, then, that this prose quality of Cowley's mind, this literal development, characteristically steps in. Where the figure has started to be emotional, it often becomes merely ludicrous. Where the figure is a figure of idea, it can, like Dryden's figures in *Absalom,* be made to carry forward an argument very prettily. In *The Welcome* this style of figure gives an enchanting gaiety; in *To Wit* it heightens and makes rapid the definition. These two are akin in objectivity and lucid definition to Ben Jonson. In *My Dyet* the subject matter once more comes from Donnian logic, but the objectivity of the new manner gives it its character and charm. The spirit of the conceit in Cowley has become intellectual and reasoning, and grows sometimes to reflection and sometimes to social comedy.

The conceit pushed too far. And Pope and Dryden wisely reprobated its excess of elaboration. In even great contexts, the image pushed to the limit not only loses its emotion but forgets its idea, and carries on in mere literal play of word. Starting in the passion to be complete in every detail of feeling and ratiocination, it is abstracted from its theme; it becomes an empty cleverness; it just trembles into periphrasis. The approach to periphrasis is widespread in his work, though not sharply focused. *My Muse* and *To Mr. Hobs,* in the lesser detail, well illustrate this:

The *Baltique, Euxin,* and the *Caspian,*
And slender limb'd *Mediterranean,*
Seem narrow Creeks to Thee, and only fit
For the poor wretched *Fisher-boats* of *Wit.*
Thy nobler Vessel the vast Ocean tries,
And nothing sees but *Seas* and *Skies,*
Till unknown *Regions* it descries,
Thou great *Columbus* of the *Golden Lands* of new *Philosophies.*

Cowley approaches here a distinct "poetic diction". His abstract intellection and the fact that ratiocination usurped the ground of his thought were tendencies pushing him, perhaps inevitably, towards such a diction. Because of these qualities in his creation he tends to generalize his adjectives; and his images, because one element of life is abstracted from the rest, lose their sensousness and become abstract symbols of ideas of objects.[8] Finally, he tends as a result of these two developments, and perhaps seeking an elegance congruous with this rhetoric, to a theory and practice of poetic words. The notes to *Davideis,* Book II, for example, explain the use of *wife* instead of *spouse* on the ground of poetic suitability of word.[9]

Here too Pope absorbed before he criticised. The abstract play of reason caught him. There were other great influences at work in forming the poetic diction of Pope.[10] But from what I have said it is, I hope, clear that the Popean periphrasis received a significant impulse from Cowley.[11] It will be remembered that Pope himself called his early work "fancy's maze" in contradistinction to the "truth" and "moralized song" of his later work.[12]

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[8] This point may perhaps be more clear if we look at imagery in another field than Cowley's. It is interesting to note that in our own day we have a group of lesser lyric poets who go through the same process. They concentrate on the experiencing of the emotion, and in so doing they isolate the emotion from the experience which caused it, and its relation to their thought and action, hoping to intensify it by the very analysis of it. They abound, of course, in series of images very specific in detail; but in effect, though their object is feeling and not reason, they strike us just as does the "poetic diction" of the Eighteenth Century. Elinor Wylie illustrates this tendency, and it is very strongly marked in some of the very minor poets.

[9] *Davideis,* Book II. *Poems,* Ed. A. R. Waller, Cambridge 1905, p. 321.

[10] See, for example, the discussion of the influence of Milton in Sir Walter Raleigh's *Milton,* London, 1900, Chapter V, pp. 218-255; and the discussion of the style of Dryden's *Virgil* in Mr. Mark Van Doren's *Dryden.*

[11] The influence in this direction would not be limited to Cowley; the extended image in Crashaw must be borne in mind.

[12] *Epistle to Dr. Arbuthnot. Poems,* Ed. H. W. Boynton, Boston, 1903, p. 181.

Thus if Cowley did not find himself as a poet, he did find himself as a man of letters. To bring to the fore this intellectual and logical temper, even though it was to prune away so much of his own time that was dear to him, was one of his tasks as a man of letters, sensitive to the current of ideas, just as to keep alive the breadth and range of perceptions and the objective imagery of the *Pindarics*, ready for greater hands to kindle to flames, was another. Cowley is an important factor in understanding how English letters passed so rapidly from the multifarious splendor of the Renaissance to the more limited but the assured accomplishment of Dryden.

WISCONSIN MYXOMYCETES

H. C. GREENE

FOREWORD

The Myxomycetes of Wisconsin have already been the subject of a comprehensive paper. In 1914 Alletta F. Dean published an article entitled 'The Myxomycetes of Wisconsin', (Trans. Wis. Acad. Sci. 17 : 1221-1299. 1914), in which a thorough treatment of the Wisconsin Myxomycetes then known, largely her collections, was undertaken. Reprints of this paper are no longer available. Moreover, it was, unfortunately, not illustrated, and since that date some forms not at that time recorded for Wisconsin have been collected. This combination of facts seems to the writer to justify the publication of a brief, illustrated paper which will bring the subject up to date, and will, it is hoped, by means of the illustrations, stimulate curiosity regarding this very interesting, but somewhat neglected group.

The classification and the generic key presented follow Macbride (*North American Slime-Moulds,* New and Revised Edition 1922, 299 pp., Macmillan Co.), and certain of the illustrations are redrawn from Lister (*Mycetozoa,* Third Edition 1925, 296 pp., 222 pls. British Museum, N. H., publication.)

It will be noted that the generic key has reference only to the Sub-class Myxogastres, and that therefore *Ceratiomyxa,* the first genus treated in the paper, is not included in the key. It is sufficiently distinctive, however, to be easily recognized on its own account. After the genus name in the key appears the number of the plate in which the illustration of the genus in question is to be found. Descriptions of the figures in the plates will be found in the latter part of this paper.

The valued and congenial aid of Dr. E. M. Gilbert of the Department of Botany of the University of Wisconsin has made this paper possible. To him, and to others who have been of assistance, the writer desires to convey his sincere thanks.

INTRODUCTION

The Myxomycetes are a compact group of animal-like fungi (or fungus-like animals, if you prefer) low in the scale of life and usually tiny and inconspicuous, which, by their great beauty, their diversity, and their availability in any moist, wooded country, form a fascinating and easily accessible subject for study by naturalists.

Myxomycetes (also called slime-moulds and Mycetozoa), in the course of their relatively simple life cycle, display characters which are diversely ascribed to both plant and animal kingdoms, so that students of classification have been, and still are, somewhat at a loss as to the proper position of these curious forms. During their vegetative existence the Myxomycetes form so-called *plasmodia* which superficially resemble giant amoebae, while during their reproductive period they resemble the Gasteromycetes, a group of higher fungi, but are distinguished from the Gasteromycetes by the total lack of a mycelium. Dr. T. H. Macbride, the preëminent American student of the Myxomycetes, makes the following remarks in the introduction to his *North American Slime-Moulds:* "But why call them either animals or plants? Was nature then so poor that forsooth only two lines of differentiation were at the beginning open for her effort? May we not rather believe that life's tree may have risen at first in hundreds of tentative trunks of which two have become in the progress of the ages so far dominant as to entirely obscure less progressive types? The Myxomycetes are independent: all that we may attempt to assert is their near kinship with one or other of life's great branches."

As above stated, Myxomycetes are found in considerable abundance in any moist, wooded area at the proper season of the year. In the Middle West these diminutive forms are to be had from the middle of May until late fall. The type of substratum chosen for vegetative growth is diverse, but must be moist and in not too bright light. Old rotten logs, sticks, humus, various large fungi, and all sorts of vegetable debris support the plasmodia of Myxomycetes. When the time for fruiting arrives the amoeboid plasmodia creep out of their dark feeding grounds, and come to fruit, as a rule, in fairly open situations such as the tops of logs, sticks, leaves, and so forth.

In general, the mature fruits, representing the plant-like phase, are much more conspicuous, than are the vegetative plasmodia, which represent the animal-like phase. Therefore, the fruiting phase will be first discussed in the following account of the life cycle characteristic of Myxomycetes.

The fruiting bodies of Myxomycetes are called *sporangia,* that is, (with the exception of one small genus, *Ceratiomyxa*) they contain within them the numerous spores which, under favorable conditions, germinate to produce the vegetative phase. The diverse morphological characters of the sporangia and the spores form the basis of our classification of these forms.

There may be many thousands of sporangia in a single fructification, there may be hundreds, or there may be only a few, or even one in the case of compound fructifications. Certain species customarily have much larger fructifications than others. The sporangia may be very closely clustered, or merely gregarious, or quite widely scattered, a matter again depending in large degree upon the species concerned. Many rudimentary sporangia may be closely crowded together in a single layer, or superimposed over each other in several layers, and the aggregate is then known as an *aethalium.* In numerous cases individual sporangia are not differentiated at all and the flatly rounded, irregular, elongated, structures resulting are termed *plasmodiocarps.*

Distinct, individual sporangia are, in most genera, small and delicate, not over 1 millimeter in their dimension. In some genera, however, as in *Stemonitis* and *Comatricha,* the length of sporangia may be as great as 25 mm. the width not exceeding 1 or 2 mm. In the case of *Arcyria,* and in lesser degree in that of *Hemitrichia,* the capillitium may expand beyond the original limits of the sporangium until the effect is one of drooping plumes, with a length of some 12 or 15 mm. or more in a few instances.

Aethalia, composed of many rudimentary sporangia, are sometimes very large. Some of the flat aethalia of *Lindbladia effusa* have been reported as having a diameter of 50 centimeters, — about 20 inches! Most aethalia are much smaller than this, but are, nevertheless, often quite conspicuous.

As mentioned above, instead of definitely delimited sporangia, there are often found elongate, sessile, flat sporangia known as plasmodiocarps. *Physarum sinuosum* furnishes a good example of the plasmodiocarp habit. Plasmodiocarps may be short and straight, with their long diameter not more than twice that of the short. They may be short and curved, long and straight, long and curved, ring-shaped, scalariform, or netted, or any combination of these. The exact shape, as is also true in the case of aethalia, is likely to be dependent on the contours of the substratum to a greater or less extent. Plasmodiocarps appear in some cases in company with perfectly formed individual sporangia, while in the case of such a form as *Hemitrichia serpula* the plasmodiocarp habit is most pronounced and distinctive, resulting in an elaborate looped, reticulate fructification. Most plasmodiocarps are slender, not over a few millimeters in width.

The typical fruiting body of a Myxomycete is composed of (1) The sporangium proper which is a more or less rounded structure enclosed by a membrane called the *peridium.* In many species the peridium is coated with lime incrustations of varied hue. Sometimes, as in the genus *Diderma,* the coating of lime is more or less remote from the membranous peridium, giving the appearance of a double wall. In species where lime is lacking the peridium may be shining or iridescent. The tint of certain peridia is definitely due to the color of the spore mass enclosed. In the genera, *Cribraria* and *Dictydium,* the peridium is pierced by many small openings. In all cases, sooner or later, it is the rupture of the peridium which permits the dispersal of the spores. In most genera a system of membranous threads or tubules is to be found within the sporangium. These threads collectively form the *capillitium.* In different forms the capillitium varies greatly and forms one of the principal differential diagnostic features. It may form an intricate branching system, the threads may radiate from a central point of attachment, or they may be free within the sporangium, or still otherwise arranged. The capillitial threads may be entirely charged with granules of lime as in *Badhamia,* or only partly so as in *Physarum.* In most genera lime is not noticeably present in the capillitium. The capillitium may be colorless or colored, depending upon the species concerned, and the threads in some forms are profusely sculptured, while other capillitial filaments are practically smooth. The spores are one-celled, usually spherical, small (not often more than 12 micra in diameter), and of various tints of brown or yellow. The color of spores in mass is usually much deeper than that of the individual spore as seen under the microscope. Spores may be practically smooth as in

Cribraria, they may be covered with warts of varying size and abundance, or they may be covered by a system of netlike bands, spoken of as reticulations. Spore size and markings are important diagnostic characters.

(2) The *stalk* or *stipe* which bears the sporangium is membranous in nature, may be charged with lime or waste matter, or both, and is most variable in shape, length, and color in different species and genera. The stipe in many forms is continued upward into the sporangium proper, and this upward continuation is called the *columella.* The columella is variable in size, shape, branching, and composition, and may or may not, according to the form concerned, attain to the apex of the sporangium. Collumellae are also found in some forms which are without stipes in which case the columella may be regarded as the thickened base of the sporangium. In many species the stipes arise from a more or less effused base spoken of as the *hypothallus.* There may be a distinct hypothallus associated with each sporangium, as for example, in the case of *Didymium nigripes,* or all sporangia of a given fructification may arise from a common hypothallus, as in *Stemonitis.* The hypothallus may be dull or shining, is also present in the case of certain forms without stipes, and is likewise found in connection with some aethalia and plasmodiocarps.

As may have already been noted from the context, the typical fruiting body thus characterized is by no means the type universally found. The stipe may be lacking and the sporangia are then sessile, the columella is often lacking, and there is no hypothallus in many species. Some species lack a capillitium, and in still other species the peridium is so early evanescent as to seem to the casual observer to be entirely absent. The reader is referred to the illustrations accompanying the article in order to gain an idea of the great variation found.

When the sporangia reach maturity, the spore mass is blown away or falls to the ground, and with the germination of the spores under the proper conditions, the vegetative animal-like phase is initiated, and will now be described.

The disseminated spores, under suitable conditions of moisture and temperature germinate, that is to say, the spore cell-wall is ruptured and the content escapes. The spore-content at this stage resembles an amoeba, has a contractile vacuole, and a nucleus, and creeps slowly about. Usually in a short time the amoeboid body produces a whip-like flagellum, with which it lashes about through its moist life-medium, showing considerable activity. This *swarm-cell* as it is now called, rotates actively for a time, and then slows down once more, again developing a creeping movement. At this point the swarm-cell becomes capable of ingesting food particles such as fungous spores and bacteria. The swarm-cells grow and multiply by division, for an indefinite period, then withdraw the flagellum, become amoeboid once more, and are henceforth known as *myxamoebae*. The myxamoebae grow and divide as do the swarm-cells, and eventually fuse in pairs. The pairs then fuse with many other pairs and a slimy, multinucleate plasmodium results. The plasmodium possesses the power of locomotion and creeps about, over or through the substratum in search of food, as a slimy vein-like mass of greater or lesser extent, its size often to some degree depending upon the species concerned. If conditions become unfavorable for continued activity, the plasmodia possess the ability to enter a resting stage, forming dry, horny masses which may assume again the plasmodial characteristics at the resumption of proper conditions.

The plasmodia are variously colored, and the colors have been used to some extent as a diagnostic feature, but ordinarily the student is unable to follow plasmodial development, and thus these colors, which are said also to vary from time to time, are of comparatively little practical aid.

This plasmodial condition may persist for months, usually in the cracks and fissures of moist logs, and in darkness more or less absolute. The plasmodia then, when conditions are favorable, creep out into the brighter light, and, after a longer or shorter period, pass rather suddenly to fruit, usually in an advantageous position for spore dissemination. This transition from the slimy amoeboid mass to the beautiful and intricate fruiting bodies is a most interesting phenomenon. That such conglomerates so similar to one another can suddenly assume forms so radically different, to some extent sets the group apart, and has made it an object of vitally engrossing study to biologists for many years.

KEY TO THE PRINCIPAL GENERA OF THE SUB-CLASS MYXOGASTRES

(after Macbride)

1. Spores in mass violet-black, or sometimes reddish-brown.
    2. Capillitium of simple or branching threads; sporangia more or less completely charged with lime. **Order Physarales.**
        3. Capillitium of hyaline, branching tubules, more or less completely charged with lime; peridium and stipe, one or the other or both, usually containing lime. FAMILY PHYSARACEAE.
            4. Fructification of cushion-like aethalia. *Fuligo (Plate I).*
            4. Fructification plasmodiocarpous, or of distinct sporangia.
                5. Peridium bearing lime externally.
                    6. Capillitial threads charged with lime throughout. *Badhamia (Plate I).*
                    6. Capillitial threads not completely charged with lime, but bearing lime nodules.
                        7. Sporangia other than goblet-shaped; dehiscence irregular. *Physarum (Plate I).*
                        7. Sporangia goblet-shaped.
                            8. Dehiscence by a distinct lid, or if not by a lid quite regularly circumscissle. *Craterium (Plate II).*
                            8. Dehiscence irregular, with peridial segments appearing as "petals". *Physarella.*
                5. Peridium without lime externally.
                    9. Fructification plasmodiocarpous. *Cienkowskia.*
                    9. Sporangia distinct. *Leocarpus (Plate II).*
        3. Capillitium of simple or rather sparingly branched threads without lime; lime, when present, usually on peridium only. FAMILY DIDYMIACEAE.
            10. Fructification an elongate, thick aethalium. *Mucilago (Plate II).*
            10. Fructification plasmodiocarpous, or of distinct sporangia.
                11. Lime deposits present on peridium.
                    12. Lime desposits of distinct, stellate crystals. *Didymium (Plate II).*
                    12. Lime deposits not in form of distinct, stellate crystals.
                        13. Lime deposits of small, rounded granules only; peridium usually distinctly double. *Diderma (Plate II),*
                        13. Lime desposits in the form of large, scattered scales, imbedded in, or resting loosely on the cartilaginous peridium. *Lepidoderma.*

11. Lime deposits not present on peridium; peridium double, the outer layer gelatinous. *Colloderma.*

2. Capillitium thread-like, much branched, arising from a columella; sporangia without lime (except in Diachaea). **Order Stemonitales.**

14. Fructification of blackish aethalia.

14. Fructification of blackish aethalia. FAMILY AMAUROCHAETACEAE.

15. Capillitium of fibrous threads, without vesicles. *Amaurochaete.*

14. Fructification of distinct sporangia, except in Brefeldia; capillitum springing from all points on the columella. FAMILY STEMONITACEAE.

16. Fructification aethalioid; capillitium charged with vesicles. *Brefeldia (Plate III).*

16. Fructification of distinct sporangia.

17. Stipe and columella black; no lime present.

18. Capillitium forming a surface net over the coarser branches; sporangia usually closely clustered and long-cylindrical. *Stemonitis (Plate III).*

18. Capillitium without surface net; sporangia usually scattered and globose, or shortly cylindrical. *Comatricha (Plate III).*

17. Stipe and columella white; heavily charged with lime. *Diachaea (Plate III).*

14. Sporangia distinct, but capillitium developed from summit of columella. FAMILY LAMPRODERMACEAE.

19. Columella extending entirely through the sporangium, and capillitium springing from a disk at the apex. *Enerthenema (Plate III).*

19. Columella shorter, not reaching beyond center of the sporangium; capillitium intricate; peridium shining, iridescent. *Lamproderma (Plate IV).*

19. Columella very short or rudimentary; capillitium of stiff, little-forked branches which at maturity bear plate-like remnants of the sporangial wall at their tips. *Clastoderma (Plate IV).*

1. Spores in mass usually some shade of brown or yellow, rarely purplish or rosy, never violaceous black.

20. Capillitium absent; pseudo-capillitium present in Reticularia and Enteridium; spores in mass yellowish through brown, rarely purplish. **Order Cribrariales.**

21. Fruiting bodies plasmodiocarpous, scattered. FAMILY LICEACEAE.

22. Plasmodiocarps variously shaped; peridium simple. *Licea.*

21. Fructification aethalioid; sporangia well defined; closely appressed, tubular, rupturing at top, side walls entire. FAMILY TUBIFERACEAE.

23. Spores in mass olivaceous-yellow; sporangia in one or several layers. *Lindbladia (Plate IV).*

23. Spores in mass rusty-red; sporangia in one layer. *Tubifera.*

21. Fructification aethalioid; sporangia not well indicated, and with side walls not entire. FAMILY RETICULARIACEAE.

24. Spores in mass brownish or reddish.

25. Aethalia covered by a firm, mottled silvery cortex; pseudo-capillitium of membranous expansions, much frayed into fine threads; hypothallus white. *Reticularia (Plate IV).*

25. Cortex evanescent, the aethalia when mature appearing as a soft, red-brown, cushion-like mass; pseudo-capillitium of broad, membranous, interweaving bands, not frayed out. *Enteridium (Plate V).*

24. Spores in mass ochraceous; sporangial tops well-defined. *Dictydiaethalium (Plate V).*

21. Sporangia separate and distinct, with the membranous sporangial well perforated so as to form a net, especially above. FAMILY CRIBRARIACEAE.

26. Peridium more or less dissipated so as to form an apical net, the intersections of which may or may not be expanded into definite nodes. *Cribraria (Plate V).*

26. Peridium more or less dissipated into a series of parallel ribs, radiating from below, and connected with each other by delicate transverse threads. *Dictydium. (Plate V).*

20. Fructification aethalioid, the individual aethalia resembling miniature puff-balls; peridium membranous; capillitium of tubules from peridium; spore mass rosy or ashen, becoming yellowish. **Order Lycogalales.**

27. As under 20. FAMILY LYCOGALACEAE.

28. As under 20. *Lycogala (Plate V).*

20. Capillitium of sculptured threads, attached or free, simple or branched; spores usually yellow; sporangia without lime, stalked or sessile, distinct, rarely plasmodiocarpous. **Order Trichiales.**

29. Capillitium plain, roughened or spinulose, simple; the threads sometimes attached to the sporangial walls. FAMILY PERICHAENACEAE.

30. Sporangia plasmodiocarpous; dehiscence irregular. *Ophiotheca.*

30. Sporangia polygonal; dehiscence circumscissle. *Perichaena (Plate VI).*

29. Capillitium a distinct net, attached below; threads roughened, but not sculptured with smoothly continuous spiral bands. FAMILY ARCYRIACEAE.

31. Peridium fragmentary, but persistent; capillitium non-elastic. *Lachnobolus.*
31. Peridium evanescent above, persistent below; capillitium elastic. *Arcyria (Plate VI).*

29. Capillitial threads usually free, but in some forms composing a loose, branched net; sculptured with definite spirals; or sometimes with rings. FAMILY TRICHIACEAE.
32. Capillitial threads forming a loose, attached net, the threads of which are spirally sculptured. *Hemitrichia (Plate VI).*
32. Capillitial threads free.
33. Threads distinctly spirally sculptured. *Trichia (Plate VI).*
33. Sculpture irregular or wanting. *Oligonema.*

CHARACTERIZATION OF WISCONSIN SLIME MOULDS

Class MYXOMYCETES (Link) De Bary

Fungus-like organisms, with an amoeba-like multinucleate vegetative phase, and a fungus-like reproductive phase; the spores, borne in connection with the reproductive phase, usually enclosed in sporangia, but rarely free, germinating to produce swarm-cells which fuse to form the vegetative phase.

Sub-Class *Phytomyxinae* Schroeter

This sub-class contains parasitic forms with which this paper is not concerned, and it is therefore omitted from consideration.

Sub-Class *Exosporeae* Rost.

Spores developed externally on columnar sporophores; sporophores white, somewhat translucent, branching; spores white, borne on stalks which project from the sporophore.

GENUS CERATIOMYXA Schroeter. This peculiar genus is unique in that the spores are borne externally on clustered, columnar, white papillae. The genus is easily recognized in the field by the fragile, translucent spore columns, characteristic of no other Myxomycetes.

Ceratiomyxa fruticolosa (Muell.) Macbr. (Plate I, fig. 1). Sporophores clustered in little tufts, white, bearing the spores externally, about 1 mm. high; spores white, ellipsoidal, each borne on a separate stalk. Found in moist situations, especially on wet logs, in spring and early summer. Common.

Sub-Class *Myxogastres* (Fries) Macbr.

This sub-class comprises practically the entire group under consideration. It is characterized by small, unicellular, usually spherical spores of various tints, enclosed in sporangia which, in most cases, bear a capillitium.

Order Physarales

Spores in mass violaceous-black; capillitium composed of hyaline tubules, either completely or partly charged with lime; peridium sometimes without lime, but in most cases containing lime in greater or less amount.

Family Physaraceae

Capillitium netted and branched, intricate, containing lime to a greater or less extent; peridium and stipe, one or the other or both, usually containing lime deposits.

GENUS FULIGO (Haller) Pers. Aethalioid fructifications, usually large and conspicuous, and giving no indication externally of the presence of individual sporangia; the outer layer of the aethalium a thin, calcareous crust usually disappearing after maturity; capillitium charged with lime to a greater or lesser extent.

Fuligo septica (Linn.) Gmel. This species can be subdivided into several forms, of which two are here characterized:

F. septica f. *ovata* (Schaeff.) Pers. (Plate I, fig. 2). Aethalium yellow to light brown, one to many centimeters in diameter, 1-2 or more cm. thick, variable in shape, lime crust prominent, with the "surface when mature extremely friable, like dry foam"; capillitium with branching yellow lime-knots; spores violet-black in mass. On dead wood, and other debris. Common.

F. septica f. *violacea* Pers. "Aethalium thin, two or three inches wide, covered by a cortex at first dull red and very soft, at length almost wholly vanishing, so that the entire mass takes on a purple violet tint, upper surface varied with white; capillitium rather open, the more or less inflated, large, irregular nodes joined by long, slender, delicate, transparent filaments; spores dark violet . . ." (Macbr.) Reported by Dean, but not seen by the writer.

Fuligo cinerea (Schw.) Morg. Aethalioid or plasmodiocarpous, white, irregular in shape and size, flat upon the substrate; capillitium charged with irregular lime-knots; spores violet-black in mass, ellipsoidal. Fruiting bodies appearing in mass on living, young tobacco plants near Madison, Wis., June 1931. Given to the writer for identification by Dr. J. J. Davis, Curator of the Herbarium, University of Wisconsin.

GENUS BADHAMIA (Berk.) Rost. Sporangia usually well-defined, sessile or stipitate; peridium of one layer; capillitium intricate, of branching tubules charged with lime throughout their extent. In external characters this genus much resembles *Physarum,* next following.

Badhamia panicea (Fries) Rost. Sporangia gregarious, or closely clustered, bluish-gray, with white lime-scales over surface, globose, about 1 mm. diam., sessile; lime tubules of capillitium white, abundant, and showing plainly when spores are blown away; spores violet-black in mass. Collected by H. J. Gorcica in the vicinity of Westboro, Wis., on dead poplar wood, September 1931.

Badhamia papaveracea Berk. and Rav. Sporangia gregarious, iridescent-gray with scanty lime-deposits on sporangium wall, globose, about 1 mm. diam.; stipes short, blackish brown; capillitium white, persistent after spores have blown away; spores violet-black in mass. On dead wood.

Badhamia rubiginosa (Chev.) Rost. Sporangia gregarious, brownish, the sporangium wall without lime above, but calcareous below, egg-shaped, .5 mm. diam.; stalk erect, stiff, reddish-brown, prolonged within the sporangium as a columella and arising from a small hypothallus; capillitium dense, white, persistent, spores violet-black in mass. On dead wood.

Badhamia utricularis (Bull.) Berk. (Plate I, fig. 3). Sporangia clustered, iridescent-gray, with lime-granules scanty; sporangia single, or lobed and confluent, about 1 mm. diam.; stalks long, membranous, straw-colored, prostrate; capillitium white, not especially prominent; spores violet-black in mass. On dead wood.

GENUS PHYSARUM (Pers.) Rost. Sporangia distinct, sessile or stipitate, or tending toward the aethalioid or plasmodiocarpous; peridium simple or double, with more or less lime;

capillitium a branching net of hyaline tubules, more or less densely charged with lime at the points of branching.

Physarum auriscalpium Cooke. Reported for Wisconsin by Dean. Specimen not available for examination by the writer.

Physarum cinereum (Batsch) Pers. Sporangia gregarious, or closely clustered, gray, sessile, subglobose, through various forms to definite plasmodiocarps, usually about .5 mm. or less in diameter; capillitium of branching threads with rather pronounced white lime-knots; spores violet-black in mass. Frequent on turf and lawns, where large numbers of sporangia may appear.

Physarum confertum Macbr. Sporangia heaped in masses, dark gray with limeless peridium, globose, .2-.4 mm. diam.; capillitium scanty, consisting of colorless threads with very small, angular lime-knots; spores violet-black in mass. On sticks, grass, etc.

Physarum contextum Pers. Sporangia closely crowded, often so much so as to be interwoven, yellow, sessile, elongate, about .5 mm. diam.; peridium in two layers, the outer thick, crustose, yellow, the inner thin, yellowish; capillitium of branching threads, with large, irregular lime-knots; spores violet-black in mass. On sticks, bark, etc.

Physarum globuliferum (Bull.) Pers. Sporangia gregarious, white, globose, .5 mm. diam.; stipe pale above, becoming brownish below, rather slender, of variable length, continued into the sporangium as a small conical columella; capillitium a dense network of colorless threads with rounded, whitish lime-knots; spores violet-black in mass. On dead wood and leaves.

Physarum leucopus Link. (Plate I, fig. 5). Sporangia gregarious, snow-white, with a dense covering of lime granules, globose, .5 mm. diam., mounted on stout, conical, fluted white stipes which arise from a white hypothallus; capillitium of colorless threads, with large, angular, white lime-knots; spores violet-black in mass. On dead leaves.

Physarum melleum (Berk. and Br.) Mass. Sporangia scattered, yellow, globose, .5 mm. diam., mounted on short, stout, furrowed white stipes, which terminate in a small, conical columella; hypothallus lacking; capillitium of colorless threads, with large, angular, white lime-knots; spores violet-black in mass. On dead wood.

Physarum notabile Macbr. Sporangia gregarious, gray, globose, .5 mm. diam., through stipitate, sessile, to plasmodiocarpous forms, frequently in the same fructification; stipe, when present, short, dark, tapering upward, furrowed; capillitium of colorless threads, with white lime-knots of variable shape; spores violet-black in mass. On dead wood.

Physarum nucleatum Rex. Sporangia gregarious, white, spherical, .5 mm. diam., stipe yellowish white, rough awl-shaped; capillitium dense, compact, and remarkably persistent, with usually a shining ball of lime suspended in the central portion of the capillitial net; lime-knots small, white, rounded; spores violet-black in mass. On dead wood.

Physarum nutans Pers. Sporangia gregarious, grayish white, subglobose, umbilicate below, nodding, .5 mm. diam.; peridium thin; stipes long, delicate, tapering decidedly upward, dark below, white above; capillitium of delicate, colorless threads with a few small, white lime-knots; spores violet-black in mass. On dead wood and bark.

Physarum polycephalum Schw. Sporangia confluent in clusters of 5-10, or thereabouts, the clusters in turn gregarious, yellowish-gray, lobed, total height up to 2 mm.; stipes reddish-yellow, slender, weak, combined in clusters which accord with the sporangial number; capillitium a branching network of colorless threads with irregular yellowish lime-knots; spores violet-black in mass. On leaves and dead wood.

Physarum psittacinum Ditm. Sporangia gregarious, iridescent-blue, mottled with red-orange spots, globose, .5 mm. or more in diam.; stipe orange-red, columnar, arising from a hypothallus of the same color; capillitium a dense network of yellowish threads, with many angular, orange lime-knots; spores violet-black in mass. On dead wood. Collected by E. M. Gilbert, Hayward, Wis., August 1930.

Physarum sinuosum (Bull.) Weinm. (Plate I, fig. 4). Sporangia usually forming long, vein-like plasmodiocarps; plasmodiocarps snow-white on upper portion, due to aggregated lime-granules, gray below, sessile, breaking open by a longitudinal fissure; capillitium with numerous, large, white lime-knots; spores violet-black in mass. On dead leaves and twigs.

Physarum variabile Rex. Sporangia scattered, dull yellow, globose to egg-shaped or cylindric, .5 mm. or more in diam.; shortly stalked or sessile; peridium roughened; capillitium a compact network of delicate, colorless threads, with irregular white or yellowish-white lime-knots; spores violet-black in mass. On dead leaves and wood.

Physarum virescens Ditmar. Sporangia heaped in groups of a dozen or more, sessile, yellow or greenish yellow, spherical to elongate, less than .5 mm. diam.; capillitium a delicate network with small, irregular, yellow lime-knots; spores violet-black in mass. On dead wood, moss or leaves. Collected by H. C. Greene, Devil's Lake, Wis., July 1929.

Physarum viride (Bull.) Pers. Sporangia gregarious, various shades of yellow or orange, subglobose, flattened below, .5 mm. diam., nodding, borne on slender, tapering yellowish stipes, which become red-brown toward the base; capillitium a loose network of colorless threads with elongated yellow lime-knots; spores violet-black in mass. On dead wood.

GENUS CRATERIUM Trentepohl. This genus is closely allied to *Physarum,* and is differentiated from it largely by the mode of sporangial dehiscence. When the sporangia mature and break open, a cup-like, persistent basal porton is left. The sporangia generally exhibit a distinct lid, and the peridium is generally of two layers.

Craterium leucocephalum (Pers.) Ditm. (Plate II, fig. 1). Sporangia gregarious, white above, brown below, ovate or top-shaped, or definitely vasiform, .5 mm. diam., mounted on short, stout stipes of the same color as the lower sporangium; sporangia often dehiscing rather irregularly; capillitium white, with large lime-knots; spores violet-black in mass. On dead leaves.

Craterium minutum (Leers) Fries. Sporangia gregarious, brown below, with a distinct, usually convex lid lighter in color, goblet-shaped, .5 mm. diam., mounted on brown stipes which arise from a circular hypothallus; capillitium white, with large lime-knots which are usually aggregated in a mass at the center of the cup; spores violet-black in mass. On dead leaves. Collected by E. M. Gilbert, Hayward, Wis. August 1930.

GENUS LEOCARPUS (Link) Rost. This genus includes a single species, *L. fragilis* (Dicks.) Rost.

Leocarpus fragilis (Dicks.) Rost. (Plate II, fig. 2). Sporangia gregarious, or closely clustered, shining red-brown to various shades of yellow, egg-shaped, 2 mm. or more in length, with weak, usually prostrate, white or yellowish stipes; capillitium of threads bearing closely clustered grayish-white lime-knots; spores violet-black in mass. On dead wood, leaves, and twigs.

Family Didymiaceae

Lime-deposits, when present, affecting the peridium only, or sometimes the stipe also; capillitium of simple threads, usually radiating from a central columella.

GENUS MUCILAGO (Mich.) Adams. This genus includes a single species, *M. spongiosa* (Leyss.) Morg.

Mucilago spongiosa (Leyss.) Morg. (Plate II, fig. 3). Aethalium white, elongated, the shape depending upon the substratum to a considerable degree, large, up to several cm.; aethalium with a crusty, porous cortex; capillitium of darkish, anastomosing threads; spores violet-black in mass. On living herbaceous stems.

GENUS DIDYMIUM (Schrad.) Fries. Sporangia distinct, not forming aethalia; peridium covered with lime granules which are distinctly crystalline, a feature serving to set the genus apart from all others except *Mucilago* which differs in its aethalioid condition. Capillitium of simple threads, radiating outward from the columella.

Didymium clavus (Alb. and Schw.) Rabenh. Sporangia gregarious, grayish-white, discoidal, 1 mm. diam., the dark peridium frosted with lime-crystals above, naked and black below; sporangia mounted on slender, cylindrical, black stipes; columella lacking; capillitium of scantily branched pale brown threads; spores violet-black in mass. On dead leaves.

Didymium melanospermum (Pers.) Macbr. Sporangia gregarious, white, hemispherical, umbilicate below, up to 1 mm. diam., mounted on short, stout, black stipes; columella large, hemispherical, dark-colored; capillitium of brown, sparingly branched threads, often with thickenings; spores violet-black in mass. On dead wood, and other debris.

Didymium nigripes (Link) Fries. (Plate II, fig. 4). Sporangia remotely gregarious, white, hemispherical, umbilicate below, .5 mm. diam., mounted on slender black stipes, each arising from a rounded black hypothallus; columella globose, dark-colored; capillitium of pale brown, scantily branched threads; spores violet-black in mass. On dead leaves and twigs.

Didymium squamulosum (Alb. and Schw.) Fries. Sporangia gregarious, white, globose, umbilicate below, up to 1 mm. diam., mounted on stout, cylindrical, furrowed white stipes each arising from a small, discoidal, white hypothallus; columella hemispherical, white; capillitium of pale, violet-brown branching threads; spores violet-black in mass. On dead leaves.

GENUS DIDERMA Persoon. Sporangia ranging from plasmodiocarps to distinct stipitate forms; peridium, as a rule, plainly double; outer wall calcareous or cartilaginous; inner wall membranous, often widely separated from the outer; columella usually in evidence, but sometimes only rudimentary or lacking; capillitial threads much as in *Didymium;* lime amorphous.

Diderma crustaceum Peck. (Plate II, fig. 5). Sporangia closely crowded, and imbedded in the massed white hypothallus, white, globose, about 1 mm. diam., sessile; outer sporangial wall of lime, smooth, pure white, fragile, and distinct from the bluish, membranous inner wall; capillitium of purplish threads; spores violet-black in mass. On leaves, twigs, and bark.

Diderma effusum (Schw.) Morg. var. *reticulatum* Rost. Sporangia gregarious, white, rounded, sessile, somewhat flattened, sometimes tending toward plasmodiocarpous, up to 1 mm. diam.; inner peridium bluish white, distinct from the fragile, lime-incrusted outer peridium; columella not well differentiated; capillitium of short, colorless, scantily branching threads; spores violet-black in mass. On dead leaves and twigs.

Diderma globosum Pers. Reported by Dean. Scarcely to be differentiated from *D. crustaceum* Peck.

Diderma hemisphericum (Bull.) Hornem. Sporangia gregarious, white, pronouncedly discoidal, about 1 mm. diam., borne on stout white stipes, about 1 mm. high, each from a small hypothallus; capillitium scanty, with colorless threads; spores violet-black in mass. On dead leaves.

Diderma simplex (Schroet.) Lister. Sporangia gregarious, or closely clustered, reddish-brown, globose, sessile, .5 mm. diam., inner peridium not to be differentiated from the outer wall of lime; brownish hypothallus present; columella not well differentiated; capillitium scanty, of pale, sparsely branching threads. Collected by H. C. Greene, Univ. of Wis. Greenhouse, May 1930. On sphagnum and leaves.

Diderma spumaroides Fries. Sporangia closely clustered, white, appearing grayish when lime is scanty, globose, sessile, .5 mm. or slightly more in diam.; inner peridium closely appressed to the outer; white hypothallus usually present; columella white, small, globose; capillitium of branching brown threads; spores violet-black in mass. On dead leaves and bark.

Order Stemonitales

Spores in mass, blackish, violet-brown, or reddish-brown. This order is characterized by the lack of lime in all genera except *Diachaea,* easily known by its stipes which are heavily charged with lime. The capillitium in this order is thread-like and branched, arising usually from a columella.

Family Stemonitaceae

Sporangia stalked (aethalioid in the case of *Brefeldia*) with a definite columella from which the abundant and branching threads of the capillitium arise; sporangium wall delicate and usually disappearing at maturity; sporangia usually arising from a common hypothallus.

GENUS BREFELDIA. This genus includes a single species, *B. maxima* (Fries) Rost.

Brefeldia maxima (Fries) Rost. (Plate III, fig. 1). Sporangia combined in an aethalium, deep blackish brown; aethalium large 3-30 cm. or more across, 5-10 mm. thick; capillitium composed of dark brown threads expanded at regular intervals into many-chambered vesicles; spores blackish in mass. On dead wood, leaves, bark, etc.

GENUS STEMONITIS (Gleditsch) Rost. Sporangia cylindric and stipitate with the abundant and flexuose capillitium springing from all parts of the long columella; spores in mass black, brown, or reddish brown, plainly in evidence in mature specimens, owing to the evanescent character of the sporangium wall; capillitium covered by a delicate surface net.

Stemonitis ferruginea Ehr. Sporangia in dense clusters, reddish-brown, cylindric, variable in height, from 5-15 mm.; stipes black, one-half to one-third total height, arising from a membranous hypothallus, and continuing through the greater portion of the sporangium as a columella; capillitium composed of branching, brownish threads springing from the columella, and connected with an outer surface network of rounded meshes; spores red-brown in mass. On dead wood.

Stemonitis fusca (Roth) Rost. (Plate III, fig. 2). Sporangia clustered in tufts, blackish brown, cylindric, height variable, from 5-20 mm.; stipes black, shining, about one quarter the total height; arising from a common hypothallus, and continued through the greater portion of the sporangium as a columella; capillitium of dark threads, springing from the columella, and ultimately giving rise to a close-meshed surface net; spores blackish-brown in mass. On dead wood.

Stemonitis pallida Wingate. Sporangia gregarious, violet-brown, cylindrical, blunt at apex, height about 5 or 6 mm.; stipes short, black, polished, rising from a thin hypothallus, and continued into the sporangium as a columella; capillitium terminating in a close-meshed surface net; spores violet brown in mass. On dead wood. Collected by H. C. Greene, Devil's Lake, Wis., July 1929.

Stemonitis splendens Rost. Sporangia clustered, purple-brown, cylindrical, height from 10-20 mm.; stipes short, black, polished, arising from a common, shining, silvery hypothallus; columella continuous through the sporangium; capillitium of dark threads which ultimately give rise to a surface net with rounded meshes; spores purple-brown in mass. On dead wood.

Stemonitis webberi Rex. Reported for Wisconsin by Dean. Original material not seen. Lister regards this as a variety of *S. splendens*.

GENUS COMATRICHA (Preuss) Rost. Sporangia usually stalked, usually cylindrical, without capillitial surface net, and with peridium disappearing at maturity; spores in mass, various shades of brown to black. This genus merges easily into *Stemonitis,* on the one hand, and *Lamproderma* on the other. From *Stemonitis* it differs in the absence of a capillitial surface net, from *Lamproderma* in the evanescent peridium. The genus is somewhat artificial and perplexing forms are repeatedly met.

Comatricha flaccida Morg. Reported by Dean. Original material not seen by writer.

Comatricha longa Peck. Sporangia in tangled, prostrate tufts, black, very long, up to several cm.; stipes shining, black, short, arising from a blackish hypothallus; columella black, slender, disappearing below apex of sporangium; capillitium of slender free threads extended stiffly outward from the columella, and often forking; spores black in mass. On dead leaves, wood, etc.

Comatricha nigra (Pers.) Schroeter. (Plate III, fig. 3). Sporangia scattered, deep brown, globose to cylindrical, mounted on long, slender, black, tapering stipes; height over all from 2-4 mm.; columella continued upward into the sporangium and becoming dissipated in the capillitial branching; capillitium of repeatedly branching purple-brown threads with very few free ends; spores dark brown in mass. On dead wood.

Comatricha pulchella (Bab.) Rost. Sporangia scattered, pale brown, ovate, mounted on short black stipes, very small, total height about 1 mm.; columella attaining almost to the apex of the sporangium; capillitium a dense network of slender brown threads; spores brown in mass. On dead leaves.

Comatricha typhoides (Bull.) Rost. Sporangia gregarious or scattered, silvery, becoming brown, cylindric, mounted on black stipes which are "clothed with the silvery, membranous continuation of the sporangium wall"; columella reaching almost to summit of the sporangium; spores deep brown in mass. On dead wood.

Comatricha typhoides (Bull.) Rost. var. *similis* Lister. Sporangia as in *C. typhoides,* except that stipes have no silvery sheath, and spores have slightly different markings. Collected by E. M. Gilbert, Hayward, Wis., July 1930.

GENUS DIACHAEA Fries. Sporangia distinct, stipitate, globose or cylindric, peridium fragile, iridescent; stipes heavily charged with lime; capillitium much as in *Comatricha.*

Diachaea leucopoda (Bull.) Rost. (Plate III, fig. 4). Sporangia gregarious, bluish-purple, with a metallic sheen, cylindric, mounted on white, columnar stalks, which arise from a continuous vein-like hypothallus and are continued as columellae through the height of the sporangia; capillitium springing from the columella as a network of slender flexuous brown threads; spores violet-brown in mass. On living and dead leaves and twigs.

Family Lamprodermaceae

This family is characterized by the fact that the capillitium is borne chiefly from the tip of the columella.

GENUS ENERTHENEMA Bowman. Sporangia distinct, stipitate, gregarious, small, globose, the apex of the trans-sporangial columella expanded into a disk from which the capillitial threads spring.

Enerthenema papillatum (Pers) Rost. (Plate III, fig. 5). Sporangia gregarious or scattered, blackish brown, spherical, approaching 1 mm. diam., mounted on short, black stipes, which pass entirely through the sporangia as columellae which emerge at the top as flattened, shining disks; sporangium wall evanescent; capillitium of long, slender, rather stiff, scantily branched threads, springing chiefly from the expanded disk of the columella; spores blackish brown in mass. On dead wood.

GENUS CLASTODERMA Blytt. This genus contains a single species, *C. debaryanum* Blytt.

Clastoderma debaryanum Blytt. (Plate IV, fig. 1). Sporangia more or less gregarious, brown, globose, borne on slender brown stipes, very minute, total height not more than 1 mm., sporangia proper .1-.2 mm.; peridium not persistent except for plates which adhere to the ultimate branches of the capillitium; capillitium composed of stiff, forking threads; spores brown in mass. Collected by E. M. Gilbert, Hayward, Wis., August 1930.

GENUS LAMPRODERMA Rost. Sporangia distinct, stipitate, characterized by the fairly persistent, shining, metallic peridium which, when shed, leaves a ring around the base of the columella; columella short, stout, with the capillitium usually arising plainly from the apical region.

Lamproderma violaceum (Fries) Rost. (Plate IV, fig. 2). Sporangia gregarious, metallic purple, or bronze, globose, .5 mm. or slightly more in diam.; stipe dark, moderately stout, usually about equal to sporangium; capillitium of dark, branching threads, anastomosing to form an open network; spores violet-black in mass. On dead wood and leaves.

Order Cribrariales

Spores in mass usually pale brown or yellowish, rarely purplish or violaceous; sporangia ranging from aethalioid forms to distinct, stipitate forms, peridium membranous, without lime; capillitium lacking.

Family Tubiferaceae

Fructifications of aethalia or distinct sporangia; sporangia tubular, irregularly dehiscent, rupturing at the apex.

GENUS LINDBLADIA Fries. This genus includes a single species, *L. effusa* (Ehr.) Rost.

Lindbladia effusa (Ehr.) Rost. (Plate IV, fig. 4). Sporangia closely crowded in a single layer, or superimposed to form an aethalium, dull brown, sessile, tubular, about .5 mm. short diam.; fruiting masses often very extensive, up to 25 cm. or more; capillitium lacking; spores deep yellow-brown in mass. On dead wood. (esp. coniferous.)

GENUS TUBIFERA Gmelin. Sporangia red-brown and angled by mutual pressure, tubular; hypothallus prominent; capillitium lacking; spore mass red-brown.

Tubifera ferruginosa (Batsch) Macbr. (Plate IV, fig. 3). Sporangia densely crowded, red-brown, cylindrical, angled by mutual pressure, up to 3 mm. high; capillitium lacking; spores red-brown in mass. On dead wood.

Tubifera stipitata Macbr. Sporangia similar to those of *T. ferruginosa,* except that they are clustered on a dark brown hypothallus which has the form of a stout stipe, 2-3 mm. high. On dead wood.

Family Reticulariaceae

Sporangia indistinctly defined and aggregated in aethalia on a common hypothallus and covered by a common cortex; pseudo-capillitium composed of interwoven or fragmentary sporangial walls; spore mass brown or yellowish.

GENUS RETICULARIA Bull. This genus is represented by a single species, *R. lycoperdon* Bull.

Reticularia lycoperdon Bull. (Plate IV, fig. 5). Aethalium subglobose, silvery-white, 2-5 cm. diam.; solitary, arising from a well-developed white hypothallus; true capillitium lacking; pseudo-capillitium formed from remnants of sporangial wall, appearing in blown specimens as a mass of strands arising from the hypothallus; spores red-brown in mass. On dead wood.

GENUS ENTERIDIUM Ehr. Sporangia fused to form aethalia; and covered by a thin, evanescent membrane; pseudo-capillitium composed of the sporangial walls interwoven to form a network of broad, membranous bands.

Enteridium splendens Morg. (Plate V, fig. 1). Aethalium cushion-like, lobed, covered by a thin, smooth, shining brown cortex, from 1-6 cm. diam.; hypothallus white; capillitium none, the sporangial wall perforate and interwoven; spores reddish-brown in mass. On dead wood.

GENUS DICTYDIAETHALIUM Rost. This genus is represented by a single species, *D. plumbeum* (Schum.) Rost.

Dictydiaethalium plumbeum (Schum.) Rost. (Plate V, fig. 2). Aethalium thin, flat, smooth, olivaceous, up to several cm. broad, in section showing columnar, hexagonal, perforated sporangia, with six threads extending from base to apex, where the sporangium is entire in the form of a cap; hypothallus white, prominent; spores in mass dull yellow. Collected by E. M. Gilbert, Hayward, Wis. 1921, and by Charles Drechsler, Park Falls (1917?).

Family Cribrariaceae

Sporangia distinct and stipitate; peridium usually well-defined, but sometimes lacking as a continuous layer, and, at any rate, opening above to form a meshed network with nodes of varied shape; spore mass various shades of yellow to brown, rarely purplish.

GENUS CRIBRARIA (Pers.) Schrader. Sporangia distinct, stipitate, the membranous peridium forming a basal cup, more or less developed; perforated above to form a meshed network; spores in mass, ochraceous or violaceous.

Cribraria aurantiaca Schrader. (Plate V, fig. 3). Sporangia gregarious, yellowish-brown, globose, approaching 1 mm. diam.; stipe brown, in length about twice the diam. of the sporangium; cup large, indented; net with irregular, expanded nodes, concolorous with the yellow-brown-cup; spores in mass yellowish-brown. On dead wood, especially coniferous wood.

GENUS DICTYDIUM (Schrad.) Rost. This genus includes a single species, *D. cancellatum* (Batsch) Macbr.

Dictydium cancellatum (Batsch) Macbr. (Plate V, fig. 4). Sporangia gregarious, reddish- or purplish-brown, of peculiar bell-like contour, or subglobose, nodding, about .5 mm. diam., mounted on dark red-brown stipes; capillitium none; sporangium wall ribbed, with ribs connected by slender cross-threads, spores reddish- or purplish-brown in mass. On dead wood.

Order Lycogalales

This order includes a single family, *Lycogalaceae*, and the single genus, *Lycogala* Micheli.

GENUS LYCOGALA Micheli. Aethalia with membranous peridia, resembling miniature puff-balls; capillitium of irregular tubules extending inward from the peridium; spore mass pale pinkish or ashen, becoming sordid or yellowish.

Lycogala epidendrum (Buxb.) Fries. (Plate V, fig. 5). Aethalia single or clustered, olivaceous, spherical, or angled by mutual pressure when clustered; inconspicuously warted, 3-10 mm. diam.; peridium tough and persistent; capillitium of branching, wrinkled tubules which extend inward from the peridium; spores ashen or yellowish in mass. Common on dead wood.

Lycogala exiguum Morg. Perhaps only a form of *L. epidendrum* differing in its small (2-5 mm. diam.), blackish, gregarious aethalia, which are never closely clustered as in typical *L. epidendrum.*

Lycogala flavo-fuscum (Ehr.) Rost. Aethalia single, or clustered in small groups, purplish-gray, tending toward spherical, usually very large, up to 4 cm. diam.; capillitium consisting of branching, irregular tubules, arising from the peridium and continued inward, enclosing within its meshes, rounded, yellowish, protoplasmic vesicles; spores grayish in mass. On dead wood.

Order Trichiales

Spore mass usually pale, brownish or yellowish, or with a reddish tinge; sporangia membranous, without lime, plasmodiocarpous, or distinct, sessile or stipitate, scattered or crowded; capillitial threads attached to wall or free, sculptured, single or combined into a net.

Family Perichaenaceae

Capillitial threads smooth or variously roughened, not forming a network, attached at one end to sporangium wall.

GENUS OPHIOTHECA Currey. Fructification characteristically of flexuose plasmodiocarps, the thin peridium breaking open irregularly; capillitium of roughened threads; spores yellowish in mass.

Ophiotheca wrightii Berk. and Curt. Plasmodiocarps brownish to black, usually bent or ring-shaped; .2-1 mm. diam.; capillitium of long threads studded with prominent spines; spores yellow in mass. On dead wood and bark, especially the inner bark of fallen trees.

GENUS PERICHAENA. Sporangia flattened, round or angled when closely clustered; peridium thick, breaking open with a more or less definite lid; capillitium of warted, yellowish threads; spores yellow in mass.

Perichaena corticalis (Batsch) Rost. Sporangia gregarious, chestnut brown, sessile, depressed hemispherical; .5-1 mm. diam., opening by a lid, the outlines of which are clearly marked in mature specimens; capillitium of slender threads, attached to the lid; spores bright yellow in mass. On bark of dead trees.

Perichaena depressa Libert. (Plate VI, fig. 1). Sporangia crowded, angled by mutual pressure, chestnut brown, sessile, flattened, opening by a definite lid; capillitium of slender yellow threads; spores bright yellow in mass. Closely allied to *P. corticalis.* On the inside bark of logs.

Family Arcyriaceae

Capillitium forming a more or less definite net, usually attached below; capillitial threads variously roughened or sculptured, but lacking a smooth spiral sculpturing; spores pale.

GENUS LACHNOBOLUS. This genus is set apart from *Arcyria* on the basis of the non-elastic capillitium, and by the fact that the upper peridium is somewhat persistent, not completely evanescent as in *Arcyria.*

Lachnobolus occidentalis Macbr. Sporangia scattered or crowded, metallic rose in color, later becoming brownish, usually sessile, globose to ellipsoidal, about .5 mm. diam.; sporangium wall breaking away above, leaving a membranous, lobed cup below; capillitium a network of warted threads, not expanding as in *Arcyria;* spores brownish flesh-colored in mass. On dead wood.

GENUS ARCYRIA (Hill) Pers. Sporangia ovoid or cylindric, stipitate, the upper portion of the peridium completely evanescent; capillitium forming an elastic net; color of spores in mass variable, pale, yellow, greenish or reddish.

Arcyria cinerea (Bull.) Pers. Sporangia scattered, or fairly closely clustered, ashen gray, short-cylindrical, 2-4 mm. high, cup small; stipe 1-2 mm. high, dark gray to black; capillitium dense; spores ashen gray in mass. On dead wood.

Arcyria denudata (Linn.) Sheldon. Sporangia crowded or gregarious, bright red, becoming brownish with age, ovoid, tapering upwards, 1-2 mm. high; cup well-defined; stipe about half total height of sporangium, and of same color; capillitium fairly lax, but firmly attached to cup; spores reddish in mass. On dead wood.

Arcyria incarnata Persoon. Similar to *A. denudata,* except that the sporangia are of a more delicate rosy hue, the stipe is usually shorter, and the mature capillitium is so loosely attached to the cup that a slight current of air suffices to blow it away.

Arcyria magna Rex. Reported for Wisconsin by Dean, but probably rare and not likely to be met with. Lister regards this as a mere variation of *A. oerstedtii,* a form not reported for Wisconsin.

Arcyria nutans (Bull.) Grev. (Plate VI, fig. 2). Sporangia closely clustered, pale yellow, cylindrical, 2 mm. high when unexpanded; cup very small; stipe short or lacking; capillitium becoming tremendously expanded (up to 3 cm. or more), giving rise to the drooping yellow plumes so characteristic of the species.

Family Trichiaceae

Capillitium spirally sculptured, the threads free or in a loose net; spore mass of various shades through yellow to reddish.

GENUS HEMITRICHIA Rost. Capillitium a loose, branching net of spirally sculptured threads centrally attached; sporangia plasmodiocarpous or distinct, sessile or stipitate.

Hemitrichia clavata (Pers.) Rost. Sporangia gregarious, scattered or crowded, yellowish, the upper portion of the peridium breaking away to leave a cup-shaped structure below, mounted on slender, brownish stipes; sporangia usually large, up to 3 mm. high, but sometimes much smaller; capillitium of slender threads, branched to form a net, yellow, the threads sculptured with spiral bands; spores yellow in mass. On dead wood.

Hemitrichia serpula (Scop.) Rost. Plasmodiocarps often of rather wide extent, branching freely, reticulate, tubular, yellow, about .5 mm. wide; spores yellow in mass. On dead wood.

Hemitrichia stipata (Schw.) Macbr. Sporangia crowded, superimposed, of a shining metallic copper color, cylindrical, mounted on short, red-brown stipes; upper portion of sporangium wall falling away, leaving a cup as in *Arcyria;* capillitium of copper-colored threads branched to form a net; spores reddish-brown in mass. On dead wood.

Hemitrichia vesparium (Batsch) Macbr. (Plate VI, fig. 3). Sporangia clustered, usually with the dark stipes welded together, dark red, clavate, 1 mm. or more high; peridium metallic gray; capillitium of reddish, sparingly branched, spirally sculptured threads; spores red in mass. On dead wood.

GENUS TRICHIA (Haller) Rost. Sporangia distinct, sessile or stipitate; capillitium of free, spirally sculptured threads, called elaters; yellowish; peridium membranous; spores in mass various shades of yellow, except in *T. lateritia* (not reported for Wisconsin) where they are brick red.

Trichia decipiens (Pers.) Macbr. (Plate VI, fig. 4). Sporangia gregarious, shining olive, depressed egg-shaped, often breaking open above in regular fashion, about .7-.8 mm. diam., mounted on olive stipes of variable length; capillitium consisting of olive-colored, much tapered elaters, sculptured with 3-5 spiral bands; spores olivaceous or yellowish in mass. On dead wood.

Trichia favoginea (Batsch) Pers. Sporangia crowded, olive-yellow, cylindric, .5 mm. or more in diam.; capillitium of cylindrical elaters with 3-5 spiral bands, usually escaping from sporangia at maturity, and hanging above them as a woolly yellow mass; spores bright yellow in mass. On dead wood.

Trichia persimilis Karst. Sporangia somewhat crowded, as a rule, bright yellow or brownish, sessile, seated on a thin hypothallus, .5-.8 mm. diam., capillitium yellow, consisting of spirally sculptured elaters; spores bright yellow in mass. On dead wood.

Trichia scabra Rost. Sporangia very closely crowded on a common hypothallus, orange-brown, globose, .7-.8 mm. diam.; capillitium an orange-yellow mass of elaters, sculptured with 3-4 closely wound spiral bands; spores orange-yellow in mass. On dead wood.

Trichia varia (Pers.) Rost. Sporangia gregarious or crowded, yellowish, globose to egg-shaped, up to 1 mm. diam., sessile or with a short, stout black stipe; capillitium of long, irregular threads, marked with only 2 spiral bands; spores yellow in mass. On dead wood.

PLATE I

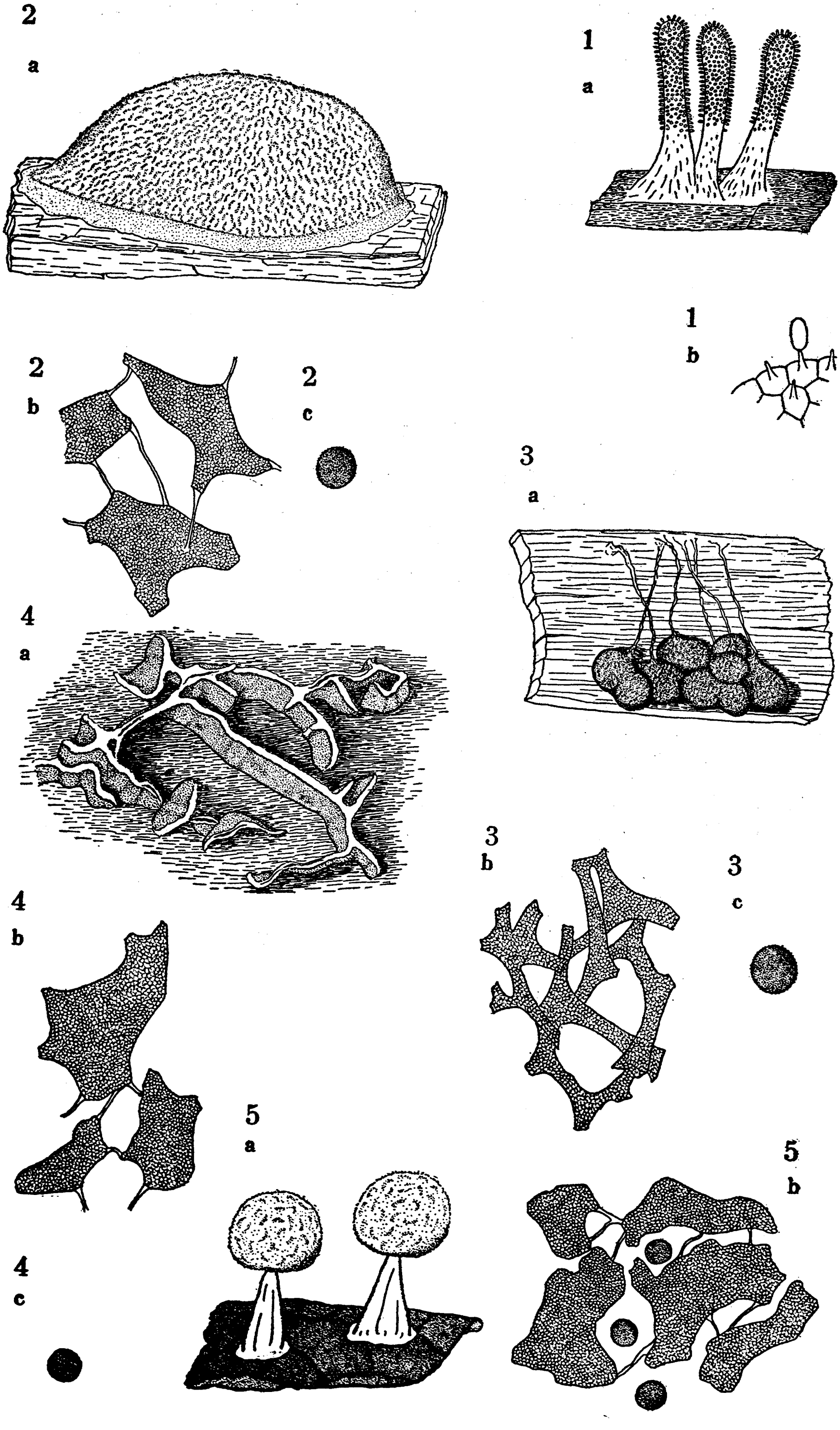
FIG. 1. (a) Sporophores of *Ceratiomyxa fruticolosa*, × 35.
(b) Portion of sporophore wall, showing attachment of spore (after Lister), × 250.

FIG. 2. (a) Aethalium of *Fuligo septica* f. *ovata*, × 1.
(b) Capillitium, × 300.
(c) Spore, × 625.

FIG. 3. (a) Sporangia of *Badhamia utricularis*, × 5.
(b) Capillitium, × 150.
(c) Spore, × 500.

FIG. 4. (a) Plasmodiocarp of *Physarum sinuosum*, × 3.
(b) Capillitium, × 250.
(c) Spore, × 400.

FIG. 5. (a) Sporangia of *Physarum leucopus*, × 25.
(b) Capillitium and spores, × 350.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a
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1
b
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b
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a
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b
3
c
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b
5
a
5
b
4
c

PLATE II

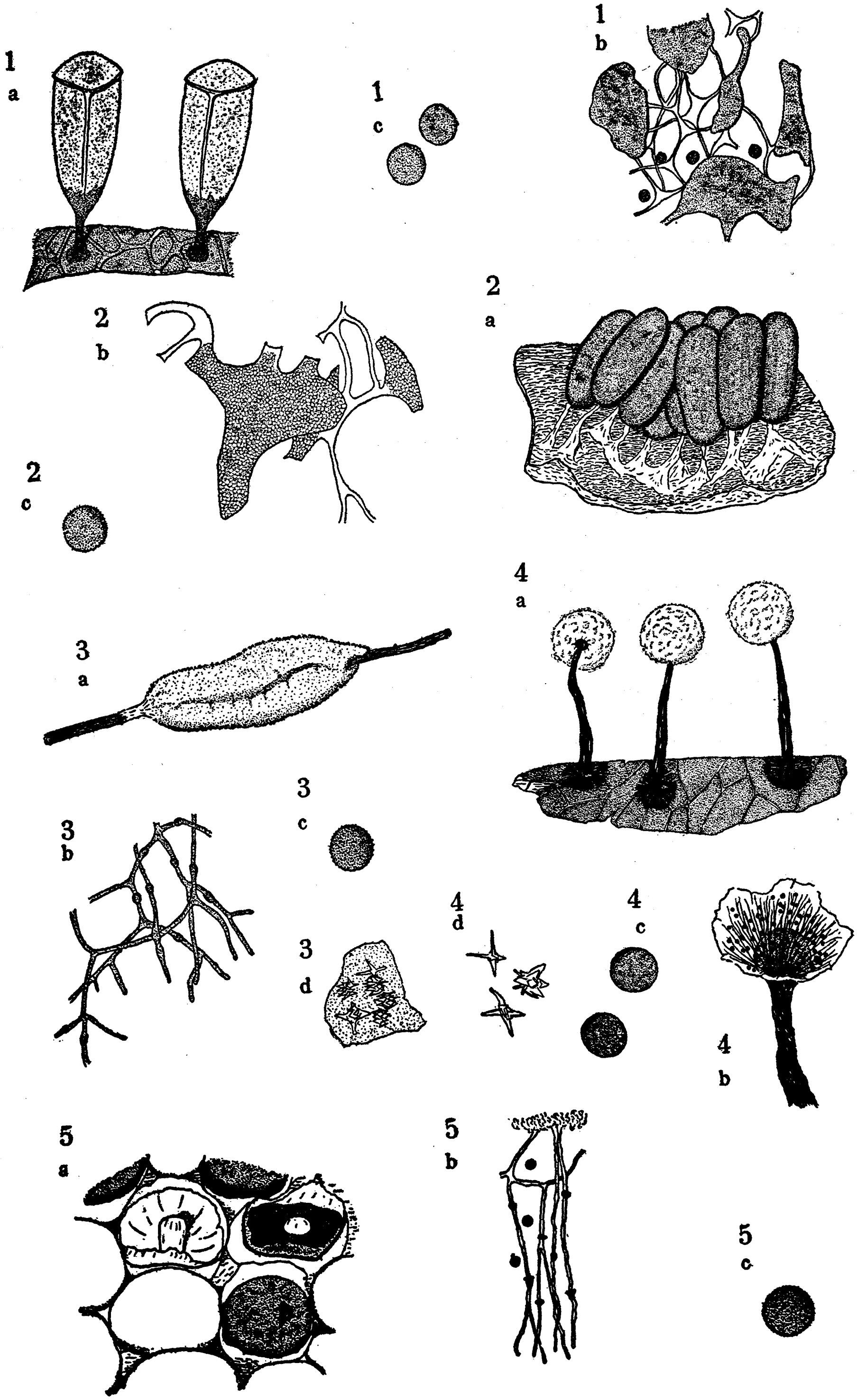
FIG. 1. (a) Sporangia of *Craterium leucocephalum*, × 20.
(b) Capillitium, × 250.
(c) Spores, × 500.

FIG. 2. (a) Sporangia of *Leocarpus fragilis*, × 5.
(b) Capillitium, × 250.
(c) Spore, × 500.

FIG. 3. (a) Aethalium of *Mucilago spongiosa*, × 1.
(b) Capillitium, × 150.
(c) Spore, × 500.
(d) Lime crystals and portion of sporangial wall, × 500.

FIG. 4. (a) Sporangia of *Didymium nigripes*, × 15.
(b) Blown sporangium, showing globose columella and capillitium, × 30.
(c) (d) Spores and lime crystals, × 500.

FIG. 5. (a) Sporangia of *Diderma crustaceum*, × 15.
(b) Capillitium, × 150.
(c) Spore, × 400.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3 a
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3 c
3 d
4 d
4 c
4 b
5 a
5 b
5 c

PLATE III

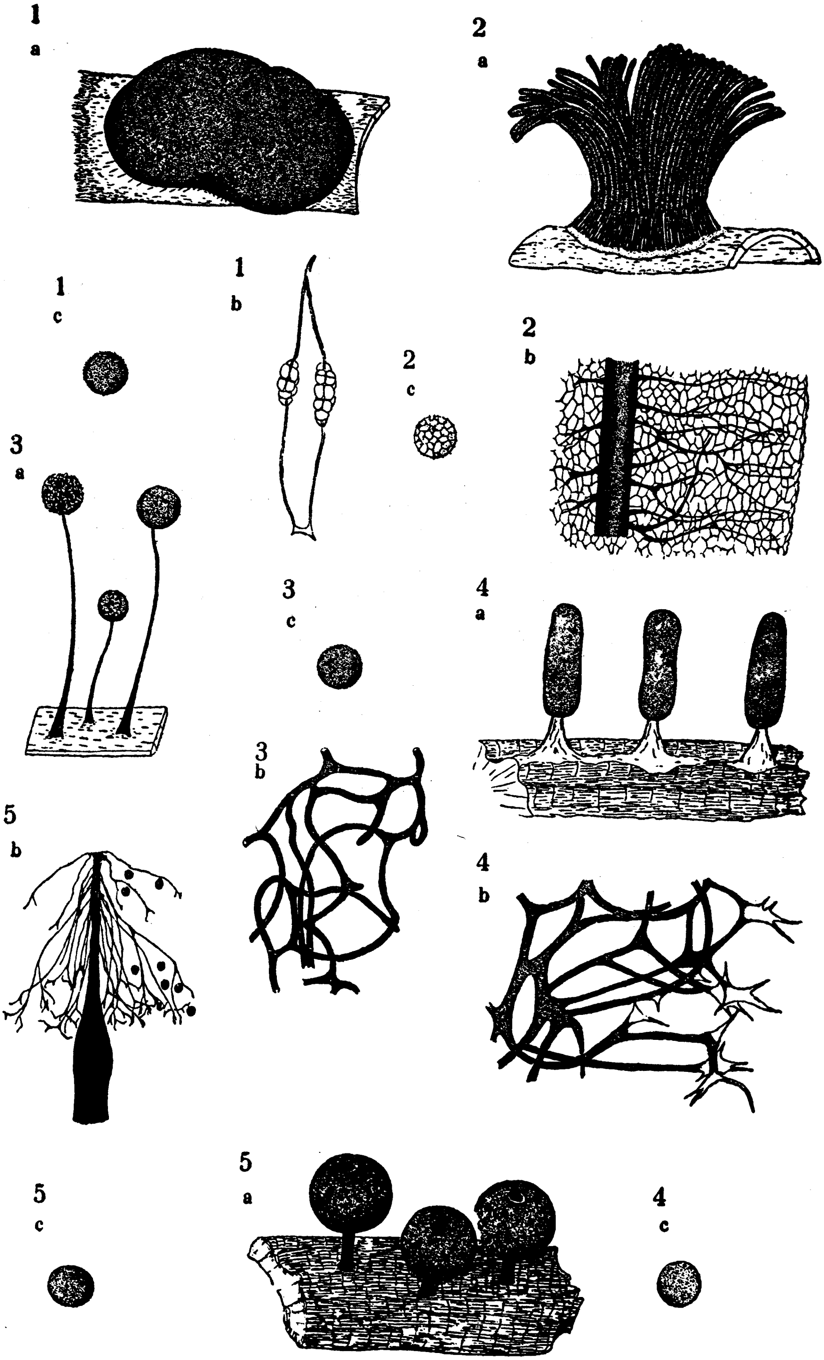
FIG. 1. (a) Aethalium of *Brefeldia maxima*, × ½
(b) Capillitium, × 100.
(c) Spore, × 400.

FIG. 2. (a) Sporangia of *Stemonitis fusca*, × 2.
(b) Capillitium, × 150.
(c) Spore, × 500.

FIG. 3. (a) Sporangia of *Comatricha nigra*, × 12.
(b) Capillitium, × 450.
(c) Spore, × 750.

FIG. 4. (a) Sporangia of *Diachaea leucopoda*, × 20.
(b) Capillitium, × 150.
(c) Spore, × 750.

FIG. 5. (a) Sporangia of *Enerthenema papillatum*, × 20.
(b) Capillitium and spores, × 35.
(c) Spore, × 500.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1 b
2 c
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3 c
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3 b
5 b
4 b
5 c
5 a
4 c

PLATE IV

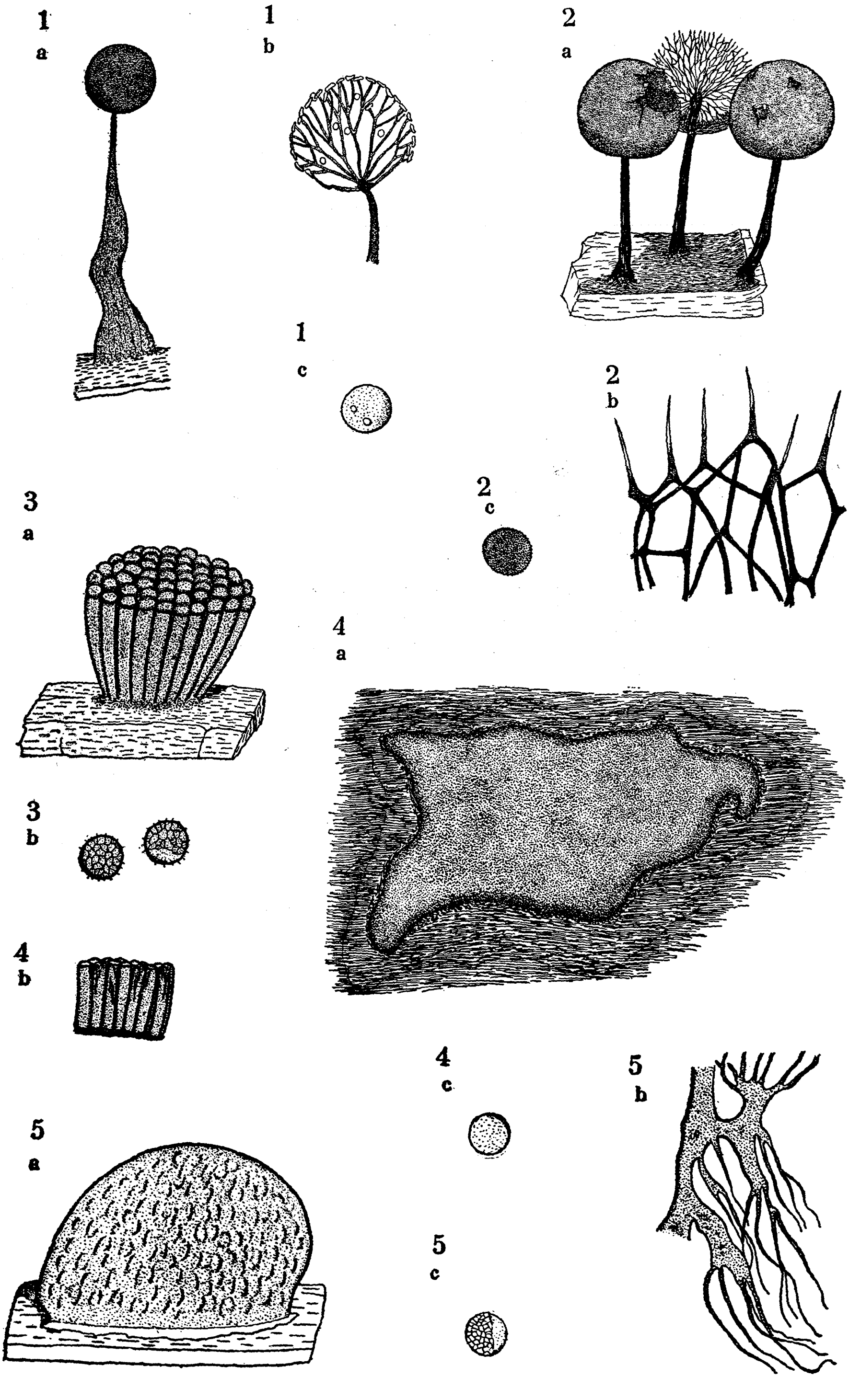
FIG. 1. (a) Sporangium of *Clastoderma debaryanum*, × 45.
(b) Section through sporangial head showing capillitium, × 75.
(c) Spore, × 600.

FIG. 2. (a) Sporangia of *Lamproderma violaceum*, × 25.
(b) Capillitium, × 500.
(c) Spore, × 600.

FIG. 3. (a) Sporangia of *Tubifera ferruginosa*, × 5.
(b) Spores, × 800.

Fig. 4. (a) Aethalium of *Lindbladia effusa*, × 1.
(b) Individual sporangia, × 4.
(c) Spore, × 1000.

FIG. 5. (a) Aethalium of *Reticularia lycoperdon*, × 1.
(b) Pseudo-capillitium, × 50.
(c) Spore, × 600.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1 b
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2 a
2 b
2 c
3 a
3 b
4 a
4 b
4 c
5 a
5 b
5 c

PLATE V

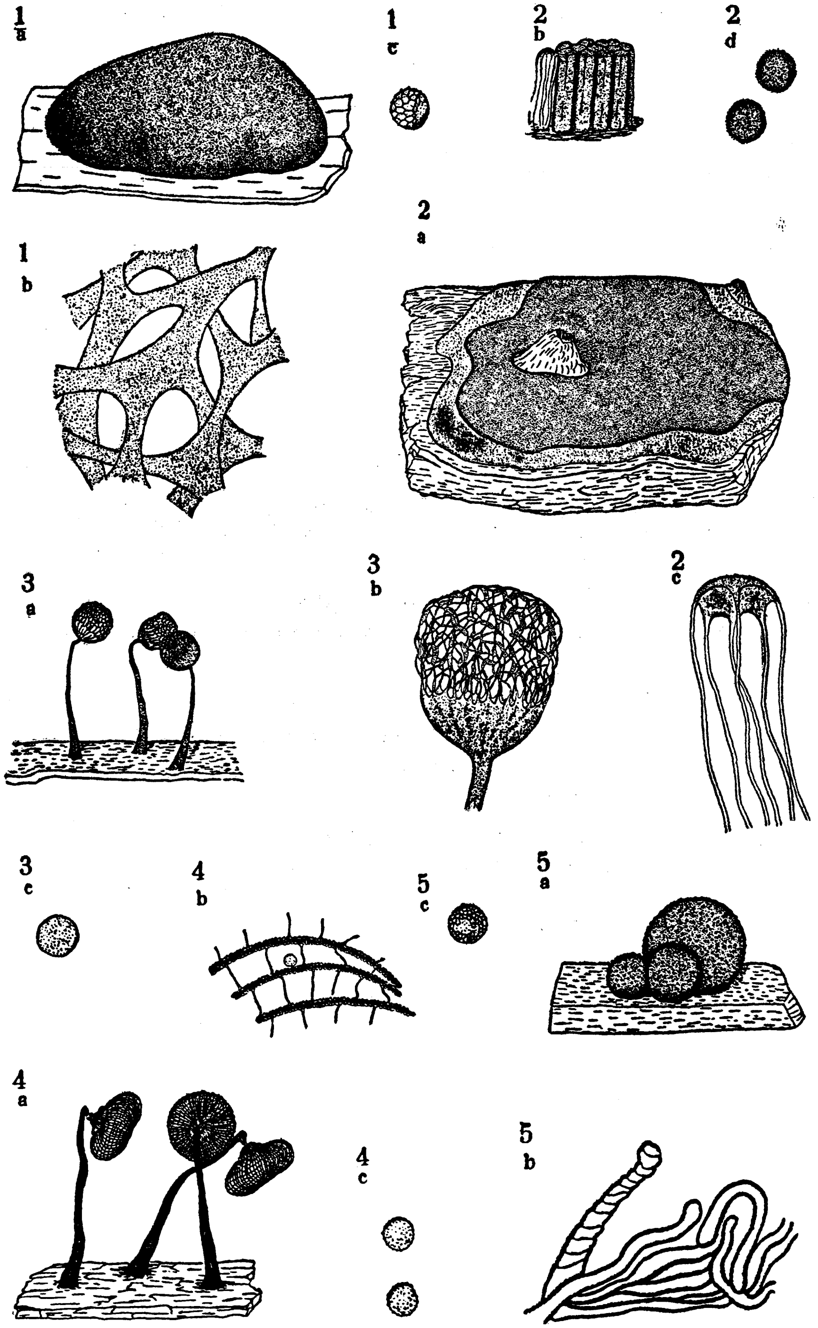
FIG. 1. (a) Aethalium of *Enteridium splendens*, × 1.
(b) Pseudo-capillitium, × 50.
(c) Spore, × 600.

FIG. 2. (a) Aethalium of *Dictydiaethalium plumbeum*, × 1.
(b) Individual sporangia (after Lister), × 20.
(c) Single sporangium, showing perforated walls, × 50.
(d) Spores, × 500.

FIG. 3. (a) Sporangia of *Cribraria aurantiaca*, × 8.
(b) Sporangial head, showing net and nodes, × 50.
(c) Spore, × 1000.

FIG. 4. (a) Sporangia of *Dictydium cancellatum*, × 15.
(b) Sporangial ribs, × 500.
(c) Spores, × 800.

FIG. 5. (a) Aethalia of *Lycogala epidendrum*, × 1.
(b) Capillitial tubules, × 400.
(c) Spore, × 1000.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2 d
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1 b
3 a
3 b
2 c
3 c
4 b
5 c
5 a
4 a
4 c
5 b

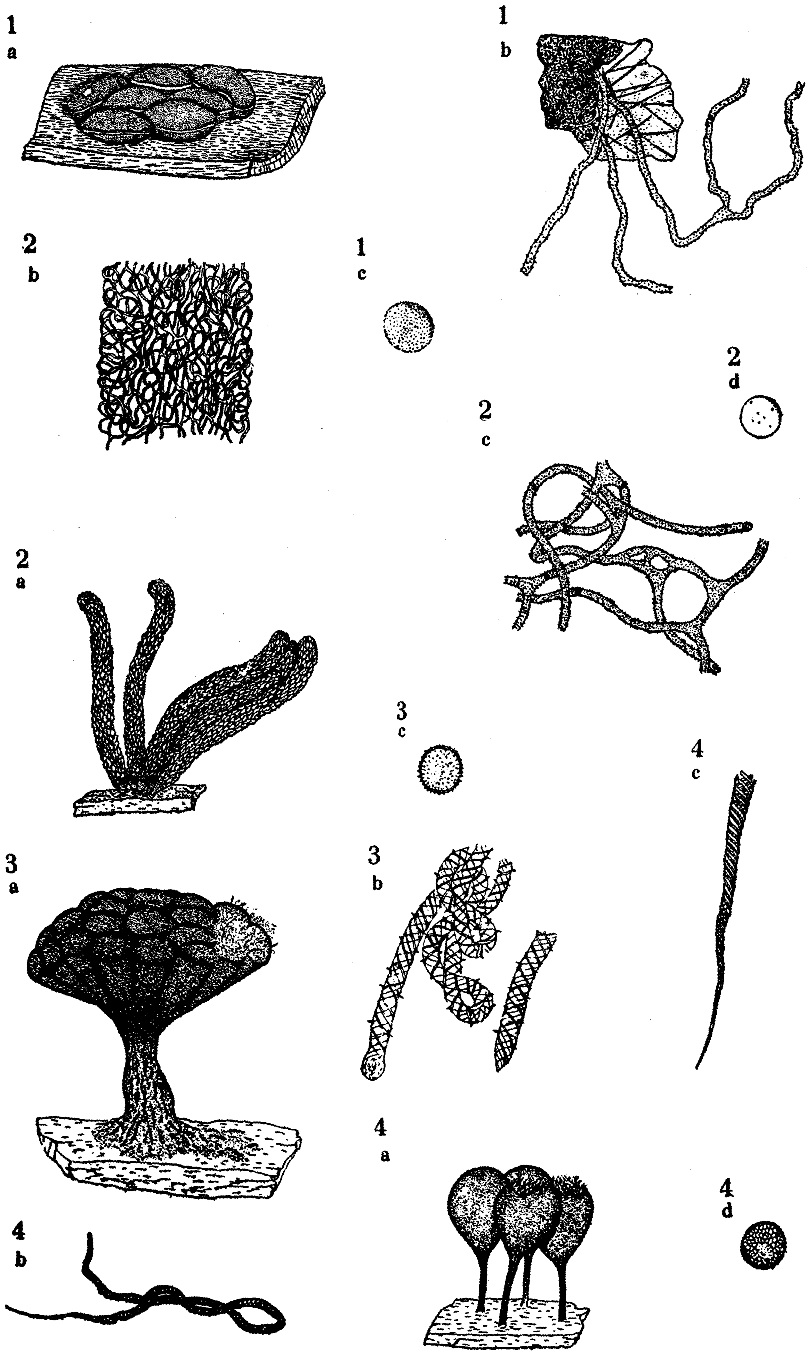
PLATE VI

FIG. 1. (a) Sporangia of *Perichaena depressa,* × 15.
(b) Capillitium and portion of sporangial wall, × 500.
(c) Spore, × 600.

FIG. 2. (a) Sporangia of *Arcyria nutans,* × 5.
(b) Section of capillitium, showing twisted threads, × 100.
(c) Capillitium, × 350.
(d) Spore, × 600.

FIG. 3. (a) Sporangial cluster of *Hemitrichia vesparium,* × 6.
(b) Capillitial threads, × 500.
(c) Spore, × 500.

FIG. 4 (a) Sporangia of *Trichia decipiens,* × 12.
(b) Single elater, × 150.
(c) Tip of elater, × 400.
(d) Spore, × 500.



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1 c
2 d
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2 a
3 c
4 c
3 a
3 b
4 a
4 d
4 b

NOTES ON PARASITIC FUNGI IN WISCONSIN. XIX.

J. J. DAVIS

The summer of 1930 was hot and dry, which had a marked deterrent effect on the development of parasitic fungi.

SYNCHYTRIUM PULVEREUM Davis, on *Laportea canadensis*, having been found to bear summer sori similar to those of *S. cellulare* on *Boehmeria cylindrica*, is now referred to that species and the binomial reduced to synonymy.

Record has been made of the presence of PERONOSPORA MELAMPYRI (Bucholtz) in Wisconsin at Friendship and Radisson (as PLASMOPARA MELAMPYRI Bucholtz, Notes XVI, pp. 287–8). In July 1931 it was found at Washington Island with oospores, mostly immature, in the leaves. Those measured were globose, 27–33μ in diameter; oogonia 40–50μ. The conidia are strongly fuscous.

In "Notes" XI, pp. 294-295, record was made of the occurrence of DOASSANSIA SAGITTARIAE (West.) Fisch on *Lophotocarpus calycinus* at Blue River. The collection was a small one, there being but few host plants. In 1930 it was found in abundance at a station on the bottom lands of the Mississippi river near Glen Haven. As at the first locality no Doassansia was found on Sagittaria and as in the first collection the sori are often irregular. Field evidence points to close host adaptation as might be expected of parasites of this character.

In 1931 plants of *Amphicarpa monoica* were exposed to infection in the greenhouse from overwintered Puccinia on Andropogon from two localities without result. One of the localities was visited later and Aecidium on *Comandra umbellata* was found to be abundant there.

PESTALOZZIELLA SUBSESSILIS Sacc. & Ell. was recorded in the first supplementary list (1894) on the authority of Dr. Trelease who had found it at Madison on *Geranium maculatum*. It was not seen by the writer until May, 1930, when it was found at Viroqua on the same host. Examination of this collection shows that the sporules are formed in definite pycnidia in which there is apparently no ostiole, the spore discharge being through rupture. The genus therefore should find place in the Sphaerioidaceae. Notes on spore measurements read 17-30 × 5-10μ.

A specimen on an *Aster* of the *paniculatus* group collected May 18, 1929 bears sporules some of which exceed 80μ in length but has been referred to SEPTORIA ASTERICOLA Ell. & Ev. because they are but about 1μ in diameter. This species develops in spring, S. ATROPURPUREA Pk. in midsummer.

A specimen on *Solidago latifolia* from Kenosha Co. (July 4, 1892) was recorded in the Supplementary list as SEPTORIA ATROPURPUREA Pk. It has the following characters: spots circular to angular, 1-2 mm. or more elongate up to 4 mm. in length, dark purple above, pale below, often confluent and sometimes, by death of intervening tissue, forming pale brown areas; pycnidia epiphyllous, few, scattered, black, 60-80μ in diameter; sporules straight or somewhat curved, 37-66 × 1½-2½μ. Another specimen (Kenosha Co., June 10, 1894) is more mature and bears larger spots, 4 mm. in diameter, which become paler in the center.

STIGMATEA ROBERTIANI Fr. on *Geranium robertianum.* Fish Creek. The material is not mature but appears to be of this species.

The Cercospora that occurs on *Smilax hispida* in Wisconsin was refered to C. MISSISSIPPIENSIS Tracy & Earle in the fourth supplementary list and in the provisional list. In "Notes" X this was referred to C. SMILACIS Thuem. following Peck. Solheim refers it to C. PETERSII (B. & C.) Atk. which appears to be the proper designation.

ADDITIONAL HOSTS

A Synchytrium occurring in small quantity on *Fragaria virginiana* at Superior has been referred to S. AUREUM Schroet. It is much like the form on Geum.

BREMIA LACTUCAE Regel. On *Lactuca villosa.* Madison.

PLASMOPARA HALSTEDII (Farl.) Berl. & De Toni. On *Eupatorium purpureum.* Viroqua.

PERONOSPORA GRISEA Unger. In a collection of *Veronica serpyllifolia* from Reedsburg one of the plants bears a little of the mildew on the upper part of the stem.

PERONOSPORA POLYGONI Thuem. On *Polygonum Convolvulus.* Lancaster. V. H. Young & J. J. Davis.

PUCCINIA HIERACII (Schwm.) Mont. On *Agoseris cuspidata.* Pine Bluff. (N. C. Fassett).

STAGONOSPORA ATRIPLICIS (West.) Lind. On *Spinacia oleracea* (Cult.). Madison. This is S. SPINACIAE Ell. & Ev., which does not seem to me to be distinct. The sporules in this collection are 14-24 × 6-8μ, 1-3 septate.

SEPTORIA HELLIANTHI Ell. & Kell. On *Helianthus scaberrimus.* Spring Green.

COLLETOTRICHUM MALVARUM (A. Br. & Casp.?) Southworth. On *Althaea* (Cult.). Baraboo. (L. R. Jones, 1911).

PHYLLACHORA GRAMINIS (Pers.) Fckl. On *Elymus striatus.* Madison.

SEPTORIA RUDBECKIAE Ell. & Hals. On *Rudbeckia subtomentosa* on the Wisconsin river bottom lands in Iowa county. In this collection the white arid portion constitutes most of the spot which has a dark purple border. Similar spots, except that the border is brown, are usual on *Rudbeckia laciniata* but not on *R. hirta.* The development of the pycnidia on the arid spots is often poor.

Of a collection on twigs of *Viburnum Lentago* made at Arena June 4, 1929 the following notes were made: Acervuli various in extent on the young growth of the season often extending up the petioles, sometimes on the principal veins very exceptionally on the lamina, subcuticular, discoid; conidia soon erumpent in white masses, hyaline, cylindrical to fusoid, usually more or less acute at the proximal end, 12-23 × 3½-6μ. This has been provisionally referred to *Gloeosporium cingulatum* Atk. Usually death of some of the young leaves results.

An OVULARIA on leaves on *Phalaris arundinacea* referred to O. PULCHELLA (Ces.) Sacc. has been collected at Spring Green.

GLOMERULARIA CORNI Pk. var. LONICERAE Pk. On *Lonicera tatarica.* Madison. I have seen no record of the occurrence of this parasite on a host of foreign origin. The plants were growing, without cultivation, on the railroad right of way. Dearness & House consider the form on Lonicera to be specifically distinct. (*New York State Museum Bulletin. Report of the Botanist for 1921,* p. 85.)

CERCOSPORA FINGENS Davis. A scanty collection on *Thalictrum dioicum* from Mazomanie. Amphigenous.

RAMULARIA VIRGAUREAE Thuem. On *Solidago patula.* Conidia catenulate. Septation and catenulation often seem to be degrees of the same process.

CERCOSPORA DAVISII Ell & Ev. On *Melilotus officinalis.* Spring Green. While this parasite is common on *Melilotus alba* in Wisconsin it is much less frequent on *M. officinalis.* In this collection the leaflets bear also small arid barren spots resembling those caused by PHYLLOSTICTA DECIDUA Ell. & Kell. suggesting a prior infection by another parasite.

In *Mycologia* 21: 304 et seq. (1929) Horsfall reports results of examination of CERCOSPORA ZEBRINA Pass. on Trifolium, C. DAVISII E. & E. on *Melilotus alba* and C. MEDICAGINIS Ell. & Ev. on Medicago in which he failed to find definite morphological characters by which to separate them and proposed that they be united as a single species. In view of the variability of conidiophoral and conidial characters in this genus perhaps it is better to await the results of cross inoculation work and comparison of ascigerous stages, if such exist, before decision.

CERCOSPORA ANTIPUS Ell. & Hol. On *Lonicera dioica.* Washington Island.

CERCOSPORA GALII Ell. & Hol. On *Galium triflorum.* Solon Springs.

ALTERNARIA HERCULEA (Ell. & Mart.) Elliott. On *Brassica nigra.* Gratiot.

ENTYLOMA COMPOSITARUM Farl. On *Bidens vulgata.* Big Bend.

AECIDIUM PLANTAGINIS Burrill. The aecial stage of UROMYCES SEDITIOSUS Kern was found on *Plantago aristata* at Avoca May 28, 1929.

PUCCINIA BARTHOLOMAEI Diet. The aecial stage, AECIDIUM JAMESIANUM Pk. on *Asclepias tuberosa.* Ferry bluff, Sauk Co.

PUCCINIA CANALICULATA (Schw.) Lagh. II III on *Cyperus esculentus.* Gratiot.

Since the connection of Aecidium on Erigeron with a Puccinia on Carex was shown by Arthur all aecia on Erigeron in Wisconsin have been referred to PUCCINIA CARICIS-ERIGERONTIS Arth. (*Journ. Mycol.* 8: 53-4) now considered to be a race of P. EXTENSICOLA Plowr. which develops aecia on Aster and Solidago as well. Of the two rusts on Cyperus in Wisconsin PUCCINIA CANALICULATA (Schw.) Lagh. and P. CYPERI Arth. the former had been found to develop aecia on Xanthium (Arthur, *Journ. Mycol.* 12: 23) but the aecial host of the latter has been unknown. In conversation with Dr. H. S. Jackson he expressed the opinion that *P.* CYPERI Arth. develops its aecial stage on Erigeron. Recalling that abundant development of aecia on *Erigeron canadensis* had been observed in localities where Cyperus was abundant rusted material of *Cyperus Schweinitzii* bearing P. CYPERI was overwintered in the open and the following spring plants of *Erigeron canadensis* were brought into the greenhouse and infected from the overwintered material resulting in abundant aecia while the controls remained normal. This Aecidium is quite similar to the one on Erigeron connected with PUCCINIA EXTENSICOLA Plowr., the only difference that has been observed being a tendency to thickening of the spore wall at or near the apex as was pointed out by Dr. Arthur. The character is most readily seen when the spores are concatenate and hence are seen in side view. A collection on *Erigeron ramosus* from Spring Green is also referred to this species.

Telial material from the same station has since been used to infect *Erigeron annuus* in the greenhouse. This indicates that there is no physiological difference between the rust occurring on Euerigeron and that on what is considered by some to be the distinct genus Leptilon.

Although PUCCINIA KARELICA Tranz. has been collected in Wisconsin on Carex the aecial stage AECIDIUM TRIENTALIS Tranz. was not found until 1930 when it was collected on *Trientalis americana* in a large swamp near Cedarburg by A. M. Fuller and the writer.

PUCCINIA VIOLAE (Schum.) DC. Aecia on *Viola sagittata.* Arena.

A collection on *Asplenium acrostichoides* from Solon Springs is presumably UREDINOPSIS COPELANDI Syd. The fronds are well infected but there are scarcely any uredospores and the teliospores do not furnish distinctive characters. Another collection on the same species of host from Haugen however bears both kinds of spores.

PUCCINIA MENTHAE Pers. On *Monarda didyma* (Cult.). Madison. (Sam Chechik.)

PUCCINIA XANTHII Schw. On *Ambrosia psilostachya.* Spring Green.

The aecial stage of COLEOSPORIUM SOLIDAGINIS (Schw.) Thuem. occurs on needles of young planted trees of *Pinus resinosa* in Peninsula State Park.

The pre-sclerotial stage of SCLEROTIUM DECIDUUM Davis occurred at Viroqua on *Ranunculus septentrionalis.*

ADDITIONAL SPECIES

SYNCHYTRIUM FULGENS Schroet. The summer spore stage on *Oenothera biennis* was found under a railroad bridge at Browntown.

SCLEROTINIA VACCINII Wor. On *Vaccinium macrocarpon.* Cranmoor. (E. E. Honey).

PHYLLOSTICTA PODOPHYLLI (Curt.) Wint. On *Podophyllum peltatum.* Big Bend.

A dead fallen leaf of Pinus Strobus from "the elephant's back" near "the dells" in Adams county bears what is probably VERMICULARIA LIBERTIANA Roum. The conidia are somewhat long, 10-13μ, and usually narrower and the bristles range up to 130μ in length. That this is parasitic is doubtful.

A small collection on a twig of *Pinus Banksiana* from Gotham, June 18, 1930, shows on dead needles depressed globose pycnidia 175-200 $\times$ 135μ in which develop deep brown (black in mass) fusoid-oblong sporules which became uniformly triseptate, 16-20 $\times$ 4-7μ; basidia indistinct. The uninfected needles on the twig were living. This probably bears relation to HENDERSONIA FOLIICOLA (Berk.) Fckl. with which it has been filed.

SEPTORIA FUMOSA Pk. A collection on leaves of *Solidago serotina* from Readstown, May 23, 1930, is referred to this species. The spots are greyish brown, paler below, more or less angular and limited by the veinlets, sometimes confluent, 1-5 mm. in diameter; pycnidia epiphyllous, scattered, subepidermal, sometimes imperfect distally, about 100μ in diameter; sporules hyaline, curved, 50-75 $\times$ 2μ. *Septoria davisii* Sacc. is probably not distinct from this.

Septoria cynoglossi n. sp. Spots definite, orbicular to irregular, brown, paler below, 2–5 mm. in diameter; pycnidia epiphyllous, scattered, rather thin-walled but usually with a more or less prominent black thickening around the pore, 50-80μ in diameter; sporules straight, 20-30 $\times$ ½μ. On *Cynoglossum boreale,* Winneboujou, Wisconsin, August 9, 1930. The material is not mature and the sporules are probably larger when fully developed.

SEPTORIA HIERACICOLA Dearn. & House. On *Hieracium longipilum.* Spring Green. The spots are conspicuous but often sterile, the small pycnidia inconspicuous.

COLLETOTRICHUM SOLITARIUM Ell. & Barth. on *Solidago latifolia.* Washington Island.

CERCOSPORA BRIAREUS Ell. & Ev. On *Acerates viridiflora.* Spring Green. In this collection the conidiophores are shorter (mostly 20-35μ) and some of the conidia longer (100μ or môre) than in the type as described.

PUCCINIA ARENARIAE (Schum.) Wint. On *Arenaria stricta.* Belmont. (N. C. Fassett.)

HYALOPSORA CHEILANTHIS (Pk.) Arth. On *Cryptogramma Stelleri.* Viroqua. (N. C. Fassett.)

UNIVERSITY OF WISCONSIN HERBARIUM,
APRIL, *1931.*

INDEX TO "NOTES" XVIII AND XIX.

(Names of parasites in italics.)

IMPERMEABILITY IN MATURE AND IMMATURE SWEET CLOVER SEEDS AS AFFECTED BY CONDITIONS OF STORAGE.

EARL A. HELGESON

INTRODUCTION

Many seeds, in common with other plant structures, undergo a dormant or so-called rest period. Methods of securing dormancy in seeds seem to be generally associated with: (1) embryo characteristics which prevent the immediate germination of a seed even though conditions favorable for germination obtain, and (2) seed coat characteristics which prevent either the ready passage of liquids or gases, or the expansion of the embryo. Crocker *(1)* has made a classification of the mechanisms of dormancy. In so far as immature embryos are a consideration, he finds that at the time of seed ripening, these may vary from an undifferentiated group of cells to a mature embryo. Individuals exhibiting this type of dormancy are present in practically all the large groups of seed plants.

Impermeable or so-called "hard" seeds are defined by Harrington (4) as "seeds whose coats are impermeable to water at temperatures favorable for germination." This type of dormancy seems to be of common occurrence in many species of the Leguminosae with the result that their seeds may lie in the soil for a number of years germinating a few at a time. A considerable amount of work has been done on fully mature impermeable seeds but comparatively few studies are available on the physiological processes which take place during the maturation of such seeds. This study was undertaken to demonstrate at what stage of maturation the impermeable condition was assumed and what the nature of the processes leading to the impermeable condition might be.

Sweet clover, Melilotus, was chosen as experimental material because of the constant high percentage of impermeable seeds produced and because of the extreme resistance to the entrance of water shown by these seeds.

Experimental

Desiccation and the production of impermeability in sweet clover seeds. Seeds used in these studies were collected when they were slightly immature. Two degrees of immaturity were recognized: (1) "Brown pod," seeds with brown pods from racemes having green peduncles, (2) "Yellow pod," seeds with slightly green or yellow pods and green peduncles. Brown pod seeds had the bright yellow color of a fully matured seed, but they had not dried down completely. Yellow pod seeds had attained their full size but had not started to dry down.

Racemes with seeds in the states of maturity mentioned above were collected, taken to the labratory, and the pods carefully stripped from the peduncles. Lots of 100 pods were counted out, an effort being made to select only healthy one-seeded pods, and these were placed in Gooch crucibles. The crucibles were then stored in a desiccator over calcium chloride or in a vacuum desiccator with the same drying agent, according to the nature of the drying desired. In the preliminary tests, the lots to be treated *in vacuo* over calcium chloride were placed in a desiccator with a side arm and the desiccator was evacuated from time to time by means of a hand pump, until the pressure was equal to 61 centimeters of mercury. It was found, however, that there was a slow leak in the desiccator, so this method was abandoned and an automatically controlled Freas vacuum oven at room temperature was used for further tests. To obtain additional dryness in the oven, a pie pan containing calcium chloride was placed under the tray supporting the seeds.

Unless otherwise stated, germination tests were always made in a Minnesota type germinator set at 20°C, moist blotters or filter paper being used as a substrate. After counts of germinated seeds had been made, the blotters were allowed to dry, the remaining seeds were then hulled by hand and the impermeable seeds counted. The seeds which softened but did not germinate were calculated by subtracting the sum of germinated and impermeable seeds from the original number of pods put to germinate. In the case of hulled seeds, all three fractions could be counted at the end of a test. Throughout this paper the following abbreviations have been used to denote the three fractions: Gm, germinated seeds; HS, impermeable

Table I. *Influence of desiccation over extended periods upon the production of impermeability in yellow pod white sweet clover seeds.*

Treatment	Duration of treatment	Time in germinator	No. of seeds	% Gm*	% HS*	% SS*
	0 days† (control)	7 days 10 "	89	80.90 100.00	....	....
Desiccator.	2 " †	7 " 10 "	82	55.00 84.00	6.00	10.00
Over	3 "	7 " 12 "	100	11.00 18.00	72.00	10.00
calcium	4 "	7 " 11 "	100	3.00 5.00	86.00	9.00
chloride	5 "	7 " 10 "	100	6.00 6.00	88.00	6.00
	6 "	7 " 10 "	100	3.00 4.00	93.00	3.00
	7 "	7 " 10 "	100	3.00 3.00	96.00	1.00
	8 "	7 " 10 "	100	4.00 5.00	95.00	0.00
Vacuum	2 " †	7 " 13 "	135	30.37 34.81	46.66	18.53
desiccator	3 "	7 " 12 "	100	1.00 4.00	90.00	6.00
over	4 "	7 " 11 "	100	4.00 4.00	88.00	8.00
calcium	5 "	7 " 10 "	100	5.00 7.00	89.00	4.00
chloride	6 "	7 " 10 "	100	6.00 6.00	90.00	4.00
	7 "	7 " 10 "	100	3.00 4.00	89.00	7.00
	8 "	7 " 10 "	100	3.00 3.00	92.00	5.00

*Total after 7 and 10 days respectively.
†Put to germinate without hulling, all other lots were hulled before being put to germinate.

seeds; and SS, soft seeds or seeds which took up water but did not germinate.

The behavior of immature seeds in a vacuum desiccator and in an ordinary desiccator is shown in Table I. The control and the first 2 day lot were unhulled. All the other lots were hand hulled and 100 seeds counted out for the germination test.

From these data it is clear that even a 2 day period of desiccation causes a considerable increase in impermeability and that a treatment in a vacuum over calcium chloride causes a somewhat greater increase in impermeability. The maximum "hardening" effect seems to have been reached after 3 days in storage in a vacuum over calcium chloride and after 4 days in storage over calcium chloride without vacuum.

To test the effects of a higher degree of desiccation on the permeability of immature seeds, the Freas vacuum oven kept at constant partial vacuum of 37.5 ± 0.2 cm. Hg. and containing calcium chloride as stated above was used. The results obtained are given in Table II.

TABLE II. *Influence of desiccation in constant partial vacuum over calcium chloride at room temperature upon the production of impermeability in immature white sweet clover seeds. The seeds used in this series of tests were unhulled.*

Kind of seed	Duration of treatment	Time in germinator	No. seeds	% Gm	% HS	% SS
Brown pod	0 days	11* days	118	53.38	43.22	3.40
	1 "	13* "	111	9.00	89.20	1.80
	3 "	12 "	100	2.00	98.00	0.00
	5 "	10 "	100	1.00	97.00	2.00
	7 "	10 "	100	4.00	96.00	0.00
	9 "	10 "	100	1.00	99.00	0.00
	21 "	11 "	100	1.00	99.00	0.00
	31 "	11 "	100	4.00	95.00	1.00
Yellow pod	0 "	11* "	100	96.00	0.00	4.00
	1 "	13* "	100	62.00	7.00	31.00
	3 "	12 "	100	23.00	71.00	6.00
	5 "	10 "	100	2.00	87.00	11.00
	7 "	10 "	100	6.00	91.00	3.00
	9 "	10 "	100	5.00	83.00	12.00
	21 "	11 "	100	0.00	96.00	4.00
	31 "	11 "	100	5.00	89.00	6.00

*Put to germinate without hulling. Lots not marked were hulled before being put to germinate.

The data in the above table are in line with those in Table I. In general, there seems to be a more rapid increase in impermeability in brown pod lots than there is in yellow pod lots. The decrease in seeds which germinate and in soft seeds is also more rapid. From the third day on, the lots used in Table II were hand-hulled before being put to germinate, this served as a rather good check on the unhulled lots used in the preceding tests and seemed to show that results secured with unhulled lots are fairly reliable.

The effect of storage over extended periods upon mature and slightly immature sweet clover seeds. A preliminary germination test, on a lot of unhulled brown pod white sweet clover seeds, brought out the fact that seeds harvested at the right stage could be held in storage under moist, cool conditions for some time without hardening (Table III).

Accordingly, a considerable number of collections from individual plants in the brown pod and yellow pod stages were made. These lots were placed in manila envelopes and stored in three places as follows: (a) Laboratory, (b) cold room, and

TABLE III. *Germination tests of brown pod white sweet clover seeds, held after harvesting under three different conditions of storage.*

Kind of seed	Original* percentage germination	Time stored	Stored in laboratory % Gm.	Stored in cold room % Gm.	Stored out-of doors % Gm.
White mixed. Lot No. 2-33	31.00	3 days	22.00	38.00	22.00
	31.00	5 "	16.00	42.00	24.00
	31.00	8 "	2.00	43.00	6.00
	31.00	12 "	3.00	41.00	4.00
	31.00	590 "	0.00	25.00	67.00†

*That is, the percentage germination at the beginning of the experiment.
†Out-of-doors 515 days; then in the cold room 75 days.

(c) out-of-doors. The cold room had a fairly constant temperature of 7° C. and had a relative humidity of approximately 85 per cent; the seeds stored out of doors were placed in a special louvered shelter. They were thus protected from rain but subjected to seasonal changes in temperature and humidity.

In practically all germination tests 100 unhulled pods were used and the percentages of germinated seeds, impermeable seeds, and soft seeds determined as for the desiccation experiments. The counts were taken after seven days in the germinator. As often as possible the first or original germination test was made as soon as the lots were collected. Whenever that could not be done, the lots were held in a moist chamber at room temperature until the test could be made, which was usually the next day. Immediately after the test sample had been taken the lots were placed in storage.

A few lots of ripe seeds were also collected, from some of the same individual plants from which immature lots were taken, and placed under similar storage conditions. These would serve as controls on any softening influence due to the various storage conditions. Some mixed lots of immature seeds were made up by using seeds from 10 or more plants of the same variety. Ripe, mixed lots were collected from the same plants from which immature lots were taken. As no significant difference between seeds from wild plants as against cultivated plants of the same variety were noted no mention is made of the seed source. Most of these samples were collected during August 1928 at Madison, Wisconsin. The data for the first tests, after a period of 7 to 8 months, are presented in Table IV.

TABLE IV. *Germination of brown pod yellow and white sweet clover seeds, after storage for 7 to 8 months in the laboratory and cold room respectively. In each case the seeds of any particular lot were from a single plant.*

Lot number	Kind of seed	Time stored	Original* percentage germination	Kept in laboratory % Gm.	Kept in cold room % Gm.
2–5	Yellow	225 days	32.00	2.00	22.00
2–8	White	238 "	56.00	6.00	52.00
2–9	"	238 "	47.00	0.00	56.00
2–10	"	238 "	40.00	2.00	46.00
2–14	"	239 "	50.00	0.00	46.00
2–15	"	239 "	92.00	2.00	58.00
2–16	"	239 "	80.00	2.00	40.00

*50 seeds used for each test.
Germination test at beginning of experiment.

As only 50 seeds were used in the tests recorded in Table IV, the findings can be regarded only as relative. It is seen that even after 7 to 8 months in storage the cold room lots gave rather high percentages of germination. The less mature lots, i. e., those giving around 80 per cent original germination, showed a greater reduction in seedling production than did those lots germinating around 40 per cent. This reduction was largely due to an increase in soft seeds, brought about probably by the action of micro-organisms during the germination test. The lots stored in the laboratory had practically all become impermeable.

After a period of from 15 to 17 months in storage, the germination of lots kept in the cold room was still relatively high, in fact, practically the same as it was after 8 months. The data in Table V show further that the percentages of soft seeds in the cold room lots are very high and seem to have increased at the expense of the hard seeds. The lots stored in the labora-

TABLE V. *Germination of brown pod white and yellow sweet clover seeds after storage from 15 to 17 months under the several conditions indicated below.* Y = *yellow*; W = *white*; I = *from an individual plant*; M = *mixed*.

Lot No.	Kind of seed	Time stored (days)	Original % Gm	Kept in laboratory			Kept in cold room		
				% Gm	% HS	% SS	% Gm	% HS	% SS
2-5	Y. I.	447	32.00	....	....	....	28.00	46.00	26.00
2-6	Y. I.	448	42.00	0.00	100.00	0.00	....	....	....
2-7	Y. I.	448	22.00	2.85*	89.54	7.61	17.14*	32.38	50.48
2-8	W. I.	448	56.00	7.00	93.00	0.00	47.00	11.00	42.00
2-9	W. I.	511	47.00	2.00	96.00	2.00	32.00	26.00	42.00
2-10	W. I.	511	40.00	2.00†	98.00	0.00	40.00	37.00	23.00
2-14	W. I.	511	50.00	1.00	78.00	21.00	29.00	2.00	69.00
2-15	W. I.	510	92.00	0.00‡	98.00	2.00	38.00	7.00	55.00
2-17	W. M.	510	86.00	2.00‡	98.00	0.00	42.00	3.00	55.00
2-21	W. M.	510	87.00	9.00	85.00	6.00	29.00	2.00	69.00
2-22	Y. I.	510	48.00	0.00	95.00	5.00	42.00	19.00	39.00
2-23	Y. I.	509	12.00	2.00	98.00	0.00	20.00	54.00	26.00
2 24	Y. I.	510	55.00	0.00	89.00	11.00	65.00	11.00	24.00

*Based on 105 seeds.
†Hand-hulled before testing.
‡10 days on germinator before counting.

TABLE VI. *Germination of mature and brown pod white and yellow sweet clover seeds after storage under the different conditions indicated below.* Y = *yellow*; R = *ripe*; W = *white*; M = *mixed*; I = *from an individual plant*.

Lot No.	Kind of seed	Time stored (days)	Original % Gm	Stored in laboratory			Stored in cold room		
				% Gm	% HS	% SS	% Gm	% HS	% SS
2-22	Y. I.	510	48.00	0.00	95.00	5.00	42.00	19.00	39.00
2-22*	Y. I. R.	510	0.00	0.00	96.00	4.00	7.92‡	92.08‡	0.00‡
2-23	Y. I.	509	12.00	2.00	98.00	0.00	20.00	54.00	26.00
2-23*	Y. I. R.	509	3.00	0.87§	99.13§	0.00§	6.04§	93.96§	0.00§
2-24	Y. I.	510	55.00	0.00	89.00	11.00	65.00	11.00	24.00
2-24*	Y. I. R.	510	6.00	2.00	94.00	4.00	15.00	70.00	15.00
2-32	W. M.	599	19.00	1.00	98.00	1.00	30.00	70.00	0.00
2-32*	W. M. R.	599	2.00	0.96‖	99.04‖	0.00‖	9.61‖	84.51‖	5.88‖
2-33	W. M.	590	31.00	0.00	94.00	6.00	25.00	67.00	8.00
2-33*	W. M. R.	590	6.00	1.00	93.00	6.00	16.00	73.00	11.00
2-34	W. M.†	584	81.00	2.00	82.00	16.00	34.00	15.00	51.00
2-34*	W. M. R.	584	5.00	0.98¶	99.02¶	0.00¶	14.70¶	85.29¶	0.01¶

*Ripe seeds from same plants as immature lots of corresponding number.
†White mixed yellow pod seed.
‡Based on 101 seeds.
§Based on 115 seeds.
‖Based on 104 seeds.
¶Based on 102 seeds.

tory still show a high percentage of impermeable seeds and relatively low percentages of permeable and soft seeds. There seems to be no apparent softening of seeds owing to storage in the dry condition in the laboratory.

Although the laboratory lots served as a good check on the effects of drying in storage, they did not give any information as to the possible softening effect of humidity and low temperature on the lots held in the cold room. To test what effect these latter agencies might have, a number of the mature lots from the same plants from which immature seeds were collected were put to test. These data, together with tests of immature lots from the same plant, are recorded in Table VI.

That there may have been some slight effect on the mature seeds stored in the cold is shown in the preceding table, but the differences are hardly large enough to account for all the permeable seeds occurring in the brown pod lots. There was also a small increase in soft seeds in ripe lots stored in the cold room as compared with the corresponding lot stored in the laboratory.

The data set down in Table VII show the effect of storing mature and immature seeds out-of-doors where they are subject to seasonal variations in temperature and humidity and then giving them constant storage in the cold room for a short period. Checking these lots against lots stored continually in the cold room, it is clear that storage out of doors reduces the

TABLE VII. *Germination of mature and brown pod white sweet clover seeds stored out-of-doors and then in the cold room.*
R = *ripe*; M = *mixed.*

Lot No.	Kind of seed	Time out-of-doors (days)	Time in cold room (days)	Original %Gm	%Gm	%HS	%SS
2–32	M.	524	75	19.00	87.00	13.00	0.00
2–32*	M. R.	524	75	2.00	66.34†	30.78	2.88
2–33	M.	515	75	31.00	67.00	32.00	1.00
2–33*	M. R.	515	75	6.00	70.00	29.00	1.00
2–34§	M.	509	75	81.00	74.00	18.00	8.00
2–34*	M. R.	509	75	5.00	47.05‡	47.05	5.90

*Ripe seed from same plants as immature lots of corresponding number.
†Based on 104 seeds.
‡Based on 102 seeds.
§Mixed yellow pod.

number of impermeable seeds in the mature lots to a considerable extent. The percentages of soft seeds in both types of seed are reduced to a minimum.

It is to be regretted that more material of this type was not available as there seems to be an indication that storage, immediately after harvest, in a place where the seeds are protected from direct exposure to weather but subject to natural temperature and humidity changes, reduces the ratio of impermeable seeds without effecting the total viability of the seeds.

The preceding storage tests have shown that cold, moist conditions prevent slightly immature seeds from becoming impermeable. The question next arose as to whether this inhibition was permanent or lasted only so long as seeds were kept in the cold room. To test this a number of 100-pod lots were counted out and placed in a desiccator over calcium chloride and left for 7 days. The desiccator was exhausted by means of a vacuum pump until the gauge registered 60 cm. of mercury and it was held at approximately this level for the first 24 hours. Then the pump was disconnected and the desiccator was allowed to come to atmospheric pressure and was so maintained for the remainder of the 7 days. At the end of the drying period the lots were taken out and put to germinate. The data for this experiment are presented in Table VIII.

Unfortunately there was not enough material left after selecting the lots for drying to run a germination test at the time the drying test was started. The counts on germination before drying were therefore made from the last previous test. The results brought forward in Table VIII indicate that the immature lots stored in the cold room are only temporarily kept from hardening. A short drying period suffices to reduce the number of permeable seeds to an extent almost equal to the reduction effected in the original lots by storage in the laboratory. Another interesting fact brought out by these data is the great reduction in the percentage of soft seeds. Here again the dried lots are comparable with the original lots which were stored in the laboratory.

The high percentage of impermeable seeds present in the dried lots suggested that perhaps many of the soft seeds had also become impermeable. To arrive at the true value of the

TABLE VIII. *Germination of brown pod sweet clover seeds stored in a cold room for various lengths of time and subsequently stored in a desiccator for 7 days.* Y = *yellow sweet clover*; I = *individual plant*; W = *white sweet clover*; M = *mixed lot.*

Lot No.	Kind of seed	Original % Gm.	Time in days between last gm. test and drying	Gm. test before drying			Time stored before drying	Gm. test after drying			No. seeds tested	Gm. of scarified hard seeds from drying test	
				%Gm.	%HS	%SS		%Gm.	%HS	%SS		% Gm.	%SS
2–5	Y. I.	32.00	165	28.00	46.00	26.00	612	9.52*	90.48	0.00	95	84.22	15.78
2–7	Y. I.	22.00	165	17.14*	32.38	50.48	613	5.71*	76.19	18.10	80	71.25	28.75
2–8	W. I.	56.00	165	47.00	11.00	42.00	613	9.00	81.00	10.00	81	65.43	34.57
2–9	W. I.	47.00	101	32.00	26.00	42.00	612	7.00	89.00	4.00	89	82.03	17.97
2–10	W. I.	40.00	101	40.00	37.00	23.00	612	7.00	91.00	2.00	91	72.53	27.47
2–14	W. I.	50.00	101	29.00	2.00	69.00	612	0.00	81.00	19.00	81	53.95	46.05
2–17	W. M.	86.00	101	42.00	3.00	55.00	611	3.00	91.00	6.00	93	58.71	41.29
2–21	W. M.	87.00	98	29.00	2.00	69.00	608	0.00	86.00	14.00	86	53.49	46.51
2–22	Y. I.	48.00	98	42.00	19.00	39.00	608	6.00	93.00	1.00	93	68.82	31.18
2–24	Y. I.	55.00	98	65.00	11.00	24.00	608	0.00	86.00	14.00	86	80.23	19.77
2–32	W. M.	19.00	0	30.00	70.00	0.00	599	11.00	87.00	2.00	87	87.40	12.60

*Based on 105 seeds.

impermeable seeds remaining after the drying test, these were rubbed between sandpaper and germinated. That a considerable number of soft seeds did become impermeable during the drying process is apparent from results obtained in this germination test. The percentages of germination in some of the scarified dried lots are, however, somewhat higher than the percentages obtained in the cold-room lots before drying. This seems to confirm the statement made before, that the cold room lots showed rather high percentages of soft seeds because of the attack of micro-organisms during the germination test, and that drying reduced the susceptibility of the seeds to such attacks (Table VIII).

To test the effects of various conditions of storage on mature lots of commercial white sweet clover seeds the following experiment was set up: Three cloth bags containing respectively, (1) scarified seeds, (2) seeds which had been hulled but not scarified, and (3) unhulled Grundy County seeds, were placed out of doors in a small house built in such manner that rain was kept out but no protection against other weather changes was afforded. Similar lots of the same seeds were kept in the cold room and in the laboratory. Small pans containing the three kinds of seeds mentioned above were also stored in desiccators in the cold room, and in the laboratory. The commercial seeds used were obtained from the Agronomy department and were of the 1927 crop. The unhulled Grundy County seeds were purchased from the L. L. Olds Seed Co. and were grown and harvested in North Dakota in 1927. The out-door lots were placed in storage October 29, 1927, and the other lots were stored February 23, 1928. On this latter date all lots were tested for germination and this test is given as the control. The final germination test of all lots was made on March 14, 1930, or after a period of 24 months and 19 days.

Two hundred seeds were used in each of the tests in this experiment and the Grundy County seeds were hand-hulled before testing. The data obtained from these tests (Table IX) show that dry storage is the best means of conserving the vitality of commercial seeds. Storage in the cold room with the prevailing high humidity was especially detrimental to the scarified and commercial-hulled seeds. In the desiccators the seeds stood up about as well as did those stored in the dry laboratory. The lots stored out of doors were intermediate between the cold room lots and laboratory lots. Here again, as in tests on immature lots, the effects of seasonal changes in reducing the number of impermeable seeds is apparent. About

TABLE IX. *Effect of storage under various conditions on mature sweet clover seeds: All counts were made after 5 days in the germinator.* D = *in desiccator.*

Place stored	Scarified			Hulled			Unhulled		
	% Gm	% HS	% SS	% Gm	% HS	% SS	% Gm	% HS	% SS
Control........	93.00	2.50	4.50	63.00	33.00	4.00	13.50	86.50	0.00
Laboratory....	45.00	0.50	54.50	45.00	45.00	10.00	9.00	89.50	1.50
Lab., D........	45.00	0.50	54.50	44.00	46.00	10.00	15.00	84.00	1.00
Cold room.....	5.00	0.00	95.00	8.00	45.00	47.00	5.50	84.00	10.50
Cold room, D..	39.50	1.50	59.00	40.00	43.00	17.00	15.00	84.50	0.50
Out-of-doors...	28.00	0.00	72.00	39.00	12.50	48.50	38.50	52.50	9.00

the same percentage of impermeable seeds in the hulled commercial and the unhulled Grundy County samples softened.

General Discussion

The data presented have brought out a number of facts which seem to throw some light on the nature of the processes leading to the impermeable state in sweet clover seeds.

The desiccation studies, as well as the studies on immature and mature seeds held under different conditions of storage, indicate that the change from the permeable to the impermeable state takes place as a final step in the maturation of the seed. The experiments have shown that the assumption of the impermeable state can be prevented by storage in a cool, moist place, or brought about by storage in a dry place. Esdorm *(1)*, working with yellow lupine, found the same to hold true for these seeds. That immature seeds of Gymnocladus and of vetch have very few impermeable seeds and that the impermeable seed percentage is increased by dry storage has been shown by Raleigh *(7)* and by Jones *(5)*. The former worker found rather high percentages of pectic materials to be present in the seeds of *Gymnocladus dioica* and concluded that perhaps drying caused these to change to some resistant anhydride form. Jones states that with vetch, *Vicia villosa,* the impermeable condition is brought about by some dehydration process which operates independently of the plant. He finds that, if the drying is continued, these seeds finally become permeable again and that the presence of moisture increases the rate at which such seeds become permeable.

In the case of sweet clover, some such dehydration process probably takes place, but it does not seem likely that pectic materials alone are concerned although they seem to be present to some extent. With fully mature impermeable seeds neither continued drying nor high humidity seem to have any appreciable effect on permeability. When, however, immature seeds are rendered impermeable by drying they seem to be rather sensitive to changes in temperature and humidity. That immature impermeable seeds of certain of the Leguminosae become permeable in storage more rapidly than do mature impermeable seeds was shown by Harrington *(4)*. That the immature seeds stored in the cold room were only temporarily kept from hardening and that such seeds become impermeable after a short period of desiccation is a matter of interest. These facts seem to indicate that dehydration, possibly associated with an oxidative process, brings about an irreversible change in some material which is colloidal in nature.

The effects of various conditions of storage on mature commercial seeds are of considerable interest. It appears that storage in a dry situation is the best means of conserving the vitality of all such seeds whether scarified or not. The rapid loss of viability in scarified sweet clover seeds stored in a dry place is in line with the results obtained by Graber *(3)* for alfalfa, and by others *(6)* for sweet clover. That high humidity is especially detrimental to the viability of all the sweet clover seeds is also brought out. It is interesting to note that very few impermeable seeds become permeable in the cold room; while the natural variations in humidity and temperature to which all lots stored out-of-doors were subjected to, caused a considerable reduction of impermeable seeds.

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Summary and Conclusions

(1) Impermeability in sweet clover seeds is probably brought about by dehydration in the late stages of maturation.

(2) Slightly immature sweet clover seeds are practically all permeable and produce high percentages of germination.

(3) The impermeable state in such immature seeds can be induced by storage in a dry place. On the other hand, hardness may be prevented for at least 19 months by storage in a moist, cold room.

(4) Immature permeable seeds taken from the cold room and placed over calcium chloride for 7 days become impermeable.

(5) Storage for 16 months in a moist, cold room causes a notable reduction in the viability of permeable seeds. Storage under dry conditions for the same period of time had little effect on either the impermeability of hand-picked seeds or on their viability.

(6) The viability of scarified seeds was greatly reduced under all conditions of storage. Storage out-of-doors reduced the percentage of impermeable seeds in all mature and immature lots.

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PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN. XV.

POLYGONACEAE

KENNETH L. MAHONY

The station records used in this study were taken from the following herbaria: Northland College, the Milwaukee Public Museum, S. C. Wadmond, and the University of Wisconsin.

RUMEX

A. None of the leaves halberd-shaped or arrow-shaped; flowers perfect
- B. Valves entire or denticulate, 3–27 mm. broad
  - C. Grains of fruiting calyx none, or single and minute, not one-third as long as the valves: valves 5–7 mm. broad
    - D. One valve bearing a small grain or its midrib merely thickened at the base .... *R. Patientia*
    - D. Valve with its grain conspicuous, 2–3 mm. long .... *R. Patientia* var. *kurdicus*
  - C. Grains 1–3, well developed, mostly one-half to three-fourths as long as the valves; valves 1.5–6 mm. broad
    - E. Pedicels filiform, curved or flexuous
      - F. Leaves crisped on margin .... *R. crispus*
      - F. Leaves flat
        - G. Pedicels with tumid joints, rarely exceeding the coriaceous, greenish, straw-colored, or dull brown calyx
          - H. Valves 1.5–3.5 mm. broad, 2.5–5.5 mm. long; pedicels semi-nodding; grains on midrib usually three; stem usually much branched and only semi-ascending .... *R. mexicanus*
          - H. Valves 3–6 mm. broad, 3.5–8 mm. long; pedicels definitely nodding; grains on midrib usually one; stem not much branched and strictly ascending.................................... *R. altissimus*
        - G. Pedicels obscurely jointed, mostly exceeding the membranous finally purplish calyx
          - I. Grains three .... *R. Britannica*
          - I. Grains solitary .... [*R. occidentalis*] [1]

[1] Species in brackets are not represented in our collections from Wisconsin, but should be looked for, as they probably occur in the state.

E. Pedicels clavate, deflexed, straightish and slightly rigid, 2–3 times as long as the subacuminate valves.....*R. verticillatus*

B. Valves with long sharp salient teeth at least near the base

J. Perennial; valves ovate-halberd-shaped; the whorls of flowers loose and distant on the leafless spike .... *R. obtusifolius*

J. Annual; valves rhombic-oblong, lance-pointed; the whorls of flowers excessively crowded in leafy and compact spikes .... *R. maritimus* var. *fueginus*

A. Some or all of the leaves halberd-shaped; flowers dioecious

K. Valves much exceeding the fruit .... [*R. hastatulus*]

K. Fruit exserted from the minute scarcely changed calyx .... *R. Acetosella*

R. PATIENTIA L. (Fig. 1) seems to be almost confined to the western half of the state, but is found as far north as Bayfield County and as far south as Iowa, Dane, and Racine Counties. This plant is one that has been introduced into this country from Europe and should have a wide distribution in the state.

R. PATIENTIA L. var. KURDICUS Boiss. (Fig. 2) is also an introduced plant, but is represented in this study by only two specimens, one collected in each Trempealeau and Pepin Counties.

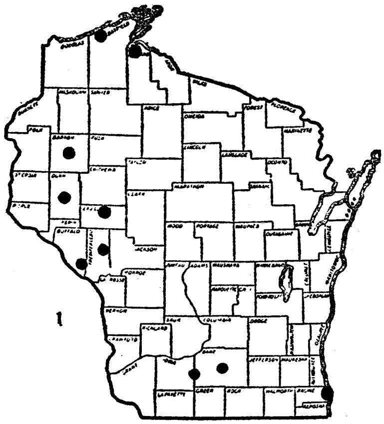
R. CRISPUS L. (including *R. elongatus* Guss.) (Fig. 3) is found over the entire state. Such a distribution is to be expected from an introduced plant.

R. MEXICANUS Meisn. (Fig. 4) is general over the state from north to south, but is found only in the western half of the state except for three stations, one in each, Milwaukee, Brown, and Ozaukee Counties.

The specimen from Ozaukee County was collected by the writer and was found growing along the harbor where Lake Michigan boats unload at Port Washington, and might possibly have been brought there in ballast. It is very evident from the distribution that this plant tends to avoid the Archean Rock region in Wisconsin.

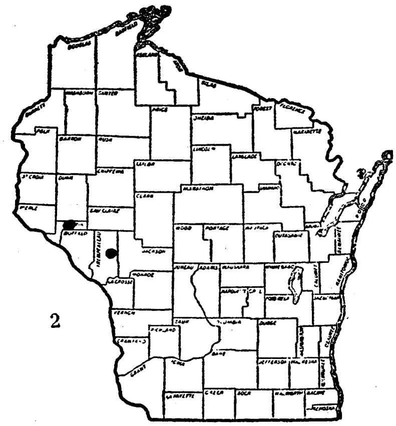
R. ALTISSIMUS Wood (Fig. 5). This species is general over the western and southern parts of the state.

R. BRITANNICA L. (Fig. 6) seems to be quite general over the glaciated portion of the state. It is often called the "great water dock", and as the name indicates it likes water or marshy



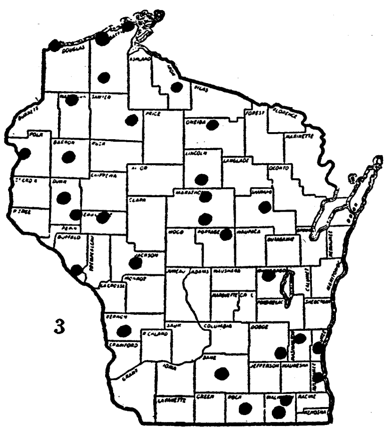
1

Rumex Patientia



2

Rumex Patientia
var. kurdicus



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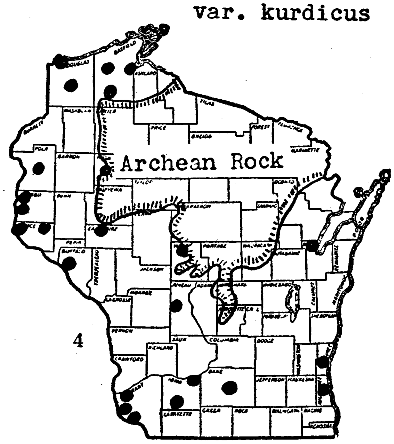
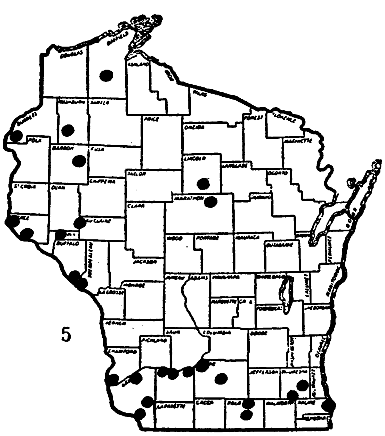
Rumex crispus



4

Rumex mexicanus



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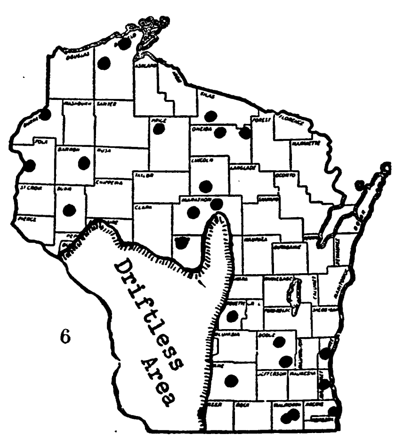
Rumex altissimus



6

Rumex Britannica

places. It is usually found in swamps and along margins of lakes and streams which are numerous in glaciated regions.

R. VERTICILLATUS L. (Fig. 7) is found north as far as Oneida County, and is especially abundant along the Mississippi river as far north as Pierce County.

R. OBTUSIFOLIUS L. (Fig. 8) is found at scattered stations ranging from the Apostle Islands south to Racine County, but seems to be absent in the northeast portion of the state. It has been naturalized from Europe and such a scattered distribution should be expected.

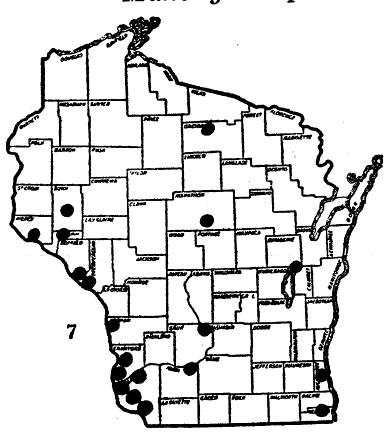
R. MARITIMUS L. var. FUEGINUS (Phil.) Dusen.; Rhodora vol. 17 : 73-83, 1915. *R. persicarioides* of Gray's Man. 7th ed. 357, 1908. Britton and Brown, Ill. Fl. 2nd ed.: 659, 1913; and recent American authors, not L. (Fig. 9). This is a plant that was found to be in the southeastern and northwestern portions of the state as far north as Superior.

Fernald writes of certain species of plants centering on the gulf of St. Lawrence, and then reappearing in the western United States.[2] The general range of *R. maritimus* var. *fueginus* in North America would suggest that it is such a species. It appears to be a preglacial plant that only persisted in the unglaciated areas and is now working back into its old range from the west and is coming into Wisconsin from the southwest, or it may have persisted in these scattered areas in Wisconsin and is now gradually working its way westward.

At practically every station in Wisconsin this plant has been collected in a region of newly formed soil, for example: along the Mississippi river the plant is found growing between wing dams on the river; in Dodge County the station is at Horicon Marsh, which is a drained lake. One station in central Dane County is an abandoned beach of Lake Mendota near Pheasant Branch; the other, in the southeastern part of the county is at Rice Lake, an intermittent lake; also the station in Polk County is on an intermittent lake.

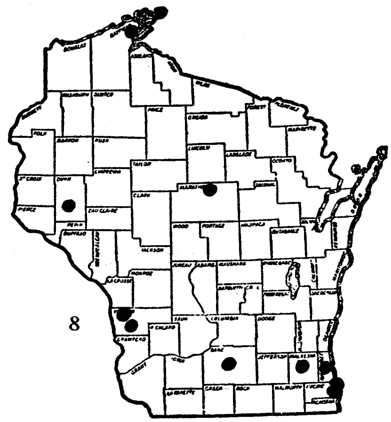
R. ACETOSELLA L. (Fig. 10) is very general and probably can be found in every county of the state. This is another Rumex that has been introduced from Europe and such a distribution is expected.

[2] Mem. Am. Acad. of Arts and Sci., vol. 15, no. 3. 1925.



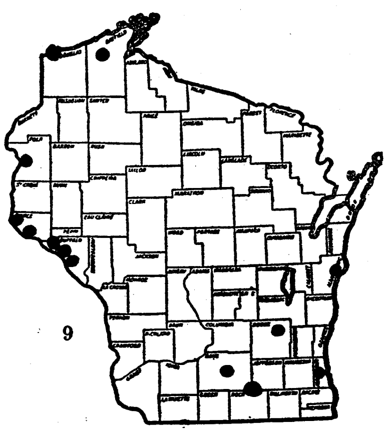
7

Rumex verticillatus



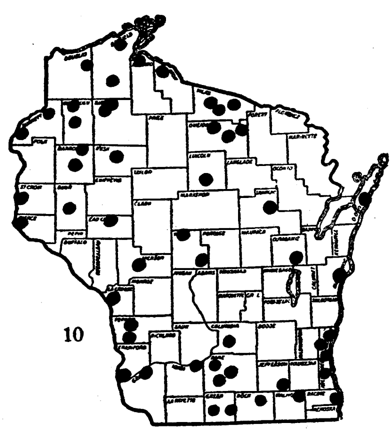
8

Rumex obtusifolius



9

Rumex maritimus var. fueginus



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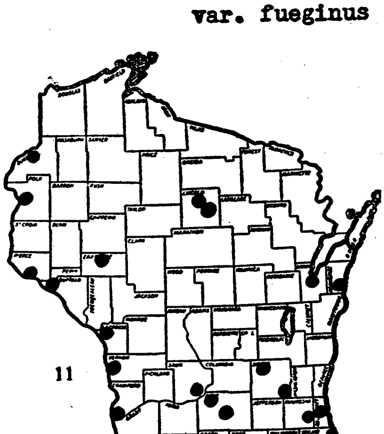
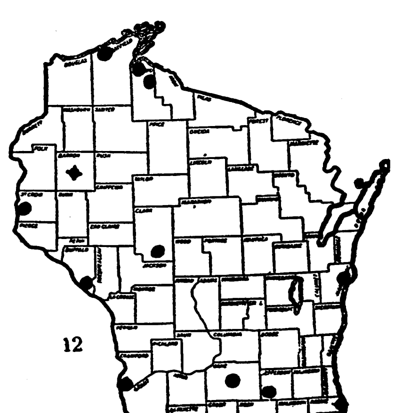
Rumex Acetosella



11

Polygonum aviculare



12

● Polygonum aviculare var. angustissimum

+ Polygonum aviculare var. crassifolium

POLYGONUM

A. Leaf-blades ovate to lanceolate, tapered at base to the petiole
  B. Flowers in axillary fascicles, or spicate with foliaceous bracts..... .... Subgenus *Avicularia*
    C. Achenes conspicuously exserted .... *P. exsertum*
    C. Achenes nearly or quite included in fruiting calyx
      D. Branches terete or nearly so
        E. Pedicels included; sepals usually white or bluish-green, 1.3–1.8 mm. long
          F. Stems prostrate or nearly so
            G. Leaves thick and broadly spatulate .... *P. aviculare* var. *crassifolium*
            G. Leaves neither thick nor broadly spatulate
              H. Leaves lanceolate, 6–20 mm. long..*P. aviculare*
              H. Leaves thin and linear, 5–9 times as long as broad .... *P. aviculare* var. *angustissimum*
          F. Stems erect or nearly so ... P. *aviculare* var. *vegetum*
        E. Pedicels exserted; sepals yellowish-green, bluish-green, greenish, yellow, pink or roseate, often 2–3 mm. long
          I. Leaves elliptical
            J. Leaves yellowish-green, obtuse .... *P. erectum*
            J. Leaves bluish-green, very rounded at the tips .... *P. achoreum*
          I. Leaves lanceolate
            K. Flowers greenish, yellow, or pink .... *P. ramosissimum*
            K. Flowers roseate .... *P. ramosissimum* f. *atlanticum*
      D. Branches rather sharply angled
        L. Leaves strongly pilcate; flowers erect .... *P. tenue*
        L. Leaves flat, with revolute margins; flowers nodding .... [*P. Douglasii*]
  B. Flowers not in axillary fascicles, but spicate without foliaceous bracts
    M. Flowers in dense spikes, with small scarious bracts; styles not deflexed in fruit and not hooked .... Subgenus *Persicaria*
      N. Sheaths nearly or quite free from ciliation
        O. Annual; achene compressed; plants with a branched fibrous root system
          P. Peduncle not glandular; achenes 1–2 mm. broad
            Q. Under surface of leaves glabrous .... *P. lapathifolium*
            Q. Under surface of leaves tomentose, at least the lower ones ..... *P. lapathifolium* var. *salicifolium*

P. Peduncle glandular; achenes 2–3 mm. broad

R. Under surface of leaves tomentose, at least the lower leaves .... *P. scabrum*

R. Under surface of leaves not tomentose

S. Glands of hairs on peduncle with red pigment.. .... *P. pennsylvanicum* var. *laevigatum*

S. Glands of hairs on peduncle without red pigment *P. pennsylvanicum* var. *laevigatum* f. *pallescens*

O. Perennial; achene compressed or turgid; plants with floating or creeping, subligneous rhizomes

T. Peduncle glabrous; panicle ovoid, 1–5 cm. long

U. Aquatic form; stems floating or somewhat emersed; leaves glabrous; sheaths without herbaceous margin .... *P. natans* f. *genuinum*

U. Terrestrial form; stems upright and leafy; leaves more or less hairy; sheaths with herbaceous margin .... *P. natans* f. *Hartwrightii*

T. Peduncles pubescent; panicle dense, cylindric, 3–10 cm. long

V. Aquatic form; stem floating or somewhat emersed; leaves glabrous .... [*P. coccineum* f. *natans*]

V. Terrestrial form; stems upright and leafy; leaves more or less hairy ......*P. coccineum* f. *terrestre*

N. Sheaths bristly-ciliate

W. Stems and peduncles glandular-hispid .... *P. Careyi*

W. Stems and peduncles not glandular-hispid

X. Sepals dotted with dark glands

Y. Achenes dull and pitted

Z. Pedicels not strongly exserted from the ocreolae; achenes mostly 3–3.5 mm. long..*P. Hydropiper*

Z. Pedicels strongly exserted from the ocreolae; achenes mostly 2–2.5 mm. long .... *P. Hydropiper* var. *projectum*

Y. Achene shining and smooth

a. Stems 0.6–1.6 m. high; leaves lanceolate, attenuate, 7–12 cm. long, taper-pointed .... *P. punctatum*

a. Stems 3–6 dm. high; leaves lanceolate, smaller, thinner, and lighter green than in the type.... .... *P. punctatum* var. *leptostachyum*

X. Sepals not dark-dotted

b. Stems hairy .... *P. orientale*

b. Stems not hairy

c. Flowers in erect, or short-cylindrical, densely flowered spikes 0.5–2.75 cm. long. . *P. Persicaria*

c. Flowers in erect slender loosely flowered often interrupted spikes 3–6 cm. long . . . . *P. hydropiperoides*

M. Flowers in loose naked long and slender spikes with no small scarious bracts; styles deflexed in fruit and hooked . . . . Subgenus *Tovara* . . . . . . *P. virginianum*

A. Leaf-blades sagittate to heart shaped, or round-ovate, truncate or cordate at the base

d. Stems armed with reflexed prickles on angles . . . . Subgenus *Echinocaulon*

e. Leaves halberd-shaped . . . . *P. arifolium*

e. Leaves arrow-shaped . . . . *P. sagittatum*

d. Stems not armed with reflexed prickles

f. Stems twining and slender . . . . Subgenus *Tiniaria*

g. Achenes minutely roughened, dull, black . . . . . . *P. Convolvulus*

g. Achenes smooth, shining, black

h. Sheaths fringed at base with reflexed bristles. . . . *P. cilinode*

h. Sheaths not fringed at the base with reflexed bristles . . . . *P. scandens*

f. Stems erect and stout. . . Subgenus *Pleuropterus*. . . *P. cuspidatum*

The subgenus *Avicularia* Meisn. is represented in Wisconsin by six species. This subgenus contains plants that are classed as European, Asiatic, road side, and prairie plants. They are a very aggressive group of plants and present many taxonomic problems.

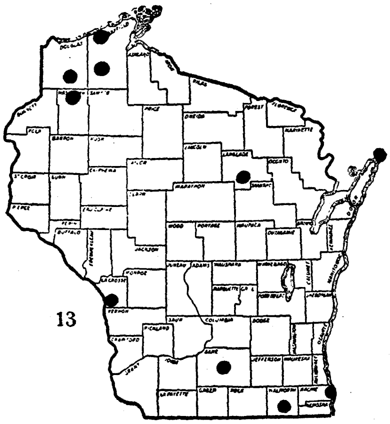
P. EXSERTUM Small is represented in this study by only one collection. The plant was collected by J. H. Schuette, in 1881, and the station is recorded as the Fox River valley.

P. AVICULARE L. (Fig. 11). This plant seems to have a scattered distribution around the margins of the state. Very few collections have been made from the central part of the state.

P. AVICULARE L. var. ANGUSTISSIMUM Meisn. (Fig. 12) also seems to be confined to the margins of the state.

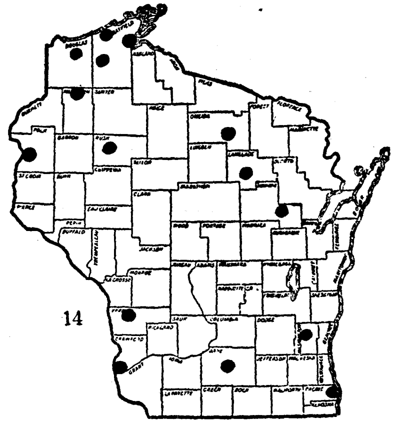
P. AVICULARE L. var. CRASSIFOLIUM Lange; House, N. Y. State Mus. Bull. 254 : 291, 1924. P. *aviculare* var. *littorale* of Gray's Manual, 7th ed. (Fig. 12). Represented in Wisconsin by only two collections.

P. AVICULARE L. var. VEGETUM Ledeb. (Fig. 13). This plant is scattered widely over the state.



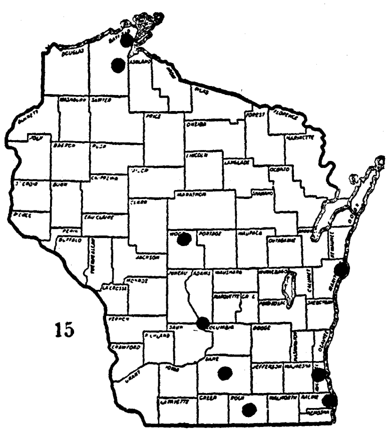
13

Polygonum aviculare
var. vegetum



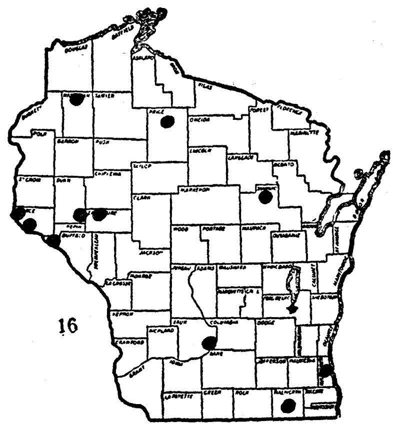
14

Polygonum achoreum



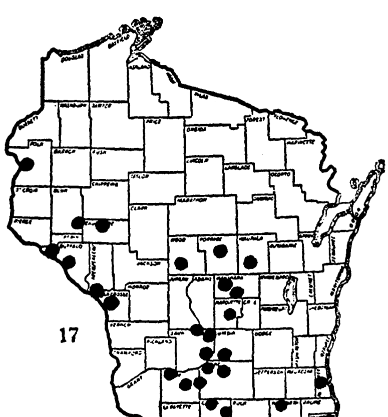
15

Polygonum erectum



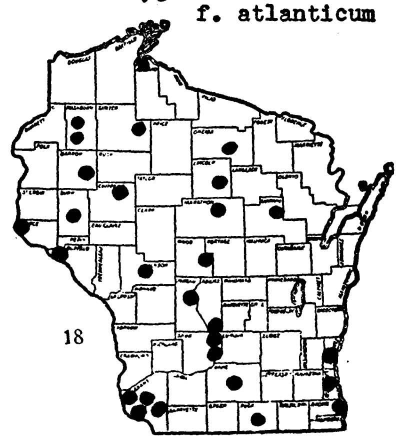
16

• Polygonum ramosissimum
+ Polygonum ramosissimum
f. atlanticum



17

Polygonum tenue



18

Polygonum pennsylvanicum
var. laevigatum

P. ACHOREUM Blake, Rhodora 19 : 232, 1917, (Fig. 14) is of a widespread distribution in Wisconsin.

P. ERECTUM L. (Fig. 15). This plant has been collected in the north, central, eastern and southern parts of the state, but no collections have been made from the western part.

P. RAMOSISSIMUM Michx. (Fig. 16). This plant is also of a general widespread distribution over the state. It has been collected in Minnesota opposite Alma, Wisconsin; and should be found in this state on the sands of the Mississippi river.

P. RAMOSISSIMUM Michx. f. ATLANTICUM Robinson, Rhodora 4 : 72, 1902 (Fig. 16). We have only one collection of this in the state, from the south end of Lake Winnebago.

P. TENUE Michx. (Fig. 17) is restricted to the southern half of the state. It has been collected as far north as Polk County but the major part of the collections have been made along the Wisconsin river south of Marathon County.

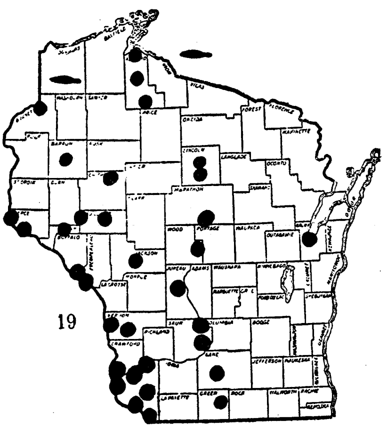
Subgenus *Persicaria* (Tourn.) L. has by far a larger representation in Wisconsin than any of the other subgenera. There are eleven species of this subgenus found in Wisconsin and numerous varieties and forms.

This subgenus like the *Avicularia* group contains European, Asiatic, road side and prairie plants. They are weedy aggressive plants and present many taxonomic problems.

P. PENNSYLVANICUM L. var. LAEVIGATUM Fernald, Rhodora 19 : 73, 1917. (Fig. 18). Of general distribution over the state, being found largely on the rivers and lakes. It appears to be less common in the Mississippi river bottoms than the form.

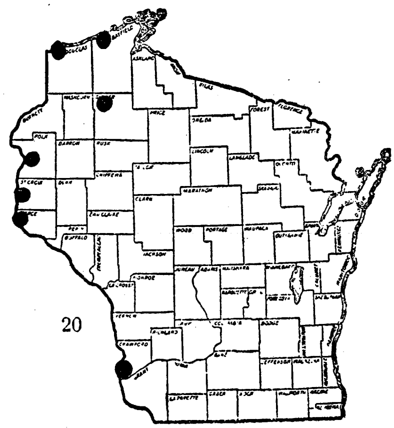
P. PENNSYLVANICUM L. var. LAEVIGATUM Fernald f. PALLESCENS Stanford, Rhodora 27 : 180, 1925. (Fig. 19). This plant is confined to the western half of the state except for one collection made near Green Bay in Brown County.

P. SCABRUM Moench. (*P. tomentosum* Schrank) (Fig. 20). For a complete synomymy see Rhodora 23 : 259, 1921. We have only a few collections of this plant from the state, and with one exception all have been collected from the northwestern part of the state.



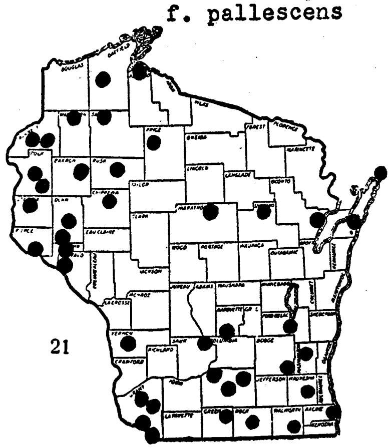
19

Polygonum pennsylvanicum
var. laevigatum
f. pallescens



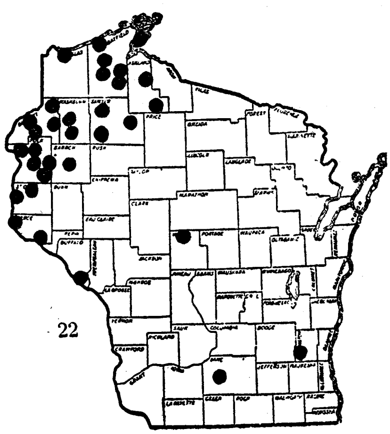
20

Polygonum scabrum



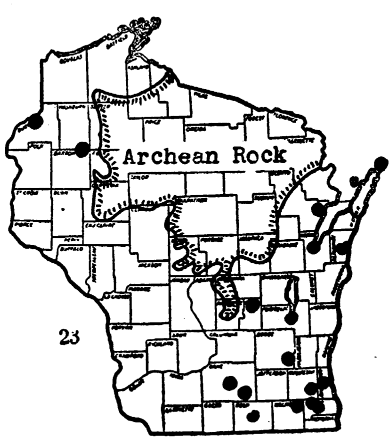
21

Polygonum lapathifolium



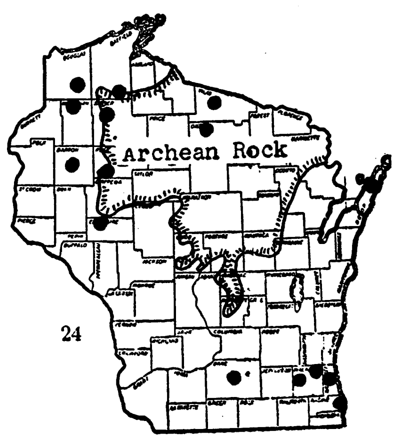
22

Polygonum lapathifolium
var. salicifolium



23

Polygonum natans
f. Hartwrightii



24

Polygonum natans
f. genuinum

P. LAPATHIFOLIUM L. (Fig. 21). This plant is of a general distribution over the state.

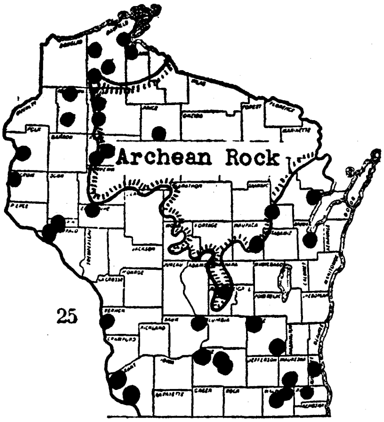
P. LAPATHIFOLIUM L. var. SALICIFOLIUM Sibth.; Wiegand and Eames, Cornell Univ. Agr. Exp. Stat. Memoir 92 : 190, 1926 (Fig. 22). This plant is largely confined to the northwestern corner of the state. However, we have one specimen that was collected near Verona in Dane County and another that was collected by the writer on a dam built along the Rubicon river at Hartford, in Washington County.

P. NATANS A. Eaton f. HARTWRIGHTII (Gray) Stanford, Rhodora 27 : 160, 1925. (*P. amphibium* Small var. *Hartwrightii* (Gray) Bissell of Gray's Manual, 7th ed.) (Fig. 23). Most of the collections of this plant have been made in the southeastern part of the state, however, we do have two stations in the northeastern part of the state.

P. NATANS A. Eaton f. GENUINUM Stanford; for complete synonymy see Rhodora 27 : 159, 1925. (The floating form of *P. amphibium* Small of Gray's Manual, 7th ed.) (Fig. 24). This plant has been found in the northwestern and southeastern part of the state.

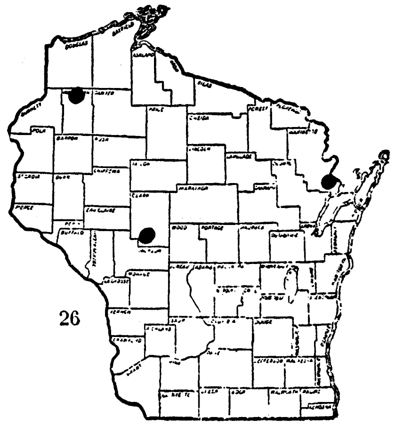
P. COCCINEUM Muhl., f. TERRESTRE (Willd.) Stanford; for complete synonymy see Rhodora 27 : 163, 1925. (*P. Muhlenbergii* (Meisn.) Wats. of Gray's Manual, 7th ed.) (Fig. 25). This plant is found over the northwestern and southeastern part of the state.

During the late spring of 1930 the writer gathered from beside a railroad track at Madison, Wisconsin a few living specimens of *Polygonum natans* f. *Hartwrightii* and transferred them to the University green house. They were planted in a tank and the water level kept at a mark which allowed the plants to be completely submerged. At first the leaves came off and roots developed at the nodes of the upright stems, but soon the whole aerial part of the plants turned brown and apparently died. About the first of May 1931 new green branches developed from these old branches of the year before. This time the leaves borne had all of the characteristics of the *Polygonum natans* f. *genuinum.* These results are similar to those obtained by other men working with the same plants. However, during the summer months the plants grew so much that



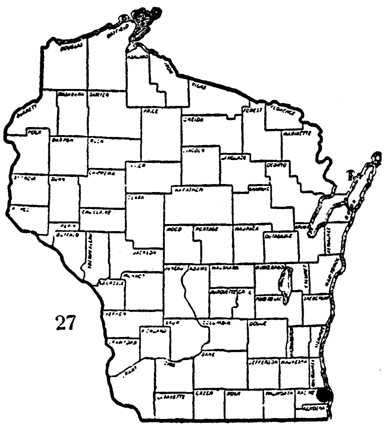
25

Polygonum coccineum
var. terrestre



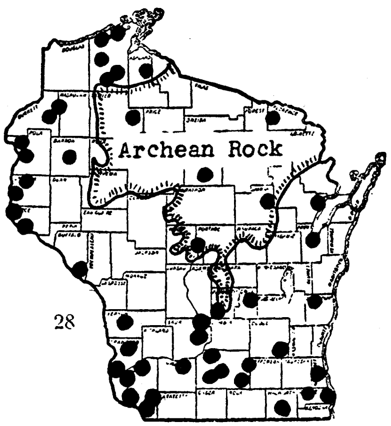
26

Polygonum Careyi



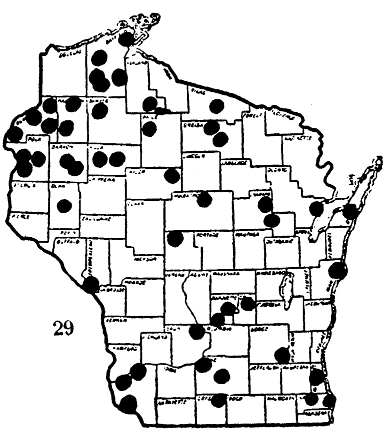
27

Polygonum Hydropiper



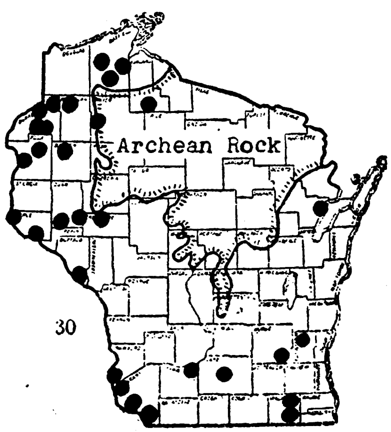
28

Polygonum Hydropiper
var. projectum



29

Polygonum punctatum



30

Polygonum punctatum
var. leptostachyum

it was impossible to keep the plants entirely submerged. As a result they grew several inches above the surface of the water. The leaves produced above the water were not like those of the submerged form, but were typical of the *P. natans* f. *Hartwrightii.* By September the submerged and floating leaves had all died and the plant gave the appearance of being the land form.

P. natans f. *genuinum, P. natans* f. *Hartwrightii* and *P. coccineum* f. *terrestre* seem to avoid the region of the Archean Rock. The rocks here are largely granite, and are covered over to various depths by glacial deposits. However, this granite rock formation tends to make most of the lakes of an acid nature. These two species seem to frequent the lake regions but apparently avoid these acid lakes.

We have two collections of *P. natans* f. *genuinum* from northern Wisconsin, one from each, Vilas and Oneida Counties. Their presence here may be due to the fact that these two lakes through some factor have had their acid nature neutralized and have become favorable for the growth of this species.[3]

There are other species of the *Polygonaceae,* for instance *Rumex mexicanus, Polygonum punctatum* var. *leptostachyum, P. Hydropiper* var. *projectum* and *P. Persicaria* that tend to stay out of this Archean Rock region. One can hardly say that it is this granite rock below these glacial deposits that is the factor in the distribution of these plants, although it may play quite an influential part.

P. CAREYI Olney (Fig. 26). We have only three collections of this in the state.

P. HYDROPIPER L. (Fig. 27). We have only one collection of this taken from Racine County. According to Stanford this is a plant that has been introduced from Europe.

P. HYDROPIPER L. var. PROJECTUM Stanford, Rhodora 29 : 86, 1927. (Fig. 28). This plant is of a scattered distribution over the state, and is according to Stanford native.

P. PUNCTATUM Ell. (*P. acre* HBK. in Gray's Manual 7th ed.) For a complete synonymy see Rhodora 29 : 77, 1927 (Fig. 29). Of a general distribution, but most of the collections seem to have been made in the northern half of the state.

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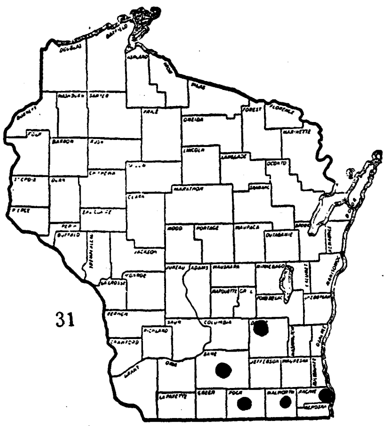
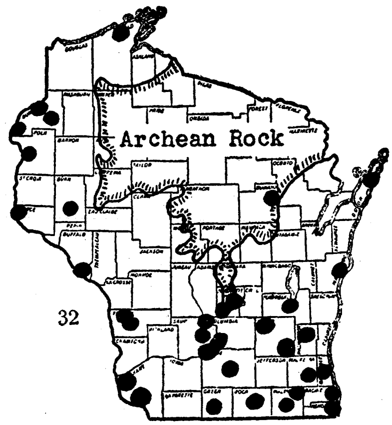
[3] Fassett, N. C. Trans. Wis. Acad. 25 : 167, 1930.



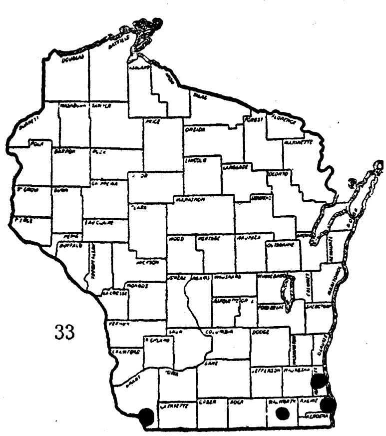
31

Polygonum orientale



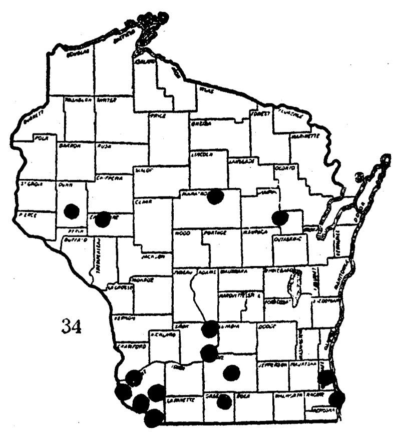
32

Polygonum Persicaria



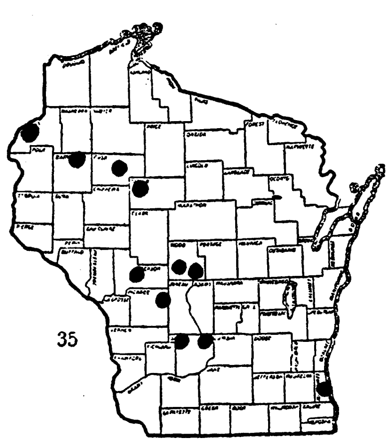
33

Polygonum hydropiperoides



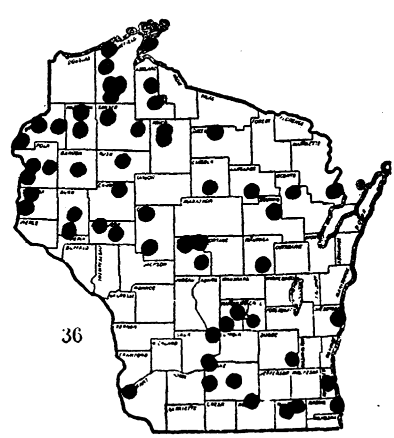
34

Polygonum virginianum



35

Polygonum arifolium



36

Polygonum sagittatum

P. PUNCTATUM Ell. var. LEPTOSTACHYUM (Meisn.) Small, (*P. acre* HBK. var. *leptostachyum* Meisn. in Gray's Manual 7th ed.) (Fig. 30) is most common along the Mississippi and St. Croix river valleys and in southern Wisconsin.

P. punctatum and *P. punctatum* var. *leptostachyum* are sometimes very hard to distinguish and an accurate separation when using herbarium sheets is almost impossible; although when found growing together the two plants are sometimes quite distinct.

P. ORIENTALE L. (Fig. 31) is a plant that has escaped from gardens and has been collected in the southeastern part of the state.

P. PERSICARIA L. (Fig. 32). This plant seems to follow the Mississippi and St. Croix river valleys on the west, Lake Michigan shore line on the east, and is very abundant in the southern part of the state. This plant is an introduced species and we should expect a scattered distribution.

P. HYDROPIPEROIDES Michx. (Fig. 33). Only four collections have been made in the state.

Subgenus *Tovara* (Adans.) Gray consists of only one species which has a rather restricted distribution. It is found in the eastern part of North America and the eastern part of Asia.

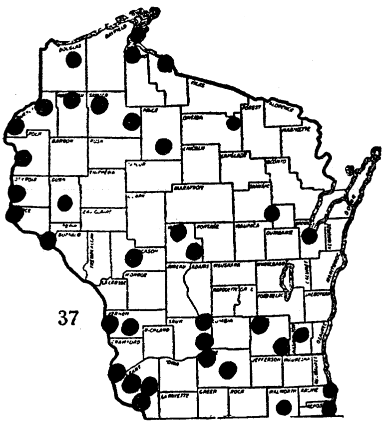
P. VIRGINIANUM L. (Fig. 34). This plant has not been collected many times in the state, but those collections with a very few exceptions have been made along the river valleys and Lake Michigan shore line.

Sub genus *Echinocaulon* Meisn. has two species and both are represented in Wisconsin. The plants of this subgenus, like that of *Tovara,* have a distribution in eastern North America and eastern Asia.

P. ARIFOLIUM L. (Fig. 35). This species seems to be found largely in the southwestern half of the state.

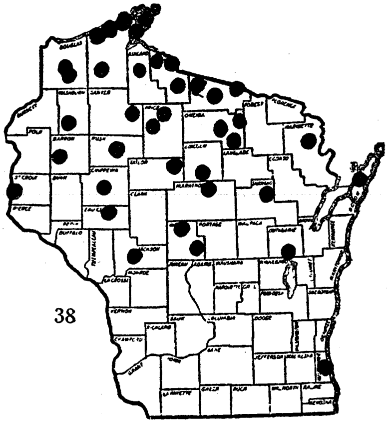
P. SAGITTATUM L. (Fig. 36) is a very common plant in Wisconsin. It seems probable that it might be collected from every county in the state.

A green flowered form of this species has been described, f. *chloranthum* Fernald. N. C. Fassett says: "Although this is usually an estuarine form, green-flowered plants may occur



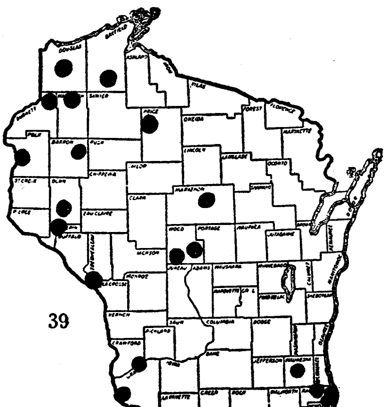
37

Polygonum Convolvulus



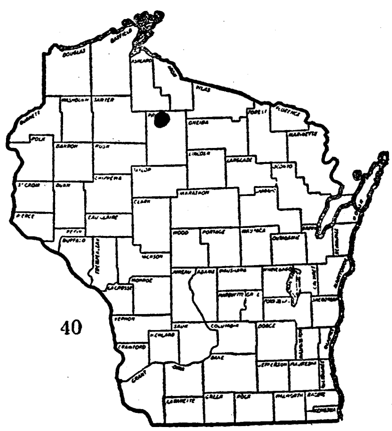
38

Polygonum cilinode



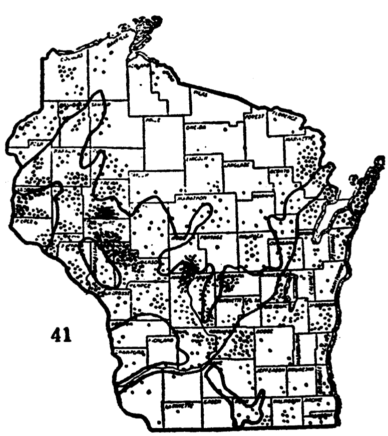
39

Polygonum scandens



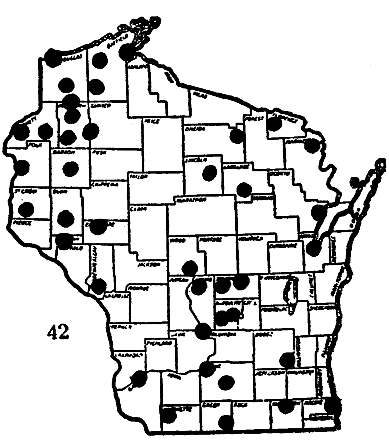
40

Polygonum cuspidatum



41

Fagopyrum esculentum



42

Polygonella articulata

elsewhere; I have found them in damp places at Ocean Point, Maine, and in some parts of northern Wisconsin. These specimens lack the habit which is ordinarily characteristic of this form, and which is probably a direct result of frequent submergence, for the estuarine plant has not only the green flowers indicated by the name, but slender stems and weak prickles."[4]

Of the abundant material collected in Wisconsin that I have worked with, I have been unable to find any specimens that could be called f. *chloranthum,* although the flower coloring may be white, pink or greenish.

Subgenus *Tiniaria* Meisn. consists of four species, three of which are found in Wisconsin.

P. CONVOLVULUS L. (Fig. 37) is of a general distribution in Wisconsin. This plant has been introduced from Europe.

P. CILINODE Michx. (Fig. 38) is restricted to the northern half of the state.

P. SCANDENS L. (Fig. 39). This plant seems to have quite a general distribution in the state except for the extreme northeast. I believe the plant to be more common in Wisconsin, however, than the collections show.

Subgenus *Pleuropterus* (Turcz.) B. & H. consists of one species.

P. CUSPIDATUM Sieb. & Zucc. (Fig. 40). Only one specimen from Wisconsin was found. This plant is often cultivated in gardens and this one specimen might be from a plant that had escaped from a nearby garden.

FAGOPYRUM

This genus is represented in Wisconsin by one cultivated species, the common buckwheat.

F. ESCULENTUM Moench. (Fig. 41). This plant being a cultivated plant and of some economic value in the state, has been mapped by the State Department of Agriculture,[5] and the map in this study was taken from that publication and is as near an exact copy as was possible to make. The original map showed the farms over the state where buckwheat was grown.

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[4] Fassett, N. C. Proc. Bost. Soc. Nat. Hist. 39 : 107, 1928.

[5] Wis. St. Dept. of Agr. Statistical Atlas of Wis. Agr., p. 49, 1926-1927.

As is evident from the map, the buckwheat region follows closely the St. Croixan Sandstone area which is outlined on the map.

POLYGONELLA

This genus is composed of two species, one of which is found in Wisconsin.

P. ARTICULATA (L.) Meisn. (Fig. 42). This plant is quite common in sandy areas over the state and seems to be particularly abundant in the northwestern part of the state.

PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN. XVI.

XYRIDALES

NORMAN C. FASSETT

This report, and the four following it, are based on specimens in the herbaria of the Milwaukee Public Museum, Northland College, Mr. S. C. Wadmond, and the University of Wisconsin. The courtesies and cooperation of Mr. Smith and Mr. Fuller, of Professor Bobb, and of Mr. Wadmond, are gratefully acknowledged.

ERIOCAULACEAE—PIPEWORT FAMILY

ERIOCAULON SEPTANGULARE With. *E. articulatum* Morong. (Fig. 1). Usually found on the sandy or slightly peaty pond-margins of northern Wisconsin. The circle in Trempeauleau County represents an oral report from Mr. F. M. Uhler. A sheet in the University herbarium bears the data: "Shebogen Co., Wisconsin. McM."; there is a pencilled comment by J. R. Heddle: [= Sheboygen Co. "McM." = ? J. F. McMullen.] I have seen no other material from the eastern counties.

XYRIDACEAE—YELLOW-EYED GRASS FAMILY

XYRIS MONTANA Ries. (Fig. 2, cross). Collected on July 23, 1896, on Lake Superior between Trout Stream and Long Island, by L. S. Cheney. This is either in Iron County or in Ashland County.

X. TORTA J. E. Smith. *X. flexuosa* Muhl. (Fig. 2, dots). In northwestern Wisconsin, definitely associated with small bodies of water which are relicts of an almost extinct lake dating back to early post-Wisconsin times[1]; in south-central Wisconsin probably related to similar lakes. A more detailed discussion of this and other like ranges is in preparation by Dr. W. T. McLaughlin.

[1] See Aldrich & Fassett, Science 70 : 45-46. 1929.

COMMELINACEAE—SPIDERWORT FAMILY

TRADESCANTIA REFLEXA Raf. Spiderwort (Fig. 3). Wadmond[2] reports this (as *T. Virginiana*) as "common; along railroad tracks, borders of woods, roadsides" in Racine and Kenosha Counties. Throughout much of southern Wisconsin it is abundant on sand plains. Its range is quite typical of the prairie plants in the state; it is abundant across southern Wisconsin, but is not common in the interior of the Driftless Area except along the sand plains of the Mississippi and Wisconsin Rivers and of the old Lake Wisconsin bed, and adventive in the north after the forests have been cut from the sand barrens.

A specimen from Muscoda, with rose-colored petals, is probably to be referred to f. LESTERI Standley, Rhodora 32 : 32. 1930. Forma ALBIFLORA Slavin & Nieuwland, Am. Midland Nat. 11 : 600. 1929 has been collected at Boscobel, Spring Green, Sparta, Fontana and Trempealeau.

T. OCCIDENTALIS (Britton) Smythe (Fig. 4). Sand plains along our western borders on the Mississippi and St. Croix Rivers; adventive on the railroad tracks at Avoca, Iowa County. Our specimens are very variable as to width of bracts and denseness of pubescence; some of them may be referable to *T. bracteata* Small, if indeed *T. occidentalis* and *T. bracteata* are distinct species. Our material has the capsules glabrous except at summit, which would, according to the key in Rydberg's Rocky Mountain Flora, exclude them from both of these species.

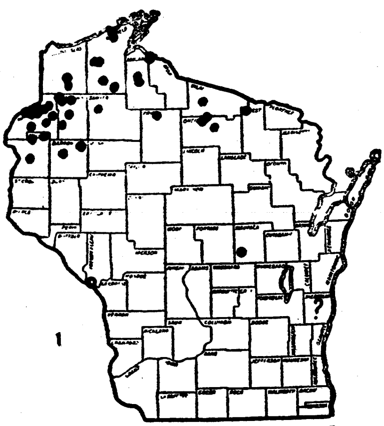
COMMELINA COMMUNIS L. Along roadsides in settlements, escaping from cultivation; Eau Claire, Pepin, Buffalo and Dane Counties.

C. ERECTA L. A narrow-leaved plant, collected at Boscobel in 1884, is apparently this species. It is without doubt a garden escape, and has probably not persisted.

PONTEDERIACEAE—PICKEREL-WEED FAMILY

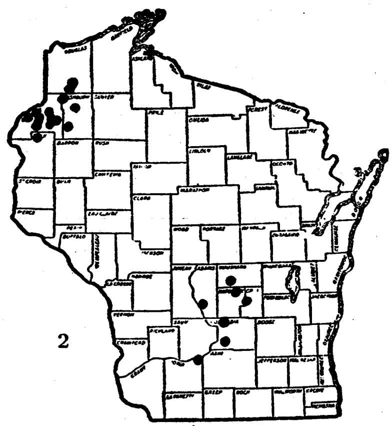
PONTEDERIA CORDATA L. Pickerel-weed (Fig. 5, dots). Occasional throughout the state; least common in the Driftless Area, where it is occasionally found along the Mississippi River. Forma LATIFOLIA (Raf.) House, N. Y. State Mus. Bul. 243-

[2] Trans. Wis. Acad. 16 : 819. 1909.



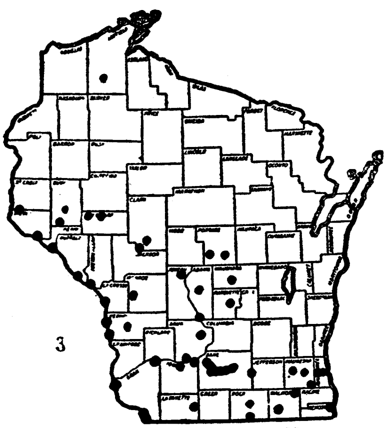
1

Eriocaulon septangulare



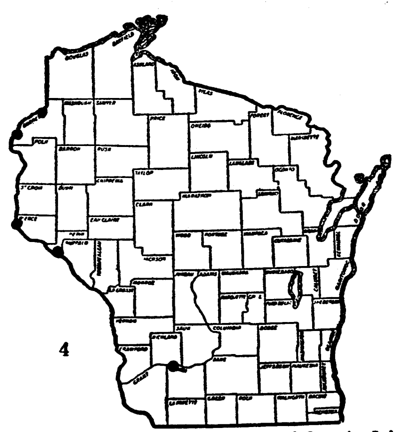
2

✚ Xyris montana
● X. torta



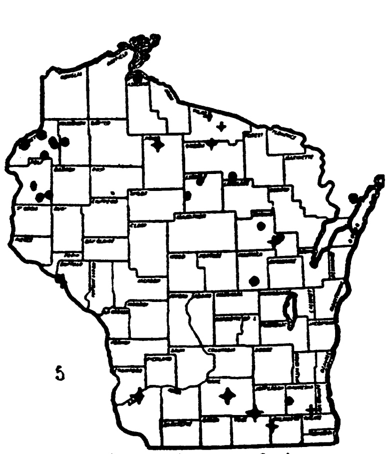
3

Tradescantia reflexa



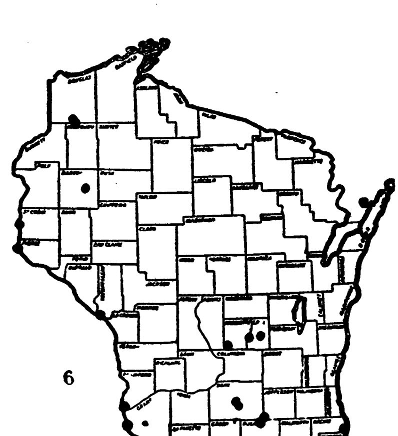
4

Tradescantia occidentalis



5

● Pontederia cordata
✚ P cordata, f. latifolia



6

Heteranthera dubia

244 : 62. 1923, is also common in the state; it has the sides of the leaf-blade rounded, instead of essentially straight as in typical *P. cordata.* Forma *angustifolia* (Pursh) House, *l. c.*, does not seem to have been collected in the state. The albino, f. ALBIFLORA (Raf.) House, *l. c.*, has been orally reported to the writer by Mr. J. A. Moore of the Missouri Botanical Garden, as having been seen in Vilas County.

HETERANTHERA DUBIA (Jacq.) MacM. (Fig. 6). Across the southern third of the state, and up the Mississippi River and its tributaries. Although we have but four collections from the Mississippi River, the plant is very common in that region; the true condition would probably be represented by a solid line following that river in Fig. 6.

PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN. XVII.

MYRICACEAE; JUGLANDACEAE

NORMAN C. FASSETT

MYRICACEAE—SWEET GALE FAMILY

MYRICA GALE L. Sweet Gale (Fig. 1, dots). Swales and wet shores, northern Wisconsin, south to Manitowoc County.

M. GALE, var. SUBGLABRA (Chevalier) Fernald, Rhodora 16 : 167. 1914. (Fig. 2, crosses). This variety, distinguished by its glabrous or glabrate lower leaf-surfaces, is said by Fernald to replace the type in some areas. In Wisconsin it seems to be much less common than typical *M. Gale.*

M. ASPLENIFOLIA L. Sweet Fern (Fig. 2). Common in the sandy and granitic areas of the state, and mostly absent from the areas of limestone. But, like some of the Ericaceae[1], it occurs about Green Bay, where the underlying rock is limy.

JUGLANDACEAE—WALNUT FAMILY

The four maps here presented are based on the unpublished studies of Mr. L. S. Cheney, as were those of other groups of trees previously published in this series. Localities represented by herbarium specimens are indicated by large dots, being shown only when they show the presence of the species where it was not recorded by Cheney.

1. JUGLANS—Walnut

1. J. CINEREA L. Butternut (Fig. 3). Cheney writes, "*Juglans cinerea* chooses a rich moist soil; it is therefore found growing on low rocky hillsides, near the banks of streams, and on alluvial lands, in the company of the black walnut, red oak, white oak, bitternut and hackberry."

2. J. NIGRA L. Black Walnut (Fig. 4; the crosses indicate planted trees). "In Wisconsin, the tree is occasionally met

[1] See Trans. Wis. Acad. 24 : 258. 1929.

with in the wild state in all of the two southern tiers of counties and in all counties fronting on the Mississippi River, north to the St. Croix River; from Vernon County northward it is confined to the immediate neighborhood of the Mississippi River or its largest tributaries. This tree chooses rich alluvial bottom-lands or rich hillsides as its natural habitat." We have a number of cases of southern plants which follow up the Mississippi River in this manner; see, for example, *Juniperus virginiana*[2], *Anemone patens* var. *Wolfgangiana*[3], and *Anemonella thalictriodes*[3].

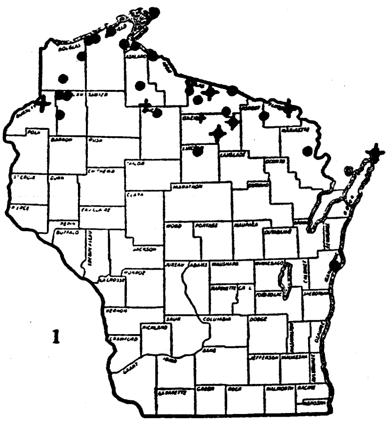
2. CARYA—Hickory

We have, apparently, but two native hickories common in the state. These are *C. ovata* and *C. cordiformis*. They are listed by S. C. Wadmond[4] (as *C. alba* and *C. amara*) as being common in Racine and Kenosha Counties. Russel[5] lists both from Milwaukee County, adding *C. glabra* as reported from Wauwatosa, where probably planted. Cheney and True[6] list *C. alba* and *C. amara* from the Madison area. In his notes, Cheney lists besides these *"Hicoria glabra odorata"*, of which he says a single tree grows near the edge of Lake Monona in the suburb of Elmside, Madison. This, according to Professor R. H. Denniston, was a large tree, perhaps old enough to antedate the settling of the city, and probably of natural occurrence. It did not satisfactarily fit descriptions of *C. glabra*, and was possibly of hybrid origin. Professor Denniston and the writer were unable to find the tree on October 9, 1931; it has apparently been cut. Dr. Denniston speaks of having seen the tree as recently as within the last ten years. Cheney's notes are fully thirty years old.

Mr. S. C. Wadmond has collected *C. glabra* in Delavan, where it is a shade tree in the city.

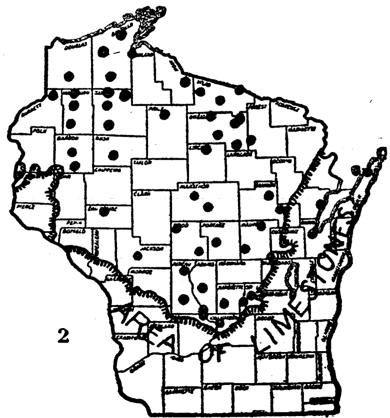
With but two common species, our hickories are easily distinguished. *C. ovata* may be recognized by the tuft of white hairs on each tooth on the leaflets, and *C. cordiformis* by its yellow buds.

[2] Trans. Wis. Acad. 25 : 180. 1930.
[3] *Ibid.* 207.
[4] *Ibid.* 16 : 825. 1909.
[5] Bull. Wis. Nat. Hist. Soc. 5 : 186. 1907.
[6] Trans. Wis. Acad. 9 : 98. 1892.



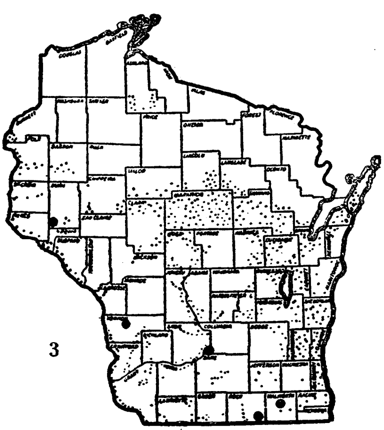
1

● Myrica Gale
+ M. Gale, var. subglabra



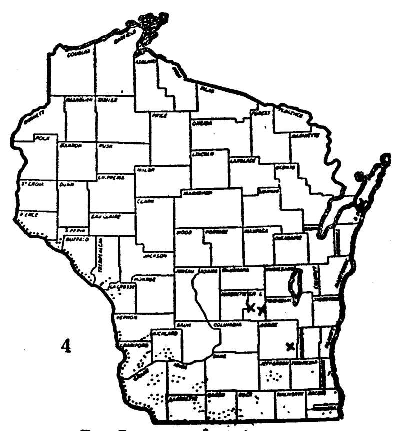
2

Myrica asplenifolia



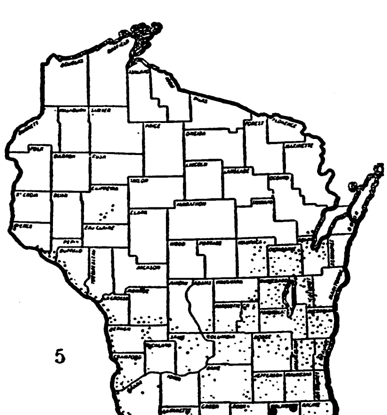
3

Juglans cinerea



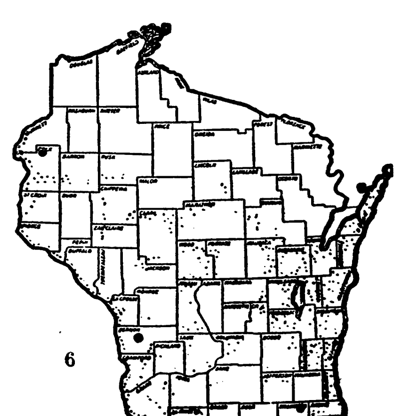
4

Juglans nigra



5

Carya ovata



6

Carya cordiformis

1. C. OVATA (Mill.) K. Koch. Shag-bark Hickory (Fig. 5). "This hickory is usually found growing on low hills or in the vicinity of streams and swamps, in rather deep, rich, and only moderately moist soils. With us its most constant companions are the oaks, bitter nut and the hard maples."

2 C. CORDIFORMIS (Wang.) K. Koch. Bitter Nut Hickory (Fig. 6). "The bitter nut selects as its home low wet woods near the borders of streams and swamps, or high rolling uplands. It is commonly associated in our territory with the hickory, the hackberry, the oaks, and in the northern part of the state with the yellow birch, basswood and hard maples."

PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN. XVIII.

SARRACENIALES.

FLORENCE B. LIVERGOOD

SARRACENIACEAE—PITCHER-PLANT FAMILY

SARRACENIA PURPUREA L. Pitcher-plant (Fig. 1). Abundant in Sphagnum bogs, mostly in the glaciated areas of Wisconsin. (The Driftless Area, occupying the southwestern quarter of the state, is indicated on the map.)

DROSERACEAE—SUN-DEW FAMILY

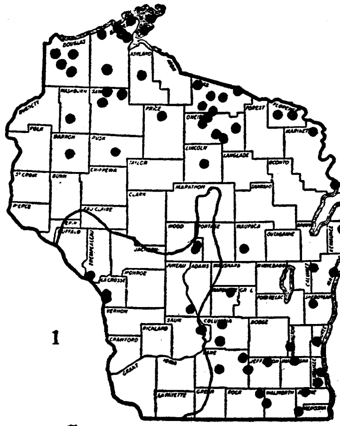
Some confusion as to the identification of the species of *Drosera,* especially between *D. anglica* and *D. intermedia,* has been found in herbaria. To aid future collectors in the state, Dr. R. I. Evans has prepared Fig. 6, showing the leaf-outlines of our four species.

DROSERA ROTUNDIFOLIA L. (Figs. 2 and 6A). Mostly in the glaciated areas.

D. ANGLICA Huds. *D. longifolia* L., in part; not of Gray's Manual, ed. 7 (Figs. 3 and 6B). Lake Superior region; rare.

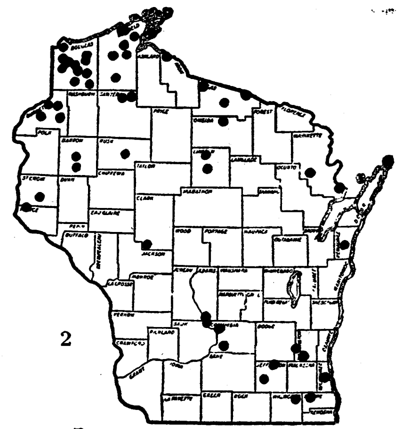
D. INTERMEDIA Hayne. *D. longifolia* L., in part; Gray's Manual, ed. 7 (Fig. 4, dots; Fig. 6C). Occasional in the glaciated parts of the state. Subcaulescent forms collected in Bayfield, Ashland, Sawyer and Marquette counties correspond to the form described by J. R. Churchill in Rhodora 2 : 70–71. 1900, and appear to be f. SUBCAULESCENS Mellvill, Mem. & Proc. Manchester Lit. & Phil. Soc. 4 : ser. IV : 195. 1891; Diels, Pflanzenreich 4 : pt. 112 : 84. 1906. (Fig. 4, crosses).

D. LINEARIS Goldie (Figs. 5 and 6D). Rare. Interrogation marks in Polk and Columbia Counties indicate old collections without precise location.



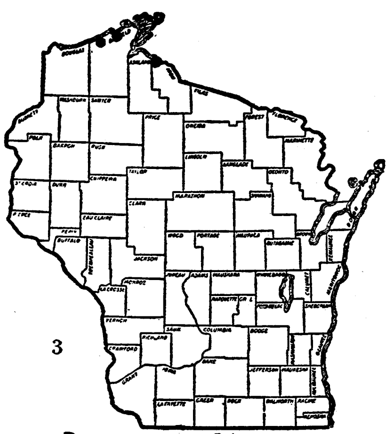
1

Sarracenia purpurea



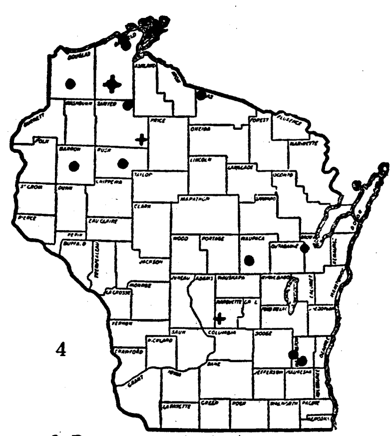
2

Drosera rotundifolia



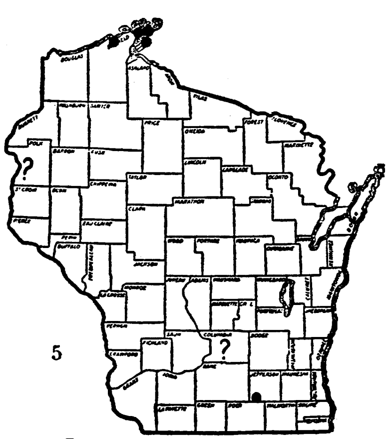
3

Drosera anglica



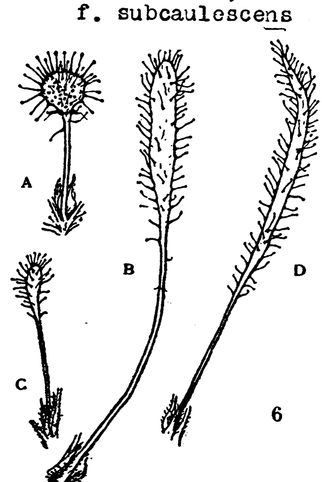
4

● Drosera intermedia
+ D. intermedia, f. subcaulescens



5

Drosera linearis



6

PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN. XIX. SAXIFRAGACEAE

NORMAN C. FASSETT

1. SULLIVANTIA

S. RENIFOLIA Rosendahl, Univ. Minn. Stud. Biol. Sci. 6 : 410, pl. 43. 1927. *S. Sullivantii,* in part, of Gray's Manual, ed. 7 (Fig. 1). Moist cliffs along streams in the Driftless Area. As treated by Dr. Rosendahl, this is one of the six very localized species of the genus; true *S. Sullivantii* occurs mostly south of the glaciated area in Ohio, *S. renifolia* is in the Driftless Area of Wisconsin and neighboring states, while the four remaining species are localized in the Far West. The Driftless Area, occupying the southwestern quarter of the state, is outlined on the map.

2. SAXIFRAGA—Saxifrage

S. PENNSYLVANICA L. (Fig. 2). In swamps and on moist cliffs throughout the state.

[*Tiarella cordifolia* is reported in Gray's Manual, ed. 7, as being found westward to Minnesota; it should be sought in Wisconsin.]

3. HEUCHERA—Alum Root

H. HISPIDA Pursh. (Fig. 3). On sandstone ledges and wooded sandy banks. Wadmond[1] records this as being common on prairies. Apparently more common southward, venturing northward along the Wisconsin, Chippewa and St. Croix Rivers.

4. MITELLA—Bishop's Cap

1. M. DIPHYLLA L. (Fig. 4). Woodlands, apparently throughout the state. Forma OPPOSITIFOLIA (Rydb.) Rosendahl, Engler, Bot. Jahrb. 50, suppl. : 380. 1914, characterized by having

[1] Trans. Wis. Acad. 16 : 841. 1909.

the cauline leaves short-petioled, is about as common (Fig. 5). A collection from Ashland Junction, June 8, 1930, *Otto Westlund* no. 150, consists of three specimens; two (in the University herbarium) are, respectively, typical *M. diphylla* and f. *oppositifolia,* while the third (in the herbarium of Northland College) is f. TRIPHYLLA Rosendahl, *l. c.,* with two petioled leaves and a smaller sessile on higher up on the stem. A specimen from Lynxville, September 3, 1915, *J. J. Davis,* lacks cauline leaves, but appears otherwise normal (Fig. 5, circle).

2. M. NUDA L. (Fig. 6). Northern Wisconsin, coming south in the eastern counties. This is a common type of distribution: see, for example, *Pyrola chlorantha,*[2] *P. asarifolia* var. *incarnata,*[3] *Corylus cornuta,*[4] and *Betula lutea.*[4] Forma INTERMEDIA (Bruhin) Rosendahl, *l. c.,* p. 383, originally described from Manitowoc County, is considered by Rosendahl to be a hybrid with *M. diphylla.* Also Lake Owen, Bayfield Co., *Griscom* 12280.

5. CHRYSOSPLENIUM—Golden Saxifrage

C. AMERICANUM Schwein. (Fig. 7). In wet woods and springy places northward, coming south to Manitowoc on the Lake Michigan shore, and to cool woods in Vernon County and cold canyons of the Dells of the Wisconsin River.

[*C. tetrandrum* Fries, which has been collected at Decorah, Iowa, should be sought, probably on damp cliffs in the Driftless Area.]

6. PARNASSIA—Grass of Parnassus

1. P. PARVIFLORA DC. (Fig. 8, dots). Known in the state only from Door County. The range as mapped includes two sheets in the Gray Herbarium, reported to me by Mr. C. A. Weatherby.

2. P. MULTISETA Fernald, Rhodora 28 : 211. 1926. *P. palustris* of Gray's Manual, ed. 7; not L. (Fig. 8, crosses). known in the state only from Douglas County.

3. P. CAROLINIANA Michx. (Fig. 9). In meadows, mostly in the limy parts of the state (see page 233, fig. 2, for illustration showing extent of limestone area).

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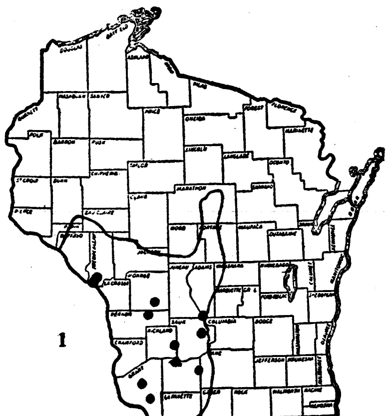
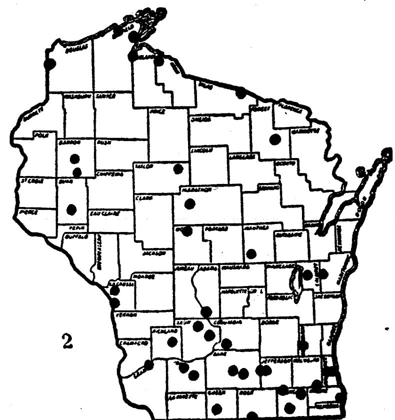
[2] Trans. Wis. Acad. 24 : 259, fig. 6. 1929.
[3] *Ibid.,* 260, fig. 12.
[4] *Ibid.,* 25 : 191. 1930.



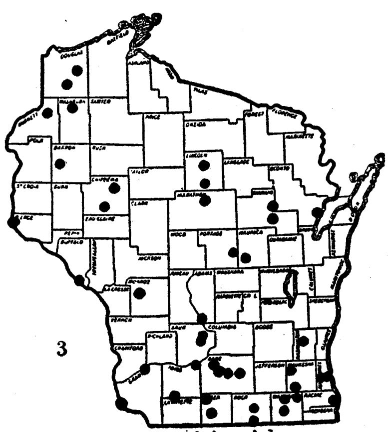
1

Sullivantia renifolia



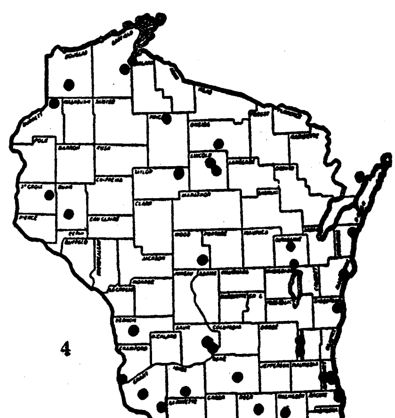
2

Saxifraga pennsylvanica



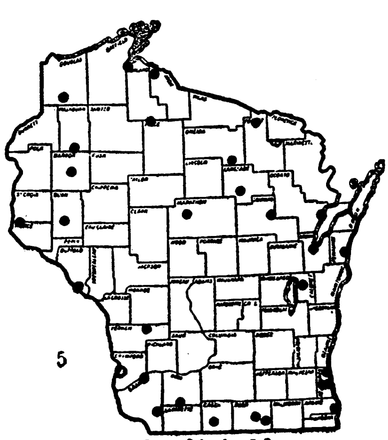
3

Heuchera hispida



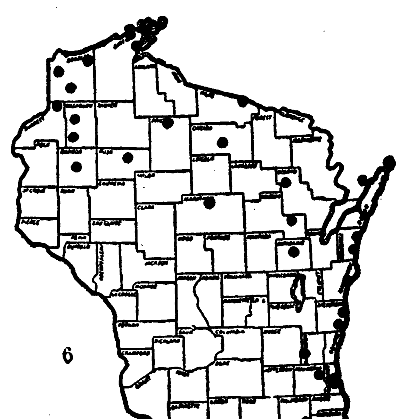
4

Mitella diphylla



5

Mitella diphylla, f. oppositifolia



6

Mitella nuda

7. PHILADELPHUS—Syringa

P. CORONARIUS L. Escaped in Columbia, Dane and Rock Counties.

8. RIBES—Currant; Gooseberry

Through the cooperation of Mr. T. F. Kouba, the collections of this genus made in Wisconsin by the Division of Blister Rust Control, U. S. D. A., have been studied. This is in addition to the herbaria listed on page 227.

The gooseberries, particularly, are a complex group and present many problems. While most of the specimens may be identified readily, some may show exceptions to almost every character listed in the key.

A. Flowers solitary or in bunches of 2–4, with spines at the base of each bunch (The Gooseberries)

B. Calyx-lobes shorter than the tube; petioles with long hairs which are usually unbranched, rarely slightly fringed, often gland-tipped; ovaries and berries usually prickly; peduncles 13–27 mm. long in fruit

C. Ovaries and berries prickly .... *R. Cynosbati*

C. Ovaries and berries nearly or quite lacking prickles .... *R. Cynosbati* f. *inerme*

B. Calyx-lobes about equalling or longer than the tube; petioles with long copiously fringed hairs; ovaries and berries never prickly; peduncles and pedicels together 1–20 mm. long in fruit

D. Stamens about 1 cm. long, about twice as long as the calyx-lobes, long-exserted, very conspicuous; bracts of the inflorescence fringed with minute stalked red or yellowish glands; peduncles and pedicels together 8–20 mm. long in fruit; spines usually stout, reddish, about 1 cm. long, rarely absent...*R. missouriense*

D. Stamens about equalling the calyx-lobes, or often slightly exserted, not very conspicuous; bracts of the inflorescence fringed with minute hairs, but without glands in our common species; spines slender, about 5 mm. long, or often absent

E. Stamens about twice as long as the petals; leaves and bracts without glands; leaf-blades wedge-shaped at base; peduncles and pedicels together 3–10 mm. long in fruit

F. Leaves glabrous or somewhat pubescent beneath .... *R. hirtellum*

F. Leaves velvety beneath ...... *R. hirtellum* var. *calcicola*

E. Stamens about equalling the petals; leaves (particularly the petioles and under sides of the blades) and bracts with minute stalked glands intermixed with the fine hairs; leaf-blades truncate or subcordate at base; pedicels 1–2 mm. long in fruit, hardly exceeding the bud-scales..*R. oxyacanthoides*

A. Flowers in racemes (The Currants)

G. Flowers about as broad as long

H. Ovaries without stalked glands

I. Calyx bell-shaped, with a well-developed tube; leaves usually with resinous dots on the lower surface; bases of petioles without gland-tipped hairs or stalked glands

J. Calyx-tube about equalling the lobes; racemes drooping; flowers greenish-yellow; leaves often with resinous dots on the upper surface

K. Bract at the base of each pedicel longer than the pedicel; calyx 8–10 mm. long; ovaries without resinous dots; young twigs with a ridge running down from the base of each petiole

L. Leaves with copious resinous dots beneath, and sparsely dotted on the upper surface .... *R. americanum*

L. Leaves without dots above, and nearly or quite lacking them on the lower surface .... *R. americanum* f. *pauciglandulosum*

K. Bract shorter than the pedicel; calyx 5–6 mm. long; ovaries with resinous dots; twigs without ridges runing down from the petioles .... *R. nigrum*

J. Calyx-tube much shorter than the lobes; racemes erect; flowers white; leaves without resinous dots on the upper surface; ovaries and fruits with resinous dots .... *R. hudsonianum*

I. Calyx saucer-shaped, the united portion flat and scarcely tube-like; leaves frequently with hairs, but never with resinous dots, on the lower surface; bases of petioles with long gland-tipped hairs, or with small stalked glands

M. Flowers yellowish or greenish; pedicels without stalked glands; middle lobe of leaf ovate, a little longer than broad .... *R. sativum*

M. Flowers purple; pedicels with minute stalked glands; middle lobe of leaf triangular, broader than long

N. Leaf-blades densely hairy beneath .... *R. triste*

N. Leaf-blades nearly or quite without hairs .... *R. triste* var. *albinervium*

H. Ovaries with stalked glands

O. Stems densely covered with prickles .... *R. lacustre*

O. Stems without prickles

P. Calyx 2–2.5 mm. long .... *R. prostratum*
P. Calyx 3–4 mm. long .... *R. prostratum* var. *wisconsinum*
G. Flowers several times as long as broad .... *R. odoratum*

1. R. CYNOSBATI L. Prickly Gooseberry. (Fig. 10, dots). Abundant throughout the state. Forma INERME Rehder, Mitt. Deutsch. Dendr. Ges. for 1910 : 250. 1910 (fig. 10, crosses), which lacks most or all of the prickles from the berries, is occasional in the state, sometimes grading into the type.

2. R. MISSOURIENSE Nutt. *R. gracile* of Gray's Manual, ed. 7; not Michx. Missouri Gooseberry. (Fig. 11). Common except northward.

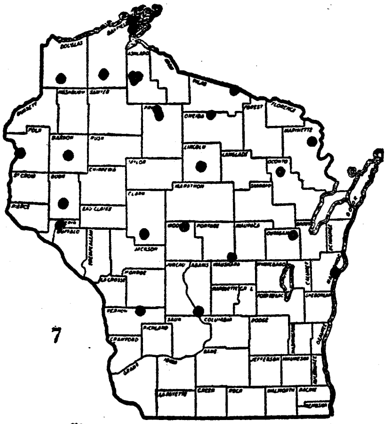
3. R. HIRTELLUM Michx. *R. oxyacanthoides* of Gray's Manual, ed. 7, in large part; not L. (Fig. 12, dots). Throughout the state, but not common southward, where it is usually found in bogs. Nearly all our material has the leaves more or less pubescent beneath; plants from Door and Racine Counties may be referred to var. CALCICOLA Fernald, which is also represented in the Gray Herbarium by a sheet from Door County.

A specimen collected at Prentice, July 18, 1919, by J. J. Davis, lacks the plumose hairs on the petiole, and has in their place unbranched hairs and glands suggestive of *R. Cynosbati,* but the short peduncles and sparsely pubescent leaf-blades with cuneate bases seem to place it with *R. hirtellum.* A specimen from Newbold, July 8, 1893, *L. S. Cheney* no. 1507, has the leaves, but not the bracts, somewhat glandular.

4. R. OXYACANTHOIDES L. Hawthorn-leaved Gooseberry. The only Wisconsin specimen I have been able to refer to this species is one from Ellison Bay, Door County, May 30, 1926, *E. J. Kraus et al.* This plant is unarmed, and the leaves are extremely velvety, but it is otherwise characteristic.

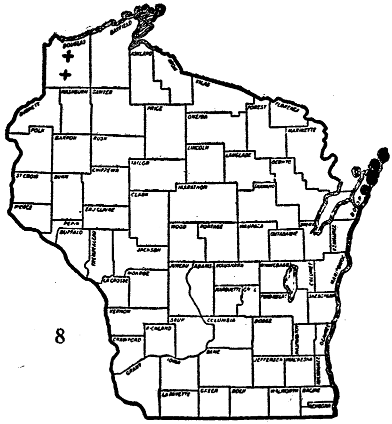
5. R. AMERICANUM Mill. *R. floridum* L'Her. American Black Currant (Fig. 13, dots). Common throughout the state, except, apparently, in a large central area; perhaps future collections will show a uniform distribution throughout Wisconsin.

R. AMERICANUM f. **pauciglandulosum,** n. f., foliis supra sine guttis et subtus saepe sine guttis.—Algoma, June 1, 1905, *Lou Damas* (TYPE in the Herbarium of the University of Wisconsin); Delavan, June 2, 1907, *S. C. Wadmond* no. 1866; ap-



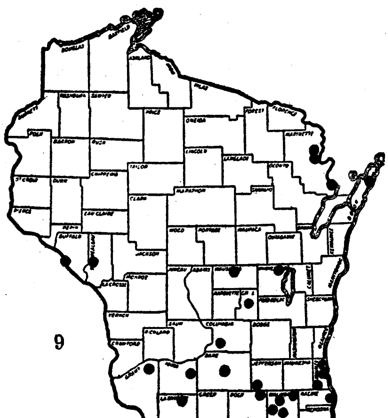
7

Chrysosplenium americanum



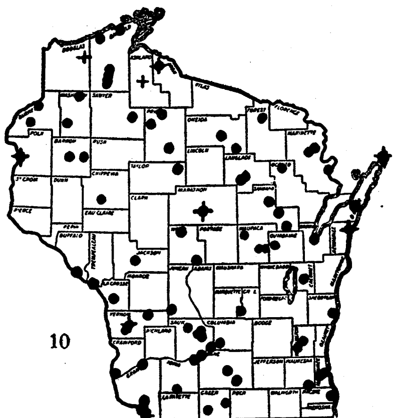
8

● Parnassia parviflora
+ P. multiseta



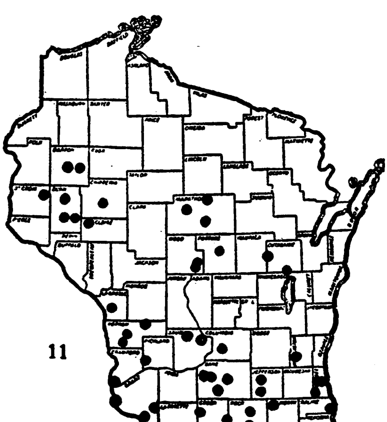
9

Parnassia caroliniana



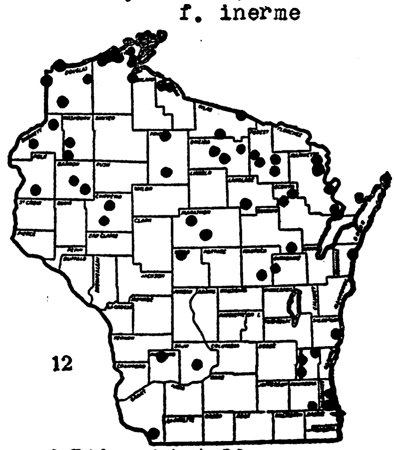
10

● Ribes Cynosbati
+ R. Cynosbati, f. inerme



11

Ribes missouriense



12

● Ribes hirtellum
+ R. hirtellum, var. calcicola

proached by a specimen from Baraboo, May 8, 1927, *N. C. Fassett* no. 5568. (Fig. 13, crosses).

6. R. NIGRUM L. Black Currant. Rarely escaping from cultivation; collections have been made in Ashland, Door and Dane Counties.

7. R. HUDSONIANUM Richards. Hudson Bay Currant. (Fig. 14). Northward.

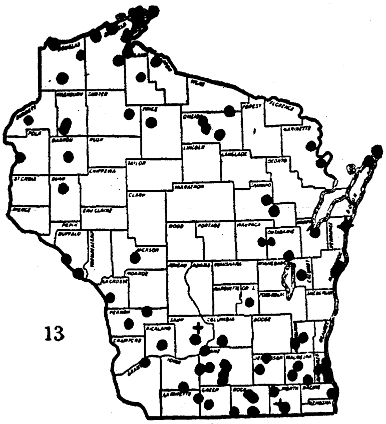
8. R. LACUSTRE (Pers.) Poir. Swamp Black Currant. (Fig. 15). Mostly northeastward; a single collection from Lake Superior shore.

9. R. PROSTRATUM L'Her. Skunk Currant. (Fig. 16, dots). Across the northern half of the state.

R. PROSTRATUM var. **wisconsinum** n. var., calycibus 3-4 mm. longis.—BAYFIELD CO.: wet sand, shore of Lake Superior, Port Wing, June 14, 1928, *Ludlow Griscom* no. 12323 (TYPE in the Herbarium of Ludlow Griscom); poorly drained area, with alder and aspen, near Cornucopia, June 5, 1931, *T. F. Kouba;* Sand Island, June 20, 1897, *L. S. Cheney* no. 6155; mainland east of Sand Bay, June 22, 1897, *L. S. Cheney* no. 6296. BARRON CO.: occasionally damp soil, Barron, May 26, 1917, *Charles Goessl* no. 6814. DUNN CO.: moist woods, Wheeler, May 19, 1917, *Charles Goessl* no. 6720. (Fig. 16, crosses).

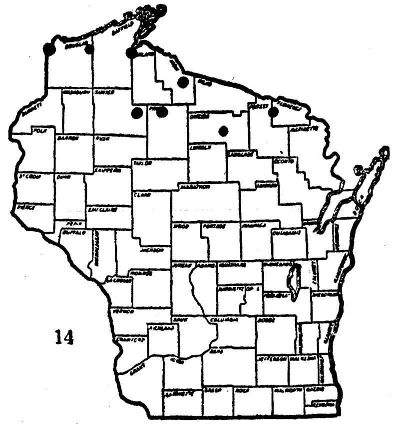
In its long calyx this resembles *R. laxiflorum* Pursh, of northwestern America, to which it is perhaps as closely related as to our eastern skunk currant. In associating it with the latter species, the writer has taken into consideration the following facts. The calyx-lobes of *R. prostratum* are characterized both by Rydberg[1] and by Coville and Britton[2] as being smooth, to distinguish them from the pubescent or glandular calyces of *R. laxiflorum.* But many specimens of the former have a sparse pubescence or even a few scattered glands on the calyx, while *R. laxiflorum* var. *japonicum* is described by Berger[3] as having glabrous sepals. A character which does not seem to be noted in our manuals is found in the stipules; these are represented in *R. prostratum* by mere narrow subscarious margins toward the bases of the petioles, while in *R. laxiflorum*

[1] Fl. Rocky Mts., ed. 2 : 397. 1922.
[2] N. Am. Fl. 22, pt. 3 : 194. 1908.
[3] N. Y. State Agric. Exper. Sta. Tech. Bull. no. 109 : 64. 1924.



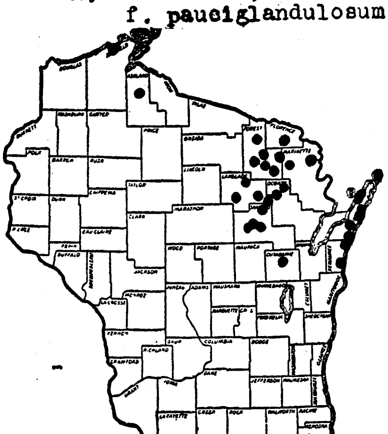
13

● Ribes americanum
+ R. americanum, f. pauciglandulosum

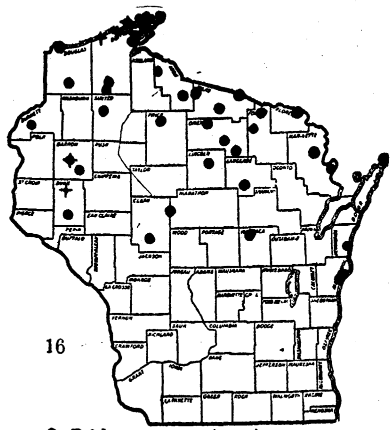


14

Ribes hudsonianum

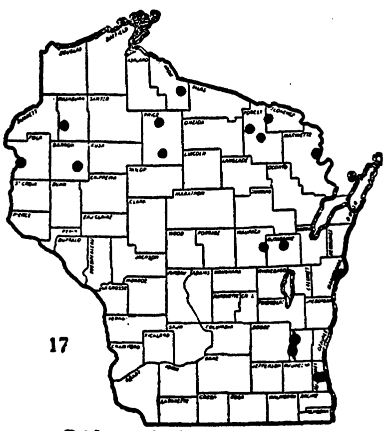


Ribes lacustre



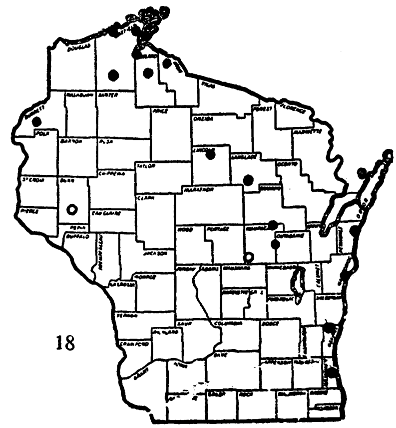
16

● Ribes prostratum
+ R. prostratum, var. wisconsinum



17

Ribes triste



18

Ribes triste, var. albinervium

they are broader, and subtruncate at the summit in most cases. The writer is not qualified to judge how generally this character may hold, since he has at his disposal only five sheets of the latter species, including var. *coloradense.* In placing the plant of the Lake Superior region with *R. prostratum* rather than with *R. laxiflorum,* he has placed reliance on the glabrous or slightly glandular and pubescent calyces, on the narrow stipular bases of the petioles, and on the narrow petals. The fruit has not been collected.

Attention was first called to this plant by Professor Ludlow Griscom, to whom the writer is indebted for the loan of the material cited as type. Professor Griscom was impressed by its erect wand-like branches, utterly unlike the usual prostrate or trailing stems of typical *R. prostratum.* Several of the collections cited above appear to have had erect stems, but in absence of collector's data it is impossible to say whether or not that habit is always associated with the larger calyx. This point must rest with future field observers.

A sheet from Kingston, Ontario, May 14, 1903, *J. Fowler,* appears to belong with this variety.

10. R. SATIVUM Syme. *R. vulgare* of Gray's Manual, ed. 7; not Lam. Garden Currant. Occasionally escaping; we have collections and reports from Waucapa, Dane, Rock, Racine[4] and Milwaukee[5] Counties. This often appears as if native; in Waupaca County the writer found it growing in wet woods with *R. triste.*

11. R. TRISTE Pall. Swamp Currant. (Fig. 17). Northern and eastern. Var. ALBINERVIUM (Michx.) Fernald (fig. 18) has essentially the same general range in Wisconsin, but there seem to be few areas where both the typical form and the variety occur, as may be seen by a comparison of figures 17 and 18. The locations of specimens intermediate between the species and the variety are shown by circles on figure 18.

12. R. ODORATUM Wendland. *R. aureum* of Gray's Manual, ed. 7; not Pursh. Occasionally found persisting or escaping from cultivation; it has been collected in St. Croix, Barron, Waupaca, Outagamie, Vernon, Dane, Rock, Racine[4] and Kenosha[4] Counties.

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[4] Wadmond, Trans. Wis. Acad. 16 : 842. 1909.

[5] Russel, Bull. Wis. Nat. Hist. Soc. 5 : 200. 1907.

PRELIMINARY REPORTS ON THE FLORA OF WISCONSIN. XX.

MALVALES

ALICE M. HAGEN

MALVACEAE—MALLOW FAMILY

ABUTILON THEOPHRASTI Medic. Velvet Leaf. (Fig. 1, dots). Occurs chiefly in waste places, fields and ditches, across southern Wisconsin. Introduced, but well established.

ALTHAEA OFFICINALIS L. Marsh Mallow. (Fig. 1, cross). Only one collection, from Lynxville, Crawford County. Introduced.

MALVA ROTUNDIFOLIA L. Cheeses. (Fig. 2). Fairly common in cultivated land and farm-yards in southern and western Wisconsin. This species seems to show a very definite range, and it will be interesting to note whether future collections will extend the range throughout the eastern and northern parts of the state. Naturalized from Europe.

M. BOREALIS Walmm.; Bergman, Geol. & Nat. Hist. Surv. Minn. 4 : 437-440. 1916. (Fig. 3, triangles). Sepals with long-ciliate margins; petals as long as or slightly longer than the sepals; carpels 8-10, their backs conspicuously reticulated and nearly or quite glabrous, their margins angled and sometimes slightly toothed. *M. rotundifolia,* with which this has been confused, is distinguished as follows: sepals not ciliate or slightly so with short hairs; petals 3-4 times the length of the sepals; carpels 12-15, their backs densely pubescent with short hairs and but slightly if at all reticulated, and margins rounded.

While *M. borealis* is much less common than is *M. rotundifolia,* it seems to occur farther to the northeast than does the latter species.

M. CRISPA L. Curled Mallow. But one collection, from Racine.

M. SYLVESTRIS L. High Mallow. (Fig. 3, crosses). An introduced species which has been collected three times in southeastern Wisconsin.

M. MOSCHATA L. Musk Mallow. (Fig. 3, dots). Naturalized in southern and eastern Wisconsin.

CALLIRHOE TRIANGULATA (Leavenw.) Gray. Poppy Mallow. (Fig. 4, dots). A native species, following dry prairies along the Mississippi and Wisconsin Rivers.

NAPAEA DIOICA L. Glade Mallow. (Fig. 4, crosses). A native plant which is locally abundant, mostly along streams, in a small section in southwestern Wisconsin. This is mostly in the Driftless Area, and to a small extent on ground covered by the Illinoian but not the Wisconsin glaciation.

HIBISCUS MILITARIS Cav. Halberd-leaved Rose Mallow. (Fig. 5, crosses). Bottomlands along the Mississippi and Wisconsin Rivers, in Grant County.

H. TRIONUM L. Flower-of-an-hour. (Fig. 5, dots). Found chiefly in the southern portion of the state, and along the Wisconsin River, on waste land. A locally established plant brought in from Europe. Its early introduction is shown by a specimen from Marquette County (precise location not given) collected by John Townley in 1861.

TILIACEAE—LINDEN FAMILY

TILIA GLABRA Vent. An. Hist. Nat. 2 : 62. 1800; Sargent, Bot. Gaz. 66 : 424. 1918; Bush, Bull. Torr. Bot. Club 54 : 235. 1927. *T. americana* Am. Auct., but probably not L., or at least in very small part. (Fig. 6). The large dots on the map represent herbarium specimens, while the more complete range, shown by the small dots, is taken from an unpublished map by L. S. Cheney. Range very similar to that of the sugar maple.[1]

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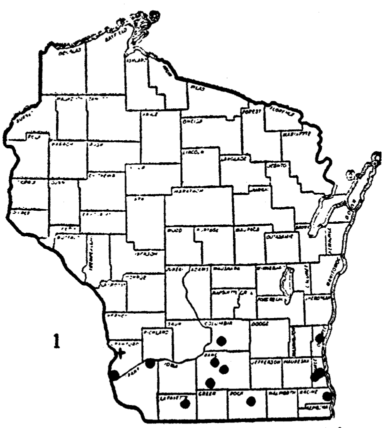
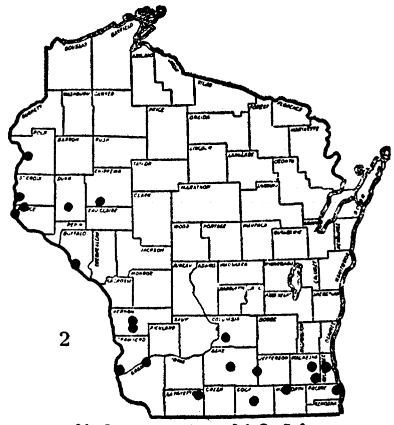
[1] See Trans. Wis. Acad. 25 : 195-196. 1930.



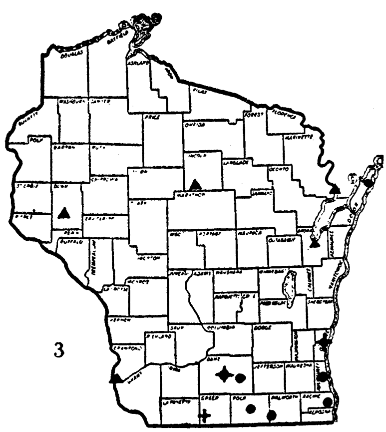
1

● Abutilon Theophrasti
+ Althaea officinalis



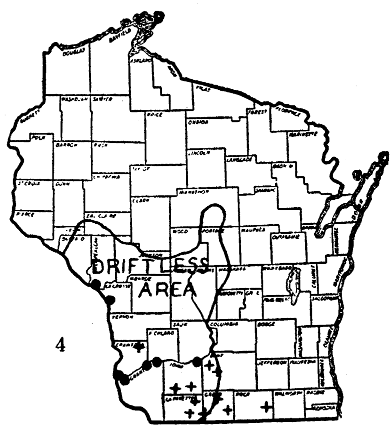
2

Malva rotundifolia



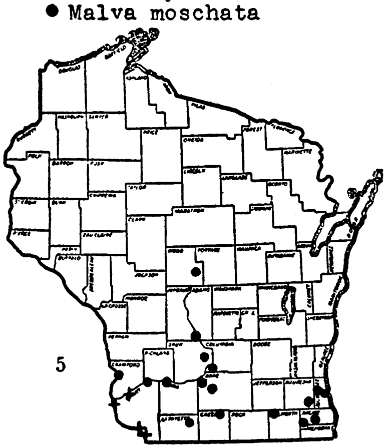
3

▲ Malva borealis
+ Malva sylvestris
● Malva moschata



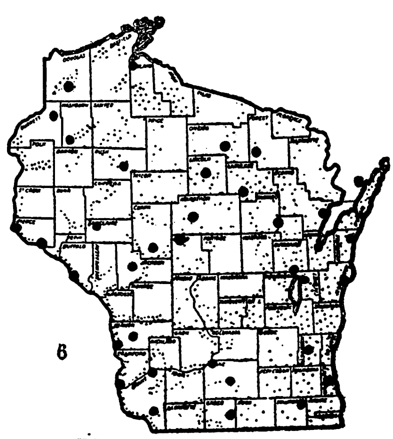
4

● Callirhoe triangulata
+ Napaea dioica



5

● Hibiscus Trionum
+ Hibiscus militaris



6

Tilia glabra

STANDARDS FOR PREDICTING BASAL METABOLISM: I. STANDARDS FOR GIRLS FROM 17 TO 21.[1]

MARIAN E. STARK

Contribution from the Department of Medicine and the Wisconsin General Hospital, University of Wisconsin.

(Submitted for publication November 1, 1931.)

CONTENTS

INTRODUCTION

Anyone who has worked at all extensively in the field of basal metabolism will have recognized that its two chief uncertainties are (1) the securing of true "basal" conditions,—i. e., complete muscular and also mental repose—on the part of the subjects; and (2) the proper choice of normal standards with which clinical tests must be compared for interpretation.

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[1] The expense of printing this study has been in part defrayed through a grant from the research funds of the Medical School of the University of Wisconsin.

Since techniques have become so thoroughly simplified and standardized and the physical conditions necessary for the "basal" state in general well understood, the difficulties of the first of these problems have been materially minimized. Though the simplification of apparatus has resulted chiefly of course in wider availability and greater accuracy of the determination itself, it has also been reflected in lessened apprehension and hence automatically better "basal" condition on the part of the subjects. This, with the better understanding of the need for mental as well as physical repose, is undoubtedly largely responsible for the fact that the metabolic rates that are being reported nowadays in connection with studies of normals in various laboratories are definitely lower than they used to be *(1, 2)*; for mental unrest, as well as most forms of technical error, lead to temporary actual, or apparent elevation of the determined rates. With all technical errors ruled out, the difficulty of controlling the mental state of the subjects must always remain the chief variable in a determination which is so peculiarly subject to psychic influences.

This is one of the reasons for the existence of the second problem—namely, the difficulty of deciding upon adequate normal standards. It is not surprising that most of the existing standards, based on older data, are found too high to express normal rates as they are being determined today. In clinical work this is not such a striking handicap as in studies that deal with normal controls, because of the mental hazard that is bound to interfere more or less with the perfect relaxation of subjects who are hospitalized for any cause whatever. However, because of the unaccountability of this factor, most people prefer to have standards for clinical comparisons that are based on "physiological" rather than "hospital" normals, and to make such practical allowances for interpretation as are dictated by weighing of all the clinical evidence for any particular case at hand.

The type of individual cooperation that must be obtained from the subjects of metabolism experiments is undoubtedly the largest single factor which has delayed for so long the compiling of adequate standards of normality for all ages. After acceptable data are obtained in sufficient quantity there comes the choice of the proper method of analysis for building up the prediction standards for this complex "physiological constant" whose ultimate basis for constancy is not and perhaps never can be fully understood, and which in practice is found to have so many, often subtle, factors of variability.

Nevertheless, working standings of comparison had to be built up before the science could advance very far. This was made possible by the first large series of carefully controlled data on normal subjects made available, that collected by Benedict and his collaborators of the Nutrition Laboratory at Boston. It was natural that most of these early data should be on adults and that the majority of these would be men. Upon this body of data, including as Benedict offered it, 136 men and 103 women, are founded in whole or in large part all of the major prediction standards that are in use today for adults of both sexes. The two classical standards among these are of course that of Aub and DuBois, the pioneer in the field in 1917, and that of Harris and Benedict which appeared in 1919.

Theoretically the question of superior validity of one or the other of the analytical methods involved in the two standards or any of the modified forms that have been proposed for one or the other, leaves so much to be said on both sides that it is doubtful if a clean-cut choice can ever be made on purely reasonable grounds. Meanwhile, either of the original standards has proved to work out with a high degree of practical satisfaction in dealing with adults. Of late, practical choice is perhaps less often than formerly being left to precept or professional "inheritance" since it is becoming increasingly evident that the Harris-Benedict prediction, whose figures average throughout lower than those of Aub and DuBois, affords by that fact a better approximation to average normal findings under modern test conditions.

It is not the purpose of this paper to discuss the adult standards excepting as their consideration must bear directly upon the subject at hand, namely the metabolism of girls and young women. This sex and age group represents one of the least adequately surveyed portions of the whole field of practical basal metabolism. In perhaps no other group is it more desirable for the physician to have every reliable means possible at his disposal for dealing with metabolic difficulties.

Part of this inadequacy is undoubtedly due to comparative dearth of data for this particular group during the time when the classical reference standards for basal metabolism were being established. Far more, however, would seem to be due to the widely divergent conceptions which have been brought to bear by men of similar authority in the field upon the choice of material to be studied and the type of analysis to which it should be submitted for establishing reference standards for the transitional years between childhood and fully adult development. The standards made available have differed so seriously that the result has been utter confusion to the physician who would try to interpret the results of basal metabolism tests on his younger feminine patients.

Among the many metabolic studies that have dealt with normal controls as the technique of metabolism measurements has become more widely available there have been numerous ones which included girls and young women as subjects; but while many of these series have been used for extensive comparisons, none of them in this country has been worked into a prediction standard to take the place of those in the field up to 1924.

The standards proposed from authoritative sources in this country for predicting the metabolism of girls under 21 have been two: the lower ranges of the Aub-DuBois adult standard *(3)*, which give expected calories per square meter of body surface in two-year age periods between 14 and 20; and the standard recommended in 1924 by Benedict *(4)* specifically for girls from 12 through 20, since the Harris-Benedict tables were limited by their authors to ages over 20. These special tables which are based upon the data obtained by Benedict and Hendry *(5)* three years earlier on Girl Scouts between 12 and 17, give calories per kilogram of weight according to age. The predictions to be obtained by the two standards disagree to a startling extent, though the discrepancies do not run parallel for all types of cases.

Such a state of affairs is particularly disconcerting in a metabolism laboratory such as that of the Wisconsin General Hospital, with which is associated the Student Health Department of the State University, and in which consequently young women of college age come in for a large share of the metabolic studies that are carried on.

The help that the clinician feels justified in expecting from the determination of the metabolic rate is by no means realized in these younger subjects. And yet the demand for the determination has continued to increase year by year, in spite of disappointments,—perhaps on the basis of occasional clear-cut cases, but mostly, no doubt, because of the unquestioned helpfulness of this laboratory adjunct in practice with adults.

For these reasons the laboratory undertook a few years ago to gather enough normal data from the same source as its clinical material to make possible either a decisive selection between existing standards for these ages, or possibly to modify one of these or to serve, if necessary, for the building of standards of comparison of its own. The material to be offered in this paper is the result of this study.

EXPERIMENTAL

Plan of Study. Our early systematic comparisons proved so thoroughly to confirm our suspicion of the need for a new prediction that we formulated our plans to include this possibility definitely. This realized on the basis of our first nearly 100 cases between the ages of 17 and 21, the rest of our study has taken the form of comparisons in which our own and the other available predictions have been "tried on" the individuals of our group to ascertain not only average fitness in various respects, but whole ranges of individual variations, with which, rather than averages, of course the clinician would be concerned in dealing with individual cases. Finally, it has been possible to impose the really crucial test of making these various comparisons on a comparable number of normals other than our own, on whom data have become available through various studies made independently here, and collected from recent reports in the literature by workers in widely different localities.

The gathering together of these data and the formation of concrete comparisons based on a significantly large body of measurements, have been illuminating to us, and we offer them in the hope that they may carry some practical suggestions to others who are interested in the same problems, either on the side of physiological normals in general, or for clinical application.

A study of this sort must be a cooperative venture. Any description of the present one must fittingly begin with acknowledgment of essential collaboration not only of the subjects of the study themselves, but of personnel from three different departments of the University and Medical School.

Normal girls of the desired ages were obtained as subjects through the cooperation of the Student Health Department of the University, who were themselves of course particularly interested in the availability of suitable prediction standards for this group. The members of the staff who thus made the work possible were Dr. William A. Mowry, Dr. Sarah I. Morris and Dr. Irma Backe, chief physician, and associate and assistant physicians, respectively, of the department.

Our statistical advisor throughout the project has been Professor Mark Ingraham of the Department of Mathematics, whose advice has been followed as to the type of prediction standard built up after statistical analysis of the original data on our group; and to whom we are indebted for helpful suggestions throughout the remainder of the studies and comparisons that have been made. The extensive computations for the original analyses and for the final prediction standard were performed by Miss Beatrice Berberich, University Computer, under the direction of Professor Ingraham.

The work as a whole was suggested in the beginning and has gone forward under the continuous sponsorship of Dr. E. L. Sevringhaus, Associate Professor of Medicine and in charge of the metabolic department of the hospital. Without his support and inspiration the project could neither have been begun nor brought to conclusion.

Acknowledgment is due, finally, to Dr. E. F. DuBois for his careful reading of the manuscript, and for the advantage of stimulating suggestions and criticisms by which the report in its final form has profited.

Policy in Securing of Subjects. In the favorable portions of three school years data were collected on 97 normal girls of ages 17 through 20, students in the University of Wisconsin. As often as possible, more than one test was performed upon each subject. 163 acceptable tests in all were secured upon the individuals of the group.

The policy adopted was that of making metabolism appointments for suitable entering students as a routine part of their physical examinations. In this way as many cases as possible were handled through the fall until the interference of examination or vacation programs made it profitless to carry the routine schedules any further. These were then supplemented by personal letters of request for cooperation, bearing brief but frank explanation of the project, during various later portions of each school year.

Of the students who were thus invited to cooperate, rather than having appointments made for them as part of a more or less required routine, a good proportion of course refused or simply failed to appear. Thus it would seem that a different type of selection had operated with these than with the ones who were studied each fall. This is doubtless true to a certain extent, but as a matter of fact, a good many of those scheduled in the fall also failed to appear, with characteristic modern independence. No effort was made to coerce the unwilling, though at times follow-up letters were sent, or personal conversations obtained in the effort to prevent rumors that might lead to mistrust in the motives of the project or the spreading of misconceptions as to the nature of the test itself. Either undue coercion or much anxiety over the test, would, we felt, operate against our getting the best results. On the other hand, experience indicated that too much interest on the part of the subject might do the same thing. We tried therefore to steer a middle course between telling too little and too much.

Choice of Normal Material. The students were taken without any effort at selection (beyond our having considered the age distribution we wanted) other than the requirement of a grading of "A" in their physical and medical examinations. A rating of "A" does not imply physical perfection, to be sure. It merely means that by the type of routine examination possible for such a group, no definite defects were judged to be present and no contraindications in the past history or present findings to the student's participation in the full University program, including physical education. Such a criterion of normality would at least seem to compare favorably with any that have governed the choice of normal material for other considerable groups forming the bases of metabolism studies.

In every case the subject was examined and interviewed by the author in order to supplement certain points of the history and physical observations that were subjects of special interest in the investigation, and to rule out acute or accidental reasons for unfitness. In this supplementary examination the girls were questioned particularly as to menstrual history and the use of goitre prophylaxis measures, and their necks were examined by gross inspection and palpation of the thyroid gland. On the basis of these findings and questionings a number of subjects on whom good tests had been secured had to be discarded.

One of the factors which make a careful study of this sort so time-consuming is the variety of reasons that can disqualify a subject even after she has come for the test. Some of the students who were secured as subjects proved unsuitable for such reasons as temporary indispositions (usually from respiratory infections); fatigue from excessive school or social activities; occasional technical difficulties in the test itself; and rarely the subject's failure to cooperate in the routine.

Experience showed it to be undesirable to attempt to get satisfactory results at certain times of the school year, such as the periods soon before or after vacations or examinations, or prominent social events. Athletic exhibitions were found to result in definitely disqualifying fatigue in the cases of some of the students from the Physical Education Department, which furnished us otherwise some of our most satisfactory and cooperative subjects.

A considerable group of subjects were discarded because of a history of menstrual difficulties or irregularities which sometimes had arisen since the girl had entered the University, or if present before, had not been counted against her in the physical examination, either because she had failed to mention it, or because it was apparently nothing that should interfere with ordinary University activities. These subjects were discarded nevertheless without regard to the tests they gave because the relation between metabolic rate and menstrual difficulties in general is still so poorly understood. This was indeed one of the phases of the problem in which we were specifically interested.

The standards which governed us in this choice were arrived at after consultation with several of the clinical staff had indicated what could safely be taken as the borderline between normal variations and the suspicion of pathology. Dysmenorrhea that was more than slight or moderate,—i. e., incapacitating,—or irregularity in time of periods of more than one week were classed as disqualifying the subjects. The mere presence of catamenia was not allowed to rule out a test. The large amount of work that is recorded on this subject, as well as general observation, have led us to the opinion that unless actual discomfort is present during the test, the metabolic rate in normal women is to be found during the menstrual period within the limits of incidental fluctuations to be expected at any time during the cycle. Of course active discomfort from menstruation, as from any other source, would rule out the results of a test. A record was kept with the majority of the tests of the time of onset of the nearest menstrual period in case any correlations of interest could later be made.

Since Wisconsin is in a goitre belt region, we were particularly interested in learning whatever we could about any demonstrable relation between thyroid development and metabolic rate of subjects in apparently normal health.—It has been observed that some degree of thyroid enlargement is so common in our Middle States that even the perfect young women reproduced on magazine covers are apt to show slight goitres! Certainly it would have been impossible to assemble a significant sized group of girls in this part of the country if one were to exclude those with thyroid enlargement. As long as our other requirements for normality were met, we could not discriminate against even slight or moderate "goitres". Of course no subject was accepted in whom symptoms were admitted or could be suspected from the history or questioning.

We also could not discriminate against those who had used iodine for prophylaxis; but we do not consider that the medications used were ever of a character that could conceivably set this group apart from others from regions where the natural ration can be counted on to furnish the necessary iodine.

In order to make later comparisons possible, we kept records in each case that would allow grouping of the subjects as to geographical source and thyroid development in relation to metabolic rate. These results will be given with the other data.

The Tests. The tests were made in the metabolism laboratory of the Wisconsin General Hospital. The experimental subjects were purposely studied under the same general conditions as the regular patients, but in the interests of unity and control in the series, were all handled exclusively by the author, with very rare exceptions when one of the hospital operators filled in in case of need.

Each student who was given an appointment was provided with the instructions for preparation and brief description of the routine which the hospital furnishes to out-patients who have had no previous experience with the test. Though a few of the subjects proved to have had similar tests before in different capacities, by far the largest majority were first tests. No practice runs were made, for a large proportion of strictly first tests in the series was felt to be desirable in making it comparable with the general run of out-patients for whom standards of comparison were being sought.

The usual requirements for preparation were followed,—i. e., the subjects came without breakfast, and were required to lie quietly, with enough covering to be comfortable, for 30 minutes before the test. The appointments were all between 7:30 and 8:30 a. m., and the students excused from University exercises for the necessary periods.

Technique. A closed circuit type of apparatus was used in all the experiments,—in an occasional test at the beginning of the series the "Sanborn Grafic" was used, but for all the rest, the Benedict Portable model with motor-driven circulation. With this equipment of course it is not possible to determine the respiratory quotient. This we do not feel to be a disadvantage for this kind of study, however, in that the most extreme variations that might conceivably be encountered in R. Q. of normal subjects under the standardized conditions could make only about a 3% difference in the figured metabolic rates. This is well within the range of variation of the latter to be expected for determinations on the same individual at different times, or even between immediately consecutive short runs within a single test. Since there seems to be no good reason in the present state of our knowledge to assume a very different probability for variations above or below the commonly assumed average of 0.82,[2] the errors incurred by assuming the latter can very well compensate each other for all practical purposes. It is probably true moreover that the variations in re-

[2]A caloric equivalent of 4.825 per liter of oxygen has been used, as is customary in calculating the heat-production from the measurement of the oxygen alone. The actual calculations have used Carpenter's tables, based on the values given by Lusk's modification of Zuntz and Schumberg for a non-protein R. Q. of 0.82. (Ref: Carpenter, T. M.,: Tables, Factors and Formulas for Computing Respiratory Exchange and Biological Transformations of Energy, *Carnegie Inst. of Wash. Publ.* 303A, 1924.) Dr. BuBois (personal communication, 1931) states that this value of oxygen corresponds more nearly to an average R. Q. of 0.86, if we take the protein factor into consideration. The validity of the assumption is not affected.

ported R. Q. due to experimental error greatly exceed its true physiological variability. In the hands of all but a very few workers, then, the substituting of the technique of gas analysis for that of the simple oxygen determination, we feel is apt to result in a net loss, rather than gain, in the dependability of the final results.

Single runs were customarily of 8-minutes' duration, and at least two acceptable runs were required for each test. The lowest run was accepted as determining the rate for any given test, but all accepted runs were figured separately for the information to be gained by their comparison. This is our routine practice, since it would hardly seem as though the subject's actual metabolical level would change materially within a short basal period, whereas whatever technical errors could conceivably influence the results with the technique we use, as well as the less readily ruled-out failure of the subject to relax, would tend to increase, rather than decrease the readings.

Readings of the pulse-rate were made near the beginning and end of each run for supplementary evidence as to the degree of relaxation of the subject. The machines were of course maintained in good condition and kept at all times free from leaks or other defects. During each run a confirmatory leak-test was made by Benedict's expedient of placing a weight of about 50 gm. on the spirometer midway through the run, in which case a leak in any of the connections would be detected by a change in slope of the respiratory tracing from the point where the weight was added.

The criterion for acceptability of a given test was not any pre-conceived standard of closeness of agreement between the constituent runs within the test nor, within any reasonable limits, of consistency of results from one test to another or with any of the existing standards of normality. Rather, the stand was taken that unless there was demonstrated some definite and convincing reason for disqualifying the subject or discarding the test, the latter must be retained; and that the first accepted test on each of the subjects was to be used as the basis of the final analyses, regardless of whether subsequent tests on the same individuals turned out to be better or worse in any detail. This plan was adopted rather than either of the two obvious alternatives that had to be considered,—i. e., of averaging all the available tests for each subject, or choosing there-from the lowest in each case as probably representing more nearly true "basal" conditions. The idea that underlay this choice was that we were interested primarily in arriving at some concrete ideas, not of ideal rates of heat-production, and not only of their average probable level; but rather in the whole *normal range* of variability within which *individual* determinations might reasonably be expected to fall for subjects of the general types we have to deal with and to study under comparable well-controlled practical conditions.

Measurements that were made. Our tentative goal before undertaking any extensive analyses was 100 cases, to be distributed equally among the four years from 17 through 20, for whom the need of adequate standards has been most keenly felt. It chanced that the collaboration of the newly-organized statistical service of the Department of Mathematics was placed at our disposal when we were within a short distance of this goal, and the final series submitted to the analyses upon which our prediction standard was based included 97 individuals, among whom ages and accepted tests were distributed as follows:

Age	*Tests*	*Subjects*
17	40	25
18	49	25
19	34	22
20	40	25
Totals	*163*	*97*

The individual measurements which were made upon this group are given in Table I.

A few additional subjects who were accepted after the analyses were under way or after the quotas for their year had been filled are included in the supplementary series of Wisconsin subjects who were used for later comparisons.

Of the 97 subjects in the standard series, 58 were accepted twice and 6 three times. Intervals between tests were 3 weeks in 35, and 7 to 55 days in the remainder. The range of total intervals in cases taken three times was 26 days to 19½ months.

Four of the girls appear in two different age-groups, and so are each counted as two different individuals in the analyses. Three of these were drawn the second time in response to a special appeal to their Physiology class to help fill the 19 and

20 year old groups. They were Physical Education students who as usual were interested and ready to help. The fourth was called in for a third test because she had appeared poorly relaxed in her second, although her first had been entirely acceptable. By the time she was obtained the third time more than 15 months had passed since her second test (and 16 since her first), so that she now belonged in the next higher age group. Since there was no valid objection to either her first or third test, it was felt that both should be retained. Since 16 months was the shortest interval between any of the first tests at the different ages it was held legitimate to consider them as representing different individuals for purposes of analysis in these few cases. Furthermore, of course most of the measurements on the girls had changed during the intervals.

Age was taken to the nearest birthday. The superscripts with age given in the data tables refer to the 1st or 2nd half of the designated year,—i. e., the subjects marked 16^2 or 17^1 would all have been considered as 17.

Weight was calculated without clothing. The subjects were instructed to undress and lie down for the rest-period in gowns that were furnished, and the known weight of these gowns was allowed for in recording the weight of the subjects.

Height was measured both standing and sitting for almost all of the subjects, with the idea that perhaps, in view of the emphasis that has been placed upon the value of the sitting height by various observers, it might prove a more representative measurement for use in predicting the metabolism than the standing height usually employed. The results of comparisons in this regard will be mentioned in connection with the statistical analysis (p. 278).

Calories per 24 hours represent the "basal" heat-production calculated from the oxygen consumption as measured during the lowest run within any given test, by the usual assumption of the average post-absorptive respiratory quotient for which the calorific equivalent of oxygen is 0.004825 per cc. (See foot-note, p. 260.)

In calculating *Calories per Square Meter* per hour, the surface area is determined by the height-weight chart of DuBois and DuBois.

TABLE I. *Measurements on 97 subjects used for the University of Wisconsin standard. In the second column, headed "Age", the small numbers printed as superscripts refer to the first or second half of the designated year.*

Record No.	Age	Weight in kg.	Standing height in cm.	Sitting Ht. in cm.	Cals./ 24 hrs.	Cals./ sq. m./ hour	Rate according to prediction of: Aub. & DuBois	Harris & Ben. extrap.	Benedict, girls 12–20	Univ. Wisc., girls 17–20
a	17^2	56.7	166.5	85	1328	33.95	—15	— 7	+ 7	± 0
b	17^1	63.6	162	85	1501	37.45	— 6	+ 1	+ 8	+ 9
c	17^2	57.6	168	87	1417	35.78	—11	— 2	+13	+ 6
	17^2	58.7	168	87	1370	34.18	—15	— 5	+ 7	+ 1
d	17^2	61.8	161	88	1250	31.57	—21	—13	— 7	— 8
e	17^2	53.1	166.5	89	1261	33.05	—17	— 9	+ 9	— 2
	17^2	54	166	89	1356	35.31	—12	— 3	+15	+ 5
f	17^2	74.4	176	88	1446	31.71	—21	—10	—11	— 6
	17^2	75.1	176.5	88	1463	31.92	—20	—10	—11	— 6
g	17^2	62.2	166	84	1320	32.55	—19	—11	— 3	— 4
h	17^2	56.1	172	90	1351	33.91	—15	— 6	+11	+ 1
i	17^2	51	171	90.5	1323	34.67	—13	— 4	+19	+ 3
	17^2	51.5	171	90	1334	34.74	—13	— 4	+19	+ 4
j	17^2	56.5	161	86.5	1289	33.78	—16	— 9	+ 5	+ 1
	17^2	57	161	86	1365	35.55	—11	— 4	+10	+ 4
k	17^2	67.7	165.5		1606	38.46	— 4	+ 5	+ 9	+12
	17^2	66.7	165.5	88.5	1591	38.32	— 4	+ 5	+ 9	+11
l	17^2	47.3	157	80	1166	33.74	—16	—12	+13	— 2
	17^2	47.2	157	81	1080	31.25	—22	—18	+ 5	— 9
m	17^1	55	163	87	1133	29.88	—25	—19	— 6	—13
	17^1	55.6	162.5	87	1094	28.85	—28	—22	—10	—16
n	17^2	55.6	161.5	85	1416	37.34	— 7	+ 1	+17	+ 9
	17^2	55.4	162	85	1262	33.28	—17	—10	+ 4	— 3
o	17^1	55.7	164	83.5	1289	33.57	—16	— 9	+ 6	— 1
	17^1	57.8	164	84	1264	32.51	—19	—12	± 0	— 5
p	17^2	53.3	168	88	1418	36.93	— 8	+ 2	+22	+10
	17^2	56.3	168	88	1278	32.47	—19	—10	+ 4	— 4
q	17^2	53.3	170	88	1251	32.38	—19	—11	+ 8	— 4
r	17^2	51.1	165.5	87	1390	37.37	— 7	+ 1	+25	+10
	17^2	51.7	165	87	1307	35.13	—12	— 5	+16	+ 3
s	17^1	42.4	148	75.5	1098	34.66	—13	—13	+19	— 1
	17^1	43.4	147.5	75.5	1027	32.42	—19	—19	+ 9	— 8
t	17^2	49	162	88	1127	31.30	—22	—16	+ 6	— 8
u	17^2	46.9	157	84.5	1291	37.35	— 7	— 2	+26	+ 9
	17^2	46.1	157	84	1238	36.07	—10	— 5	+23	+ 5
v	17^1	55.7	173	90.5	1382	34.69	—13	— 3	+14	+ 4
	17^1	57.8	173	90.5	1390	34.48	—14	— 4	+10	+ 2
w	17^2	57.7	164	88	1359	34.95	—13	— 5	+ 8	+ 2
x	17^2	44.8	165	83	1199	33.98	—15	— 8	+23	+ 1
y	17^2	66.3	169	89	1321	31.28	—22	—13	— 9	— 8
1	18^2	56.9	166	84.5	1266	32.36	—15	—11	+ 2	— 4
2	18^2	47.1	159	88.5	1171	33.65	—11	—11	+14	— 2
	18^2	47	159	88.5	1098	31.55	—17	—17	+ 7	— 8
3	18^2	56.1	160.5	83	1227	32.36	—15	—13	± 0	— 6
	18^2	57.2	160	83	1252	32.81	—14	—11	± 0	— 4
4	18^1	63.6	169		1490	36.10	—10	± 0	+ 8	+ 6
	18^1	63.8	169	87	1384	33.53	—16	— 7	— 1	— 2
5	18^1	57.8	160.5	84.5	1203	31.33	—22	—15	— 5	— 9
	18^1	58.4	160.5	84	1209	31.29	—20	—14	— 3	— 9

TABLE I. *Continued*

Record No.	Age	Weight in kg.	Standing height in cm.	Sitting Ht. in cm.	Cals./ 24 hrs.	Cals./ sq. m./ hour	Rate according to prediction of: Aub. & Du-Bois	Harris & Ben. extrap.	Benedict, girls 12–20	Univ. Wisc., girls 17–20
6	18^1	43.6	152	81	1215	37.23	— 7	— 4	+28	+ 7
	18^1	43.1	152	81.5	1251	38.61	— 3	— 1	+33	+10
7	18^2	61.9	171	90	1562	38.06	± 0	+ 6	+16	+12
	18^2	62.2	171	90	1455	35.25	— 7	— 2	+ 7	+ 4
8	18^1	60	167	88	1396	35.04	—12	— 4	+ 7	+ 3
	18^1	64.4	167	88.5	1376	33.33	—17	— 8	— 8	— 2
9	18^1	49.6	170	89.5	1373	36.37	— 8	+ 1	+27	+ 9
	18^1	50.5	170.5	89.5	1337	35.26	—12	— 2	+21	+ 5
10	18^1	56.3	166.5	87.5	1292	33.03	—17	—10	+ 5	— 2
	18^1	57.1	166.5	87.0	1370	34.81	—13	— 4	+10	+ 3
11	18^2	56.2	162.5	86	1456	37.92	±0	+ 3	+19	+11
	18^2	58.2	162.5	86	1404	36.11	— 5	— 2	+11	+ 6
12	18^2	60.7	170	91.5	1337	32.77	—14	— 9	+ 1	— 3
	18^2	60.4	170	92.3	1345	33.56	—13	— 8	+ 2	— 2
13	18^2	55.3	160	82	1262	33.71	—11	—10	+ 5	— 2
	18^2	54.4	160	82	1236	33.23	—13	—11	+ 4	— 3
14	18^2	61.7	157.5	88	1550	39.87	+ 5	+ 7	+15	+15
	18^2	63.0	157.5	88	1466	37.48	— 1	± 0	+ 7	+ 8
15	18^1	54.0	165	89	1312	34.38	—14	— 6	+11	+ 2
	18^1	54.4	165	88	1289	33.57	—16	— 8	+ 9	— 1
16	18^2	52.9	166	88	1445	37.87	± 0	+ 4	+25	+13
	18^2	53.1	166.5	88	1556	40.78	+ 7	+12	+34	+21
17	18^1	63.1	168	92	1404	34.21	—15	— 6	+ 2	± 0
	18^1	64.3	168	92	1370	33.00	—18	— 9	— 2	— 3
18	18^2	50.9	150	82	1285	37.18	— 2	— 4	+16	+ 6
	18^2	51.0	150	82	1337	38.69	+ 2	± 0	+20	+10
19	18^1	52.9	154.5	86	1196	33.22	—17	—12	+ 4	— 4
	18^1	52.6	154.0	86	1164	32.55	—19	—14	+ 2	— 6
20	18^2	66.4	157	82.5	1387	34.60	— 9	— 7	— 4	— 1
	18^2	66.2	157	82	1409	35.15	— 7	— 6	— 2	+ 1
21	18^2	55.5	163	87	1268	33.23	—13	—10	+ 5	— 3
	18^2	55.3	163	87	1109	29.25	—23	—21	— 8	—15
22	18^2	56.6	154	84	1187	32.33	—15	—15	— 4	— 7
	18^2	57.3	154	84	1210	32.74	—14	—14	— 3	— 6
23	18^2	52.6	155	85	1432	39.78	+ 5	+ 5	+25	+15
	18^2	53.5	156	84.5	1302	35.93	— 5	— 5	+12	+ 4
24	18^2	47.3	162	82	1258	35.42	— 7	— 5	+22	+ 4
	18^2	47.4	162	83	1208	34.01	—11	— 9	+17	± 0
25	18^1	53.8	173	93	1251	31.98	—20	—11	+ 7	— 5
	18^1	54.8	173.5	93	1285	32.45	—19	— 9	+ 8	— 3
1	19^1	63.7	171	86	1377	32.98	—13	— 8	— 1	— 3
2	19^2	49.8	161.5	84	1133	31.26	—18	—15	+ 4	— 8
	19^2	50.4	161	84	1201	32.92	—13	—11	+ 9	— 3
3	19^1	57.4	166	88	1420	36.30	— 5	± 0	+14	+ 7
	19^1	57.4	166	88	1418	36.25	— 5	± 0	+13	+ 7
4	19^1	56.0	165	84	1296	33.54	—12	— 8	+ 6	— 1
5	19^1	64.4	172	87	1252	29.64	—22	—17	—11	—12
	19^1	65.3	172.5	87	1264	29.75	—22	—16	—11	—12
6	19^2	57.8	168	85	1296	32.73	—14	— 9	+ 3	— 3
7	19^1	59	160.5	87	1245	32.22	—15	—13	— 3	— 6

TABLE I. *Continued*

Record No.	Age	Weight in kg.	Standing height in cm.	Sitting Ht. in cm.	Cals./ 24 hrs.	Cals./ sq. m./ hour	Rate according to prediction of: Aub. & Du-Bois	Harris & Ben. extrap.	Benedict, girls 12–20	Univ. Wisc., girls 17–20
8	19[1]	57.8	168	92	1266	32.17	—15	—12	± 0	— 6
	19[1]	60.1	168	91.5	1303	32.32	—15	—10	— 1	— 5
9	19[1]	48.2	160.5	83	1168	32.88	—14	—12	+11	— 4
	19[1]	49.1	160	82.5	1231	34.43	— 9	— 8	+15	+ 1
10	19[1]	54	159	84	1383	37.42	— 2	± 0	+18	+ 9
11	19[1]	48.8	153	81	1208	35.20	— 7	— 8	+14	+ 1
	19[1]	49.4	153	81	1299	37.59	— 1	— 2	+21	+ 8
	19[1]	49.2	152	81	1293	37.68	— 2	— 2	+21	+ 8
12	19[1]	49.9	160	85	1224	34.00	—11	— 9	+13	— 1
13	19[2]	63.2	168	86	1271	30.97	—19	—14	— 8	— 9
	19[2]	64.2	168	86	1248	30.23	—20	—16	—11	—11
14	19[1]	52.7	161.5	85	1282	34.46	— 9	— 6	+12	+ 1
	19[1]	53.1	161.5	85	1326	35.65	— 7	— 4	+14	+ 4
15	19[2]	52.1	164.5		1274	34.03	—10	— 7	+12	± 0
	19[2]	53.6	164.5	89	1258	33.39	—12	— 9	+ 8	+ 2
16	19[2]	52.5	168	87	1245	32.63	—14	—10	+ 9	— 3
17	19[1]	53.3	167	86	1435	37.60	— 1	+ 4	+24	+11
	19[1]	53.6	166	85	1210	31.71	—17	—13	+ 4	— 6
18	19[1]	50.5	159	82	1278	35.50	— 7	— 5	+16	+ 3
	19[1]	50.2	159	82	1303	36.20	— 5	— 3	+19	+ 6
19	19[2]	50.2	174	94	1268	33.02	—13	— 7	+16	— 1
20	19[1]	57.7	168	89	1344	33.94	—11	— 6	+ 7	± 0
21	19[1]	47	159		1223	35.14	— 7	— 7	+19	+ 2
22	19[2]	56	172.5		1330	33.38	—12	— 7	+ 9	— 1
I	20[1]	59.4	162.5	85	1217	30.86	—18	—15	— 6	— 9
II	20[1]	45.8	148	81	1081	33.36	—12	—15	+ 8	— 6
	20[1]	46.4	148	81.5	1112	33.58	—11	—13	+10	— 4
III	20[1]	82	175	95	1816	38.41	+ 1	+ 8	+ 2	+12
	20[1]	83	175	95	1662	24.98	— 8	— 1	— 8	+ 2
IV	20[2]	61.1	174	90	1404	33.63	— 9	— 4	+ 5	+ 1
	20[2]	60.8	174	91	1383	33.31	—10	— 6	+ 4	— 1
V	20[2]	52.9	161	81	1298	35.12	— 5	— 5	+13	+ 3
VI	20[1]	57.5	165	87	1215	31.06	—18	—14	— 4	— 9
VII	20[2]	57.8	170	88	1417	35.57	— 4	— 1	+12	+ 5
	20[2]	58.7	171	88	1370	33.98	— 8	— 5	+ 7	+ 1
VIII	20[2]	52.1	155	87	1299	36.33	— 2	— 4	+14	+ 5
IX	20[2]	52	166	90	1104	29.30	—21	—19	— 3	—13
	20[2]	52.3	166	90	1137	30.18	—18	—17	± 0	—11
X	20[1]	55.2	166.5	86	1335	34.55	— 9	— 5	+11	+ 2
	20[1]	55.7	166.5	86	1298	33.38	—12	— 8	+ 7	— 1
XI	20[1]	57.5	161.5	87	1230	32.03	—16	—13	— 2	— 7
	20[1]	56.3	161	87	1208	31.65	—17	—14	— 2	— 7
XII	20[1]	53.9	160.5	83	1216	32.69	—14	—12	+ 4	— 5
	20[1]	54.6	160	84	1209	32.29	—15	—12	+ 2	— 6
XIII	20[2]	52.4	163	84	1146	30.81	—17	—16	± 0	— 9
	20[2]	53.4	163	84	1196	31.94	—14	—13	+ 3	— 6
XIV	20[2]	52.2	161	85	1157	31.30	—15	—15	+ 2	— 8
	20[2]	51.3	160	84	1237	33.91	— 8	— 8	+11	— 1

TABLE I. *Continued*

Record No.	Age	Weight in kg.	Standing height in cm.	Sitting Ht. in cm.	Cals./ 24 hrs.	Cals./ sq. m./ hour	Rate according to prediction of			
							Aub. & DuBois	Harris & Ben. extrap.	Benedict, girls 12–20	Univ. Wisc., girls 17–20
XV	20[1]	51.7	166.5	86.5	1323	35.11	— 8	— 3	+17	+ 4
XVI	20[2]	58.8	161.5	90	1251	32.18	—13	—12	— 2	— 6
XVII	20[1]	50.5	158	86	1247	34.64	— 9	— 7	+13	+ 1
	20[1]	51	158	86	1305	36.25	— 5	— 3	+17	+ 5
	20[1]	52.4			1181	32.38	—13	—13	+ 3	— 6
XVIII	20[1]	55.7	166.5	88	1387	35.68	— 6	— 1	+14	+ 6
	20[1]	56	166.5	88	1379	35.47	— 7	— 2	+13	+ 5
XIX	20[2]	57.6	165	89	1370	35.02	— 5	— 3	+ 9	+ 3
	20[2]	56.5	165	89	1163	29.91	—19	—17	— 6	—12
XX	20[1]	51	165	84	1195	32.13	—13	—13	+ 8	— 5
	20[2]	50.2	165	84	1152	31.17	—16	—15	+ 5	— 8
XXI	20[1]	59	166	84	1289	32.55	—14	—10	± 0	— 4
XXII	20[1]	50	159	81	1281	35.82	— 3	— 4	+18	+ 4
XXIII	20[1]	53.3	156.5	85	1223	33.53	—12	—10	+ 5	— 3
XXIV	20[2]	56.4	164.5	89	1383	35.57	— 4	— 2	+12	+ 5
XXV	20[2]	64.3	166	88	1295	31.37	—15	—13	— 8	— 8

Metabolic Rates represent the customary percentage deviation of the measured basal heat-production from a given prediction for the individual. The comparisons based on their calculation according to the various available predictions are reserved for the final section on analysis of data.

ANALYSIS OF DATA

The analyses which we have carried out may be presented under three general heads:

I. Generalizations and comparisons among the data on the original 97 individuals upon which our prediction standard was built.

II. Statistical analysis and the final prediction standard based on the data from this group.

III. Testing of this standard in comparison with the others that are available for this age-range:

1) Applied to the individuals of our own standard series; and finally

2) Applied to a comparable series of different individuals upon whom data have become available partly

from additional studies here, and partly from data given in the recent literature by other investigators from widely different localities.

The various comparisons will be offered wherever possible in the form of summary tables, with only brief additional discussion. When metabolic rates are given in these general comparisons, they are figured according to our own prediction (based on this group), and refer unless otherwise stated to the lowest value found for each individual.

I. *General Studies of the Data within the Wisconsin Series.*

Geographical Distribution of Material. Most of the students, (80%) as has been indicated were drafted from newly entering classes, so that their prevailing living conditions can be taken as determined by the places which they called their homes. Wisconsin material of course predominated very largely (58 of the 97); but it was interesting to note that the rest of the group represented 16 other states. Of these, as would be expected, other mid-western states were in the majority. Illinois furnished 11, Ohio 8, Indiana 3, Iowa and Michigan each 2. Of the rest, 2 were from Pennsylvania, and one each from Mississippi, Missouri, Kansas, Alabama, New Jersey, New York, Idaho, New Hampshire, Virginia and California. An effort was made to subdivide these into goitrous and non-goitrous sources, using the maps of McClendon *(6)* as guides. The number of subjects from the former so far exceeded the latter that no fair comparisons could be made. The comparative showings, however, are appended in connection with the thyroid observations.

Classification by Colleges was made chiefly to find how our group would compare with the student body at large, and further, how large a percentage of the total was represented by Physical Education students, since these had seemed to be easier to obtain as subjects than other girls in general. This is the only feature of the classification which would seem to merit quoting. The Physical Education group was found to have constituted just 1/3 (32 out of 96 who could be classified) of the total, which is three times the proportion in a representative Wisconsin freshman class, and six times that among all women registered at the time of the study. This preponderance can be attributed to several factors: the physical fitness of these girls, their early registration for their physical examinations, and their consistent willingness to cooperate. We were interested to know, in view of the various comparisons that have been recorded which show definite influence on the metabolic level of such factors as muscular development and degree of activity, whether these girls as a group would show any such distinctions from the relatively non-athletically inclined students.

A very general comparison in the matter of heat-production which was all that was felt warranted, showed practically the same percentage of plus and minus rates among the athletic and non-athletic groups. It is true, of course, that these girls were really just starting their intensive athletic careers, though they must have inclined naturally to more vigorous lives than the average. Some investigators have maintained that individuals who lead a very active life show greater variability in metabolic rate from day to day than do those of a more sedentary occupation. In a study of this kind no such tendency could be detected, and it might well be the case that in comparison with other untrained subjects it would be more than counteracted in such a group as this by the stabilizing effect of superior cooperativeness and understanding of the aims of the experiments.

Thyroid Observations. A survey of the notes made on cervical inspection and palpation of the subjects in our standard series resulted in their grouping under 4 rough classifications as to thyroid condition. The groupings have been designated as follows: "0" indicates that neither isthmus nor lobes were palpated; "1" that lobes or (and) isthmus were just palpated but not seen; "2" that either or both were considered both palpable and slightly visible; and "3" that there was definite prominence of the gland, amounting to what could be considered slight or moderate degree of goitre. These observations are not meant to indicate that any sharp classifications were or could be attempted under the conditions of the examinations. They are grouped and presented merely for any general interest they may suggest, or comparisons for future studies.

Groupings have been made in two ways: Table II gives distributions according to geographic sources of subjects, together with the types of metabolic rates found in these groups. Table

III gives the relation between thyroid observations and (a) ages; and (b) metabolic rates in the group as a whole.

Reference to Table II will show that the slighter degrees of prominence of the gland are not confined to subjects from the so-called goitre regions. To be sure, it was not possible by the manner in which the survey was undertaken to establish how long the reported residences had been in effect. Comparisons with a group of girls of the same age who have grown up in strictly non-goitrous regions would be interesting. That both

TABLE II *Thyroid observations according to geographical source of subjects. Wisconsin Standard Series.*

From homes in	States	Number of subjects	Freq. of various thyroid classifications (See p. 00)	Frequency of different levels of metabolic rate
Group I: Goitrous Areas	Wis. Ohio Indiana Iowa Michigan Idaho	74	"0"...... 1* "1"......26 "2"......24 "3"......19	0 to + 5: 16 + 6 to +10: 8 } 25 +13: 1 0 to — 5: 22 — 6 to —10: 23 } 49 —11 to —16: 4
Group II: Non-Goitrous Areas	Miss. Missouri Kansas Alabama New Jersey Virginia California	7	"0"...... 1 "1"...... 4 "2"...... 1 "3"...... 0	0 to + 5: 1 + 6 to +10: 1 } 2 0 to — 5: 4 — 6 to —10: 1 } 5
Group III: Areas not Possible to Classify	Illinois New York Pa. New Hamp.	13	"0"...... 0 "1"...... 8 "2"...... 3 "3"...... 2†	

*Michigan: reported Iodine in drinking water.
†Pennsylvania: 1; Illinois: 1.

the lowest and the highest rates observed for the whole group occurred in subjects from the goitrous areas may or may not be entirely coincidental with the greater number of subjects from this group of states.

The most striking feature shown in Table III is the exceeding rarity of entirely negative thyroids,—i. e., cases in which neither isthmus nor lobes were found visible or palpable. There were only two such cases in our whole series of 97 girls.

TABLE III *Thyroid observations according to (a) age; and (b) metabolic rates. Wisconsin Standard Series.*

(a) Ages	"0" Neither isth. nor lobes palpable	"1" Isth. or (&) lobes just palpable	"2" Isth. or (&) lobes also visible	"3" "Goitre" (more definite than "2")
17:	1	12	4	8
18:	....	8	14	3
19:	....	11	4	6
20:	1	7	6	7
TOTALS:	2 (2%)	38 (41%)	28 (30%)	24 (26%)
(b) Metabolic rates	"0"	"1"	"2"	"3"
0.....+5:	2	11	8	6
+6....+10:	....	2	3	4
Higher than +10:	....	....	1 (+13)	....
Plus rates:	2 (2%)	13 (14%)	12 (13%)	10 (11%)
0....— 5:	....	14	6	6
—6....—10:	....	9	8	6
Lower than —10:	....	2 (—11, —16)	2 (—12, —15)	2 (—11, —12)
Minus rates:	0	25 (27%)	16 (17%)	14 (15%)

Total = 92. (One not classified. Three are individuals who appear in two different age-groups, and hence are only classified once)

Nearly 1/3 of these subjects had visible glands. More than 1/4 showed what could be called slight or moderate goitre. They were of course as far as could be ascertained free from any suspicion of thyroid symptoms, else they would not have been accepted as normal subjects for the study.

Plus and minus metabolic rates are quite equally distributed in groups "2" and "3". There are definitely more minus than plus rates among the negative and practically negative groups ("0" and "1").

Variations between Duplicate Runs in the Same Test and between Different Tests on the Same Individuals: *(a) Duplicate Runs within Tests.* The closeness of agreement between duplicate runs in a given test is an index of the technical acceptability of the test and of the success with which relaxation has been maintained by the subject. Anyone who works in the field of course realizes that incidental and wholly unaccountable factors of variation make exact agreement between duplicate runs rare. Many laboratories specify agreement within 5% of the duplicate runs within a test as constituting a satisfactory test. In dealing with the general run of sick patients the practical allowance is usually extended to 10%. We purposely refrained from specifying any such arbitrary standards of acceptability in advance in order to test by impartial comparisons the frequency with which these expectations built up in hospital practice would be fulfilled in our series of untrained subjects in normal health.

In Table IV are summarized comparisons between successive runs in all of the accepted tests on the individuals of our standard series plus the seven extra subjects from the same group.

There is doubtless a larger proportion of perfect agreement and small differences in this series than one could expect in any clinical group of comparable size; but our general impression gained from experience is fulfilled, namely that a large majority of well-controlled tests would agree within 5%, while there would always be a few larger differences. To sum up the table

TABLE IV. *Agreement of duplicate runs within tests*. Wisconsin Standard Series +7 extra subjects from the same group.*

Tests in which runs after the 1st were the lowest obtained	Tests in which the first runs were the lowest obtained	Cumulative groupings	
		No.	Proportion
No difference.......26		26	15%
Deviations 0.5 to 1%.......12	Deviations 0.5 to 1%...... 8	46	27%
Deviations 1 to 3%.........34	Deviations 1 to 3%........42	122	72%
Deviations 3 to 5%.........13	Deviations 3 to 5%........14	149	88%
Deviations 5 to 10%........ 3	Deviations 5 to 10%.......18	170	100%
Total.........62	Total.........82		

*The percentage deviations are figured in each case on the basis of the low run. They are therefore larger than if they had been given as deviations from their mean.

itself: it is seen that all of the duplicates agree within 10%, about 9/10 within 5%, and about 3/4 within 3%.

It seems rather surprising that notably more cases showed the lowest values in the first runs. One might perhaps conclude from this that on the whole the preliminary rest-period had succeeded in building up a good degree of relaxation and that there was seldom initial tenseness because of the strangeness of the procedure. It is to be remembered that first runs for most of these subjects meant absolutely the first experience with the test. It is to be noted further, that most of the largest discrepancies (5—10% difference between successive runs) were among the group who gave the lowest readings in the first runs. Perhaps these were the lively or excitable types who found it difficult to remain perfectly quiet for long at a time. They would correspond to the class of irritable and easily fatigued patients with whom nothing is to be gained by too persistent striving for good results at any one appointment.

(b) *Repeated Tests on Same Individuals.* For intelligent practical use of the metabolism test it is essential to have some working conception of the range of variability of rates that one can reasonably expect to find at different times in the same individual. This tendency to vary evidently entirely independently of observational errors, is of course itself extremely variable in subjects or groups of subjects of different types, degrees of training, or in different circumstances.

DuBois considers *(7, p. 130 f.)* that one may expect differences of about the same order of magnitude in almost any large series of tests made on the same man over a long period of time as one finds in a large group of normal men of the same age and size,—i. e., almost all of the determinations will fall within 10% of the average, with a few variations between 10 and 15%. Some of the records of individual series which he quotes showed striking and consistent uniformity, though occasional rates that deviated to an extreme degree from the mean of the series without apparent reason are mentioned in at least two of the classical series. He quotes Magnus-Levy as pointing out the significance of this, namely that we cannot trust too much in the tests of any one day.

Griffith et al *(8)* in a recent extensive study of 5 normals list the extreme "intra-individual variabilities" that they found as falling between 8.6 and 11.3% of the respective yearly *means.* They made 55-246 determinations apiece on the 5 subjects, over periods of 1-2 years.

Comparable conclusions cannot be drawn from studies such as ours, of course, in which each individual was examined only two or three times. However the summary of such a study of a significantly large and representative group of untrained subjects should offer a fairly logical basis of comparison for an average group of untrained patients of the same types for which the series is designed to serve as standard.

Table V summarizes the findings in our standard series.

TABLE V. *Agreement between repeated tests on the same individuals* Wisconsin Standard Series.*

Successive tests lower than first	Successive tests higher than first	Cumulative groupings	
		No.	Proportion
Deviations 0 to 1%......... 5	Deviations 0 to 1%........ 5	10	14%
Deviations 1 to 3%.........12	Deviations 1 to 3%........11	33	47%
Deviations 3 to 5%......... 8	Deviations 3 to 5%........ 4	45	64%
Deviations 5 to 10%........11	Deviations 5 to 10%....... 9	65	93%
Larger Differences.. 4	Larger Differences. 1		
Total.........40	Total.........30		

*Differences are figured on the basis of the calories calculated in the first accepted test for each individual, i. e., they represent successive *changes* in measured heat-production for the individual, and *not differences from a mean.*

The total number represents the changes in 6 third tests, in addition to tests repeated once.

That there is a majority tendency toward lower rates in tests subsequent to the first one undoubtedly indicates in part the true effect of experience with the routine. The significance of this factor is minimized for the present group, at least, by the smallness of the majority that showed downward changes, and by the similar magnitudes and distribution of the changes in the two groups. This does not hold true, however, for the larger changes (greater than 10%), which were found with one unimportant exception in the group whose rates decreased with practice. These larger changes no doubt occurred in the more nervous type of subject, and in at least one or two cases where there was a definite suggestion that the girl had been worried the first time by a suspicion that she had been singled out for the test because she wasn't as normal as she was told she was! This of course is a mild example of the "mental hazards" that operate to elevate the rates in hospital cases. It suggests again the need for caution in judging borderline rates.

In summarizing *inter*-individual variations of rates in the final section of the present study (Table XVI) it is found that 87% of the rates *in first tests* of this same group fell within plus or minus 10% of the average normal prediction by our standard and 100% within plus or minus 15%. Corresponding figures for a group of other normal girls of the same ages collected for comparisons are 86 and 96% respectively. Allowing for the different ways in which the two types of deviations have been calculated, it appears that for a normal group at least it is not necessary to expect quite as large a range of intra- as inter-individual variability in making practical use of the test. If observations are repeated frequently enough, occasional larger deviations can be expected.

Pulse-Rates. Readings of the individual pulse-rates have not been included in our tables of fundamental data because the lability of this measurement and the fact that it varies only roughly parallel with the metabolic rates from one individual to another, are matters of common observation. For any given individual of course the general type of pulse and any observed tendency for it to change markedly during a metabolism test are valuable supplementary data for the operator and the clinician. For the present study it has seemed of interest only to present a summary of the average and extreme pulse-rates that were noted in these normal girls, for general comparison with other groups that have been studied. This summary is given in Table VI.

It is observed that the group averages for pulse-rate throughout are only slightly lower or remain the same in tests after the original ones. (The pulse-rates for first tests were averaged for this comparison of course only for those subjects who had repeat tests.) This together with the low range of rates

TABLE VI. *Average and extreme pulse-rates by groups. All tests on Wisconsin Standard Series. Each rate represents the average of counts made near the beginning and near the end of each run, and refers to the lowest run (or the average in two runs in which the metabolic rates may have agreed exactly) for a given test.*

Age group	Summary of findings
17 yrs.	Results of 25 standard tests: Average: 69; extremes: 48-86 Averages from 15 repeated tests: Original test: 70; later: 68.
18 yrs.	Results of 25 standard tests: Average: 69; extremes: 53-86. Averages from 24 repeated tests: Original test: 69; later: 69.
19 yrs.	Results of 22 standard tests: Average: 68; extremes: 43-89. Averages from 11 repeated tests: Original test: 71; later: 63.
20 yrs.	Results of 25 standard tests: Average: 72; extremes: 59-88. Averages from 14 repeated tests: Original test: 71; later: 69.
17 to 20 years inclusive	Results of 97 standard tests: Average: 70; extremes: 43-89. Averages from 64 repeated tests: Original test: 70; later: 68.

can be taken as further evidence of a satisfactory degree of repose on the part of the subjects as a whole.

As was the expectation for given *individuals*, deviations in pulse-rate did not by any means always occur parallel in direction with changes in metabolic rate. The lowest pulse-rates were not found invariably to be associated with the lowest metabolic rates, either with the same subjects in repeated tests, or moreover in the series as a whole. Though different combinations of forces are evidently effective to different degrees in causing temporary fluctuations (within normal limits) in these two physiological functions, we know of course that their correlation is much more instructive when we come to deal with cases of pathological metabolism.

A further point is of passing interest,—namely, the prevalence of low pulse rates throughout our group in comparison with what is generally considered as "normal" for a girl or woman. Though the breathing of pure oxygen may have a tendency to lower the pulse-rate, personal observations suggest that this is probably not a factor of significance in such short-period experiments and with normal individuals. A more logical explanation would seem to be the fact that our common conceptions of "normality" are founded upon observations made in non-basal conditions, whereas not enough truly basal measurements have been recorded to impress themselves on our manner of thinking.

It is interesting to note that the minimum which we found in three of our four groups of healthy American girls is lower than the minimum (54) found by MacLeod, Crofts and Benedict *(9)* in their study of 9 Oriental young women who had lived in this country for from 15 months to 4½ years. The unmistakable *average* tendency for what we consider low levels of such vital functions as pulse and metabolism in Orientals, even after prolonged exposure to our conditions of living, is often referred to as an indication of a constitutionally superior capacity for repose on the part of these races, rather than an essential difference in metabolic processes. It would appear, then, that a good many of our girls were quite comparable to the Orientals in this respect.

The more formal analyses upon which our prediction standard was based are summarized in the following section.

II. Statistical Analyses of Data and the Final Prediction Standard.

It was decided to use the first accepted test only, on each subject for the standard, so only these were submitted to the formal analyses. Our reasons for this course have been sufficiently indicated in the foregoing discussion, but it is well to keep the fact in mind throughout any comparisons that are made.

A survey of the data on our first two groups of 25 each that were completed — the 18 and 20 year groups — convinced Professor Ingraham that 25 subjects of any single age were sufficient to justify some rather extensive preliminary analyses.

These preliminary analyses, together with consideration of what has already been accomplished in the field, and of the nature and needs of the specific problem at hand, indicated quite definitely what types of study would be profitable to continue and what should be dropped. The chief decisions thus arrived at were three: (1) That the method of ordinary linear correlation was suitable for expressing the relations indicated between metabolism and body measurements for the groups studied. (2) That the use of the *sitting height* measurements did not add anything of value to the study. And (3) That the volume of data on hand, though decidedly large as studies of this sort go, and of definite statistical significance, was still not by any means extensive enough to define with certainty the *age-factor* within the narrow range of ages of the present study. These points may bear some further brief consideration:

1. The Method of analysis. Two general types of formulas that are suggested for studies of this sort were investigated, — In one of the "normal" metabolism was expressed as a linear function of the age, weight and height, and in the other the logarithm of the metabolism was a linear function of the logarithms of the age, weight and height. Within the comparatively small range of values here available for study, the two gave such closely similar results (i. e., the curves were sensibly alike) that in the absence of apparent theoretical reasons for preferring the one rather than the other, the logarithmic formula was dropped in favor of the simpler method of calculation.

2. The use of the measurement of sitting height. For the two separate age-groups submitted to the preliminary analyses, equations were formulated in which metabolism was correlated with (a) weight and sitting-height alone; (b) weight and standing height alone; and (c) weight and both sitting height and standing height. It was immediately apparent that the inclusion of both measurements for height did not increase the accuracy of the prediction, so that (c) was dropped. In the list of statistical constants figured for all four age-groups given in Table VII will be found the standard errors of estimating the metabolism by the first two forms of equation, the one including the sitting height and the other the standing height measurement. These figures show the average expectations to be the same in one group, and actually very slightly in favor of the equations using standing heights in the other three. Actual figuring of the individual metabolic rates by the two equations for half the individuals of the total series showed a negligible advantage in favor of the sitting-height equation in the matter of extreme range of rates. There is the further practical consideration in favor of the more common measurement, namely, that the greater errors inherent in the making of the smaller measurement, that of sitting height, would probably in practice fully outweigh any theoretical advantage of using that measurement as possibly being physiologically more representative.

3. The age-factor. A problem of fundamental interest in the study of heat-production from the physiological stand-point is the general picture to be gained of the changes of metabolism with changes in age throughout life. The status of information along these lines, based upon extensive studies of composite data on record up to about 1924, is instructively summarized by DuBois in the second edition of his book, "Basal Metabolism in Health and Disease" *(7)* in the chapter dealing with factors which influence the normal basal metabolism. These composite studies agree in indicating unmistakably that the metabolism for both sexes when referred to height, weight or surface-area, is relatively high in childhood and that some time around the age of maturity the curves flatten out and henceforth show a more or less gradual decline throughout adult life. Certain interesting details in the configuration of these curves still await better definition, and with it, a better understanding of the physiological processes effective at particular periods of development. Notably these are the disputed "jog" in the curve just before or at the age of puberty, necessarily difficult to confirm and fully define; and the exact point where the age-curve flattens out as maturity becomes established. Lack of statistically significant volumes of data for these transitional years has been keenly felt by those interested in studying the age-curves from either a practical or a theoretical point of view.

It was reasonable to hope that the range and relatively large volume of homogeneous data of the present study could throw light on the second of these two questions. That this hope must remain incompletely realized until similar studies are ex-

TABLE VII. *Coefficients of correlation of measurements and standard errors of estimating metabolism by prediction equations, with standing or with sitting height included. Wisconsin Standard Series.*

Age	No.	r_{12} Calories and Weight	r_{13} Calories and Stand. Height	r_{14} Calories and Sit. Height	r_{23} Weight and Stand. Height	r_{24} Weight and Sit. Height	r_{34} Stand. Ht. and Sit. Height	Std. Error of Estimate, Equation Using: Weight and Stand. Ht.		Weight and Sit. Ht.	
								Cal.	%	Cal.	%
17	25	0.67 ±0.07	0.50 ±0.10	0.42 ±0.11	0.54 ±0.10	0.47 ±0.10	0.80 ±0.05	85	6.5—	86	6.5+
18	25	0.54 ±0.10	0.35 ±0.12	0.31 ±0.12	0.32 ±0.12	0.24 ±0.13	0.72 ±0.06	92	6.9	92	6.9
19	22	0.43 ±0.12	0.37 ±0.12	0.18 ±0.15	0.58 ±0.10	0.24 ±0.14*	0.71 ±0.08*	69	5.4—	70	5.4+
20	25	0.82 ±0.04	0.66 ±0.08	0.64 ±0.08	0.70 ±0.07	0.74 ±0.06	0.67 ±0.08	77	6.0	80	6.2
17+18	50	0.61 ±0.06	0.40 ±0.08	....	0.42 ±0.08	....	....	89	6.7	......	......
19+20	47	0.70 ±0.05	0.54 ±0.07	....	0.63 ±0.06	....	....	80	6.2	......	......
17+18+ 19+20	97	0.65 ±0.04	0.45 ±0.05	....	0.51 ±0.05	....	....	87	6.7	......	......

*20 individuals, only, measured for sitting height.

TABLE VIII. *Averages, standard deviations and coefficients of variability of measurements; Wisconsin Standard Series by age-groups. All first tests as used for standard.*

Age	No.	Weight in Kg.			Standing Ht. in Cm.			Sitting Ht. in Cm.			Calories per 24 Hrs.		
		Average	σ	V, % Coeff. of Var. = $\frac{\sigma \times 100}{\text{Aver.}}$	Average	σ	V, %	Average	σ	V, %	Average	σ	V, %
17	25	55.79	7.3	13.1	164.9	5.7	3.5	86.3	3.2	3.7	1317	118	9.0
18	25	55.71	5.4	9.7	162.2	6.3	3.9	86.3	3.3	3.8	1329	112	8.4
19	22	54.64	5.0	9.1	164.8	5.3	3.2	86.0*	3.0*	3.5*	1283	74	5.8
20	25	56.00	6.7	12.0	163.3	5.6	3.4	86.4	3.2	3.7	1287	140	10.9
17+18	50	55.75	6.4	11.5	163.6	6.1	3.7	**	....	....	1323	115	8.7
19+20	47	55.36	6.0	10.8	164.0	5.5	3.4	....	....	....	1285	114	8.9
17+18 +19+20	97	55.54	6.2	11.2	163.8	5.8	3.5	....	....	....	1305	116	8.9

*20 individuals only measured for sitting height.
**The use of sitting-height had been abandoned with the studies of the separate years.

TABLE VIIIa. *Average measurements in Univ. Wisc. Standard group of subjects subdivided according to age, and first and later tests.*

Subjects	Tests Averaged	Ages	No. Subj. in Group	No. Tests in Group	Average Wt. in Kg.		Average Ht. in Cm.		Aver. Cals/24 Hrs.		Aver. Cal/Sq. M./Hr.	
					Sep. Age Groups	Combined	Sep. Age Groups	Combined	Sep. Age Groups	Combined	Sep. Age Groups	Combined
All who contributed to U. W. Std.	All Tests	17–18	50	89	55.97	55.69	163.4	163.5	1313	1296	34.40	34.01
		19–20	47	74	55.36		163.8		1280		33.54	
Those only who had More than One Test	1st Test	17–18	39	39	55.36	55.35	163.0	163.4	1330	1312	35.00	34.44
		19–20	25	25	55.32		164.0		1284		33.57	
	Later Tests	17–18	39	39	56.00	55.73	163.0	163.1	1304	1291	34.14	33.85
		19–20	25	27	55.34		163.3		1272		33.43	

tended to cover a larger range of years becomes apparent when we examine some of the data of the following tables.

In the summary of the more important of the statistical constants which were figured in the preparation of our prediction (Table VIII) it is to be noted that the figures for average calories per 24 hours in first tests for the separate ages, 17, 18, 19 and 20, do not show a consistent trend. The inconsistency appears moreover not only in the figures for group averages, but also in the slopes of the regression lines of metabolism on weight or height as plotted for the separate years in the course of our preliminary analyses (not here reproduced). Accidental fluctuations can readily obscure the picture of the relatively small changes in metabolism intrinsically due to changes of age over these short periods, unless an impracticably large number of cases could perhaps illustrate mass tendencies by smoothing out the incidental irregularities.

A general trend downward with age is however indicated when the series is considered in two two-year groups, 17-18 and 19-20 years, by which larger grouping some of the smoothing out is accomplished. In the supplementary calculations of Table VIIIa, this point is examined in greater detail. For better comparison the heat-production is now calculated as calories per square meter per hour, as well as being given in the absolute figures for calories in 24 hours, and the two-year age-groups are considered from various angles. The average body measurements are shown to illustrate the average similarity of the different groups. The following points are noted:

The downward tendency with increasing age is evident throughout the data, whether we average all tests in each group, or consider first and later tests separately for those subjects who were observed more than once. In these latter sub-groups the average differences with age, considering either first or later tests, are in all cases larger than the differences within the same age-groups between first and subsequent tests, whether the heat-production is expressed as total calories or as calories per square meter of body surface. Somewhat closer analysis of the table suggests however that some of this difference between the younger and the older girls in the matter of metabolic level is apparent and due to better relaxation on the average among the older girls. Looking at the figures for calories per square meter per hour, it is noted that the older girls show a considerably smaller drop from first to later tests than do the younger group. This may well be a type of pitfall which makes valid generalizations admittedly so much more difficult to make as we deal with less mature subjects.

That the data at hand justify the conclusion that there is a definite downward trend of the metabolic level in girls between 17-18 and 19-20 years, however, is hardly to be questioned. The same indication is seen in the larger composite series of controls assembled for the comparisons of the last part of our present study. Though the age-distribution among these 119 subjects is not regular enough to justify formal comparisons, it is nevertheless interesting to find that the calories per square meter per hour for the 31 subjects who were 17-18 years old average 35.04, while the corresponding average is 33.94 for the 88 who were from 19 to 20 years old. The more definite outlining of this portion of the age-curve can be looked forward to with some degree of confidence when similarly large groups of younger and perhaps some older subjects are studied in exactly comparable fashion. With this in mind we have made a beginning upon a study similar to the present one of boys and girls from the upper grammar school through high school ages. Meanwhile we have met our pressing need for a workable practical standard for predicting the metabolism of girls of college ages not covered by the adult standards, by lumping the data on our girls of 17, 18, 19 and 20, leaving the small age-factor for the time being out of consideration. This prediction table is presented (Table X) in the hope that it may also prove serviceable to others who have to meet problems similar to our own in the clinical application of the basal metabolism test.

TABLE IX. *Extreme variations in individual measurements Wisconsin Standard Series. First tests, as used for standard.*

Age Group	Weight in Kg.	Standing Ht. in Cm.	Calories per 24 Hrs.	Calories per Sq. M./Hour
17 years.	42—74	148—176	1098—1606	29.88—38.46
18 years.	44—66	150—173	1171—1562	31.33—39.87
19 years.	47—64	153—174	1133—1435	29.64—37.60
20 years.	46—82	148—175	1081—1816	29.30—38.41
17—20 years.	42—82	148—176	1081—1816	29.30—39.87

Various data assembled in the preparation of the final standard, which may be of interest for future comparisons, are summarized in Tables VII through IX.

In Table VII, in addition to the standard errors of estimating the metabolism by equations using sitting and those using standing-height, already referred to, are recorded the correlation coefficients obtained between the various measurements made on our subjects. Table VIII gives the variabilities encountered in the different measurements. These variabilities have been indicated in the two ways which are apt to convey the most meaning to the statistically-inclined reader: (1) in terms of the Standard Deviation[3]; and (2) as "Coefficients of
$(\text{"V"} = \frac{\sigma \cdot 100}{\text{Aver.}})$
Variability" which express the percentage of the group average in question represented by each standard deviation.

For the best determination of the relation of one variable, such as level of heat-production, to one or more others with which it is being correlated, it is desirable to analyze groups in which the variables can be established at both extremes of the normal ranges of measurements, rather than to have the groups so homogeneous that all of the individual measurements fall within a narrow range of variation. Predictions based on groups composed almost entirely of individuals of average build would be bound to describe the average individual well, but might or might not fit individuals who deviated markedly from the general average of a similar population in one or another body measurement.

Our four groups were noticeably unequal in the matter of homogeneity. Weight is of course the most significant variable in influencing the level of the metabolism in groups of otherwise fairly similar individuals. While two of our groups included a satisfactory number of lighter and heavier individuals to approximate the relationship between weight and heat-production fairly satisfactorily, the other two contained mainly

[3] Standard Deviation, "σ", of a group of measurements (the usual root-mean-square measure of dispersal) is equal to the square root of the average of the squares of the deviations of individual measurements from their group average. Statisticians use the standard deviation because of considerations based on the theory of dispersion of samples. It is worth pointing out that in choosing a prediction standard which minimizes the standard deviation of the error of estimate rather than the average of their magnitudes, the larger deviations are weighted more heavily than the smaller.

individuals of average build. This indicates the most plausible reason for the inconsistent slopes of the regression lines for the separate years, noted above.

It is observed from Table VIII that statistically the 18 and 19 year groups showed considerably smaller variability in the factor of weight than did the 17 and 20 year ones. While the groups did not show the same order of differences in the constants which measure the average dispersion of standing or sitting height measurements, Table IX brings out the fact that extreme *individual* measurements for height[4] were again found only in the two outside groups, whereas the two middle ones departed less in either direction from the general averages for height, as well as weight.

The separate correlation coefficients (Table VII) are higher in every case for the less homogeneous groups. The fact that the standard error of estimate is proportionally lower for the most homogeneous group of all, that of 19 years, merely expresses the fact that a prediction based on a group of individuals who are nearly all alike is bound to describe closely any individual whose measurements are similar to those of the group average. This constant does not include any measure of the success with which such a prediction would fit individuals who differed from this group average in one or more respects.

Since body-measurements, and particularly weight, are apt to be changing somewhat rapidly at these ages and under these conditions of living, one would not, perhaps, expect the various correlations to be as high as could be found in a group of adults. Comparing the figures for our total group with those published in the classical biometric study of Harris and Benedict *(10)*, we find that in every instance our coefficients are lower than those found for their group of 136 men, but are higher than the average of their two series of women (total number = 103).

These 103 women, on whom the Harris-Benedict prediction for females is based, included 12 girls from the ages of 15 through 20 years, whose measurements were apparently included in all the general analyses, though the final prediction

[4] Standing height, only, observed in this respect, since the desirability of the sitting height measurement had by this time been decided against.

tables begin with 21 years, and the authors specify that their equations should not be used for younger individuals.

Our objective findings throughout in connection with our relatively large group of girls from 17 through 20 confirm the feeling which we have entertained all along, — namely, that it would have saved a great deal of confusion in the field of practical metabolism if Benedict had considered these girls along with his adult women, rather than thinking of them as more safely classed physiologically with the younger Girl Scouts whom he studied later in an entirely different way, and whose curves he extrapolated upwards to include the years 17-20.

That the Harris-Benedict equation for adult women, used without any modification, affords the best fit of any of the older standards for both ours and other normals of the same ages which we have been able to collect, we shall bring out in the final section of this report. We have also extended the study to indicate the amount by which the original standard, now too high, may be lowered to "center" it for these groups, which procedure then yields for the total series, by every criterion which we have been able to apply, a fit that is almost as good as that of our own standard, which was worked out by similar methods, but specifically for these ages.

These various considerations, and the character of the statistical constants which we have found in general, strengthen us in our early impression that our four groups together constitute a series of representative significance for a study of this sort.

The Wisconsin Prediction for Girls from 17 through 20. The final equation arrived at by the standard methods of multiple correlation for predicting the metabolism of these ages was:

$$h = 10.63\ w + 3.23\ s + 184.61$$

where h = heat-production in calories per 24 hours; w = body-weight in kilograms; and s = standing height in centimeters.

The predictions which this yields for a large range of body measurements is embodied in the accompanying standard prediction table (Table X).

TABLE X. *University of Wisconsin*

PREDICTION TABLE FOR BASAL METABOLISM OF YOUNG WOMEN
AGES 17 - 21

Height in Centimeters

Weight in Kilograms	140	145	150	155	160	165	170	175	180
40	1062	1078	1094	1110	1127	1143	1159	1175	1191
41	1073	1089	1105	1121	1137	1153	1170	1186	1202
42	1083	1099	1116	1132	1148	1164	1180	1196	1212
43	1094	1110	1126	1142	1158	1175	1191	1207	1223
44	1105	1121	1137	1153	1169	1185	1201	1218	1234
45	1115	1131	1147	1164	1180	1196	1212	1228	1244
46	1126	1142	1158	1174	1190	1207	1223	1239	1255
47	1136	1153	1169	1185	1201	1217	1233	1249	1266
48	1147	1163	1179	1196	1212	1228	1244	1260	1276
49	1158	1174	1190	1206	1222	1238	1255	1271	1287
50	1168	1184	1201	1217	1233	1249	1265	1281	1298
51	1179	1195	1211	1227	1244	1260	1276	1292	1308
52	1190	1206	1222	1238	1254	1270	1286	1303	1319
53	1200	1216	1232	1249	1265	1281	1297	1313	1329
54	1211	1227	1243	1259	1275	1292	1308	1324	1340
55	1221	1238	1254	1270	1286	1302	1318	1335	1351
56	1232	1248	1264	1281	1297	1313	1329	1345	1361
57	1243	1259	1275	1291	1307	1323	1340	1356	1372
58	1253	1270	1286	1302	1318	1334	1350	1366	1383
59	1264	1280	1296	1312	1329	1345	1361	1377	1393
60	1275	1291	1307	1323	1339	1355	1372	1388	1404
61	1285	1301	1318	1334	1350	1366	1382	1398	1414
62	1296	1312	1328	1344	1360	1377	1393	1409	1425
63	1306	1323	1339	1355	1371	1387	1403	1420	1436
64	1317	1333	1349	1366	1382	1398	1414	1430	1446
65	1328	1344	1360	1376	1392	1409	1425	1441	1457
66	1338	1355	1371	1387	1403	1419	1435	1451	1468
67	1349	1365	1381	1397	1414	1430	1446	1462	1478
68	1360	1376	1392	1408	1424	1440	1457	1473	1489
69	1370	1386	1403	1419	1435	1451	1467	1483	1499
70	1381	1397	1413	1429	1446	1462	1478	1494	1510
71	1392	1408	1424	1440	1456	1472	1488	1505	1521
72	1402	1418	1434	1441	1467	1483	1499	1515	1531
73	1413	1429	1445	1461	1477	1494	1510	1526	1542
74	1423	1440	1456	1472	1488	1504	1520	1536	1553
75	1434	1450	1466	1483	1499	1515	1531	1547	1563
76	1445	1461	1477	1493	1509	1525	1542	1558	1574
77	1455	1471	1488	1504	1520	1536	1552	1568	1585
78	1466	1482	1498	1514	1531	1547	1562	1579	1595
79	1477	1493	1509	1525	1541	1557	1573	1590	1606
80	1487	1503	1520	1536	1552	1568	1584	1600	1616

III. Tests of Fit of the Available Prediction Standards for Girls between 17 and 21.

Outline of Study. Four prediction standards, including our own, have been subjected to comparative studies as applied to the Wisconsin and other normals which we have collected. These are:

1. The original Aub-DuBois tables.
2. The Harris-Benedict prediction for adult women, extrapolated for these ages under 21.
3. Benedict's special prediction for girls from 12 through 20; and
4. The University of Wisconsin prediction just described for girls from 17 through 20.

Based on the average showings of the rates as figured for our original series, the first three predictions have been modified by applying a constant percentage correction such as would center them for our standard group. On this more legitimate basis, all of the comparisons have been repeated, not only for our series, but also the other normals tabulated, and the comparative findings summarized.

The Standards that were Investigated: *The Aub-DuBois.* A brief mention of the history of the Aub-DuBois prediction as it bears directly on its application to the restricted group at hand may not be amiss as a matter of interesting background. The figures given for boys of these ages were arrived at by DuBois with his collaborators by tentative development of their composite curve for changes of metabolism for all ages, over the admittedly dubious area between childhood and 21 years. DuBois studied a group of 8 Boy Scouts of 12 and 13 years *(11)* to try to define better the trend of his curve through the pre-adolescent period. How nearly a truly "basal" condition could be enforced upon these boys under the conditions of the tests is a matter of question which is left more or less open by the author himself *(12, p. 184)*. Other data on boys that were included were taken from Magnus-Levy and Falk, whose measurements on adults were also used. Analyses by Harris and Benedict show that in comparison with their own and other then available data practically all of the measurements of the German investigators run high *(10, pp. 232,* *236, 239, 242)*. This fact is probably important in accounting for the observation that the Aub-DuBois predictions are higher in general than the other American standards. To obtain the figures for girls, approximately 7% was subtracted from each of the constants for the males of the same ages, as was done throughout the table in the case of females. This procedure was specified by DuBois to be entirely tentative *(7, p. 169)*.

The Harris-Benedict Adult Prediction, extrap. Our reasons for trying out the predictions obtained by extrapolating the Harris-Benedict tables for adults for these younger subjects have already been referred to in connection with the statistical comparisons among our own data, p. 287.

Benedict's Prediction for Girls. The Girl Scouts upon whom this prediction is based were all from 12 to 17 years old, and the figures from 17 to 21 were obtained by extrapolating the curve that had been sketched through the data for the younger girls. Benedict himself did not claim that these standards were ideal or even entirely logical. But in 1924 when he found it desirable to record recommendations for predicting the basal metabolism of girls of various ages from then available data *(4)*, he reasoned that in the absence of sufficient evidence to justify classing girls of these ages with adults in the matter of metabolic stability, it was reasonable to assume that they were still in the developmental period physiologically, and hence to be considered with the younger girls.

The hope of coming to some more definite conclusions as to the validity of this logic was not improved by the unusual way in which the predictions for these younger girls, who set the standards, were arrived at. To overcome the seemingly prohibitive difficulties at that time of trying to secure individual cooperation in a significantly large number of such young subjects, Benedict and Hendry resorted to two unusual expedients: (1) the group method of study; and (2) the recording of the lowest rate of metabolism found during the night, while the groups of girls slept in the large calorimeter chamber. While Benedict maintained that the effect of sleep on the metabolic rate was too much in doubt to invalidate the results of such a study for comparison with waking metabolism under good "basal" conditions, the fact remains that the figures found in his tables are almost universally considered much too low for practical use in the majority of cases.

One of the things that started us on the present study was the disconcerting observation that the discrepancies between the standards available for these ages from equally authoritative sources were so inconsistent, and, to us, unpredictable. Thus it was not unusual to have to report to a clinician that the metabolic rate of his patient had turned out to be something like +12 or +13% according to Benedict's standard, whereas according to DuBois' the rate found had been —12 or —13%! Occasional cases without just suspicion of hyperthyroidism might show rates as high as +40% by the Benedict prediction, which could hardly be put down to nervousness entirely, since according to DuBois the rates were normal. On the other hand, occasional subjects would show practically the same rate by both the predictions. Feeling incapable of judging of the superior merits of one or the other of these standards on theoretical grounds, in the face of apparently better satisfaction in practice now from one and now from the other, we decided to leave the choice to a thoroughgoing series of comparisons on normal subjects of the same ages as the patients who were proving so baffling.

From time to time in the course of assembling the amount of data which we set out to compare, we had transitory hopes of finding our problem already solved for us by one or another modification or adaptation of one of the major standards that was apparently giving satisfaction in other quarters. The most widely-circulated of these should be mentioned in this connection:

Krogh's Changes in the Aub-DuBois Tables. In 1925 there appeared in connection with Krogh's respiration apparatus some tables in which the Aub-DuBois predictions were modified by a uniform reduction of 6%, to meet more accurately the unusually rigid conditions which Krogh exacted for the performance of the standard "basal" test *(13)*. Even had we given attention to this proposal earlier than we did, we would hardly have felt that Krogh's recommendations, proposed under working conditions quite different from our own, would justify our acceptance without a thorough trial. By this time, moreover, we had become interested in making other comparisons than merely the success with which a given standard would predict the average absolute level of the metabolism of groups of normal subjects like our own. Hence the Krogh tables need not be considered as a separate standard.

Boothby and Sandiford's Proposed Tables. More recently Boothby and Saniford *(14)* have proposed more fundamental revisions of the DuBois constants on the basis of the large number of "hospital normals" whom they had studied prior to 1929 at the Mayo Clinic. Though their proposed constant are somewhat lower than DuBois' for girls of the ages in which we are interested, they are still far too high to describe our normal subjects. For this reason, in addition to our theoretical preference for standards based on physiological rather than "hospital" normals, we have not considered their standard.

The Sanborn Tables. We have also not at any time considered the widely-used predictions put out by Sanborn *(15)* with the Benedict type of machine which he markets, since his modified tables have been found inaccurate in some respects and their manner of origin stigmatized as unscientific *(16)*.

Kestner and Knipping's Predictions. In Germany, Kestner and Knipping *(17)* have extended and adapted the Harris-Benedict prediction tables to fit all ages of both sexes. Though their adaptations evidently afford an excellent fit for the German cases which they handle, they have not proved the solution for our problems, since the original formulas have been changed in the direction of raising the predictions for girls under 21, whereas the whole tendency of our data is to lower them. Hence these tables, also, have been left out of consideration in the comparisons which we have made.

Test Series of Normals other than the Wisconsin Standard Series. A total series of data on 119 normal controls has been collected for concrete comparisons as to the suitability of the different prediction standards. The 119 individuals include those subjects within the age-range of our original series furnished by the following sources:

Wisconsin Supplementary Series. (1) The 7 extra subjects who were studied by the author after the data for the Wisconsin Standard were under analysis. (2) A series of 21 presumably normal sorority girls studied by Jean Fish in 1928 in connection with a thesis in psychology for the degree of

TABLE XI. *Subjects within the range of the University of Wisconsin prediction, reported by Remington and Culp (1931)*; student nurses, Medical College of the State of South Carolina. Rates given refer to the first test for each subject.*

Sub. ject No.	Age	Wt. in kg.	Ht. in cm.	Cals./ 24 hrs.†	Cals./ sq. m./ hour	Rate according to prediction of			
						Aub & Du-Bois	Harris & Ben., extrap.‡	Bene-dict, girls 12-20‡	Univ. Wisc., girls 17-20‡
54	20	53	158	1901 941 1083	29.9 25.8 29.7	—19	—20	— 6	—13
69	20	49	155	1041 1100	29.9 31.6	—19	—21	— 3	—14
78	19	48	160	1274	36.1	— 5	— 4	+22	+ 5
88	19	52	161	1307 1318 1377	35.6 35.9 37.5	— 6	— 4	+15	+ 4
96	19	59	158	1221 1294 1248	31.8 33.7 32.5	—15	—14	— 5	— 8
107	19	53	168	1336 1321 1244	34.8 34.4 32.4	— 7	— 4	+16	+ 3
131	18	61	163	1279 1148 1259	32.3 29.0 31.8	—15	—12	— 4	— 6
141	18	61	165	1531 1463 1547	38.2 36.5 38.6	+ 2	+ 5	+15	+12
149	18	56	168	1295 1283 1295	33.1 32.8 33.1	—13	— 9	+ 6	— 2
150	20	58	151	1204 1228 1351	32.8 33.3 36.8	—11	—14	— 5	— 7
158	20	46	164	1328 1357 1275	37.3 38.2 35.9	+ 1	+ 2	+32	+10
164	19	51	161	1485 1324 1404	40.7 36.3 38.5	+ 7	+ 10	+34	+19
201	19	57	170	1346 1386 1481	34.0 35.0 37.4	— 9	— 6	+ 8	∓ 0
210	20	58	158	1370 1317 1301	35.9 34.5 34.1	— 4	— 3	+ 8	+ 4
213	19	48	165	1287 1330 1313	35.5 36.7 36.0	— 5	— 3	+23	+ 5
220	20	51	164	1265 1205 1342	34.2 32.6 36.3	— 7	— 6	+14	+ 1
226	19	63	170	1212 1241	29.2 29.9	—23	—18	—12	—14
232	20	52	161	1201 1135 1124	32.7 30.9 30.6	—12	—11	+ 6	— 4
239	20	48	163	1246 1163 1242	34.6 32.3 34.5	—6	— 6	+19	+ 2

*Remington, Roe E., and Culp, F. B., *Basal Metabolic Rate of Medical Students and Nurses in Training in Charleston, S. C.*, Arch. Int. Med., 1931 XLVII, 366.
†Recalculated from Calories/sq. m./hr.
‡Added to data of authors.

TABLE XI. *Continued*

Sub-ject No.	Age	Wt. in kg.	Ht. in cm.	Cals./ 24 hrs.†	Cals./ sq. m./ hour	Rate according to prediction of: Aub & Du-Bois	Harris & Ben., extrap.‡	Bene-dict, girls 12-20‡	Univ. Wisc., girls 17-20‡
244	20	60	170	1411 1699 1541	34.8 41.9 38.0	— 8	— 3	+ 8	+ 3
245	19	65	163	1497 1612 1485	36.7 39.5 36.4	— 2	± 0	+ 6	+ 7
250	20	68	160	1383 1272 1166	33.7 31.0 28.4	— 9	— 9	— 7	— 3
251	20	54	155	1262 1270 1255	34.6 34.8 34.4	— 7	— 8	+ 7	∓ 0
259	18	66	156	1502 1570 1426	37.7 39.4 35.8	— 1	+ 1	+ 4	+ 8
260	18	52	164	(1992)§ 1419 1509	(53.2)§ 37.9 40.3	± 0	+ 4	+25	+12
268	20	52	165	1213 1082 1082	32.4 28.9 28.9	—12	—11	+ 7	— 4
277	18	55	169	1421 1298 1321	38.2 34.9 35.5	± 0	+ 1	+19	+ 8
278	18	69	165	1453 1520 1562	34.6 36.2 37.2	— 9	— 5	— 3	± 0
297	19	62	166	1614 1655 1590	39.8 40.8 39.2	+ 6	+10	+19	+17
298	19	62	162	1307 1370 1343	32.8 34.4 33.7	—14	—10	— 3	— 4
322	20	50	166	1379 1297 1260	37.3 35.1 34.1	+ 1	+ 2	+27	+10
323	20	49	159	1048 1119 1048	29.5 31.5 29.5	—20	—21	— 2	—14
331	20	59	166	1354 1338 1271 1287	34.2 33.8 32.1 32.5	—8	— 6	+ 5	± 0
349	20	53	160	1300 1201 1245	35.4 32.7 33.9	— 4	— 5	+13	+ 3
358	19	55	164	1363 1379 1432	35.5 35.9 37.3	— 7	— 2	+14	+ 5
372	19	49	164	1280 1280 1164	35.1 35.1 31.9	— 6	— 4	+20	+ 4

†Recalculated from Calories/sq. m./hr.
‡Added to data of authors.
§Omitted from calculations.

TABLE XI. *Continued*

Subject No.	Age	Wt. in kg.	Ht. in cm.	Cals/ 24 hrs.†	Cals./ sq. m./ hour	Rate according to prediction of: Aub. & Du. bois	Harris & Ben., extrap.‡	Benedict, girls 12-20‡	Univ. Wisc., girls 17-20‡
373	19	52	164	1302 1190 1179	35.0 32.0 31.7	—13	— 5	+ 1	+ 3
388	19	72	174	1616 1585 1513	36.2 35.5 33.9	— 3	+ 2	+ 3	+ 7
389	18	59	164	1563 1567 1511	39.7 39.8 38.4	+ 4	+ 9	+22	+17
394	20	57	157	1310 1213	35.0 32.4	— 7	— 6	+ 5	+ 1
395	20	39	161	1005 1044 1106	30.8 32.0 33.9	—18	—18	+18	—10
400	19	56	158	1176 1131 1146	31.4 30.2 30.6	—16	—16	— 4	— 9
406	19	60	166	1347 1291 1351	33.8 32.4 33.9	—10	— 7	+ 3	— 1
407	19	60	168	1407 1447 1310	34.9 35.9 32.5	— 7	— 3	+ 8	+ 3
412	18	55	152	1339 1267 1415	37.2 35.2 39.3	— 2	— 3	+12	+ 6
422	19	58	164	1479 1487 1354	37.8 38.0 34.6	— 1	+ 4	+17	+11
423	19	57	168	1279 1326	32.5 33.7	—13	—10	+ 3	— 4
452	20	63	167	1486 1555 1490	36.2 37.9 36.3	— 2	+ 1	+ 8	+ 7

†Recalculated from Calories/sq. m./hr.
‡Added to data of authors.

TABLE XII. *Subjects within the range of the University of Wisconsin prediction, reported by Jennie Tilt (1930)* students at the State College for Women, Tallahassee, Florida.*

Subject No.	Age	Wt. in Kg.	Ht. in cm.	Cals./ 24 hrs.†	Cals./ sq. m./ hour	Rate according to prediction of: Aub and Du-Bois‡	Harris and Ben., extrap.‡	Benedict girls 12–20§	Univ. Wisc., girls 17–20§
1	17^{2}	43.2	157	1077	32.8	—17	—16	+14	— 6
2	17^{4}	51.1	163	1174	31.9	—20	—14	+ 5	— 6
3	17^{7}	58.9	152	1237	33.25	—12	—13	— 4	— 5
4	18^{0}	61.3	159	1181	30.19	—20	—19	— 7	—13
5	18^{0}	52.7	168	1466	38.18	+ 1	+ 6	+28	+14
6	18^{1}	47.5	156	1105	31.98	—15	—16	+ 7	— 7
7	18^{2}	47.3	152	1160	34.28	— 9	—11	+13	— 2
8	18^{3}	58.9	158	1348	35.10	— 8	— 5	+ 5	+ 2
9	18^{10}	63.4	170	1445	34.80	— 8	— 3	+ 5	+ 3
10	19^{0}	54.5	159	1126	30.27	—20	—18	— 5	—12
11	19^{2}	56.2	153	1265	34.45	— 9	— 9	+ 3	— 1
12	19^{2}	54.3	159	1299	34.92	— 8	— 6	+10	+ 2
13	19^{2}	56.1	162	1278	33.28	—12	— 9	+ 4	— 2
14	19^{3}	54.2	156	1174	31.97	—15	—14	— 1	— 7
15	19^{4}	49.6	164	1126	30.87	—19	—16	+ 4	— 9
16	19^{7}	45.6	152	1146	34.35	—10	—10	+15	— 1
17	19^{7}	49.9	169	1348	36.00	— 5	± 0	+24	+ 7
18	19^{8}	52.2	165	1188	31.53	—17	—13	+ 4	— 7
19	19^{8}	55.7	157	1306	35.11	— 7	+ 1	± 0	+ 2
20	19^{9}	55.3	154	1209	33.14	—13	—12	± 0	— 5
21	19^{10}	55.6	160	1188	31.53	—17	—14	— 2	— 8
22	19^{11}	58.9	163	1452	37.12	— 2	+ 2	+15	+ 9
23	20^{0}	52.2	147	1181	34.41	— 7	—11	+ 4	— 3
24	20^{0}	54.6	169	1292	33.23	—10	— 7	+ 9	— 1
25	20^{1}	52.8	162	1292	34.73	— 6	— 5	+12	+ 2
26	20^{1}	51.6	163	1188	32.14	—13	—12	+ 6	— 6
27	20^{2}	52.9	161	1153	31.20	—16	—16	± 0	— 9
28	20^{4}	56.3	165	1369	35.21	— 4	— 3	+11	+ 4
29	20^{5}	47.0	150	1049	31.22	—15	—19	+ 2	—10

*Tilt, Jennie, J. Biol. Chem. 1930 LXXXVI, 635.
†Represent averages of two or more determinations.
‡Refigured from measurements given.
§Added to data of author.

TABLE XIII. *Supplementary data from the University of Wisconsin*

Sub. ject No.	Age	Wt. in kg.	Ht. in cm.	Cals./ 24 hrs.	Cals./ sq. m./ hour	Rate according to prediction of: Aub & Du-Bois	Harris & Ben., extrap.	Bene-dict, girls 12-20	Univ. Wisc., girls 17-20
(a) Subjects by Jean Fish (1927-28, thesis in psychology).									
1	19	50.2	158	1196	33.45	—12	—11	+ 9	— 3
2	20	59	168	1292	32.43	—19	—10	± 0	— 5
3	18	40.4	152.5	1190	37.56	— 1	— 4	+35	— 4
4	19	45.9	159	1133	32.78	—14	—13	+13	— 4
5	19	62	169	1460	35.78	— 6	— 1	+ 1	+ 5
6	20	58.3	172.5	1414	35.07	— 8	— 2	+11	+ 4
7	18	67.5	165	1330	32.00	—16	—13	—10	— 7
8	20	58.7	164	1359	34.74	— 6	— 5	+ 6	+ 2
9	20	51.8	160	1080	29.60	—20	—20	— 4	—14
10	18	59.3	169	1359	33.70	—11	— 6	+ 5	± 0
11	18	52.2	159	1192	32.89	—13	—13	+ 5	— 5
12	20	59.4	157	1327	34.78	— 6	— 7	+ 2	± 0
13	18	53.4	166	1220	31.97	—16	—12	+ 5	— 5
14	19	49.5	156	1195	33.64	—15	—10	+11	— 2
15	19	57.6	159	1325	34.94	— 7	— 6	+ 5	+ 1
16	19	57.9	164.5	1293	33.25	—10	— 9	+ 2	— 3
17	20	55.6	166	1243	32.17	—13	—11	+ 3	— 5
18	20	59	166	1304	32.93	—11	— 9	+ 1	— 3
19	20	59.9	165	1217	30.73	—17	—15	+ 1	—10
20	18	43	154	1205	36.65	— 3	— 5	+29	+ 6
21	20	48.8	160	1243	34.76	— 6	— 6	+17	+ 2
(b) Subjects by Shipley (1930, thesis in psychology).									
1	20	62.6 62.1	158.5 159.5	1362 1323	34.60 33.41	— 6 — 9	— 6 — 9	± 0 — 2	± 0 — 3
2	18	56.2 57.2	169 168.5	1323 1387	33.61 35.03	—12 — 7	— 7 — 3	+ 8 +11	± 0 + 4
3	20	58.1 58.1	158.5 158.5	1152 1174	30.00 30.58	—19 —17	—18 —17	— 9 — 7	—12 —11
4	20	54.5 54.5	164.5 164.5	1303 1362	34.15 35.69	— 7 — 4	— 6 — 2	+10 +15	+ 1 + 5
5	19	51.0	168.5	1323	34.89	— 8	— 3	+19	+ 4
6	19	53.6	155.5	1168	32.23	—15	—14	± 0	— 7
7	19	59.0	149.5	1266	34.70	— 9	— 9	— 2	— 2
8	20	65.8	171.5	1390	32.91	—11	— 8	— 3	— 3
9	19	54.9	168.5	1330	34.21	—10	— 5	+11	+ 1
(c) Additional subjects by M. E. Stark (not included in U. W. Standard)									
I	18	54.1	165	1245	32.63	—14	—11	+ 6	— 4
II	18	56.6	163	1354	35.04	—12	— 4	+10	+ 3
III	18	58	173.5	1465	36.13	—10	+ 1	+16	+ 8
IV	18	59.7	161	1291	33.20	—17	—10	— 1	— 4
V	18	57	162	1217	31.69	—21	—14	— 2	— 7
VI	18	53.2	170	1305	33.78	—11	— 6	+12	± 0
a	20	60	166	1223	30.70	—19	—15	— 7	—10

TABLE XIV. *Subjects within the range of the University of Wisconsin prediction, reported by Benedict (1928)*. Supplementary series of normals from the Nutrition Laboratory of Boston.*

Subject No.	Age	Wt. in Kg.	Ht. in cm.	Cals./ 24 hrs.†	Cals./ sq. m./ hour	Rate according to prediction of: Aub and Du-Bois	Harris and Ben., extrap.	Benedict girls 12–20‡	Univ. Wisc., girls 17–20‡
132	20	65.3	169	1362	32.62	—12	— 9	— 4	— 4
133	20	57.0	160	1320	34.59	— 6	— 6	+ 6	+ 1
134	20	53.9	154	1244	34.55	— 7	— 8	+ 6	— 1
135	19	64.1	162	1515	37.58	— 1	+ 2	+ 8	+ 9
136	18	64.5	160	1237	30.86	—19	—17	—12	—11

*Benedict, F. G., "Basal Metabolism Data on Normal Men and Women (Series II) with Some Considerations on the Use of Prediction Standards"—Am. J. Physiol., 1928, LXXXV, 607
†Average of several runs on 1-4 days.
‡Added to data of Author.

Master of Arts. (3) A series of 9 presumably normal students investigated by W. C. Shipley in 1930 in connection with a problem in psychology.

These three groups together constitute a supplementary Wisconsin series of 37 cases which we were glad to have available for comparisons. The two phychology studies were made independent of the hospital under carefully controlled experimental conditions, for the physiological comparisons which they might afford. Miss Fish and Mr. Shipley were both instructed in the technique and fundamental principles of the metabolism measurements by the author.

Other Series: The Florida College for Women. For the most crucial test of all we were fortunate in finding two large series of normal controls that have been published in 1930 and 1931: (4) A study of the basal metabolism of young college women made by Jennie Tilt *(18)* at the State College for Women at Tallahassee, Florida was published in the Journal of Biological Chemistry for April, 1930. Among her 52 subjects whose ages ranged from 17 to 25, there were 29 girls between 17 and 20½ years, so that they fell within the limits of our group. Miss Tilt used technique similar to ours and calculated the rates of her subjects by both the Harris-Benedict and the Aub-DuBois predictions. By both standards the rates of most of her subjects were decidedly low, and she interpreted her findings as evidence that the basal metabolism of young women in Florida tends to be significantly lower than that predicted for young women of the same ages and living in the north.

Student Nurses in S. Carolina. (5) More recently still, there appeared a study by Remington and Culp *(19)* of basal metabolic rates of medical students and nurses in training at Charleston, South Carolina. Of the 93 student nurses, 48 were within our age-range, and thus afforded another large homogeneous group for comparison. The technique used was similar in principle to ours, but only one standard, the Aub-DuBois, was used for prediction. The study was evidently a result of Remington's general interest in problems connected with differences in iodine distribution. He felt that since most of the metabolic studies made so far have been in regions where there is iodine deficiency, and goitre is common, it might add something of interest to the subject to make such a study in a region where neither of these conditions is found.

Remington and Culp noted the prevalence of low rates according to the DuBois standards, for both sexes, but having noted that both lower and higher figures have been reported from studies made in northern states, concluded that the low values could not be regional. They suggest nutritional level as a possible factor in trend of metabolic rates, though they feel that this factor must be slight in groups of normal individuals. When their subjects were grouped as to their deviations from standard weight tables, the low-weight classes showed the lowest average metabolic rates. They did not consider the possible bearing which the choice of standards might have on warranted interpretations.

Supplementary Normals from the Nutrition Laboratory of Boston. (6) We were interested to see how our data compared with the more modern studies of normals from the Nutrition Laboratory of Boston, but found just 5 subjects within range of our study in Benedict's 1928 series of normals *(1)*. Benedict made a definite effort in this later series to secure a wider range of body-builds in his subjects than had been the case in the original Nutrition Laboratory series, and three of these five girls are heavy in proportion to their heights. As a separate group the small series is therefore unbalanced; but for this very reason, as well as its source, it offers some interesting comparisons.

The Test Data. The measurements reported on all of these subjects are reproduced herein. We have indicated with each table the recalculations we have made and the derived data that have been added to afford consistent comparisons.

Tilt's data are found in Table XII. Her results were presented as *averages* of all the observations made on each subject, representing from 2-8 consecutive or scattered tests in each. All of the calculations of metabolic rates are our own, since many of those given by Tilt failed to fit in with our methods of calculation based on the reported body measurements.

The data on the 5 subjects from Benedict (Table XIV) also represent, as is the practice at the Nutrition Laboratory in seeking the most representative normal values, the average of several basal periods, on from 1 to several days.

The data from Remington and Culp are found in Table XI. Their plan of study of making two or usually three determinations per subject on *consecutive* days allowed of the logical averaging of the body measurements taken on the different occasions, while the results of each metabolism test are given separately. Hence this series is more strictly comparable with our own in one respect while the wide difference in locality and also the fact that the subjects are student nurses rather than college students, as are almost all the rest, lends breadth to the discussion.

Tests of Fitness of Prediction Standards: DuBois *(2)* remarks that *selection* can operate so as to make a group prove any point with regard to trends in metabolic rate! Difference in such factors as repose, physical condition, manner of living, and experience with the test on the part of the subjects investigated can combine in different ways to determine real or apparent group differences. The investigator adds his share of variabilities in the matter of what constitutes "normality" and a suitable standard of comparison for any group in question, which will naturally depend to some extent upon the aims of the investigation.

Preconceived criteria and prejudicial selection have been avoided as far as possible in the present study. The aim has been to make possible a practical choice primarily for the solution of a definite problem of our own in clinical metabolic work. This problem is not confined to us. We have undoubtedly had exceptional opportunities, however, in the way of sources of material and cooperative effort in the search for a solution. We believe that the nature of our material, of the criteria we have set ourselves, and the results of the extensive comparisons we have been able to make with our own and a significant number of data from widely separate sources are such as would make our findings of interest to others who may be concerned with the availability of adequate normal data for physiological or clinical comparisons in this small but important age and sex-group for whom the question of normal standards has been bafflingly unsettled.

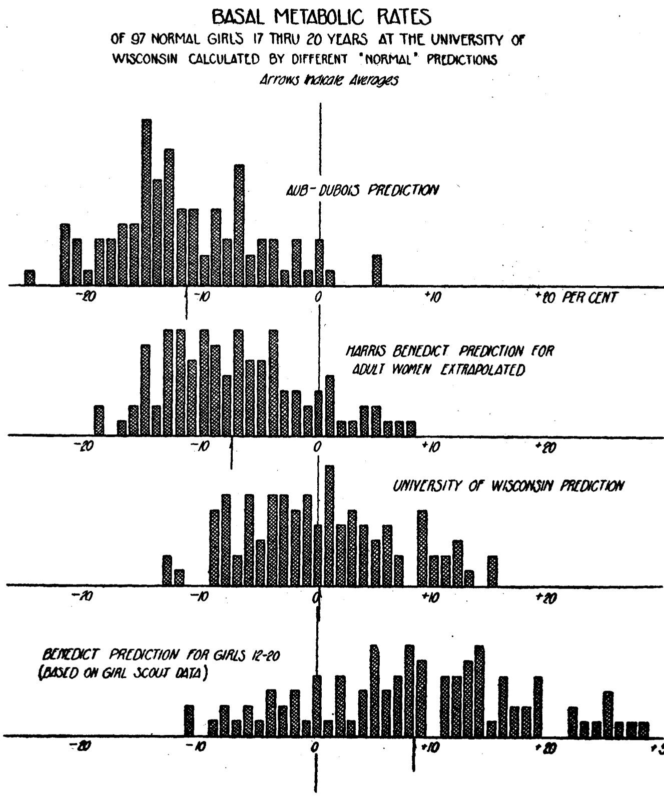

FIG. 1.

The criterion of fitness of a standard that is most universally applied is of course the *average* of the metabolic rates figured for a given group according to that standard. This is instructive, but it is only a part of the information which we need to be able to judge the comparative merits of different predictions on which to base standards of individual normality. The clinician is not interested in the average metabolic rate of a group of individuals, nor does it help him materially if, out of the borderline cases with the same general type of history in whom he is anxious to rule out hyper- or hypo-thyroidism, one is reported to show a metabolic rate of +20% and the other of —20%, thus yielding a perfect average fit with a "normal" standard of reference.

Therefore we have compared not only average, but individual ranges of showings in various salient respects of our different groups and standards. The results of the different comparisons have been summarized in the accompanying tables and graphs.

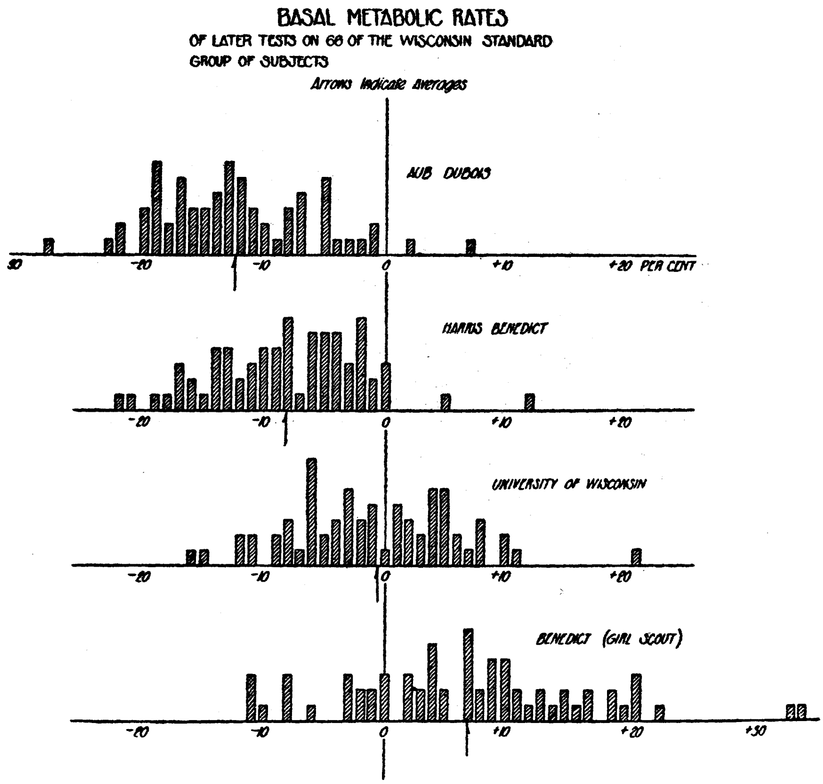

FIG. 2.

The Comparisons: For general comparisons among our six groups we have calculated average body measurements, average determined heat-production as calories per 24 hours and as calories per square meter of body surface per hour; and average metabolic rates according to the four prediction standards which we are comparing. These figures are collected in

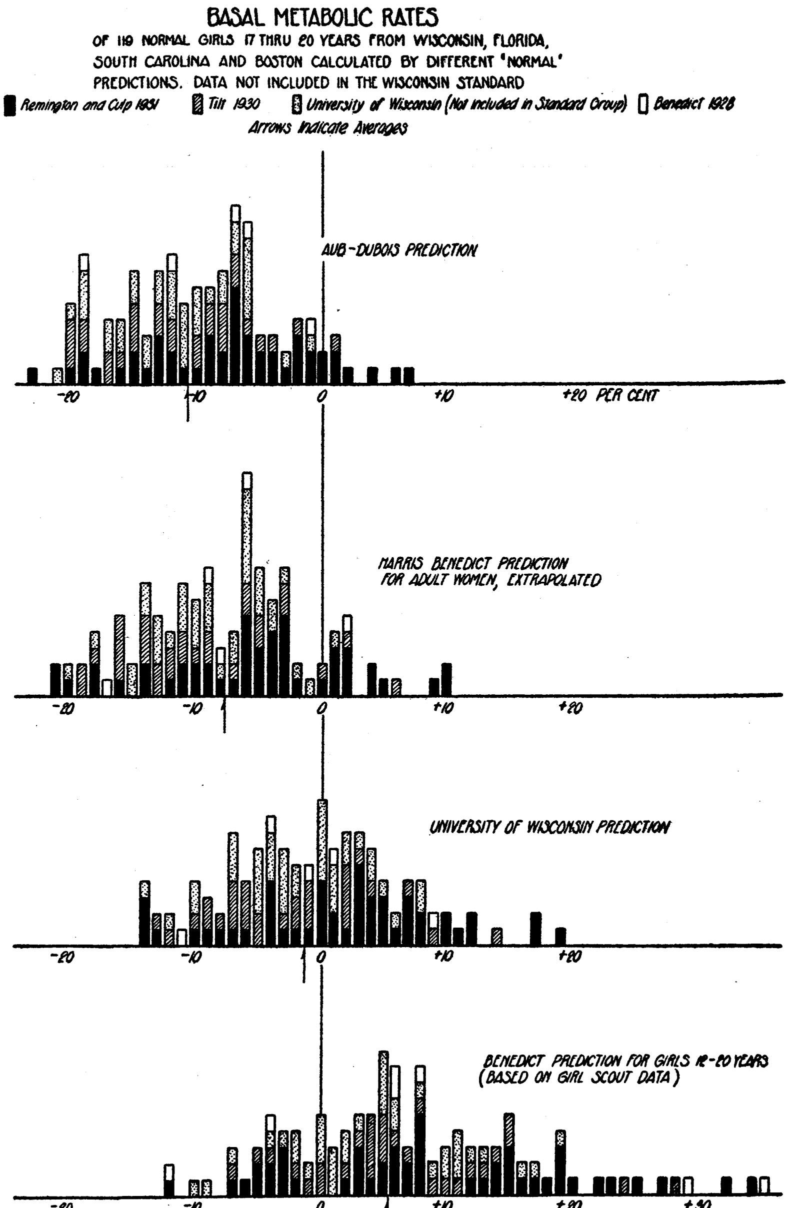

FIG. 3.

Table XV. The actual ranges and scatter of individual rates by the four standards are charted in Figures 1, 2 and 3, which bring out the general similarity of the showings by the four predictions when applied separately to the two groups of controls represented by our own standard subjects and the other series combined. Separate charts have been made for first and repeated tests for our 97 subjects (Figs. 1 and 2) for the emphasizing of their essential similarities, with the slight average tendency that would be expected toward lower values in repeated tests. A single chart (Fig. 3) was made to give average determined rates throughout for the 119 individuals of the combined comparison series, since only part of these allowed of the separation of first from later tests. The general similarity of the three pictures is striking. They make it obvious at a glance that both the Aub-DuBois and the Harris-Benedict standards are too high, while the Benedict prediction is almost equally too low, to describe with any degree of accuracy either these groups of normal girls examined in the north, or those in the south.

In the first two cases the suggestion immediately offers itself that it should be a simple matter to adapt either prediction, as it stands, by merely subtracting a uniform percentage from the original constants, as Krogh suggested for the Aub-DuBois tables (see page 291). In the case of the Benedict prediction, however, the excessive scatter leaves no room for hope from the mere expedient of centering.

Leaving out of consideration the fact that the Benedict standard gives values that are too low to represent the waking metabolism of the average girl, even under well controlled basal conditions, it proves inferior to the other three by every standard of comparison which we have been able to apply. The reason for this is undoubtedly the group method of study on which it is based, which smoothed out individual variabilities in body measurements and left only average relationships to be defined. The metabolism was expressed as a simple function of the weight (obviously the most important single variable) with slight changes for age, leaving height entirely out of consideration. When we try to use this prediction for individuals whose weight varies out of the average proportion to their height, the results are bizarre, as our further actual comparisons will bring out. Meanwhile it is interesting to note in Table XV that the only one of the six series for which the Benedict prediction offers the best average "fit" is Benedict's own small group of normals! The averages by the other predictions

TABLE XV. *Average Measurements and Calculated Metabolic Rates in Different Groups of Normal controls. All tests made on each subject are included:*

Source	Subjects	No. of Subj.	No. of Tests	Aver. Wt., Kg.	Aver. Ht., Cm.	Aver. Cals. per 24 Hrs.	Aver. Cals. per Sq. M. per Hr.	Average Metab. Rate acc. to Pred. of			
								Aub-Dubois	Harris-Benedict, Women, extrap.	Benedict for Girls 12–20	Univ. of Wisc., Girls 17–20
Univ. Wisc. Std. Subj.	Univ. Students	97	163	55.63	163.5	1296	34.01	—11.9	—7.6	+7.7	—0.3
Univ. Wisc. Supplementary Series	Univ. Students other than Std. Series	7	7	56.9	165.8	1300	33.31	—15.0	—8.4	+5.0	—2.0
By Jean Fish	Univ. Wisc. Thesis Subj.	21	21	54.8	162.4	1266	33.61	—11.0	—9.0	+7.0	—1.8
By Shipley	Univ. Wisc. Experimental Subj.	9	13	57.5	162.7	1297	33.54	—10.1	—7.8	+3.9	—0.2
By Tilt (15)	College Stud. in Florida	29	*	53.4	159.4	1235	33.40	—11.6	—10.0	+6.5	—2.6
Benedict 1928 (1)	Normal Series, Boston	5	*	60.9	161.0	1336	34.04	— 9.0	—7.6	+0.8	—1.2
Remington & Culp (16)	Student Nurses in South Carolina	48	138	56.1	162.9	1320	34.56	— 8.1	—6.1	+8.5	—1.0

*Each test reported = average of several observations.

do not indicate any characteristic difference in rate of heat production for this group compared with the others; but these girls happen to be predominantly overweight.

Table XV shows a remarkably close agreement between the six groups when heat-production is calculated as calories per square meter of body surface — the most logical single unit of reference we know of for comparing levels of heat-production among different individuals or groups. There is no indication of a lower metabolic level predominating in the southern girls. Rather, the highest average figure is noted for the large series reported by Remington and Culp from South Carolina. While the different type of life led by the student nurse in comparison with that of college students may have something to do with this finding, the difference is not large enough to suggest this as a definite conclusion.

For the more exact comparisons summarized in the last two tables we have used from the total data only those series which allow the separation of first from later tests on individuals. This has left us for logical comparison with our own standard, which was based on first tests only, a group of 85 subjects consisting of the 48 by Remington and Culp and the 37 embraced by the three Wisconsin Supplementary series.

The following comparisons have been made within these two groupings for the four predictions being tested: (Table XVI):

Column 1: Algebraic averages of individual rates.

Column 2: "Standard Errors" of estimating rates by the different predictions, i. e., the root-mean-square measure of dispersal of the individually calculated rates, thus analagous to the standard deviation method of evaluating dispersal among the original measurements.

Column 3: Percentiles falling within the range conventionally specified as strictly "normal" ($\pm 10\%$) in clinical metabolic studies with adults.

Column 4: Percentiles falling within the range customarily accepted as normal for practical purposes.

Column 5: Extreme ranges of rates outside plus or minus 10%.

Special Comparisons of Fit of Standards for Individuals of Unusual Body Build. A traditional argument of those who prefer the DuBois prediction to the Harris-Benedict has been that while either standard may be relied upon to afford a fairly good fit for individuals of average dimensions, the DuBois prediction alone, because it is based on the universally applicable surface-area concept, is apt to prove suitable for reference in the case of subjects of unusual bodily configuration. For this *a priori* opinion the classical dictum of Krogh *(20)* may have been not a little responsible. This rationalizing of a preference is not at all the reasoning of DuBois himself, who believes that some form of standard which relates the heat-production to surface area is the most desirable because of the general biological significance of the comparisons which this permits, even *at the expense* of some degree of accuracy in predicting for individuals, as is inevitable when in practice we estimate the surface-area from the simple measurements of height and weight.

Among those who lean toward the statistical method of predicting directly from the body-measurements without introducing the intermediate estimation of the surface-area some have ascribed superiority in predicting for people of unusual build to the Harris-Benedict, and some to the formulas of Dreyer[5]. Benedict himself wrote in 1928 *(1)* that the latter point of view was gaining ground. He did not feel that this was borne out however in his group of 27 men who had been chosen definitely to include wide differences in both age and configuration. For this group the average deviation of measured from predicted heat-production was least by the Harris-Benedict standard. Large discrepancies for certain individual rates according to the three predictions that were compared led him to conclude that though the prediction for even a small group may be made with surprising accuracy, the prediction of the basal metabolism of *individuals* of unusual configuration is very uncertain. It is clear that different criteria of suitability have been applied by the different observers who have formed these diverging opinions.

We were interested in finding as a final test of the various standards of our study, which would prove by actual comparisons to afford the best all-round "fit" for the least typical individuals of the various groups of controls at hand. We decided

[5] Actual comparisons based on the Dreyer prediction, which is no doubt too little known in America, would have been interesting in the present study. Regrettably it was not considered, after noting that its figures are too high for these girls. Ref.: Stoner, W. H., (Tabulation of Dreyer formulas): Bost. Med. & Surg. J., 1923, clxxxix, 239.

TABLE XVI. *Comparisons of "fit" of different "normal" predictions of metabolic rates. Only the first tests on each individual are included in the computations.*

Series from which subjects were taken	No.	Predictions	1 Algebraic average of calculated rates	2 Standard error of estimating rates	3 Proportion of Rates Within ±10% of prediction	4 Proportion of Rates Within ±15% of prediction	5 Extreme Rates (outside ±10%
Univ. Wisc. Standard Subjects. (Tests used for Std.)	97	Harris Benedict Adult, extrapolated	—7.1	9.39	62%	94%	— —19
		Aub-DuBois	—11.5	13.08	41%	73%	— —25
		Benedict, Girls 12–20	+8.4	12.24	48%	74%	+28, —11
		Univ. W., Girls 17–20	(+0.1)	6.54	87%	100%	+15, —13
Series Other Than Univ. Wisc. Std.*	85	Harris-Benedict Adult, Extrapolated	—6.8	9.48	72%	91%	— —21
		Aub-DuBois	—9.2	11.27	57%	84%	— —23
		Benedict, Girls 12–20	+9.1	13.00	62%	78%	+35, —12
		Univ. W., Girls 17–20	+0.1	7.07	86%	96%	+19, —14

*Other series (first tests) included: U. W. Total Supplementary Series (Fish, Shipley, Stark): 37; Remington and Culp: 48.

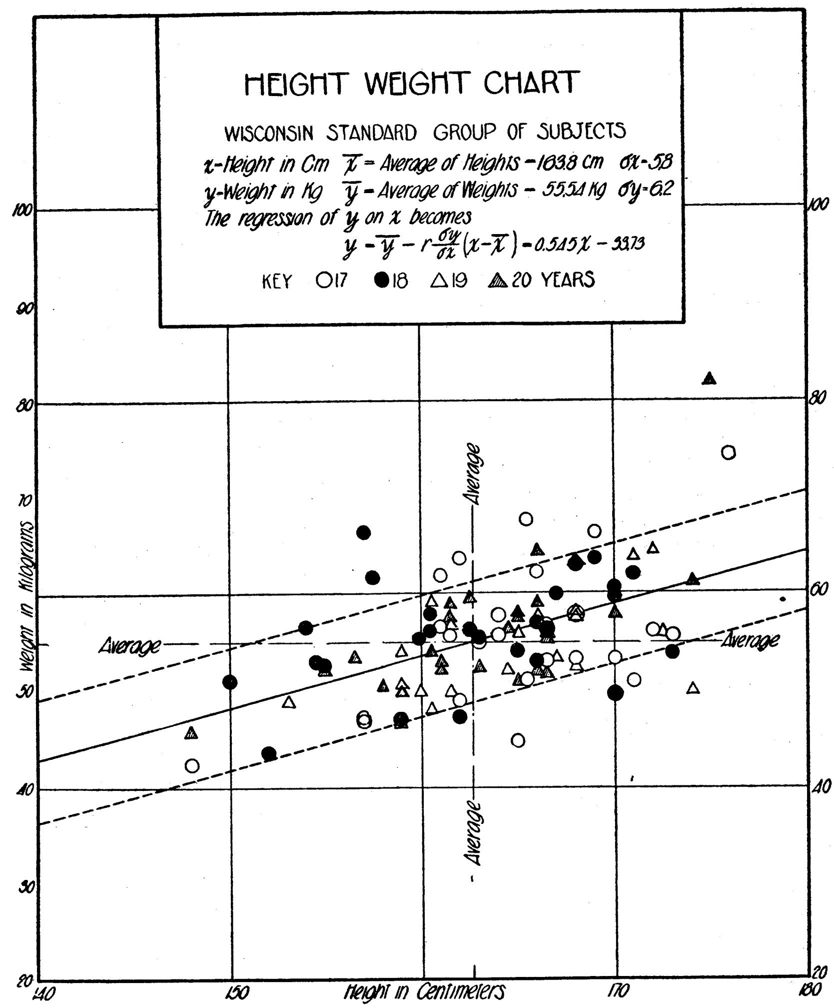

FIG. 4.

upon what constituted atypical build among essentially normal subjects by the graphic method, as follows, in preference to judging what should be considered over- or under-weight by standards worked out on other groups:

Using the data of our original standard series as basis of reference, we plotted heights against weights of the 97 subjects. Through this map we then drew the regression line of weight on height, calculated from the statistical constants at hand for this group, and drew other lines on either side of this average at distances equal to the standard deviation for weight. This set apart 17 subjects outside (or just at) these limits as being significantly below or above the group averages in weight for height, and these subjects were used as the special group for comparisons from our series. By fitting the data from the other series to the curve, 21 individuals of unusual builds were picked out in the same way. The height-weight chart is reproduced as Figure 4, for the graphic representation of the distribution of measurements that obtained in our standard group of subjects. The list of those of unusual build picked out as described include the following:

From the Wisconsin Standard Series (Data pp. 264-267): Overweight subjects b, d, f, k, y, age 17; subjects 14, 20, 22, age 18; and subjects III and XXV, age 20. Underweight subjects i and x, age 17; subjects 9, 24 and 25, age 18; and subjects 19 and 21, age 19.

From the series by Remington and Culp (Data pp. 293-295): Overweight subjects 150, 245, 250, 259, 278 and 388. Underweight subjects 158, 213, 239 and 395.

From Benedict's series (Data p. 298): Overweight subjects 132, 135 and 136.

From the series by Tilt (Data p. 296): Overweight subjects 3 and 4.

From the Wisconsin total supplementary series (Data p. 297): Overweight subjects 1 and 7 by Shipley; and 7 and 12 by Fish. Underweight subjects 3 and 20 by Fish.

To check our selections by a more conventional standard, we calculated the degree of over- or underweight of each of the selected subjects according to Bardeen's height-weight tables *(21)* which are our standards for clinical reference. Measurements taken at different times on the same subject were averaged for these comparisons. It was interesting to us to find how closely similar were the weights predicted by Bardeen and those predicted from our own regression equation for the individuals throughout both series. The two predictions were within 1 or 2 pounds in over half of the cases, and in only one case was the difference over 5 pounds. We cite this as evidence that our group was anthropometrically representative.

Of the subjects picked out as unusual, 25 were overweight for their heights by from 15 to 47 pounds according to our standards, and from 12 to 40 pounds by Bardeen. The other 13 were underweight by 12 to 34 pounds by our formula, and by 13 to 35 pounds by Bardeen. The average showings of these four groups as to measurements and metabolic rates are given in Tables XVII and XVIII. The groups were not large enough to justify the calculation of any statistical constants, but are sufficiently large for some illuminating general comparisons. Average rates have been used for the individuals of these series since the groups of Benedict and Tilt were brought in for the comparisons.

A natural question to ask ourselves in making comparisons like this is whether these girls who are so much larger or smaller than the great majority of their group, though presumably in good health, should be expected to show essentially "normal" metabolic rates by the same standards used to judge their fellows. This question cannot of course be answered in our present state of ignorance about the factors which determine body build. It might help us to gain some impression about the essential normality of this particular atypical group, however, if we pick out some of the most extreme examples and compare their measured rates of metabolism in calories per square meter of surface area with the average for the group at large.

Thus on Figure 4, the four most strikingly aberrant points are found to correspond to subjects III, age 20, and f, age 17, who are both exceptionally tall and exceptionally heavy; subject 20, age 18, who is the heaviest of the short subjects; and subject x, age 17, who is very thin for her height. In addition we might look at the two tiniest of all the subjects, albeit the proportion of their measurements does not bring them outside the standard lines. Consulting the data tables for the Wisconsin series we find the following relationships:

Subject No.	*Age*	*Average height in cm.*	*Average weight in Kg.*	*Cals. /sq. m./ hour*
f	17	176+	74.7	31.71 31.92
III	20	175	82.3	38.41 34.98
20	18	157	66.3	34.60 35.15
x	17	165	44.8	33.98
II	20	148	46.1	33.36 33.58
s	17	148	42.9	34.66 32.42
		Average		34.07

While they do not rule out the possibility that some of our atypical girls may not have been strictly normal, the figures in the last column certainly do not give us any reason for feeling that accurate prediction for these girls should not be a reasonable requirement for a good working standard.

If we calculate the rates, then, of the underweight and overweight subjects of our two large series according to the 4 prediction standards in their present forms, we see in Table XVIII that the best average prediction is afforded in all 4 cases by the University of Wisconsin standard, with Benedict's prediction for girls, which fell so far behind for the groups as a whole, almost as good for the *overweight* subjects. For this group the two standards are about equally satisfactory also in the matter of extreme range of rates. — But when we come to the underweight subjects, the Benedict prediction is startlingly aberrant by both criteria. The fact that the two types of subject show a rather close agreement by all the other criteria applied is against a reasonable suspicion that intrinsic differences in metabolic levels are involved. It seems surprising that the average calories per square meter are so similar in all four groups.

There is no suggestion so far of the superiority of the Aub-DuBois prediction in describing these groups of subjects who are at the extreme ranges of body measurements for the populations from which they were selected.

TABLE XVII. *Average measurements of underweight and overweight individuals taken from various series of normal controls. The figures given include all the tests on each individual.*

	Source	No.	Average deviations weight for height according to		Average calories per 24 hrs.	Average cals./sq. m./hour
			U. of W. Std. Equ.	Bardeen tables		
			lbs.	lbs.		
Over-weight for height	Univ. of Wisc. Std. subjects	10	23.5	23.0	1447	34.85
	Other normal controls	15	23.0	21.3	1363	34.12
Under-weight for height	Univ. of Wisc. Std. subjects	7	18.4	18.4	1278	34.30
	Other normal controls	6	21.2	23.5	1216	35.57

TABLE XVIII *Comparisons of "fit" of different "normal" predictions of metabolic rates for overweight and underweight individuals from various series of normal controls. The figures include all tests made on each individual.*

Series from which subjects were taken	No. of subj.	Predictions	OVERWEIGHT Alge-braic aver. of rates	OVERWEIGHT Range of rates	UNDERWEIGHT Alge-braic aver. of rates	UNDERWEIGHT Range of rates
Univ. Wisc. Standard Subjects	Over Wt. 10	Harris-Benedict adult, extrapolated	—11.5	+5, —15	— 6.2	—1, —10
		Aub-DuBois	—14.4	+2, —22	—12.4	—7, —20
	Under Wt. 7	Benedict for girls 12–20	— 1.7	+11,—11	+18.2	+24, +8
		Univ. Wisc. for girls 17–20	+ 0.2	+12, —8	+1.5	+ 7, —4
Series Other Than Univ. Wisc. Std.*	Over Wt. 15	Harris-Benedict adult, extrapolated	— 7.8	+ 3,—19	— 5.5	+1, —15
		Aub-DuBois	— 9.4	— 1,—20	— 5.2	± 0,—13
	Under Wt. 6	Benedict for girls 12–20	— 2.1	+ 8,—14	+26.8	+35, +16
		Univ. Wisc. for girls 17—20	— 1.5	+ 9,—13	+ 4.2	+9, —6

*Overweight subjects: U. W. total Supplementary Series: 4; Tilt: 2; Remington & Culp: 6; Benedict '28: 3.
Underweight subjects: U. W. total Supplementary Series: 2; Remington & Culp: 4.

But really legitimate comparisons are not possible between standards that are "off center" for any given group to such different degrees as are the three original standards which we are trying to compare, and hence has undoubtedly arisen much disagreement in judgment. Each of these predictions as they stand will score for rates in different ranges, but they will not be the same ranges over any considerable series of trials. Hence the evidence can be prejudiced in either direction, depending on what one may be looking for. For example, with all of the obvious shortcomings to disqualify the Benedict standard for girls for average usefulness, it has just been proven to afford an excellent "fit" for sufficiently overweight girls!

The Centering of the Original Prediction Standards for Legitimate Comparisons. Hence for fairness and our own satisfaction, we have applied such constant percentage corrections to the Harris-Benedict, the Aub-DuBois, and also the Benedict predictions as would center them for our standard series, and then have repeated our previous comparisons on the now comparable bases for judgment. These comparisons based on the revised predictions, together with the original showings of the University of Wisconsin prediction, have been collected in Tables XIX and XX.

Observations on the Final Comparisons. If the Harris-Benedict predictions are lowered by 7%, and the Aub-DuBois by 12%[6], either one affords a satisfactory fit for the two series of normal controls that have been studied in the search of suitable normal standards for girls under 21.

The constants in Table XIX show that by all four criteria applied, — average prediction of rates, standard error of estimating the rates, percentiles within "normal" limits, and extreme ranges of rates, — the fit afforded both for groups and individuals is somewhat better when the Harris-Benedict prediction is used than is the case with the Aub-DuBois.

The standard developed at the University of Wisconsin specifically for girls between 17 and 21 affords a slightly better fit than either of the others. This is supported not only by the comparisons on the series of 97 girls upon whom the Wisconsin standard itself was based — which would be expected — but the same order holds throughout similar comparisons in the composite series of 85 normal controls of the same ages from other sources. This with the various general comparisons which we have been able to make leads us to believe that our material can have more than local significance.

A small series of special tests to try to determine objectively which of the various standards would most closely predict the metabolism for individuals presumably normal but of unusual bodily proportons showed for the 38 over- and underweight girls of the above two and two other series of normal controls, no consistent superiority of the Aub-DuBois, the Harris-Benedict or the University of Wisconsin standard. The total spread of individual rates was somewhat smallest by the Wisconsin standard.

The Benedict prediction for girls from 12 to 20 is improved by centering only to the extent that having offered a passibly

[6] This necessary correction should be nearer 10% according to the observation of Mrs. Bradfield (Amer. J. Physiol., 1927, LXXXII, 570) that the DuBois Height-Weight formula for estimating the surface-area gives figures that average about 2% too high when applied to women. This finding does not of course affect any of the comparisons between the different standards which we consider fundamental,—i. e., those which are made after all the predictions are centered for the same body of data.

TABLE XIX. *Comparisons of "fit" of different "normal" predictions of metabolic rates when older standards are centered to fit average University of Wisconsin data. Only the first tests on each individual are included in the figures.*

Series from which subjects were taken	No.	Predictions	1 Algebraic average of calculated rates	2 Standard error of estimating rates	3 Proportion of Total Rates Within ±10% of prediction	4 Proportion of Total Rates Within ±15% of prediction	5 Extreme Rates (outside ±10%)
Univ. Wisc. Standard Subjects. (Tests used for Std.)	97	Univ. of Wis. for Girls 17-20:	(+0.1)	6.54	87%	100%	+15, —13
		Harris-Ben. Adult, Extrapolated, Corrected*:.....	(—0.2)	6.57	88%	99%	+16, —13
		Aub-DuBios, Corrected†	(+0.5)	7.13	84%	98%	+19, —15
		Benedict for Girls 12–20, Corr.‡.................	(+0.4)	8.67	74%	89%	+19, —18
Series Other Than Univ. Wisc. Std.§	85	Univ. of Wis. for Girls 17-20	+0.1	7.07	86%	96%	+19, —14
		Harris-Ben. Adult, Extrapolated Corrected*:......	+0.4	7.26	86%	96%	+18, —15
		Aub-DuBois, Corrected†	+3.1	7.96	84%	95%	+22, —13
		Benedict for Girls 12–20 Corr. ‡................	+0.02	8.90	75%	91%	+25, —19

*By adding a constant correction of —7% to center for the University of Wisconsin Standard Series.
†By adding a constant correction of —12% to center for the University of Wisconsin Standard Series (see footnote, p. 000).
‡By adding a constant correction of +8% to center for the University of Wisconsin Standard Series.
§See Table XVI, footnote.

TABLE XX. *Comparisons of "fit" of different "normal" predictions of metabolic rates for overweight and underweight individuals from various series of normal controls, when older standards are centered to fit average University of Wisconsin data. All the tests made on each individual are included in the figures.*

Series from which subjects were taken	No.	Predictions	OVERWEIGHT		UNDERWEIGHT	
			Algebraic aver. of rates	Range of rates	Algebraic aver. of rates	Range of rates
Univ. Wisc. Standard Subjects	Over Wt. 10	Univ. of Wisc. for girls 17—20	+ 0.2	+12,— 8	+ 1.5	+ 7,— 4
		Harris-Ben. adult, extrap., corrected*	+ 1.6	+13,— 8	+ 2.2	+10, —3
	Under Wt. 7	Aub-DuBois, corrected*	+ 0.9	+16,—11	— 0.3	+ 6,— 8
		Benedict for girls 12–20 corrected*	—10.2	+ 1,—18	+ 7.9	+15,— 1
Series Other Than Univ. Wisc. Std.†	Over Wt. 15	Univ. of Wisc. for girls 17–20	— 1.5	+ 9,—13	+ 4.2	+ 9,— 6
		Harris-Benedict. adult extrap., corrected*	+ 0.9	+11,—13	+ 1.6	+ 9,— 9
	Under Wt. 6	Aub-DuBois, corrected*	+ 2.9	+13,— 9	+ 7.7	+14,— 1
		Benedict for girls 12–20, corrected*	— 9.3	± 0,—20	+17.4	+25, + 7

*Corrections given in Table XIX.
†See Table XVIII, footnote.

good fit before for overweight girls, and an extremely bad one for the underweight, the latter disadvantage is now about equally divided among both atypical groups. There is no need to consider any longer the Benedict standard for girls in the presence of three other predictions that are actually, or by simply translating their zero-points, superior to it in every respect.

The older standards have the benefit of an age-factor, which as yet we cannot define for our group, but we hope eventually to do so to its further improvement after our observations shall have been extended to cover a wider range of ages.

Meanwhile since there is slightly better prediction by our present simple table embodying the equation $h = 10.63\ w + 3.23\ s + 184.61$ (Table X) than is possible by modifying any of the pre-existing standards — a procedure preferably to be avoided until it can be done by general agreement, — we propose to use that for clinical prediction in girls from 17 to 20, inclusive.

SUMMARY

On the basis of practical experience that the standards so far available for predicting the basal metabolism of girls under 21 are contradictory and in no wise satisfactory in clinical application, a possible solution of the problem was sought by the collection of a statistically significant number of data on normal girls between 17 and 21. This is an age and sex group of particular importance in an institution which handles student health problems.

Basal metabolic rates were determined in 163 tests on 97 girls, of ages quite uniformly divided between the 4 years 17, 18, 19 and 20. These were students at the University of Wisconsin who were judged to be Grade A in their medical and physical examinations and who were determined by special examination and questioning at the time of the tests to be free from defects that should disqualify them from serving as physiological normals.

The tests were performed by the author between 7:30 and 8:30 a. m. in the metabolism laboratory of the Wisconsin General Hospital, under the same general conditions of technique and control used for hospital cases. All tests were accepted for analysis unless specific grounds for their rejection were apparent in technical flaw, lack of cooperation, or state of health of the subject at the time of the test. The aim was in this way to establish reasonable ranges of variation rather than strictly minimum or average ideal levels of "basal" metabolism,

The results of the tests were subjected to various comparative analyses, and the *first accepted tests* on the 97 subjects were made the basis of a prediction standard which was based on the equation:

Heat Production in Calories per 24 hours $= 10.63 \times$ Weight in Kilograms $+ 3.23 \times$ Height in Centimeters $+ 184.61$.

The equation was arrived at by standard methods of multiple correlation. A factor for age, not yet possible to include because of the narrow range of years observed, we shall hope to add in time when our data shall have been extended to younger and perhaps older subjects.

The above prediction standard was used to calculate the metabolic "rates" of the individuals in the original series, both first and later tests; and the rates for the same tests were also

calculated by the Aub-DuBois prediction, the Harris-Benedict prediction for adult women, extrapolated for these ages, and Benedict's special prediction for girls from 12 to 20. The same calculations were carried out for a comparable test-series of presumably normal girls of the same ages from Wisconsin (other than standard series), Florida, South Carolina and Boston, whose metabolic measurements have been reported by various recent observers.

Distribution charts of the rates in the same tests as indicated by the 4 different predictions showed very similar pictures for the two large series, and demonstrated in a striking way that the Aub-DuBois and the Harris-Benedict predictions give figures which are markedly too high, and the Benedict prediction figures which are too low, to represent with any degree of satisfaction the "basal" or standard metabolism of large groups of normal girls of these ages. The Benedict prediction showed itself inferior to the other three by excessive scatter of rates about the average expectation. It proved to indicate "normal" rates for overweght girls, but abnormally high ones for the underweight.

The older predictions were then centered by applying the constant percentage correction to each which would make its zero-point correspond practically to that of the Wisconsin standard series by their own prediction. This was done, not as a permanent suggestion, but as the only basis possible to permit fair comparisons in respects more fundamental than mere success in predicting the average absolute level of heat-production for groups of subjects. Various criteria were then applied to determine which of the standards, with predictions now in the same range, would afford the best all-around "fit" for these two considerable groups of normal subjects.

The criteria of suitability that were applied included: average rates, standard error of predicting the rates, percentiles within plus or minus 15% of the average expectation, and extreme ranges of rates by the different predictions.

Conclusions

By all the above criteria the Wisconsin standard proved to furnish a somewhat better fit for both Wisconsin and other normals than did either of the two most satisfactory of the older standards, that of Harris and Benedict, or that of Aub and DuBois, even after centering to make their zero-points coincide. However, of the two latter, the Harris–Benedict, when extrapolated for the ages in question and lowered by 7%, showed itself nearly as satisfactory in the various respects as did the Wisconsin Standard which was established by similar methods of analysis for a comparatively large number of subjects within a narrow range of ages.

A special series of comparisons which determined average and extreme ranges of rates for the 38 individuals from the total series of controls who were from 12 to 40 pounds over- or underweight for their heights according to the standard Bardeen height-weight tables, showed practically the same degree of satisfaction from any of the three standards after the two older ones were centered to fit the average Wisconsin data. The Wisconsin standard showed a slight advantage in smaller total spread of individual rates. General comparisons indicated that these subjects could be expected to show essentially "normal" rates.

The various studies of the Wisconsin group and of the measurements made upon it, in comparison with those of a large series of normal girls of the same ages from widely different localities, suggest that the Wisconsin prediction may safely be used as a standard of reference for similar classes of girls who are studied with comparable technique anywhere in America.

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THE DECAPOD CRUSTACEANS OF WISCONSIN

EDWIN P. CREASER

Previous lists of the decapod crustacean fauna of Wisconsin have been published by Bundy (1882), Faxon (1885), Harris (1903), and Graenicher (1913). The first list compiled by Bundy contained eleven species. Many of these are synonyms. Graenicher's list contains seven species of crayfish, including *C. rusticus* of which no specimens from Wisconsin were examined. Six species of crayfish are now definitely known to occur within the state, and in addition the shrimp, *Palaemonetes exilipes*.

The writer has examined the extensive collections obtained through the efforts of the Wisconsin Geological and Natural History Survey. For two summers the writer collected for the Survey in Wisconsin. In addition to these collections, those belonging to the Zoology Department of the University of Wisconsin have been examined, and also a few of the specimens in the collections of the Public Museum of Milwaukee. Dr. Waldo L. Schmitt of the United States National Museum has furnished several records of Wisconsin crayfish. Miss Myrtle Creaser of Kenosha has very kindly furnished many specimens from that region. Decapod crustaceans have been examined from nearly every section of Wisconsin. The following counties are not represented: Door, Kewaunee, Brown, Oconto, Calumet, Manitowoc and Sheboygan. Most of these counties are bordered by either Lake Michigan or Green Bay.

Most of the collecting has been done with seines. This method does not allow a fair sampling for distributional studies of the borrowing species, *Cambarus diogenes* and *Cambarus gracilis*. Additional collections are especially needed of these two species.

FAMILY ASTACIDAE

Two families of decapods occur in Wisconsin. Most of these, the crayfishes, are classed in the Astacidae, a family of freshwater custaceans found in Asia, Europe, North and Central America. Two genera, as now defined, occur in the United

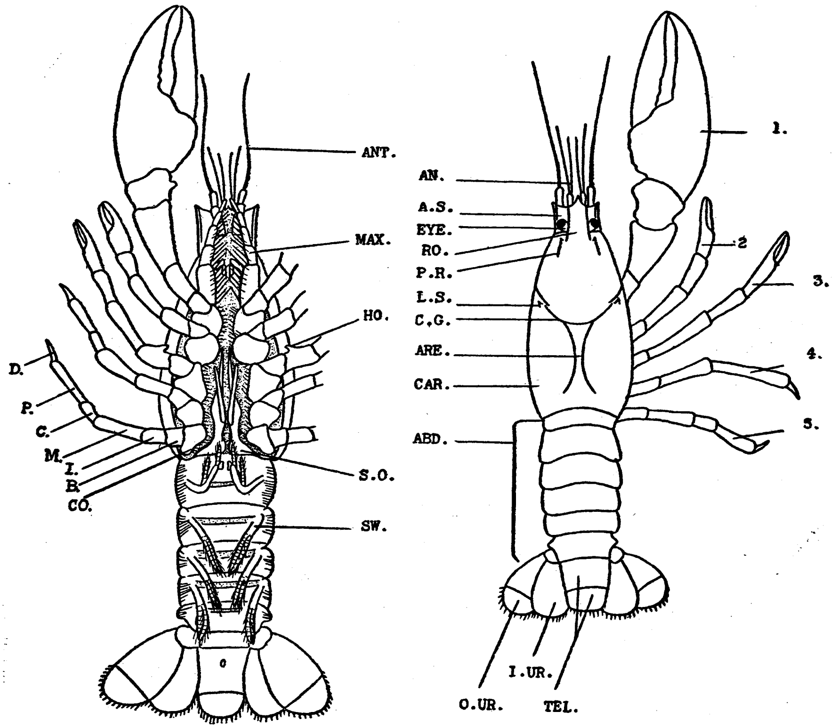

FIG. 1. Diagrams of *Cambarus virilis*. *ABD.*, abdomen; *AN.*, antennule; *ANT.*, antennae; *ARE.*, areola; *A. S.*, antennal scale; *B.*, basipodite; *C.*, carpopodite (carpus); *CAR.*, carapace; *C. G.*, cephalic groove; *CO.*, coxopodite; *D.*, dactylopodite; *EYE*, eye; *HO.*, hook; *I.*, ischiopodite (ischium); *I. UR.*, inner ramus of uropod; *L. S.*, lateral spine; *M.*, meropodite (merus); *MAX.*, third maxilliped; *O. UR.*, outer ramus of uropod; *P.*, propodite (propodus); *P. R.*, postorbital ridge; *RO.*, rostrum; *S. O.*, sexual organ; *SW.*, swimmeret; *TEL.*, telson; *1, 2, 3, 4, 5,* walking legs.

States; the genus *Astacus* in California, Washington, Oregon, Idaho and Wyoming; and the genus *Cambarus* in the states which drain into the Atlantic Ocean. In Mexico the crayfishes of the genus *Cambarus* are found in the Pacific as well as in the Atlantic drainage areas. A species of *Cambarus*, *(C. clarkii)* has apparently been introduced in California within recent years.

The word crayfish is possibly derived from the French *écrevisse*, or the Low Dutch *crevik*. Names commonly applied to these animals are: crayfish, crawfish, crawdads and inappropriately, crabs.

The crayfish frequently serve as an intermediate host of parasitic worms, of which *Paragonimus sp.* is a typical example. An ostracod, *Entocythere cambaria,* originally described from Wisconsin, is parasitic on the gills of crayfish. Aquatic oligochaetes (earthworms) of the family Discodrilidae are often found as parasites or symbionts on crayfish.

Identification of the species of crayfish is based largely upon the structure of the first abdominal appendages (sexual organs) of the male. Two forms of this appendage are known in each species of the genus *Cambarus.* These are usually designated as Form I and Form II. Males of the first form can be immediately distinguished by the horny color of the tips of the outer part of the sexual organ. Female specimens have an organ between the last pair of walking feet called either an *annulus ventralis* or *receptaculum seminalis.* Its shape is characteristic for any given species.

The key which follows is based largely on males of the first form. The reader is cautioned at the outset that some variability exists in the form of the male sexual organ. All of the drawings, except those of *C. gracilis* and *C. immunis,* were made from Wisconsin specimens. Figure 1 and the glossary at the end of this paper explain the terminology used in the key.

KEY TO THE WISCONSIN CRAYFISHES

GENUS CAMBARUS

1a. Sexual organ of male terminating in two, slender, elongated, tapering tips, either straight or gently curved. Third walking legs of male with hooks. Wisconsin species of subgenus *Faxonius.*

2a. Both tips of male sexual organ curved posteriorly.

3a. Antennal scale uniformly rounded. Chelae moderately broad, moveable finger with straight cutting edge. Length of posterior section of carapace contained less than twice in the length of the anterior section. Male sexual organ gently curved. Female annulus ventralis with a median transverse fossa. (Fig. 2.)
Cambarus virilis Hagen 1870.

3b. Antennal scale irregularly rounded. Chelae narrow, moveable finger with incision at base of cutting edge. Length of posterior section of carapace contained twice in the length of the anterior

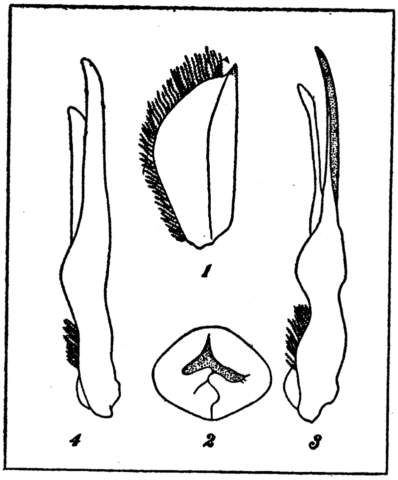

FIG. 2. *Cambarus virilis.* *1*, antennal scale; *2*, annulus ventralis; *3*, sexual organ, form I; *4*, sexual organ, form II.

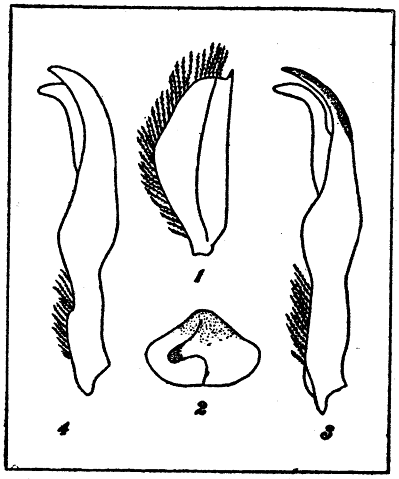

FIG. 3. *Cambarus immunis.* *1*, antennal scale; *2*, annulus ventralis; *3*, sexual organ, form I; *4*, sexual organ, form II.

section. Male sexual organ abruptly curved. Female annulus ventralis with a deep fossa to the left.[1] (Fig. 3.)

Cambarus immunis Hagen 1870.

2b. Tips of male sexual organ straight.

4a. Rostrum with a well developed median carina or elevation above. Sexual organ stout with short tips; outer tip about the same length as the inner. Annulus ventralis flat, fossa very small or absent, sinus nearly straight. (Fig. 4.)

Cambarus propinquus Girard 1852.

1b. Sexual organ of male terminating with two short tips curved at about right angles with the main shaft, the outer of the two tips (the top one) flattened laterally, the inner one rounded. Hooks on the third walking legs of the male. (See also item 1c. below). Wisconsin species of the subgenus *Cambarus.*

5a. Areola obliterated. Carapace higher than wide. Anterior margin of carapace with a triangular protuberance behind the antennal scale. Rostrum without lateral spines.

Cephalothorax without lateral spines. Annulus ventralis with sinus curved to the right[2]; fossa short, median and transverse. (Fig. 5.)

Cambarus diogenes Girard 1852.

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[1] That is, to the observer's left when the animal is seen in ventral view with the anterior end up.

[2] That is, to the observer's right when the animal is seen in ventral view with the anterior end up.

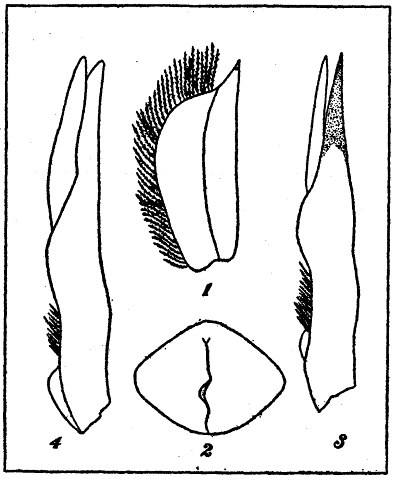

FIG. 4. *Cambarus propinquus.* *1*, antennal scale; *2*, annulus ventralis; *3*, sexual organ, form I; *4*, sexual organ, form II.

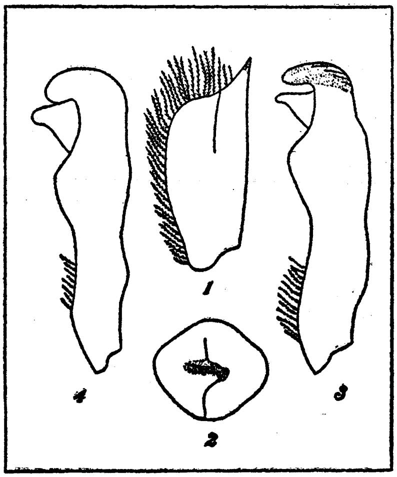

FIG. 5. *Cambarus diogenes.* *1*, antennal scale; *2*, annulus ventralis; *3*, sexual organ, form I; *4*, sexual organ, form II.

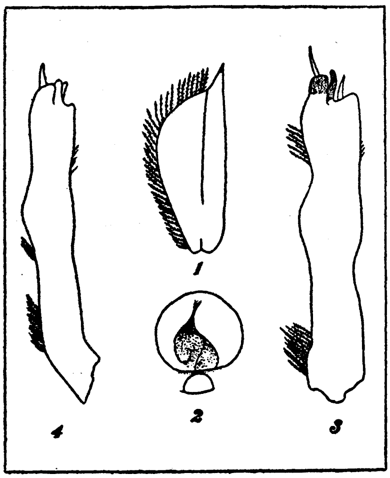

FIG. 6. *Cambarus gracilis.* *1*, antennal scale; *2*, annulus ventralis; *3*, sexual organ, form I; *4*, sexual organ, form II.

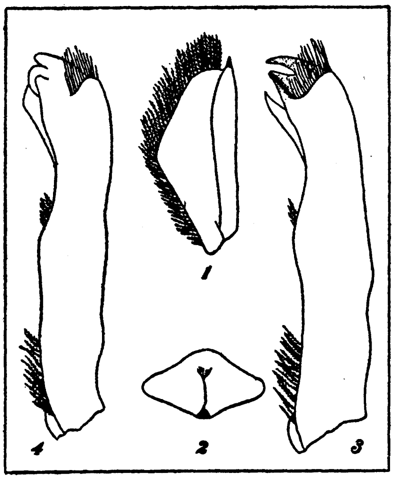

FIG. 7. *Cambarus blandingii acutus.* *1*, antennal scale; *2*, annulus ventralis; *3*, sexual organ, form I; *4*, sexual organ, form II.

1c. Sexual organ of male truncate or blunt at the tip; outer part ending in three rather short teeth; inner part terminating in an acute spine. Hooks on the third or on the third and fourth walking legs of the male. Wisconsin species of the subgenus *Ortmannicus.*

6a. Areola obliterated. Margin of antennal scale evenly rounded. Hooks on third walking legs of male. Chelae broad with moderate fingers. Inner tip of sexual organ exceeding teeth of outer part. Outer part without row of setae at apex. Female annulus ventralis nearly round, sinus irregular, fossa shallow. (Fig. 6.)
Cambarus gracilis Bundy 1876.

6b. Areola narrow but distinct. Margin of antennal scale irregular. Hooks on third and fourth walking legs of male. Chelae long, fingers slender, palm oval. Inner tip of sexual organ curved obliquely outward, not exceeding teeth of outer part. Apex of outer part with row of setae. Female annulus ventralis wide, with two longitudinal tubercles. (Fig. 7.)
Cambarus blandingii acutus Girard 1852.

Distribution and Habits of Wisconsin Crayfish

1. *Cambarus virilis* Hagen

Range: Chihuahua, Texas, Colorado, Oklahoma, Kansas, Arkansas, Alabama (?), Missouri, Iowa, Minnesota, North Dakota, South Dakota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Ontario, Saskatchewan and Manitoba.

Distribution in Wisconsin (Fig. 8): Without question this species is the commonest in the state. It occurs in all the major drainage areas and probably will be found in every county.

Ecology: Cambarus virilis inhabits lakes, streams and rivers. It is found typically under stones, although I have often taken specimens from muddy creeks and in aquatic vegetation. Females with eggs are found during the early spring, usually before the last of April. This species occurs even in cold trout streams. In the region of Green Bay it is of considerable economic importance. At certain seasons great numbers are caught and shipped to the Chicago market. This species is the largest in the state and frequently attains a size of over eight inches.

2. *Cambarus immunis* Hagen

Range: Colorado, Oklahoma, Kansas, Missouri, Nebraska, Iowa, Wyoming, North Dakota, Minnesota, Wisconsin, Illinois, Indiana, Ohio, Michigan, Ontario, New York and Massachusetts.

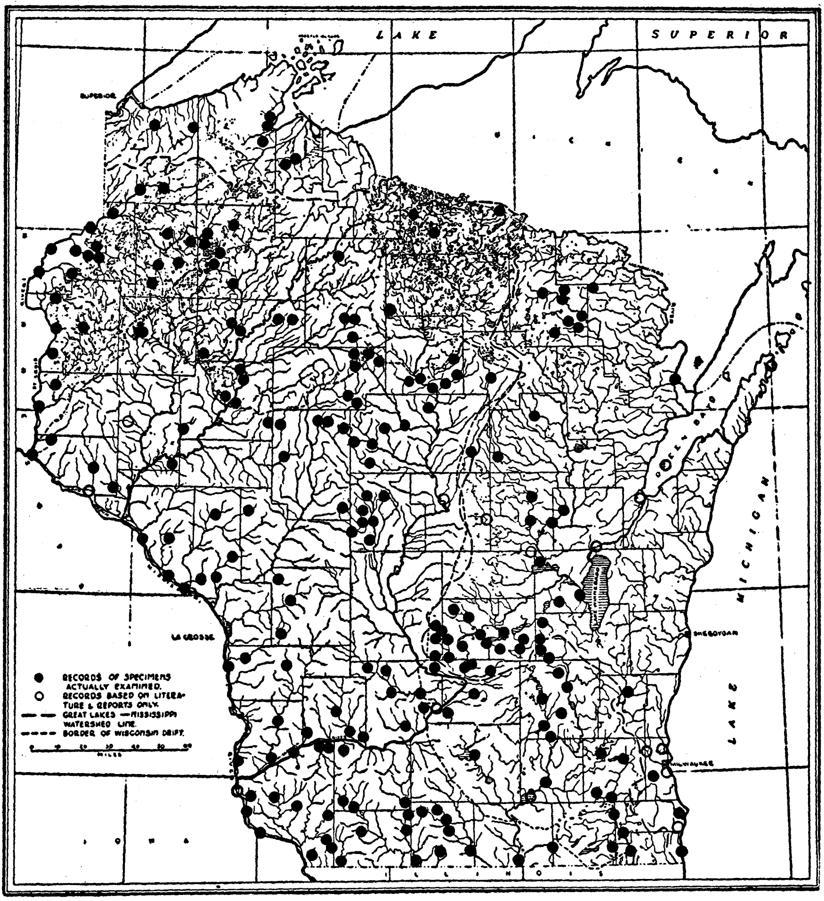

FIG. 8. Distribution of *Cambarus virilis* in Wisconsin.

Distribution in Wisconsin (Fig. 9): This crayfish is apparently very local, being confined, as far as we now know, to the southeastern corner of the state and in the region of Lake Pepin. It is not common in Wisconsin, but probably is more abundant than indicated on the map, as it frequently occurs in temporary ponds which have not been adequately examined for crayfishes.

Ecology: This species is encountered in various types of ecological situations. In rivers and streams it avoids strong currents. It is frequently found in small lakes, especially those with muddy bottoms. When disturbed, it often darts back-

FIG. 9. Distribution of *Cambarus immunis* in Wisconsin.

wards and downwards, striking the bottom so forcibly that the specimen cannot be seen through the murky mud. *Cambarus immunis* occurs sometimes in temporary ponds. As the season advances and the ponds become dry, it resorts to shallow burrows. Females with eggs are found from November to February. During the winter months this crayfish remains in a dormant state, buried in the mud. Graenicher (1913, p. 122) gives the following note regarding this species in Wisconsin: "Along the Wisconsin side of Lake Pepin north of Maiden Rock in Pierce Co., the water is extremely shallow, and in many places the bottom is covered with a dark, sticky mud. In the summer

FIG. 10. Distribution of *Cambarus propinquus* in Wisconsin.

of 1910 the water in the Mississippi river was extremely low, and males and females of *C. immunis* were found on August 3, and 9, in burrows along the wet shore, quite a distance from the lake." In life this crayfish is greenish brown on the carapace and abdomen. On the dorsal surface of the abdomen a design is formed by a contrasting lighter color.

3. *Cambarus propinquus* Girard

Range: Quebec, Ontario, Michigan, Wisconsin, Iowa, New York, Pennsylvania, West Virginia, Ohio, Indiana, Illinois.

Distribution in Wisconsin (Fig. 10): This species presents a most unique distribution in the state. It occurs throughout

FIG. 11. Distribution of *Cambarus diogenes* in Wisconsin.

the Lake Michigan drainage area to the east, and in the Mississippi drainage northward as far as the Wisconsin river and tributaries. It is not found over the western half of the state above the Wisconsin river drainage area. To the writer it seems quite apparent that this indicates a relatively recent invasion from the south and from the east.

Ecology: This species is typically a stream and lake form. It has a habitat preference similar to *C. virilis,* being found most frequently in clear streams and lakes with stony bottoms. It occurs, however, in other habitats and is frequently taken in dense mats of aquatic vegetation. This species never attains the size of *C. virilis* and accordingly has an economic use only as bait and as fish food. Females with eggs attached occur in Michigan from April to June (Pearse, 1910, p. 16).

4. *Cambarus diogenes* Girard

Range: Wyoming, Colorado, Kansas, Arkansas, Missouri, Iowa, Minnesota, Wisconsin, Illinois, Indiana, Ohio, Michigan, Ontario, New York, Pennsylvania, New Jersey, Maryland, West Virginia, Virginia, North Carolina. The subspecies *ludovicianus* occurs in Mississippi and Louisiana.

Distribution in Wisconsin (Fig. 11): This burrowing crayfish doubtless occurs throughout the entire state. The gaps in the map are explainable as resulting from the fact that most of the crayfish collecting in the state has been done with seines.

Ecology: Cambarus diogenes is a burrowing species which resorts to streams, rivers and lakes only during the breeding season in the early spring. It is a common sight to see hundreds of the burrows of this species along a water course. Frequently the tops are covered with mud "chimneys". These burrowing crayfish are often forced to go down several feet before they reach the water level. I have dug this species from burrows which extended more than three feet beneath the surface. Sometimes many small crustaceans, amphipods, ostracods, and copepods, are found in the water pocket of these burrows (Creaser, 1931, pp. 243-244). Female specimens with eggs were found in Indiana on April 17, 1930. Pearse (1910, p. 20) records a female with young taken in Michigan in June.

5. *Cambarus gracilis* Bundy

Range: Oklahoma, Kansas, Missouri, Iowa, Illinois, Wisconsin, Indiana (?), Ohio (?).

Distribution in Wisconsin (Fig. 12): As yet this species is known only from Racine and Milwaukee Counties. It may occur elsewhere in the prairie regions of southern Wisconsin, where it may have escaped notice on account of its burrowing habits.

Ecology: Cambarus gracilis is another burrowing crayfish. Its burrows, unlike those of *Cambarus diogenes* are seldom found along streams, rivers, or lakes but are most frequently

FIG. 12. Distribution of *Cambarus gracilis*, *Cambarus blandingii acutus* and *Palaemonetes exilipes* in Wisconsin.

found in the vicinity of small ponds. In Missouri I dug a specimen from a burrow which extended more than six feet beneath the surface before the water level was reached. Females with young attached are taken in Missouri as late as October. This crayfish can often be obtained after a rain storm, when individuals leave their burrows.

6. *Cambarus blandingii acutus* Girard

Range: Michigan, Ohio, Indiana, Illinois, Wisconsin, Iowa, Missouri, Arkansas, Kansas, Oklahoma, Tennessee, Mississippi (?), Texas, Vera Cruz, N. Carolina (?), S. Carolina (?).

Distribution in Wisconsin (Fig. 12): In the Mississippi river drainage this species extends northward slightly further than La Crosse, and in the Lake Michigan drainage as far northward as Milwaukee.

Ecology: This crayfish frequently occurs in temporary ponds where it builds shallow burrows, probably for mating. It is also found along rivers, especially those with marshy banks. It never occurs in rapidly flowing streams. Turner (1926, p. 154) records this species as carrying eggs or young during the months of March, July, and September. This species probably does not have a restricted breeding season.

FAMILY PALAEMONIDAE

First two pairs of legs chelate. Pleura of first abdominal segment overlapped by those of the second. Abdomen with a sharp bend. Rostrum armed with teeth, immoveable, long and compressed. Mandibles deeply cleft. Gills developed as phyllobranchiae.

The crustacean family Palaemonidae, essentially a marine group, is represented in the fresh-water fauna of the United States by five species: (1) *Macrobrachium jamaicensis* from Florida and Texas, (2) *M. acanthurus* from Florida, (3) *M. ohionis* from the Mississippi and Ohio rivers, (4) *Palaemonetes antrorum,* a blind species, from an artesian well at San Marcos, Texas, (5) *P. exilipes* from the eastern half of the United States.

Genus *Palaemonetes*

Both pairs of legs approximately the same size. Rostrum with teeth above and usually below. Mandibles without a palp.

7. *Palaemonetes exilipes* Stimpson

Range: Iowa, Wisconsin, Michigan, Ontario, New York, Pennsylvania, Ohio, Indiana, Illinois, Kentucky, Tennessee, Arkansas, Oklahoma, Texas, Nuevo Leon, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina, Virginia, District of Columbia, Maryland.

Distribution in Wisconsin (Fig. 12): This species is known from four localities along the Mississippi river in Wisconsin.

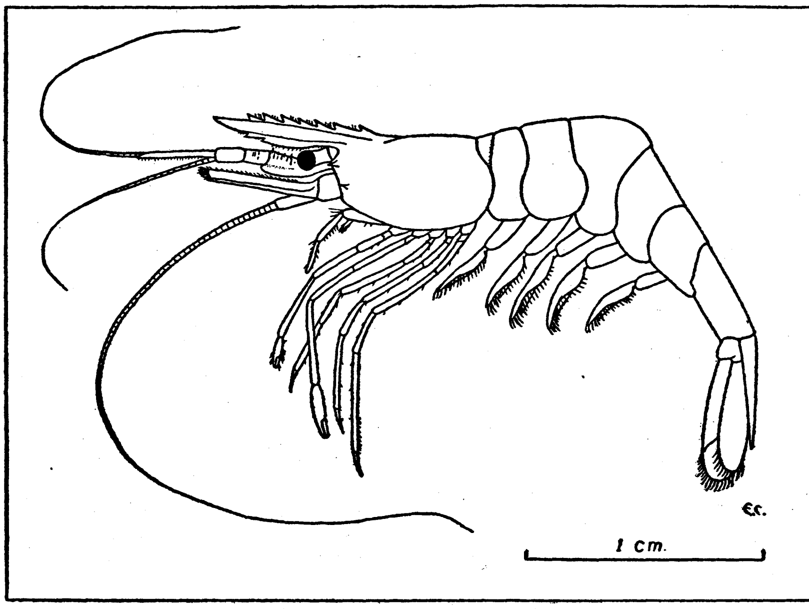

FIG. 13. *Palaemonetes exilipes.*

It is doubtless of general occurrence in and near the Mississippi river.

Diagnostic characters: Fifth walking leg exceeding rostrum. Antennae longer than body. Antennules triflagellate, shortest flagellum closely attached to longest and free but for a short distance. Antennal scale reaching to a point even with apex of rostrum. Rostrum long, vertical, armed above with 6-8 teeth, and below with 1-3. Second dorsal tooth of rostrum usually above base of eye stalk. Carapace rounded above, branchiostegal and hepatic spine present. Abdomen abruptly curved at end of third segment.

Ecology: Palaemonetes exilipes prefers slowly moving or stagnant waters. It is frequently abundant in overflow ponds where its enemies are few. These small crustaceans are eaten by many species of fishes. They could be very easily raised in large numbers and could be used as food for trout in hatcheries. *Palaemonetes exilipes* can be kept for long periods in the laboratory and they make admirable aquarium animals. Eggs are found attached to the females in the spring and fall. This indicates two breeding seasons a year, but adequate studies of the life history of this interesting shrimp have not been made.

SPECIES OF DOUBTFUL OCCURRENCE OR VALIDITY

In this study no specimens of *C. rusticus* have been found. This species has previously been recorded in Wisconsin from Racine Co., Ironton, Sauk Co., and Beloit, Rock Co. It is my belief that *C. rusticus* does not occur in Wisconsin, and that the specimens previously referred to this species are, in reality, aberrant forms of *C. propinquus*.

Bundy (Forbes, 1876, pp. 3-4) has described a new species of crayfish *(C. stygius)* from Lake Michigan, near Racine. This species has persisted in the literature as one of doubtful validity. From Bundy's later account (1882, p. 180) it is quite apparent that he described immature, newly moulted specimens. The differences noted between this species and *C. blandingii acutus* are so slight that it seems almost certain that *C. stygius* is a synonym of *C. b. acutus*.

The following list gives the synonymy of the Wisconsin species mentioned by Bundy (1882, p. 180–183).

SPECIES	SYNONYMY OF BUNDY
1. *C. blandingii acutus.*	1a. *C. acutus.*
	1b. *C. stygius.*
2. *C. virilis.*	2a. *C. virilis.*
	2b. *C. wisconsinensis.*
	2c. *C. debilis.*
3. *C. propinquus.*	3a. *C. propinquus.*
	3b. *C. placidus.* (?)
	3c. *C. rusticus.* (?)
4. *C. gracilis.*	4a. *C. gracilis.*
5. *C. diogenes.*	5a. *C. obesus.*
6. *C. immunis.*	6a. ____________
7. ______________	7a. *C. bartonii.*[3]

The Wisconsin species with the exception of *C. gracilis,* are of general occurrence in adjacent states as shown in Table I. *C. gracilis* is a southwestern form which has probably become established in Wisconsin by an immigration up the Mississippi drainage. The decapod fauna of Wisconsin and adjacent states may be conveniently grouped as follows:

[3] *Cambarus bartonii* has never been taken in Wisconsin.

1. Species of general occurrence: *C. diogenes, C. b. acutus, C. immunis, C. propinquus, P. exilipes.*
2. Southwestern prairie species: *C. gracilis.*
3. Species of northeastern drainage areas: *C. robustus, C. virilis.*
4. Species of the Ohio valley: *C. rusticus* (A confusing array of subspecies of this crayfish exist elsewhere.)
5. Species confined to the Mississippi and Ohio rivers: *M. ohionis.*
6. Blind cave species: *C. pellucidus* and *C. pellucidus testii.*
7. Local species: *C. bartonii laevis, C. ortmanni, C. sloanii* and *C. indianensis.*
8. Species of southeastern occurrence: *C. juvenilis.*

TABLE I. *Decapod occurrence in Wisconsin and adjacent states.*

Species	Wis.	Mich.	Minn.	Iowa	Ill.	Ind.
C. diogenes	+	+	+	+	+	+
C. fodiens		+			+	+
C. robustus		+			+	+
C. bar. laevis						+
C. ortmanni						+
C. b. acutus	+	+	+	+	+	+
C. gracilis	+			+	+	
C. pellucidus						+
C. p. testii						+
C. virilis	+	+	+	+	+	+
C. immunis	+	+	+	+	+	+
C. propinquus	+	+		+	+	+
C. rusticus		+			+	+
C. indianensis					+	+
C. juvenilis						+
C. sloanii						+
P. exilipes	+	+		+	+	+
M. ohionis					+	+

C. fodiens (C. argillicola) has been reported from Michigan, Lower Ontario, Ohio, Indiana, Illinois, Mississippi, Louisiana, Texas and North Carolina. The records for the four states last named are surely doubtful. Consequently *C. fodiens* may be a species of rather wide spread occurrence in the north central states. This species is a burrower and is found in the springtime in temporary woodland ponds. A search should be made for this crayfish in southern Wisconsin. (It is a species of the subgenus *Cambarus,* and is characterized by having the areola obliterated and the moveable finger of the chela with a deep incision at the base of the inner margin.)

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Glossary

Branchiostegal spine, a spine situated near the anterior margin of the carapace, ventrad to the hepatic spine (in shrimp).

Cephalothorax, the solid front part of the body covered by a continuous chitinous shield. The cephalic groove divides this into an anterior and a posterior section. Also called the carapace.

Fossa, a cavity, pit or depression.

Hepatic spine, a spine laterally situated on the carapace, behind and below the eye.

Obliterated areola, areola limited to posterior and anterior triangular fields by the fusion of the limiting (branchio-cardiac) grooves.

Palp, the endopodite or inner ramus of a mouth part.

Phyllobranchiae, gills with two rows of broad flat lamellae.

Pleura, the side of an abdominal segment.

Sinus, an elongated groove.

Truncate, having the terminal edge square or even.

PRELIMINARY LIST OF THE HYDRACARINA OF WISCONSIN

PART II

RUTH MARSHALL

Part I of the *Preliminary List of the Hydracarina of Wisconsin* (Marshall, 1931) recorded fourteen species belonging to seven genera of the red water mites, the super-family *Limnocharae.* The present paper treats in the same way a portion of the much larger super-family *Hygrobatae,* namely, seventeen species of nine genera belonging to four large families found in the state. Of these, one species is new. Notes on distribution and one or more drawings are given for each species. For complete characterizations of the species the student is referred to titles in the bibliography. A few outstanding features of each are noted, however, which, together with the drawings will, it is hoped, be sufficient in most cases to identify the species.

The water mites of this group are of medium size, variously and often brightly colored, the skin usually thin but sometimes heavily chitinized; the paired eyes of each side do not lie on capsules; the palpi are not chelate; the epimera are extensive and varied and more or less united; the legs usually end in claws which are double toothed; the genital plates are well developed and often placed apart from the epimera and sexual dimorphism is usually well marked.

For most of the extensive collections from Green Lake and the Trout Lake, Vilas County, region and for all of the collections from given depths the author is indebted to the courtesy of the Wisconsin Natural History Survey.

Lebertia porosa Thor
Pl. VII, fig. 1.

The epimera in the Lebertia are united into a shield which partly encloses the genital area. This cosmopolitan species is recognized by details of the palpi and epimeral plates and their relation to the genital plates.

The species is found throughout Europe and in northern Asia; in Canada, Alaska, Colorado, Montana, Wyoming, Illinois, Iowa, Michigan, Indiana and New York. In Wisconsin it has been found in Lake Winnebago, the Madison lakes, Drake Lake (Waupaca), Goose Pond (Adams Co.), in four lakes of Vilas County and in several collections from Green Lake at depths from the surface to a few meters.

Lebertia quinquemaculosa Mar.
Pl. VII, fig. 2-4.

Adults, which may attain a length of 2 mm., are usually recognized when alive by the presence of five red spots on the dorsal surface. The first epimera are narrow and the fourth forms a wide bay for the genital plates. The nymphs have ventral plates characteristic for the genus.

Specimens have been found in British Columbia and Indiana; in Wisconsin they have been taken in Mirror Lake (Delton), Deep and Parker lakes (Adams Co.) and in Green, Powers and Twin Lakes, all from shallow water.

Oxus connatus Mar.
Pl. VIII, fig. 9, 10.

In the genus Oxus the epimera are fused into a shield. In *O. connatus* this shield is not extensive and it only partly encloses the genital area and the body is relatively low.

Specimens have been found in Ontario. In Wisconsin they have been taken in Mirror Lake, Goose Pond (Adams Co.), Lake Mendota, Green Lake and several of the lakes of Vilas County.

Oxus elongatus Mar.
Pl. VIII, fig. 13, 14.

The epimeral shield is somewhat more extensive than in the last species and the body is higher.

The species has been found in Ontario and in Wisconsin in several of the lakes of Vilas County, near the surface and at depths of a few meters.

Oxus intermedius Mar.
Pl. VIII, fig. 11, 12.

The epimeral shield is extensive, extending to the dorsal side, and the body is elevated.

It has been taken in Minnesota, in the Madison lakes and in several of the lakes of Vilas County together with specimens of the last two species.

Frontipoda americana Mar.
Pl. VIII, fig. 15–17.

This species, the only one of the genus so far reported in North America, is common in shallow waters. It is green (occasionally red), with brown markings, and is readily recognized by the laterally compressed body and the great development of the epimeral shield which entirely encloses the genital area and extends over most of the dorsal surface, crowding the leg attachments well to the front.

The nymph is now known. It shows the epimeral shield in two parts and the typical genital area for the genus.

Specimens have been found in Maine, New York, Michigan, Indiana, Iowa, Minnesota and Louisiana. In Wisconsin they have been found in lakes and ponds near Cable, Madison and Eagle River; in Green, Fox, Mirror and Storr lakes; in Adams County and in thirteen lakes in Vilas County.

Atractides jordanensis Mar.
Pl. X, fig. 46, 47.

Water mites of the genus Atractides (formerly Torrenticola) have hard and porous integuments and an unusual development of plates so that the body appears to lie in layers. This species shows a typical arrangement of the dorsal plates, one being very large with four small ones on its anterior border. The rostrum of the mouth region is short. Colors are bright and variegated.

Individuals are usually found in silt. They have been taken in small numbers in Jordan Lake and in the neighboring Goose Pond; in Razor Back Lake, Vilas Co., and in Green Lake at a depth of fifteen meters.

Atractides indistinctus Mar.
Pl. X, fig. 42-45.

This species is distinguished by the incomplete development of the four anterior dorsal plates and by the large rostrum, which with the ends of the first epimeral pair extend well forward beyond the body margin.

The male is now known. It is smaller than the female (0.575 mm. to the end of the rostrum); as usual in this sex, the united first pair of epimera do not reach to the genital area, as they do in the female, due to the greater development of the second and third pairs.

The nymph has likewise been found. The surface is finely ridged and the dorsal side shows the typical four conspicuous plates, the posterior one large and shield shaped.

Specimens have been found at moderate depths in Indiana and in Green and Winnebago lakes in Wisconsin.

Tyrrellia ovalis nov. spec.
Pl. VIII, fig. 18-21.

The body is oval; the largest individual found measures 0.95 mm. The surface is thickly beset with tiny thorns directed backward; the epimera and legs are porous. Colors are not known. The anterior dorsal surface shows two pairs of small irregularly oblong chitinized plates and a number of small hair plates. The epimera are heavy; in form they resemble those of Limnesia and all bear a few hairs; the fourth is broad and bears the articulation for the last leg well toward its inner posterior margin. The two elongated genital plates lying close to the epimera bear each three conspicuous acetabula, the two posterior ones close together; in the specimens found these resemble the plates of female Limnesia. The palpi resemble those of *T. circularis* and are likewise similar to those of certain species of the related genus; a small peg on a conspicuous papilla shows on the second segment, while the fourth bears a cluster of hairs on the inner side near the distal end. The legs are heavy and short, none of them being as long as the body; all are provided with many small bristles but no swimming hairs and they end in large weak claws. The third leg is slightly shorter than the others. The fifth segment of the fourth leg is bent, as in the related species.

The genus Tyrrellia was erected by Dr. Koenike to contain the one species, *T. circularis,* found near Ottowa. The author has examined this material which is deposited in the Department of Agriculture in Ottawa. Unfortunately the two slides containing the specimens are not in good condition, but Dr. Koenike's descriptions and figures are clear and detailed. The new species falls well within his characterization of the genus except that in place of a single dorsal anterior plate there is present a pair of small plates. It is distinguished from the type species not only by this difference in the dorsal surface but also by its more elongated form and by the shape of the genital plates of the female. In the few recorded measurements individuals of the new species are smaller.

Three specimens of *T. ovalis* were found in Mendota Bay at Madison; it is inferred that they are females. Dr. R. W. Wolcott, in Ward & Whipple's *Fresh Water Biology* (p. 869) states that he found specimens of the genus in Michigan lakes; two species were present, one of which was apparently *T. circularis*, but further data are not given.

Limnesia cornuta Wol.
Pl. IX, fig. 22-24.

This rare species of the large genus Limnesia is recognized by the unusual chitinous meshwork of the body surface, the presence of a small posterior dorsal plate and the large, finely serrated antenniform bristles.

It is known for Ontario, Michigan and Tennessee. In Wisconsin it has been taken in Clear-Crooked Lake (Vilas Co.) and in Goose Pond (Adams Co.) at depths from the surface to six meters.

Limnesia maculata (Müll.)
Pl. VII, fig. 5.

Dr. R. Piersig (1905), commenting on Dr. Wolcott's detailed account of this species in North America (1903), designated it as a new variety, *L. americana*, basing his opinion on certain details of palpi, epimera and genital plates as shown in Wolcott's figures of a young female. The author, after examining a large number of specimens and comparing them with identified European material, does not find any constant or important differences existing between them which justifies the formation of a variety and consequently the name has been dropped. In respect only to color does there appear to be any appreciable difference. In European literature the species is described as almost always red; observations on living material here indicate that the entire body is only seldom entirely red, though red spots are common, and that green, yellow and blue predominate. These color varieties, however, have been reported for various parts of Europe.

Re-examination of material shows that *L. elliptica* Mar. (1924), described from one young female taken in Alaska, is a synonym for *L. maculata* and that the name must be dropped.

The species *L. maculata* is one of the largest, individuals sometimes measuring 2 mm. It is recognized by the small size of the palpi and correlated with this the small size of the maxillary shield which bears them, as well as by the form of the first epimera, the inner borders of which tend to approach each other for a greater part of their length.

The species has been found all over Europe, in Turkestan, northern Asia and northern Africa. In North America it is known for British Columbia, Ontario, Alaska, New York, Michigan, Iowa and Montana. In Wisconsin it has been found in Spooner and Green lakes, Goose Pond (Adams Co.), pools near East Winona and in Trout Lake and twenty smaller lakes in its vicinity. It appears to be commoner in northern waters and at some distance below the surface, since the greater number of individuals have been found at depths from two to twenty-nine meters.

Limnesia paucispina Wol.
Pl. IX, fig. 25-27.

Mites of this fairly common species are small, measuring less than 1 mm. Colors are pale browns, sometimes with reds or blue and orange. Spines and swimming hairs on the legs are scarce; the maxillary shield has straight sides; and the palpi are distinctive, being large and stout with a long spine on the second segment resting on a very short papilla.

Dr. Wolcott erected the species from the examination of a single preserved female. The male is now known. The relative size and position of the three acetabula of the genital plates in both sexes have been found to be variable, as in other species of the genus.

This species is known for Michigan and Ohio; in Wisconsin it has been found in small numbers in Green, Lauderdale and Buffalo Lakes; in pools near Wisconsin Dells and Green Bay; in the Yahara River and pools near Madison; and in several lakes in Vilas County at depths from the surface to 7.5 meters. (One record for 29 meters may be accidental.)

Limnesia fulgida Koch

Pl. IX, fig. 31-33.

American forms of this species have been referred to as variety *wolcotti,* a name given by Dr. Piersig (1905) in reviewing Dr. Wolcott's description of the species in North America (1903), since he found certain small differences in details of the genital plates and palpi. The author is now of the opinion that the creation of a new variety was not justified.

This species and the following, *L. undulata,* both common in the Old World, are very closely related; their separation is difficult and has given rise to much confusion in the literature. The author, after the examination of hundreds of North American Limnesia and the study of identified European specimens has come to the conclusion that the two species intergrade and are not clearly separated. The same condition has been found true for two other common American species, *Arrhenurus megalurus* and *A. marshallae,* as already reported. There appears to be, in these Limnesia, individual, sex and age variations; perhaps the particular environment affects the individual in some cases, and crossing may occur. Results of this study indicate that, in general, the two species are separated chiefly on the basis of certain small, more or less constant difference in color, palpi and genital plates, especially those of the male; that the decision as to which of the two species a given individual is assigned to rests largely on the judgment of the investigator in balancing these small and sometimes variable characters. Both species are common, large, and frequently found together.

As interpreted by the author, *L. fulgida* (formally *L. histrionica*) is brightly colored, sometimes entirely red (as usually given in European literature) ; the palpi are large and the stout second segment has two rows of bristles and a moderately large, sometimes conical process provided with a peg, often set obliquely; and on the male genital plates the small hair papillae are numerous and conspicuous and closely follow the outer margins of the large acetabula.

This cosmopolitan species is found in nearly all shallow waters in the state and probably throughout eastern United States and Canada.

Limnesia undulata (Müll.)
Pl. IX, fig. 28-30.

The species is closely related to *L. fulgida,* as stated under the description of the latter species, and is distinguished from it with difficulty. In general it is duller in color and never entirely red; the palpi, relative to the legs, are larger and stouter, although the fifth segment is slimmer, its second segment shows fewer spines and its process with a peg is longer and slimmer; and on the male genital plates the fine hair papillae are not usually so numerous nor conspicuous nor placed as irregularly as in *L. fulgida.*

This large species appear to be somewhat more widely distributed in the United States and Canada than the related species. It is found, usually abundantly, in all shallow waters of Wisconsin.

Limnesiopsis anomala (Koen.)
Pl. VII, fig. 6-8.

This species, the only one known for the genus, closely resembles the large Limnesia but is never so abundant. It is readily recognized by the presence of the numerous small acetabula on the genital plates.

The nymph is now known; its genital plate closely resembles that found in Limnesia larvae.

The species was first described by Dr. Koenike who took it for an unusual Limnesia; it is still regarded by some authors as forming only a subgenus. The original material came from Ontario; this has been examined by the author as well as material since taken from Lake Simcoe, near Toronto. It has also been found in New York and Michigan. In Wisconsin it has been found in Green, Winnebago, Pewaukee, Waukesha and the Madison lakes and in thirteen bodies of water in Vilas County, usually near the surface.

Hygrobates longipalpis (Herm.)
Pl. X, fig. 38-41.

Details of the anterior epimeral group and the structure of the palpi distinguish this genus from Megapus which it closely resembles; all of these mites are of moderate size, usually one millimeter or less in length. Characteristic of this species is the well developed process on the second palpal segment, the shape of the fourth epimera and the position of the acetabula on the genital plates of the female. Adults when alive are usually recognized by their bright brown color on which are conspicuous irregular white branched streaks and sometimes red spots.

The species *H. ruber* (Marshall, 1926) has been found on re-examination of the material to be a young *H. longipalpis;* hence the name, being a synonym, must be dropped.

The species is common in Europe and has also been found in Asia Minor and northern Africa. It was first reported for the New World by Dr. Koenike who recognized it in material from British Columbia which the author has also examined. It has since been found in Ontario, Wyoming, Montana, Iowa, Illinois, Michigan, Indiana, Ohio, Tennessee and New York. In Wisconsin it has been taken from Winnebago, Green, Spooner, Pewaukee, Lauderdale, Nashota and Twin Lakes (Kenosha Co.), the Madison lakes and from ten lakes in Vilas County, at depths from the surface to ten meters.

Megapus parviscutus (Mar.)
Pl. X, fig. 34-37.

Members of the genus Megapus (formerly Atractides) are distinguished from Hygrobates by the more complete separation of the first pair of epimera from the capitulum and by differences in the palpi and first pair of legs. This species shows less modification of the ends of the last two segments of the first pair of legs than do most species of the genus.

Re-examination of material now shows that *M. (Atractides) orthopes* (Marshall, 1915) is the male of *M. parviscutus* and the former name becomes invalid in consequence. The status of the species *M. phenopleces* described by the author in the same paper from one female found in Lake Spooner is in doubt and will await the study of more material.

The species *M. parviscutus* has been found in Indiana, Illinois and Michigan. In Wisconsin it has been found in shallow water, usually in southern counties, the localities as follows: lakes Lauderdale, Como, Delavan, Twin, Green, Mirror, Nashota, Nagowicka, Buffalo and Spooner, Goose Pond (Adams Co.) and pools near Minocqua.

ROCKFORD COLLEGE,
SEPTEMBER 1, 1931.

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PLATE VII.

1. *Lebertia porosa*, ventral plates.
2. *Lebertia quinquemaculosa*, palpus.
3. *Lebertia quinquemaculosa*, ventral surface.
4. *Lebertia quinquemaculosa*, nymph, ventral plates.
5. *Limnesia maculata*, ventral plates, female.
6. *Limnesiopsis anomala*, ventral plates, female.
7. *Limnesiopsis anomala*, genital plates, male.
8. *Limnesiopsis anomala*, genital plates, nymph.

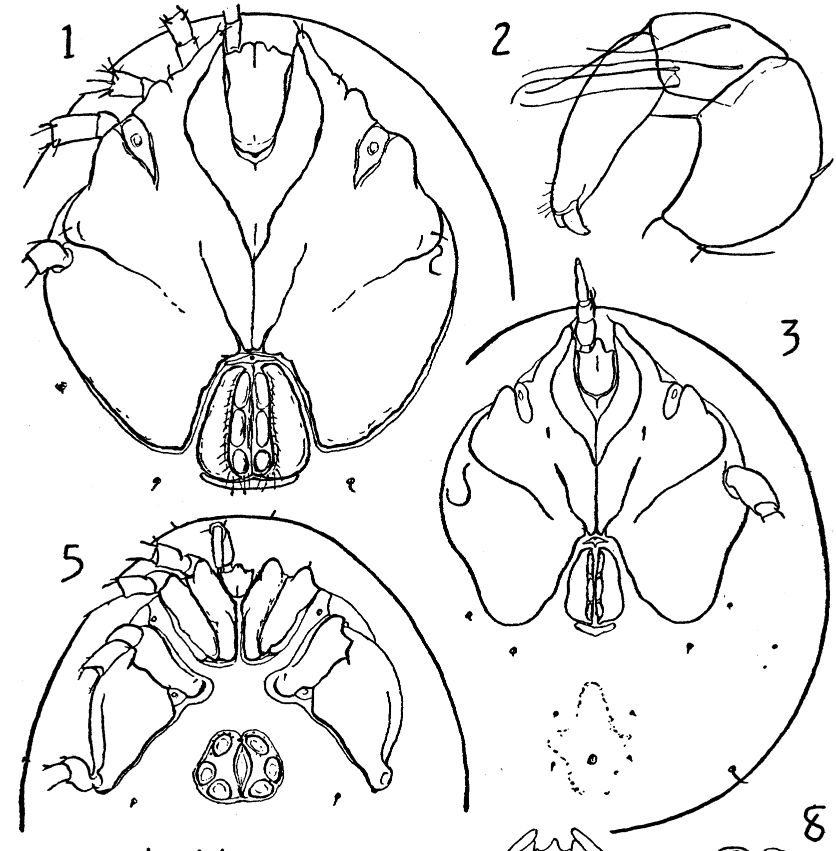
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PLATE VIII.

9. *Oxus connatus*, ventral view.
10. *Oxus connatus*, lateral view.
11. *Oxus intermedius*, ventral view.
12. *Oxus intermedius*, dorsal view.
13. *Oxus elongatus*, ventral view.
14. *Oxus elongatus*, palpus.
15. *Frontipoda americana*, dorsal view.
16. *Frontipoda americana*, nymph, ventral view.
17. *Frontipoda americana*, lateral view.
18. *Tyrrellia ovalis*, ventral view.
19. *Tyrrellia ovalis*, right palpus.
20. *Tyrrellia ovalis*, dorsal view.
21. *Tyrrellia ovalis*, leg I, left.

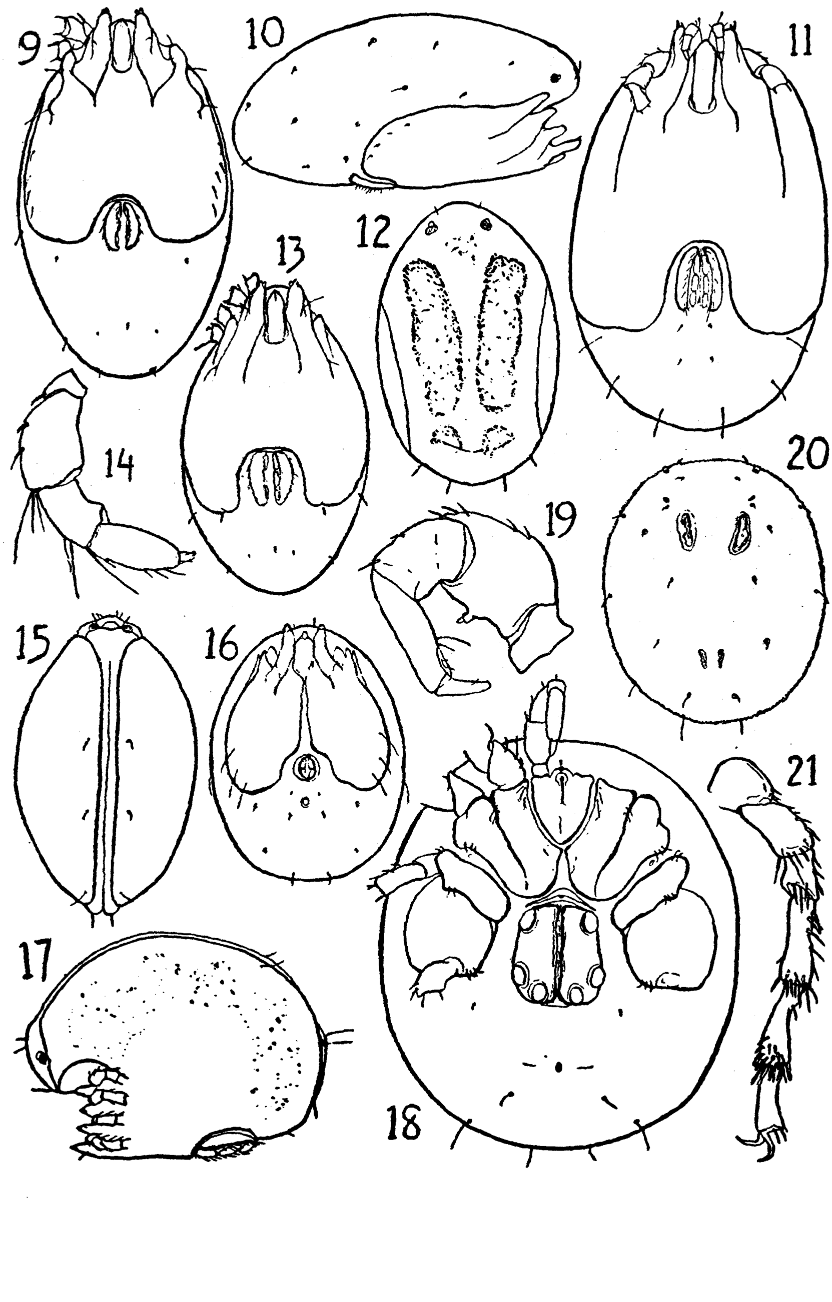
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PLATE IX.

22. *Limnesia cornuta,* dorsal view.
23. *Limnesia cornuta,* ventral plates, male.
24. *Limnesia cornuta,* hair plate and chitinous meshwork, (after Wolcott).
25. *Limnesia paucispina,* end of leg IV.
26. *Limnesia paucispina,* ventral view, male.
27. *Limnesia paucispina,* palpus.
28. *Limnesia undulata,* left palpus.
29. *Limnesia undulata,* genital plates, male.
30. *Limnesia undulata,* genital plates, nymph.
31. *Limnesia fulgida,* genital plates, male.
32. *Limnesia fulgida,* left palpus.
33. *Limnesia fulgida,* ventral plates, female.

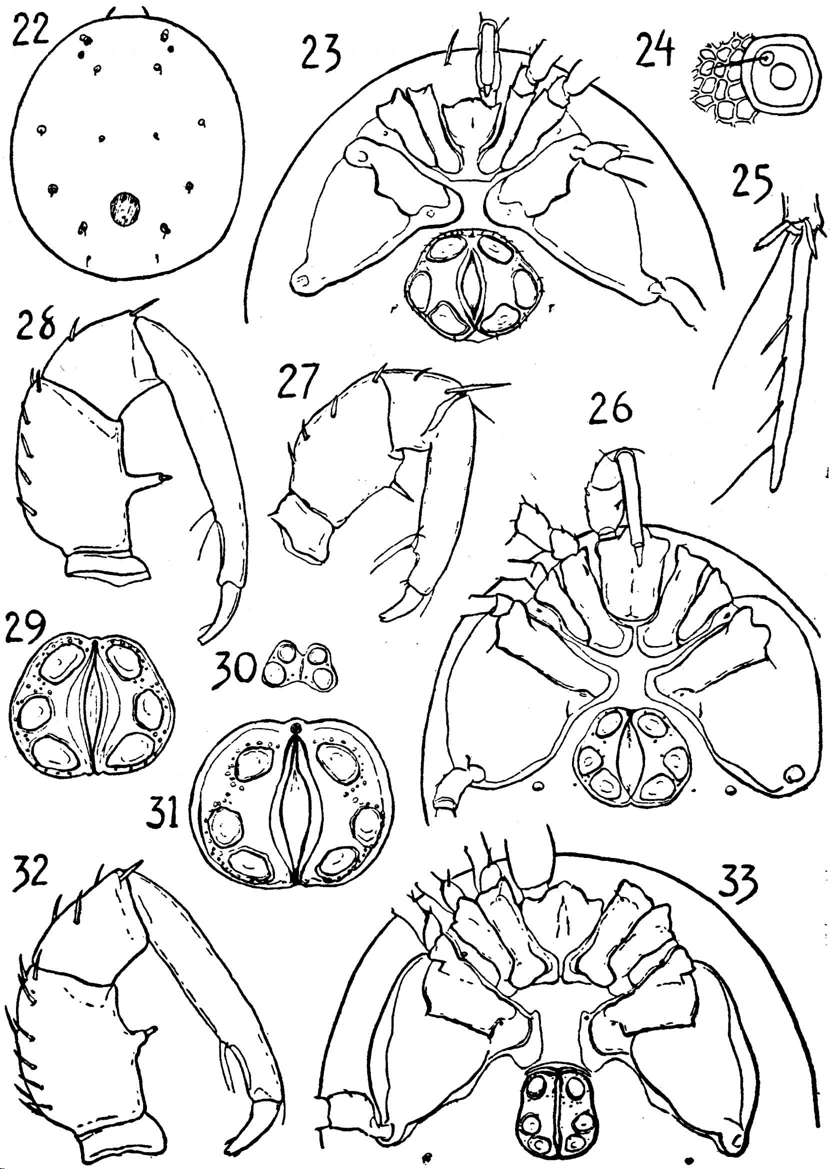
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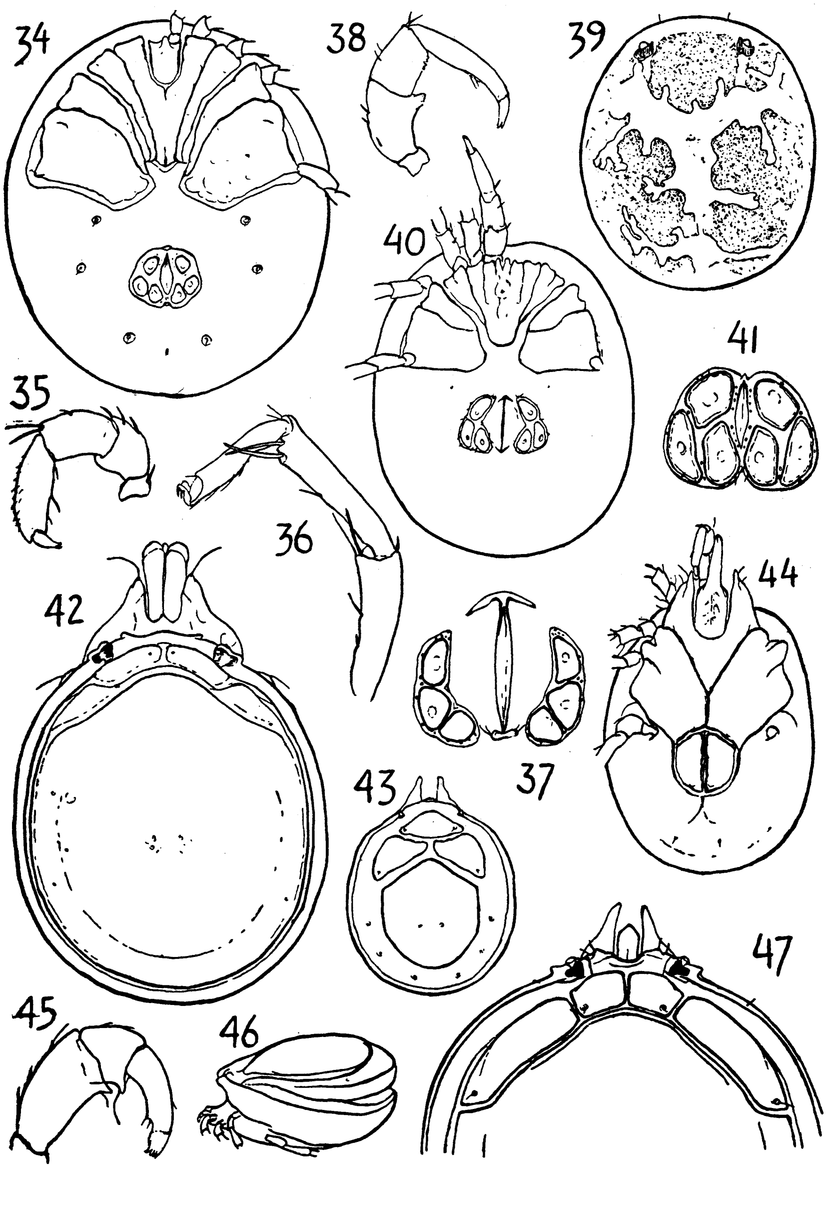
PLATE X.

34. *Megapus parviscutus*, ventral view, male.
35. *Megapus parviscutus*, palpus.
36. *Megapus parviscutus*, end of leg I.
37. *Megapus parviscutus*, genital plates, female.
38. *Hygrobates longipalpis*, palpus.
39. *Hygrobates longipalpis*, dorsal view.
40. *Hygrobates longipalpis*, genital plates, female.
41. *Hygrobates longipalpis*, genital plates, male.
42. *Atractides indistinctus*, dorsal view.
43. *Atractides indistinctus*, nymph, dorsal view.
44. *Atractides indistinctus*, ventral view, male.
45. *Atractides indistinctus*, palpus.
46. *Atractides jordanensis*, lateral view.
47. *Atractides jordanensis*, anterior dorsal region.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A REPORT ON THE MOLLUSCA OF THE NORTHEASTERN WISCONSIN LAKE DISTRICT

J. P. E. MORRISON

Notes from the Limnological Laboratory of the Wisconsin Geological and Natural History Survey
No. XLVII.

INTRODUCTION

The following is a report on the present knowledge of the molluscan life of the Highland Lake District of Wisconsin. This region of the state has been practically unexplored as far as this group of animals is concerned.

The work of Chadwick was limited, including a few records from the Wisconsin drainage, near the town of Eagle River. The work of Winslow was largely limited to the vicinity of the Arbor Vitae lakes, in the Tomahawk drainage. The records of Cahn come principally from the vicinity of Sayner and include some from Muskellunge Lake.

Baker's work on Tomahawk Lake was largely descriptive, being a fairly complete account of one of the large lakes in the district. He described the habitats of all the species collected, and classified them on the basis of ecological succession. Strikingly brought out in his report is the great diversity of ecological conditions within such a small area.

There are many lakes without inlets or outlets in the area studied, since the region is topographically young, so little removed from the effects of the last glacial era, and the streams have not had time enough to cut back to drain all the lakes that were left. A brief study of the drainage lines, together with the great abundance of the lakes, of all sizes, will indicate the youthfulness of the region. This region is one of the headwaters of several drainage areas. It includes the headwaters of the Flambeau River (Chippewa drainage), of the Tomahawk and Wisconsin Rivers (Wisconsin drainage), of the Montreal River, West Branch of the Ontonagon River, and the South Branch of the Presque Isle River (Lake Superior drainage), and of the Pine River (Lake Michigan drainage).

Examination of the district was undertaken at the suggestion of Prof. C. Juday, under whom the writer had the pleasure of working during the summers of 1929 and 1930. The work on the Mollusca was done in whatever time was to spare from the quantitative work on the bottom fauna of these lakes.

In the preparation of the lists, records have been secured from the following sources: (1) Collections made during the summers of 1929 and 1930. (2) Previous collections, hitherto unrecorded, including those from the Wis. Geol. & Nat. Hist. Survey (1928), and some made by Dr. O. Park, near Sayner, during September 1927. (3) Previous records, included in Baker's Monograph of Wisconsin Fresh Water Mollusca.

Acknowledgments are due the following people who have aided the work: Prof. Juday under whose supervision the work was done; Dr. Wm. J. Clench for determination of the Physidae; Dr. Victor Sterki for determination of the Sphaeriidae; Dr. Bryant Walker for determination of the Ancylidae; to Edward Schneberger, Mrs. J. P. E. Morrison, and others whose assistance in the field has been invaluable.

The lakes in the region examined for Mollusca show a wide range in degree of softness, with a corresponding range in acidity. The amount of fixed carbon dioxide present in the open water of the lakes varies from 1.0 to 30.5 parts per million. The pH range is from 5.1 to 8.3. In the softest lakes the calcium content of the water is as low as 0.1 part per million.

It would seem at first sight that molluscs would be unable to exist in such soft waters as is indicated by a fixed carbon dioxide content of from 1.0 to 5.0 parts per million. However, careful search has shown their presence in even the softest and most acid of the lakes. There are two general types of the extremely soft lakes: (1) the type with clear water and usually a sandy or rocky gravel margin, more or less devoid of plants; (2) the type with highly colored water, surrounded usually in part by bog.

Two of the characteristic forms of molluscs found in the soft, clear lakes are *Pisidium* and *Campeloma*. It is a puzzle as to how *Pisidium* can draw enough substance for a shell (thin, to be sure) from water with a pH of 6.0 and a fixed carbon dioxide content of 1.0 part per million. The snail *Campeloma* builds a much larger and thicker shell under the same conditions.

In lakes of the soft, bog-surrounded type, there is usually a little more dissolved carbonate (3.0-5.0 p.p.m.), with a pH of 5.1 to 6.1. Here are to be found in certain lakes, some of the largest and finest specimens of *Pisidium* (sp. undescr.), nearly reaching the dimensions of the largest found in the state. Are these small bivalves able to hoard enough of the shell building materials from the water, or is there a better supply in the particular place in the bottom they inhabit?

None of the family Valvatidae are found at a pH lower than 7.1 and in water softer than that containing 8 parts per million of fixed carbon dioxide.

The Campelomas, the only representatives of the family Viviparidae in the region are able to withstand the more extreme conditions of a pH of 5.7 or 5.8 and a fixed CO_2 content of 1.0 part per million. The range of the two species is almost identical, showing both of them to be equally generalized in their habitats.

Among the Amnicolidae, only two species are widespread, and of these only one is found at any great range below neutrality. The commonest species *(Amnicola limosa porata)* is found in situations ranging from pH 5.7 to 8.3, and from 1 to 30 parts per million of fixed CO_2; all the other species are found above pH 6.8 and 8 parts per million of fixed CO_2.

Among the gill-breathing snails, only three species are able to tolerate the conditions of the extremely soft waters of the clear lake type. There is a probability that the data used for these snails may be in error in certain cases. It is only reasonable to suppose that *Campeloma,* where found in abundance in the (glacial till) clay bottom of an extremely soft water lake, is getting its necessary supply of carbonates from the clay bottom directly, and not from the open water of the lake. In the case of *Amnicola,* an extra source of shell-building materials must be sought in the plant food.

Among the Lymnaeidae, three forms are especially tolerant of acid water (pH to 6.0), while the majority of the species are found only in water having an alkaline reaction (pH 7.0 to 8.0). Specialization of habitat seems to be rather well marked in this group, as indicated by the attendant chemical data. The genus *Lymnaea* is restricted to waters of pH 7.2 or more, and a fixed carbon dioxide content of 15 or more parts per million. In the genus *Stagnicola,* we find the common form of southern Wisconsin *(S. palustris elodes)* largely replaced in the northern lakes and ponds by *S. exilis* and *S. lanceata.* These two last named species are found in more acid and softer lakes than is *palustris elodes.* On the other hand, the species of the *emarginata* group seem to be confined to lakes of pH 7 to 8. In the genus *Fossaria,* the common species *obrussa* is found from pH 5.9 to 8.3, while the supposed ancestral form *F. o. decampi* is found under much more restricted conditions, chiefly in waters having a H-ion concentration of pH 7.5. This immediately raises the question as to which is the ancestral form, and which the special form found under a peculiar set of conditions attendant upon recently formed glacial lakes.

Examination of the family as a whole shows that only *Stagnicola* and *Fossaria* are generally distributed under variable conditions while *Lymnaea, Acella, Pseudosuccinea,* and *Bulimnaea* are restricted to greater or less degree. Must not the four last-named genera be considered as more highly specialized or "senescent" groups as compared with *Stagnicola* and *Fossaria?*

Examination of the several described varieties of *Helisoma antrosa* brings out some interesting conclusions. The thin-shelled form, *H. a. unicarinata,* seems to be restricted to the softer, more acid waters of the region, while *H. a. sayi,* which has a noticeably thicker shell, is not found in lakes that are acid (pH below 7.0). On the other hand, the two other varieties, *H. a. antrosa* and *H. a. cahni,* are found under variable conditions (pH 6.0 to 8.0).

The range of the varieties of *H. trivolvis* and *H. campanulata* show simply that the varieties are more restricted in habitat than is the typical form of each species; for example, *H. t. pilsbryi* is found within narrower pH limits than is the typical *H. trivolvis.*

In the case of *campanulata,* the varieties listed in order of increasing restriction are *H. c. campanulata, c. wisconsinensis, c. minor,* and *c. ferrissii.*

Different sets of chemical conditions in these lakes seem to produce specific varieties in a few cases. Also, it would seem that the variation in chemical nature of the habitat may be the stimulus for production of non-specific variation in form of the animal or of the shell it builds.

Among the small Planorbids, the forms of the Genus *Gyraulus,* when regarded in the subgeneric groups, show a tendency toward serial arrangement of the different forms across the different conditions of the lakes. In the subgenus *Gyraulus sensu stricto* listed from more acid to more alkaline limits of range are: *G. deflectus, G. d. obliquus, G. hirsutus.* Of these three species, that found in the more acid conditions is most carinate, and the one found under most alkaline conditions is the least carinate on the periphery of the whorl. In the subgenus *Torquis,* a much more marked series is indicated, consisting of: *G. circumstriatus, G. parvus, G. arcticus.*

In spite of the paucity of records in the Ancylidae, one difference is indicated. *Ferrissia parallela* is the only species in the region found in neutral or acid waters. The other three species are bunched (with one record each) at about pH 7.6. *Parallela* is to be found from pH 6.0 to the most alkaline of the lakes examined for mollusks (pH 8.4).

Two species of *Physa* show up in a wide range of conditions. These two are large, thin-shelled, and apparently annuan in these lake habitats. *P. sayii* ranges as far as pH 5.7 on the acid side, while *P. laphami* is found down to pH 6.4. *P. gyrina,* which is more common in southern Wisconsin than in these northern lakes, is not in acid waters in the lakes. Likewise, the four other forms recorded were restricted to alkaline water (pH 7.6-8.0).

All the species of the *Unioninae* in the region are restricted to streams of slightly alkaline reaction (pH 7.0-8.0). The lower limit of fixed carbon dioxide observed was 12.07 parts per million. The only one of the forms of this subfamily found in lakes in Vilas Co., is recorded from a lake in the same range of acidity and hardness of water.

In the subfamily *Anodontinae,* all except species of *Anodonta* are similarly restricted in the chemical nature of the habitat. Thinnest-shelled of the genus, among the species to be found in northern Wisconsin, *Anodonta marginata* is found in many of these northern lakes, in water varying from pH 6.0 to 8.4 and in fixed carbon dioxide content from 2.6 to 30.5 parts per million. Under the extremely soft and acid water conditions, the shell developed by this form is so thin, that it may be twisted (when fresh and still wet) through about 20 degrees, without even cracking. It is impossible to twist the thicker shells developed when the animals have grown under slightly alkaline conditions.

All of the species of the subfamily *Lampsilinae,* like the majority of species of the fresh water mussels, are limited to slightly alkaline waters. Detailed examination of the range of the two species of *Lampsilis* shows that the lake and the stream variety of each have approximately the same limits. The development of the lake form is not due to differences of H-ion concentration or of the amount of fixed carbon dioxide present, as far as the writer's studies are concerned.

In the Sphaeriidae, some striking differences of chemical nature of the habitat are seen. In general the distribution of species of the "Finger-nail" and "Pill" Clams shows the condition expected of a diversified group, some widespread, some intermediate, and some species confined to narrow limits of H-ion concentration and of amount of fixed carbon dioxide present in the water.

On examination of the groups within the family, or within genera, we get more precise information. For example: *Pisidium* surpasses the other two genera in tolerance for acidity and ability to thrive in the softest waters. It is found in water with pH 5.7 and a fixed carbon dioxide content of 1.5 parts per million. *Musculium,* which has a proportionately thinner shell, is found only as low as pH 5.9 and with a fixed carbon dioxide content of 2.6 parts per million. *Sphaerium,* as a unit, is found in habitats approximately neutral, or alkaline in reaction (pH 6.8-8.4) and with a fixed carbon dioxide content of 9.3 or more parts per million. But there is one straggler. *S. occidentale is* restricted to the acid side of the scale, having been taken in the region only from temporary ponds, with pH 5.8-5.9 and a fixed carbon dioxide content of 5.5 to 7.5 parts per million. Is this physiological difference not marked enough to indicate that *S. occidentale* may be less closely related to the other Sphaeria than usually regarded? Another good example of physiological isolation of species is seen in the group of *Pisidium rotundatum.* In this group *P. ferrugineum* and *P. vesiculare* are both found between pH 7.2 and 8.2 and a fixed carbon dioxide content between 11 and 22.5 parts per million. In direct contrast, *P. rotundatum* is found between pH 5.8 and 6.2 and from a fixed carbon dioxide content of 2.0 to 9.0 parts per million.

The lakes that are intermediate in hardness (10.0-20.0 p.p.m. fixed carbon dioxide, and a pH of 7.0-7.6) harbor the greatest number of species. As would be expected, the hardest lakes examined contain the greatest abundance of individuals.

Stream conditions are chemically rather uniform in the district, paralleling the intermediate lakes in character (Fig. 127). Chemical factors are thus not a limiting factor for molluscs in the streams. Geographic distribution and size and flow of the streams do seem to be important.

The number of species of Unionids in the small headwater streams of the Lake Superior and Green Bay (Lake Michigan) drainages is about one-half that found in similar streams, under comparable conditions, in the headwaters of the Flambeau, Tomahawk, and Wisconsin drainages.

The Wisconsin River, examined at various places from its source to a point in northern Oneida County, shows remarkably well the variation and increase of the molluscan fauna in coordination with the increase in size of the stream, as noted by Adams, Ortmann, Grier, and Baker.

In this northern lake region, where some streams are ponded for mile after mile, with swampy or bog margins, and others are rapid, with sand or gravel beds, the molluscan fauna of the streams shows a corresponding difference. For example, *Sphaerium fallax* and *S. rhomboideum* are found in the swampy margins of ponded streams, while *S. stamineum* and *S. emarginatum* are characteristic of streams with a good current over sandy bottom.

In all, some ninety-six lakes and thirty-eight stream localities have been examined, included in Vilas County and the adjoining portions of Iron, Price, Oneida, and Forest Counties. A total of one hundred twenty-nine forms of molluscan life are here recorded from the area. These are distributed as follows in the major groups:

Gill-breathing univalves	11
Lung-breathing univalves	51
Unionidae (bivalves)	26
Sphaeriidae (bivalves)	41
Total	129

Three forms are added to those known to occur in the state, namely: *Pseudosuccinea columella chalybea* (Gould), *Pisidium fallax septentrionale* Sterki, *Pisidium punctatum* Sterki.

The system of classification followed in this report is that of Baker's Monograph. For further references, the reader is referred to that publication.

SYSTEMATIC CATALOGUE OF SPECIES

In the following list the name of each species or variety is followed by a record of the localities where it is known to occur, listed according to drainage areas. Except where the authority for the record is otherwise stated, the records are those of the 1929-1930 collections of the Wisconsin Geological and Natural History Survey.

The area included in this brief report has not been exhaustively explored: there are about a thousand lakes in the entire district! Any additions and corrections will be gratefully received by the author.

Class GASTROPODA.
Subclass STREPTONEURA Spengel.
Order CTENOBRANCHIATA Schweigger.
Suborder PLATYPODA Lamarck.
Superfamily TAENIGLOSSA Bouvier.
Family VALVATIDAE Gray.

Genus *Valvata* Műller.

Valvata tricarinata (Say).

pH=7.16-8.37; fixed carbon dioxide=8.16-30.56 p.p.m. (Fig. 1.).
Lake Superior Drainage: Palmer Lake.
Flambeau Drainage: Allequash L.; Lake Laura; Mann L.; Silver L.; Trout L.; White Sand L.; Wildcat Lake.
Tomahawk Drainage: Kawaguesaga L.; Little Arbor Vitae Lake (Winslow, Baker).
Wisconsin Drainage: Plum L.; Razorback L.; Star Lake.

Valvata sincera nylanderi Dall.

pH=7.6; fixed carbon dioxide=22.5 p.p.m. (Fig. 2.).
Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker).

Valvata lewisii (Currier).

pH=7.35-7.7; fixed carbon dioxide=10.65-22.1 p.p.m. (Fig. 3.).

Lake Superior Drainage: Palmer Lake.
Flambeau Drainage: Papoose L.; Trout L.; Upper Gresham L.; Whitefish L.; White Sand Lake.
Tomahawk Drainage: Brandy Lake.
Wisconsin Drainage: Plum Lake.

Family VIVIPARIDAE (Gray) Gill.

Subfamily LIOPLACINAE (Gill) Baker.

Genus *Campeloma* Rafinesque.

Campeloma decisum (Say).

pH=5.68-8.37; fixed carbon dioxide=1.2-25.75 p.p.m. (Fig. 4).

Lake Superior Drainage: South Branch, Presque Isle River, at Winegar.

Green Bay Drainage: Butternut Lake.

Flambeau Drainage: Big L.; Diamond L.; Fishtrap L.; Helen L.; High L.; Inlet of Trout L.; Little Long L.; Manitowish River, at Boulder Junction and 4 mi. southwest; Mann L. Outlet; Marion L.; Rest L.; South Fork, Flambeau River, at Fifield; Trout L.; Trout River, at Trout L.; Turtle River, below Lake of the Falls; White Sand Lake inlet.

Tomahawk Drainage: Little Star Lake.

Wisconsin Drainage: Gilmore Creek and Wisconsin River, northeast of Lake Tomahawk (Baker); Deerskin River, 6 mi. south of Phelps; Finley L.; Plum L.; Wisconsin River, at Lac Vieux Desert, at Otter Rapids, 5 mi. west of Eagle River, and at Rainbow Rapids, southeast of Lake Tomahawk.

Campeloma milesii (Lea).

pH=5.86-8.0; fixed carbon dioxide=1.1-24.73 p.p.m. (Fig. 5).

Lake Superior Drainage: Anna L.; Carlin L.; Palmer L.; Katinka L.; Presque Isle Lake.

Flambeau Drainage: Big Muskellunge and White Sand Lakes (Cahn, Baker); Lower Gresham Lake (Juday, Baker); Big Muskellunge L.; Boulder L.; Crooked L.; Ike Walton L.; Inlet of White Sand L.; Irving L. Outlet; L. Constance; Little White Birch L.; Lost Canoe L.; Mary L.; Trout L.; Turtle River, at Winchester; Whitefish L.; White Sand Lake.

Tomahawk Drainage: Tomahawk Lake (Baker); Brandy L.; Johnson L.; Skunk L.; Tomahawk River, 4 mi. west of Minocqua; Weber Lake.

Wisconsin Drainage: Plum Lake (Cahn, Baker); Crescent L.; Plum L.; Razorback L.; Star L.; Sterrett L.; Wisconsin River, 5 mi. below Lac Vieux Desert.

Family AMNICOLIDAE (Tryon) Gill.
Subfamily AMNICOLINAE Gill.

Genus *Amnicola* Gould and Haldeman.

Amnicola limosa (Say).

pH=7.95; fixed carbon dioxide=30.56 p.p.m. (Fig. 6).
Flambeau Drainage: Wildcat Lake.

Amnicola limosa porata (Say).

pH=5.68-8.37; fixed carbon dioxide=1.2-30.56 p.p.m. (Fig. 7).

Lake Superior Drainage: Harris L.; Montreal River, at Pine L.; Palmer L.; Presque Isle L.; South Branch, Presque Isle River, at Winegar.

Flambeau Drainage: Allequash L.; Big Lake Outlet; Big Muskellunge L.; Boulder L.; Catfish L.; Clear Crooked L.; Dead Pike L.; Diamond L.; Fishtrap L.; Harvey L.; Helen L.; High L.; Ike Walton L.; Inlet of White Sand L.; Inlet of Trout L.; L. Laura; Little Crooked L.; Little White Birch L.; Lost Canoe L.; Mann L.; Mann Lake Outlet; Nebish L.; Nixon Lake Outlet; Papoose L.; Partridge L.; Trout L.; Whitefish L.; White Sand L.; Whitney L.; Wildcat L.; Wolf Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker); Tomahawk Lake (Baker); Blue L.; Brandy L.; Carroll L.; Clear L.; Kawaguesaga Lake.

Wisconsin Drainage: Bragonier L.; Crescent L.; Plum L.; Razorback L.; Star L.; Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk.

Amnicola limosa parva (Lea).

pH=7.64; fixed carbon dioxide=18.87 p.p.m. (Fig. 8).
Flambeau Drainage: Trout Lake.

Amnicola lustrica decepta Baker.

pH=6.85-8.37; fixed carbon dioxide=9.3-30.56 p.p.m. (Fig. 9).

Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; Palmer L.; Presque Isle Lake.

Flambeau Drainage: Big Muskellunge L.; Boulder L.; High L.; Lake Laura; Little Crooked L.; Little Rice L.; Little White Birch L.; Mann L.; Trout L.; Upper Gresham L.; Whitefish L.; White Sand L.; Whitney L.; Wildcat L.; Wolf Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker).

Wisconsin Drainage: Plum Lake (Cahn, Baker); Crescent L.; Plum L.; Star Lake.

Amnicola walkeri Pilsbry.

pH=7.16-7.64; fixed carbon dioxide=8.16-22.5 p.p.m. (Fig. 10).

Flambeau Drainage: Big Muskellunge Lake (Cahn, Baker); Fishtrap L.; Trout River, at Trout Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker).

Wisconsin Drainage: Razorback Lake.

Subfamily LITHOGLYPHINAE Fisher.

Genus *Somatogyrus* Gill.

Somatogyrus tryoni Pilsbry and Baker.

pH=7.0; fixed carbon dioxide=13.0 p.p.m. (Fig. 11).

Wisconsin Drainage: Wisconsin River, at Otter Rapids, 5 mi. west of Eagle River, and at Rainbow Rapids, southeast of Lake Tomahawk.

Subclass EUTHYNEURA Spengel.
Order PULMONATA Cuvier.
Suborder BASOMMATOPHORA A. Schmidt.
Superfamily LIMNOPHILA.
Family LYMNAEIDAE (Broderip) Baker.

Genus *Lymnaea* Lamarck.

Lymnaea stagnalis jugularis Say.

pH=7.6-8.16; fixed carbon dioxide=15.8-23.0 p.p.m. (Fig. 12).

Flambeau Drainage: Inlet stream, Trout Lake; Outlet of Big Lake.

Tomahawk Drainage: Tomahawk Lake (Baker); Brandy L.; Carroll L.; Johnson Lake.

Wisconsin Drainage: Plum Lake; Plum Creek.

Lymnaea stagnalis lillianae F. C. Baker.

pH=7.2-8.02; fixed carbon dioxide=14.9-30.56 p.p.m. (Fig. 13).

Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot Lake.

Flambeau Drainage: Big L.; Fishtrap L.; High L.; Trout L.; Trout River at Trout Lake; Wildcat Lake.

Tomahawk Drainage: Tomahawk Lake (Baker).

Wisconsin Drainage: Star Lake.

Lymnaea stagnalis sanctamariae Walker.

pH=7.35-8.0; fixed carbon dioxide=16.45-24.73 p.p.m. (Fig. 14).

Lake Superior Drainage: Presque Isle Lake.

Green Bay Drainage: Butternut Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Juday, Winslow, Baker); Ponds and Stream at State Fish Hatchery, Woodruff.

Genus *Stagnicola* (Leach) Jeffreys.

Stagnicola palustris elodes (Say).

pH=7.4; fixed carbon dioxide=21.0 p.p.m. (Fig. 15).

Lake Superior Drainage: Pond near South Branch, Presque Isle River, at Winegar.

Flambeau Drainage: Stream at Fish Hatchery, Woodruff.

Stagnicola exilis (Lea).

pH=5.9-7.74; fixed carbon dioxide=7.5-22.56 p.p.m. (Fig. 16).
Flambeau Drainage: Fishtrap L.; Forest Ponds, 10 mi. northeast of Boulder Junction; High L.; Turtle River, below Lake of the Falls.
Tomahawk Drainage: Little Star Lake.

Stagnicola lanceata (Gould).

pH=6.95-7.7; fixed carbon dioxide=7.5-22.56 p.p.m. (Fig. 17).
Lake Superior Drainage: Armour Lake.
Flambeau Drainage: High Lake.
Tomahawk Drainage: Tomahawk Lake (Baker); Little Rice River.
Wisconsin Drainage: Plum Lake (Cahn, Baker).

Stagnicola emarginata (Say).

pH=7.5-8.0; fixed carbon dioxide=14.3-24.73 p.p.m. (Fig. 18).
Lake Superior Drainage: Presque Isle Lake.
Flambeau Drainage: Rest Lake.
Tomahawk Drainage: Kawaguesaga Lake.
Wisconsin Drainage: Plum Lake (Cahn, Baker); Plum Creek and Lake.

Stagnicola emarginata vilasensis F. C. Baker.

pH=7.21; fixed carbon dioxide=9.59 p.p.m. (Fig. 19).
Flambeau Drainage: Big Muskellunge Lake (Cahn, Baker).

Stagnicola emarginata wisconsinensis F. C. Baker.

pH=7.21; fixed carbon dioxide=16.7-22.5 p.p.m. (Fig. 20).
Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker); Tomahawk Lake (Baker).

Stagnicola catascopium (Say).

pH=7.64; fixed carbon dioxide=18.87 p.p.m. (Fig. 21).
Flambeau Drainage: Trout Lake.

Genus *Acella* Haldeman.

Acella haldemani ("Desh." Binney).

pH=7.36-7.7; fixed carbon dioxide=17.0-22.56 p.p.m. (Fig. 22).
Lake Superior Drainage: Harris Lake.
Flambeau Drainage: Fishtrap Lake; Channel between Fishtrap and High Lakes; High Lake.

Genus *Pseudosuccinea* Baker.

Pseudosuccinea columella (Say).

pH=6.13-7.6; fixed carbon dioxide=2.75-16.7 p.p.m. (Fig. 23).
Lake Superior Drainage: Anna Lake.
Flambeau Drainage: Channel between Fishtrap and High Lakes.
Tomahawk Drainage: Tomahawk Lake (Baker); Clear Lake.

Pseudosuccinea columella chalybea (Gould).

pH=6.06-7.8; fixed carbon dioxide=3.06-18.36 p.p.m. (Fig. 24).
Flambeau Drainage: Catfish L.; Fishtrap L.; Helen Lake.

Genus *Bulimnaea* Haldeman.

Bulimnaea megasoma (Say).

pH=6.6-8.37; fixed carbon dioxide=9.3-25.75 p.p.m. (Fig. 25).
Lake Superior Drainage: Pond near South Branch, Presque Isle River, at Winegar.
Flambeau Drainage: Duck L.; Fishtrap L.; Channel between Fishtrap and High Lakes; High L.; Little Rice L.; Mann L. Outlet; Pike L. inlet; Trout L.; Turtle River, below Lake of the Falls; White Sand Lake.
Tomahawk Drainage: Tomahawk Lake (Baker).
Wisconsin Drainage: Plum Lake (Cahn, Baker); Slough along Wisconsin River, northeast of Lake Tomahawk (Baker).

Genus *Fossaria* Westerlund.

Fossaria modicella (Say).

pH=7.0; fixed carbon dioxide=13.0 p.p.m. (Fig. 26).
Wisconsin Drainage: Wisconsin River, northeast of Lake Tomahawk (Baker).

Fossaria obrussa (Say).

pH=5.86-8.37; fixed carbon dioxide=1.26-25.75 p.p.m. (Fig. 27).
Flambeau Drainage: Ike Walton L.; Little Rice L.; Mann L. Outlet; Pond along Mann L. Outlet; Trout Lake.
Tomahawk Drainage: Tomahawk Lake (Baker).
Wisconsin Drainage: Found Lake (Cahn, Baker); Star Lake.

Fossaria obrussa decampi (Streng).

pH=7.42-7.7; fixed carbon dioxide=10.65-18.87 p.p.m. (Fig. 28).
Flambeau Drainage: Upper Gresham Lake (Juday, Baker); Little White Birch L.; Trout L.; Whitefish Lake.
Wisconsin Drainage: Plum Lake.

Fossaria exigua (Lea).

pH=7.7-8.37; fixed carbon dioxide=13.0-25.75 p.p.m. (Fig. 29).
Lake Superior Drainage: Montreal River, at Pine Lake.
Flambeau Drainage: Mann Lake.

Family PLANORBIDAE H. & A. Adams.

Genus *Helisoma* Swainson.

Helisoma antrosa (Conrad)

pH=6.03-8.02; fixed carbon dioxide=2.66-30.56 p.p.m. (Fig. 30).
Lake Superior Drainage: Montreal River, at Pine Lake; Palmer L.; Presque Isle Lake.

Green Bay Drainage: Butternut Lake.

Flambeau Drainage: Big L.; Big Muskellunge L.; Boulder L.; Helen L.; High L.; L. George; Lost Canoe L.; Manitowish River, 4 mi. southwest of Boulder Junction; Outlet of Big L.; Rest L.; Trout L.; Trout River, at Trout L.; Whitefish L.; Wildcat Lake.

Tomahawk Drainage: Brandy L.; Little Star L.; Skunk L.; Stream, 10 mi. southwest of Hazelhurst; Willow River Flowage, 14 mi. southwest of Hazelhurst.

Wisconsin Drainage: Crescent L.; Deerskin River, 6 mi. south of Phelps; Plum L.; St. Germaine River; Star L.; Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk.

Helisoma antrosa unicarinata (Haldeman).

pH=6.05-7.85; fixed carbon dioxide=1.1-18.36 p.p.m. (Fig. 31).

Green Bay Drainage: Kentuck Lake.

Flambeau Drainage: Big Muskellunge L.; Fishtrap L.; Channel between Fishtrap and High Lakes; Mary L.; Nixon L. Outlet; White Sand L. Inlet.

Tomahawk Drainage: Tomahawk Lake (Baker); Little Rice River; Pond near State Fish Hatchery Ponds, at Woodruff; Weber Lake.

Wisconsin Drainage: Razorback L.; Star Lake.

Helisoma antrosa sayi F. C. Baker.

pH=7.13-8.37; fixed carbon dioxide=9.59-25.75 p.p.m. (Fig. 32).

Flambeau Drainage: Big Muskellunge L.; Nixon Lake (Cahn, Baker); Fishtrap L.; Mann L.; Outlet of Mann L.; White Sand Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker); Tomahawk Lake (Baker).

Wisconsin Drainage: Plum L.; Found Lake (Cahn, Baker).

Helisoma antrosa cahni F. C. Baker

pH=6.13-8.0; fixed carbon dioxide=2.75-24.73 p.p.m. (Fig. 33).

Lake Superior Drainage: Anna L.; Armour L.; Presque Isle Lake.

Flambeau Drainage: Big Muskellunge Lake (Baker); Silver Lake.

Helisoma trivolvis (Say).

pH=6.6-8.37; fixed carbon dioxide=7.5-30.56 p.p.m. (Fig. 34).

Lake Superior Drainage: Black Oak L.; Palmer Lake.

Flambeau Drainage: Allequash L.; Duck L.; Fishtrap L.; High L.; Inlet of Trout L.; Inlet of White Sand L.; Irving L. Outlet; Little Rice L.; Mann L.; Outlet of Mann L.; Outlet of Nixon L.; Pike L.; Trout L.; Trout River, at Trout L.; Turtle River, below Lake of the Falls; White Sand L.; Wildcat Lake.

Tomahawk Drainage: Tomahawk Lake (Baker); Willow River Flowage, 14 mi. southwest of Hazelhurst.

Wisconsin Drainage: Crescent L.; Deerskin River, 6 mi. south of Phelps; Plum L.; Rice Creek, near Plum Lake.

Helisoma trivolvis pilsbryi (F. C. Baker).

pH=7.2-8.37; fixed carbon dioxide=13.3-25.75 p.p.m. (Fig. 35).

Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot Lake.
Flambeau Drainage: Boulder L.; Fishtrap L.; High L.; Mann Lake.
Tomahawk Drainage: Tomahawk Lake (Baker); Brandy Lake.

Helisoma trivolvis winslowi (F. C. Baker).
pH=7.6-7.65; fixed carbon dioxide=22.5-22.6 p.p.m. (Fig. 36).
Flambeau Drainage: Manitowish River (Winslow, Baker).
Tomahawk Drainage: Big and Little Arbor Vitae Lakes (Winslow, Baker).

Helisoma pseudotrivolvis (F. C. Baker).
pH=7.23; fixed carbon dioxide=10.8 p.p.m. (Fig. 37).
Flambeau Drainage: Lake Laura.

Helisoma campanulata (Say).
pH=6.6-8.16; fixed carbon dioxide=7.5-30.56 p.p.m. (Fig. 38).
Lake Superior Drainage: Palmer Lake.
Green Bay Drainage: Butternut L.; Kentuck Lake.
Flambeau Drainage: Allequash L.; Big L.; Big Muskellunge L.; Boulder L.; Fishtrap L.; High L.; Papoose L.; Trout L.; Whitefish L.; Wildcat L.; Wolf Lake.
Tomahawk Drainage: Brandy L.; Carroll L.; Johnson L.; Kawaguesaga L.; Little Star L.; Willow River Flowage, 14 mi. southwest of Hazelhurst.
Wisconsin Drainage: Crescent L.; Plum L.; Razorback L.; Star Lake.

Helisoma campanulata minor (Dunker).
pH=6.6-7.85; fixed carbon dioxide=9.59-18.87 p.p.m. (Fig. 39).
Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot Lake.
Flambeau Drainage: Big Muskellunge L.; Catfish L.; Inlet of White Sand L.; Outlet of Nixon L.; Trout Lake.
Wisconsin Drainage: Plum L.; Star Lake.

Helisoma campanulata ferrissii (F. C. Baker).
pH=7.05; fixed carbon dioxide=13.7 p.p.m. (Fig. 40).
Flambeau Drainage: Island Lake.

Helisoma campanulata wisconsinensis (Winslow).
pH=6.95-8.37; fixed carbon dioxide=7.5-25.75 p.p.m. (Fig. 41).
Lake Superior Drainage: Armour L.; Harris L.; Presque Isle Lake.
Flambeau Drainage: Big Muskellunge L.; Nixon L.; White Sand Lake (Cahn, Baker); Allequash L.; Big Muskellunge L.; High L.; Lost Canoe L.; Mann L.; Turtle River, below Lake of the Falls; White Sand Lake.
Tomahawk Drainage: Big Arbor Vitae L.; Little Arbor Vitae L.; Tomahawk L.; Madeline Creek, near Woodruff (Winslow, Baker); Little Arbor Vitae Lake (Cahn, Baker); Tomahawk Lake (Baker).
Wisconsin Drainage: Found L.; Plum Lake (Cahn, Baker); St. Germaine Lakes (Winslow, Baker).

Genus *Planorbula* Haldeman.

Planorbula armigera (Say).

pH=6.6-7.6; fixed carbon dioxide=7.5-16.7 p.p.m. (Fig. 42).

Tomahawk Drainage: Tomahawk Lake and swamp ponds in vicinity (Baker); Willow River Flowage, 14 mi. southwest of Hazelhurst.

Wisconsin Drainage: Ponds in swamp along Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker).

Genus *Menetus* H. & A. Adams.

Menetus exacuous (Say).

pH=7.0-7.64; fixed carbon dioxide=9.3-22.5 p.p.m. (Fig. 43).

Lake Superior Drainage: Palmer Lake.

Flambeau Drainage: Fishtrap L.; Little Rice L.; Manitowish River, 4 mi. southwest of Boulder Junction; Pond along outlet of Mann L.; Trout Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker).

Wisconsin Drainage: Crescent Lake.

Menetus exacuous megas (Dall).

pH=7.1-8.37; fixed carbon dioxide=9.59-25.75 p.p.m. (Fig. 44).

Flambeau Drainage: Big Muskellunge Lake (Cahn, Baker); Big Muskellunge L.; Mann L.; Outlet of Nixon L.; Trout Lake.

Tomahawk Drainage: Kawaguesaga Lake.

Genus *Gyraulus* Charpentier.

Gyraulus hirsutus (Gould).

pH=7.1-7.95; fixed carbon dioxide=9.5-30.56 p.p.m. (Fig. 45).

Flambeau Drainage: Boulder L.; Little White Birch L.; Nelson L.; Partridge L.; Trout L.; Wildcat Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker); Tomahawk Lake (Baker).

Wisconsin Drainage: Found L.; Plum Lake (Cahn, Baker); Plum L.; Star Lake.

Gyraulus deflectus (Say).

pH=6.2-8.37; fixed carbon dioxide=2.1-30.56 p.p.m. (Fig. 46).

Lake Superior Drainage: Armour Lake.

Flambeau Drainage: Allequash L.; Dead Pike L.; Fishtrap L.; High L.; Inlet of Trout L.; Outlet of Mann L.; Pond along Mann L. Outlet; Whitefish L.; Wildcat Lake.

Tomahawk Drainage: Clear L.; Little Rice River; Willow River Flowage, 14 mi. southwest of Hazelhurst.

Wisconsin Drainage: Bragonier Lake.

Gyraulus deflectus obliquus (DeKay).

pH=6.4-8.37; fixed carbon dioxide=8.16-30.56 p.p.m. (Fig. 47).

Lake Superior Drainage: Montreal River, at Pine L.; Palmer L.; Presque Isle Lake.

Flambeau Drainage: Fishtrap L.; Inlet of Trout Lake; Mann L.; Papoose L.; Trout L.; Whitefish L.; White Sand L.; Wolf Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker); Brandy L.; Carroll L.; Johnson L.; Pond near State Fish Hatchery, at Woodruff.

Wisconsin Drainage: Plum Lake (Cahn, Baker); Shore pools, Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker); Crescent L.; Razorback Lake.

Gyraulus parvus (Say).

pH=7.0-8.16; fixed carbon dioxide=8.16-30.56 p.p.m. (Fig. 48).

Lake Superior Drainage: Montreal River, at Pine L.; Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; Pond, near South Branch, Presque Isle River, Winegar; Presque Isle Lake.

Flambeau Drainage: Big Muskellunge Lake (Cahn, Baker); Big Muskellunge L.; Boulder L.; Inlet of Trout L.; Lake Laura; Little Rice L.; Little White Birch L.; Outlet of Big L.; Outlet of Nixon L.; Silver L.; Trout L.; Upper Gresham L.; Whitefish L.; White Sand L.; Wildcat Lake.

Tomahawk Drainage: Tomahawk Lake and kettle hole ponds in vicinity (Baker); Carroll L.; Stream, 10 mi. southwest of Hazelhurst.

Wisconsin Drainage: Plum Lake (Cahn, Baker); Razorback Lake.

Gyraulus circumstriatus (Tryon).

pH=5.9-7.7; fixed carbon dioxide=2.9-18.87 p.p.m. (Fig. 49).

Flambeau Drainage: Forest Ponds, 10 mi. northeast of Boulder Junction; Trout L.; Whitefish Lake.

Tomahawk Drainage: Clear Lake.

Wisconsin Drainage: Plum Lake.

Gyraulus arcticus ("Beck" Mőller).

pH=8.37; fixed carbon dioxide=25.75 p.p.m. (Fig. 50).

Flambeau Drainage: Mann Lake.

Family ANCYLIDAE Menke.

Subfamily FERRISSIINAE Walker.

Genus *Ferrissia* Walker.

Ferrissia parallela (Haldeman).

pH=6.05-8.37; fixed carbon dioxide=2.75-25.75 p.p.m. (Fig. 51).

Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; Palmer Lake.

Flambeau Drainage: Boulder L.; Fishtrap L.; High L.; Mary L.; Mud L.; Outlet of Mann L.; Turtle River, below Lake of the Falls.

Tomahawk Drainage: Tomahawk Lake, and kettle hole ponds in the vicinity (Baker); Stream, 10 mi. southwest of Hazelhurst.

Wisconsin Drainage: Deerskin River, 6 mi. south of Phelps; Plum L.; Razorback Lake.

Ferrissia tarda (Say).

pH=7.63; fixed carbon dioxide=20.1 p.p.m. (Fig. 52).
Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Ferrissia fusca (C. B. Adams).

pH=7.58; fixed carbon dioxide=15.2 p.p.m. (Fig. 53).
Flambeau Drainage: White Sand Lake.

Ferrissia kirklandi (Walker).

pH=7.6; fixed carbon dioxide=22.5 p.p.m. (Fig. 54).
Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker).

Family PHYSIDAE Dall.

Genus *Physa* Draparnaud.

Physa laphami (Baker).

pH=6.4-8.02; fixed carbon dioxide=2.9-24.73 p.p.m. (Fig. 55).

Lake Superior Drainage: Armour L.; Harris L.; Montreal River, at Pine L.; Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; Presque Isle Lake.

Flambeau Drainage: Big L.; High L.; Lost Canoe L.; Whitney Lake.

Tomahawk Drainage: Clear L.; Little Star L.; Pond near State Fish Hatchery ponds, at Woodruff.

Wisconsin Drainage: Crescent L.; Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk.

Physa sayii Tappan.

pH=5.68-7.96; fixed carbon dioxide=1.2-22.5 p.p.m. (Fig. 56).

Lake Superior Drainage: Palmer Lake.

Flambeau Drainage: Big Muskellunge L.; Nixon Lake (Cahn, Baker); Allequash L.; Ballard L.; Big Muskellunge L.; Catfish L.; Crystal L.; Dead Pike L.; Diamond L.; Fishtrap L.; Harvey L.; Island L.; Little Rice L.; Manitowish River, 4 mi. southwest of Boulder Junction; Marion L.; Silver Lake.

Tomahawk Drainage: Little Arbor Vitae Lake (Cahn, Winslow, Baker); Tomahawk Lake (Baker); Brandy L.; Johnson Lake.

Wisconsin Drainage: Plum Lake (Cahn, Baker); Deerskin River, 6 mi. south of Phelps; Plum L.; Razorback L.; Star Lake.

Physa obrussoides (F. C. Baker).

pH=7.64; fixed carbon dixoide=18.87 p.p.m. (Fig. 57).

Flambeau Drainage: Roadside spring, 3 mi. northwest of Winchester; Trout River, at Trout Lake.

Physa gyrina Say.

pH=7.1-8.37; fixed carbon dioxide=9.5-25.75 p.p.m. (Fig. 58).

Flambeau Drainage: Mann L.; Nelson Lake.

Tomahawk Drainage: Stream, 10 mi. southwest of Hazelhurst.

Wisconsin Drainage: Pools along Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker); Rice Creek, near Plum Lake.

Physa gyrina elliptica Lea.

pH=7.64; fixed carbon dioxide=18.87 p.p.m. (Fig. 59).
Flambeau Drainage: Trout Lake.

Physa integra Haldeman.

pH=8.0; fixed carbon dioxide=24.73 p.p.m. (Fig. 60).
Lake Superior Drainage: South Branch, Presque Isle River, at Winegar.

Physa michiganensis Clench.

pH=8.02; fixed carbon dioxide=23.0 p.p.m. (Fig. 61).
Flambeau Drainage: Outlet of Big Lake.

Genus *Aplexa* Fleming.

Aplexa hypnorum (L.).

No chemical data.
Wisconsin Drainage: Pools in swamp along Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker).

Class PELECYPODA Goldfuss.

Order PRIONODESMACEA Dall.

Superfamily NAIADACEA Menke.

Family UNIONIDAE (d'Orbigny) Ortmann.

Subfamily UNIONINAE (Swainson) Ortmann.

Genus *Fusconaia* Simpson.

Fusconaia flava (Rafinesque).

pH=7.1-8.02; fixed carbon dioxide=12.07-23.0 p.p.m. (Fig. 62).
Flambeau Drainage: Inlet of White Sand L.; Manitowish River, at Boulder Junction, and 4 mi. southwest; Outlet of Big L.; South Fork, Flambeau River, at Fifield, and 2 mi. east; Turtle L.; Turtle River, below Lake of the Falls.
Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.
Wisconsin Drainage: Clear Water Lake (Chadwick, Baker); St. Germaine River; Wisconsin River, at Lac Vieux Desert, and 5 mi. below.

Genus *Amblema* Rafinesque.

Amblema costata Rafinesque.

pH=7.1-7.7; fixed carbon dioxide=12.07-18.87 p.p.m. (Fig. 63).
Flambeau Drainage: Manitowish River, at Boulder Junction; Trout River, at Trout L.; Turtle River, at Winchester, and below Lake of the Falls.
Wisconsin Drainage: Clear Water Lake (Chadwick, Baker); Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker); Wisconsin River, 5 mi. below Lac Vieux Desert, and at Otter Rapids, 5 mi. west of Eagle River.

Genus *Pleurobema* (Rafinesque) Agassiz.

Pleurobema coccineum (Conrad).

pH=7.15-7.63; fixed carbon dioxide=12.07-20.1 p.p.m. (Fig. 64).

Flambeau Drainage: Manitowish River, at Boulder Junction; Turtle River, at Winchester.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Wisconsin River, 5 mi. below Lac Vieux Desert.

Genus *Elliptio* Rafinesque.

Elliptio dilatatus (Rafinesque).

pH=7.3-7.5; fixed carbon dioxide=13.3-14.0 p.p.m. (Fig. 65).

Flambeau Drainage: Manitowish River, at Boulder Junction.

Wisconsin Drainage: Wisconsin River, 5 mi. below Lac Vieux Desert.

Elliptio dilatatus delicatus (Simpson).

pH=7.1-8.02; fixed carbon dioxide=12.07-23.0 p.p.m. (Fig. 66).

Flambeau Drainage: Manitowish River, 4 mi. southwest of Boulder Junction; Outlet of Big L.; South Fork, Flambeau River, at Fifield, and 2 mi. east; Turtle River, at Winchester, and below Lake of the Falls.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Elliptio dilatatus sterkii Grier.

pH=7.15; fixed carbon dioxide=12.07 p.p.m. (Fig. 67).

Flambeau Drainage: Turtle Lake.

Subfamily ANODONTINAE Ortmann.

Genus *Lasmigona* Rafinesque.

Lasmigona compressa (Lea).

pH=7.1-8.02; fixed carbon dioxide=12.07-24.73 p.p.m. (Fig. 68).

Lake Superior Drainage: Montreal River, at Pine L.; Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; South Branch, Presque Isle River, at Winegar.

Flambeau Drainage: Inlet of White Sand L.; Manitowish River, 4 mi. southwest of Boulder Junction; Outlet of Big L.; South Fork, Flambeau River, at Fifield; Trout River, at Trout L.; Turtle L.; Turtle River, at Winchester.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Gilmore Creek (Baker); Wisconsin River, at Lac Vieux Desert, and 5 mi. below.

Lasmigona costata (Rafinesque).

pH=7.1-8.14; fixed carbon dioxide=12.07-23.0 p.p.m. (Fig. 69).

Flambeau Drainage: Inlet of Trout L.; Inlet of White Sand L.; Outlet of Big L.; Manitowish River, at Boulder Junction, and 4 mi. southwest; South Fork, Flambeau River, at Fifield, and 2 mi. east; Trout River, at Trout L.; Turtle River, at Winchester, and below Lake of the Falls.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Gilmore Creek (Baker); Little St. Germaine River; Plum Creek; St. Germaine River; Wisconsin River, 5 mi. below Lac Vieux Desert, and at Otter Rapids, 5 mi. west of Eagle River.

Lasmigona complanata (Barnes).

pH=7.3-8.14; fixed carbon dioxide=13.4-16.95 p.p.m. (Fig. 70).

Wisconsin Drainage: Little St. Germaine River; Plum L.; St. Germaine River; Wisconsin River, at Lac Vieux Desert, 5 mi. below Lac Vieux Desert, and at Otter Rapids, 5 mi. west of Eagle River.

Genus *Anodonta* Lamarck.

Anodonta grandis plana Lea.

pH=6.9-8.37; fixed carbon dioxide=9.3-25.75 p.p.m. (Fig. 71).

Lake Superior Drainage: Montreal River, at Pine L.; South Branch, Presque Isle River, at Winegar.

Flambeau Drainage: Inlet and outlet of Big L.; Inlet of White Sand L.; Little Rice L.; Manitowish River, at Boulder Junction; Outlet of Irving L.; Outlet of Mann L.; Outlet of Tamarac L.; Trout River, at Trout Lake; Turtle River, at Winchester, and below Lake of the Falls.

Tomahawk Drainage: Stream at State Fish Hatchery, near Woodruff.

Wisconsin Drainage: Gilmore Creek (Baker); Deerskin River, 6 mi. south of Phelps; Plum Creek; St. Germaine River; Wisconsin River, at Lac Vieux Desert, 5 mi. below Lac Vieux Desert, and at Otter Rapids, 5 mi. west of Eagle River.

Anodonta grandis footiana Lea.

pH=6.7-8.02; fixed carbon dioxide=3.2-30.56 p.p.m. (Fig. 72).

Lake Superior Drainage: Presque Isle Lake.

Flambeau Drainage: Adelaide L.; Big L.; Fishtrap L.; Little Long L.; Lost Canoe L.; Trout L.; Turtle L.; Whitefish L.; Wildcat Lake.

Tomahawk Drainage: Tomahawk Lake (Baker); Brandy L.; Johnson L.; Little Star Lake.

Wisconsin Drainage: Found Lake (Cahn, Baker); Plum Lake.

Anodonta kennicottii Lea.

pH=7.35-8.0; fixed carbon dioxide=15.46-24.73 p.p.m. (Fig. 73).

Lake Superior Drainage: Palmer L:; Presque Isle Lake.

Flambeau Drainage: High L.; Silver L.; Trout Lake.

Anodonta marginata Say.

pH=6.03-8.37; fixed carbon dioxide=2.6-30.56 p.p.m. (Fig. 74).

Lake Superior Drainage: Anna L.; Armour L.; Horsehead L.; Montreal River, at Pine L.; Ontonagon River, 3 mi. north of Tenderfoot L.; Presque Isle Lake.

Green Bay Drainage: Butternut L.; Kentuck Lake.

Flambeau Drainage: Adelaide L.; Allequash L.; Big Muskellunge L.; Big L. Outlet; Big L.; Cranberry L.; Favil L.; Fishtrap L.; High L.; Inlet of Trout L.; Inlet of White Sand L.; Irving L. Outlet; L. Constance; L. George; L. Laura; Little Long L.; Little Rice L.; Little White Birch L.; Lost Canoe L.; Manitowish River, at Boulder Junction, and 4 mi. southwest; Mann L.; Marion L.; Outlet of Mann L.; Outlet of Nixon L.; Outlet of Tamarac L.; Silver L.; Trout L.; Trout River, at Trout L.; Turtle L.; Turtle River, at Winchester; Wildcat Lake.

Tomahawk Drainage: Tomahawk Lake (Baker); Brandy L.; Clear L.; Johnson L.; Stream at State Fish Hatchery, near Woodruff.

Wisconsin Drainage: Gilmore Creek (Baker); Crescent L.; Deerskin River, 6 mi. south of Phelps; Little St. Germaine River; Plum L.; St. Germaine River; Razorback L.; Star L.; Wisconsin River, at Lac Vieux Desert.

Genus *Utterbackia* F. C. Baker.

Utterbackia imbecillis (Say).

pH=7.1; fixed carbon dioxide=17.3 p.p.m. (Fig. 75).

Flambeau Drainage: Inlet of White Sand L.; Manitowish River, at Boulder Junction; Turtle River, below Lake of the Falls.

Genus *Anodontoides* Simpson.

Anodontoides ferussacianus (Lea).

pH=7.0; fixed carbon dioxide=9.3 p.p.m. (Fig. 76).

Flambeau Drainage: Little Rice Lake.

Anodontoides ferussacianus subcylindraceus (Lea).

pH=6.9-8.37; fixed carbon dioxide=10.65-30.56 p.p.m. (Fig. 77).

Lake Superior Drainage: Montreal River, at Pine Lake.

Flambeau Drainage: Fishtrap L.; High L.; Inlet of White Sand L.; Irving L. Outlet; Manitowish River, 4 mi. southwest of Boulder Junction; Mann L.; Silver L.; Trout River, at Trout L.; Turtle River, at Winchester; Whitefish L.; Wildcat Lake.

Tomahawk Drainage: Brandy L.; Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Deerskin River, 6 mi. south of Phelps; Plum L.; Wisconsin River, at Lac Vieux Desert, and 5 mi. below.

Anodontoides birgei F. C. Baker.

pH=8.0; fixed carbon dioxide=24.73 p.p.m. (Fig. 78).

Lake Superior Drainage: South Branch, Presque Isle River, at Winegar.

Genus *Alasmidonta* Say.

Alasmidonta marginata variabilis F. C. Baker.

pH=7.1-8.14; fixed carbon dioxide=13.3-20.1 p.p.m. (Fig. 79).

Flambeau Drainage: Manitowish River, 4 mi. southwest of Boulder Junction; South Fork, Flambeau River, at Fifield, and 2 mi. east.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Little St. Germaine River; Wisconsin River, at Otter Rapids, 5 mi. west of Eagle River.

Genus *Strophitus* Rafinesque.

Strophitus rugosus pavonius (Lea).

pH=7.1-8.14; fixed carbon dioxide=12.07-23.0 p.p.m. (Fig. 80).

Flambeau Drainage: Big L. Outlet; Inlet of Trout Lake; Inlet of White Sand L.; Manitowish River, 4 mi. southwest of Boulder Junction; South Fork, Flambeau River, at Fifield; Trout River, at Trout L.; Turtle River, at Winchester, and Below Lake of the Falls.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Gilmore Creek (Baker); Little St. Germaine River; Plum Creek; St. Germaine River; Wisconsin River, at Lac Vieux Desert.

Subfamily LAMPSILINAE Ortmann.

Genus *Actinonaias* Fischer & Crosse.

Actinonaias carinata (Barnes).

pH=7.0-8.14; fixed carbon dioxide=12.07-23.0 p.p.m. (Fig. 81).

Flambeau Drainage: Inlet of Trout L.; Outlet of Big L.; South Fork, Flambeau River, at Fifield; Turtle River, at Winchester, and below Lake of the Falls.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Clear Water Lake Creek (Chadwick, Baker); Gilmore Creek, and Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker); Little St. Germaine River; St. Germaine River; Wisconsin River, at Lac Vieux Desert, 5 mi. below Lac Vieux Desert, at Otter Rapids, 5 mi. west of Eagle River, and at Rainbow Rapids, southeast of Lake Tomahawk.

Genus *Ligumia* Swainson.

Ligumia recta (Lamarck).

pH=7.15; fixed carbon dioxide=12.07 p.p.m. (Fig. 82).

Flambeau Drainage: Turtle Lake.

Ligumia recta latissima (Rafinesque).

pH=7.1-8.14; fixed carbon dioxide=12.07-20.1 p.p.m. (Fig. 83).

Flambeau Drainage: Manitowish River, at Boulder Junction, and 4 mi. southwest; South Fork, Flambeau River, at Fifield, and 2 mi.

east; Turtle River, at Winchester, and below Lake of the Falls.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker); Little St. Germaine River; Wisconsin River, at Otter Rapids, 5 mi. west of Eagle River.

Genus *Lampsilis* Rafinesque.

Lampsilis siliquoidea (Barnes).

pH=6.9-8.14; fixed carbon dioxide=9.3-24.73 p.p.m. (Fig. 84).

Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; South Branch, Presque Isle River, at Winegar.

Flambeau Drainage: Inlet and Outlet of Big L.; Inlet of Trout L.; Little Rice L.; Manitowish River, at Boulder Junction, and 4 mi. southwest; Outlet of Tamarac L.; South Fork, Flambeau River, at Fifield, and 2 mi. east; Trout River, at Trout L.; Turtle River, at Winchester, and below Lake of the Falls.

Tomahawk Drainage: Stream at State Fish Hatchery, near Woodruff.

Wisconsin Drainage: Clear Water Creek (Chadwick, Baker); Gilmore Creek, and Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker); Deerskin River, 6 mi. south of Phelps; Little St. Germaine River; St. Germaine River; Wisconsin River, at Lac Vieux Desert, 5 mi. below Lac Vieux Desert, at Otter Rapids, 5 mi. west of Eagle River, and at Rainbow Rapids, southeast of Lake Tomahawk.

Lampsilis siliquoidea rosacea (DeKay).

pH=6.95-8.37; fixed carbon dioxide=7.5-30.56 p.p.m. (Fig. 85).

Lake Superior Drainage: Armour L.; Horsehead L.; Presque Isle Lake.

Flambeau Drainage: Allequash L.; Big L.; Boulder L.; Fishtrap L.; High L.; Mann L.; Trout L.; Turtle L.; Whitefish L.; White Sand L.; Wildcat Lake.

Tomahawk Drainage: Tomahawk Lake (Baker); Brandy Lake.

Wisconsin Drainage: Plum Lake; Plum Creek.

Lampsilis ventricosa occidens (Lea).

pH=7.0-8.14; fixed carbon dioxide=12.07-23.0 p.p.m. (Fig. 86).

Flambeau Drainage: Inlet and Outlet of Big L.; Manitowish River, at Boulder Junction, and 4 mi. southwest; South Fork, Flambeau River, at Fifield, and 2 mi. east; Trout River, at Trout L.; Turtle River, at Winchester, and below Lake of the Falls.

Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.

Wisconsin Drainage: Clear Water Creek (Chadwick, Baker); Gilmore Creek, and Wisconsin River, 4 mi. northeast of Lake Tomahawk (Baker); Little St. Germaine River; St. Germaine River; Wisconsin River, at Lac Vieux Desert, 5 mi. below Lac Vieux Desert, at Otter Rapids, 5 mi. west of Eagle River, and at Rainbow Rapids, southeast of Lake Tomahawk.

Lampsilis ventricosa lurida Simpson.
pH=7.15-8.02; fixed carbon dioxide=12.07-23.0 p.p.m. (Fig. 87).
Flambeau Drainage: Big L.; Fishtrap L.; High L.; Inlet of Trout L.; Trout Lake.

Order TELEODESMACEA Dall.

Superfamily CYRENACEA Tryon.

Family SPHAERIIDAE Dall.

Subfamily SPHAERIINAE F. C. Baker.

Genus *Sphaerium* Scopoli.

Sphaerium sulcatum (Lamarck).
pH=6.9-8.37; fixed carbon dioxide=9.3-25.75 p.p.m. (Fig. 88).
Flambeau Drainage: Big L.; Big Muskellunge L.; Fishtrap L.; Irving L. Outlet; Little Rice L.; Outlet of Mann L.; Outlet of Nixon L.; Trout L. Inlet.
Tomahawk Drainage: Tomahawk Lake (Baker).
Wisconsin Drainage: Deerskin River, 6 mi. south of Phelps; Plum L.; Rice Creek, near Plum Lake.

Sphaerium crassum Sterki.
pH=7.1; fixed carbon dioxide=17.3 (Fig. 89).
Flambeau Drainage: Turtle River, below Lake of the Falls.
Wisconsin Drainage: Wisconsin River, at Otter Rapids, 5 mi. west of Eagle River.

Sphaerium fallax Sterki.
pH=6.85-8.37; fixed carbon dioxide=11.75-30.56 p.p.m. (Fig. 90).
Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; Palmer L.; Presque Isle Lake.
Flambeau Drainage: High L.; Island L.; Marion L.; Outlet of Mann L.; Outlet of Tamarac L.; Turtle River, at Winchester; Wildcat Lake.
Wisconsin Drainage: Wisconsin River, at Lac Vieux Desert.

Sphaerium solidulum (Prime).
pH=7.7; fixed carbon dioxide=16.95 p.p.m. (Fig. 91).
Wisconsin Drainage: Plum Creek.

Sphaerium stamineum (Conrad)
pH=6.9-8.37; fixed carbon dioxide=13.0-25.75 p.p.m. (Fig. 92).
Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; South Branch, Presque Isle River, at Winegar.
Flambeau Drainage: Inlet of Trout L.; Manitowish River, at Boulder Junction; Mann L. Outlet; Outlet of Big L.; Trout River, at Trout Lake.
Tomahawk Drainage: Tomahawk River, 4 mi. west of Minocqua.
Wisconsin Drainage: Deerskin River, 6 mi. south of Phelps; Wiscon-

sin River, 5 mi. below Lac Vieux Desert, at Otter Rapids, 5 mi. west of Eagle River, and at Rainbow Rapids, southeast of Lake Tomahawk.

Sphaerium emarginatum (Prime).

pH=7.1-7.95; fixed carbon dioxide=15.5-17.3 p.p.m. (Fig. 93).
Flambeau Drainage: Inlet of Trout L.; Inlet of White Sand L.; Manitowish River, at Boulder Junction; South Fork, Flambeau River, at Fifield; Turtle River, below Lake of the Falls.

Sphaerium bakeri Sterki.

pH=7.7; fixed carbon dioxide=16.95 p.p.m. (Fig. 94).
Wisconsin Drainage: Plum Creek.

Sphaerium striatinum (Lamarck).

pH=7.1; fixed carbon dioxide=17.3 p.p.m. (Fig. 95).
Flambeau Drainage: Turtle River, below Lake of the Falls.
Wisconsin Drainage: Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker).

Sphaerium rhomboideum (Say).

pH=7.1-7.36; fixed carbon dioxide=14.0-18.5 p.p.m. (Fig. 96).
Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot Lake.
Flambeau Drainage: Fishtrap L.; Outlet of Nixon Lake.

Sphaerium occidentale Prime.

pH=5.8-5.9; fixed carbon dioxide=5.5-7.5 p.p.m. (Fig. 97).
Green Bay Drainage: Pools in lumber slashings, 4 mi. east of Butternut Lake.
Flambeau Drainage: Forest Ponds, 10 mi. northeast of Boulder Junction.
Wisconsin Drainage: Swamp along Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker).

Genus *Musculium* Link.

Musculium jayense (Prime).

pH=7.1-7.23; fixed carbon dioxide=10.8-13.0 p.p.m. (Fig. 98).
Flambeau Drainage: L. Laura; Outlet of Tamarac Lake.

Musculium partumeium (Say).

No chemical data.
Wisconsin Drainage: Small Ponds in swamp along Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker).

Musculium truncatum (Linsley).

pH=6.05-8.37; fixed carbon dioxide=2.75-25.75 p.p.m. (Fig. 99).
Flambeau Drainage: Catfish L.; Fishtrap L.; Harvey L.; L. Laura; Mary L.; Outlet of Mann Lake.
Tomahawk Drainage: Little Rice River.

Musculium rosaceum (Prime).

pH=6.4-7.64; fixed carbon dioxide=9.3-18.87 p.p.m. (Fig. 100).

Flambeau Drainage: Big Muskellunge L.; Little Rice L.; Outlet of Nixon L.; Trout Lake.

Tomahawk Drainage: Pond, near State Fish Hatchery ponds, near Woodruff.

Musculium ryckholti (Normand).

No chemical data.

Tomahawk Drainage: Small Kettle-hole Pools near Tomahawk Lake (Baker).

Musculium securis (Prime).

pH=5.9-8.37; fixed carbon dioxide=2.75-25.75 p.p.m. (Fig. 101).

Lake Superior Drainage: Black Oak Lake.

Flambeau Drainage: Allequash L.; Forest ponds, 10 mi. northeast of Boulder Junction; Helen L.; Little Long L.; Mary L.; Outlet of Mann L.; Pond along Mann L. Outlet.

Tomahawk Drainage: Pond near Tomahawk Lake, and Tomahawk Lake (Baker); Pond, near State Fish Hatchery ponds, at Woodruff.

Wisconsin Drainage: Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk.

Musculium steinii (A. Schmidt).

pH=6.6; fixed carbon dioxide=12.9 p.p.m. (Fig. 102).

Flambeau Drainage: Inlet of White Sand Lake.

Subfamily PISIDIINAE F. C. Baker.

Genus *Pisidium* C. Pfeiffer.

Pisidium virginicum (Gmelin).

pH=7.0-7.7; fixed carbon dioxide=13.0-16.95 p.p.m. (Fig. 103).

Wisconsin Drainage: Wisconsin River, 4 mi. northeast of Tomahawk Lake (Baker); Plum L.; Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk, and ½ mi. below.

Pisidium idahoense Roper.

pH=5.8; fixed carbon dioxide=1.5 p.p.m. (Fig. 104).

Tomahawk Drainage: Walker Lake.

Pisidium compressum Prime.

pH=7.0-8.37; fixed carbon dioxide=9.3-30.56 p.p.m. (Fig. 105).

Lake Superior Drainage: Palmer L.; Presque Isle L.; South Branch, Presque Isle River, at Winegar.

Flambeau Drainage: Big L. Outlet; Big Muskellunge L.; Boulder L.; Inlet of Trout L.; Irving L. Outlet; Little Rice L.; Little White Birch L.; Lost Canoe L.; Mann L. Outlet; Trout L.; Upper Gresham L.; Whitefish L.; White Sand L.; Wildcat Lake.

Tomahawk Drainage: Brandy L.; Kawaguesaga Lake.

Wisconsin Drainage: Little St. Germaine River; Plum L.; Star L.; Wisconsin River, at Lac Vieux Desert, at Rainbow Rapids, southeast of Lake Tomahawk, and ½ mi. below.

Pisidium fallax septentrionale Sterki.

pH=7.95; fixed carbon dioxide=16.6 p.p.m. (Fig. 106).
Flambeau Drainage: Inlet of Trout L.; Inlet of White Sand Lake.

Pisidium punctatum Sterki.

pH=7.0; fixed carbon dioxide=13.0 p.p.m. (Fig. 107).
Wisconsin Drainage: Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk.

Pisidium variabile Prime.

pH=5.72-8.37; fixed carbon dioxide=1.72-30.56 p.p.m. (Fig. 108).
Lake Superior Drainage: Ontonagon River, Mich., 3 mi. north of Tenderfoot L.; Palmer L.; Presque Isle Lake.
Flambeau Drainage: Big Muskellunge L.; Boulder L.; Clear Crooked L.; Dead Pike L.; Fishtrap L.; Little Rice L.; Mann L.; Outlet of Mann L.; Outlet of Nixon L.; Outlet of Tamarac L.; Pauto L.; Trout L.; Upper Gresham L.; Whitefish L.; White Sand L.; Wildcat Lake.
Tomahawk Drainage: Brandy L.; Kawaguesaga L.; Trilby Lake.
Wisconsin Drainage: Crescent L.; Plum L.; Razorback L.; Star L.; Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk.

Pisidium minusculum Sterki.

pH=7.48-7.64; fixed carbon dioxide=12.96-18.87 p.p.m. (Fig. 109).
Flambeau Drainage: Little White Birch L.; Trout Lake.

Pisidium adamsi Prime.

pH=6.05-7.7; fixed carbon dioxide=2.75-18.36 p.p.m. (Fig. 110).
Flambeau Drainage: Fishtrap L.; Irving L. Outlet; Mary Lake.
Wisconsin Drainage: Plum Lake.

Pisidium sargenti Sterki.

pH=6.05-8.14; fixed carbon dioxide=2.75-23.0 p.p.m. (Fig. 111).
Lake Superior Drainage: Palmer Lake.
Flambeau Drainage: Big L. Outlet; Little White Birch L.; Manitowish River, at Boulder Junction; Mary L.; Trout L.; Trout River, at Trout L.; Whitefish Lake.
Tomahawk Drainage: Clear Lake.
Wisconsin Drainage: Crescent L.; Little St. Germaine River; Plum L.; Star L.; Wisconsin River at Lac Vieux Desert, and at Rainbow Rapids, southeast of Lake Tomahawk.

Pisidium neglectum Sterki.

pH=6.66-7.1; fixed carbon dioxide=2.9-14.0 p.p.m. (Fig. 112).
Flambeau Drainage: Outlet of Nixon Lake.
Tomahawk Drainage: Clear Lake.

Pisidium lilljeborgi Clessin. (=*scutellatum* Sterki.)

pH=6.16-8.02; fixed carbon dioxide=1.97-23.0 p.p.m. (Fig. 113).
Lake Superior Drainage: Katinka Lake.
Flambeau Drainage: Big L. Outlet; Boulder L.; Little White Birch L.; Trout L.; Whitefish Lake.
Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker).
Wisconsin Drainage: Crescent L.; Plum L.; Star Lake.

Pisidium lilljeborgi cristatum Sterki.

pH=7.35-7.64; fixed carbon dioxide=18.87-19.5 p.p.m. (Fig. 114).
Lake Superior Drainage: Palmer Lake.
Flambeau Drainage: Trout Lake.

Pisidium roperi Sterki.

pH=5.8-6.4; fixed carbon dioxide=5.5-9.5 p.p.m. (Fig. 115).
Green Bay Drainage: Pools in lumber slashings, 4 mi. east of Butternut Lake.
Flambeau Drainage: Forest ponds, 10 mi. northeast of Boulder Junction.
Tomahawk Drainage: Kettle-hole pools near Tomahawk Lake (Baker); Pond, near State Fish Hatchery ponds, near Woodruff.

Pisidium strengi Sterki.

pH=5.84-7.95; fixed carbon dioxide=2.13-30.56 p.p.m. (Fig. 116).
Flambeau Drainage: Wildcat Lake.
Tomahawk Drainage: Trilby Lake.
Wisconsin Drainage: Finley Lake.

Pisidium abditum Haldeman.

pH=7.6; fixed carbon dioxide=16.7 p.p.m. (Fig. 117).
Tomahawk Drainage: Tomahawk Lake and kettle-hole pools in vicinity (Baker).

Pisidium subrotundatum Sterki.

No chemical data.
Wisconsin Drainage: Wisconsin River, swampy places, 4 mi. northeast of Tomahawk Lake (Baker).

Pisidium splendidulum Sterki.

pH=6.32; fixed carbon dioxide=1.98 p.p.m. (Fig. 118).
Wisconsin Drainage: Sterrett Lake.

Pisidium levissimum Sterki.

pH=7.64; fixed carbon dioxide=18.87 p.p.m. (Fig. 119).
Flambeau Drainage: Trout Lake.

Pisidium pauperculum Sterki.

pH=7.0-8.0; fixed carbon dioxide=9.3-24.73 p.p.m. (Fig. 120).
Lake Superior Drainage: Palmer L.; Presque Isle Lake.
Flambeau Drainage: Big Muskellunge L.; Boulder L.; L. Laura; Little Rice L.; Trout Lake.

Tomahawk Drainage: Brandy Lake.
Wisconsin Drainage: Crescent L.; Plum L.; Star L.; Wisconsin River, at Rainbow Rapids, southeast of Lake Tomahawk.

Pisidium rotundatum Prime.

pH=5.8-6.2; fixed carbon dioxide=1.97-9.0 p.p.m. (Fig. 121).
Lake Superior Drainage: Katinka Lake.
Green Bay Drainage: Pools in lumber slashings, 4 mi. east of Butternut Lake.
Flambeau Drainage: Forest pond, 10 mi. northeast of Boulder Junction.

Pisidium vesiculare Sterki.

pH=7.64; fixed carbon dioxide=18.87 p.p.m. (Fig. 122).
Flambeau Drainage: Trout Lake.

Pisidium ferrugineum Prime.

pH=7.23-8.14; fixed carbon dioxide=10.8-22.5 p.p.m. (Fig. 123).
Flambeau Drainage: L. Laura; Trout Lake.
Tomahawk Drainage: Little Arbor Vitae Lake (Winslow, Baker).
Wisconsin Drainage: Crescent L.; Little St. Germaine River; Star Lake.

Pisidium concinnulum Sterki.

pH=5.72-7.48; fixed carbon dioxide=1.72-15-46 p.p.m. (Fig. 124).
Green Bay Drainage: Pools in lumber slashings, 4 mi. east of Butternut Lake.
Flambeau Drainage: Forest ponds, 10 mi. northeast of Boulder Junction; Pauto L.; Silver L.; Springs in Tamarack bog north of Trout Lake.

Pisidium pusillum (Gmelin) Jenyus.

No chemical data.
Flambeau Drainage: Pool along Mann Lake Outlet.

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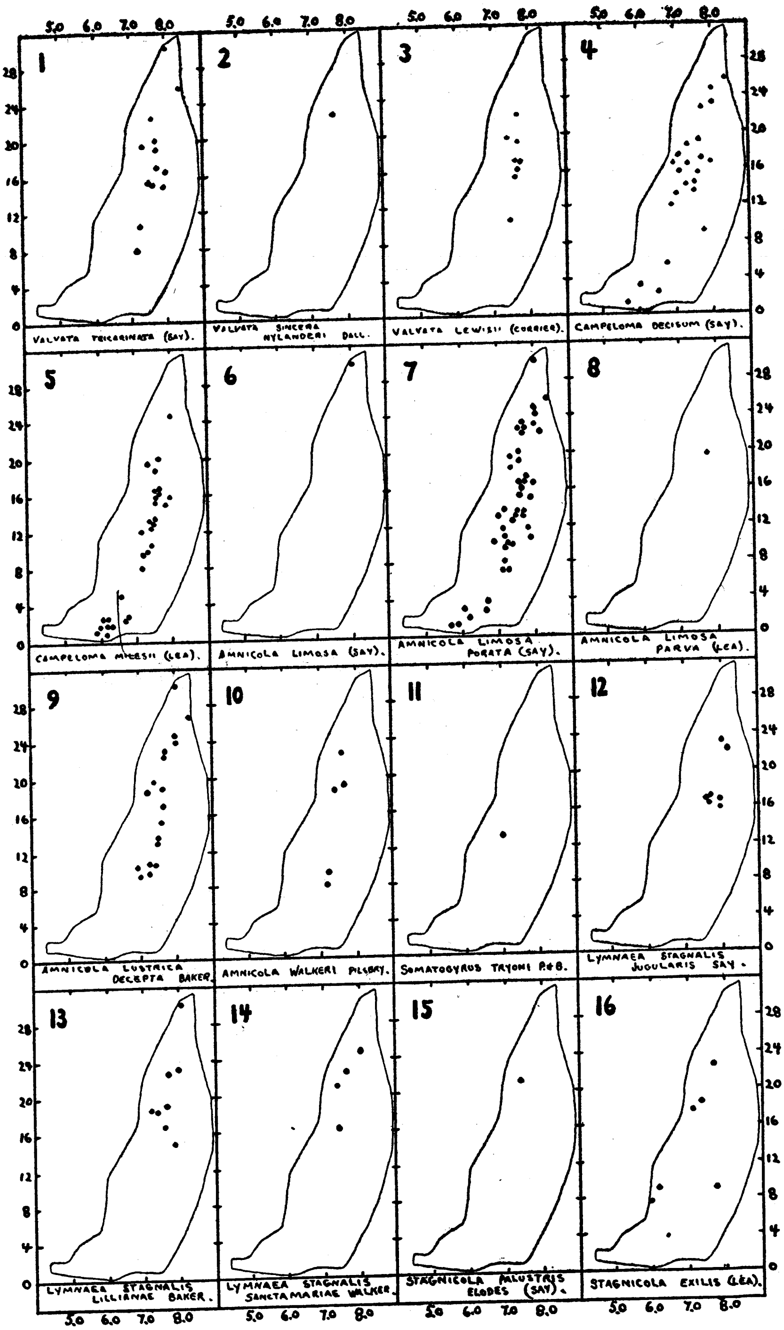


FIGS. 1-16. The pH and fixed carbon dioxide ranges of various mollusks. Ordinates indicate fixed carbon dioxide in parts per million; abscissae indicate pH. The circumscribed area presents for comparison the total range of these factors in all the lakes of the Highland Lake District for which data are available.

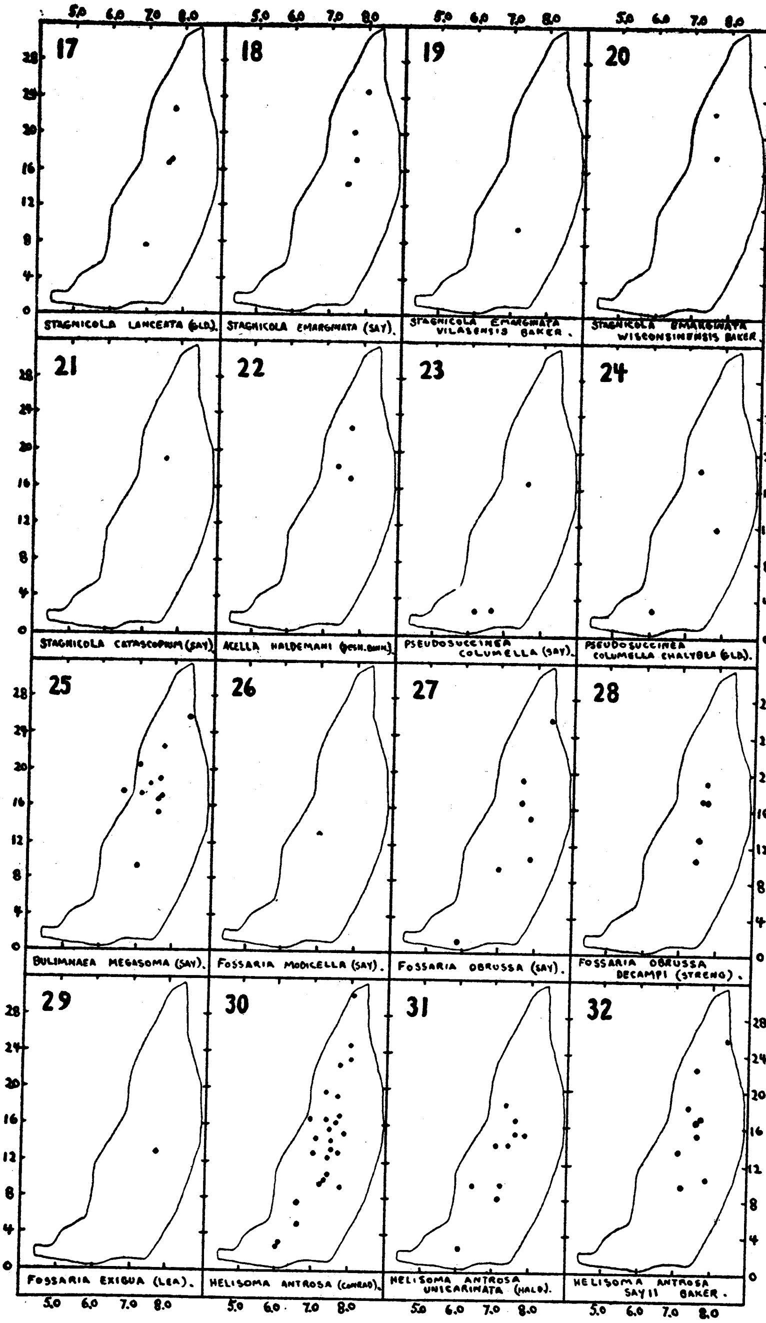
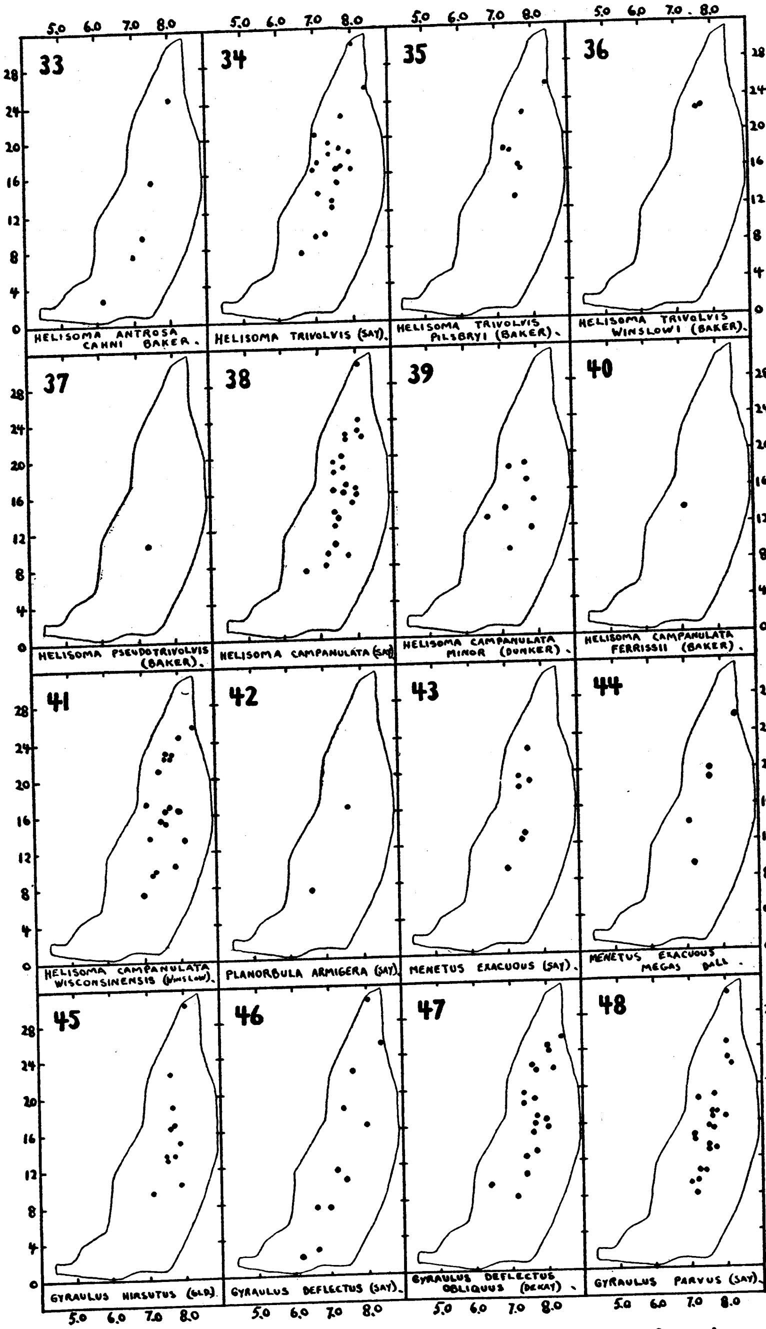
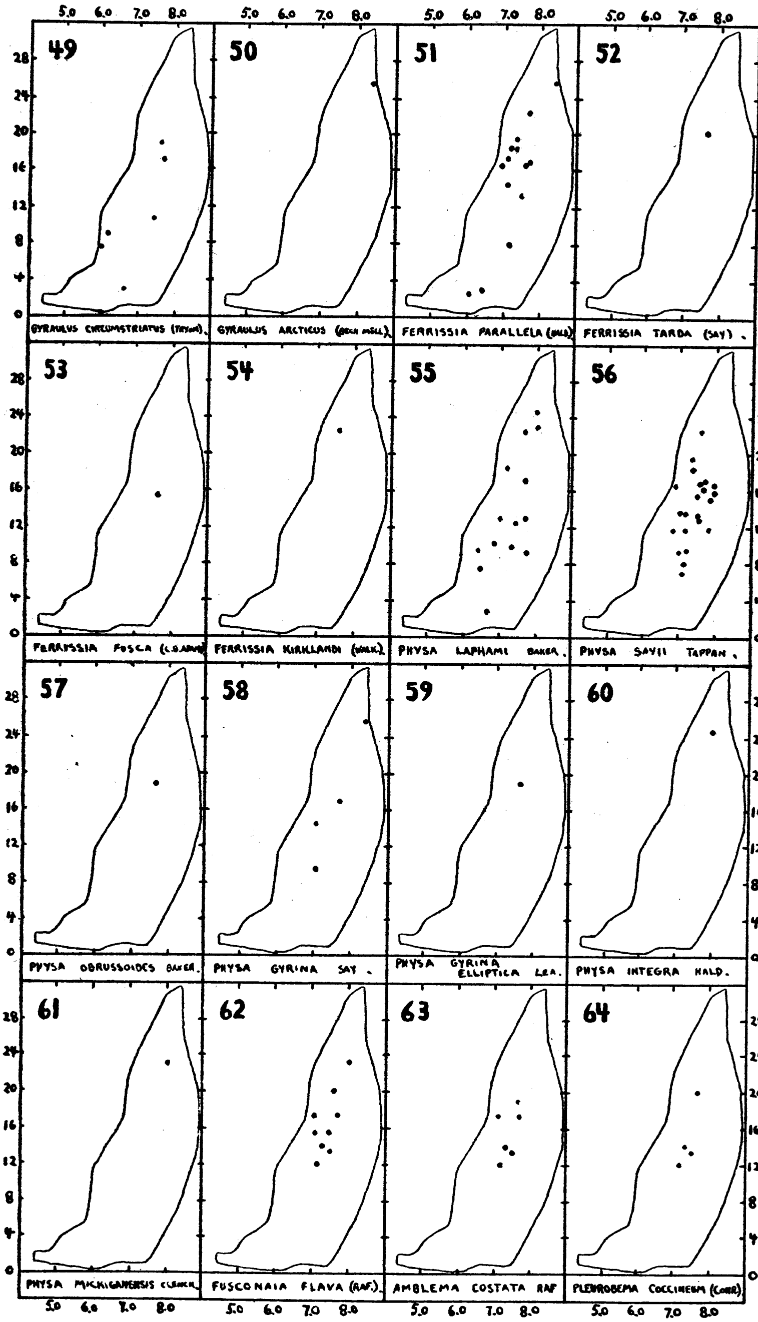


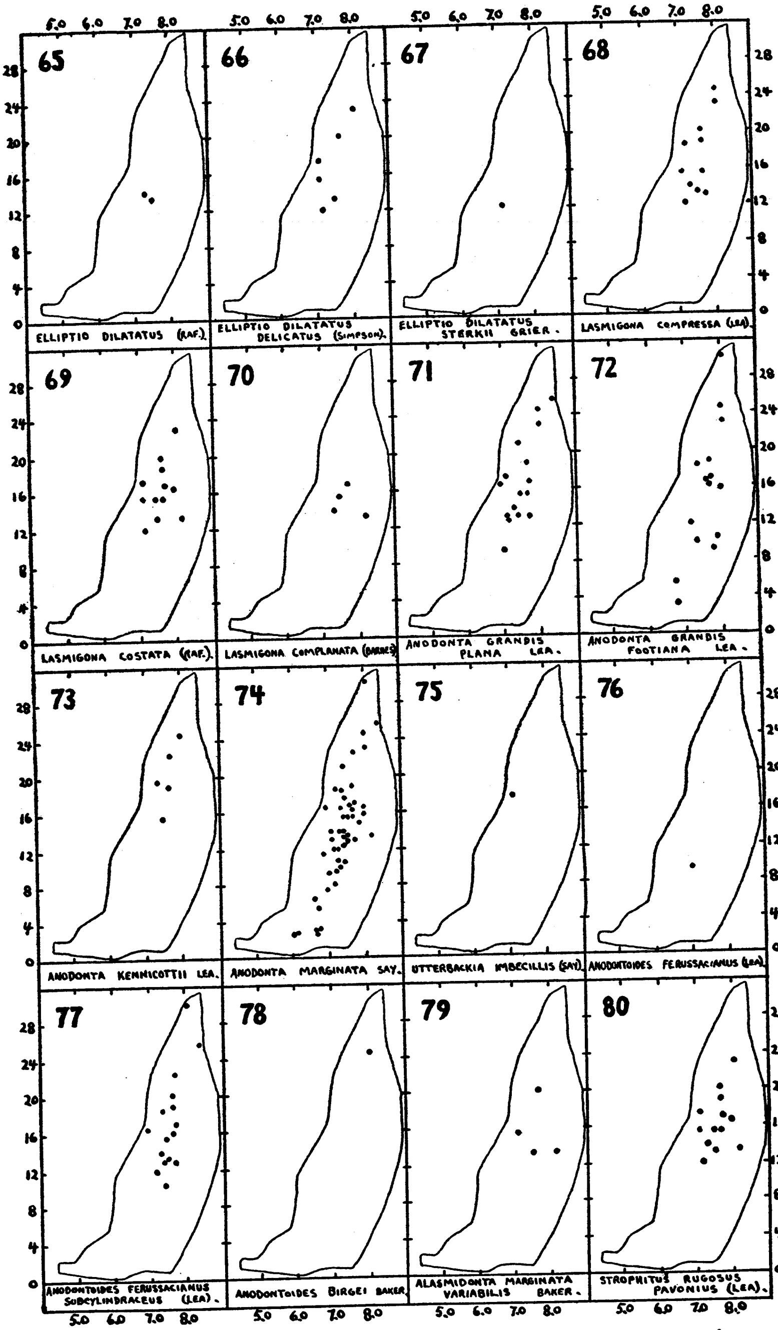
FIG. 17-32. The pH and fixed carbon dioxide ranges of various mollusks. Ordinates indicate fixed carbon dioxide in parts per million; abscissae indicate pH. The circumscribed area presents for comparison the total range of these factors in all the lakes of the Highland Lake District for which data are available.



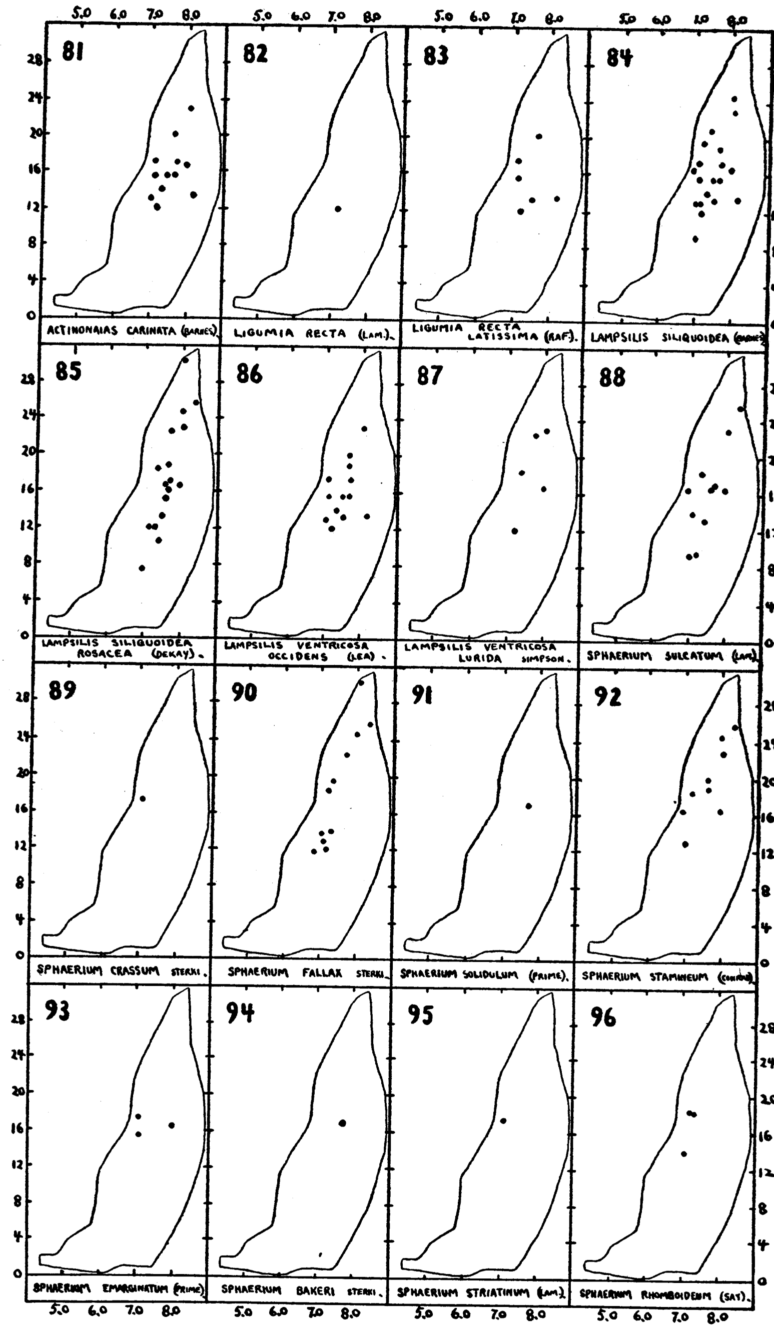
FIGS. 33-48. The pH and fixed carbon dioxide ranges of various mollusks. Ordinates indicate fixed carbon dioxide in parts per million; abscissae indicate pH. The circumscribed area presents for camparison the total range of these factors in all the lakes of the Highland Lake District for which data are available.



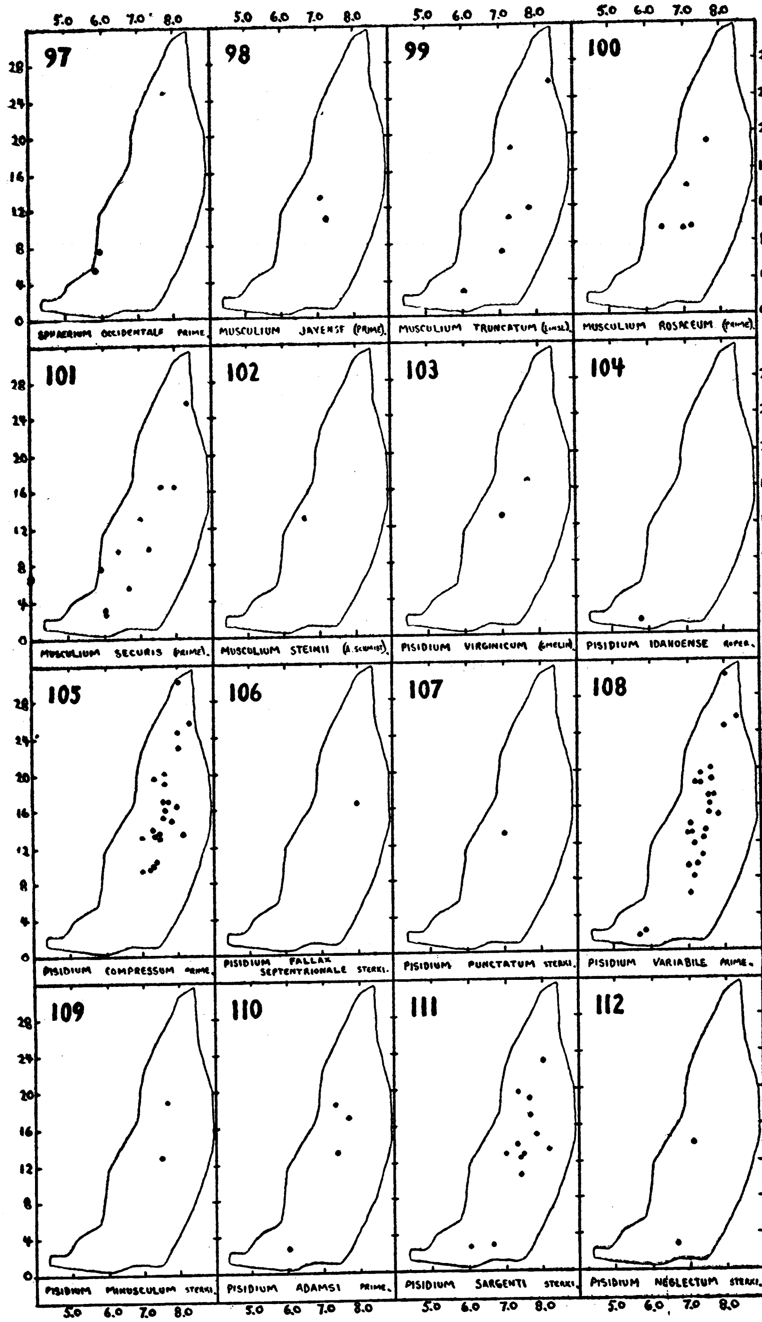
FIGS. 49-64. The pH and fixed carbon dioxide ranges of various mollusks. Ordinates indicate fixed carbon dioxide in parts per million; abscissae indicate pH. The circumscribed area presents for comparison the total range of these factors in all the lakes of the Highland Lake District for which data are available.



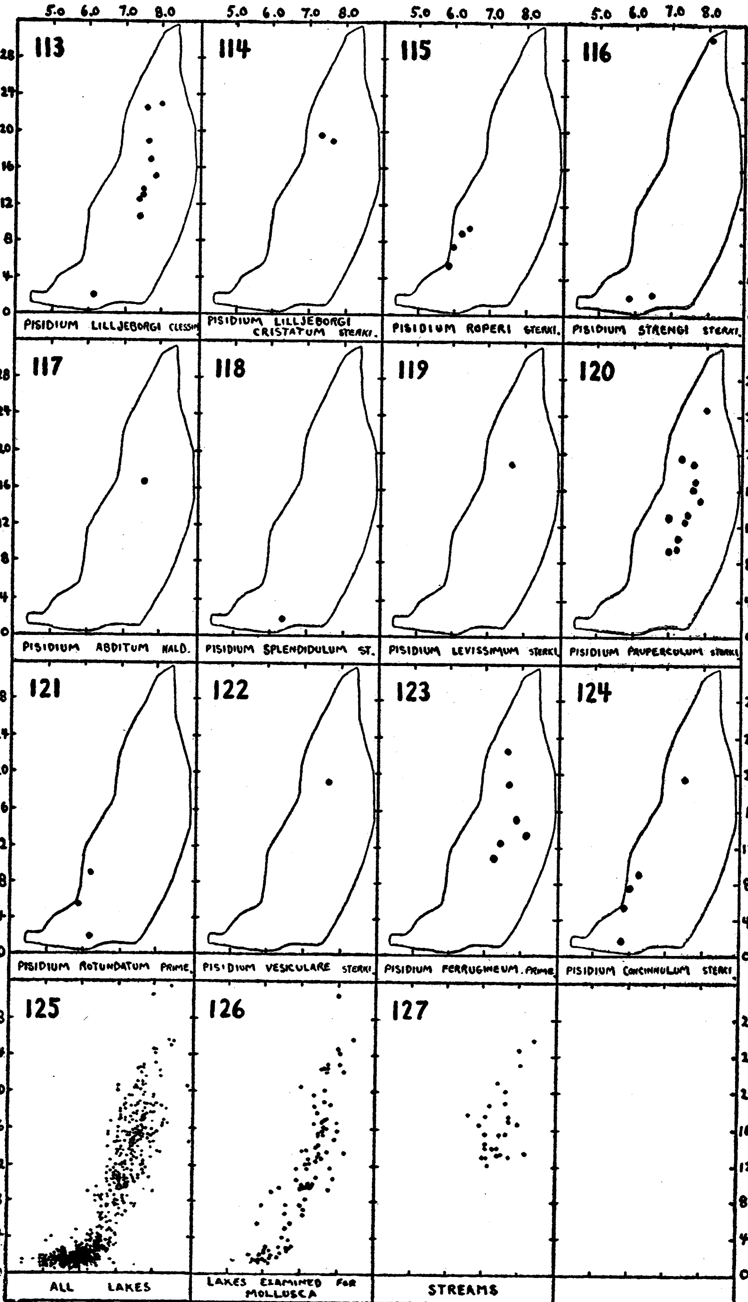
FIGS. 65-80. The pH and fixed carbon dioxide ranges of various mollusks. Ordinates indicate fixed carbon dioxide in parts per million; abscissae indicate pH. The circumscribed area presents for comparison the total range of these factors in all the lakes of the Highland Lake District for which data are available.



FIGS. 81-96. The pH and fixed carbon dioxide ranges of various mollusks. Ordinates indicate fixed carbon dioxide in parts per million; abscissae indicate pH. The circumscribed area presents for comparison the total range of these factors in all the lakes of the Highland Lake District for which data are available.



FIGS. 97-112. The pH and fixed carbon dioxide ranges of various mollusks. Ordinates indicate fixed carbon dioxide in parts per million; abscissae indicate pH. The circumscribed area presents for comparison the total range of these factors in all the lakes of the Highland Lake District for which data are available.



FIGS. 113-127. pH and fixed carbon dioxide ranges: (113-124) for various mollusks, (125) for all the lakes of the Highland Lake District for which records are available, (126) for all lakes in which mollusks were found, and (127) for stream localities found to harbor mollusks. Ordinates represent fixed carbon dioxide; abscissae indicate pH.

STUDIES ON THE LIFE HISTORY OF ACELLA HALDEMANI ("DESH." BINNEY.)

J. P. E. MORRISON

Notes from the Limnological Laboratory of the Wisconsin Geological and Natural History Survey No. XLVIII.

INTRODUCTION

There are several problems that are outstanding in regard to the snail *Acella*. Among these are the breeding season, length of life, and whereabouts during most of the year. This paper is written in answer to these questions.

This species, the slenderest of American Lymnaeas, has a limited range, in the Great Lakes Drainage, from Vermont to northern Minnesota, and from lower Canada to northern Illinois and northern Ohio. Described by Jay, from Lake Champlain in 1839, little was known of the ecology for many years. Kirkland has contributed many interesting observations. Baker, in monographing the American Lymnaeas, has collected all the available notes on *Acella*. All of the earlier collectors found the species only in the fall of the year, and only in the adult condition. One important reference in the literature has been overlooked. This is the note of DeCamp's collecton of *Acella* *(6)* "in one year in May. He once told me he collected eighty-five on the rushes, 'where they had come to spawn'." Just why Kirkland should have forgotten this lead, is hard to understand. In later notes *(1)* he says, "This is a deep water species, which migrates shoreward in the fall, doubtless for spawning purposes, as adults only have been captured, — ".

Baker *(3)* after finding young individuals in July 1916, says, "It may be that the animal descends to the Pond-weed Zones in the winter and lays its eggs on the *Potamogeton* and that they subsequently hatch out in the spring."

In the course of studies on the mollusks of the Northeastern Wisconsin Lakes, *Acella* was found. Additional collecting in these lakes at various times of the year has resulted in tracing the complete life history.

The writer is indebted to the following people: Dr. F. C. Baker, Univ. of Ill. Museum; Dr. W. J. Clench, M.C.Z. at Harvard; Dr. Paul Bartsch, U. S. Nat. Museum; and Dr. W. G. Van Name, Am. Mus. Nat. Hist.; for information regarding *Acella* in the collections of these museums; to W. A. Dence, N. Y. State College of Forestry for loan of specimens; to Paul Armand, Fishtrap Lake, Vilas Co. Wis.; to G. E. Burdick, for assistance in Photography and to Prof. Chancey Juday for chemical data on the lakes and many helpful suggestions and criticisms.

The ecological conditions under which *Acella* is found in Vilas Co., Wisconsin, are restricted. The observed average pH of the lakes it inhabits in this region is between 7.36 and 7.7. The amount of fixed carbon dioxide present in these same lakes is also within relatively narrow limits of variation.

Fishtrap Lake	—pH 7.36	fixed CO_2	18.36	p.p.m.
Harris Lake	—pH 7.7	fixed CO_2	17.0	p.p.m.
High Lake	—pH 7.7	fixed CO_2	22.56	p.p.m.

The narrowness of the limits under which *Acella* has been found in these lakes is made significant by the fact that the variation in all the lakes of the district for which there are data is so much greater. There are lakes here that have an average pH of 4.4 and others as alkaline as 8.9. The range in hardness of water of these lakes is indicated by the fixed carbon dioxide content, which is as low as 0.2 in some lakes, and as high as 31.5 p.p.m. in others (Fig. 1).

minimum	—pH 4.4	fixed CO_2	0.2	p.p.m.
maximum	—pH 8.9	fixed CO_2	31.5	p.p.m.

It was at first thought that the species would be restricted to a muddy type of bottom (silted), but further observations have shown that the species is found in situations having both sand and silt bottoms, though perhaps more often on the silted type. This is in direct support of the observed preference for a more or less protected situation.

As regards its niche in the habitat, it is primarily an inhabitant of vegetation. But what becomes of the snail, when the winter conditions kill down the annual growths of such plants as the reeds, pond lilies, etc.? Assuredly it must have some other places for protection from being silted under on the bot-

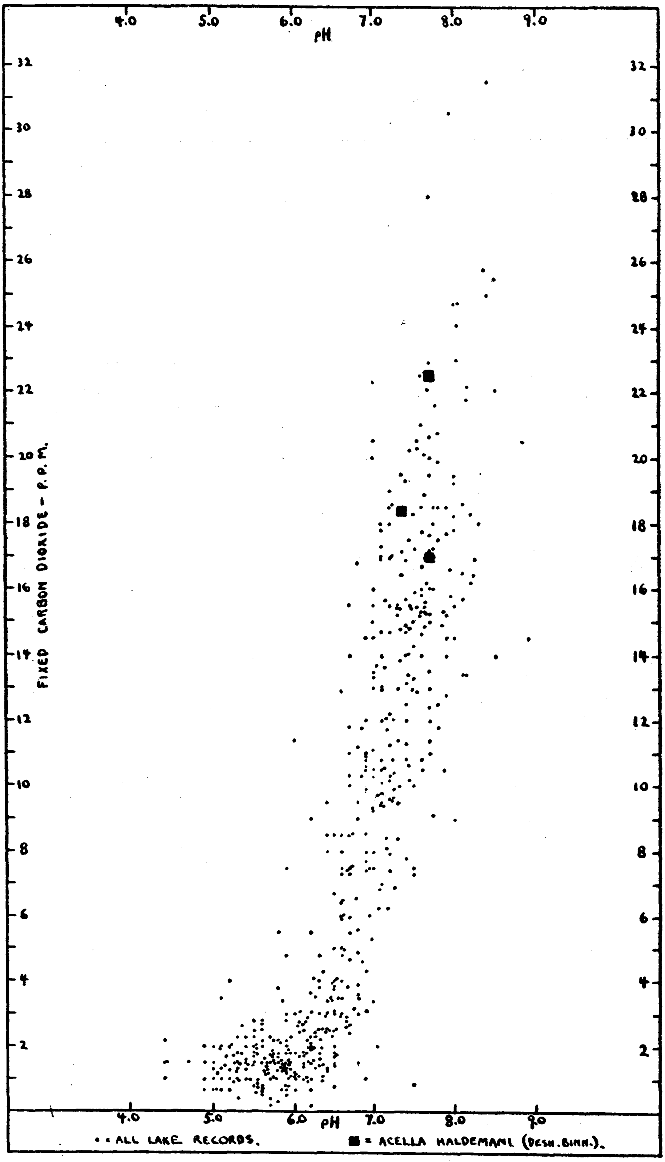


FIG. 1. Distribution of lakes of the Northeastern Wisconsin District in regard to hydrogen-ion concentration (pH) and hardness of water (represented by fixed carbon dioxide in parts per million), with the restricted distribution of *Acella* indicated on the same scales.

tom and for the procuring of food. It is pretty well established that this species feeds on the small filamentous algae growing on the plants on which it has been collected. Why should not this snail be found on any other object in the habitat upon which these plant foods are found? It stands as unquestioned that the snail should be able to move on the bottom, in order to travel from one plant to another, and the observations of the species both in the juvenile and the adult stages, show that it frequently moves about over the bottom.

The fallacy that has done most to create the mystery in regard to *Acella,* is the inference that it must migrate, since it had been found in shallow water only in the adult stage. As will be evident from observations to be mentioned later, this erroneous idea must be given up; there are, in fact, only occasional wanderings of individuals away from the places where they feed to another plant or log.

As previously noted by Kirkland and Baker, this species is more sluggish in its movements than others of the family. This slowness of motion will account in part for the colonial habits, since none of the individuals ever go very far from the spot where they hatched from the egg, and near the same place they will lay their eggs, thus keeping the species in the same location from generation to generation.

The habitat of *Acella* has always been listed by previous writers as vegetation. Decamp, Kirkland and others have recorded it from rushes *(Scirpus)*; Sargent *(5)* mentions having collected it from the under side of pond lily leaves; Baker *(3)* has recorded it from Oneida Lake, N. Y., from the following plants: "Smith's bullrush *(Scirpus smithii)* on the stem. Floating pond-weed *(Potamogeton natans)* on leaves and stem. Pond-weed *(P. interruptus)* on leaves and stem. White water-lily *(Castalia odorata)* on leaves and stem. Yellow water-lily *(Nymphaea advena)* on leaves and stem."

The writer has found the habitat of *Acella* even more variable, including objects other than vegetation. The eggs have been noted on rushes, on the dead and decaying portions of *Potamogeton* and burreed plants, and on the small sticks and logs on the bottom, in the same zone of vegetation.

Juvenile individuals have been collected from *Potamogeton,* from Yellow water-lily leaves, from burreed leaves and stems, and from rushes (*Scirpus,* 2 species), and from stumps and snags in the same marginal zone. One stray individual was taken from silt bottom in deeper water and another from gravel bottom (at mouth of Dead River, Illinois). Adults have been collected from rushes (both living and dead stems), from *Potamogeton,* burreed, pickerel weed, yellow pond-lily stems, and from snags and logs. This last mentioned habitat of snags, etc., has been observed only in the spring season.

As to depth of water in which *Acella* is to be found, Kirkland says, *(1)* "in water from one to three feet deep; and invariably from six to eight inches from the bottom, the apex of the shell pointing downwards, — though in a few instances the apex has been upwards, as if in the act of descending." Baker says it is found in water of about the same depth limits (.3 to over 1 m. deep.). The writer has noted the following depths: Dead River: most of the *Acella* were found near the surface, in from 4 to 24 inches of water; Fishtrap Lake: the snails were generally distributed, from near the bottom to near the top, on all parts of the plants, and with the apex of the shell pointing in any direction, in water 10 to 30 inches deep; in the channel between Fishtrap and High Lakes: in 15-36 inches of water, just on the edge of the current, the snails always within 18 inches of the surface; High Lake: near the surface in water 10 to 18 inches deep; Harris Lake: in water 16-20 inches deep.

Three of the colony locations in Vilas County were examined on February 1st and 2nd, 1931, to find out to what winter conditions these snails are subjected. At the site of the colony on Fishtrap Lake, the following conditions were found: ice 9 inches thick, 2 inches slushy-snow ice, and about 10 inches snow over all; the temperature of the water was 1.5 degrees Centigrade; the depth of water was 24 inches. No specimens were found at this time. The channel between Fishtrap and High Lakes showed the following: ice ½ to 3 inches thick; snow covering the ice 8 to 10 inches thick; water about 10 inches deep; water temperature 1.5 degrees Centigrade. Two adults were found on decaying burreed stems on this date. Harris Lake showed: 1 foot of ice, 2 inches soft snow-ice, and 2 to 4 inches of snow; water 2 feet 5 inches deep; water temperature near 0 degrees Centigrade, since it froze rapidly over the holes cut in the ice, even at 1 p. m. No *Acella* found here, because the exact location of the colony was not found. These measurements indicate conditions for the snails in a mild winter. In the case of the channel habitat, the extremely thin ice indicates either that there are springs in this swamp along the channel, or that the current is spread out more than in the summer when the water is open.

Egg masses of these animals were seen on May 16, 1925 from Dead River, Illinois, on the stems of rushes. At this time, the eggs had not hatched, but the embryonic shell was of such size as to almost fill the egg capsule. These egg masses were identified as belonging to *Acella* by the shape of the embryonic shell, which, as Baker *(1)* has said, is peculiar in that it alone of all the slender Lymnaeids shows elongation of the nuclear whorls. Again May 10, 1930, egg masses were found sparingly on the stems, leaves, of *Potamogeton* and burreed plants, in the colony previously discovered on the south side of Fishtrap Lake, Vilas Co., Wisconsin. Further collections have brought out the fact that in this northern Wisconsin region, the period of egg laying extends from some time previous to May 10 to about the middle of June. One egg mass was collected on June 21, 1930. When examined, it was in the early developmental stages.

The process of egg laying was observed on March 5, 1931. One of the adult individuals in an aquarium in the laboratory was seen laying eggs on the leaf of eel-grass (*Vallisneria*). The process is as follows: The animal remains almost stationary, with the long axis of the shell parallel to the leaf, and pointing upward; first, the gelatinous covering of the eggmass is laid down in part and then the long, oval egg capsules are deposited inside this envelope; when all the eggs are laid, the covering of the egg mass is completed and the animal moves slowly away. As the eggs are being deposited, the snail moves forward very slowly, just enough to make room for them. The whole process of laying this egg mass containing eight eggs, took approximately fifteen minutes. For the first few hours after deposition, the egg mass is less transparent than it becomes later. The gelatinous material of the sheath is apparently more dense, and somewhat milky in appearance. The milkiness disappears as time passes, apparently as the sheath absorbs more water, and swells to full thickness.

The egg masses are elongate, semi-cylindrical, with rounded ends. The width is approximately two millimeters; the length varies from 3.5 to 6 mm. The individual egg capsules are 1 mm. long and 0.6 mm. wide. The gelatinous outer covering of the egg mass is about 0.3 mm. thick. The number of eggs varies from 3 to 12 (Plate XI, fig. 1-4).

Eggs from the individuals collected in February were first seen one month later (March second). In the case of the individuals collected in May, eggs were seen one week after the date of collection (Plate XI, fig. 1). This indicates that egg laying is controlled by some sort of rhythm which is attendant on the arrival of more favorable conditions of growth in the spring. Temperature seems to be the controlling factor, or the immediate one at any rate.

The problem of studying the growth of the earliest juveniles of *Acella* is much more easily accomplished when the eggs are brought into the laboratory and hatched out in small aquaria. In this way the rate of development may be more accurately noted and the obvious difficulty of searching over all surfaces of the water plants in a colony location for minute individuals that are less than 2 mm. in length is overcome. The specimens upon which the early growth studies were made, were all raised in battery-jar aquaria, kept under more or less constant temperature conditions, though somewhat warmer than those prevailing in the shallow water habitats.

After three days, the embryos are in the trochophore stage, slowly revolving in the uppermost end of the elongate egg capsule. About five days after the eggs are laid, the embryos have developed a shell and are seen to be continually crawling (or moving by ciliary action?) in all directions over the inner surface of the capsule (Plate XI, fig. 2-3). At the end of ten days, hatching of the young has started and continues over four or five days. (Plate XI, fig. 4.) There is apparently some variation in the hatching of the snails as in the growth of the young afterwards.

The shell is 1.3 to 1.5 mm. in length when the young are hatched; its width is about 0.5 mm. Sixteen days after the eggs are laid and about three after the young individuals are hatched, the shell averages 1.8 mm. in length and 0.6 mm. in width. In twenty days (one week after hatching) the young

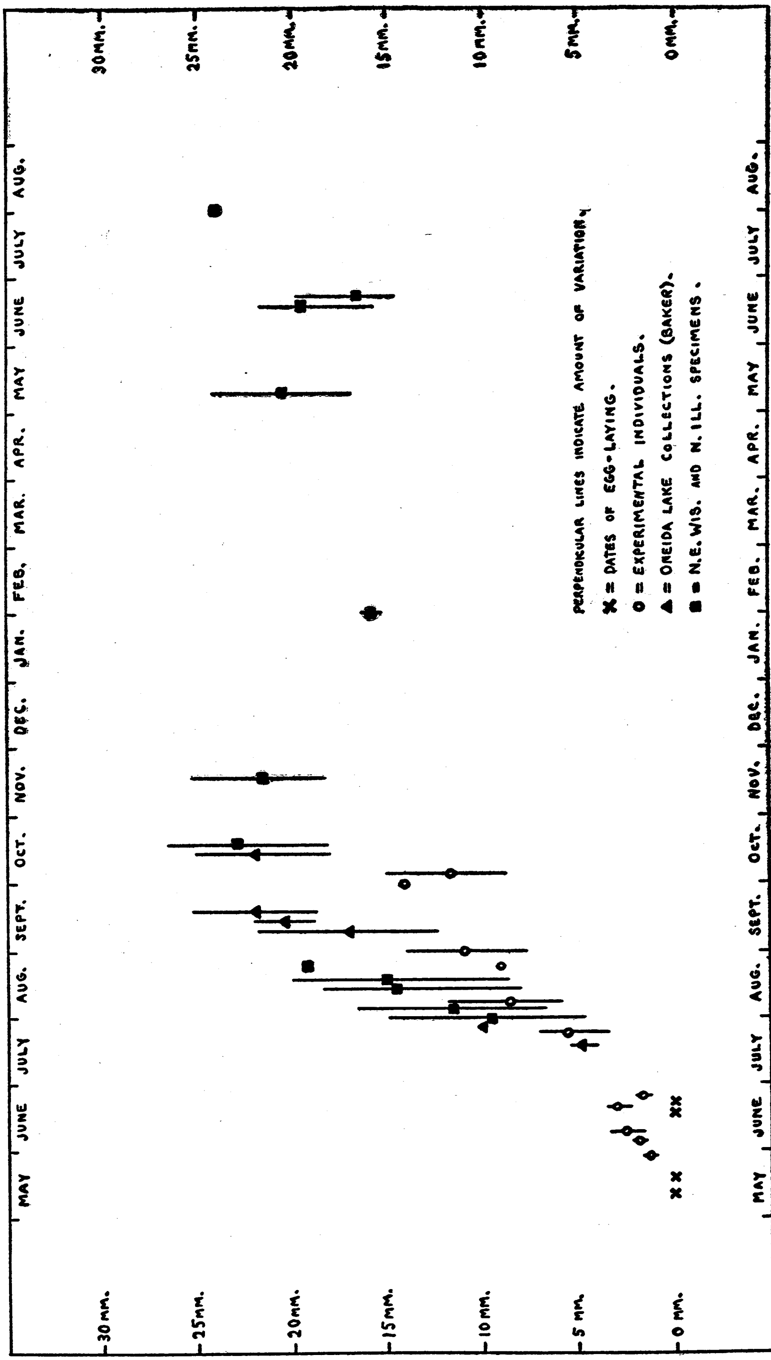


FIG. 2. The growth of *Acella*, including experimentally raised individuals. The vertical lines represent variation in size from the average.

individuals vary in size from 1.6 to 3.4 mm. with an average shell length of 2.6 mm. The nuclear whorls of these individuals shows as a portion visibly distinct from the growth that has occurred since hatching. (Plate XI, fig. 5-6). After a month (two weeks after hatching) the shell of the juvenile individuals varies in length from 2.4 to 3.5 mm., with an average size of 3.1 mm.

One group of juvenile *Acella* was raised in the laboratory for three and one half months. Measured shortly after hatching (June 22, 1930) they averaged 1.8 mm. in shell length, varying from 1.4 to 2.0 mm. One month later (July 23, 1930) they measured between 3.5 and 7.0 mm. with an average length of 5.5 mm. At the end of six weeks (August 6, 1930) they were between 5.7 and 11.7 mm. long. The average was 8.5 mm. One individual 9.0 mm. long was found dead August 22, 1930. (Plate XII, fig. 34). After nine weeks (Sept. 1, 1930) they averaged 10.8 mm. with a variation of 7.6 to 13.9 mm. One individual found dead on Sept. 30, 1930, had grown to a length of 14.0 mm. (Plate XII, fig. 35). The shell length of the remainder (dead Oct. 5, 1930) varied from 8.7 to 15.0 mm., with an average of 11.6 mm. (Plate XII, fig. 36-41).

Juvenile individuals have been collected in the summer months of the year only. Baker, in the course of ecological studies on Oneida Lake, New York, found immature individuals on July 17 and 24, 1916. He says, "The specimens collected were all young, none exceeding 11 mm. in length, the greater number being 3 to 5 mm. long. . . . Five specimens gave the following measurements:

Whorls 2 ; length 3.0; breadth .6; aperture length 1.5; breadth .5 mm.
Whorls 2¼; length 4.0; breadth 1.0; aperture length 2.0; breadth .75 mm.
Whorls 2½; length 5.5; breadth 1.4; aperture length 2.0; breadth 1.0 mm.
Whorls 3 ; length 8.0; breadth 1.7; aperture length 3.5; breadth 1.0 mm.
Whorls 3¼; length 10.5; breadth 2.5; aperture length 5.0; breadth 1.5 mm.

The whorls are usually flatsided as in the adult shell, but in two specimens, they were somewhat rounded."

Of the few specimens of these juvenile individuals of *Acella* loaned by the New York State College of Forestry, two were dated July 17, 1916. These were 4.0 and 5.4 mm. long and averaged 4.7 mm. in shell length (Plate XI, fig. 7-8). Another specimen, collected July 24, 1916, measured 10.0 mm. (Plate XI, fig. 9).

Juvenile *Acella* were collected on July 31, 1930, from a small bit of marshy shore in a small bay at the southeast corner of High Lake, Vilas Co., Wisconsin. Measurements of these varied from 4.6 to 14.9 mm., with the average of 9.7 mm. shell length. (Plate XII, fig. 1-11). Again on August 2, 1930, juveniles were found in the small bay immediately to the west of that collected in a few days previously. The shell length of these individuals varied from 6.7 to 16.5 mm. with an average of 11.4 mm. (Plate XII, fig. 12-15). The Fishtrap Lake colony of *Acella* was searched for young on August 15, 1930. This search revealed one empty juvenile shell and seven live ones. These had a shell length of 8.0 to 18.4 mm. with an average of 14.3 mm. (Plate XII, fig. 16-20). The Harris Lake colony was located by the finding of juveniles on August 16, 1930. Here, the individuals varied in size between 8.6 and 20.0 mm. with an average shell length of 15.0 mm. (Plate XII, fig. 21-25). One individual was collected from Dead River, Illinois on August 22, 1925. This specimen, almost full grown, was taken by a member of Dr. W. C. Allee's Field Zoology Course of the University of Chicago, in the course of ecological studies on Dead River. This individual had a shell length of 19.2 mm.

Specimens collected in September and October in Oneida Lake, N. Y., by Baker, were loaned by the New York State College of Forestry. Thirty-seven specimens collected Sept. 10, 1916 vary in size from 12.3 to 21.8 mm., with an average shell length of 16.9 mm. Eight collected Sept. 14, 1916 vary from 18.8 to 22.0 mm., with an average shell length of 20.3 mm. Five collected Sept. 18, 1916 vary from 18.5 to 25.2 mm., with an average length of 21.6 mm. Five individuals collected October 12, 1915 vary from 18.0 to 25.0 mm., with an average of 21.9 mm. shell length.

Of the specimens collected in Dead River, Illinois on October 13, 1929, twenty-two individuals were measured. They vary in size between 18.1 and 26.5 mm., with an average shell length of 22.8 mm. (Plate XII, fig. 26-29, 42). Of the *Acella* collected in Fishtrap Lake, Vilas Co., Wisconsin on November 16, 1929, sixty-one were measured. They vary in size between

18.2 and 25.2 mm., with an average length of 21.6 mm. (Plate XII, fig. 30-33, 43).

Two individuals were collected from the colony in the channel between Fishtrap and High Lakes on Feb. 1, 1931. These measured 15.4 and 16.1 mm. when collected. The average shell length was 15.7 mm. That these individuals are not just juveniles that have not completed their growth is indicated by the amount of erosion evident at the apex of the shell. These had just 3 and 3½ whorls remaining when collected. Observations on the growth of these two specimens while they were in the laboratory are of interest. Measured before they started laying eggs, on February 24th, they were 16.1 and 17.3 mm. long. Measured at the end of the egg laying period, they were seen to be 16.0 and 17.2 mm. long, respectively. Later, on March 19, they showed a total length of 17.7 and 18.7 mm. From these observations it is evident that shell growth stops during the egg laying period. The decrease in length at this time, may be explained by continued erosion of the shell.

There were thirty-seven adult individuals collected from the Fishtrap Lake colony on May 10, 1930. The erosion of the spire of these shells is in direct contrast to the perfect specimens collected the preceding fall. Instead of 5 full whorls, there were only 2 to 3 whorls to the shell. The tip of the animal was about one quarter turn behind the eroding tip of the shell. These varied in length from 16.8 to 24.1 mm. with an average shell length of 20.4 mm. These shells also show some additional shell growth, after a winter ring on the shell. When kept in the laboratory, these same individuals show more shell growth after the date of collection. Examination of the individuals that lived longest, under laboratory conditions, shows as much as two or three millimeters growth of shell beyond the line of the aperture on the date of collection. Again on June 17, 1930, six adults were collected from the Fishtrap Lake Colony. These individuals also show a winter ring with additional growth beyond. The smaller shells, probably those that were under slightly less favorable growth conditions the preceding summer, have more nearly cylindrical shells, while the larger ones, with a shell of greater diameter, have the aperture flared out distinctly, more especially on the second season's growth. These varied in length from 15.6 to 21.7 mm., with an average shell length of 19.3 mm. Thirty-three individuals were collected from the colony in the channel between Fishtrap and High Lakes on June 21, 1930. They have an average shell length of 16.5 mm., varying between 14.5 and 19.8 mm. These *Acella* show the same erosion of the apex of the shell as was noticed on the individuals collected in May and on June 17. There were about three whorls remaining. The shell shows a crowded group of growth lines, representing the winter and there is a narrow band of new shell growth, lighter in color from one to two millimeters in width. This evidently represents the growth up to the date of collection, this season. (Plate XII, fig. 45-50). One adult individual was found in the second High Lake colony on July 31, 1930. While there is not much erosion of the apex of this shell, the surface is pitted somewhat (Plate XII, fig. 44). This individual measured 24.0 mm. when collected. The writer was unable to keep any of the *Acella* alive in the laboratory beyond August 11, 1930. That these snails died of "old age" is the most probable explanation. This opinion is supported by observations on the amount of general activity and of the heart beat rate, contrasting them with the juvenile individuals being reared in the laboratory. The heart beat rate of the individuals in their second season (after laying eggs) is approximately one-half that of the juveniles two weeks after they are hatched.

The Dead River habitat was examined for *Acella* in October 1924 and again in November 1925. These searches resulted only in the finding of empty shells, probably those of the season preceding. These shells are all full grown, with the flared aperture with a thickened peristome. In some of the individuals, a rest mark and an additional band of shell representing the second season's growth can be seen.

The growth of *Acella* is shown graphically in Fig. 2.

The shell of this species shows variation in convexity of whorls and shape of the aperture. An analysis of this variation, shows that it has a correlation with the type of plant habitat. In the material studied by the writer, two growth forms can be seen. One is the form produced when the individuals live on rushes *(Scirpus)*. This narrow growth form has flat-sided whorls and a proportionately narrower aperture. Measurements of the individuals from Dead River, Illinois, collected from rushes, show the following average:

Aperture length 9.7 mm. Breadth 3.2 mm.
Length-breadth ratio 33.0%

This average includes the measurements from 22 specimens. The wider growth form is produced when *Acella* grows on other plants, such as: yellow and white pond lilies, burreed *(Sparganium),* and pondweed *(Potamogeton).* This wider growth form has slightly more convex whorls, and a wider aperture, with the outer portion of the peristome evenly arched.

Measurements of the wide form are as follows:

Fishtrap Lake, Vilas Co., Wisconsin, Nov. 16, 1929.
Average of 61 individuals.
Aperture length 8.9. Breadth 3.4 mm.
Length-breadth ratio 38.2%

Channel between Fishtrap and High Lakes, Vilas Co., Wis.
February 1, 1931. Average of 2 individuals.
Aperture length 7.3 mm. Breadth 2.8 mm.
Length-breadth ratio 38.3%

Fishtrap Lake, Vilas Co., Wis. May 10, 1930.
Average of 37 individuals.
Aperture length 9.2 mm. Breadth 3.5 mm.
Length-breadth ratio 38.0%

Fishtrap Lake, Vilas Co., Wis. June 17, 1930.
Average of 6 individuals.
Aperture length 8.8 mm. Breadth 3.3 mm.
Length-breadth ratio 37.5%

Channel between Fishtrap and High Lakes, Vilas Co., Wis.
June 21, 1930. Average of 36 individuals.
Aperture length 7.6 mm. Breadth 2.8 mm.
Length-breadth ratio 36.8%

High Lake, Vilas Co., Wis. July 31, 1930.
Average of 1 individual.
Aperture length 10.0 mm. Breadth 4.0 mm.
Length-breadth ratio 40.0%

The wide growth form is illustrated by fig. 30-33, 43-50; Plate XII. The narrow form is illustrated by fig. 26-29, 42; Plate XII. The difference is strikingly seen on comparison of figures 42 and 43.

Summary

The snail *Acella* has a life-span of only one year. The eggs are laid in the spring, a month or so after the ice leaves the

PLATE XI.

FIG. 1. Newly laid eggs of *Acella*. May 21, 1930. Still unsegmented after 28 hours.

FIG. 2. Eggs of *Acella* laid May 17. Average development at 5 days.

FIG. 3. Eggs laid May 17. Maximum development at 5 days.

FIG. 4. Eggs laid May 17. Juveniles just before hatching. June 2, 1930.

FIGS. 5-6. Experimentally raised individuals. June 6, 1930. One week after hatching.

FIGS. 7-8. Juvenile individuals collected by Baker in Oneida Lake, N. Y. July 17, 1916. N. Y. S. C. F. #834 g.

FIG. 9. Juvenile individual collected by Baker in Oneida Lake, N. Y. July 24, 1916. N. Y. S. C. F. #1021 d.

A convenient scale for figures 1-4 is furnished by the individual egg capsules, which are approximately 1 mm. long. Figures 5-9 enlarged 10 diameters.

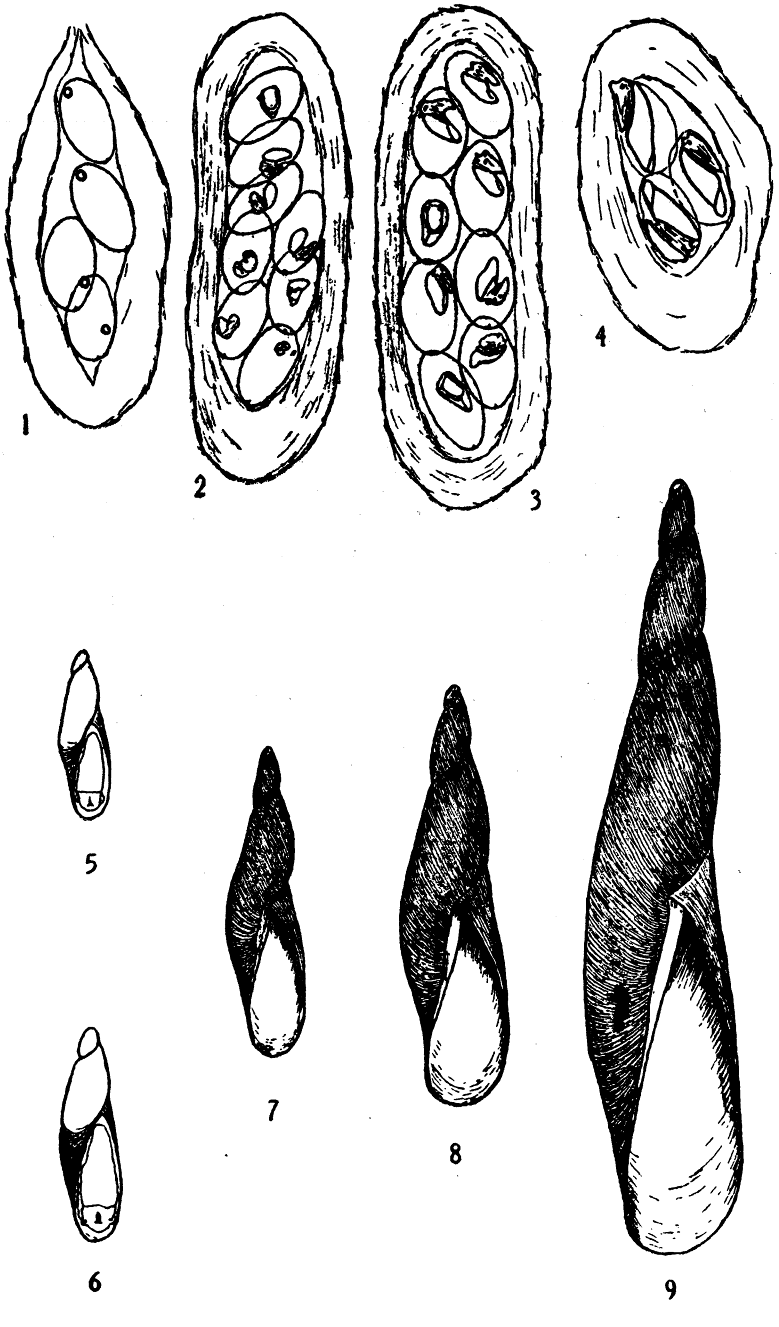

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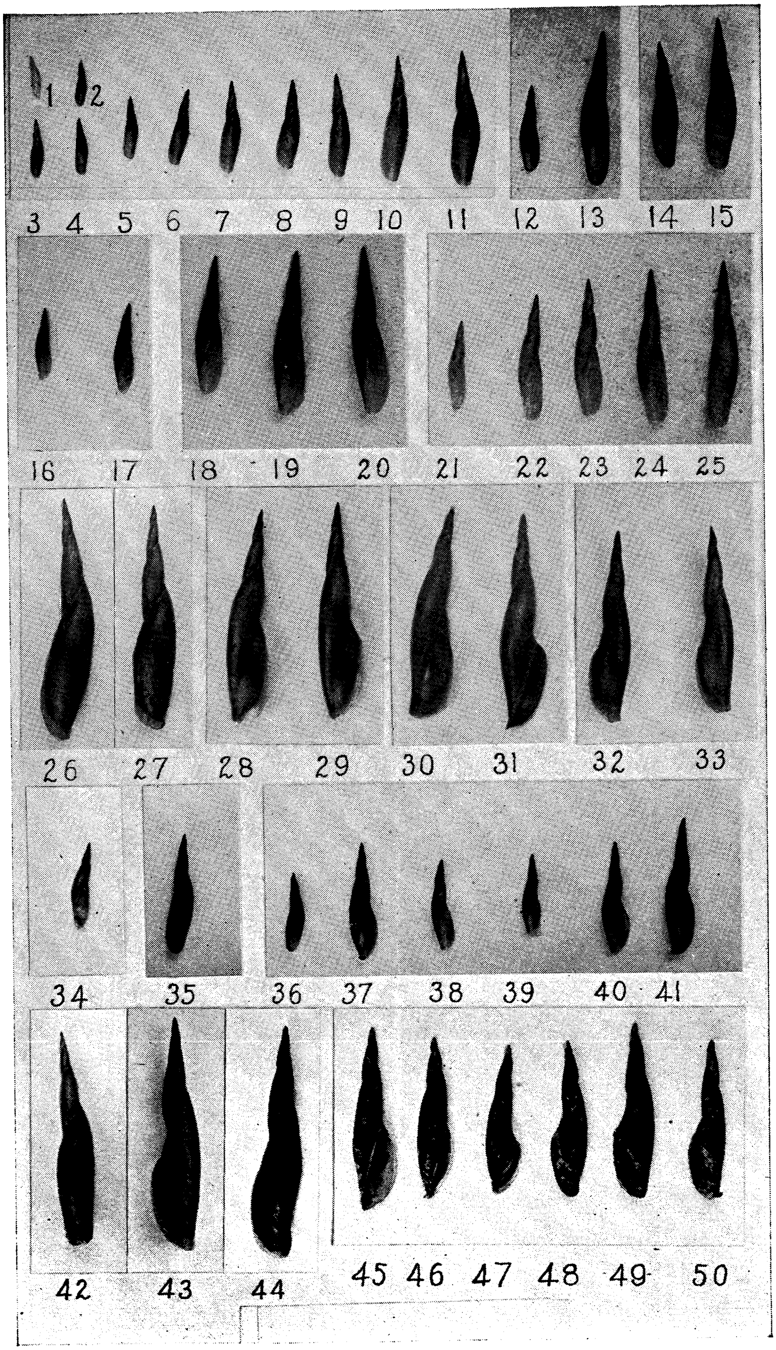
PLATE XII.

FIGS. 1-11.	From colony #1, High Lake, Vilas Co., Wis. July 31, 1930.
FIGS. 12-15.	From colony #2, High Lake, Vilas Co., Wis. August 2, 1930.
FIGS. 16-20.	Fishtrap Lake, Vilas Co., Wis. Aug. 15, 1930.
FIGS. 21-25.	Harris Lake, Vilas Co., Wis. Aug. 16, 1930.
FIGS. 26-29.	Dead River, Lake Co., Illinois. Oct. 13, 1929.
FIGS. 30-33.	Fishtrap Lake, Vilas Co., Wis. Nov. 16, 1929.
FIGS. 34-41.	Experimentally raised. Hatched from eggs, June 22, 1930. Fig. 34. Dead, Aug. 22, 1930. Fig. 35. Dead Sept. 30, 1930. Fig. 36-41. Dead Oct. 5, 1930.
FIG. 42.	Dead River, Lake Co., Ill. Oct. 13, 1929, specimen showing narrow growth form as found on Rushes *(Scirpus)*.
FIG. 43.	Fishtrap Lake, Vilas Co., Wis. Nov. 16, 1929, specimen showing wider growth form as found on Burreed, Pondweed, etc.
FIG. 44.	High Lake, Vilas Co., Wis. July 31, 1930, specimen in second season.
FIGS. 45-50.	Channel between Fishtrap and High Lakes, Vilas Co., Wis. June 21, 1930, specimens in second season showing extreme amount of erosion.

All figures slightly enlarged.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lakes. The juvenile individuals hatch and grow to full size by early fall. They overwinter as adults, lay eggs the following spring and die by mid-summer.

Acella does not migrate to deep water, but remains in the zone of vegetation near shore at all times of the year. When the vegetation has been killed down by winter conditions, the snags and logs serve as a substitute habitat on which to live and lay eggs.

The shell of this species shows variation directly produced by the habitat. The individuals living on rushes *(Scirpus)* have narrower apertures, with almost parallel margins, while those from other plants show greater convexity of the whorls and wider apertures, with more evenly arched outer lips.

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DISSOLVED OXYGEN AND OXYGEN CONSUMED IN THE LAKE WATERS OF NORTHEASTERN WISCONSIN

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

INTRODUCTION

Quantitative determinations of the dissolved oxygen content and of the oxygen consumed by the lake waters of the Highland Lake District of northeastern Wisconsin were made during a general chemical survey of a considerable number of these lakes between 1925 and 1931. These studies were confined chiefly to the summer season, that is, between late June and the first of September. During the investigation more than 2,000 dissolved oxygen determinations were made, and of this number 1,150 were surface samples. The other 850 samples represented 273 series which covered the entire depth of a considerable number of lakes; all of the lakes in the district which were known to have a maximum depth of 18 m. or more were included in these series. Similar observations were made on a number of the shallower lakes also, in which the maximum depth ranged between 4 m. and 18 m. The series taken on the various lakes consisted of 2 to 14 samples each, the number of samples depending upon the maximum depth of the lake and also upon the status of the dissolved oxygen in the hypolimnion of the different bodies of water. Where there was a marked decrease in the quantity of dissolved oxygen in the lower water, samples were taken at one meter intervals through the region of rapid decrease and at two or three meter intervals below this stratum.

Determinations of oxygen consumed were made during the summers of 1929, 1930 and 1931.

METHODS

The standard Winkler method was used for the determination of dissolved oxygen. For purposes of comparison a number

* The investigation was made in cooperation with the U. S. Bureau of Fisheries and the results are published with the permission of the Commissioner of Fisheries.

of duplicate determinations were made in which the standard Winkler method was used for one sample and the Rideal-Stewart modification for the other; the differences were within the limits of error of the two methods and the standard method was adopted for the routine determinations because it required less time. The nitrite content of these lake waters rarely exceeded a trace, most frequently not even a trace, so that the modified method for dissolved oxygen was unnecessary.

The method given in Standard Methods of Water Analysis (A. P. H. A., 1925 edition) was employed in making the oxygen consumed determinations.

I. Dissolved Oxygen

Surface samples. Surface samples of water for dissolved oxygen determinations were obtained from 510 lakes during the period of this investigation. Only a single observation was made on the surface water of 281 of these lakes, but two or more surface samples were secured from each of the other lakes at different times during the progress of this work. These samples were taken at a depth of 2 cm. to 5 cm. below the surface of the water so that they came from the stratum which was freely exposed to the air through the action of the wind and also from the region where photosynthesis was taking place.

In spite of the fact that these samples were obtained from the surface stratum which was in circulation and which was thus freely exposed to the air where any deficiency or excess of oxygen tension could be equalized, there was nearly a fourfold difference in the amount of dissolved oxygen in them. Some of this difference was due in part to differences in the temperature of the water, which affected its oxygen holding capacity, but the major differences were due to other factors, such as the respiration of the living organisms, the decomposition of organic matter, and photosynthesis.

The variations in the quantity of dissolved oxygen in the surface samples are shown graphically in Figure 1. This diagram includes 1047 surface samples and the range is from 5.0 mg. to 10.9 mg. of oxygen per liter of water. The maximum number of samples (108) falls in the 8.0–8.1 mg. group, while 605 of

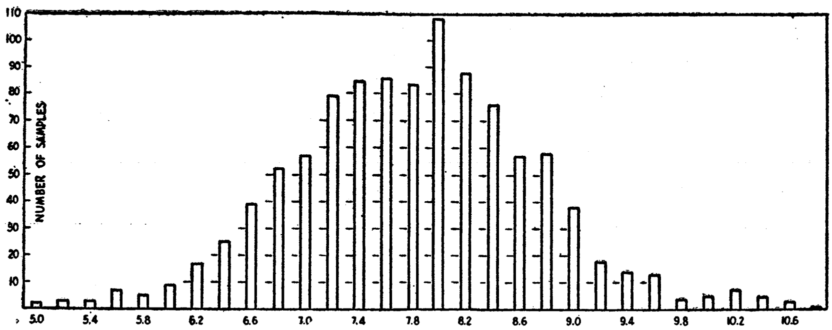

FIG. 1. The dissolved oxygen in the surface samples of water from the lakes of northeastern Wisconsin. The vertical scale represents the number of samples in the various groups and the horizontal spaces show the amount of dissolved oxygen in milligrams per liter of water, ranging from 5.0 mg. to 10.9 mg., inclusive.

them, or more than 57 per cent of the total number, fall between 7.2 mg. and 8.5 mg. per liter.

The smallest amounts of dissolved oxygen in surface waters were found in the samples from small bog lakes and bog pools or ponds. These waters usually contain a relatively large amount of dissolved organic matter and, in addition, the water is kept in intimate contact with a large amount of decaying bog material around the margin and on the bottom. In such bodies of water, therefore, decomposition is usually taking place at a vigorous rate. Their small size also makes them less subject to disturbance by the wind and thus tends to prevent a vigorous circulation and aeration of the upper stratum. The water usually gives a rather strong acid reaction, the hydrogen ion concentration ranging from pH 4.4 to 6.7. A considerable number of chlorophyll bearing organisms was found, however, the number varying from 260 to more than 1700 cells and colonies per cubic centimeter of water in these bog lakelets and ponds.

Figure 2 shows the distribution of the individual surface samples on the basis of their percentage of saturation with oxygen; this diagram covers the range from 64 per cent to 108 per cent. The samples above and below these percentages are so widely scattered that they were omitted from the diagram. The maximum number of samples, namely 99, falls in the 86-87 per cent group. The 88-89, 90-91, and 92-93 per cent groups contain 94, 85, and 86 samples respectively, and there are 77 samples in the 84-85 per cent group. These five columns contain 441 samples out of the 951 represented in the diagram, or a little more than 46 per cent of the total number included. Half of the surface samples, namely 477, fall between 83 per cent and 93 per cent of saturation.

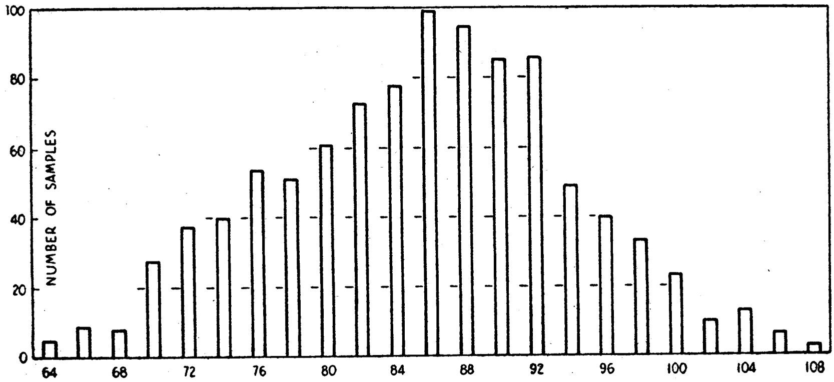

FIG. 2. The percentage of oxygen saturation in the surface samples of water. The vertical scale shows the number of samples in each group and the horizontal spaces indicate the percentage of saturation at 2 per cent intervals from 64 per cent to 109 per cent, inclusive; the first column represents 64 per cent and 65 per cent, the second column 66 per cent and 67 per cent and so on to 108 per cent and 109 per cent in the last column. Note the maximum of 99 samples in the 86–87 per cent column. The figure includes 951 samples.

It will be noted that there is a marked difference between the number of samples in the 68-69 per cent column and that in the 70-71 per cent column; there are 8 in the former as compared with 27 in the latter. Another abrupt change is shown between the 92-93 per cent column and the 94-95 per cent column; the former represents 86 and the latter 49 samples.

Below the column representing 70 per cent of saturation, there are 4 samples from bog lakelets or ponds which fall between 34 per cent and 53 per cent, 7 lake samples between 55 per cent and 59 per cent, and 23 lake samples between 60 per cent and 69 per cent, inclusive.

In 32 samples the oxygen varied from 106 per cent to 129 per cent of saturation. Thirty-nine samples fall between 101 per cent and 105 per cent, inclusive; adding these to the 32 above 105 per cent gives a total of 71 samples in which the quantity of dissolved oxygen exceeds the amount required for saturation. This is approximately 7 per cent of the total number of surface samples, namely, 1,056. The percentages of saturation found in some of the lakes are given in Tables I, III and VIII.

Table I shows the variations in the oxygen content of the surface waters of a few lakes that were visited several times during the progress of the investigation. These results show the range of variation that is to be expected from irregular visits to such bodies of water. A much more detailed study of each lake would be required to ascertain the seasonal and diurnal changes which take place in the dissolved oxygen content of the surface water. The various bodies of water represented in this table were selected for the purpose of illustrating the results obtained on the different types of lakes and lakelets.

Adelaide Lake is rather small (22 ha.), but has a maximum depth of 21.5 m.; the water is soft and has a certain amount of brown color, ranging from 32 to 45 on the platinum-cobalt scale. Bear Lake has an area of about 104 ha., but it is shallow (maximum depth 10 m.) so that the water is not thermally stratified in summer. The water is soft and the brown color is generally low (16). The open water in the Cardinal Bog is only about 25 m. in diameter and it is surrounded by a wide margin of typical bog; the maximum depth of the water is 5.8 m. The water is soft and the brown color ranges from 32 to 49. Crystal Lake has an area of 31 ha. and a maximum depth of 21 m.; its water is clear, transparent and soft, with no brown color at all or only a trace.

Lake Mary has an area of 1.2 ha. and a maximum depth of 22 m. Its water is soft and rather highly colored, the color ranging from 100 to 122 on the platinum-cobalt scale. Muskellunge Lake has an area of about 375 ha. and a maximum depth of 21 m. The water has a medium quantity of fixed or bound carbon dioxide and very little brown stain, the latter ranging from 0 to 10. Nebish Lake has an area of 47 ha. and a maximum depth of 15.8 m. The water is soft and has a brown color ranging from 0 to 14. Silver Lake has an area of 87 ha. and a maximum depth of 19.5 m. The water has a fairly large amount of fixed carbon dioxide for this region and very little or no brown color at all.

Trout Lake, with an area of about 1683 ha., is the second lake in size in the Highland Lake District; it has a maximum depth of 35 m., which makes it the deepest lake in the district. The water carries a relatively large amount of fixed carbon dioxide and it has very little brown color (0-14). Weber Lake has an area of 15.6 ha. and a maximum depth of 13.5 m.; its depth is sufficient, however, to produce a thermal stratification of the water in summer. The water is very soft and has very little or no brown color. Wild Cat Lake has an area of 102 ha. and a maximum depth of 12 m.; the water is thermally stratified in the deepest part of the lake in summer. The water contains a larger amount of fixed or bound carbon dioxide than any other lake in this district and the brown color ranges from 16 to 26 on the platinum-cobalt scale.

The lowest percentage of oxygen saturation in surface water was found in the Cardinal Bog where only 34 per cent of the amount required for saturation was noted in the surface sample on August 20, 1927. The largest amount found in this bog pool reached only 73 per cent of saturation, so that there was somewhat more than a twofold difference between maximum and minimum. In the Forestry Bog the range was from 45 per cent to 84 per cent, just a little less than a twofold difference. In Little Star Bog it was from 60 per cent to 98 per cent; the open water in this bog has an area of about 2 ha. so that the surface water is more thoroughly aerated.

Low percentages of saturation were also noted in the surface samples of Lake Mary; though none of them fell below 70 per cent, only 2 out of the 6 samples were above 80 per cent. These low percentages may be accounted for, in part at least, by the fact that this lakelet is partially surrounded by boggy shores.

In the other bodies of water represented in Table I, 12 surface samples fell between 68 per cent and 80 per cent of saturation, 76 between 81 per cent and 100 per cent and 6 above 100 per cent. The maximum percentage (120) was found in Bear Lake on July 1, 1928; the lowest percentage in this lake was 68 per cent, so that there was almost a twofold range between maximum and minimum. The surface samples included in Table I were taken at different hours of the day, but most frequently during the forenoon, so that they do not represent the daily maximum quantities in most cases; neither do they represent the minimum amount that would be found in the early morning.

The mean quantity of dissolved oxygen in the surface waters of the 510 lakes was 7.6 mg. per liter; the range was from a minimum of 3.4 mg. to a maximum of 12.4 mg. per liter of water. The mean percentage of saturation of all of these surface samples was 82 per cent; the percentage varied from a minimum of 34 per cent noted in a surface sample from the Cardinal Bog to a maximum of 129 per cent in a sample from the surface of Little St. Germain Lake.

During the summers from 1907 to 1910 observations were made on the dissolved oxygen content of 60 of these northeastern lakes; 70 determinations were made on surface waters during this period. In 59 of the 70 surface samples the quantity of oxygen ranged from 7.5 mg. to 8.9 mg. per liter; in the entire number of samples the amount varied from 6.8 mg. to 9.6 mg. per liter, while the mean quantity was 8.2 mg. In percentages the range was from 71 per cent to 102 per cent of saturation, with a mean of 88 per cent. The mean percentage of saturation in these 70 samples, therefore, was 6 per cent larger than that of the samples obtained between 1925 and 1931. No bog samples, however, were included in the former observations.

In the summers of 1907 to 1909 surface samples were obtained from 62 lakes in northwestern Wisconsin and they included 64 determinations of dissolved oxygen. In 45 cases the quantity of oxygen fell between 8.0 mg. and 9.4 mg. per liter, while the mean quantity in the 64 surface samples was 8.7 mg. per liter. The percentage of saturation in the surface waters of the various lakes varied from 68 per cent to 168 per cent; that is, the maximum was about two and a half times as large as the minimum. The mean percentage for the 64 samples was 99 per cent, or 17 per cent above the mean percentage found in the surface samples taken between 1925 and 1931 in the northeastern lakes.

Oxygen determinations were made on 120 surface samples obtained from 24 lakes in southeastern Wisconsin, exclusive of Lake Mendota, between 1905 and 1910. Of this number 101 samples yielded between 8.0 mg. and 9.4 mg. per liter; the range for all samples was from a minimum of 6.7 mg. to a maximum of 14.2 mg. per liter. More than half (66) of the samples contained 96 per cent to 104 per cent of the quantity of oxygen required for saturation; the mean for the 120 samples was just a little over 100 per cent, with a minimum of 77 per cent and a maximum of 131 per cent. Thus the mean percentage of oxygen saturation in these surface samples from the southeastern lakes was a little more than 18 per cent higher than that in the surface samples of the northeastern lakes and somewhat more than 1 per cent above that in the northwestern lakes.

Vertical Distribution of Dissolved Oxygen

Series of oxygen samples covering the entire depth of the water were obtained from 76 of the northeastern lakes. In the shallowest ones, those having a maximum depth of 4 m. to 5 m., only surface and bottom samples were taken in some instances, but in the deeper lakes the number of samples in a series varied from 3 to 14, depending upon the depth of the lake and the scarcity or abundance of oxygen in the hypolimnion. Including those of 1931, 261 series of samples were taken; the largest number from a single lake, namely 32, was obtained from Trout Lake.

For convenience in the discussion of the results, the lakes are separated into four groups on the basis of their depth. The maximum depth and the area of the various lakes are shown in Table II. The first group includes the 17 lakes which do not exceed 9.5 m. in depth, the second group 15 between 10 m. and 14.5 m. in depth, the third group 19 between 15 m. and 19.5 m., and the fourth 25 that are 20 m. to 35 m. deep. The vertical distribution of the dissolved oxygen in some of these lakes is given in Table III.

Group I. Jag Lake in the first group has a maximum depth of only 4 m. and the bottom water contained substantially the same amount of oxygen as the surface. The next in order of depth are the Cardinal Bog (5.5 m.) and Little Star Bog (6 m.). The open water in the Cardinal Bog is only about 25 m. in diameter and is well protected from wind by the surrounding forest, so that its water is subject to only slight disturbances by air currents. As a result there is a marked thermal stratification of the water in spite of the shallowness of the pool; the temperature at a depth of 5.5 m., for example, was only 4.7° C. on July 18, 1926, and 5.2° on August 18, 1931. A lower temperature than this has been found in summer in only one other northeastern lake, namely Lake Mary, where a median stratum usually has temperatures ranging between 4.0° and 4.5°.

The upper 2 m. of the Cardinal Bog contained only 50 per cent to 53 per cent of the quantity of oxygen required for saturation on July 18, 1926 and less than 1 per cent of saturation was found at 3 m. to 5 m.; only a trace of oxygen was found below 3 m. on August 18, 1931. Little Star Bog has an area of about 2 ha., so that the wind produces a fair circulation of the water; the upper stratum contained from 60 per cent to 98 per cent of the amount of oxygen required for saturation, while the quantity varied from 34 per cent to 48 per cent of saturation at a depth of 5 m. Yolanda is also a bog lakelet and its water possessed only a trace of oxygen at 3 m. and none below this depth on August 23, 1931.

The vertical distribution of the oxygen in three of the lakes belonging to the shallow group is shown in Figures 3 to 5. These diagrams show that there was a decrease in the quantity of dissolved oxygen in the lower water of these three lakes. In Dorothy Dunn Lake the decrease took place between 3 m. and 6 m., corresponding to the fall in the temperature of the water. Only 3 mg. of oxygen per liter were found at 6 m., which was only 30 per cent of saturation at that depth. (See Fig. 3).

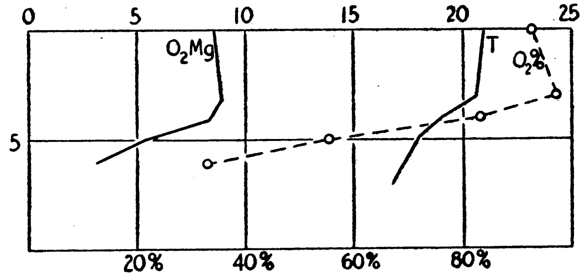

Fig. 3. The dissolved oxygen *(O_2)* and the temperature *(T)* of Dorothy Dunn Lake on August 28, 1926. The vertical spaces represent the depth in meters and the horizontal spaces show the amount of oxygen and the temperature of the water. The quantity of oxygen is given in milligrams per liter and in percentage of saturation. The scale at the top of the diagram indicates the quantity of oxygen in milligrams per liter of water and the temperature in degrees centigrade, while that at the bottom of the diagram represents the percentage of oxygen saturation.

In Finley Lake (Fig. 4) the water was well supplied with oxygen down to a depth of 7 m.; the quantity at this depth was above 82 per cent of saturation in each of the three summers in which observations were made on this lake. There was a more or less marked decrease at 8 m.; this decrease was most marked in 1927 when the quantity fell to 3.1 mg. per liter on July 28 at 8 m. The oxygen content of the surface water was smallest in 1929. The water of this lake is fairly transparent, the readings with a Secchi disc varying from 3.7 m. to 6 m. Readings with a pyrlimnometer in this lake on July 19, 1929 showed that more than 1.5 per cent of the energy delivered to the surface of the lake by the sun penetrated to a depth of 7 m.; at this depth the energy is in the form of light and would represent twice this amount if expressed in terms of illumination. The energy is sufficient to enable the chlorophyllaceous organisms to carry on photosynthesis at this depth and help to keep the lower water well supplied with oxygen.

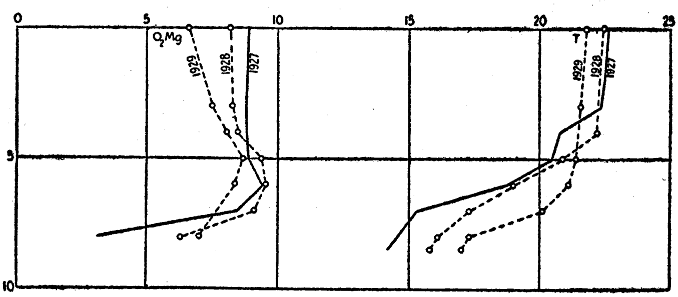

FIG. 4. The dissolved oxygen *(O_2)* and the temperature *(T)* of Finley Lake on July 28, 1927, July 19, 1928, and August 10, 1929, indicated in milligrams per liter of water and in degrees centigrade, respectively. Compare with Fig. 5.

Figure 5 shows the oxygen results obtained on Bragonier Lake. This body of water is less than half a kilometer from Finley Lake and it is smaller than the latter, having an area of 19.2 ha. as compared with 62.8 ha. in Finley. As a result of its smaller size and its protection from wind by the surrounding forest, the epilimnion of Bragonier is only 1 m. to 2 m. thick in July and August as compared with 4 m. in Finley. Bragonier also has a brown stained water with the color ranging from 22 to 45 on the platinum-cobalt scale at the surface and from 60 to 126 at 8 m.; in Finley Lake the brown color does not exceed 8. The vegetable stain in Bragonier Lake adds materially to the quantity of organic matter in the water and thus increases the demand for oxygen in the process of decomposition; the average amount of organic carbon in the surface water of Bragonier Lake was 6.1 mg. per liter as compared with 4.5 mg. in Finley Lake. As a result of the brown stain in the water of Bragonier Lake the sun's energy is reduced to less than 0.2 per cent at a depth of 4 m.

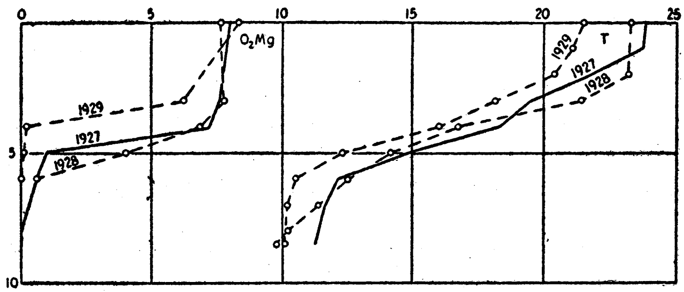

FIG. 5. The dissolved oxygen *(O_2)* and the temperature *(T)* of Bragonier Lake on July 28, 1927, July 19, 1928 and August 10, 1929, indicated in milligrams per liter of water and in degrees centigrade. Compare with Fig. 4.

The oxygen was substantially uniform in quantity in the upper 4 m. of Bragonier Lake in 1927 and in 1928, but there was a marked decrease at 5 m. and only a trace or none at all was found at 8 m. Similar results were obtained in 1929 except that the decrease in the quantity of oxygen was noted in the 3 m.-4 m. stratum instead of in the 4 m.-5 m. stratum as in the former years. There was a large increase in the free carbon dioxide below 4 m. on July 28, 1927; the amount of fixed or bound carbon dioxide at 8 m. on this date was a little more than twice as large as that at the surface. In general the lower water of Bragonier Lake is eutrophic in character, while that of Finley Lake is oligotrophic.

Group II. With the exception of Diamond Lake, the lakes included in Group II show a more definite thermal stratification in summer than those in Group I. Diamond Lake has an area of 48.4 ha. and a maximum depth of only 12.3 m., so that from 80 per cent to 87 per cent of its water is kept in circulation during the summer; as a result, the difference in temperature between surface and bottom water is not as great in this lake as it is in the other members of this group. Figure 6 shows that the water was well aerated at all depths in the three years represented in the diagram. On July 24, 1929, the amount of dissolved oxygen at 10 m. was 109 per cent of that required for saturation, while the quantity at 11 m. was 99 per cent. The curves for 1927 and 1929 coincide down to a depth of 7 m., but in the latter year there was a more marked increase below this depth than in the former year. The water of Diamond Lake is transparent, the disc readings ranging from 7.6 m. to 9 m. and about 2 per cent of the sun's energy penetrates to the bottom in the deepest water. This light is sufficient to enable the phytoplankton to carry on the process of photosynthesis in the lower water and thus furnish enough oxygen to keep the lower stratum well supplied with this gas.

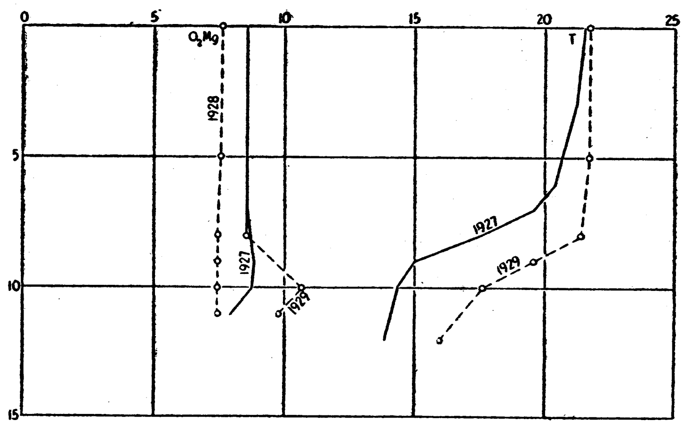

FIG. 6. The dissolved oxygen *(O_2)* and the temperature *(T)* of Diamond Lake on July 15, 1927, August 29, 1928 and July 24, 1929.

Blue and Weber lakes (Figs. 7 and 8) contained an abundance of dissolved oxygen down to a depth of 8 m., more than 90 per cent of the amount required for saturation being present in this stratum. Both lakes showed an excess of oxygen at 9 m. and 10 m.; the quantity of this gas rose to 106 per cent and 102 per cent of saturation at these depths, respectively, in Blue Lake on August 6, 1929, and to 111 per cent and 101 per cent in Weber Lake on August 21, 1929. The percentage of saturation at the various depths is shown for both lakes in

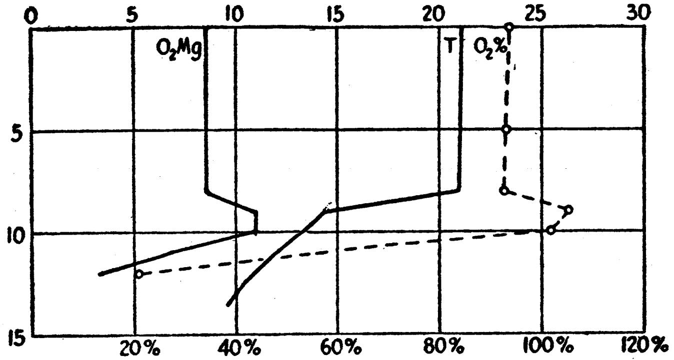

FIG. 7. The dissolved oxygen *(O_2)* and the temperature *(T)* of Blue Lake on August 6, 1929. The quantity of oxygen is indicated both in milligrams per liter of water and in percentage of saturation. The scale at the top of the diagram indicates the quantity of oxygen in milligrams per liter and the temperature in degrees centigrade, while that at the bottom shows the percentage of oxygen saturation.

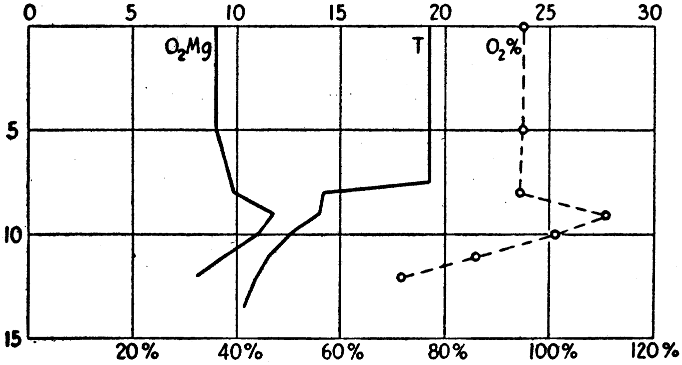

FIG. 8. The dissolved oxygen and the temperature of Weber Lake on August 21, 1929. The oxygen is shown in milligrams per liter and in per cent of saturation. The quantity of oxygen was above the saturation point at 9 m. and 10 m. Compare with Fig. 7.

Figures 7 and 8. There was a rather marked decrease in the quantity of oxygen below 10 m. in both lakes. The water of these two lakes is transparent, so that photosynthesis can take place at considerable depths. More than 3 per cent of the sun's energy penetrates to a depth of 10 m. in Weber Lake and a little less than 3 per cent is found at that depth in Blue Lake.

A more pronounced decrease of dissolved oxygen in the lower water was noted in Midge Lake on July 31, 1929 (Fig. 9); the quantity of oxygen in this lake ranged from 83 per cent of saturation at the surface to 10 per cent at the bottom. Long Lake (Fig. 10) showed a still more marked decrease in oxygen in the lower water; only a trace was found between 8 m. and 10 m., and none below the latter depth. Even the surface water reached only 76 per cent of saturation on August 23, 1928. There was a marked increase in the free carbon dioxide in the lower water correlated with the decrease in oxygen.

Group III. This group includes 19 lakes and they belong to three general types. Two of these lakes had an abundance of dissolved oxygen at all depths; 5 showed a more or less marked

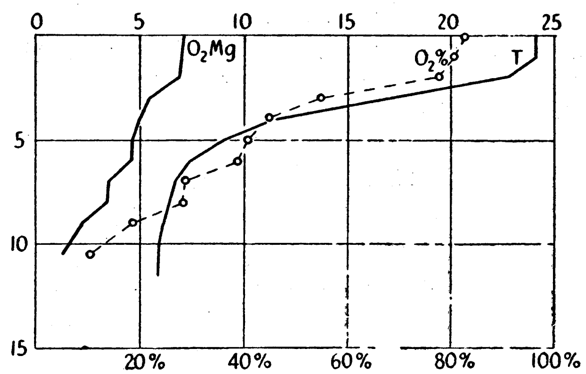

FIG. 9. The dissolved oxygen and the temperature of Midge Lake on July 31, 1929. The oxygen was well below the saturation point at all depths, especially in the lower strata.

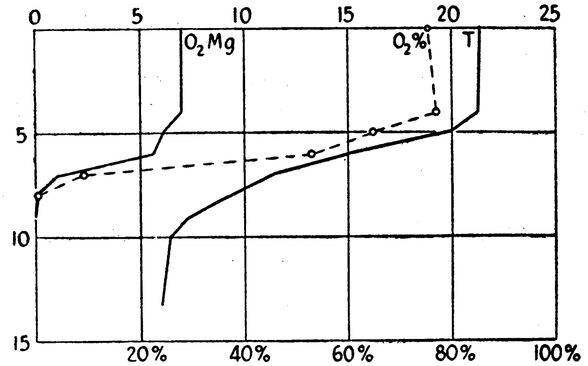

FIG. 10. The dissolved oxygen and the temperature of Long Lake (south of Crystal Lake) on August 23, 1928. No dissolved oxygen was found below 10 m.

excess of oxygen in the thermocline or mesolimnion, with a decrease in the amount below this stratum; in 12 of them there was no increase in the thermocline and there was a marked decrease in the amount of oxygen in the lower stratum or hypolimnion.

Island and Little Long lakes are the two members of this group which possessed a good supply of dissolved oxygen at all depths. In Island Lake (Fig. 11) the oxygen content of the surface water was 8.7 mg. per liter, or 91 per cent of saturation, on August 25, 1926; at 14 m. (1 m. above the bottom) it was 4.7 mg. per liter, or 42 per cent of saturation.

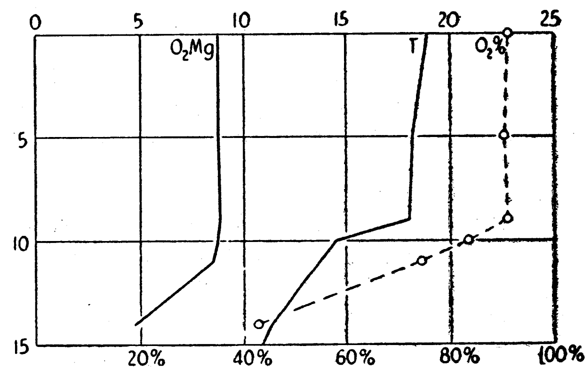

Fig. 11. The dissolved oxygen and the temperature of Island Lake (near Forest Lake) on August 25, 1926. Dissolved oxygen was abundant in the hypolimnion.

The surface sample of Little Long Lake (Fig. 12) contained 7.6 mg. of oxygen per liter on August 22, 1931, equivalent to 83 per cent of saturation; the 17 m. sample yielded 3.1 mg. of oxygen per liter, or 24 per cent of saturation. On July 24, 1930 the percentages of saturation at surface and bottom were 75 per cent and 31 per cent respectively. Attention may be called to the notch at 5 m. in the two oxygen curves in Figure 12; the quantity of oxygen fell from 7.1 mg. per liter at 3 m. to 5.0 mg. at 5 m. and then rose to 6.1 mg. and 6.3 mg. per liter at 7 m. and 8 m. respectively. A similar decrease was found at 5 m. in the series taken in this lake on July 24, 1930.

Pallette Lake (Fig. 13) represents the type in which there is an excess of oxygen in the thermocline. On August 22, 1928, the sample from a depth of 8 m. yielded 13.6 mg. of oxygen per

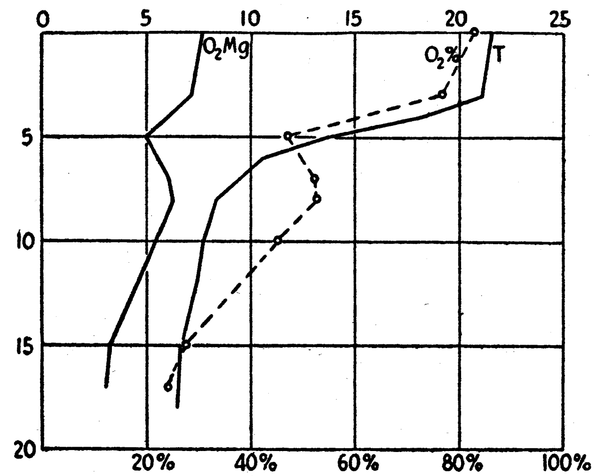

FIG. 12. The dissolved oxygen and the temperature of Little Long Lake on August 22, 1931. Note the irregular distribution of the oxygen below 3 m.

liter of water and that from 9 m. contained 12.6 mg. per liter; these amounts represented saturations of 139 per cent and 119 per cent, respectively. The curve for oxygen saturation in Figure 13 shows that all the samples between 7 m. and 10 m. contained more oxygen than was required for saturation. The phenolphthalein alkalinity amounted to 2.6 mg. per liter at 8 m. and 0.9 mg. at 9 m. A marked difference was noted in the hydrogen ion concentration at 8 m.; there was a change from pH 6.6 at 7 m. to pH 9.1 at 8 m. and back again to pH 6.9 at 9 m., while the surface water was pH 6.7 and that at 16 m. was pH 6.3. Excess oxygen was also found in the region of the thermocline of Pallette Lake on July 24, 1925 (123 per cent at 8 m.), on August 18, 1927 (112 per cent at 8 m.) and on July 21, 1931 (118 per cent at 7 m.); on the latter date the water was alkaline to phenolphthalein between 5 m. and 8 m., but this was accompanied by only a slight change in the hydrogen ion reading. In 1927 the water was alkaline to phenolphthalein at 8 m. and 9 m. and the hydrogen ion readings changed from pH 6.5 at 7 m. to pH 7.8 at 8 m., pH 8.2 at 9 m. and back to pH 6.7 at 10 m.; the surface was pH 6.4 and 12 m. and 15 m. pH 6.0.

Excess oxygen was also obtained in the thermocline of Anderson, Day, Pauto and Silver lakes, but the percentages in

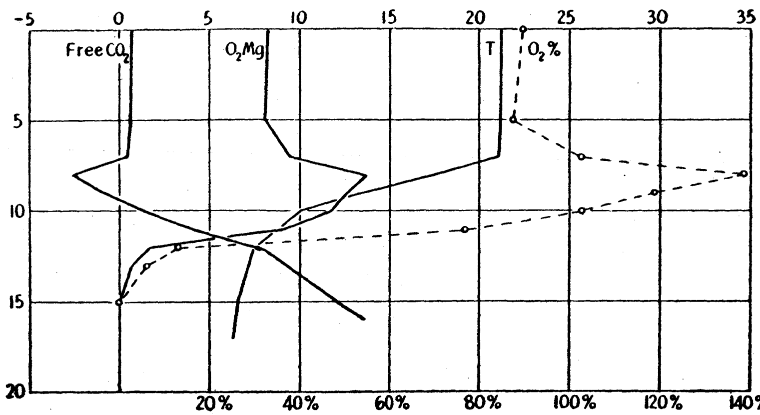

FIG. 13. The dissolved oxygen and the temperature of Pallette Lake on August 22, 1928. There was a considerable excess of oxygen at 8 m.

these four lakes were not as large as the maximum in Pallette Lake. In Anderson Lake the dissolved oxygen amounted to 12.8 mg. per liter at 7 m., 14.2 mg. at 8 m. and 13.4 mg. at 9 m. on August 8, 1929, representing respectively 123 per cent, 128 per cent and 116 per cent of saturation at these depths. There was a distinct phenolphthalein alkalinity at 7 m. and 8 m. and corresponding to this was a change in hydrogen ion readings from pH 7.5 at 6 m. to pH 8.4 at 7 m. and 8 m.

In two of the four series of observations made on Day Lake, an excess of oxygen was noted in the thermocline. On August 4, 1928 the sample from 8 m. yielded 10.0 mg. of oxygen per liter, or 102 per cent of saturation and that from 9 m. gave 10.8 mg., or 103 per cent. A series taken on July 23, 1929 yielded 10.8 mg. per liter at 7 m. and 11.4 mg. 8 m., representing 104 per cent and 106 per cent of saturation respectively. The series taken in 1926 and 1927 did not show excess oxygen at any depth.

The highest percentage of dissolved oxygen obtained in the thermocline of Pauto Lake was 111 per cent, which was found in a 6 m. sample on July 10, 1929; 108 per cent was noted at 7 m. on this same date. An excess of oxygen was found at 8 m., 9 m. and 10 m. on July 30, 1927, with 108 per cent at 9 m. as the maximum. In neither of these series was there any change in the phenolphthalein alkalinity or in the hydrogen ion concentration corresponding to the excess oxygen. A series of samples obtained from Pauto Lake on July 10, 1928 did not show an excess of oxygen at any depth.

There was a marked decrease in the quantity of dissolved oxygen in the lower water of these 5 lakes, but in 4 of them the amount did not fall below 0.5 mg. per liter at the bottom in any of the series. In Pallette Lake, on the other hand, only a trace was found at the bottom in the series represented in Figure 13.

The third type of lake in this group, namely those which have a bottom stratum with comparatively little or no dissolved oxygen in late August, are represented in Figures 14 to 16. Two Sisters Lake (Fig. 14) shows a much more marked decrease in oxygen in the lower stratum than Island and Little Long lakes; although the sample at 18.5 m. in Two Sisters Lake yielded a little more than 1 mg. of oxygen per liter on August 13, 1929, a series of samples taken on August 27, 1907 showed only a trace of this gas at 17 m. and none at 19 m. The free carbon dioxide showed a large increase in the hypolimnion, with a miximum of 15.6 mg. per liter at 18.5 m.

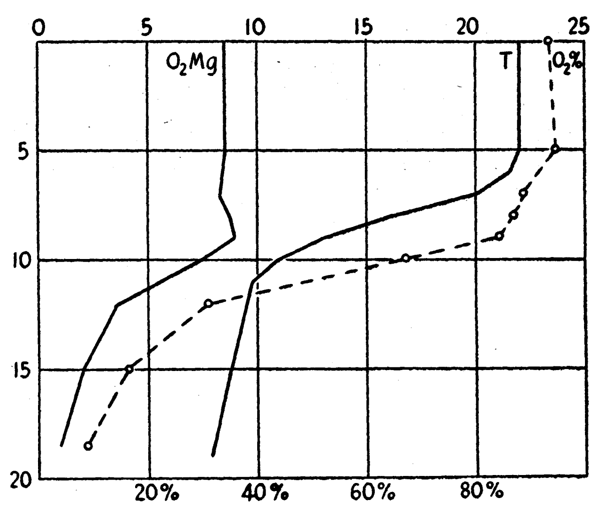

FIG. 14. The dissolved oxygen and the temperature of Two Sisters Lake on August 13, 1929. There was a marked decrease in the quantity of oxygen below 9 m.

The bottom water of Papoose Lake (Fig. 15) contained only a small amount of dissolved oxygen during the latter part of August, both in 1926 and in 1929. The curves show that there was a larger amount of oxygen between 9 m. and 15 m. in 1929 than in 1927. The saturation curve for 1926 is not shown in the diagram because it falls on the temperature curves in the epilimnion; the percentage of saturation throughout the epilimnion in this year was below that of 1929, ranging from 79

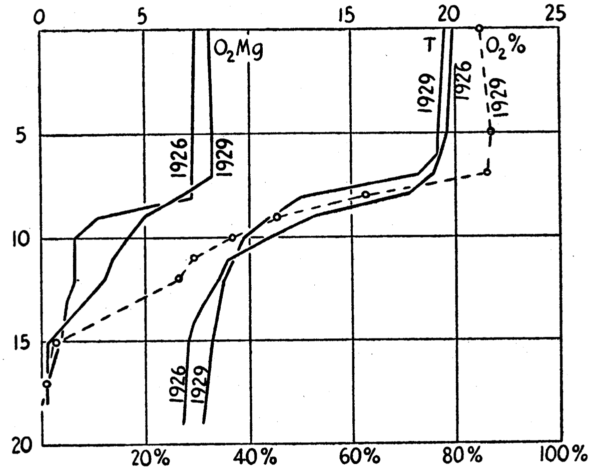

FIG. 15. The dissolved oxygen and the temperatures of Papoose Lake on August 27, 1927 and on August 15, 1929. Very little oxygen was found below 15 m. in both years.

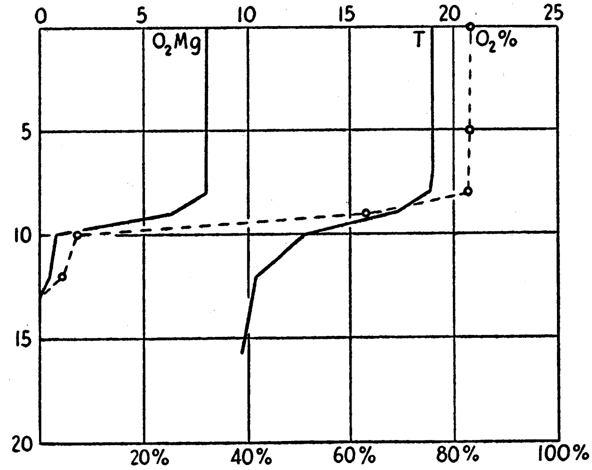

FIG. 16. The dissolved oxygen and the temperature of Nebish Lake on August 29, 1931. Only a small quantity of oxygen was found below 10 m.

per cent at the surface to 76 per cent at 8 m. Big Lake represents a somewhat more advanced stage in the disappearance of the oxygen in the lower stratum; usually only a trace or no oxygen at all was present at 15 m. in this lake in late August and none below this depth.

Nebish Lake (Fig. 16) also shows a total disappearance of the dissolved oxygen in the greater part of the hypolimnion in late August; very little oxygen was found below 10 m. on August 29, 1931. There was a very large increase in the free carbon dioxide below 8 m. on this date, the amount rising to 29 mg. per liter of water at 14.5 m.

Group IV. This group includes 25 lakes with a maximum depth of 20 m. or more (Table II). The oxygen results obtained on 10 of them are shown in Figures 17 to 27, inclusive; several series of oxygen determinations are included in Tables III, VI and VIII. The upper stratum or epilimnion of these lakes contained from 7 mg. to about 9 mg. of dissolved oxygen per liter, which represented from 70 per cent to 100 per cent of saturation; a few of the surface samples yielded an excess of oxygen.

Excess oxygen was found in the thermocline of six lakes belonging to this group. It was noted in 5 of the 11 series from Crystal Lake, in one out of 5 series from Big Carr, in one out of 4 series from Black Oak and in one out of 7 series from Clear Lake. Only one series has been taken on Catfish Lake and on Yawkey Lake, and excess oxygen was obtained at 8 m. in the former and at 10 m. in the latter. The excess was relatively small in all cases, however, ranging from 101 per cent to 111 per cent of the amount required for saturation. The maximum percentage, namely 111 per cent, was observed in Crystal Lake at 10 m. on August 12, 1931.

The various lakes in this group show marked differences in the quantity of dissolved oxygen that persists in the hypolimnion, or lower stratum of water during the summer; they form a fairly continuous series ranging from those which have an abundant supply of oxygen (4 mg. to 8 mg. per liter) in the lower water during late August to those in which the hypolimnion is practically devoid of free oxygen by the latter part of August. The results shown in the diagrams (Figs. 17 to 27) were selected for the purpose of illustrating the different stages in the disappearance of the dissolved oxygen in the hypolimnion during the course of the summer.

Crystal Lake (Fig. 17) has soft water, since it has only an average of about 1 mg. of fixed or bound carbon dioxide per liter, and it supports a relatively small crop of phytoplankton. The number of chlorophyll bearing organisms ranged from a minimum of 137 cells and colonies per cubic centimeter of water in early July to a maximum of 1035 cells and colonies per cubic centimeter in late August. The lake also supports a rather large crop of Daphnias and these cladocerans are an important factor in keeping the crop of phytoplankton down to the limits indicated above. The water is clear and the most transparent of any that has been found in the northeastern group of lakes. Disc readings of 12 m. or more have been obtained and more than 1 per cent of the sun's energy that is delivered to the surface of the lake penetrates to a depth of 18 m. So much sunlight reaches the lower water that the moss *Drepanocladus aduncus* var. *aquaticus* grows abundantly upon the bottom at depths of 17 m. to 20 m.

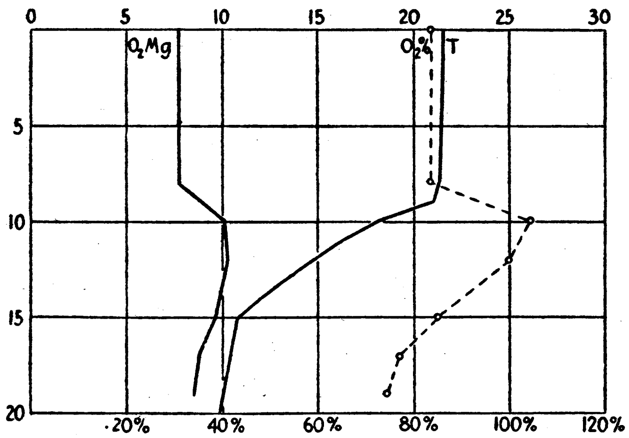

FIG. 17. **The dissolved oxygen and the temperature of Crystal Lake on August 21, 1928. The quantity of oxygen was above the saturation point at 10 m. Compare with Fig. 13 and Fig. 18.**

Figure 17 shows that the lower water of Crystal Lake contained an abundant supply of dissolved oxygen on August 21, 1928. The water at 19 m. (1 m. above the bottom) yielded 8.5 mg. of oxygen per liter, which was equivalent to almost 75 per cent of saturation; the quantity at 10 m. was 104 per cent of saturation and that at 12 m. was 100 per cent. With such a small supply of phytoplankton as this lake supports, a proportionately small amount of organic material derived from this source sinks into the lower stratum and decays there, and this material is probably the most important factor in the depletion of the dissolved oxygen in the hypolimnion. The shores are sandy and there is neither an inlet nor an outlet, so that very little organic matter reaches the lake from outside sources. It seems probable also that an important factor in maintaining the supply of oxygen in the lower stratum is the photosynthesis carried on in this region both by the phytoplankton and by the moss Drepanocladus which thrives on the bottom in the deeper water. Thus the relatively small quantity of organic matter that reaches the hypolimnion from the epilimnion makes a correspondingly small demand for oxygen in its decomposition, and this small demand, together with the oxygen that may be liberated in the process of photosynthesis carried on in this region, leaves an abundant supply of oxygen in the bottom stratum throughout the summer. The free carbon dioxide furnishes a good index of the comparatively small amount of decomposition in the lower water; it shows only a small increase in the bottom water.

Similar results were obtained on Crystal Lake on August 20, 1929 and on August 12, 1931. In the former year the percentage of saturation varied from 91 to 93 per cent in the epilimnion, from 98 to 104 per cent in the thermocline and from 71 to 83 per cent in the hypolimnion; in the 1931 series the quantity of oxygen ranged from 91 to 92 per cent in the epilimnion, from 100 to 111 per cent in the thermocline and from 73 to 83 per cent in the hypolimnion.

Big Carr Lake (Fig. 18) has soft water (1.5 mg. of fixed or bound carbon dioxide per liter) and a fair degree of transparency, so that approximately 2 per cent of the sun's energy penetrates to a depth of 10 m. The phytoplankton is somewhat more abundant than in Crystal Lake; the number of organisms ranges from 283 to 1135 cells and colonies per cubic centimeter of water in the upper 10 m., with an average of about 730. A slight excess of dissolved oxygen was obtained at a depth of 7 m. on July 18, 1927 and the bottom sample yielded 3.6 mg. per liter, representing a little more than 30 per cent of saturation. In the 5 series of samples taken on Big Carr Lake, the minimum noted at the bottom was 2.4 mg. per liter, or 21 per cent of saturation, on July 22, 1925. A maximum of 8.5 mg. of free carbon dioxide per liter was found at 21 m. on this date.

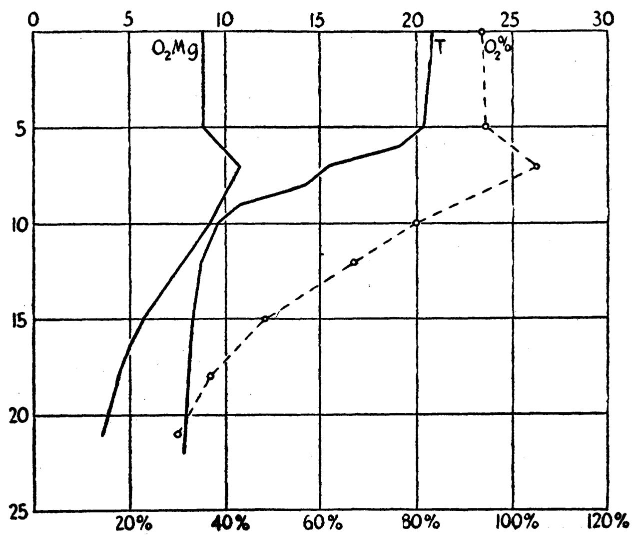

FIG. 18. The dissolved oxygen and the temperature of Big Carr Lake on July 18, 1927. The quantity of oxygen was a little above the saturation point at 7 m. Compare with Fig. 17.

The results of the two series of oxygen samples obtained from Dead Pike Lake are shown in Fig. 19. The water of this lake has an average of about 11.5 mg. of fixed carbon dioxide per liter and it contains a moderate amount of vegetable stain, so that the color readings range from 60 to 68 on the platinum-cobalt scale. The epilimnion contained from 73 per cent to 75 per cent of the quantity of oxygen required for saturation in the series taken on August 9, 1927, the thermocline from 44 per cent to 64 per cent and the hypolimnion from 30 per cent to 41 per cent; the curves for the percentages have been omitted from the diagram because they fell too close to the temperature curves in the region of the epilimnion. The quantity of free carbon dioxide at the bottom amounted to 8.5 mg. per liter in 1927 and 7.0 mg. in 1928.

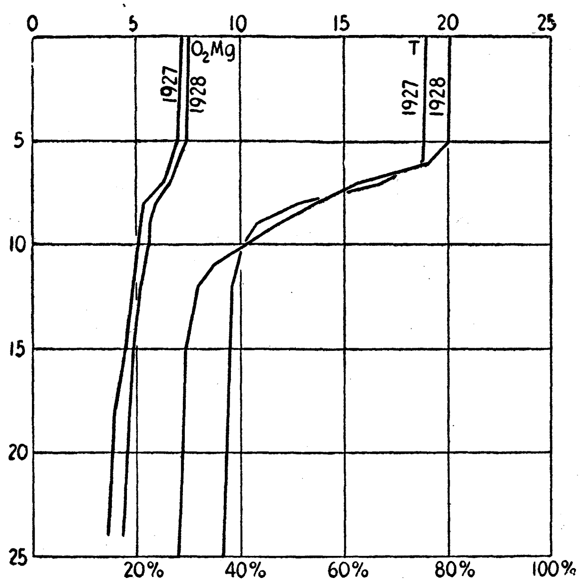

FIG. 19. The dissolved oxygen and the temperature of Dead Pike Lake on August 9, 1927, and on July 28, 1928. Note that the amount of oxygen was substantially the same in the two years. Compare with Fig. 12.

Fence Lake (Fig. 20) is third in size among the lakes belonging to this group. Its water contains 16 mg. to 17 mg. of fixed carbon dioxide per liter and the hydrogen ion ranged from pH 7.7 at the surface to pH 6.8 at 27.5 m. The upper 5 m. of the epilimnion contained a slight excess of dissolved oxygen (101 to 102 per cent of saturation) and this was correlated with a rather large crop of phytoplankton; the surface water yielded 2845 cells and colonies of chlorophyll bearing organisms per cubic centimeter and that at 5 m. 2337 per cubic centimeter, with 2658 per cubic centimeter at 10 m. The lower part of the epilimnion yielded 97 per cent to 98 per cent of the amount of oxygen required for saturation, but there was a marked decrease in the thermocline; the hypolimnion yielded from 32 per cent to 47 per cent of saturation. The free carbon dioxide showed an increase in the thermocline and rose to a maximum of 7.8 mg. per liter at 27.5 m.

One series of oxygen samples was obtained from Crawling Stone Lake and the results are shown in Figure 21. This lake ranks fifth in size among those included in the group. The

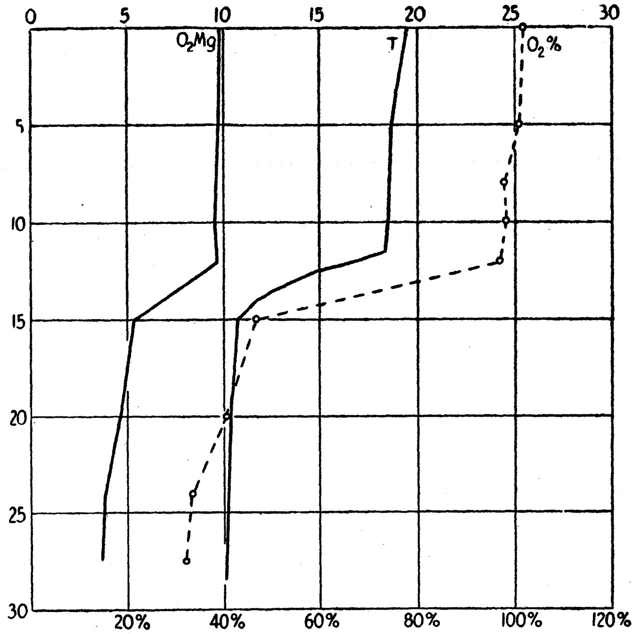

FIG. 20. The dissolved oxygen and the temperature of Fence Lake on August 23, 1929. The quantity of oxygen was slightly above the saturation point in the upper 5 m.

water contains about 11 mg. of fixed carbon dioxide per liter and the hydrogen ion readings in this series varied from pH 7.4 at the surface to pH 7.0 at 23 m. On August 10, 1927 the quantity of oxygen amounted to about 75 per cent of saturation in the epilimnion, declined to about 35 per cent in the thermocline and gave an average of about 32 per cent in most of the hypolimnion, with a decrease to 12 per cent of saturation at 23 m. The free carbon dioxide in this series rose to a maximum of 9 mg. per liter of water at 23 m.

Thirty-two series of oxygen determinations covering the entire depth of Trout Lake were made between June 1925 and the close of the field work in 1931. The number of series per annum varied from 2 in the summer of 1930 to 9 in 1925. The 32 series consisted of 259 samples, or an average of 8 samples for each series. Each year the first series was taken in late June or early July and the last series was taken as late in August as practicable; one series was obtained as late as Sep-

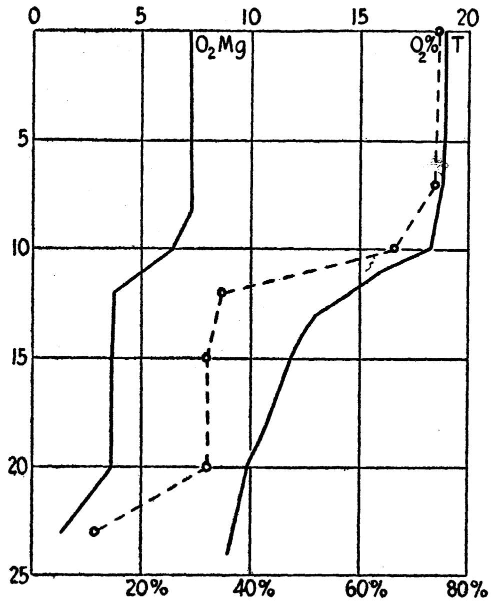

FIG. 21. The dissolved oxygen and the temperature of Crawling Stone Lake on August 10, 1927. Note that the hypolimnion contained a smaller quantity of oxygen than that of Fence Lake, Fig. 20.

tember 21 in 1925. The various series were distributed in such a way each year that they would give a general idea of the changes that took place in the quantity of oxygen at different depths during the summer period of stagnation.

With an area of 1683 ha., Trout Lake is the second lake in size in the Highland Lake District of northeastern Wisconsin. It is exceeded in size by Lac Vieux Desert which has an area of 1934 ha., but which has a maximum depth of only 6 m. The water of Trout Lake contains an average of 19 mg. of fixed carbon dioxide per liter and the hydrogen ion readings during the summer fall between pH 7.3 and pH 8.2 at the surface and between pH 6.5 and pH 7.3 at the bottom. There is only a small amount of vegetable stain in the water, the color readings varying from 6 to 14 on the platinum-cobalt scale. About 1 per cent of the sun's energy that is delivered to the surface of the lake reaches a depth of 8 m.

Figures 22 and 23 show the changes which took place in the dissolved oxygen of Trout Lake during the summer stagnation period in 1928 and in 1931. On June 24, 1928 the dissolved

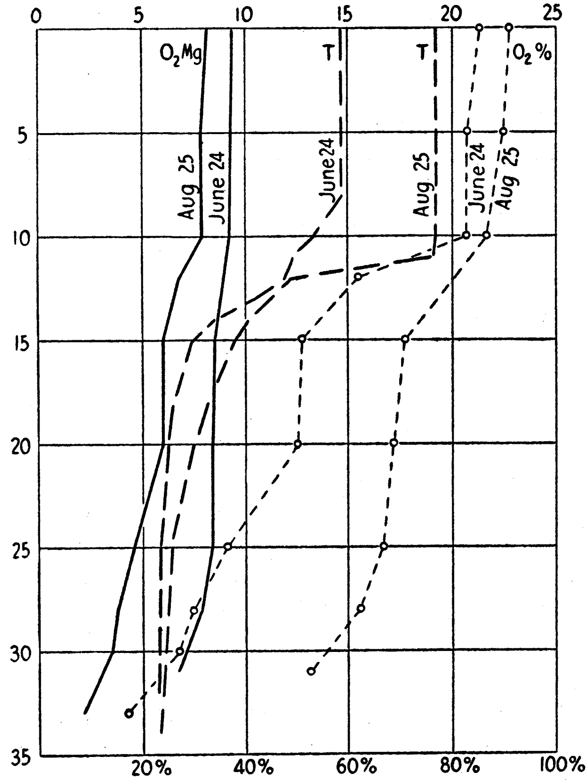

FIG. 22. **The dissolved oxygen and the temperature of Trout Lake on June 24, 1928 and on August 25, 1928. Note the marked decrease in quantity of oxygen, especially in the lower water, during these two months. Compare with Fig. 23.**

oxygen in the upper 10 m. varied from 86 per cent to 91 per cent of the amount required for saturation; between 10 m. and 15 m. the quantity was between 86 per cent and 71 per cent of saturation, and between 15 m. and 30 m. it varied from 71 per cent to 60 per cent, with a minimum of 53 per cent at 31 m. On August 25, 1928 the quantity of oxygen in the upper 10 m. was between 85 per cent and 83 per cent of saturation; between 10 m. and 15 m. it amounted to 83 per cent to 53 per cent and between 15 m. and 30 m. it declined from 52 per cent at the former depth to 28 per cent at the latter, with a minimum of 17 per cent at 32 m. Thus there was only about half as much oxygen below 25 m. on August 25 as on June 24, but 2.1 mg.

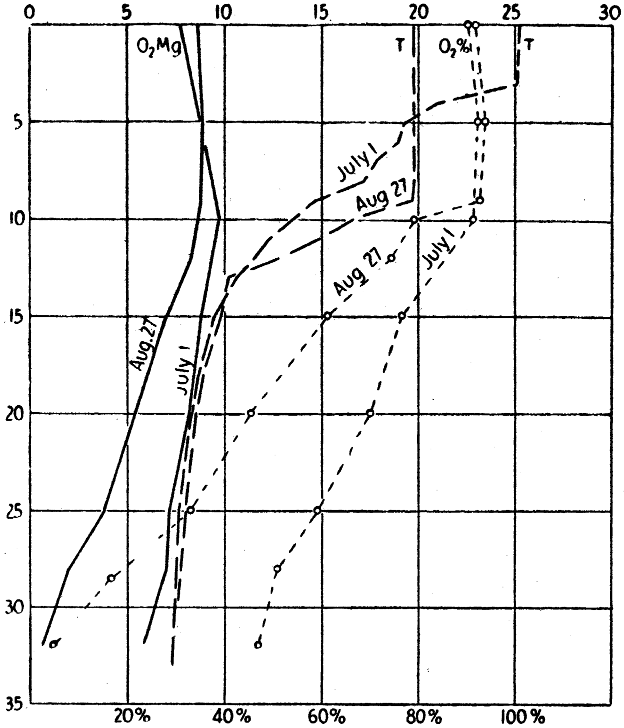

Fig. 23. The dissolved oxygen and the temperature of Trout Lake on July 1, 1931 and on August 27, 1931. Note the decrease of dissolved oxygen below 5 m. during this period. Compare with Fig. 22.

per liter was still present at 32 m. on August 25. This is the largest amount that has been found in the bottom water in late summer.

Figure 23 shows that the changes which took place during the summer of 1931 differed somewhat from those noted in 1928. In 1931, for example, the percentage of saturation on August 27 was somewhat higher at the surface than on July 1 and there was a more marked decrease in the quantity of dissolved oxygen below 25 m. in 1931 than in 1928. The decline in percentage between 10 m. and 25 m., however, was substantially the same in the two years. Only 0.6 mg. per liter of water remained at 31 m. on August 27, 1931. The smallest amount of oxygen that has been found in the bottom water of Trout Lake in late summer, was obtained on August 22, 1930, namely 0.3 mg. per liter at a depth of 32 m.; this represents a sevenfold difference between the maximum and minimum amounts found at the bottom in these summer observations covering a period of seven years.

Oxygen in excess of the amount required for saturation was noted in 8 of the 259 samples; 3 of these samples were taken at the surface, 2 from 5 m., 1 from 8 m. and 2 from 10 m. The surface, 5 m. and 8 m. samples showed an excess of oxygen in the series taken on August 27, 1929. The maximum percentage was observed at a depth of 5 m. on July 23, 1925, namely 115 per cent of saturation and the second highest, 110 per cent, was found at 10 m. on the same date.

Black Oak Lake (Fig. 24) shows a more advanced stage in the depletion of the dissolved oxygen in the bottom stratum in late summer. The average quantity of fixed carbon dioxide in the upper water in summer is between 9 mg. and 10 mg. per liter and the hydrogen ion readings in this stratum vary from pH 7.0 to pH 7.8. The color of the surface water ranges from 0 to 14 and the sun's energy is reduced to 1 per cent of the amount delivered to the surface of the lake at a depth of about 10 m.

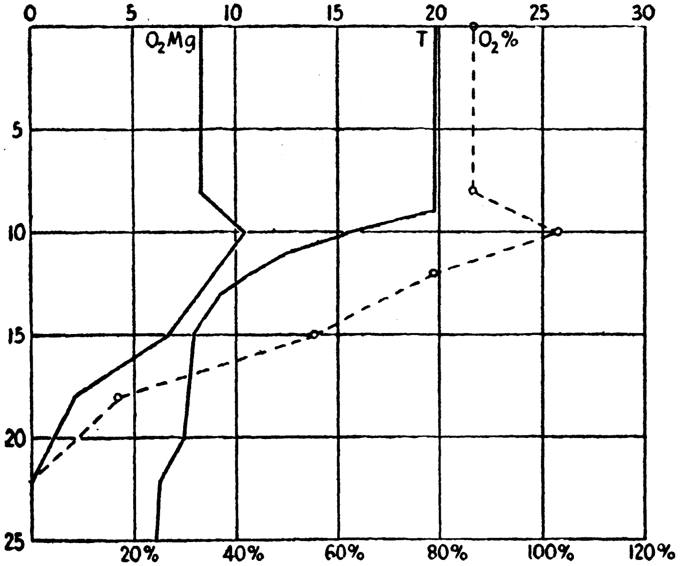

Fig. 24. The dissolved oxygen and the temperature of Black Oak Lake on August 24, 1928. There was a small excess of oxygen at 10 m. and none below 22 m. Compare with Fig. 25.

The epilimnion of Black Oak Lake yielded about 87 per cent of the quantity of oxygen required for the saturation of the water, but there was a slight excess in the thermocline (103 per cent at 10 m.); below 10 m. there was a rapid decrease in the amount of oxygen, the quantity falling to about 1 mg. per liter at a depth of 20 m. in the different series. By late August the quantity of oxygen at 22 m. and below that depth ranged from just a trace or none at all up to 0.2 mg. per liter. A maximum of 11 mg. of free carbon dioxide per liter was found at 25 m. on August 24, 1928.

Presque Isle Lake is one of the larger members of this group. It has fairly hard water for this region, the fixed or bound carbon dioxide amounting to 23 mg. to 25 mg. per liter in the upper water. The color of the surface water ranged from 8 to 15 and the hydrogen ion from pH 7.7 to pH 8.5.

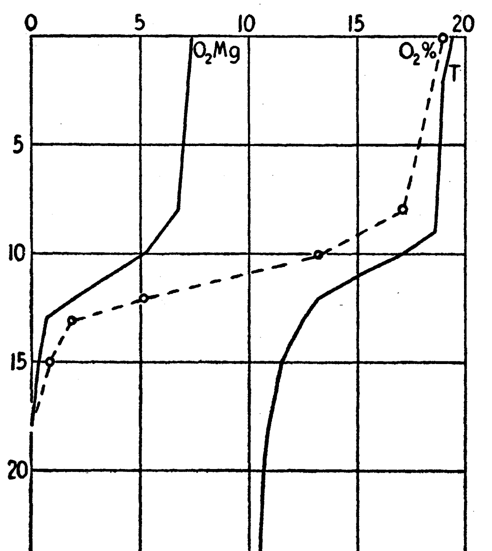

FIG. 25. The dissolved oxygen and the temperature of Presque Isle Lake on August 11, 1927. Very little oxygen was found below 13 m. Compare with Fig. 24.

The oxygen in the epilimnion on August 11, 1927 amounted to only 68 per cent to 78 per cent of saturation (Fig. 25); there was a rapid decrease in the quantity in the thermocline and in the upper part of the hypolimnion, so that only 7 per cent of saturation was left at a depth of 13 m. None was found at 20 m. or below this depth. The entire hypolimnion, therefore, contained only a small supply of dissolved oxygen. Free carbon dioxide was abundant in the hypolimnion also, the amount reaching a maximum of 11 mg. per liter at the bottom in one series of samples.

Adelaide Lake is one of the small members of this group. Its water is relatively soft, the upper water containing from 3 mg. to 4 mg. of fixed carbon dioxide per liter. The hydrogen ion concentration varied from pH 6.3 to pH 8.8 at the surface. The color of the surface water ranged from 24 to 38 and the sun's energy is reduced to about 1 per cent at a depth of 4 m.

The upper 3 m. of Adelaide Lake (Fig. 26) contained from 78 per cent to 80 per cent of the amount of oxygen required

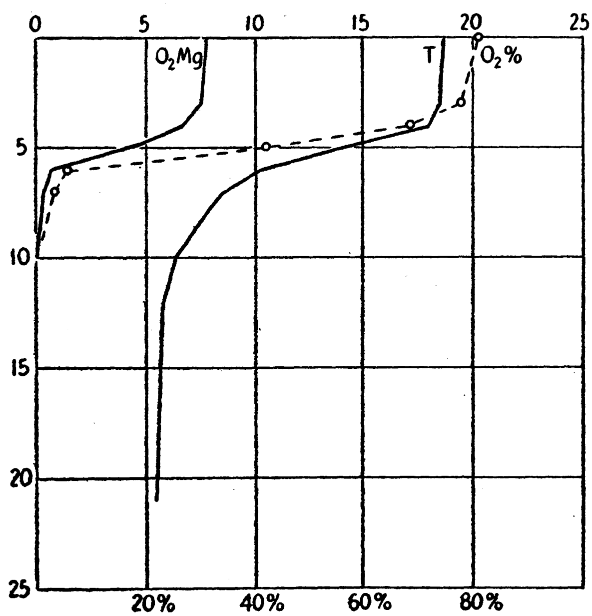

FIG. 26. The dissolved oxygen and the temperature of Adelaide Lake on August 21, 1926. Very little oxygen was found below 6 m. Compare with Fig. 25.

for saturation on August 21, 1926, but there was a very rapid decrease in the amount between 3 m. and 6 m., with only a trace left at 10 m. and none below this depth. More than half of the maximum depth of the lake, therefore, was devoid of free oxygen on this date. An abundant supply of free carbon dioxide was found in the hypolimnion, with a maximum amount of 19.5 mg. per liter of water at 20 m.

Lake Mary (Fig. 27) shows the most extreme case of oxygen depletion among the lakes of Group IV. This lakelet has an area of slightly more than one hectare, but the maximum depth is 22 m. It is well protected from wind, so that only a very thin upper stratum is kept in circulation during the summer. The upper water contains less than 4 mg. of fixed carbon dioxide per liter; the hydrogen ion ranges from pH 6.0 to pH 6.2 at the surface and from pH 5.7 to pH 5.9 at the bottom. The color of the surface water ranged from 100 to 123 on the platinum-cobalt scale and the sun's energy is reduced to 0.5 per cent at a depth of only 2 m.

The upper meter was the only stratum that was well aerated on August 29, 1929 (Fig. 27). The quantity of oxygen at the

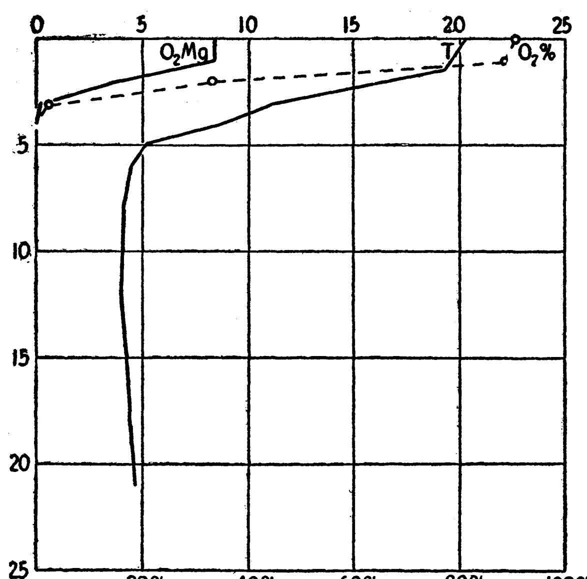

FIG. 27. The dissolved oxygen and the temperature of Lake Mary on August 29, 1929. Very little oxygen was found below 3 m. Strongly eutrophic in character.

surface was equivalent to a little more than 90 per cent of the amount required for saturation and that at 1 m. was 87 per cent of saturation; the sample at 2 m. contained 33 per cent of the amount necessary for saturation and that at 3 m. less than 2 per cent. In all of the series taken on Lake Mary, very little or no dissolved oxygen was obtained below a depth of 3 m. Observations made on May 7, 1929 indicate that the vernal overturning and circulation of the water are not complete, so that the oxygen deficiency in the summer is due in part to the winter stagnation and in part to the summer stagnation as a result of the incomplete mixture of the water in the spring.

The phenolphthalein titrations of samples from the lower water represent a large amount of free carbon dioxide in that stratum; the titrations of the bottom samples of the various series, for example, represented from 32 mg. to 52 mg. of free carbon dioxide per liter. Whether all of this acidity is due to free carbon dioxide, or whether part of it is due to free carbon dioxide and part to organic acids has not been determined up to the present time.

Attention may be called to the unusual character of the temperature curve in Lake Mary (Fig. 27). The coldest stratum of water was found at an intermediate depth and not at the bottom in summer. Temperature readings of 4.0° C. were obtained at 10 m. and 12 m. on August 29, 1929. Similar results were obtained in 4 other sets of temperature readings taken in Lake Mary during the months of July and August between 1926 and 1928, inclusive. In each of these 5 series the coldest water was found between 8 m. and 12 m. The readings at the bottom (22 m.) were from half a degree to three-quarters of a degree higher than the minimum found in the 8 m.-12 m. stratum.

General Discussion

Sources and Distribution of Oxygen

Lakes receive their supplies of dissolved oxygen from two primary sources, namely, (1) from the atmosphere and (2) from the photosynthetic activities of the aquatic plants which populate their waters. The former may be regarded as the more important source, particularly with reference to supplying an entire lake with dissolved oxygen when its water is in complete circulation. Considerable amounts of oxygen may be obtained from photosynthesis, as illustrated in the diagram for Pallette Lake (Fig. 13), but the quantity obtained from this source depends upon the abundance of the aquatic plants and upon the extent of their activities. They are usually most abundant from spring to early autumn, so that they make their largest contributions of oxygen during this part of the year. A certain amount of oxygen is liberated by bacteria in the process of denitrification, which is carried on under certain conditions, but the quantity derived from this source is too small to play any important rôle in the household economy of a lake.

In lakes of the temperate class, such as those of northeastern Wisconsin, the dissolved oxygen is distributed throughout the lake chiefly by means of the general movements of the water. These bodies of water are subject to four seasonal changes each year, namely, spring and autumn periods of overturning and circulation which are separated by summer and winter periods of stratification and stagnation. In the process of overturning and circulation the whole body of water is freely exposed to the air at the surface of the lake, so that a general aeration of the water takes place at these times; the quantity of dissolved oxygen becomes substantially uniform from surface to bottom. During the summer and winter periods of stratification, however, there is no complete circulation of the water and the oxygen supply of the lower water is limited to the amount that it possesses at the time that stratification takes place. Any decrease in the quantity of dissolved oxygen in the lower stratum when the water is thermally stratified remains as a deficiency until the subsequent period of overturning and circulation. A certain amount of oxygen may be transferred by diffusion, but this process goes on so slowly in water that it may be disregarded as a factor in the transference of oxygen from one stratum to another.

Classification of Lakes

The biological processes that take place within a lake make a constant demand upon the supply of dissolved oxygen therein. Most of the aquatic organisms require free oxygen for their respiration and the decomposition of organic matter at all depths consumes an additional amount. The extent of the consumption of the dissolved oxygen in the lower stratum or hypolimnion of a lake during the summer period of stratification depends upon various physical, chemical and biological factors. The preceding diagrams (Figs. 3 to 27) show that only a relatively small amount of the oxygen supply of the lower stratum is consumed in some lakes, while in others there is very little dissolved oxygen left in this stratum by the latter part of August.

Thienemann (1921) has divided lakes into three general types on the basis of the chemical and biological conditions that obtain in the hypolimnion in late summer, and the quantity of dissolved oxygen in this stratum is an important factor in his system of classification. Naumann (1921) proposed a more elaborate system of classification in which the three main types were divided into a number of subclasses, but these northeastern Wisconsin lakes show such a great diversity of characteristics that it is not worth while to attempt a classification of them beyond the three general types; in fact, it is doubtful whether a separation into more than two general types has any particular value.

These three general types are designated as oligotrophic, eutrophic and dystrophic lakes. Oligotrophic lakes possess a good supply of dissolved oxygen at all depths during the two periods of stagnation, even including the hypolimnion in late summer. They receive relatively small amounts of organic matter from their drainage basins and their waters do not produce an unusual amount of such material, so that the demand for dissolved oxygen in the process of decomposition is not great enough to consume all of the free oxygen even at the bottom. Their waters are transparent owing to the scarcity of plankton and other suspended material. Crystal Lake (Fig. 17) is an outstanding example of this type of lake; Big Carr (Fig. 18) and Fence (Fig. 20) also belong in this group. Trout Lake (Fig. 23) may be regarded as a member of this group, but it lies near the lower limit of this type of lake on account of the small quantity of oxygen found below a depth of 30 m. in late August of some years.

Eutrophic lakes are characterized by a marked paucity of dissolved oxygen in the lower water in late summer. In lakes of this type the physical and chemical conditions are favorable for the production of a large amount of organic matter and the decomposition of this material uses up the free oxygen in some or frequently in practically all of the hypolimnion in summer. Owing to the abundance of plankton and other suspended material, the water has a low degree of transparency. Examples of this type are found in Long (Fig. 10), Nebish (Fig. 16), Black Oak (Fig. 24) and Presque Isle (Fig. 25) lakes.

Dystrophic lakes are characterized by their brown colored waters. The color is due to the presence of vegetable extractives (humic substances) which are derived from peat bogs or from marshes that are tributary to such lakes. These stains give their waters a low degree of transparency. The European lakes on which the definition of this type is based, are said to be poor in phytoplankton as well as in electrolytes, especially in phosphorus and calcium, and in available nitrogen compounds. Both Thienemann and Naumann state that the waters of the European dystrophic lakes range from yellow to brown in color, but they do not give any definite standard of color for the minimum limit of the group. Neither are any definite limits given by Lönnerblad (1931) who has made a special study of the dystrophic lakes in the vicinity of Aneboda, Sweden.

During this investigation color readings have been made on the waters of 530 lakes situated in northeastern Wisconsin and the colors ranged from zero up to 340 on the platinum-cobalt standard. The waters of two lakes gave readings of 314 and 340, respectively, 11 fell between 200 and 300 and 61 between 100 and 200, making a total of 74 lakes with color readings of 100 or more; an additional 18 lakes gave readings between 90 and 99. It will probably be best, however, to limit the present consideration to those lakes with color readings of 100 or more on the platinum-cobalt scale, although those with readings as low as 60, or even 50, show the brown color distinctly in the lake itself. Lake waters having colors of 100 to 120 resemble weak tea in appearance, so that there is no question whatever about an abundant supply of humic substances in them; in fact 100 is probably too high rather than too low for the minimum limit of these brown colored waters.

With respect to the electrolytes found in these 74 Wisconsin lakes having colors of 100 or more, the conductivity or specific conductance varied from a minimum of 11 up to a maximum of 81 when expressed in terms of reciprocal megohms; this represents more than a sevenfold difference. A conductivity of 11 reciprocal megohms indicates a very soft water, with few electrolytes in solution, while one of 81 reciprocal megohms indicates that the water has a fair degree of hardness, especially in the region in which these lakes are situated. In the former lake, for example, the calcium amounted to 0.6 mg. per liter and in the latter to 11.2 mg. A maximum of 12.2 mg. of calcium per liter was found in one of these brown water lakes with a color of 118.

The phosphorus content of these brown waters was substantially as large as in the lakes with color readings below 20. The quantity of soluble phosphorus ranged from a trace up to 0.012 mg. per liter of water, with an average of 0.003 mg. per liter for 62 of the 74 lakes; no soluble phosphorus determinations were made on the other 12 lakes. The quantity of nitrate nitrogen, also, was as large in these brown water lakes as in those having little or no color; it varied from a minimum of 0.01 mg. to a maximum of 0.045 mg. per liter. Likewise the hydrogen ion concentration showed about the same range in the brown water lakes as in those with little or no stain, varying from pH 4.9 to pH 9.1. The waters of 24 of these lakes were near the neutral point, the readings falling between pH 6.8 and pH 7.2, inclusive.

The vegetable extractives which produce the brown color in these Wisconsin lakes are chiefly carbon compounds, so that these humic substances increase the organic carbon content of the water in a marked degree. The quantity of organic carbon in these brown waters varied from a minimum of 9.2 mg. to a maximum of 25.8 mg. per liter; the organic nitrogen content ranged from 0.38 mg. to 1.75 mg. per liter, so that the carbon-nitrogen ratio varied from 10 to 36. The lake waters in which the brown color fell between 0 and 20 on the platinum-cobalt scale yielded from 1.3 mg. to about 8.0 mg. of organic carbon per liter and had carbon-nitrogen ratios of 8 to 15. There is thus some overlapping of the carbon-nitrogen ratio at the lower limit of the high colored waters and at the upper limit of those with little or no brown color and this is accounted for by the fact that some of the high colored lakes contained large crops of phytoplankton in addition to the humic substances. This plankton material was rich in organic nitrogen, so that the carbon-nitrogen ratio in them was brought down below the upper limit of that in lakes having little or no stain in their waters.

The European lakes with high colored waters are said to be plankton poor, but this is not true of a considerable number of the high colored lakes of northeastern Wisconsin. In the latter the centrifuge phytoplankton in the upper water ranged from 2300 to 5900 cells and colonies per cubic centimeter in 6 lakes with color readings of 200 or more, and from 2100 to 11,800 cells and colonies per cubic centimeter in 18 of the 62 lakes having color readings between 100 and 200. Lakes that support phytoplankton crops of this size can hardly be regarded as plankton poor. In the other 59 members of this group of lakes having brown waters, the number of centrifuge phytoplankton organisms ranged from 300 to 2000 cells and colonies per cubic centimeter. The number fell below 1000 per cubic centimeter in 17 of the 74 lakes; these may be regarded as rather poor in plankton. Little Long Lake (Fig. 12) yielded the minimum number of 300 cells and colonies per cubic centimeter in the upper 5 m.

The phytoplankton crop of very few of the lakes having little or no stain in their waters exceeded that of the more productive ones in the high colored group. In Trout Lake, with a color not exceeding 14 on the platinum-cobalt scale, the centrifuge phytoplankton in 23 catches from the upper 5 m. gave an average of 1200 cells and colonies per cubic centimeter of water. In Black Oak Lake, the average was 1260 per cubic centimeter in 3 series, in Muskellunge Lake 1900 in 8 series and in Little St. Germain Lake 2480 in 4 surface samples taken in different years. Mann Lake, with a color ranging between 20 and 34, yielded the largest number of phytoplankton organisms, namely 40,500 cells and colonies per cubic centimeter of water on August 14, 1928; a second maximum of 12,300 per cubic centimeter was obtained from this lake on August 26, 1927.

Lőnnerblad (1931) states that some of the dystrophic lakes which he studied, were oligotrophic and some eutrophic in character in so far as the dissolved oxygen was concerned. The same is true of the brown water lakes of northeastern Wisconsin. Little Long Lake (Fig. 12) contained a good supply of dissolved oxygen throughout the hypolimnion on August 22, 1931, so that it possessed one of the important characteristics of an oligotrophic lake. Dead Pike Lake (Fig. 19) has not been included in the brown water group, but its water has a distinct brown color, with readings of 60 to 70, and its lower water was well supplied with free oxygen in late summer.

Lake Mary (Fig. 27), on the other hand, is an extreme case of the eutrophic type. Three small lakes in the same vicinity, namely Helen, Rose and Yolanda, which have highly colored waters with readings ranging from 95 to 160, are also markedly eutrophic in character. These 4 lakelets may perhaps be regarded as typical dystrophic lakes, yet they support fairly large crops of phytoplankton. The upper water of Lake Mary yielded from 1000 to more than 6000 phytoplankton cells and colonies per cubic centimeter, while the other 3 were not so productive, yielding from 800 to 4300 phytoplankton organisms. The organic carbon content of these 4 lakelets ranged from a minimum of 12 mg. in Helen to a maximum of 17 mg. per liter in Mary. These results may be compared with those of Trout Lake where the color does not exceed 14 and where the organic carbon averages about 4 mg. per liter of water.

In view of the marked chemical and biological differences between the brown colored lakes of northeastern Wisconsin and those of Europe, the separation of this group from the other two types is of very doubtful value in the case of the Wisconsin lakes.

Oxygen Deficit

Thienemann (1928) computed the total oxygen content of a number of lakes from series of oxygen determinations and discussed the relation between the quantity in the hypolimnion and that in the epilimnion. He also considered the relation of the total quantity of oxygen found in a lake to the amount required to saturate the water at all depths; the difference between these two amounts is a measure of the deficiency or excess of oxygen in the different strata of a lake. The vertical distribution of the oxygen and the deficits and excesses at the various depths are given in Table III for some of the lakes of northeastern Wisconsin. These data enable one to compute the total quantity of oxygen present when the volume of the lake is known. The results of such computations are given in Table IV. The quantity of oxygen required to saturate the water at the different temperatures is taken from the table published by Birge and Juday in 1914; the values given in this report were based upon those given by Fox (1907) and they are somewhat higher than those published by Birge and Juday in 1911. The total amount of oxygen in a given stratum of water has been determined by multiplying the mean quantity of oxygen per cubic meter in that stratum by the volume of the stratum; the amount required for the saturation of the stratum has also been determined in the same manner.

It will be noted in this table that the quantity of oxygen actually found at the different depths in the various series was below the theoretical point of saturation except in a few cases where the oxygen liberated in the process of photosynthesis in the region of the thermocline brought the amount up to the saturation point or higher. As already pointed out the deficiency is due chiefly to the demand for oxygen in the respiratory processes of aquatic organisms and in the decomposition of organic matter. It is due in part also to the elevation of these lakes above sea level. The theoretical amount required for saturation is based upon an atmospheric pressure of 760 mm. at sea level, but the lakes of northeastern Wisconsin are about 500 m. above sea level, so that they receive a correspondingly smaller atmospheric pressure. Thus the oxygen tension in the air and that in the lake water come to an equilibrium below the amount required for saturation at sea level; the saturation point for an altitude of 500 m. is a little more than 94 per cent of that at sea level.

Table IV shows the quantity of oxygen in the several strata of these lakes as well as the total amount in each of the lakes. It also shows the quantity of oxygen required for the saturation of the strata and of the entire lake. In only two of the lakes was there an actual excess of oxygen in any of the strata; the 6 m.-10 m. stratum of Pallette Lake had 16 per cent more than the quantity required for saturation and the 8 m.-10 m. stratum in Weber Lake yielded a small excess of oxygen.

The data given in Table IV are summarized in Table V, with the addition of the absolute deficit of oxygen for comparison with the actual deficit and also a column showing the relation between the quantity of oxygen in the hypolimnion and that in the epilimnion. In 1929 Alsterberg suggested that the summer oxygen deficit may be considered from two standpoints, namely (1) that of the actual deficit and (2) that of the absolute deficit. The actual deficit is the difference between the quantity of oxygen present at a certain depth and the amount required to saturate the water at the temperature observed at that depth; the absolute deficit represents the difference between the quantity of oxygen found at any depth and the amount required to saturate the water at a temperature of 4° C., which is 9.26 cc. or 13.23 mg. per liter minus a correction for the elevation of the lake above sea level. The lakes of northeastern Wisconsin have an elevation of about 500 m., so that the quantity of oxygen required to saturate the water at 4° at this altitude is approximately 12.5 mg. per liter without any correction for temperature and humidity. Since the temperature of the water in the lakes of northeastern Wisconsin is above 4° in summer, the oxygen deficit on the absolute basis is always larger than that on the actual basis.

The actual percentage of saturation, when the entire lake is considered, ranges from a minimum of 16 per cent in Lake Mary to a maximum of almost 95 per cent in Weber Lake. Adelaide Lake ranks second in the minimal percentage of actual deficiency, with approximately 43 per cent of saturation. Two of the lakes are above 90 per cent of actual saturation and 5 fall between 80 per cent and 90 per cent; thus 7 of the 14 lakes included in the table have more than 80 per cent of the quantity of oxygen required for actual saturation.

The percentage of saturation on the absolute basis ranges from 14 per cent in Lake Mary to 70 per cent in Weber Lake. Only 5 of the 14 lakes are above 60 per cent on this basis, while 5 are between 50 and 60 per cent.

The ratio of the quantity of oxygen in the hypolimnion to that in the epilimnion, as shown in the last column of Table V, depends upon the relation between the volumes of these two strata and also upon the quantity of oxygen in them. Two of the lakes, namely Diamond and Finley, do not have a well marked hypolimnion and no ratios are given for them. The thickness of the epilimnion in the other lakes ranges from a minimum of 2 m. in Lake Mary to a maximum of 10 m. in Black Oak and Crystal. Differences in the thickness of the epilimnion in the various lakes, together with differences in amount of oxygen in the epilimnion and hypolimnion, produce wide differences in the ratio of the oxygen content of the latter to that of the former stratum. These ratios range from a minimum of 0.08 in Bragonier Lake to a maximum of 1.22 in Big Carr Lake, which represents a fifteenfold difference. The low ratio in Weber Lake is due to the small volume of the hypolimnion as compared with that of the epilimnion.

Oxygen Gradient

Maucha (1931) has recently presented a discussion of the vertical distribution of dissolved oxygen in lakes from a new standpoint. In his computations he takes into account the atmospheric pressure corrected for the elevation of the lake, the vapor pressure, and the hydrostatic pressure at the different depths. Three formulae are involved in these computations. The first formula relates to the determination of the general barometer reading at the elevation of the lake in question.

$$1.\ h = 18400\ (1 + 0.004t) \times (\log 760 - \log b_1).$$

In this formula h is the elevation of the lake in meters, t the temperature of the surface water in degrees centigrade and b_1 the barometer reading in millimeters.

The following formulae are used for the computation of the saturation values at the various depths:

$$2.\ g = \frac{o_2}{o'_2} \times \frac{b + mp - 760}{b + mp - f} \times 100$$

$$3.\ g' = \frac{b + mp - 760}{b + mp - f} \times \frac{b - f}{760 - f} \times 100$$

In these two formulae, o_2 is the dissolved oxygen present at a given depth, o'_2 the amount of oxygen required to saturate the water at the observed temperature, b the general barometer reading at the elevation of the lake expressed in millimeters, m the depth of the water in meters, p the hydrostatic pressure of 1 m. of water (73.5 mm.) and f the vapor pressure of saturated air at the temperature of the water at the various depths. The pressure of saturated aqueous vapor at different temperatures is given in the Smithsonian Physical Tables.

While hydrostatic pressure is taken into account in these computations, it does not play any important rôle in reality except where the water obtains a supply of oxygen from the photosynthetic activities of plants. In general the summer supply of oxygen for the hypolimnion is obtained from the atmosphere at

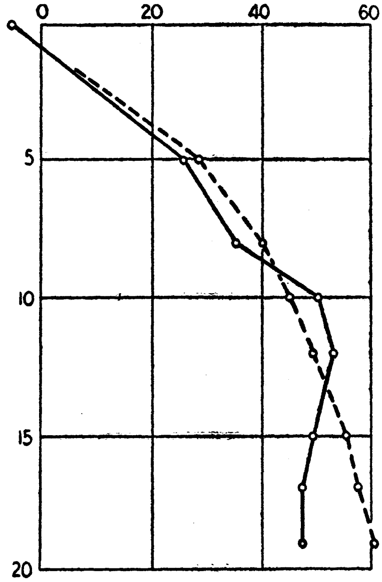

FIG. 28. The oxygen saturation values of Crystal Lake on August 21, 1928. The vertical spaces show the depth in meters and the horizontal spaces indicate the saturation values. The solid line indicates the actual saturation value and the broken line the theoretical value. Note that the former exceeds the latter at 10 m. and 12 m. Compare with Fig. 17.

the surface of the lake during the vernal period of circulation, so that hydrostatic pressure does not play any part in determining the amount of oxygen that is absorbed by the water at this time. When this aerated water is carried down to a depth of 30 m., for example, in the process of circulation, where the hydrostatic pressure is equivalent to about 3 atmospheres, no more oxygen is absorbed at that depth because there is no extra supply from which the water may obtain oxygen. Any oxygen liberated in the process of photosynthesis at a depth of 10 m., for instance, is readily retained in that stratum if the water is not disturbed by circulation, because the hydrostatic pressure at that depth is equivalent to about one atmosphere thus making a total pressure of two atmospheres at that depth.

The results obtained for 6 of the lakes of northeastern Wisconsin are given in Table VI and in Figures 28 to 33. The column marked *g* in this table represents the actual oxygen saturation values as found in the series of determinations, while

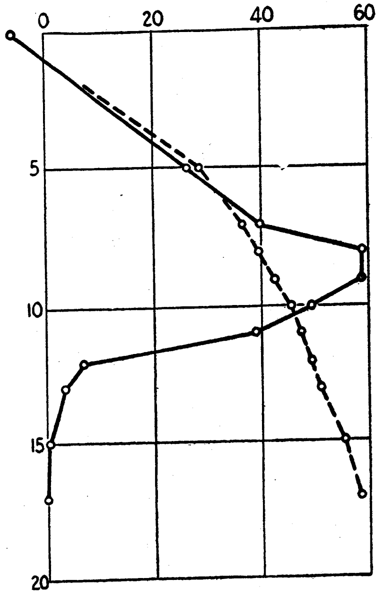

FIG. 29. The oxygen saturation values of Pallette Lake on August 22, 1928. The actual value (solid line) exceeds the theoretical value (broken line) between 7 m. and 10 m. Compare with Fig. 13 and Fig. 28.

g' represents the values for water that is saturated with oxygen. These oxygen values have been designated as oxygen gradients by Maucha, or simply gradients. The difference between these two gradients shows to what extent the oxygen supply of the water is affected by the biological processes that take place within a lake.

In Crystal Lake (Fig. 28) the quantity of oxygen found in the upper 8 m. on August 21, 1928 was a little less than that shown by the theoretical gradient, but it exceeded the latter in the 10 m.-12 m. stratum and then fell below the theoretical value between 15 m. and 19 m. Pallette Lake (Fig. 29) yielded similar results on August 22, 1928, but there was a larger excess of oxygen in the 7 m.-10 m. stratum and a much more marked decrease of oxygen below 10 m. The actual and theoretical oxygen gradients in Silver Lake (Fig. 30) are so near each other in the upper 6 m. that they can not be platted separately; an excess of oxygen is shown between 7 m. and 10 m., with a marked decline in the quantity of oxygen below the latter depth. The excess oxygen in these three lakes was due to

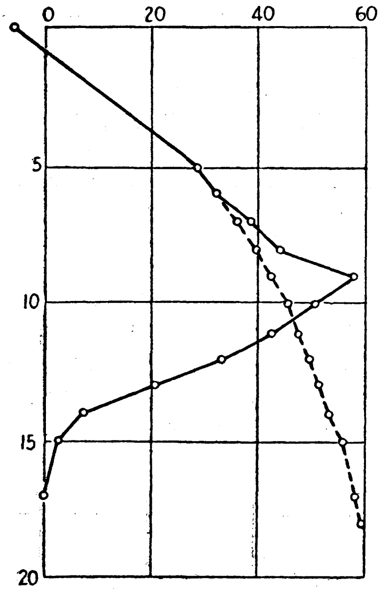

FIG. 30. The oxygen saturation values of Silver Lake on August 28, 1931. The actual value (solid line) exceeds the theoretical value (broken line) between 7 m. and 10 m. Compare with Fig. 29.

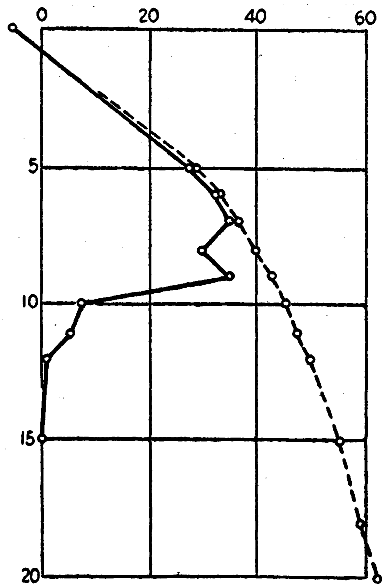

FIG. 31. The oxygen saturation values of Muskellunge Lake on August 26, 1931. This is a typical eutrophic lake. Note the large difference between the actual value (solid line) and the theoretical value (broken line) below 7 m. Compare with Fig. 28.

the photosynthetic activities of the various aquatic plants. Muskellunge Lake (Fig. 31) shows the eutrophic type of dissolved oxygen gradient. The two gradients are substantially the same down to a depth of 7 m., but the actual gradient shows a marked decline below this depth and falls to zero at 15 m. The irregularity in the actual gradient curve between 7 m. and 9 m. is similar to that shown by Maucha for the lower water of Grosser Plőner See.

Figures 32 and 33 show the change that took place in the oxygen supply of Trout Lake between June 24 and August 25, 1928. The curves indicate a marked decrease in the oxygen supply below a depth of 5 m. during this period of two months; the greatest decline was found below 20 m.

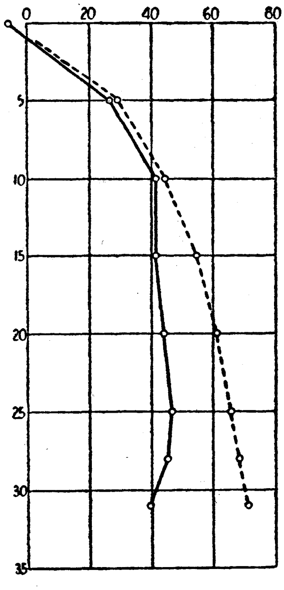

Fig. 32

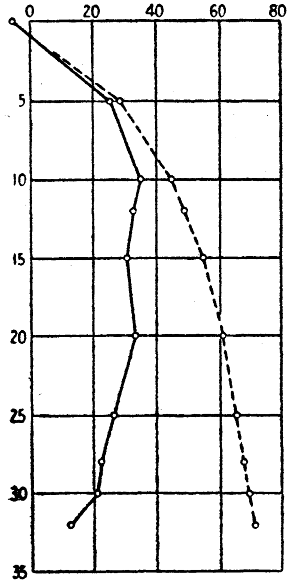

Fig. 33

FIG. 32. The oxygen saturation values of Trout Lake on June 24, 1928. The actual value (solid line) is below the theoretical value (broken line) at all depths. Compare with Fig. 33 and Fig. 22.

FIG. 33. The oxygen saturation values of Trout Lake on August 25, 1928. Compare the difference between the actual value (solid line) and the theoretical value (broken line) in this figure with that in Fig. 32. See Fig. 22.

The general status of the oxygen of the hypolimnion is indicated by dividing the sum of the actual saturation values in that stratum by the sum of the theoretical values for that stratum; such results are given in Table VII where the ratio of the actual to the theoretical values range from 92.2 in Crystal Lake to 11.5 in Muskellunge Lake. The former is oligotrophic and the latter eutrophic in character. Maucha's computations show a maximum ratio of 102.1 in Seneca Lake, New York. No other ratio given in his tables is as high as that of Crystal Lake.

II. Oxygen Consumed

The determinations of oxygen consumed or oxygen absorbed were made by the usual method of adding sulphuric acid and potassium permanganate to the samples and digesting them for 30 minutes in a bath of boiling water; ammonium oxalate was then added to the digested samples and they were titrated with potassium permanagate. In this procedure only the more readily oxidized carbon is affected, so that the results show only a part of the organic carbon that is present in the water; it is a fairly large proportion of the organic carbon, however.

Determinations of oxygen consumed were made on 509 samples of lake water during the summers of 1929, 1930 and 1931. Of this number 365 were surface samples obtained from 290 different lakes; 144 samples represent 28 series taken on 21 different lakes. The results obtained on some of the lakes are given in Table VIII. In the surface samples the quantity of oxygen consumed ranged from a minimum of 1.2 mg. in Dorothy Dunn Lake to a maximum of 34.5 mg. per liter in Helmet Lake. Only 4 samples showed less than 2.0 mg. of oxygen consumed per liter of water and the maximum number of samples, namely 52, fell between 4.0 mg. and 4.9 mg.; there were 46 samples in the 3.0-3.9 mg. group and 45 in the 5.0-5.9 mg. group. In 283 surface samples, or 77 per cent of the total number, the oxygen consumed varied between 2.0 mg. and 10.0 mg. per liter; the amount exceeded 17.0 mg. in 20 samples, but only 4 exceeded 25.0 mg.

The majority of the lakes from which these surface samples were secured have waters that are more or less deeply stained by humic substances derived from peat bogs and marshes; some of them, however, do not show any trace of brown color. Thus the brown color in the various samples ranged from zero in several of them up to 268 in Helmet, which is a small bog lake. The color readings in 62 samples did not exceed 9 on the platinum-cobalt scale; in such waters the brown color is not perceptible in the lake itself. The largest number of samples in the different color groups, namely 93, gave readings between 10 and 19, while 59 samples were between 20 and 29; thus 206 surface samples, or 56 per cent of the total number, possessed only a comparatively small amount of stain or none at all. The readings for 71 samples fell between 30 and 49 and these waters show a more or less distinct brown color, especially those with readings above 40; 88 of the surface samples gave color readings of 50 or more.

The relation between the color of the water and the quantity of oxygen consumed is shown in Table IX, which includes 354 of the surface samples; 20 samples gave color readings varying from 150 to 340, but determinations of oxygen consumed were made on only 11 of them. These 11 samples are not included in the table because they are distributed over such a wide color range. The samples are grouped at color intervals of 10 up to 59, but above the latter group it is necessary to combine them into larger color groups in order to obtain a fair mean.

There are rather wide differences between minimum and maximum amounts of oxygen consumed in the various color groups, but the means for the different groups show a gradual increase in the quantity of oxygen consumed with increasing

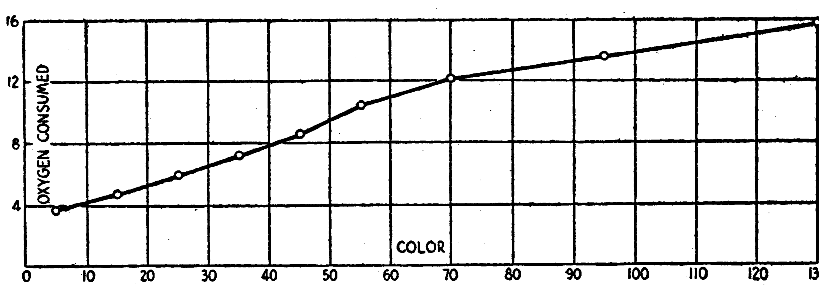

FIG. 34. The relation between the color of the water and the quantity of oxygen consumed in 354 surface samples. The vertical spaces represent the number of milligrams of oxygen consumed per liter of water and the horizontal spaces show the color of the water based on the platinum-cobalt standard. See Table IX.

color; the mean quantity rose from 3.7 mg. per liter in the 0–9 color group to 15.9 mg. in the 110-149 group. The maximum amount of oxygen consumed was noted in the surface water of Helmet Lake, namely 34.5 mg. per liter with a color of 260; the next in rank was Red Bass Lake where the oxygen consumed was 31.6 mg. per liter and the color 166.

The correlation of color and oxygen consumed is shown graphically in Figure 34 in which the mean quantity of oxygen consumed in the different color groups has been platted at middle of each group. The curve shows a steady rise from the 0-9 group up to the 50-59 group; beyond the latter group the rise is not so marked, but it continues up to the limit of the last group.

Quantitative determinations of the organic carbon were made on 282 of the surface samples that were analyzed for oxygen consumed. The results obtained for a considerable number of these samples are given in Table VIII. The organic carbon in these 282 surface samples varied from a minimum of 1.2 mg. to a maximum of 25.3 mg. per liter of water. Figure 35 represents the mean quantity of organic carbon platted against the mean quantity of oxygen consumed in the different groups of samples. The curve shows a fairly regular increase in the amount of oxygen consumed correlated with the increase in the amount of organic carbon found in the samples. In general an increase of 1.0 mg. of organic carbon per liter is correlated with an increase of approximately 0.9 mg. of oxygen consumed per liter. The individual samples, however, show a certain amount of variation; in some of them the amount of oxygen consumed is larger than that of the organic carbon, in others the reverse is true, and in still others the two quantities are about the same.

In the lower part of the curve, where the amount of oxygen consumed and that of organic carbon do not exceed 8.0 mg. per liter, the mean quantity of the former is somewhat larger than that of the latter, but above the 8.0 mg. point the two are more evenly balanced. The general mean of oxygen consumed in the 282 samples represented in this diagram is 9.0 mg. and that of organic carbon is 8.7 mg. per liter, so that the variations tend to balance each other. The fact that the mean quantity of oxygen consumed and that of organic carbon are so nearly the same in these surface samples indicates that about

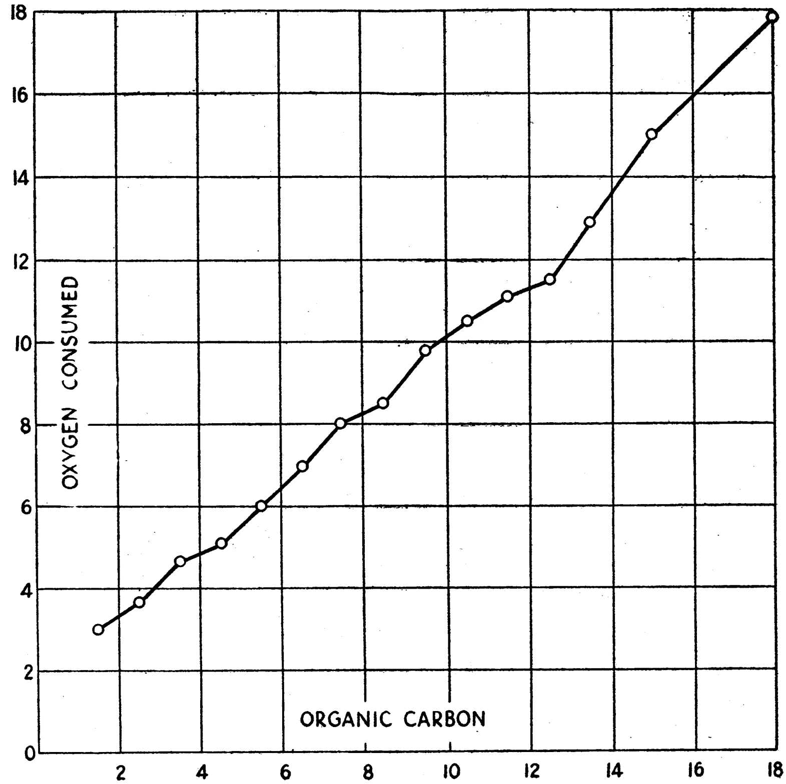

FIG. 35. The relation between the amount of oxygen consumed and the quantity of organic carbon in 282 surface samples. The vertical spaces show the number of milligrams of oxygen consumed per liter of water and the horizontal spaces indicate the number of milligrams of organic carbon per liter of water.

40 per cent of the organic carbon in them, on an average, is oxidized by the potassium permanganate, since two atoms of oxygen are required to oxidize one atom of organic carbon.

The relation of the quantity of oxygen consumed to that of the dissolved oxygen present in the surface samples shows marked differences in the different lakes. In those lakes showing a relatively small amount of oxygen absorbed, the dissolved oxygen is in excess of the oxygen consumed; examples of this relation are given in Table VIII, such as the surface samples of Black Oak, Clear, Crystal, Day, Fence, Trout and Weber lakes. In other lakes the quantity of dissolved oxygen is substantially the same as that of the oxygen consumed; the surface samples of Adelaide, George and Little Papoose lakes are representatives of this type. In the more highly colored waters, on the other hand, the quantity of oxygen consumed is much larger than that of the dissolved oxygen; Black, Findler, Helen, Mary, Summit and Yolanda lakes are good examples of this group. The humic substances in the colored waters give them a larger oxygen consuming capacity and as a result there is a greater demand for dissolved oxygen in them than in the waters that have little or no stain. This increased demand for free oxygen usually keeps the quantity of dissolved oxygen well below the saturation point in these colored waters. In Black Lake, for example, the percentage of oxygen saturation in the surface water was only 69 per cent, in Circle Lily Lake 65 per cent, in Findler Lake 62 per cent, and in Summit and Yolanda lakes 72 per cent.

Three general types of vertical distribution of the oxygen consumed have been found in the northeastern lakes. In one group the quantity of oxygen consumed was substantially the same from surface to bottom. Such results are shown in Table VIII for Anderson, Bragonier, Long and Nokomis lakes. The second type is represented by lakes that show a smaller amount of oxygen consumed at the bottom than at the surface; Black Oak and Trout lakes belong to this class. In the third type the quantity of oxygen consumed is larger at the bottom than at the surface; George, Mary and Papoose lakes are representatives of this class. The vertical distribution of the organic carbon is similar to that of the oxygen consumed in Anderson Lake; that is, the quantity is substantially uniform from surface to bottom, but there are more or less marked differences in the vertical distribution of the two in the other lakes. These differences are more prominent in the lower than in the upper water.

Figure 34 shows that there is a close correlation between the color and the amount of oxygen consumed in the surface samples and similar results were obtained in two of the series; in Lake George there was a marked increase in the amount of oxygen consumed at the bottom which corresponded to a five-fold rise in the color of the water and a similar change was noted in the bottom water of Papoose Lake. (See Table VIII). The increase in the color of the water in these two lakes may be attributed to the presence of vegetable extractives at these depths. Very different conditions were noted in the lower water of three other lakes, however. In Anderson Lake the color rose from zero at the surface to 180 and 240, respectively, at 15 m. and 18 m., yet there was no corresponding increase in the oxygen consumed. This lack of correlation is due to the fact that the color of the lower water was due to the presence of iron; 3.0 mg. of iron per liter were found at 15 m. and 7.0 mg. per liter at 18 m. in this series of samples. A similar increase in the color of the lower water without a corresponding increase in the oxygen consumed was noted in Mary and Nokomis lakes. The series of samples from Nokomis Lake yielded 1.2 mg. of iron per liter at 18 m. and 2.2 mg. at 20 m., so that iron was the factor involved in the increased color of the lower water of this lake. No iron determinations were made on the series of samples from Lake Mary, but it seems probable that it was responsible for most of the increase in the color of the lower water of this lake also.

Summary

1. Quantitative determinations of dissolved oxygen were made on the waters of 510 lakes and lakelets situated in northeastern Wisconsin.

2. The quantity of dissolved oxygen in the surface samples ranged from 3.4 mg. to 12.4 mg. per liter of water, or from 34 per cent to 129 per cent of saturation.

3. The smallest amounts of oxygen in the surface waters were found in bog lakes and lakelets.

4. Some of the lakes had an abundance of dissolved oxygen at all depths during the summer period of stratification (oligotrophic lakes), while the lower stratum of others was characterized by a marked deficiency of oxygen in summer (eutrophic lakes). (Figs. 17-27).

5. Excess oxygen was found in the thermocline of a few of these lakes (Fig. 13).

6. The oxygen gradients showed striking differences in the different types of lakes. (Figs. 28-33).

7. Determinations of oxygen consumed were made on the waters of 290 lakes and lakelets.

8. The quantity of oxygen consumed varied from 1.2 mg. to 34.5 mg. per liter of water.

9. The quantity of oxygen consumed was correlated rather closely with the amount of vegetable extractives or humic substances in the water which give it a brown color. (Fig. 34).

10. The quantity of oxygen consumed was also closely correlated with the amount of organic carbon present in the water. (Fig. 35).

11. An average of about 40 per cent of the organic carbon present in the water was oxidized by potassium permanganate in the oxygen consumed procedure.

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TABLE I. *Variation in the quantity of dissolved oxygen in the surface waters of the various lakes, together with the hydrogen ion concentration and the fixed or bound carbon dioxide. The results for oxygen are indicated in milligrams per liter of water and in per cent of saturation. The fixed carbon dioxide is indicated in milligrams per liter of water.*

Lake	Date	Temperature °C.	Oxygen		pH	Fixed Carbon dioxide
			Mg. per liter	Per cent of saturation		
Adelaide.....	July 20, 1925	22.6	7.9	88	7.1	3.2
	Aug. 23, 1925	20.9	9.1	99	8.8	3.9
	July 17, 1926	21.2	8.0	87	6.7	3.2
	Aug. 21, 1926	18.7	7.7	80	6.6	3.2
	Aug. 5, 1927	20.0	7.8	83	6.6	2.6
	July 17, 1928	23.0	7.6	86	6.8	2.7
	Aug. 29, 1929	20.5	9.7	104	6.3	3.7
	Aug. 4, 1930	24.5	7.3	84	6.4	3.2
Bear........	July 25, 1925	20.6	8.4	91	6.4	2.0
	Aug. 6, 1926	21.5	6.4	70	6.2	1.6
	July 9, 1927	19.9	7.8	84	6.2	2.0
	July 1, 1928	20.0	11.3	120	6.1	2.0
	Aug. 18, 1929	19.6	6.4	68	6.2	2.0
	July 11, 1930	23.5	9.4	106	5.9	3.5
Cardinal Bog	July 18, 1926	21.5	4.8	53	5.4	1.2
	Aug. 20, 1927	16.5	3.4	34	5.4	2.1
	Aug. 4, 1928	20.5	5.8	62	5.4	1.2
	Aug. 22, 1929	22.5	6.6	73	5.2	2.7
	Aug. 18, 1931	21.2	6.4	70	5.5	1.3
Crystal......	June 26, 1926	15.4	8.9	86	6.3	2.0
	Aug. 17, 1926	20.0	8.3	89	6.3	1.4
	July 1, 1927	21.8	8.2	91	6.7	1.3
	June 26, 1928	14.5	9.1	88	6.1	1.3
	Aug. 21, 1928	21.5	7.7	84	5.9	1.3
	June 28, 1929	18.6	8.8	92	6.3	1.5
	Aug. 20, 1929	19.1	8.7	91	6.0	1.8
	July 7, 1930	19.8	8.2	87	5.1	2.0
	July 14, 1931	20.9	8.2	87	5.1	0.5
	Aug. 12, 1931	20.3	8.6	92	6.8	0.5
Mary........	Sept. 23, 1925	15.2	7.5	73	6.0	2.5
	July 12, 1926	19.5	7.3	77	6.2	2.5
	July 29, 1927	22.0	7.6	84	6.2	2.5
	July 11, 1928	20.8	6.7	72	6.2	2.7
	Aug. 29, 1929	20.2	8.5	90	6.1	3.7
	Aug. 4, 1930	25.2	6.0	70	5.4	3.0
Muskellunge.	Aug. 8, 1925	21.9	8.6	95	8.2	9.9
	Sept. 27, 1925	16.2	8.1	80	7.1	10.0
	June 29, 1926	18.0	7.9	81	7.4	10.5
	Aug. 20, 1926	19.2	7.6	80	7.0	9.9
	July 2, 1927	20.9	9.0	97	7.1	9.0
	June 27, 1928	15.5	9.8	96	7.1	9.2
	July 19, 1929	22.0	8.4	93	7.5	9.0
	July 10, 1931	21.2	8.6	93	7.1	10.5
	Aug. 26, 1931	20.2	8.6	92	7.5	10.0

TABLE I.—Continued

Lake	Date	Temperature °C.	Oxygen Mg. per liter	Oxygen Per cent of saturation	pH	Fixed carbon dioxide
Nebish......	July 29, 1925	20.5	8.0	86	6.9	3.2
	Aug. 29, 1925	20.7	7.9	85	7.0	4.0
	Aug. 3, 1926	23.5	7.5	84	6.7	3.1
	Aug. 13, 1927	20.2	7.1	76	6.8	3.6
	Aug. 1, 1928	21.4	8.1	88	6.7	3.0
	Aug. 26, 1929	21.4	8.9	97	6.6	5.2
	July 11, 1930	23.3	8.8	99	6.6	5.0
	July 6, 1931	23.3	7.7	86	6.3	4.2
	Aug. 11, 1931	22.3	7.7	85	7.5	4.5
	Aug. 29, 1931	19.0	8.0	84	7.2	3.5
Silver........	July 12, 1925	22.5	8.7	97	7.7	15.3
	July 8, 1926	21.7	7.3	80	7.2	15.2
	Aug. 19, 1926	19.5	7.9	83	7.5	15.0
	July 7, 1927	19.5	8.9	94	7.5	15.2
	June 25, 1928	14.5	9.0	87	7.8	15.5
	July 9, 1929	20.1	8.7	93	7.7	15.5
	July 9, 1930	21.7	8.0	88	7.6	16.0
	July 25, 1931	23.2	7.7	87	7.7	15.0
	Aug. 28, 1931	20.2	8.7	93	7.7	15.0
Trout.......	July 17, 1925	21.5	8.4	92	8.0	18.5
	Aug. 28, 1925	19.8	8.9	94	8.2	20.0
	Sept. 21, 1925	17.5	8.6	87	7.6	19.6
	June 24, 1926	14.9	9.1	88	7.4	20.0
	July 31, 1926	21.5	7.6	84	7.6	19.0
	Aug. 23, 1926	19.0	8.8	93	7.4	18.8
	June 24, 1927	15.2	9.4	92	7.3	18.4
	July 19, 1927	19.5	9.2	97	7.4	18.4
	Aug. 20, 1927	18.3	7.4	77	7.6	19.0
	June 24, 1928	14.8	9.4	91	7.7	19.0
	July 25, 1928	22.0	8.3	91	8.2	18.5
	Aug. 25, 1928	19.3	8.1	85	7.9	17.8
	June 26, 1929	21.0	9.1	98	7.4	18.0
	July 16, 1929	21.5	8.2	90	7.7	18.0
	Aug. 27, 1929	20.0	9.5	102	7.7	19.0
	Nov. 15, 1929	5.2	11.1	86	7.2	19.1
	June 30, 1930	19.1	10.4	109	7.8	18.8
	Aug. 22, 1930	20.6	9.4	101	7.6	18.5
	July 1, 1931	25.4	7.8	91	7.5	19.5
	Aug. 10, 1931	20.6	8.3	90	7.7	18.0
	Aug. 27, 1931	19.9	8.6	91	7.7	18.5
Weber.......	July 27, 1925	20.5	8.8	95	6.3	1.3
	July 5, 1926	20.6	7.4	79	6.4	1.1
	Aug. 18, 1926	20.3	8.5	91	6.4	0.9
	July 13, 1927	20.4	8.6	93	6.2	0.9
	June 28, 1928	16.7	8.9	89	6.1	1.0
	Aug. 29, 1928	19.9	8.1	89	5.8	0.9
	June 29, 1929	19.5	8.7	92	6.7	1.5
	Aug. 21, 1929	19.3	9.0	95	6.3	1.8
	July 9, 1931	21.3	8.2	90	6.1	1.4
	Aug. 11, 1931	21.2	8.5	92	6.8	1.0
	Aug. 25, 1931	20.6	8.0	86	6.9	1.0

TABLE I.—Continued

Lake	Date	Temperature °C.	Oxygen		pH	Fixed carbon dioxide
			Mg. per liter	Per cent of saturation		
Wild Cat....	July 4, 1925	20.8	9.3	100	8.4	....
	Aug. 3, 1925	21.3	9.0	98	8.4	33.5
	Sept. 22, 1925	16.8	7.8	78	8.1	32.3
	July 11, 1926	21.1	7.0	76	7.8	30.3
	Aug. 24, 1926	19.0	8.6	90	7.6	30.8
	June 29, 1927	20.6	8.1	86	7.6	26.8
	Aug. 17, 1928	23.2	7.9	89	8.3	29.0
	July 20, 1929	21.9	8.0	88	7.7	30.5
	Nov. 16, 1929	2.7	11.5	84	7.2	30.0
	July 22, 1930	19.7	6.8	72	8.0	31.0

TABLE II. *Lakes on which series of oxygen determinations were made; the area of each lake is given in hectares and the maximum depth in meters. The last column shows the number of series taken on the various lakes.*

Lake	Area	Maximum depth	Number of series
GROUP I			
Bragonier	19	8.7	3
Cardinal Bog	....	5.5	2
Dorothy Dunn	22	7.0	1
Finley	62	8.5	3
Fish Trap	88	9.5	2
Hillis	5	9.0	2
Jag	94	4.0	1
Little Crooked	109	7.0	1
Little John	75	6.8	4
Little John Junior	10	9.0	2
Little Star Bog	2	6.0	2
Lost	248	5.0	1
Razor Back	142	9.5	1
Upper Gresham	145	8.0	2
Upper Sugar Bush	44	9.0	1
Wolf	194	7.5	2
Yolanda	2	7.5	1
GROUP II			
Bird	54	13.0	3
Blue	89	13.5	6
Brandy	32	13.6	1
Clear Crooked	269	10.5	2
Diamond	48	12.3	4
Laura	259	12.0	1
Little Bass	6	13.0	1
Little Tomahawk	54	14.6	3
Long (S. of Crystal)	19	12.7	4
Lost Canoe	119	13.1	6
Midge	3	11.6	1
Rose	1	13.0	1
Turtle	259	14.5	5
Weber	15	13.5	11
Wild Cat	104	12.4	8
GROUP III			
Anderson	21	19.5	1
Big	429	18.5	4
Day	52	17.0	4
Helen	6	16.0	1
Ike Walton	524	18.5	2
Island by Black Oak	189	15.3	4
Katinka	112	18.5	1
Kawaguesaga	836	17.0	2

TABLE II.—Continued

Lake	Area	Maximum depth	Number of series
GROUP III—Continued			
Little Long	14	18.0	2
Nebish	47	16.5	8
Pallette	82	19.0	5
Papoose	207	19.5	4
Pauto	10	17.2	3
Plum	440	18.0	4
Silver	87	19.5	10
Star by Manitowish	106	18.0	4
Sugar Bush	109	16.0	1
Two Sisters	208	19.5	1
Upper Kabasheen	90	17.0	1
GROUP IV			
Adelaide	22	22.0	6
Big Carr	94	22.0	5
Black Oak	230	26.0	5
Catfish	109	23.0	1
Clear	373	28.0	7
Crawling Stone	647	28.3	1
Crooked (Flambeau)	161	22.0	1
Crystal	31	21.0	11
Dead Pike	156	25.0	2
Fence	1413	28.5	1
George	28	21.5	1
Little Trout	388	28.0	2
Long (Phelps)	440	28.0	1
Mary	1	22.0	6
Muskellunge	375	21.0	10
Nokomis	198	22.0	1
Presque Isle	764	29.0	3
South Two	124	21.0	1
Star	466	21.0	4
Stone (Crandon)	342	23.3	1
Stormy	200	20.0	1
Tomahawk	1476	22.5	3
Trout	1683	35.0	32
White Sand	216	20.5	4
Yawkey	44	21.0	1

TABLE III. *Dissolved oxygen deficiency or excess at different depths in 14 lakes of northeastern Wisconsin. The column marked* O_2 *shows the amount actually found at the different depths,* O'_2 *indicates the amount of oxygen required to saturate the water at the observed temperatures and* D *represents the deficiency or excess of the oxygen at the various depths; the amount of oxygen is indicated in these three columns in milligrams per liter of water. The minus sign indicates a deficiency of oxygen and the plus sign an excess.* Tr. *means trace.*

Lake and date	Depth in meters	Temperature in °C.	O_2	O'_2	D	Per cent of saturation
Adelaide	0	18.7	7.22	9.61	— 1.89	80.3
	3	18.5	7.50	9.65	— 2.15	77.7
August 21, 1926	4	18.0	6.64	9.73	— 3.09	68.2
	5	14.0	4.40	10.53	— 6.13	41.7
	6	10.2	0.67	11.41	—10.74	5.8
	7	8.5	0.43	11.87	—11.44	3.6
	8	7.6	0.21	12.12	—11.91	1.7
	10	6.4	0.16	12.47	—12.31	0.2
	12	5.9	Tr.	12.62	—12.62	0.0
	20	5.5	0.00	12.75	—12.75	0.0
Big Carr	0	20.8	8.70	9.26	— 0.56	93.9
	5	20.4	8.83	9.32	— 0.49	94.6
July 18, 1927	7	15.5	10.75	10.22	+ 0.53	105.2
	10	9.7	9.22	11.54	— 2.32	79.8
	12	8.9	7.92	11.76	— 3.84	67.3
	15	8.4	5.75	11.89	— 6.14	48.3
	18	8.2	4.45	11.95	— 7.50	37.2
	22	7.9	3.64	12.03	— 8.39	30.2
Black Oak	0	19.8	8.19	9.42	— 1.23	86.9
	8	19.8	8.14	9.42	— 1.28	86.8
August 24, 1928	10	15.7	10.47	10.18	+ 0.29	102.8
	12	10.6	8.95	11.31	— 2.36	79.1
	15	7.9	6.70	12.03	— 5.33	55.6
	18	7.6	2.09	12.12	—10.03	17.2
	22	6.3	0.10	12.50	—12.40	0.7
	25	6.1	0.00	12.56	—12.56	0.0
Bragonier	0	23.3	7.57	8.87	— 1.30	85.2
	3	21.4	7.72	9.17	— 1.45	84.2
July 19, 1928	4	16.7	6.85	9.98	— 3.13	68.6
	5	14.2	4.05	10.49	— 6.44	38.6
	6	12.5	0.62	10.86	—10.24	5.7
	7	11.4	0.25	11.11	—10.86	2.3
	8	10.2	0.00	11.41	—11.41	0.0
Crystal	0	21.5	7.68	9.15	— 1.47	83.9
	5	21.4	7.70	9.17	— 1.47	84.0
August 21, 1928	8	21.4	7.68	9.17	— 1.49	83.8
	10	18.2	10.13	9.70	+ 0.43	104.4
	12	14.7	10.33	10.38	+ 0.05	100.0
	15	10.8	9.55	11.25	— 1.70	84.8
	17	10.3	8.74	11.38	— 2.64	76.9
	19	10.0	8.52	11.46	— 2.94	74.3
Diamond	0	20.4	7.63	9.32	— 1.69	81.8
	8	20.4	7.45	9.32	— 1.87	80.0
August 29, 1928	10	20.3	7.47	9.34	— 1.87	80.0
	12	20.2	7.53	9.36	— 1.83	80.4

TABLE III.—Continued

Lake and date	Depth in meters	Temperature in °C.	O_2	O'_2	D	Per cent of saturation
Finley	0	22.5	8.20	9.00	— 0.80	91.1
	3	22.4	8.33	9.01	— 0.68	92.4
July 19, 1928	4	22.2	8.50	9.04	— 0.54	94.0
	5	21.4	9.43	9.17	+ 0.26	102.8
	6	19.0	9.53	9.56	— 0.03	99.6
	7	17.3	9.12	9.86	— 0.74	92.4
	8	16.2	6.28	10.08	— 3.80	62.3
Little Bass	0	22.8	7.44	8.95	— 1.51	83.1
	5	22.8	7.53	8.95	— 1.42	84.1
August 14, 1928	6	22.7	7.50	8.96	— 1.46	83.6
	7	22.6	7.61	8.98	— 1.37	84.7
	8	20.0	9.71	9.39	+ 0.32	103.4
	9	17.0	11.00	9.92	+ 1.08	110.9
	10	13.1	10.00	10.73	— 0.73	93.2
	11	11.1	6.90	11.18	— 5.28	61.7
	12	9.9	4.21	11.49	— 7.28	36.6
	14	8.5	0.13	11.87	—11.74	1.1
Little Long	0	21.6	7.60	9.14	— 1.54	83.1
	3	21.1	7.10	9.22	— 2.12	77.0
August 22, 1931	5	13.8	5.00	10.58	— 5.58	47.3
	7	9.5	6.10	11.60	— 5.60	52.5
	8	8.4	6.30	11.90	— 5.60	53.0
	10	7.7	5.50	12.09	— 6.59	45.5
	15	6.6	3.30	12.41	— 9.11	26.6
	17	6.6	3.10	12.41	— 9.31	24.1
Mary	0	20.2	8.47	9.36	— 0.89	90.5
	1	19.6	8.48	9.46	— 0.98	89.6
August 29, 1929	2	16.6	3.63	10.00	— 6.37	36.3
	3	11.1	0.22	11.18	—10.96	2.0
	4	8.6	0.00	11.84	—11.84	0.0
	5	5.2	0.00	12.84	—12.84	0.0
	10	4.0	0.00	13.23	—13.23	0.0
	15	4.2	0.00	13.17	—13.17	0.0
	20	4.6	0.00	13.04	—13.04	0.0
	22	4.7	0.00	13.00	—13.00	0.0
Midge	0	24.2	7.24	8.75	— 1.51	82.8
	1	24.2	7.10	8.75	— 1.65	81.2
July 31, 1929	2	22.7	7.00	8.96	— 1.96	78.1
	3	17.1	5.48	9.90	— 4.42	55.3
	4	11.6	5.05	11.07	— 6.02	45.6
	5	9.1	4.78	11.70	— 6.92	40.8
	6	7.5	4.70	12.15	— 7.45	38.6
	7	6.8	3.56	12.35	— 8.79	28.8
	8	6.5	3.56	12.44	— 8.88	28.6
	9	6.2	2.35	12.53	—10.18	18.7
	10	6.0	1.72	12.59	—10.87	13.6
	11	5.9	1.32	12.62	—11.30	10.4

TABLE III.—Continued

Lake and date	Depth in meters	Temperature in °C.	O_2	O'_2	D	Per cent of saturation
Pallette	0	21.3	8.23	9.18	— 0.95	89.6
	5	21.2	8.06	9.20	— 1.14	87.6
August 22, 1928	7	21.2	9.45	9.20	+ 0.25	102.7
	8	17.5	13.64	9.82	+ 3.82	138.8
	9	13.4	13.76	10.66	+ 3.10	129.0
	10	10.0	11.79	11.46	+ 0.33	102.8
	11	8.9	9.08	11.76	— 2.68	77.2
	12	7.5	1.57	12.15	—10.58	12.9
	13	7.2	0.74	12.23	—11.49	6.0
	15	6.6	0.08	12.41	—12.33	0.6
	17	6.4	Tr.	12.47	—12.47	0.0
Weber	0	19.3	9.00	9.51	— 0.51	94.6
	5	19.3	9.05	9.51	— 0.46	94.7
August 21, 1929	8	14.2	9.88	10.49	— 0.61	94.2
	9	14.0	11.70	10.53	+ 1.17	111.1
	10	12.5	11.00	10.86	+ 0.14	101.3
	11	11.6	9.50	11.07	— 1.57	85.8
	12	11.0	8.05	11.20	— 3.15	71.8
White Sand	0	21.0	8.44	9.23	— 0.79	91.4
	5	21.0	8.44	9.23	— 0.79	91.4
July 23, 1926	8	17.4	7.61	9.84	— 2.23	77.3
	10	14.5	6.55	10.42	— 3.87	62.8
	13	9.8	4.72	11.52	— 6.80	41.0
	15	8.2	4.03	11.95	— 7.92	33.7
	17	7.8	3.46	12.06	— 8.60	28.6
	19	7.2	1.95	12.23	—10.28	16.0

TABLE IV. *Amount of dissolved oxygen in 14 lakes of northeastern Wisconsin The volume of water in the different strata is expressed in cubic meters.* O_2 *represents the amount of oxygen present,* O'_2 *the amount required for saturation at the observed temperatures and* D *the deficit or excess of oxygen in the various strata; the results for these three items are indicated in kilograms of oxygen. The minus sign indicates a deficit and the plus sign an excess of oxygen in the stratum in question. The results shown in this table are based on those given in Table III.*

Lake and date	Stratum	Volume	O_2	O'_2	D
Adelaide..........	0—2	411,300	3,175	3,953	—778
August 21, 1926	2—5	484,700	2,995	4,832	—1,837
	5—10	455,200	534	5,317	—4,783
	10—15	108,000	6	1,355	—1,349
	15—21	21,200	0	269	—269
	Total	1,480,400	6,710	15,726	—9,016
Big Carr..........	0—2	1,747,000	15,199	16,182	—983
July 18, 1927	2—5	2,202,400	19,304	20,469	—1,165
	5—10	2,835,800	27,224	29,385	—2,161
	10—15	1,680,300	12,821	19,713	—6,892
	15—18	369,600	1,885	4,406	—2,521
	18—22	44,900	182	538	—356
	Total	8,880,000	76,615	90,693	—14,078
Black Oak........	0—2	4,114,200	33,695	38,772	—5,077
August 24, 1928	2—5	4,855,200	39,764	45,755	—5,991
	5—10	6,262,800	55,946	60,593	—4,647
	10—15	4,512,700	39,306	50,420	—11,114
	15—18	2,024,400	8,907	24,455	—15,538
	18—22	1,318,000	1,450	16,223	—14,773
	22—26	214,700	11	2,697	—2,686
	Total	23,302,000	179,079	238,905	—59,826
Bragonier..........	0—2	339,500	2,570	3,013	—443
July, 19, 1928	2—4	220,300	1,605	2,109	—504
	4—8.7	105,000	339	1,109	—770
	Total	664,800	4,514	6,231	—1,717
Crystal...........	0—5	1,170,000	8,986	10,709	—1,723
August 21, 1928	5—10	851,800	7,243	7,960	—717
	10—15	585,300	5,855	6,139	—284
	15—18	179,800	1,645	2,047	—402
	18—21	52,400	452	600	—148
	Total	2,839,300	24,181	27,455	—3,274
Diamond..........	0—10	3,291,000	24,748	30,705	—5,957
August 29, 1928	10—12.2	94,000	705	879	—174
	Total	3,385,000	25,453	31,584	—6,131
Finley............	0—4	2,164,000	18,054	19,513	—1,459
July 19, 1928	4—6	838,000	7,670	7,757	—87
	6—8.5	406,000	3,374	3,992	—618
	Total	3,408,000	29,098	31,262	—2,164
Little Bass........	0—4	208,800	1,557	1,869	—312
August 14, 1928	4—8	112,800	882	1,017	—135
	8—14	36,800	323	385	—62
	Total	358,400	2,762	3,271	—509

TABLE IV.—Continued

Lake and date	Stratum	Volume	O_2	O'_2	D
Little Long........ August 22, 1931	0—2	272,200	2,069	2,487	—418
	2—5	342,400	2,246	3,301	—1,055
	5—10	402,600	2,349	4,658	—829
	10—14	166,600	716	2,038	—1,322
	14—18	46,000	150	571	—421
	Total	1,229,800	7,530	13,055	—5,525
Mary............. August 29, 1929	0—2	21,430	157	205	—48
	2—5	24,990	19	284	—265
	5—10	27,270	0	357	—357
	10—15	14,330	0	189	—189
	15—22	4,550	0	60	—60
	Total	92,570	176	1,095	—919
Midge............ July 31, 1929	0—2	56,000	398	494	—96
	2—4	39,000	228	389	—161
	4—8	47,600	213	567	—354
	8—11.6	10,400	25	130	—105
	Total	153,000	864	1,580	—716
Pallette........... August 22, 1928	0—4	2,480,700	20,322	22,791	—2,469
	4—6	1,055,300	8,506	9,709	—1,203
	6—10	1,729,300	20,190	17,305	+2,885
	10—14	1,212,900	5,738	14,681	—8,943
	14—18	216,800	11	2,696	—2,685
	Total	6,695,000	54,767	67,182	—12,415
Weber............ August 21, 1929	0—4	512,700	4,614	4,875	—261
	4—8	381,900	3,525	3,713	—188
	8—10	138,000	1,508	1,474	+34
	10—13.5	99,900	931	1,107	—176
	Total	1,132,900	10,578	11,169	—591
White Sand........ July 23, 1926	0—2	3,911,900	33,016	36,115	—3,099
	2—5	4,878,000	41,170	45,034	—3,864
	5—10	5,879,800	44,292	57,822	—13,530
	10—15	3,311,200	16,887	37,403	—20,516
	15—21	1,294,100	4,043	15,605	—11,562
	Total	19,275,000	139,408	191,979	—52,571

TABLE V. *This table shows the total quantity of oxygen present in the various lakes and the actual and absolute amounts required for complete saturation, expressed in kilograms, as well as the percentages of saturation. The last column shows the relation of the quantity of dissolved oxygen found in the hypolimnion (H) to that present in the epilimnion (E).*

Lake	Date	Quantity of O_2 present	Quantity of O_2 required for saturation		Per cent of saturation		$\frac{H}{E}$
			Actual	Absolute	Actual	Absolute	
Adelaide....	Aug. 21, 1926	6,710	15,726	18,505	42.6	36.2	0.09
Big Carr....	July 18, 1927	76,615	90,693	111,000	84.4	69.0	1.22
Black Oak...	Aug. 24, 1928	179,079	238,905	289,275	74.9	61.9	0.38
Bragonier...	July 19, 1928	4,514	6,231	8,310	72.4	54.3	0.08
Crystal.....	Aug. 21, 1928	24,181	27,455	35,491	88.1	68.1	0.49
Diamond....	Aug. 29, 1928	25,453	31,584	42,312	80.6	60.0	....
Finley......	July 19, 1928	29,098	31,262	42,600	93.1	68.3	....
Little Bass..	Aug. 14, 1928	2,762	3,271	4,480	84.7	61.6	0.13
Little Long	Aug. 22, 1931	7,530	13,055	15,372	57.6	49.0	0.74
Mary.......	Aug. 29, 1929	176	1,095	1,157	16.0	15.2	0.12
Midge......	July 31, 1929	864	1,580	1,912	54.7	45.2	1.17
Pallette.....	Aug. 22, 1928	54,767	67,182	83,687	81.5	65.4	0.43
Weber......	Aug. 21, 1929	10,578	11,169	14,161	94.7	74.6	0.29
White Sand	July 23, 1926	139,408	191,979	240,937	72.6	57.8	0.38

TABLE VI. *Temperature, dissolved oxygen and saturation values for 5 lakes of northeastern Wisconsin.* O_2 *is the oxygen present and* O'_2 *the quantity of oxygen required for saturation, expressed in milligrams per liter;* **g** *is the actual and* **g'** *the theoretical saturation value. The elevations of the lakes and the mean barometer readings used in computing the saturation values are given in Table VII.*

Lake and date	Depth in meters	Temperature in °C.	O_2	O'_2	g	g'
Crystal...........	0	21.5	7.68	9.15	— 5.2	— 5.8
August 21, 1928	5	21.4	7.70	9.17	+25.5	+28.6
	8	21.4	7.68	9.17	+35.5	+39.9
	10	18.2	10.13	9.70	+50.2	+45.3
	12	14.7	10.33	10.38	+52.9	+49.8
	15	10.8	9.55	11.25	+49.6	+55.1
	17	10.3	8.74	11.38	+47.4	+58.0
	19	10.0	8.52	11.46	+47.8	+60.6
Pallette...........	0	21.3	8.23	9.18	— 5.4	— 5.6
August 22, 1928	5	21.2	8.06	9.20	+26.7	+28.8
	7	21.2	9.45	9.20	+39.8	+36.6
	8	17.5	13.64	9.82	+58.7	+39.9
	9	13.4	13.76	10.66	+58.3	+42.6
	10	10.0	11.79	11.46	+49.3	+45.3
	11	8.9	9.08	11.76	+39.0	+47.6
	12	7.5	1.57	12.15	+ 6.8	+49.7
	13	7.2	0.74	12.23	+ 3.3	+51.7
	15	6.6	0.08	12.41	+ 0.3	+55.1
	17	6.4	Tr.	12.47	0.0	+58.1
Silver............	0	20.2	8.70	9.36	— 5.5	— 5.6
August 28, 1931	5	20.2	8.90	9.36	+29.0	+28.7
	6		8.80	9.36	+32.4	+32.7
	7	20.2	9.20	9.36	+38.2	+36.7
	8	18.8	9.90	9.60	+43.6	+39.9
	9	14.7	13.20	10.38	+57.6	+42.7
	10	11.4	11.70	11.11	+50.5	+45.2
	11	9.4	9.80	11.62	+42.6	+47.6
	12	8.6	7.50	11.84	+33.4	+49.8
	13	8.2	4.40	11.95	+20.2	+51.7
	14	7.7	1.60	12.09	+ 7.5	+53.5
	15	7.2	0.60	12.23	+ 2.7	+55.2
	17	6.9	0.00	12.32	0.0	+58.1
	18	6.8	0.00	12.35	0.0	+59.4
Trout............	0	14.8	9.43	10.36	— 5.4	— 5.6
June 24, 1928	5	14.8	9.28	10.36	+27.1	+28.3
	10	13.4	9.22	10.66	+41.6	+44.8
	15	7.5	8.62	12.15	+41.5	+54.6
	20	6.3	8.37	12.50	+43.9	+61.6
	25	5.9	8.40	12.62	+46.8	+65.7
	28	5.9	7.85	12.62	+45.2	+67.9
	31	5.8	6.65	12.65	+39.5	+70.8

TABLE VI—Continued

Lake and date	Depth in meters	Temperature in °C.	O_2	O'_2	g	g′
Trout............	0	19.3	8.13	9.51	— 5.1	— 5.5
August 25, 1928	5	19.3	7.89	9.51	+25.2	+28.4
	10	19.3	7.85	9.51	+35.1	+45.0
	12	12.3	6.74	10.90	+32.6	+49.3
	15	9.5	5.99	11.60	+30.2	+55.1
	20	7.5	6.10	12.15	+33.0	+61.1
	25	6.4	4.57	12.47	+25.8	+65.7
	28	6.2	3.80	12.53	+22.1	+67.9
	30	6.1	3.54	12.56	+20.9	+69.1
	32	5.8	2.12	12.65	+12.6	+71.2
Muskellunge......	0	20.2	8.60	9.36	— 5.6	— 5.8
August 26, 1931	5	20.2	8.50	9.36	+27.6	+28.6
	6	20.1	8.80	9.37	+32.8	+32.9
	7	20.0	8.50	9.39	+35.0	+36.5
	8	19.7	6.70	9.44	+30.0	+39.8
	9	17.8	7.60	9.77	+35.2	+42.7
	10	14.8	1.60	10.36	+ 7.4	+45.3
	11	13.0	1.10	10.75	+ 5.1	+47.6
	12	12.0	0.20	10.98	+ 1.0	+49.7
	15	10.2	0.00	11.41	0.0	+55.1
	18	10.0	0.00	11.46	0.0	+59.3
	19	9.9	0.00	11.49	0.0	+60.6
	20	9.8	0.00	11.51	0.0	+61.7

TABLE VII. *This table shows the ratio of the sum of the actual saturation values of the hypolimnion to the sum of the theoretical saturation values in that stratum, together with the elevations of the surfaces of the lakes and the mean barometer readings for such elevations.*

Lake	Date	Elevation in meters	Barometer reading in millimeters	Σg 247.9	$\Sigma g'$ 268.8	$\frac{\Sigma g}{\Sigma g'} \times 100$
Crystal......	Aug. 21, 1928	502	717	247.9	268.8	92.2
Pallette......	Aug. 22, 1928	496	718	215.7	390.0	55.3
Silver.......	Aug. 28, 1931	495	718	214.5	463.2	46.3
Trout.......	June 24, 1928	492	718	258.5	364.9	70.8
Trout.......	Aug. 25, 1928			214.3	484.4	44.2
Muskellunge.	Aug. 26, 1931	501	717	48.7	422.0	11.5

TABLE VIII. *Color, oxygen consumed, dissolved oxygen and organic carbon from a number of northeastern lakes which represent the different types. The color determinations are based on the platinum-cobalt scale and the readings were made with the standard instrument used by the U. S. Geological Survey. The oxygen consumed and organic carbon are expressed in milligrams per liter of water, and the dissolved oxygen in milligrams per liter and in per cent of saturation.*

Lake	Date	Depth meters	Color	Oxygen consumed	Dissolved oxygen		Organic carbon
					Mg.	Per cent	
Adelaide	Aug. 29, 1929	0	45	9.1	9.7	104	8.3
	Aug. 4, 1930	0	32	8.9	7.3	84	7.4
Adella	July 16, 1930	0	18	4.0	8.3	90	2.8
Allequash	July 27, 1929	0	36	7.4	9.4	111	7.4
Anderson	Aug. 8, 1929	0	0	2.0	8.1	88	3.4
		10	8	2.1	11.9	100	3.4
		15	180	2.0	0.5	4	3.3
		18	240	2.2	0.3	2	3.7
Armour	July 12, 1930	0	49	10.2	7.6	84	9.6
Bear	Aug. 18, 1929	0	14	4.2	6.4	68	4.2
	July 11, 1930	0	26	6.3	9.4	106	4.7
Big St. Germain	July 2, 1930	0	32	5.6	9.0	94	5.7
Birch	July 17, 1930	0	78	13.0	8.4	92	12.9
Bird	Aug. 6, 1930	0	8	4.6	7.9	86	4.1
Black (west)	Aug. 18, 1929	0	206	25.6	6.5	69	23.5
Black Oak	July 5, 1930	0	14	4.4	8.6	90	4.0
		15	14	3.5	6.7	56	3.7
		23	30	3.5	1.2	10	4.0
Bog, Cardinal	Aug. 22, 1929	0	35	7.2	6.6	73	6.6
Bog, Forestry	Aug. 22, 1929	0	58	11.8	7.4	82	12.1
Bragonier	Aug. 10, 1929	0	45	9.4	8.3	91	8.1
		6	91	9.4	0.1	1	8.0
		7.5	126	9.6	0.0	0	9.0
Circle Lily	June 26, 1930	0	126	18.0	5.8	65	19.2
Clear (Oneida)	July 8, 1930	0	6	3.0	8.0	87	3.3
Clear Crooked	July 22, 1930	0	18	4.4	7.9	86	3.8
Crab	July 14, 1930	0	40	9.0	6.7	71	9.1
Crawford	July 16, 1930	0	68	12.2	7.4	80	11.8
Crystal	Aug. 20, 1929	0	0	1.9	8.7	91	1.2
		5	0	2.2	8.7	91	1.7
		10	0	2.5	10.8	104	1.6
		15	0	2.5	9.6	83	1.9
		19	Tr.	2.4	8.4	72	1.9
Day	July 23, 1929	0	8	2.9	8.3	92	3.2

TABLE VIII. *Continued*

Lake	Date	Depth meters	Color	Oxygen consumed	Dissolved oxygen Mg.	Dissolved oxygen Per cent	Organic carbon
Dead Pike	July 25, 1930	0	70	9.2	7.6	85	8.5
Deer	Aug. 18, 1929	0	196	22.0	6.8	72	19.6
Diamond	July 9, 1930	0	6	3.5	7.7	85	1.7
Dorothy Dunn	June 27, 1930	0	14	1.2	8.3	90	5.2
Dynamite	Aug. 11, 1929	0	78	13.6	7.0	78	14.8
Echo (Mercer)	Aug. 16, 1930	0	68	12.9	6.6	72	13.7
Edith	June 30, 1930	0	12	3.8	8.1	92	2.1
Fence	Aug. 23, 1929	0	14	2.0	9.7	102	3.8
		5	14	2.6	9.7	101	3.8
		10	14	2.7	9.5	98	3.8
		15	14	2.6	5.3	47	3.1
		20	14	2.7	4.6	40	3.1
		27	16	2.8	3.7	32	3.1
Findler	Aug. 18, 1929	0	150	20.3	6.0	62	14.4
Finley	Aug. 10, 1929	0	0	3.9	6.6	73	4.6
		6	0	4.1	8.4	90	4.9
		7.5	10	4.8	7.0	73	6.2
George	Aug. 24, 1929	0	43	7.9	8.8	94	8.7
		5	43	7.9	4.9	46	8.3
		10	43	7.8	4.8	38	7.7
		15	74	8.0	3.0	23	7.3
		21	220	12.5	0.3	2	10.8
Gunlock	July 3, 1930	0	32	8.3	8.1	87	6.9
Hasbrook	Aug. 7, 1930	0	14	4.6	8.6	99	5.1
Helen	Aug. 18, 1930	0	97	13.3	6.8	72	12.7
Helmet	Aug. 9, 1930	0	268	25.7	6.7	76	25.3
	Aug. 20, 1931	0	260	34.5	6.2	......	......
Henion	Aug. 5, 1930	0	20	7.4	7.6	87	6.5
High	July 1, 1930	0	22	3.8	9.6	102	4.2
Ike Walton	Aug. 2, 1930	0	18	6.8	8.9	99	4.0
Jag	July 24, 1929	0	17	4.8	8.0	90	5.5
Jerems	July 3, 1930	0	8	4.1	8.0	90	3.2
Katherine	Aug. 5, 1930	0	8	5.7	8.2	94	4.4
Kawaguesaga	July 8, 1930	0	16	3.3	7.5	82	4.4
Knife	Aug. 9, 1930	0	230	22.1	7.5	84	21.8
Laura	Aug. 23, 1929	0	14	2.4	9.0	96	3.3
Little Bass	July 5, 1930	0	22	5.4	7.9	84	5.1

TABLE VIII. *Continued*

Lake	Date	Depth meters	Color	Oxygen consumed	Dissolved oxygen		Organic carbon
					Mg.	Per cent	
Little Long	July 24, 1930	0	132	16.7	6.9	76	14.4
Little Papoose	July 18, 1930	0	49	8.9	8.1	88	8.1
Lone Pine	Aug. 8, 1930	0	118	16.4	7.3	84	18.3
Long (Phelps)	Aug. 21, 1929	0	24	5.9	8.0	83	7.9
		5	24	6.0	8.1	84	6.9
		10	24	6.4	5.8	57	6.8
		15	24	5.6	7.0	58	6.4
		20	24	6.0	5.8	47	5.9
		27	35	6.0	3.6	29	6.4
Lost Canoe	Aug. 17, 1929	0	14	3.8	8.5	90	5.8
Mann	Aug. 14, 1929	0	30	7.9	7.9	81	10.4
Marion	Aug. 18, 1929	0	107	15.4	6.8	71	16.6
Mary	Aug. 29, 1929	0	118	19.6	8.5	91	17.1
		3	143	19.9	0.2	2	15.6
		5	151	20.6	0.0	0	15.8
		10	166	21.2	0.0	0	18.7
		15	194	21.5	0.0	0	19.9
		20	252	21.8	0.0	0	22.1
McGrath	Aug. 6, 1930	0	6	3.6	8.1	93	3.1
McKinney	July 26, 1930	0	39	7.9	7.3	84	6.8
Midge	July 9, 1930	0	35	7.9	6.9	78	6.5
Moon	July 2, 1930	0	12	4.6	9.2	98	3.8
Nebish	Aug. 26, 1929	0	0	3.0	8.9	97	4.0
Nelson	Aug. 1, 1930	0	10	4.4	7.6	85	2.7
Nokomis	Aug. 28, 1929	0	20	4.4	10.0	107	5.0
		5	20	4.6	9.5	101	5.8
		10	20	4.0	3.9	35	4.8
		15	32	4.2	2.4	21	4.8
		20	53	4.2	1.4	12	4.5
Oswego	July 1, 1930	0	18	4.1	9.0	97	3.9
Oxbow	July 12, 1930	0	97	15.5	7.2	80	14.9
Pallette	Aug. 26, 1929	0	6	4.8	9.3	101	6.8
Papoose	Aug. 15, 1929	0	20	5.8	8.1	85	6.8
		5	20	6.1	8.3	87	7.0
		12	26	6.0	3.1	26	6.5
		15	38	6.0	0.4	3	7.0
		18	78	7.3	0.2	1	7.1
Pauto	July 9, 1930	0	6	2.8	7.7	85	2.1
Presque Isle	July 15, 1930	0	14	4.5	8.5	90	6.0
Red	July 14, 1930	0	14	6.3	9.8	105	7.1

TABLE VIII. *Continued*

Lake	Date	Depth meters	Color	Oxygen consumed	Dissolved oxygen		Organic carbon
					Mg.	Per cent	
Red Bass	Aug. 9, 1930	0	182	22.2	6.4	72	22.3
Rock	Aug. 18, 1929	0	32	8.3	7.3	76	9.5
Ross Allen	Aug. 16, 1929	0	20	5.0	7.8	79	3.9
Rudolph	Aug. 9, 1930	0	55	11.1	7.4	84	10.0
Sand (Phelps)	Aug. 21, 1929	0	22	5.4	8.6	91	6.4
Silver	Aug. 8, 1929	0	0	3.6	8.8	93	3.6
Snake	June 29, 1930	0	45	7.6	8.1	90	8.8
South Two	Aug. 7, 1930	0	8	4.5	8.0	92	4.8
Sterrett	July 11, 1930	0	16	6.7	8.9	101	4.5
Stormy	July 30, 1930	0	16	5.0	8.6	94	3.8
Summit	Aug. 11, 1929	0	180	16.1	6.6	72	17.7
Tenderfoot	Aug. 26, 1930	0	49	10.1	7.8	87	10.5
Trout	Aug. 11 ,1929	0	6	3.4	9.5	102	4.0
		5	6	3.4	10.0	106	4.0
		10	8	3.5	9.6	100	3.8
		15	8	3.1	8.0	81	3.9
		20	8	2.8	7.6	63	3.3
		25	8	2.7	6.1	50	2.9
		30		2.8	2.6	21	
		33	14	2.9	1.7	14	3.1
Trude	Aug. 25, 1929	0	53	11.2	8.2	89	11.4
Twenty-one	Aug. 25, 1929	0	16	4.1	7.7	87	3.9
Twin Island	Aug. 8, 1930	0	80	13.4	8.6	97	15.4
Two Sisters	Aug. 13, 1929	0	14	2.6	8.5	94	4.7
		5	14	3.1	8.6	94	5.0
		10	14	3.4	7.5	66	4.5
		15	32	2.9	1.9	16	4.1
		18	43	2.3	1.0	8	3.8
Upper Gresham	July 24, 1929	0	19	4.0	8.7	97	4.1
Venus	Aug. 11, 1929	0	118	16.3	8.1	90	16.6
Vieux Desert	July 27, 1930	0	42	8.6	8.0	80	8.2
Walker	Aug. 28, 1930	0	35	7.3	8.4	93	6.6
Weber	Aug. 21, 1929	0	0	2.1	9.0	95	2.5
		8	0	2.5	9.9	94	2.7
		12	8	3.2	8.0	72	2.2
Wheeler	Aug. 28, 1929	0	0	2.6	9.0	98	2.8
White Sand	July 22, 1930	0	20	4.2	6.9	75	4.9
Wild Cat	July 22, 1930	0	26	8.0	6.8	72	7.9
Wind Pudding	Aug. 25, 1929	0	20	4.9	8.0	88	5.3
Wolf	July 22, 1930	0	32	6.9	8.2	88	6.3
Yolanda	Aug. 18, 1929	0	118	16.6	6.8	72	15.4

TABLE IX. *The color of the surface samples and the minimum, maximum and mean quantities of oxygen consumed by the waters belonging to the different color groups. The color readings are based on the platinum-cobalt standard and the oxygen consumed is expressed in milligrams per liter of water.*

Number of samples	Color range	Oxygen consumed		
		Minimum	Maximum	Mean
62	0—9	1.2	7.6	3.7
93	10—19	1.4	7.6	4.7
51	20—29	2.2	10.5	6.0
45	30—39	3.1	10.1	7.3
26	40—49	3.8	12.3	8.6
16	50—59	4.2	15.7	10.5
19	60—79	7.4	17.9	12.2
21	80—109	7.0	20.3	13.7
21	110—149	9.4	22.6	15.9

RACES, ASSOCIATIONS AND STRATIFICATION OF PELAGIC DAPHNIDS IN SOME LAKES OF WISCONSIN AND OTHER REGIONS OF THE UNITED STATES AND CANADA.

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Notes from the Limnological Laboratory of the Wisconsin Geological and Natural History Survey. No. L.

INTRODUCTION

There are three very different groups of aquatic animals which show most clearly the recent differentiation of races after their immigration into the postglacial lakes of Europe and North America. These are the coregonids among the fishes, the pulmonates among the mollusks and some cladocerans (Daphnia and Bosmina) among the pelagic crustacea. The differentiation of inheritable races of these animals is one of the last evolutional changes in the animal kingdom except the differentiation of some parasites and of the domesticated animals. Local differentiates in postglacial lakes can not be much older than 10,000 to 20,000 years, because these bodies of water did not become habitable until after the retreat of the ice.

The factors determining the differentiation of these three kinds of animals have been the same presumably, namely, changed environment (acting directly or indirectly), isolation and the internal tendency or potentiality to react by proper alterations to changed external influences.

A comparison of the recent races of coregonids, pulmonates and daphnids shows some important differences, but principally a striking resemblance in the general process of differentiation. The local races and the so called species and subspecies of the freshwater coregonids are well known; there are hundreds of them in the United States and Canada and some dozens in Europe. We know their geographical origin; they were derived from marine fishes which migrated into the lakes only temporarily at the spawning season at first and later became established permanently in the lakes. Here they have become differentiated into local and ecological forms, such as inhabitants of the pelagic zone, of the deep water and of the shore region. Many of the observed differences are certainly inheritable characters, while others may be only modifications; it is a pity that experimental investigation of these races is almost impossible since they will not survive in aquaria or small ponds for any considerable period of time.

The differentiation of some of the freshwater pulmonates is fairly well known relative to their paleontological history because their shells are found in the aquatic sediments of earlier periods, especially of the Pleistocene. In this group of animals the recent differentiation and multiplication of species and races, in comparison with the periods before the existence of the present postglacial lakes, are especially well known. If we take as examples the lacustrine pulmonates of Illinois, investigated by F. C. Baker, we find 31 recent species and some older ones in the latest deposits of that region, but only 13 species in the deposits of the early Wisconsin period, and between 2 and 9 species in the deposits of earlier Pleistocene intervals (Peorian, Sangamon, Yarmouth). The few species of Stagnicola, Fossaria, Helisoma and Physella living at the beginning and during the earlier part of the Pleistocene have been split up and differentiated from each other since the recent lakes came into existence. There are, in addition to the larger systematic units with more or less prominent differences in internal structure, a certain number of smaller local differences relating to dimensions and shapes; these latter are described by Baker as variations. He found similar varieties in artificial lakes also, in habitats where the changes have taken place during a period of less than a century. Again we do not know which of these smaller local peculiarities are modifications only and which are more than that, but probably Baker is right in considering some of these young differentiations as species, or at least races, in the making.

The differentiation of local races in Daphnidae and Bosminidae has peculiar features as compared with those of the coregonids and mollusks. There are innumerable local differentiates and we know by experimental cultivation under definite and varied conditions that these races in most instances are hereditarily different. Almost all of these innumerable races of Cladocera of postglacial lakes belong to only four species: *Daphnia longispina* and *D. longiremis* in Europe, Asia and America, *Daphnia pulex*[1] in America and *Bosmina coregoni* in Europe. Other variable species, usually distinguished but not sharply distinguishable from *Daphnia longispina* or *Daphnia pulex,* such as *D. cucullata* and *D. retrocurva,* indicate only groups or series of differentiates within these species, which are themselves connected by transitional forms. So there are only a very few exploding species which have produced all of this immense richness of endemic differentiates in postglacial lakes.

THE PELAGIC DAPHNIDS OF NORTH AMERICA

The various forms of daphnids that are distributed all over the earth fall into two very different groups[2]. The first group contains the above named three species and their subspecies, all very near to *Daphnia pulex* and to *D. longispina.* These two species are found in all continents, so that they seem to be rather old; their undifferentiated forms ("primitiva" Burckhardt) are of preglacial origin; *D. pulex* appears as large, heavy animals living in all kinds of freshwater ponds, bogs and pools, sometimes together with *D. magna,* while *D. longispina* prefers the open water of the same ponds and of freshwater lakes. Following the same line of development from littoral to pelagic organisms, many different daphnids of the plankton of American and European lakes have been derived from this *D. longispina,* such as *hyalina, galeata, mendotae* and so forth, and also the whole series of forms called *D. cucullata* (in Europe and Asia) and the northern species *D. longiremis* and *D. cristata*; the latter is found only in Europe and it is closely related to *longiremis.*

The second group is very different from this one; it contains *Daphnia magna* and some related species, some of them living as pelagic animals in tropical and subtropical lakes of Asia, Africa and Australia. These pelagic "M-daphnids", being mor-

[1] This species is abundant in all continents, but it is split into many very different shapes and races only in North America.

[2] See Woltereck 1919. The nomenclature applied in this paper and in other publications of the author will be treated in a special article next year.

phologically and geographically very different from the other group ("P-daphnids"), have nothing to do with postglacial lakes and are not found in North America, northern Europe or northern Asia[3] The continents and their lakes are divided between the derivatives of *Daphnia longispina* and *D. pulex.* The former has been well developed in all of these continents, but we find their terminal pelagic races only in northern Eurasia as the *cucullata* series. *Daphnia pulex* has no pelagic development in Europe and Asia, but a very strange and manifold pelagic differentiation in North America. The third species, *Daphnia longiremis,* is found in the high northern latitudes of Scandinavia, in Alaska, and in the cold water of the hypolimnion of some Wisconsin lakes. (See Plate XVIII).

The Daphnia pulex Series

The differentiation of the American *pulex* derivatives shows the same peculiar trend as the differentiation of *Daphnia longispina*→ *hyalina* (*galeata,* etc.)→ *cucullata*→ *longiremis* and as the other series *Daphnia magna*→ *barbata*→ *lumholtzi*→ *cephalata*; that is, in the direction from littoral life to pelagic life. This tendency in the American *Daphnia pulex* we see developed or developing in various ways and with very different morphological results. (See Plates XIII and XIV).

1. There are many populations of *Daphnia pulex* and some of *Daphnia pulex obtusa* living in the plankton of large and of small lakes without any alteration of the body except a certain transparency. This single physiological and ecological differentiation of the originally littoral (benthonic) animals occurs, for instance, in Lake Erie, and in Devils, Nebish, Clear and many other Wisconsin lakes.

2. There are some differentiates of *Daphnia pulex* that show no other visible alteration than a modest crest as a beginning elongation of the head (Plate XIII, fig. 2). A race like this is living in Nebish Lake, for instance, together with the usual short headed form of this water flea.

3. In the western part of the United States, there are populations of *Daphnia pulex,* first described by Forbes from the Yellowstone Park lakes as *D. clathrata* and *D. arcuata,* with

[3] A species of the M-group occurs also, as I found recently, on Kauai, Hawaiian Islands.

elongated shape, slightly elongated head and with an alteration of the postabdomen (claw). I found similar forms in Clear Lake, California, and in some other lakes in California. The Clear Lake Daphnia has characters of *clathrata* and of *arcuata* together, so that it is not possible to apply one of these names to this form; it may be best to distinguish all races related to these forms as the *pulicoides* series or subspecies of *Daphnia pulex.* The diagnostic characters of these subspecies are: elongated shape of the shell, in some races also of the head, long terminal spine which may be straight or curved, large eye and ocellus, claw with fewer (2-5) and longer teeth in the distal pecten as compared with the main type of *Daphnia pulex.*

4. In Wisconsin and other middle western lakes, in the Great lakes and also in many of the eastern lakes of the United States and Canada, the most interesting derivatives of *Daphnia pulex* are found; they are small animals with elongated shell and in most cases elongated head (helmet), with a small eye and without any eye spot or ocellus (pigment of the primary eye), and with a pecten that contains more numerous and shorter teeth than the main type of *Daphnia pulex.* Daphnids of this kind have been described as *Daphnia retrocurva* by Forbes and as *Daphnia breviceps* by Birge; the latter are races without a helmet. In some lakes of Wisconsin, Minnesota, and Canada, there are many other shapes of the head, such as round helmets not curved and long, pointed helmets like the European *cucullata,* but combined with the claw of *Daphnia pulex.* All of these small transparent *pulex* forms without an eye spot appear to be members of the same group which we can not call *retrocurva* or *breviceps.* So it may be advisable to apply a comprehensive name and call all of these races the *parapulex* series of *Daphnia pulex.* By using these two names for the two different series, we avoid the use of a number of new systematic names for the races which are on the same level as *retrocurva* and so forth. *Retrocurva* and *breviceps* or *brachycephala* remain as important indications of certain shapes which occur in *Daphnia pulex* as well as in *Daphnia longispina (hyalina)* and in *Daphnia longiremis,* but they can not be used as specific names.

The most remarkable daphnids of this series are the *retrocurva* forms of some of the smaller lakes, such as lakes Mendota and Wingra; in the Great lakes the development of the helmet is much inferior (Plate XIV, figs. 6-9) to that developed by the races of the Wisconsin lakes. The extreme elongations of these heads are to be compared only with the extreme pelagic helmets of some races of *cucullata* (derived from *longispina*) and of *cephalata* (derived from *magna*). These races are indeed the "terminal races" (Grinnell) of the polymorphic genus Daphnia, each one a terminus in a different series, parallel to the others, but independent of them.

The center of the differentiation of these *retrocurva* forms seems to be located in southern Wisconsin, where the pelagic life may be somewhat older than that of the Great lakes, the latter presumably becoming inhabitable for pelagic algae and crustacea much later than the smaller and shallower lakes.

Another shape of the *parapulex* daphnids has been developed in Minnesota, where daphnids with very much elongated but not distinctly curved helmets (Plate XIV, figs. 12-13) are found in Bemidji and Vermilion lakes. A similar shape is found in some very distant lakes in eastern Canada in material which was kindly shown me by Dr. Klugh of Kingston.

Daphnids of the same group with shorter helmets, not curved beyond the dorsal side, are rather common in Wisconsin and in other lakes as well as in some of the Great lakes. Races like *breviceps* are found in a large number of the smaller lakes of Wisconsin, often together with a helmeted race of the same group, the *breviceps* being found chiefly in the deeper strata of these lakes as indicated in the tables.

Besides the regional "centers" of development of certain shapes in these daphnids, we have to consider the fact that the whole, or at least the main, differentiation of the *parapulex* forms is confined to the region of the northern glaciation in and around Wisconsin, reaching to about Oneida Lake in the east and to some parts of Minnesota in the west, but not extending very far south of this area. On the other hand the differentiation of the *pulicoides* forms (*clathrata,* etc.) seems to be confined entirely, or at least mainly, to a western region, out of the reach of the northern glaciation and outside of the lakes remaining after the retreat of the last enormous ice sheet (Plate XIII, figs. 3a-5b).

A close examination of the preglacial distribution of the different types of American daphnids is very desirable and may afford a better understanding of these trends of evolution.

Since I am now preparing a monograph of the pelagic daphnids of the world and realize especially the great importance of their distribution in North America, I should be greatly pleased to receive plankton samples collected during the summer months from as many North American lakes as possible[4].

The Daphnia longispina Series

The American races of *Daphnia longispina* are not quite so interesting as the *D. pulex* series; the difference between the American and the European development of this species is not very large, and in this case in favor of Eurasia where the extremes of this development are found. If we exclude the special differentiation of the *D. cucullata* series, the number of the pelagic differentiates of *Daphnia longispina hyalina* is larger in North America than in Europe. More important is the fact that the character of the American shapes of this species is different from that of the European shapes, although these animals are living on both continents in about the same types of postglacial lakes and under about the same range of conditions. The predominant forms in Europe are those with pointed heads *(galeata)* very often with procurved helmets *(procurva)*, round heads of the *pellucida* type, and the true *hyalina* form. (Plates XV and XVI).

In about a hundred American lakes, most of them in Wisconsin, we find arched heads like the "lancet arch" of the architects, or others like the "rampart arch"; some have slender and pointed heads which are retrocurved and with an elongated rostrum (Plate XVI, fig. 26, "nasuta"); there are also strangely curved heads and helmets like a rococo ornament and low, tent-like heads of some races living in the Great lakes and in the deeper strata of smaller lakes (Plate XVI, figs. 27, 28).

More important than these single differences, but much more difficult to explain, is the fact that there is a common style of all of these different American shapes and another general style of all of the Eurasian types. After examining more than a hundred American races as well as a large number of European and some Asiatic types in the past 20 years, I feel able to recognize every race of *Daphnia longispina* as either American or Eurasian without knowing its locality. One type of *D. longi-*

[4] Address: Biolog. Laboratorium, Seeon bei Obing, Bavaria, Germany.

spina is common to some European and American lakes; it has a round head without any helmet and has been called *"primitiva"* by Burckhardt. It is found not only in this, but in all species of the P-series of Daphnia. There is, however, a physiological and ecological peculiarity of some of the *"primitiva"* races of *D. longispina* in North America. They are very small dwarf-like races living in the deep water of some lakes that are not eutrophic, being found in the cold, dark hypolimnion near the bottom. The same small *primitiva* type of *Daphnia longispina* may live in small shallow lakes and in ponds, but in a quite different way, namely near the surface as they do in some European ponds and small artificial lakes, in municipal parks, for instance. (Plate XV, figs. 15, 16).

In some warm California lakes (Clear, S. Andreas, Upper and Lower Crystal and others), I found the same *primitiva* type of *D. longispina* without any elongation of the head, and a form like this is living in the warm Lake Victoria Nyanza in East Africa and in other tropical lakes. (Plate XVI, fig. 22). I saw the same form in material collected by Prof. Juday in the very deep Lake Atitlan in Guatemala, while in another lake of the same region, the shallow Lake Amatitlan, a race with elongated head *(galeata)* was found. (Plate XVI, fig. 23).

Similar daphnids of the same species, without any elongation of the head, are also common in the cool lakes of the mountains of North America as in those of our European Alps. It seems that they have this kind of shape in all lakes, hot or cold, when they are living and migrating within a thick layer of water, but they develop elongated, procurved or retrocurved heads only in lakes where they have to live and migrate in a distinctly stratified medium and within rather narrow layers of water. The effect of these elongations and curved rudders seems to be that the originally steep direction of swimming (jumping) becomes more or less horizontal. The animals living in narrow layers only 2 m. or 3 m. thick are moving upwards and downwards in directions of small elevation; if they have to migrate in about 12 hours from a depth of 50 m. to the surface, the elevation of their movement has to be a much steeper one.

The Daphnia longiremis Series

These animals, easily distinguished by their elongated swimming antennae, have been found in northern Norway and Sweden by Sars and Lilljeborg. I found them in plankton material from Karluk Lake, Alaska, and Dr. Birge found the same form in Wisconsin lakes many years ago. I saw these strange little daphnids in the plankton of 8 Wisconsin lakes out of about 40 examined and in one out of 6 Indiana lakes. In all cases they were found only in the cool water below the thermocline. They live near the bottom if there is enough oxygen, and near the thermocline if there is a lack of oxygen in the deeper strata. If all of the hypolimnion is without oxygen for some time during the year, such lakes are not inhabitable for cold water organisms like *Daphnia longiremis.* (Plate XVII).

In lakes where the water is well supplied with oxygen from thermocline to bottom these races have no elongation of the head, while other local races living for some months in a narrow layer between the thermocline and the oxygen-free depth, develop prolongations of the head, either straight or retrocurved helmets (Plate XVII, figs. 33-35). This indicates again that not the high temperature of the water but its stratification and the necessary change in the direction of swimming are the factors determining the peculiar prolongations and the curved "rudders" attached to the head of so many pelagic daphnids and bosminids. (See Woltereck 1928).

Associations of Pelagic Daphnids in Some American Lakes

There is a very conspicuous difference between the lakes of the old and the new world, even if we compare only lakes of about the same size, the same history (as glacial relicts) and the same conditions of temperature, light, oxygen, pH and so forth. In European lakes of this kind, we find only one or two differentiates of pelagic daphnids; if there are two, they belong almost always to different series, such as *longispina* and *cucullata.* Most of the Wisconsin lakes that I have been able to examine closely enough contain more than two differentiates; the average of 22 lakes from which I have examined living material of all strata, is three to four different races for one lake. All of these lakes have a maximum depth of only 20 m. to 30 m. except Trout Lake which is 35 m. deep.

One reason for the greater number of races in these small American lakes and for only one or two races in similar and also in much larger and deeper European lakes, is the fact that there are only two pelagic species or series *(longispina* and *cucullata)* in Europe, while there are three pelagic species in America, namely *longispina, pulex* and *longiremis.* But this explanation is not sufficient; there is another and more interesting difference. If we have two different races in a single European lake, one is invariably a *longispina* race and the other a *cucullata* race. Many American lakes of the same postglacial character, on the other hand, contain two races of *longispina* or two races of *pulex (parapulex).* Crawling Stone Lake, for instance, which has a maximum depth of 28 m., contains one *pulex,* two different *parapulex* races, one *longispina* and one *longiremis* race. It is not possible at the present time to explain this kind of polymorphism in American lakes of the usual postglacial type.

I have examined plankton material from a large number of other lakes in Wisconsin, Indiana, Michigan, Minnesota, New York, Ontario (Canada) and from the Great lakes, but not complete series from all depths, only occasional samples; from this material I have obtained the impression that the usual association of pelagic daphnids in the eastern part of the United States is one smaller race of *parapulex* (mostly *retrocurva*), and one larger race of *longispina* (mostly *mendotae* or *galeata*). This is similar, ecologically, to the common association of one *longispina* with one smaller *cucullata* in Europe. Many American lakes contain, in addition to this "standard association", one of the common *pulex* races and in some instances a race of *D. longiremis* is found. The Great lakes, which have not been very thoroughly investigated so far, seem to contain a number of races with different and characteristic forms in the different parts of each lake, such as found in Lake Erie for example. In Ontario, Oneida, Nipigon and Simcoe lakes, I found the same association of *parapulex* and *longispina (galeata* or *mendotae).* In Clear Lake (California) I obtained two races of *longispina* (one large and helmeted, the other very small and short—*primitiva),* and one *D. pulex (pulicoides).* In San Andreas and the two Crystal lakes near San Francisco, I saw one large and helmeted *D. longispina,* a small *primitiva* form of the same species — both very near to the Clear Lake populations —, one large *D. pulex (obtusa),* and another *pulex* of the *pulicoides* type. In many of the lakes in the Sierra and Rocky mountains, simpler associations of *Daphnia longispina* and *D. pulex* are found.

Some of the Wisconsin associations are represented in Tables I to XII. Future work may account for some of these different types of communities, but we do not understand most of these differences at present, in spite of the fact that the physical and chemical conditions of the Wisconsin lakes are so well known. One example will show that it is still too early to discuss the relation between environmental conditions and these associations. I wished to understand why *Daphnia longiremis* is present in some lakes and not in others when the conditions of temperature and oxygen are about the same. I was glad to see that the first 7 lakes where I found this small species in the hypolimnion, all contained hard water, with between 10 mg. and 25 mg. of fixed or bound carbon dioxide per liter; but the next lake in which I found a colony of this same species was Big Carr, which has very soft water, or an average of less than 2 mg. of fixed carbon dioxide per liter. The shape of the animals of this race is very different from that of all of the other races; Big Carr Lake contains a race similar to Lilljeborg's *D. longiremis* from Storsjőn in Jemtlandia (Table XX, Plate XIV, fig. 13). This lake is situated in the granite region of northern Sweden and presumably contains very soft water. But the presence of this species in some lakes and its absence in others is not understood at present.

Stratification of Pelagic Daphnid Populations in Some Wisconsin Lakes

I had a good opportunity to examine the vertical distribution of the various daphnids in 16 very different lakes in northeastern Wisconsin with a most effective instrument for such an investigation, namely a plankton trap. Most of the catches were obtained by Prof. Juday personally or by one of his trained assistants; the night catches were secured by Mr. Baum and myself. Each catch represents the pelagic animals of 10 liters of water, and all of the daphnids present in a sample have been counted and not estimated. These observations were made during my visit at the Trout Lake Limnological Laboratory of the Wisconsin Survey.

The results of these catches and countings are represented in Tables I to XII, which show the vertical distribution of the different populations of daphnids in the several Wisconsin lakes. In the different series, the catches were taken at intervals of 2 m. to 5 m.; the numbers of young, adult (egg bearing), and the total number of daphnids in each 10 liter catch, are given in the tables. There were almost no males during the time of this investigation, which extended from August 20 to September 9, 1931. The maxima of each race in every vertical series are indicated in the tables in italics; the position of the thermocline is shown by a broken line.

The stratification of the different daphnids living in the same body of water seems to be sufficiently expressed by the location of the maxima; the total "zone of habitation" of every race can be estimated if we neglect the very small numbers (less than 10 per cent of the maximum) which are found in the lower strata and which possibly represent dying or moulting specimens that sink below their normal habitat.

The results shown in the tables may be distinguished as follows:

1. They confirm plainly the earlier statements made by Juday (1904) that the helmeted daphnids in Wisconsin lakes live above the short headed ones, and similar observations made later by Dr. Ter-Poghossian (1928) and others in lakes near Seeon in Bavaria. A report on the "zonare Verteilung der helmlosen und der helmtragenden Biotypen von Daphnia" has been published by Woltereck (1930). The new investigation of the vertical distribution in some Wisconsin lakes has produced an unexpected variety of other results. Some of these results will be published after the examination of the stratification of the nannoplankton algae is completed, but some others may be discussed in this connection.

2. There are great differences in the thickness of these racial "zones of habitation" in the different lakes; the zones range from a thickness of about 15 m. or 20 m. for *Daphnia longispina* in Fence and Trout lakes to only 1 m. or 2 m. for *Daphnia longiremis* in Muskellunge Lake.

3. The latter case is especially interesting because this is a population of cold water animals that usually lives near the bottom, but it is compelled to live temporarily in a very thin stratum of water just below the thermocline in Muskellunge and some other lakes owing to a lack of oxygen in the deeper strata. The main point is that these populations of *D. longi-*

remis develop elongations of the head, namely straight or retrocurved helmets, while the other races of the same species living in lakes that possess enough oxygen to enable them to occupy the whole hypolimnion, are of the same short headed shape as the races living in lakes of Alaska and northern Scandinavia.

4. We found populations of pelagic daphnids in the hypolimnion which belong to three different types, but which are very similar in shape. After Juday, Kikuchi (1930) was the first investigator who described special populations of Cladocera and other plankton organisms that were confined to the hypolimnion of some Japanese lakes during the summer months; he found round headed populations of *Daphnia longispina* in this situation.

In Day Lake, Wisconsin, there is a population of small *D. longispina (primitiva)* with round heads living between the thermocline and the bottom, that is, between 9 m. and 15 m. In Dead Pike Lake, there is a population of large *D. longispina (apicata)* living between 10 m. or 14 m. and 21 m. Also there are many populations of *Daphnia longiremis,* all living below the thermocline; they are always found near the bottom if there is enough oxygen in the deepest layers, as in Trout Lake, Wisconsin and in James Lake, Indiana, for instance. In these lakes they seem to be concentrated especially in the deepest holes. In Trout Lake we found 300 individuals in a 10 liter catch taken at 31 m. (1 m. above the bottom) in the afternoon, while in the late evening of the same day when the buoy marking the 32 m. water could not be found, we obtained only 36 individuals in a 10 liter catch taken at 30 m.

5. Some series of catches taken about 9 p. m. in Trout Lake and in Day Lake show the beginnings of an upward migration of some but not of all populations in these lakes. The maxima of *Daphnia longispina (galeata)* and of *parapulex (retrocurva)* in Trout Lake are nearer the surface at this time; the first moves upward from 5 m. to 3 m. and the latter from 12 m. to 5 m., while the position of the deep water population of *Daphnia longiremis* is unchanged. (See Table IX).

In Day Lake the maximum of *D. longispina (nasuta)* is transferred from 7 m. at 4 p. m. to 5 m. at 9 p. m. and 17 specimens were found in the 10 liter catch made at the surface in the evening where none was found at this depth in the afternoon. The maximum of *D. longispina mendotae* moved upward somewhat in the evening, that is, from 10 m. at 4 p. m. to between 7 m. and 9 m. at 9 p. m. In this lake also the maximum of the *primitiva* form of *D. longispina* moved from 14 m. at 4 p. m. to 11 m. at 9 p. m.; a very large maximum (swarm ?) was found at the latter depth in the evening. No specimens were present in the 7 m. catch, which was in the upper part of the thermocline, or in the catches taken nearer the surface. (See Table X.)

6. Two other results, or questions for further investigation rather than definite results, can only be indicated at present because the number of ascertained facts concerning them is now too limited to permit an explanation of these phenomena.

In some lakes, such as Trout, Fence and Big Carr, we find *Daphnia longispina galeata* occupying a thick stratum of water; in Trout Lake and Fence Lake they extend from the surface to a depth of 20 m. and in Big Carr Lake from the surface to 12 m. All of these populations are living both above and below the thermocline, and this is true also of the same species in many European lakes.

In Trout Lake there are two distinct maxima of this race, but I could not distinguish any morphological difference between those living in the epilimnion and those found in the hypolimnion. There may be a physiological difference, and surely there must be an ecological difference between the animals living in the warm upper water and those found in the cool water below the thermocline. In Day Lake there are two different races of the same helmeted *Daphnia longispina*; one is a slender form *(nasuta)* living above the thermocline and the other is a heavy form *(mendotae)* which lives in the thermocline, with a maximum at 10 m. at 4 p. m. and between 7 m. and 9 m. at 9 p. m.

The questions that we cannot answer at present regarding these forms are as follows: Have these two races been differentiated within this same lake, at first ecologically, then physiologically and at last morphologically? Or have they been introduced into these lakes from elsewhere as already differentiated races? Further investigation, both ecological and experimental, are necessary before these questions can be answered.

7. The same applies to another observation and question. Different species which live in the same lake under identical conditions, near the bottom or near the thermocline for instance, show the same or a very similar shape of the head in many cases. We have experimental evidence in European forms that such characteristic shapes are not only modifications but inheritable peculiarities of the different races.

I wish only to mention this fact and to indicate as a striking example the two races *Daphnia longiremis* and *D. longispina* which live at the same level in Dead Pike Lake and which have the same short, tent-like head. (See Plate XVII, fig. 31). Other examples are the local races of *Daphnia pulex (parapulex)* and of *D. longispina (hyalina)* in Silver, Muskellunge and some other lakes. These inheritable local characters induced by certain conditions as well as the complexities concerning the general "style" of such features and shapes, and their regional distribution in America, constitute the most important subjects of future investigations in this field of limnology. Today we are only at the beginning of this kind of ecological, and at the same time genetical, research.

Some General Results

Taxonomic. All American (and European) races of pelagic daphnids have been derived from two main species that are very nearly related, namely *Daphnia pulex* and *Daphnia longispina.* Each of these *species* has been split into numerous *races* which form a few very distinct *series* or *subspecies. Daphnia pulex* occurs in America mainly in four series, as follows: *Daphnia pulex pulex; Daphnia pulex obtusa; Daphnia pulex parapulex* (including *retrocurva* and many others); *Daphnia pulex pulicoides* (including *clathrata* and others).

Biogeographic. a. The third American species, namely *Daphnia longiremis,* which is closely related to *D. longispina,* is an arctic form. It is found in northern Scandinavia and in Alaska, and it has developed some local races which are now living in the cold deep strata of some Wisconsin and Indiana lakes. It is very probable that these forms occur also in Canadian lakes.

b. The pelagic series of *Daphnia pulex (parapulex* and *pulicoides)* have been developed only in North America; the differentiation area of *parapulex* is located in the postglacial lakes of the northern and eastern part of the continent, while the differentiation center of the *pulicoides* series seems to be located in the western part of the United States.

c. The geographical distribution of five of the main groups of daphnids is shown in Plate XVIII.

Ecologic. *a.* There are some definite and different *associations* of pelagic races of Daphnia in American lakes; from three to five races are found in the associations noted in Wisconsin lakes, but only one or two occur in the associations observed in European lakes.

b. Every lake that has stratified water in summer, contains during that time a clear stratification of the different populations or races of Daphnia. Some associations belong to the epilimnion, others to the thermocline and still others to the hypolimnion.

c. The differences between the populations living in the different strata of the same lake may be only ecological and physiological in character, or they may be morphological characters of ecological value in relation to the necessary direction of swimming as determined by the shape of certain appendages of the head.

Genetic. *a.* Three orders of inheritable characters may be distinguished: *Local* peculiarities of the races; *regional* qualities of groups of local types; *continental* "style" of all American and of all European races of *Daphnia longispina* for instance.

b. Racial characters in pelagic daphnids show a close correlation with the special conditions of life in most cases (see above). This correlation proves that alteration of racial qualities in daphnids is either caused or directed by certain environmental factors.

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TABLE I. *Vertical distribution of Daphnia in Nebish Lake on August 29, 1931. The figures in italics represent the maxima.*

Depth in meters	Temperature °C.	*Daphnia pulex pulex* (brachycephala)			*Daphnia pulex pulex* (dolichocephala)		
		Juv.	Adult	Total	Juv.	Adult	Total
0	19.0	....	....	....	....	....	....
3		4	....	4	19	4	23
5	19.0	8	....	8	29	7	*36*
8		1	....	1	5	2	7
9	17.2	43	14	*57*	6	5	11
....	....	....	thermocl	ine........	....	....	....
10	12.9	5	8	13	2	4	6
12	10.4	....	2	2	....	1	1
14		....	....	....	....	....	....
15.8	9.7	....	....	....	....	....	....

TABLE II. *Vertical distribution of Daphnia in Little Long Lake on August 25, 1931 The figures in italics represent the maxima.*

Depth in meters	Temperature °C.	*Daphnia pulex pulex*			*Daphnia longispina apicata* (galeata)		
		Juv.	Adult	Total	Juv.	Adult	Total
0	21.6	....	....	....	4	....	4
3	21.1	....	....	....	5	1	6
....	....	....	thermo	cline.....	....	....	....
5	13.8	1	....	1	4	....	4
8	8.4	1	....	1	5	2	7
13	6.8	3	1	4	3	8	*11*
17	6.5	2	3	*5*	....	....	....

TABLE III. *Vertical distribution of Daphnia in Weber Lake on August 25, 1931. The figures in italics represent the maxima.*

Depth in meters	Temperature °C	*D. pulex pulex* (brachycephala)			*D. pulex parapulex* (breviceps)			*D. longispina apicata* (galeata)		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
0	20.6	......	......	......	......	......	......	......	......	......
1	......	......	......	......	......	......	......	1	......	1
3	......	......	......	......	......	......	......	4	1	5
5	20.4	......	......	......	......	......	......	5	3	8
8	20.2	......	......	......	1	1	2	7	2	*9*
9	15.4	......	......	......	..ther	mocli	ne....	......	......	......
10	14.0	1	......	1	9	4	*13*	1	6	7
13	11.8	2	3	*5*	4	3	7	......	2	2

TABLE IV. *Vertical distribution of Daphnia in Silver Lake on August 28, 1931. The figures in italics represent the maxima.*

Depth in meters	Temperature °C	*D. pulex parapulex* (retrocurva)			*D. longispina apicata* (galeata)			*D. longiremis* (primitiva)		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
0	20.2	......	......	......	......	......	......	......	......	......
3	......	......	......	......	1	......	1	......	......	......
5	20.2	......	......	......	......	1	1	......	......	......
8	18.8	......	......	......	......	4	4	......	......	......
9	14.7	......	......	......	..ther	mocli	ne....	......	......	......
10	11.4	5	2	7	4	1	*5*	2	......	2
12	8.6	3	6	*9*	......	2	2	10	3	13
15	7.2	......	2	2	......	......	......	7	10	*17*
18	6.8	......	2	2	......	2	2	1	5	6

TABLE V. *Vertical distribution of Daphnia in Dead Pike Lake on September 2 1931. The figures in italics represent maxima.*

Depth in meters	Temperature °C.	*D. pulex parapulex* (retrocurva)			*D. longispina apicata* (brachycephala)			*D. longiremis* (brachycephala)		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
0	16.4	4	1	5	...	...	...	...	...	...
3	...	8	6	14	...	...	...	...	...	...
5	...	13	8	*21*	...	...	...	...	...	...
8	15.6	3	1	4	...	...	...	...	...	...
9	14.0	...	...	...	..ther	mocli	ne....	...	...	...
10	10.9	4	5	9	2	...	2	...	...	...
12	9.0	1	3	4	1	...	1	...	...	...
15	8.8	...	3	3	...	2	2	3	2	5
18	8.6	...	1	1	3	6	9	11	3	14
20	...	...	1	1	4	11	*15*	9	15	*24*
22	8.4	...	...	...	1	2	3	1	2	3

TABLE VI. *Vertical distribution of Daphnia in Big Carr Lake on September 5, 1931. The figures in italics represent maxima.*

Depth in meters	Temperature, °C.	*D. longispina apicata* (dolichocephala)			*D. longiremis* (dolichocephala)		
		Juv.	Adult	Total	Juv.	Adult	Total
0	18.0	...	...	...	...	...	...
3	17.8	15	6	21	...	...	...
5	17.3	8	32	40	...	...	...
8	17.0	21	26	*47*	1	...	1
9	13.4	...	...	.thermoc	line....	...	...
10	11.0	28	13	41	3	2	5
12	8.8	8	5	13	46	31	*77*
15	8.0	...	3	3	3	4	7
18	7.8	...	1	1	...	...	...
20.5	7.6	...	...	...	...	...	...

TABLE VII. *Vertical distribution of Daphnia in Presque Isle Lake on August 31, 1931. Cloudy. Figures in italics represent maxima.*

Depth in meters	Temperature, °C.	*D. pulex parapulex* (retrocurva)			*D. longispina apicata* (galeata)			*D. longiremis*		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
0	17.0	6	...	6	2	6	8	...	...	...
3	17.0	21	4	*25*	7	2	9	...	...	...
5	17.0	5	2	7	17	24	*41*	...	...	...
10	17.0	6	3	9	17	19	36	...	...	...
12	14.2	...	...	...	..ther	mocli	ne....	...	...	...
15	11.7	2	4	6	5	8	13	2	...	2
17	...	...	...	...	2	5	7	...	1	1
19	...	...	1	1	...	3	3	...	...	...
20	11.2	...	...	...	1	3	4	...	...	...
23	11.0	...	...	...	...	...	...	...	...	...

TABLE VIII. *Vertical distribution of Daphnia in Muskellunge Lake on August 26, 1931. The dissolved oxygen amounted to 0.21 mg. per liter at 12m.; none was found at 15m. and below that depth. Figures in italics represent maxima.*

Depth in meters	Temperature, °C.	*D. pulex parapulex* (retrocurva)			*D. longispina apicata* (galeata)			*D. longiremis* (retrocurva)		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
0	20.2	......	......	......	3	......	3	......	......	......
5	20.2	......	......	......	29	5	34	......	......	......
8	19.7	3	2	5	31	15	*46*	......	......	......
9	17.8	7	14	21	22	17	39	......	......	......
		......	......	......	..ther	mocli	ne....	......	......	......
10	14.8	21	12	*33*	3	5	8	21	31	*52*
12	12.0	2	4	6	1	1	2	......	2	2
15	10.2	......	......	......	......	......	......	......	......	......
18	......	3	3	6	......	2	2	......	......	......
20.3	9.8	......	......	......	......	......	......	......	......	......

TABLE IX. *Vertical distribution of Daphnia in Trout Lake on August 21, 1931, at 2:30 and 9:00 p. m. respectively. Figures in italics represent maxima.*

Depth in meters	Temperature, °C.	*D. pulex parapulex* (retrocurva)			*D. longispina apicata* (galeata)			*D. longiremis*		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
					Distribution at 2:30 p. m.					
0	22.2	......	......	......	2	......	2	......	......	......
5	20.7	8	......	8	9	4	*13*	1	......	1
8	19.8	9	5	14	3	......	3	......	......	......
10	17.0	5	14	19	1	......	1	1	......	1
11	13.3	......	......	......	..ther	mocli	ne....	......	......	......
12	11.2	10	23	*33*	1	......	1	2	3	5
15	9.8	1	28	29	3	6	*9*	1	4	5
20	8.6	1	4	5	......	4	4	1	5	6
25	8.0	1	1	2	......	......	......	5	4	9
31	7.4	......	3	3	......	......	......	115	208	*323*
					Distribution at 9:00 p. m.					
0	......	4	2	6	8	4	12	......	......	......
3	......	12	16	28	16	3	*19*	......	......	......
5	......	13	27	*40*	7	2	9	......	......	......
8	......	3	......	3	3	1	4	......	......	......
10	......	2	......	2	2	2	4	1	2	3
11	......	......	......	......	..ther	mocli	ne....	......	......	......
12	......	3	......	3	1	1	2	2	4	6
15	......	1	......	1	1	4	5	3	3	6
20	......	......	......	......	......	2	2	......	5	5
25	......	......	......	......	......	......	......	1	7	8
30	......	......	2	2	......	......	......	14	22	*36*

TABLE X. *Vertical distribution of Daphnia in Day Lake on August 20, 1931 at 4:00 p. m. and 9:00 p. m. respectively. The figures in italics represent the maxima.*

Depth in meters	Temperature °C	*D. pulex parapulex* (breviceps)			*D. longispina longispina* (primitiva)			*D. longispina elongata* (mendotae)			*D. longispina apicata* (nasuta)		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
Distribution at 4:00 p. m.													
0	22.1	....	....	....	....	....	....	....	....	....	....	....	....
4	21.9	....	....	....	....	....	....	....	....	....	8	11	19
5.5	20.9	....	....	....	....	....	....	1	....	1	5	12	17
7	19.5	2	3	5	....	....	....	1	2	3	16	15	*31*
8	18.3												
9	14.8	....	....	....	....	.... ther	mocline	....	....	....	....	....	....
10	11.6	3	8	*11*	2	....	2	7	10	*17*	2	3	5
12		....	1	1	1	....	1	....	2	2	....	....	....
14	10.8	....	....	....	4	11	*15*	....	3	3	....	....	....
Distribution at 9:00 p. m.													
0		....	....	....	....	....	....	....	....	....	12	5	17
3		....	....	....	....	....	....	....	....	....	17	4	21
5		1	....	1	....	....	....	1	1	2	25	9	*34*
7		1	2	3	....	....	....	5	4	9	17	5	22
9		2	3	*5*	5	10	15	10	3	*13*	3	7	10
....	....	....	....	....	....	.... ther	mocline	....	....	....	....	....	....
11		....	....	....	29	93	*122*	....	3	3	2	3	5
13		....	....	....	5	9	14	....	1	1	....	....	....
15		....	....	....	....	7	7	1	1	2	....	1	1

TABLE XI. *Vertical distribution of Daphnia in Fence Lake on September 1, 1931. The figures in italics represent the maxima:*

Depth in meters	Temperature °C.	*D. pulex parapulex* (breviceps)			*D. pulex parapulex* (rectrocurva)			*D. longispina apicata* (galeata)			*D. longiremis*		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
0	17.0	......	......	......	......	......	......	3	......	3	......	......	......
3		......	......	......	......	......	......	58	5	*63*	......	......	......
5		......	......	......	1	......	1	15	7	22	......	......	......
8		......	......	......	5	2	*7*	25	12	37	1	......	1
10		......	......	......	2	2	4	13	11	24	2	......	2
12	16.9	......	......	......	......	1	1	12	9	21	6	1	7
14	14.7	......	......	......	......	ther	mocline	......	......	......	......	......	......
15	12.8	9	5	*14*	......	......	......	6	4	10	5	6	11
18	11.7	1	2	3	2	......	2	3	5	8	21	19	40
20		......	......	......	......	......	......	2	4	6	31	15	*46*
23	11.1	......	......	......	......	......	......	......	2	2	2	5	7

TABLE XII. *Vertical distribution of Daphnia in Crawling Stone Lake on September 1, 1931. The figures in italics represent the maxima.*

Depth in meters	Temperature °C.	*D. pulex pulex*			*D. pulex parapulex* (breviceps)			*D. pulex parapulex* (retrocurva)			*D. longispina apicata* (galeata)			*D. longiremis*		
		Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total	Juv.	Adult	Total
0	17.2	......	......	......	......	......	......	......	......	......	2	......	2	......	......	......
3		......	......	......	......	......	......	3	3	6	10	1	11	......	......	......
5		2	......	2	......	......	......	2	4	6	15	2	17	3	......	3
8		......	......	......	......	......	......	5	11	*16*	4	2	6	1	......	1
10	17.0	1	......	1	......	......	......	1	7	8	6	4	10	......	......	......
13	16.1	1	1	2	2	......	2	1	1	2	9	29	*38*	3	10	13
14.5	13.7	21	7	*28*	8	3	*11*	......	1	1	4	21	25	11	8	*19*
15	12.4	......	......	......	......	......	......	ther	mocline	......	......	......	......	......	......	......
16	11.8	14	1	15	6	2	8	1	......	1	1	3	4	10	5	15
19	10.3	......	......	......	......	1	1	1	2	3	......	1	1	1	......	1
21		......	......	......	......	......	......	......	1	1	......	......	......	3	1	4
23	9.0	......	......	......	......	......	......	......	......	......	......	......	......	1	1	2

PLATE XIII

FIGS. 1–5. Examples of racial series ("subspecies") of *Daphnia pulex* with ocellus and without helmet. Summer forms only; young females. x 50. Camera drawings.

FIG. 1a. *Daphnia pulex pulex.* Usual form without helmet. Nebish Lake, Wisconsin.

FIG. 1b. *Daphnia pulex pulex.* Usual form of the claw.

FIG. 2 *Daphnia pulex pulex (cristata).* With short crest. Nebish Lake, Wisconsin.

FIG. 3a. *Daphnia pulex obtusa.* A small pellucid race. Lake San Andreas, California.

FIGS. 3b, 3c. *Daphnia pulex obtusa.* Two views of claw.

FIG. 4. *Daphnia pulex pulicoides.* Elongated form, large eye. Lake San Andreas, California.

FIG. 5a. *Daphnia pulex pulicoides (cristata).* With short crest (from a fall catch, summer form possibly a little more elongated). Clear Lake, California.

FIG. 5b. *Daphnia pulex pulicoides (cristata).* The claw of this race is near *D. clathrata* Forbes, while the head is near *D. arcuata* Forbes.

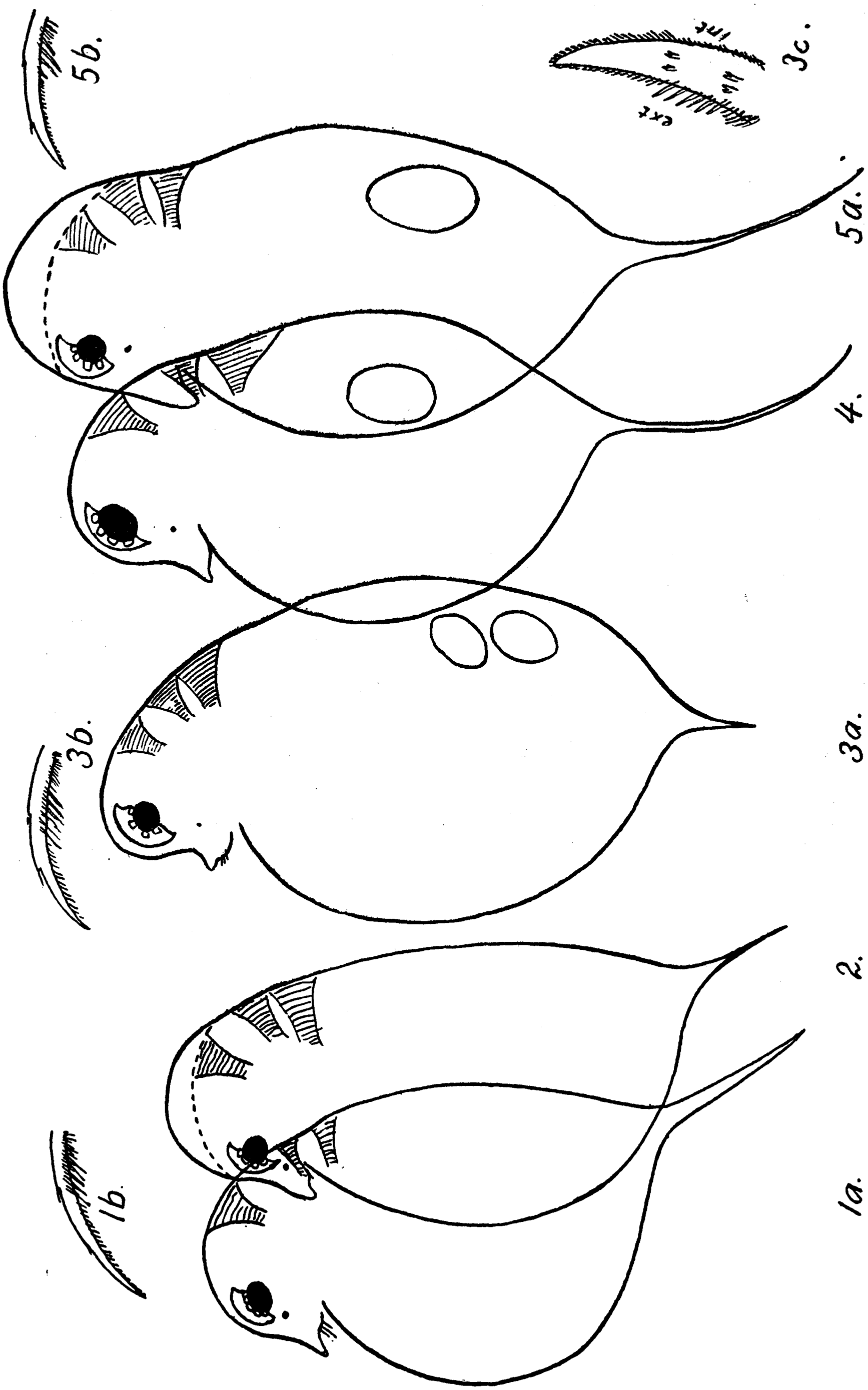
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PLATE XIV

FIGS. 6–14. Examples of racial series ("subspecies") of *Daphnia pulex* without ocellus and with helmet, which has been secondarily reduced in *D. breviceps* Birge (figs. 10, 11). Summer forms only; young females with first brood of eggs. x 35. Camera drawings.

FIG. 6. *Daphnia pulex parapulex* (*retrocurva* Forbes). Specimen from the original material of Dr. Forbes used for describing this race as "*Daphnia retrocurva*". Lake Mendota, Wisconsin.

FIGS. 7–9. Three local races of the same subspecies selected out of a large number of differentiates: Fig. 7. Lake Erie. Fig. 8. Presque Isle Lake. Fig. 9. Kawaguesaga Lake, Wisconsin.

FIGS. 10–11. *Daphnia pulex parapulex* (*breviceps* Birge). From Weber and Fence lakes, Wisconsin.

FIGS. 12–13. *Daphnia pulex parapulex (elongata)*. From Vermilion and Bemidji lakes, Minnesota. The shape of these races of *D. pulex parapulex* is very similar to that of some races of *D. longispina cucullata* in Europe.

FIG. 14. Typical claw of *Daphnia pulex parapulex*.


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PLATE XV

FIGS. 15–21. Examples of racial series ("subspecies") of *Daphnia longispina* without or with a rounded helmet and with ocellus. Summer forms only: young females with the first brood of eggs. x 50. Camera drawings.

FIGS. 15–16. *Daphnia longispina longispina (primitiva* Burckhardt). From Fair View Pond, Decatur and from Clear Lake, California. From fall catches, but presumably without alteration in summer. Similar races in Day Lake, Wisconsin and other races have the same shape in August–September.

FIGS. 17–19. *Daphnia longispina elongata.* Three different *dolichocephala* types of races. Fig. 17. Forma *mendotae* Birge, very common in many races of the middle west and eastern parts of the United States; this specimen from Day Lake, Wisconsin. Fig. 18. Forma *indianae;* found in some lakes of northern Indiana. This specimen from Tippecanoe Lake, Indiana. Fig. 19. Forma not yet named; found in some western lakes. This specimen from Clear Lake, California.

FIG. 20. *Daphnia longispina elongata.* With only a short helmet or crest in summer *(mesocephala* type). From Weber Lake, Wisconsin.

FIG. 21. Typical claw of all races of *D. longispina.*

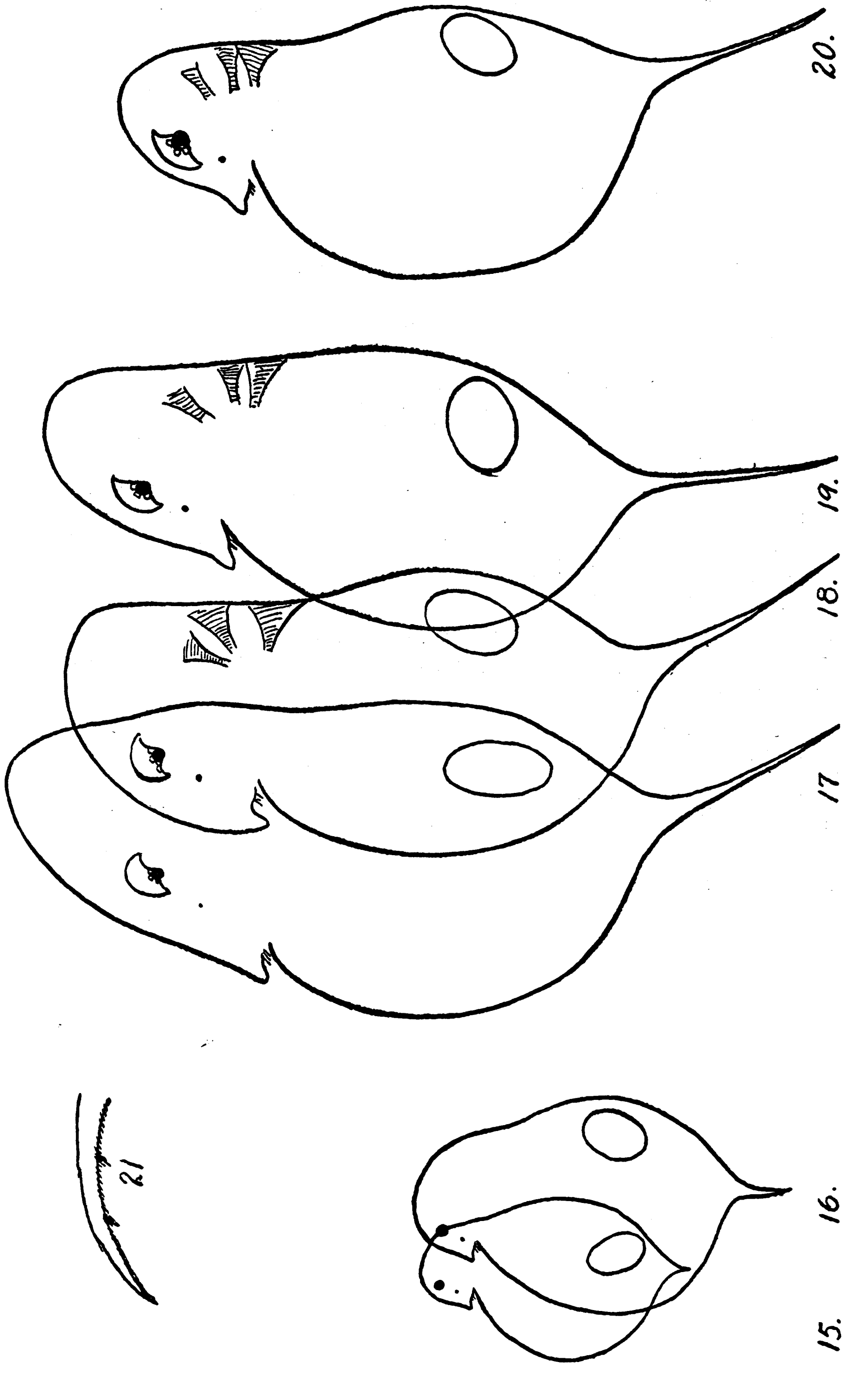
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PLATE XVI

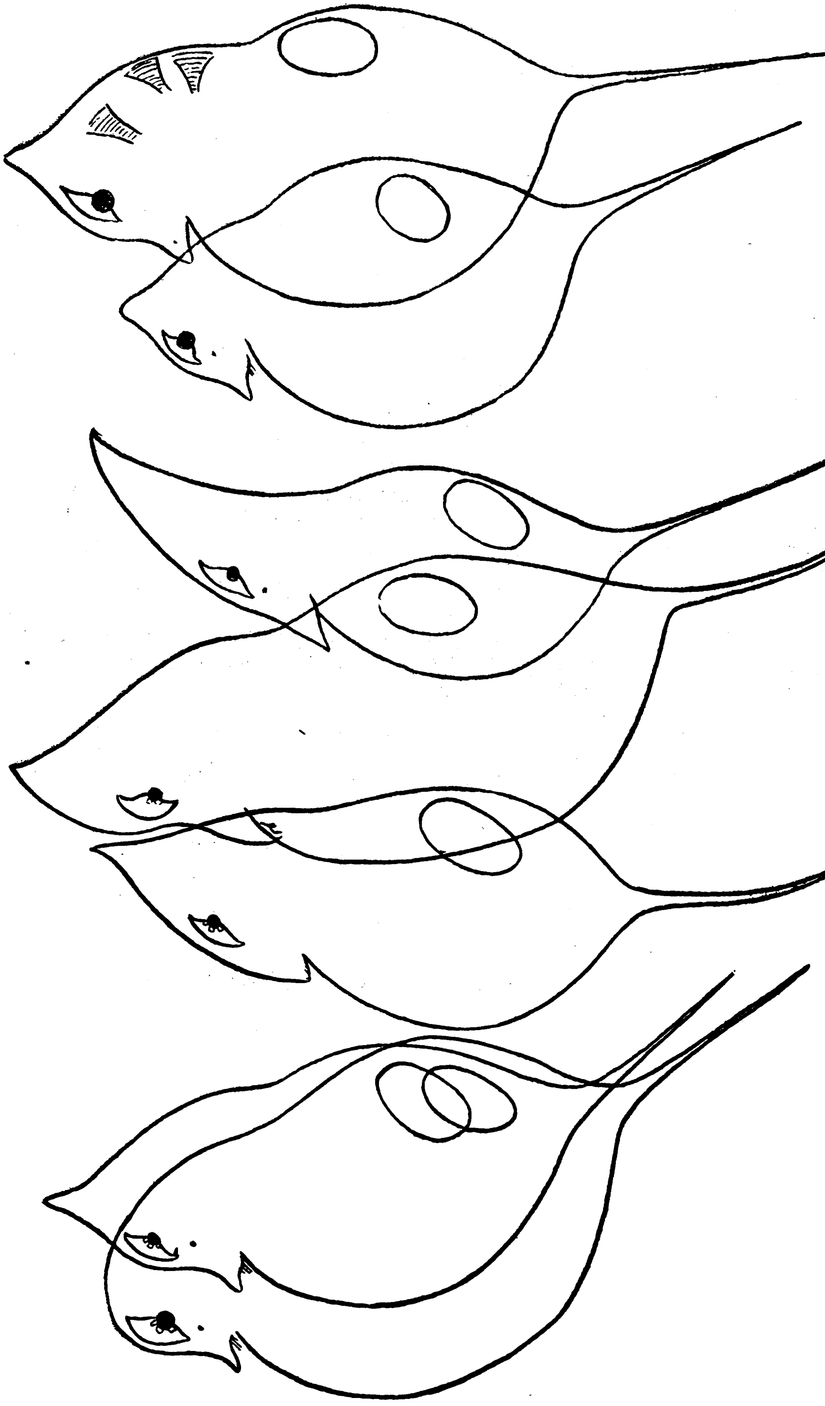
FIGS. 22–28. Examples of racial series ("subspecies") of *Daphnia longispina apicata.* With pointed crests or helmets and with ocellus. Claw as in fig. 21. Summer forms only; young females with the first brood of eggs. x 50. Camera drawings.

FIG. 22. *Daphnia longispina.* Without crest or helmet. From the tropical Lake Atitlan, Guatemala. Forma *primitiva* as in figs. 15–16 and as in Day Lake, Wisconsin, Victoria Nyanza Lake, East Africa, and in many other lakes and ponds.

FIG. 23. *Daphnia longispina apicata.* From the tropical Lake Amatitlan, Guatemala.

FIGS. 24–26. Examples of *dolichocephala* races of *D. longispina apicata.* Fig. 24. Typical forma *galeata* from Crawling Stone Lake, Wisconsin. Fig. 25. Forma *curvata* from Lake Erie. Fig. 26. Forma *nasuta* from Day Lake, Wisconsin.

FIGS. 27–28. Examples of *mesocephala* and tent-like types of *D. longispina apicata.* Fig. 27. From Dead Pike Lake, Wisconsin. Fig. 28. From Lake Michigan.



28. 27 26. 25 24. 23 22

PLATE XVII

FIGS. 29–35. Examples of racial differences (not yet named) of *Daphnia longiremis.* Summer forms only; young females with the first brood of eggs. x 50. Camera drawings.

FIG. 29. *Primitiva* type from Karluk Lake, Alaska.

FIG. 30. Race with similar head and very long spine from Silver Lake, Wisconsin. The elongated antennae and the peculiar curve of the shell are the same in all races of this species.

FIG. 31. Race with tent-like head from Dead Pike Lake, Wisconsin.

FIG. 32. Larger race with elongated rostrum *(nasuta)* from Trout Lake, Wisconsin.

FIG. 33. Similar race with slightly elongated head from Presque Isle Lake, Wisconsin.

FIG. 34. Race with elongated and curved helmet *(retrocurva)* from Muskellunge Lake, Wisconsin.

FIG. 35. Race with elongated and rounded helmet from Big Carr Lake, Wisconsin.

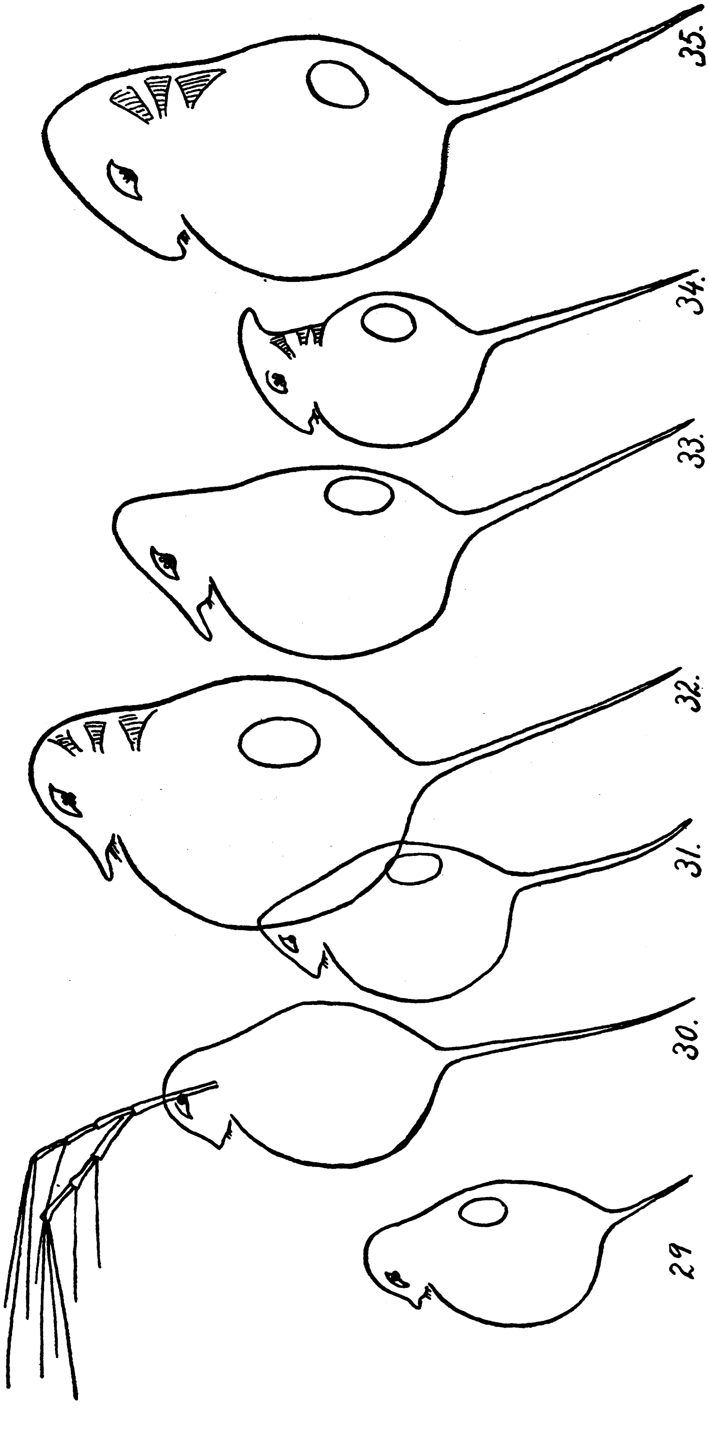

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PLATE XVIII

The areas indicated on the map show the present geographical distribution of the various types of Daphnia. Areas A and B are occupied by derivatives of *Daphnia pulex;* A representing the *pulicoides* series, and B the *parapulex* series. Areas C and D are occupied by derivatives of *D. longispina;* C representing the *cucullata* series, and D the *longiremis* series. The distribution of the derivatives of *D. magna* is shown by area E.


C
E
D
B
D
A
D

SOLAR RADIATION AND INLAND LAKES. FOURTH REPORT. OBSERVATIONS OF 1931

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This paper reports the work of the summer of 1931 on the transmission and absorption of solar radiation by the waters of the lakes of the Highland Lake District. The percentile relation is determined between the amount of radiation delivered to a unit of area at the surface of the lake and that delivered to a similar unit at different depths of the lake. From these data are platted transmission curves of radiation, both those observed and those computed for zenith sun. The main task of 1931 was to extend observation to greater depths of water and to smaller quantities of radiation, by employing a sensitive galvanometer in addition to the millivoltmeters already in use. Much work was done on the form of the solar energy spectrum and on the changes which it suffers in the lakes. The results of this part of the study were of a type similar to those reported in our third paper (Birge and Juday '31[1]); they were carried to greater depths, corresponding to the increased sensitivity of the receiving instrument. Many observations were also made on the transmission of total radiation in lakes of various types, and these are the subject of the present report. They enable us to give a general notion of the transmission of solar radiation through the waters of small inland lakes during the period of summer stratification. This can be done for lakes of widely different types, which present a more complicated story than does the ocean or even large and deep fresh-water lakes.

The observations reported in earlier papers, made with thermopile and millivoltmeters, were carried down to the value of 1.0 per cent ('29) or 0.10 per cent ('30) of the radiation delivered to the surface of the lake. Under similar conditions of observation we can now follow transmission until the limit

[1] For the sake of brevity our earlier papers on this subject will be cited as '29, '30, '31, without using the names of the authors.

of 0.01 per cent has been reached or even passed; the extreme values observed being less than one-tenth of those reported in earlier papers. The curves platted on semi-logarithmic paper extended through two logarithmic cycles in the first report; in the second paper three cycles were shown and in the present paper the curves extend through four cycles and even into the fifth. The result is that in many of our lakes observation has been extended into the region where the increased opacity of the hypolimnion greatly modifies the rate of transmission. In the diagrams of the first report ('29) very few observations went beyond the straight-line curves that mark the characteristic transmission of epilimnion and the water immediately below it. In this respect they resemble most of the curves given for much greater depths of the ocean by Shelford and Gail ('22) and Poole and Atkins ('28, '29); and those for the Bodensee by Oberdorfer ('28). The second report ('30) carried the curves nearly to the bottom of six lakes whose water is so transparent that more than 0.10 per cent of incident radiation is left at such depths. In the present report similar curves are extended to 0.01 per cent with corresponding fullness of knowledge regarding lakes of a much less transparent type.

The work of 1930 was devoted mainly to a more careful study of the effect of the lake waters on the form and composition of the solar energy spectrum and observation rarely went below the epilimnion ('31 : 391) and thus was limited to the region of characteristic transmission. In 1931 observation extended into the hypolimnion of all lakes whether transparent or relatively opaque. The most important effects of hypolimnion on radiation could therefore be worked out in lakes of widely different types. There is still incomparably more to be known about the transmission of solar radiation in these lakes than has already been ascertained, but the general outlines of the story have been traced. Just as our earlier reports showed the characteristic transmission of radiation in a wide variety of lakes, so the present report carries the story on to include the general effect of the hypolimnion, with its increase of color and turbidity, on the transmission of the sun's radiation.

Our studies have been made on small lakes and after summer stratification has been established. All observations are made in full sunshine unless expressly stated otherwise. In all tables radiation is stated as a percentage of that delivered to the surface. In computing results all radiation is assumed to be direct from sun; none is regarded as diffuse. Correction is made for difference of reading of thermopile in air and in water as stated in earlier reports ('29 : 515). Observed values are recomputed and stated for zenith sun, in the same way as in former reports. By this process all observations are reduced to a common denominator. All of these corrections and adjustments are approximate rather than minutely accurate.

In the report of 1929 the value of the surface reading was given in cal/cm^2/min. In later papers this has been omitted as having no special significance. If the amount of radiation present at any depth is stated as a percentage of that delivered to the surface, it is easy to compute its value in units of any kind. There is no difficulty in using meter-candles rather than calories, so far as the surface illumination is concerned. But for observations in the depths of lakes in whose water the form of the solar energy spectrum is modified profoundly and rapidly, with consequent change in the color of the light, the term "candle" becomes little more than a conventional expression for energy; it does not mean "illumination" of a type discernible by the eye.

In all of our papers the term "transmission" refers to the passage of solar radiation through the waters of a lake. The unit of distance is one meter; rate of transmission is expressed by the percentile ratio between radiation at the top and the bottom of a one-meter stratum.

Results — General Statement

1. By the use of pyrlimnometer and galvanometer the passage of solar radiation through the water of lakes may be followed until it is reduced to about 0.01 per cent of that incident on the surface. This limit is approximately the same as that reported in observations made with other instruments, such as the photoelectric cell or photography. The pyrlimnometer, whose central component is a thermopile, registers radiation of all wave-lengths; other instruments are more selective and are sensitive to the radiation in the short-wave part of the visible spectrum.

2. Most of the infra-red radiation and much of the ultraviolet are absorbed in the first meter of lake water. For prac-

tical purposes the remainders of such radiation present at one meter below the surface may be neglected, and all radiation at that depth and below may be considered as light.

3. If transmission of radiation is measured by instruments which are sensitive to short-wave light only, the transmission of the upper meter of the water will be substantially the same as in the meter below. If the instrument gives full value to radiation of wave-length 6000 Å and more, transmission of light in the upper meter will be smaller than below on account of the rapid rise of absorption by water of light in the longer wave-lengths. If the pyrlimnometer is used transmission in the upper meter should be stated by itself as it will differ considerably from that below. In fairly transparent lakes transmission below one meter will be much the same, whatever the instrument used.

4. Transmission of radiation through the water of lakes depends on (1) the effect of water as such; (2) the color of the water due to stains; (3) the turbidity of the water. Color differs greatly in different lakes, but is a fairly constant quality in any one lake. It renders the water highly selective toward radiation, cutting off the short-wave radiation. Turbidity depends on particles suspended in the water and is very variable both in different lakes and in the same lake at different times and depths. If particles are large their action on radiation is nearly or quite non-selective; if small, the shorter wave-lengths are more rapidly extinguished. In any ordinary lake all sizes of particles are likely to be present. Transmission as actually found is therefore a result of several variable factors, whose separate influence has not been adequately studied.

5. In general the water of the ocean and of large lakes is free from stain or has only a slight color. Differences in transmission of radiation are primarily due to turbidity and in a large body of water this is likely to be fairly uniform to depths reached by observation. A series of observations is likely to disclose a *characteristic transmission,* which extends without notable change to the limit of observation. This limit may be found in the ocean at 60-75 m. (Poole and Atkins '28, '29) or even 120 m. (Shelford and Gail '22); the same minimum of radiation may be reached at 20-30 m. in the Bodensee (Oberdorfer). These series both in fresh and salt water, yield substantially straight line curves of average transmission when

platted on semi-logarithmic paper. Differences in the turbidity of different strata may cause sudden and great changes in these curves (Poole and Atkins, '28 : 276), but such changes are not frequently observed.

RESULTS — SMALL LAKES

1. These general statements must be modified in order to represent the situation in small lakes like those of the Highland Lake District. The color of the water in different lakes is very different; turbidity may be very slight or present in a high degree; both color and turbidity may be fairly uniform through the whole water of the lake or may change greatly with depth. The effect of currents induced by wind may be almost absent or may be very great; turbidity due to wave action on the shores is variable but is usually small and may be almost entirely absent. The result of these numerous factors is to complicate the story of transmission of radiation in such lakes.

2. Small lakes have a characteristic transmission, found from 1 m. on for a variable distance. Its value is dependent on color and turbidity, and if these are uniform it may continue without marked change to the bottom of the lake or to the limit of observation. It usually continues through the epilimnion and for some distance into the hypolimnion. No observable differences in transmission are traceable to changes of temperature and density of water at the thermocline.

3. Transmission in the ocean and in large lakes, so far as these have been examined, is ordinarily high, rarely below 70. In small lakes it ranges from 85 or more, as a maximum, to 10-12 or even less. Its value in any lake is primarily determined by the color of the water, which in the lakes reported in this paper, ranges from 0 to 260 on the platinum-cobalt scale. Color is a fairly constant quality of the water of these lakes, varying relatively little from year to year. It is ordinarily higher near the bottom of the lake; but usually such increase has much less effect on transmission of radiation than is exerted by the increased turbidity at the same depths. Color in the upper water of the lakes is of organic origin; in the deeper water, where oxygen is absent, it may be due to iron. The relation between color and transmission, so far as this is known, is shown in Table IV and Fig. 7.

4. Turbidity depends on particles, either organic or inorganic, suspended in the water. In the Highland Lake District there is little inorganic turbidity, since the soil is sandy, there is little cultivation, and the District is densely covered with second growth trees. Organic particles consist of plankton and its immediate derivatives, particles from the bottom ooze, and debris from marsh and peat. These particles exert a mechanical obstruction to the passage of radiation. Particles of all sizes are usually present in these lakes; but great growths of plankton algae are rare. Nannoplankton constitutes the bulk of the living organic material. There is no quantitative measure for turbidity, as there is for color, and therefore statements regarding its effect on radiation are less definite. Turbidity is the prime factor which determines the range of transmission in lakes belonging to the same color group (Table IV), and to variations in turbidity are due most of the changes in transmission as radiation passes downward through the water of lakes.

5. The hypolimnion is ordinarily more turbid than the epilimnion; turbidity usually increases with depth and is at a maximum in any lake just above the bottom of the deepest water. This condition causes most of the changes in transmission shown in the curves of Figs. 1, 2, and 3.

6. In lakes with very high colored water, radiation is rapidly reduced to that region of the spectrum to which the water is most transparent. This may aid in causing a marked increase of transmission immediately below the depth of, say, 2 m. Transmission in the 2-3 m. stratum may be twice as great as between 1 m. and 2 m. This situation is seen in different degrees in the last five lakes of Table I. In such lakes there is no characteristic transmission, within the limits to which radiation can be followed by the instruments. This situation has not been found by us in lakes with color less than 60; but the lakes examined are not numerous enough to permit general statements as to this limit. This change of transmission is not present, in observable degree, in lakes with colors from 20 to 36, as shown in Table I and Figs. 1 and 2.

INSTRUMENTS

The instrument for receiving the sun's radiation during the season of 1931 was the pyrlimnometer, as described and figured in '31 : 384-387. Its central part is a Moll large surface thermopile made by Kipp and Sons of Delft, Holland.

The instruments for reading the electric currents from the thermopile were the two millivoltmeters described in the same paper. The most sensitive range has a scale of 100 divisions for 0.333 millivolt. There was also a new and much more sensitive instrument — a galvanometer of the D'Arsonval type, made by Leeds and Northrup, of Philadelphia. This galvanometer is of the construction called 2500 A in their catalogue. It is furnished with a street-tripod and has an attached telescope and scale. The scale extends to 250 divisions on each side of the central zero and the sensitivity of the galvanometer is 0.5 microvolt for one scale-division. The arrangement of tripod and galvanometer is that listed under number 2123 in the catalogue.

This galvanometer must be set up on shore and connected by a cable with the boat from which the pyrlimnometer is operated. The cable is 183 m. (600 ft.) long and it fixes the limit of distance between boat and shore, thus determining the depth to which observation may extend. In the smaller lakes the maximum depth would be reached, or at any rate a depth so great that the limit of observation is determined by the instruments. In larger lakes, whose bottom has a gentle slope, the possibilities of the pyrlimnometer were not exhausted at the depth which could be reached.

The tripod and telescope have proved entirely satisfactory as mounting for the galvanometer; there has been no trouble from unsteadiness. A hood of nickle-plated metal was provided for the galvanometer in order to prevent any possible disturbing effect of the sun on its readings; but it was not found necessary to use it, since the banks of the lakes are densely wooded almost everywhere.

A series of shunts is provided by which five ranges of sensitivity can be used with the galvanometer; these were numbered 0, 1, 2, 3, 4, in the order of sensitivity; range 4 giving the maximum sensitivity of the instrument. Range 0 gave about the same scale reading as that of range 2 of the millivoltmeter; range 4 gave a scale reading about 210 times as great as range 0.

Observing

Observation regularly began and ended with a reading in the air and one or more air readings were made during longer series. All observations were made in direct sunshine. Below the surface readings were made at the depth of one meter and below this ordinarily at 3 m., 5 m., etc., until readings became small, when they were made at every meter. In lakes with high colored water they would be made at every meter from the first, and in extreme cases at every half meter. Readings in air were made with the millivoltmeter and the 20 range, i. e., the range in which 100 divisions of the scale indicate 20 millivolts. The reading at one meter was regularly made with the millivoltmeter and the 2 range; and readings were continued with the 2 mv. range and the 0.333 mv. range so far as these gave an adequate movement of the needle.

In general change was made from the 0.333 range of the millivoltmeter to the 3 range of the galvanometer, which gives a scale-reading 10 times as great for the same amount of radiation. As readings became smaller change was made to the 4 range of the galvanometer. In all cases of change of range or instrument readings were made with both types at the same depth.

Computation of Results

Transmission in the first meter. No attempt was made to determine the rate of transmission of radiation through the successive parts of the upper meter of the lake: comparison is made directly between the reading in air and that at the depth of one meter. Two computations are needed: (1) The ratio of the scale-reading of the 20 mv. range to that of the 2 mv. range. This has been determined by numerous comparisons as 2.5 ('29 : 513). (2) The ratio between readings of the instrument in air and in water: a difference due to the glass cover of the thermopile. It has been determined and computed as stated in '29 : 515; the thermopile gives in air 81 per cent of the full reading and 95 per cent in water. This correction may be combined with that for the difference in the scale-reading of the two ranges by multiplying the reading of the 20 mv. range by 2.94 instead of 2.5.

Transmission below one meter. In any complete series readings were likely to be made with two instruments and four ranges; 2 and 0.333 of the millivoltmeter and 3 and 4 of the galvanometer. These must be reduced to a common value; and for the same amount of radiation the relative values of the scale-readings are as follows:

One scale-division of 2 mv. equals 6 divisions of 0.333 mv.
One scale-division of 0.333 mv. equals 10 divisions of 3 gal.
One scale-division of 3 gal. equals 3.5 divisions of 4 gal.

It thus appears that scale readings from the 2 mv. range must be multiplied by 210 in order to express them in terms of the 4 gal. range. Those from the 20 mv. range in air must be multiplied by 617 (2.94×210) in order to express them on the 4 gal. scale as used in water.

The values of readings below one meter were first computed as percentages of the one-meter reading; the value of the one-meter reading was determined as a percentage of that in air; and from these data was computed the value of subjacent readings.

Reduction to Zenith Sun. The percentages thus obtained are platted on semi-logarithmic paper at the proper depths and the points are connected by straight lines so as to constitute the *curve of observed transmission.* This is changed to the *curve for zenith sun* by the method stated in '30 : 289. The altitude of the sun at the time of observation is taken to the nearest degree; and the value of the cosine of the angle of refraction corresponding to this altitude is taken to the nearest centimeter. At any depth of the observed curve the distance is measured in millimeters from the 100 per cent line to the intersection of the curve; this number is multiplied by the cosine; and the product is the distance from the 100 per cent line to the value of the percentage for zenith sun. In this way a new curve is constructed, that for zenith sun, and the new percentages are taken from it. In practice the cosine used is ordinarily that for the mean altitude of the sun during the observations; it has not been thought necessary to adjust for changes in altitude at every successive reading.

All percentages given in this paper are expressed in terms of total radiation delivered to the surface of the lake, including ultra-violet and infra-red. It has been already stated that all radiation below one meter may be considered as light. In the solar energy spectrum the amount of energy between 3000 Å and 7640 Å varies with the air-mass and the amount of precipitable atmospheric water; and may lie between 58 per cent and 33 per cent. If, therefore, the percentages given in this paper are doubled they will roughly express the percentile energy equivalent of the radiation delivered to the surface in the form of light.

Chapman ('31 : 308) states that the pyrlimnometer will "give us the depth to which the heat rays penetrate". By this he probably means the heat equivalent, at various depths, of the radiation which is measured; not the penetration of the infrared or so-called "heat rays". But such results may be expressed in any units which are desired; heat, light, or electricity.

Pietenpol ('18 : 574), relying on the "corresponding slopes of the curves" which show the coefficient of absorption of light in filtered and unfiltered water, states that the action of unfiltered water on light is non-selective. But Harvey ('28 : 158) points out that Pietenpol's measurements of transmission in filtered and unfiltered water from Lake Mendota indicate that turbidity has a selective influence. The measurements are as follows:

Wave length	*Color*	*Transmission*	
		Filtered	*Unfiltered*
4900 Å	Blue	72.5	17.0
5580 Å	Yellow	83.0	31.5

The rate of transmission of blue in the filtered water is 87 per cent of that of yellow; in unfiltered water blue has a transmission only 54 per cent of that of yellow. It appears therefore that the particles in the unfiltered water have a considerable selective capacity. Probably also much of the difference between blue and yellow in the filtered water is due to particles remaining after filtration.

Accuracy of Observations

In general duplicate readings at the same depth are in good agreement, differing not at all or by one or two divisions of the scale. Such correspondence was especially close in the epilimnion where the temperature of the water is constant during the observations. Illustrations may be taken at random from great numbers. In Big Lake readings at 3 m. were 18 and 19 scale-divisions; in Pauto Lake (Aug. 4) at 1 m. they were 31 + and 32 —; at 3 m., 91 and 94; at 11 m., 51, 56, 57; at 15 m., 13, 15. The third reading at 11 m. was taken because of the divergence of the first two. The difference in the numbers for the several depths is due to the use of different sensitivities.

In the case of Pauto Lake the entire series was read without difficulty, but in many other cases records of series in the thermocline or below might be marked "galvanometer unsteady" and the results of such readings may be seen as irregularities in the curves of Figs. 1-3. It also happens that the sun varies during the period of observation and that readings are thrown out of line from this cause. The series in Nelson Lake (Fig. 1) shows the result of selecting concordant readings from a large number made under conditions of varying sun. Small clouds were forming and disappearing and in such case the amount of radiation may vary from minute to minute, even when the sun is unclouded. Much time was consumed in waiting for favorable minutes and the six determinations platted in this curve are the most concordant out of 28 that were taken.

Study of the details of the curves given in Figs. 1-3 will show many cases where we should expect the per cent to be higher or lower than that recorded. The curve from Big Carr Lake (Fig. 1) shows perhaps the most conspicuous irregularities. Some of them probably represent facts in the lake at the time of observation; others represent accidents of sun or instruments; but none are so great as to cause any serious doubt as to the general value of the transmission. In other cases single readings seem to be out of line. In Pauto Lake Aug. 4, (Fig. 1) the reading at 11 m. should probably be higher, perhaps 0.23 per cent instead of 0.19. There are obvious small irregularities in the two curves for Clear Lake (Fig. 3) and also in the lower part of that for Trout Lake, and for these we have no definite explanation. On the other hand, the sudden drop in transmission at 13 m. in the curve for Crystal Lake, Aug. 19, (Fig. 1) has an adequate explanation (p. 541) and no doubt other similar changes in transmission represent temporary local opacities and transparencies in the water.

Perhaps it is not out of place to state that we have been surprised at the general agreement of observations and the satisfactory nature of the conclusions to be drawn from them, rather than disappointed by unexplainable irregularities.

TABLE I. *General results. Transmission as observed and as computed for zenith sun.* Char. Trm. =*characteristic transmission*; galv =*galvanometer*; Inst. =*instrument*; Max. =*maximum*; mv =*millivoltmeter*; Obs. =*observed*; Trp. =*transparency*; Z. S. =*zenith sun.*

Lake	Date 1931	Depth Obs.	Depth Max.	Inst.	Trp.	Color	Cos r	Char. Trm.	Z. S. % 1 m.	Zenith Sun Depth in meters for				Obs. % 1 m.	Observed Depth in meters for				Lake
										10%	1.0%	0.1%	0.01%		10%	1.0%	0.1%	0.01%	
Crystal	July 10	19	21	mv	13.0	0	84	83	40	10.4	21.0	......	......	32	7.8	18.0	......	......	Cr
Pauto	July 3	13	17	mv	11.0	0	93	78	40	6.3	(15.7)	......	......	35	5.5	13.2	......	......	Pt
Crystal	July 19	18	21	mv	13.0	0	86	80	38	7.9	16.4	......	......	32	6.0	14.5	(20.0)	......	Cr
Diamond	July 24	11	12	mv	8.3	0	85	81	38	7.2	(12.0)	......	......	32	5.5	11.2	......	......	Di
Pauto	July 9	14	17	mv	11.0	0	83	79	38	6.3	14.5	......	......	31	4.6	13.1	......	......	Pt.
Weber	July 15	11	13	galv	8.7	8	86	76	35	5.9	(13.1)	......	......	30	4.6	11.4	......	......	W
Clear	Aug. 18	18	28	galv	7.6	0	85	72	34	4.7	12.7	18.5	......	26	3.8	10.4	15.5	(21.2)	Cl
Silver	July 24	15.7	18	galv	5.8	5	86	66	34	4.3	9.3	12.6	15.8	39	3.6	8.3	11.2	14.4	Si
Little Bass	Aug. 11	11	15	mv	7.0	0	86	71	32	4.0	9.5	(13.3)	......	27	3.2	8.5	11.6	......	LB
Trout	July 23	15	35	galv	5.3	6	83	71	32	4.2	11.1	16.5	......	25	3.1	9.0	13.6	(18.5)	Tt
White Sand	July 20	13	21	galv	3.1	12	87	70	32	4.1	8.6	12.0	(15.4)	25	3.3	7.7	10.4	13.4	WS
Day	July 20	14	16	galv	8.3	0	85	73	30	4.1	10.5	13.4	(15.7)	24	3.2	9.3	12.3	14.2	Dy
Clear	Aug. 13	18	28	galv	7.5	0	82	74	28	4.5	12.6	17.8	......	22	3.4	10.1	16.0	(22.6)	Cl
Big Carr	Aug. 3	14	22	galv	5.3	10	82	62	27	3.0	7.8	12.6	......	21	2.3	6.2	10.5	(13.6)	BC
Pauto	Aug. 4	15	17	galv	8.3	5	86	73	27	3.9	11.3	15.1	(17.0)	22	3.0	9.6	14.0	16.0	Pt
Muskellunge	Aug. 27	10	21	galv	4.6	8	82	67	27	3.4	9.2	(14.0)	......	20	2.4	7.2	(12.0)	......	Mk
Tomahawk	Aug. 12	13	22	galv	6.5	8	84	70	26	3.2	9.4	17.0	......	20	2.4	7.0	13.0	......	Tk
Little Tomahawk	Aug. 3	9	14	mv	5.2	8	91	70	26	2.8	7.0	(11.0)	......	23	2.4	6.3	10.1	......	LT
Plum	Aug. 12	11	17	galv	4.9	16	84	60	25	2.6	7.0	10.5	......	19	2.0	5.4	9.1	11.4	Pl
Nelson	Aug. 21	11	15	galv	4.0	10	81	56	25	2.5	6.8	10.3	13.5	18	1.8	5.2	8.3	11.2	N
Midge	Aug. 5	9	11	galv	4.2	20	88	48	20	2.0	5.0	7.4	9.4	17	1.6	4.3	6.5	8.4	Mg
Big	Aug. 20	7	18	galv	3.2	26	83	49	19	1.8	5.0	(8.5)	......	14	1.3	3.9	6.7	(9.3)	B
Bragonier	Aug. 5	5.5	8.5	galv	3.6	28	85	41	18	1.6	4.2	6.8	......	13	1.2	3.4	5.6	(7.5)	Br
Adelaide	Aug. 26	8	22	galv	4.8	36	84	44	16	1.6	4.0	7.1	(10.0)	11	1.1	3.3	5.8	8.4	Ad
Turtle	Aug. 26	6	14	galv	2.5	68	82	note	11	1.0	2.7	5.3	7.0	7.3	......	2.1	3.9	5.7	Tr
Little Long	July 27	6	18	galv	2.0	96	93	note	7.9	......	2.3	4.3	6.6	6.4	......	2.0	3.8	6.1	LL
Little Pickerel	Aug. 27	3	5	galv	0.8	108	88	note	5.3	......	1.7	2.7	(4.0)	3.5	......	1.5	2.3	3.2	LP
Mary	July 18	5	22	galv	1.7	132	90	note	4.2	......	1.8	4.1	6.2	2.9	......	1.6	3.4	5.3	Ma
Mary	Aug. 26	2	22	galv	.....	.....	90	6	4.5	......	1.4	1.8	2.5	3.2	......	1.3	1.7	2.3	Ma
Helmet	Aug. 19	3	8.5	galv	0.8	260	86	note	1.7	......	1.3	2.6	(3.8)	1.0	......	1.0	1.9	3.3	He

Notes on Table I

Table I shows the general results of the observations of 1931 and must be considered with Figs. 1–6. It includes 30 sets of readings in 25 lakes arranged, as in '31 : 422, in a series beginning with the most transparent. There are 8 columns of general data following the names of the lakes. Column 4, *Inst.*, states the type of instrument used; *mv.* means millivoltmeter, *galv*, galvanometer. Col. 5, *Trp*, gives the depth in meters to which Secchi's disc was visible. Col. 6, *Color*, gives the color on the U. S. G. S. or platinum-cobalt scale. Col. 7, *cos r*, is the cosine of the angle of refraction corresponding to the altitude of the sun at the time of observation. See p. 531. Col. 8, *Char. Trm.*, gives the value of the characteristic transmission with zenith sun; that in the epilimnion and usually for some distance farther.

There follow two sets of five columns each. The first set gives the facts for zenith sun, computed by the aid of *cos r* from data in the second set of five columns, that for observed data. The first column of the five in each set, *%* 1 m., gives the percentage of total incident radiation found at the depth of one meter. The following four columns give the depth at which the transmission curves intersect the principal lines of the semi-logarithmic paper on which the curves are platted in Figs. 1–6. These lines are those for 10%, 1.0%, 0.1%, 0.01%. Blanks in the several columns mean that the value in question does not occur in the lake or that lines could not be safely extended to that depth and value. Numbers are bracketed when the extension is so long that the exact position of the intersection is doubtful.

In the case of the last five lakes in the table there is no characteristic transmission of the sense in which that is found in the other lakes. Transmission rises immediately below the 1–2 m. stratum. The following table shows the facts for zenith sun. The situation as observed is given on p. 555.

Lake	Stratum and Transmission				
	1–2 m.	2–3 m.	3–4 m.	4–5 m.	5–6 m.
Turtle.......	21	28	38	35	34
Little Long...	18	32	29	40	40
Little Pickerel	9	12	....	....	....
Mary........	18	28	45	30	....
Helmet......	13	28	....	....	....

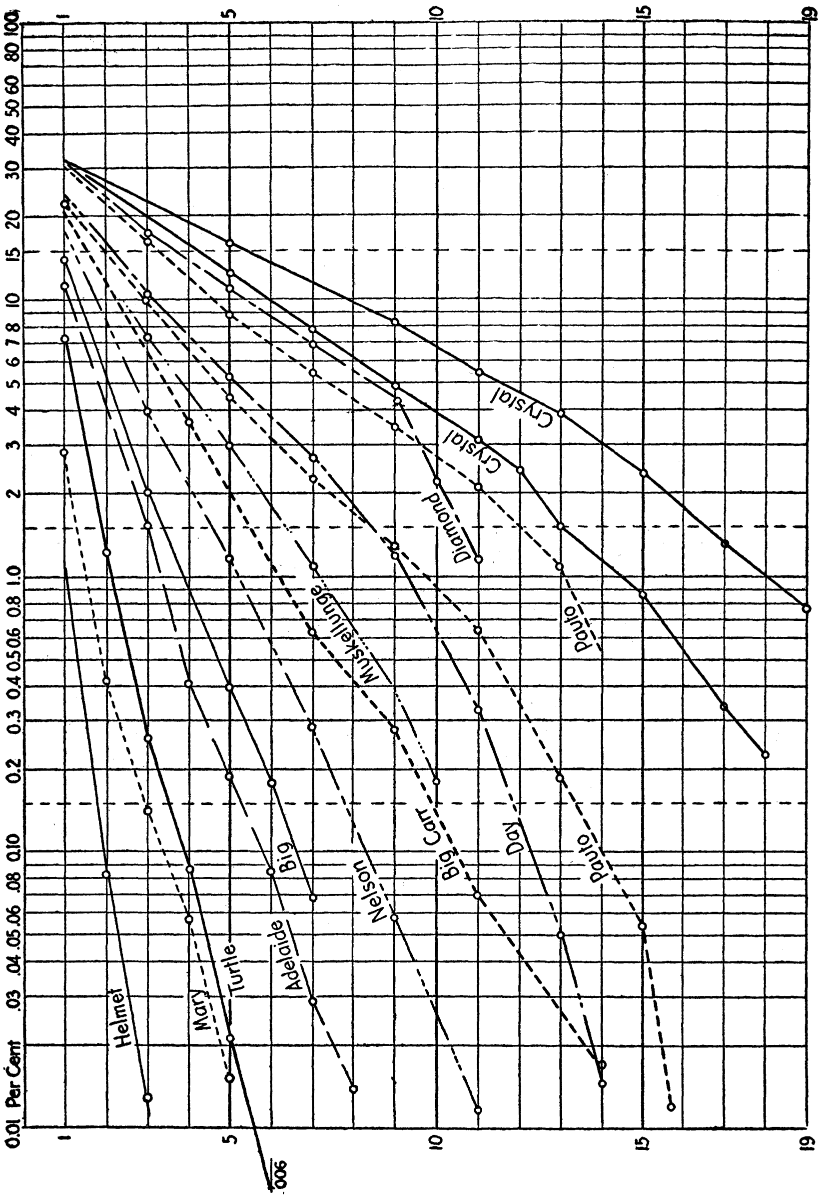

FIG. 1. Curves of observed transmission for a series of lakes, ranging from the most opaque to the most transparent. Note the two curves for Crystal Lake and for Pauto Lake, showing the general loss of transparency as summer advances, while the character of the curve is retained. In Diamond Lake the marked loss of transmission in the lower water is due

OBSERVATIONS ON LAKES, 1931

The general results of the work of 1931 are given in Table I and in Figs. 1-6. Figures 1-3 show the curves of observed transmission of radiation and Figs. 4-6 those of transmission computed for zenith sun. Table I gives a summary of both sets of curves and also adds other pertinent details. The lakes are arranged in the table in the order of color and transparency, as in our third report ('31). Other facts regarding these lakes are stated in Table VI, p. 562.

In Figs. 1 and 2 are shown series of observations in lakes ranging from those with low transmission to those which are very transparent; and the curves for zenith sun are given for the same lakes in Figs. 4 and 5. Figures 3 and 6 contain five sets of observations from lakes whose transmission in the upper water is very similar, while in the deeper water there is wide divergence. On the same figures curves are also shown for two lakes for which there was no place in the other figures.

These transmission curves resemble in general those given in earlier reports ('29 : 527, '30 : 303, '31 : 397) but with two important differences. The curves are carried out to smaller values of radiation and to greater depths in the several lakes; and in many cases they show great changes in transmission as radiation passes into the deeper water. In the former reports very few curves extended beyond the region of characteristic transmission; Marl Lake ('29 : 527) being the most conspicuous case of a curve where there was marked difference between the epilimnion and the deeper water. One main purpose of the work of 1931 was to ascertain whether such differences are not common phenomena in small lakes and this was found to be the case. In all cases observation went to a considerable distance below the epilimnion, which even in Trout Lake does not become more than 8 m. thick during the summer. In most lakes its thickness is 5 m. or less, especially in lakes with high colored water.

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to proximity to bottom of lake. The same is seen in the curves for Muskellunge and Big lakes, in these cases due to turbidity in bottom water of the slope of the lake. In both cases characteristic transmission would go on without such change in the deeper water of the lakes. Big Carr Lake shows an unusually irregular curve, due to accidents of observation. Curves for Helmet, Mary, and Turtle lakes show increase of transmission with depth (see p. 554). Curves for Pauto and Day lakes show curves for lakes with increasing turbidity in hypolimnion.

The 25 lakes may be classified according to their characteristic transmission with zenith sun, as was done in a former report ('30 : 305). The result is as follows:

Lakes with low transmission (6—30), Helmet, Little Long, Little Pickerel, Mary, Turtle.

Transmission low medium (31—50), Adelaide, Big, Bragonier, Midge.

Transmission high medium (51—70), Big Carr, Little Tomahawk, Muskellunge, Nelson, Plum, Silver, Tomahawk, White Sand.

Transmission high (71—85), Clear, Crystal, Day, Diamond, Little Bass, Pauto, Trout, Weber.

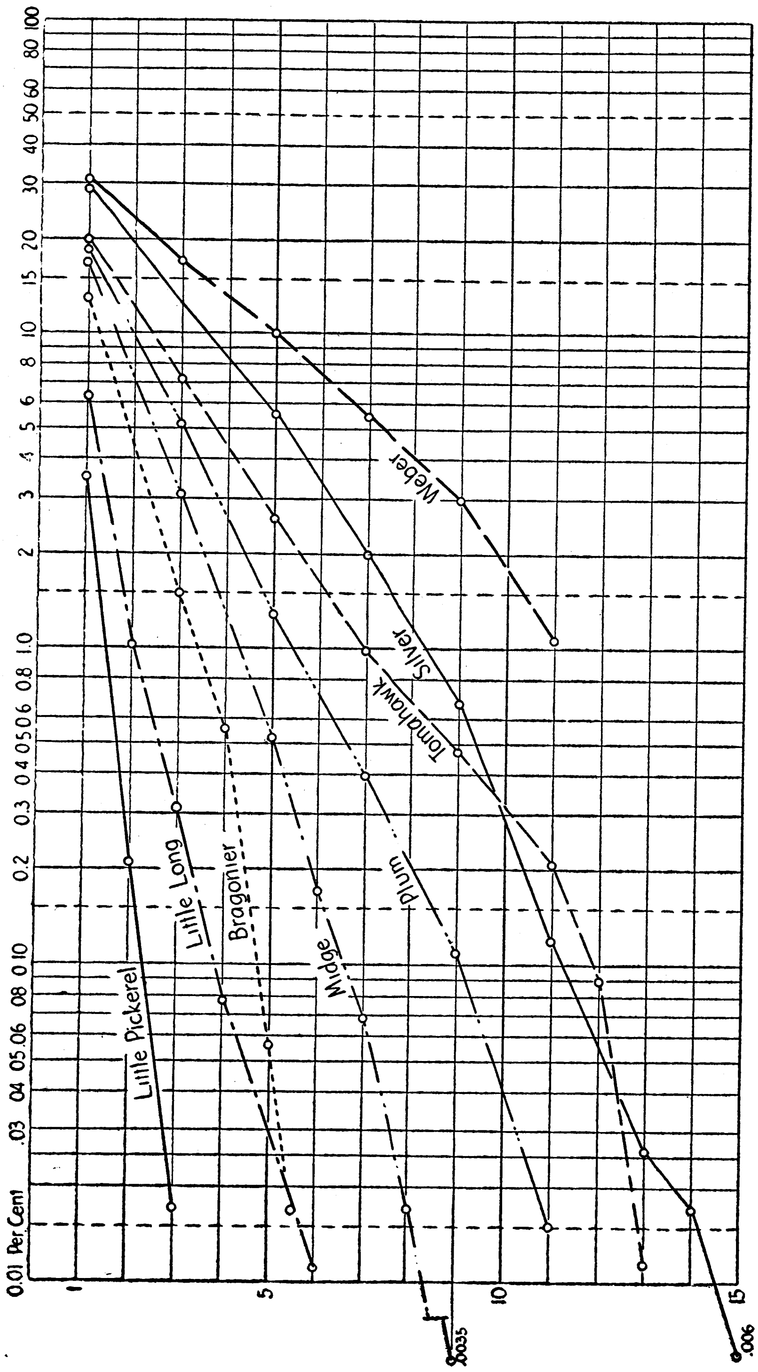
Since the earlier observations hardly went beyond the region of characteristic transmission, a more convenient classification for the purposes of this report groups the lakes according to the results reached by the use of the several kinds of instruments and the types of transmission found. This method gives five groups as follows:

1. Transparent lakes in which the characteristic transmission is high and extends with little change either to the bottom of the lake or nearly to that depth. To this group belong Crystal, Diamond, and Weber lakes; they belong to that group on which detailed report was made by us in 1930 ('30 : 291–302; Fig. 2-7).

2. Lakes in which characteristic transmission continues nearly or quite to the instrumental limit of observation without essential change; Adelaide, Big Carr, and Nelson lakes. This statement, in a modified form, also applies to the more opaque lakes in the list. See group 5 below.

3. Large and deep lakes, as lakes go in the Highland Lake District, in which observation was limited in depth by the length of cable from shore. In these lakes observation did not extend beyond the region of characteristic transmission, and this, whatever may be its numerical value, should continue beyond the depth reached by observation. Here belong Big, Clear, Muskellunge, Tomahawk, and Trout lakes. Little Tomahawk Lake belongs in this class, so far as the character of the curve is concerned; but observation ended so close to the bottom that transmission can not continue much farther without change.

4. Lakes in which there is a notable decrease of transmission in the deeper water. Here belong Day and Pauto lakes (Fig. 1), Midge, Plum and Silver (Fig. 2), White Sand and Little Bass lakes (Fig. 3). These lakes offer the most interesting addition to our knowledge made by the work of 1931.


0.01 Per Cent
.03
.04
.05
.06
.08
0.10
0.2
0.3
0.4
0.5
0.6
0.8
1.0
2
3
4
5
6
8
10
15
20
30
40
50
60
80
100
1
5
10
15
.0035
.006
Weber
Silver
Tomahawk
Plum
Midge
Bragonier
Little Long
Little Pickerel

5. In the lakes with most deeply stained water observations in earlier years hardly went deeper than 2 m. The galvanometer enabled us to carry readings to greater depths in 1931 and showed that there might be a considerable increase of transmission with depth; an increase probably associated with the reduction of the solar spectrum to that region which passes most freely through water of the particular color of the lake. This is also an interesting addition to our knowledge.

Group 1. Transparent lakes with high transmission.

The observations of 1931 in these lakes were much like those of 1929, which were reported in detail in the paper of 1930 (pp. 293, 296, 301), and there is little to add to that report. In all of these lakes there is a perceptible, though small decrease of transmission in the hypolimnion; in Crystal and Weber lakes this turbidity begins several meters below the epilimnion; in Diamond Lake the hypolimnion occupies only the lower 2 m. or 3 m. of the water and the whole of this is turbid to much the same degree ('30 : 296) as is the bottom of the hypolimnion in the other lakes. No growth of moss has been noted on the bottom of Diamond Lake as it has been in Crystal and Weber.

Crystal and Diamond lakes are the only lakes of this District whose transmission has been regularly found to be above 80 for any considerable distance. No other Wisconsin lakes have been found to equal them. Characteristic transmission as high as 85 has been found in Crystal Lake, and even 90 has been observed for strata of one or two meters ('29 : 559, '30 : 293).

But these lakes are less transparent than the ocean. Poole and Atkins ('29 : 324) found average transmission from 86 to about 90 in the ocean near Plymouth. They report maximum transmission up to about 95 and very few cases below 80; "the most turbid water" had an extinction coefficient of 0.228, which is equivalent to a transmission of about 79.5. On the other

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FIG. 2. A second series of curves of observed transmission ranging from low to high. Much the same types are present as in Fig. 1. Silver Lake has a curve much like that of Day, but shows accidental irregularities in lower water. Tomahawk Lake shows a great effect of bottom turbidity found on the slope of the lake. Midge and Plum lakes have curves like that of Day, but effect of turbidity of hypolimnion is less marked because of color and turbidity of epilimnion. Bragonier Lake shows very great and sudden effect of bottom turbidity; see p. 553.

hand, Oberdorfer ('28 : 476) reports transmission from the Bodensee to depths of 20 m., or more, and therefore comparable with those from Crystal Lake so far as the depth reached is concerned. The lake is far larger and deeper and is a characteristic oligotrophic lake of the first order in area and depth. The mean transmission of eight series, each in a different month, is 77.2; the maximum, 82.7; the minimum, 71.7. Percentages at 1 m. ('28 : 482) were: winter, 81.2-83.0; summer, 69.0-72.5; these are percentages of incident light and would correspond to about one-half that per cent of total incident radiation. It appears therefore that the transmission of the Bodensee closely resembles that of Crystal Lake, but is a little lower.

Crystal Lake. (Figs. 1, 4.) Two series are shown in Figures 1 and 4; taken on July 10 and on August 19. Readings were made with the millivoltmeter in the deep water of the lake; that at 19 m. was about 0.5 m. above the mud.

In both series there is an increase of opacity in the lower part of the hypolimnion; but transmission went on without noticeable change from the epilimnion into and below the thermocline; as is also shown in the series reported in '30 : 293.

On July 10 the transmission to 19 m. was 83; to 15 m. it was 85; there was 40 per cent of incident radiation present at 1 m., and this was reduced to 4 per cent at 15.3 m. In the August series transmission was lower, being 78 to 18 m. and there was 38 per cent of incident radiation present at 1 m. and this was reduced to 3.8 per cent at 12 m. There was an active growth of Dinobryon in the lake on this date and this was the probable cause of the lower transmission. It was especially abundant at the depth of 13 m. as was shown by catches made with the plankton trap. The effect of this condition on the light is seen in the curve of observed transmission (Fig. 1). Secchi's disc was clearly visible a little above 13 m. and suddenly disappeared when lowered a few centimeters.

Diamond Lake. (Figs. 1, 4.) This lake presented about the same condition in each of the three years in which it was visited. There was an average transmission of 81 to the depth of 9 m., followed by an abrupt decline of transmission below that depth. Transmission from 3 m. to 9 m. was reported as 85 ('30 : 292); lower transmission in the upper water reduces this to about 81. This lake has a flat bottom and the percentile

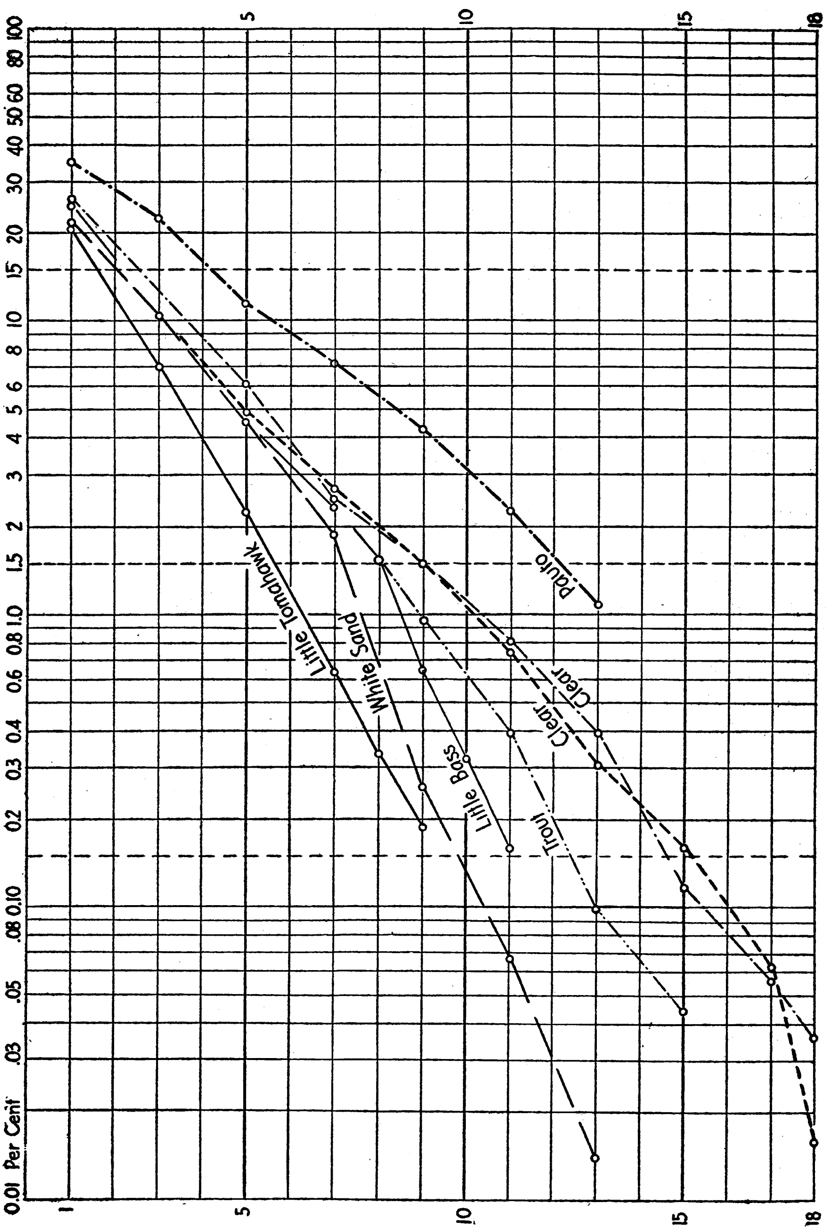

FIG. 3. Five sets of observations from lakes which are much alike at one meter and also in their characteristic transmission, but whose transmission in the lower water is widely different. With these are the curves for two lakes for which there was no place in the other figures. Trout Lake

area and volume fall off rapidly with increase of depth. At 9 m. there is present about 35 per cent of the surface area but only 8 per cent of the volume lies below that depth. The effective length of the lake is about the same as that of Crystal Lake and the wind would have about the same power of creating currents. But in Crystal Lake the 9 m. level has about 55 per cent of the surface area and nearly 35 per cent of the total volume lies below it. The wind currents therefore concentrate the debris and plankton of Diamond Lake into a far smaller volume of water than in Crystal Lake, with consequent greater reduction of transmission.

Weber Lake. (Figs. 2, 5.) Two series were taken in this lake, July 8 and July 15, each extending to 11 m. This represented the deepest water which could be reached with the cable from the shore. Characteristic transmission was 76, about the same as in former years. The more complete curve shown in '30 : 301 extends quite to the bottom of the lake and is in general identical with those of 1931. In this lake the characteristic transmission extends without noticeable change into the hypolimnion and nearly to the bottom of the lake.

It thus appears that in these lakes observations can be obtained with the pyrlimnometer, reaching to the bottom of the lake. In all cases transmission continues with little change nearly or quite to the bottom; only a small effect can be traced to increased turbidity of the hypolimnion, due to debris or growths of algae, except in the lower 2 or 3 meters.

Group 2. Lakes whose characteristic transmission extended to the instrumental limit of observation.

In this group and the next one the use of the galvanometer carried observation to greater depths than were formerly

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shows an irregular series, but one which should extend with little change to greater depths. This is true for Clear Lake also, whose two series show the kind of resemblance and difference that would be expected from observations made at about the same time. In White Sand Lake the whole hypolimnion is turbid, while in Little Bass Lake transmission goes on with small alteration almost to the bottom. In Little Tomahawk Lake there is almost no change in transmission, although the deepest reading is only about a meter above the mud and within three meters of maximum depth. Note that White Sand Lake and Clear Lake had about the same amount of radiation at the surface and at 7 m., while at 13 m. Clear Lake had nearly 30 times as much as had White Sand.

reached, but the character of the transmission did not suffer any essential change. There are three lakes in this group; two with water of low color (10) and one, Adelaide, whose water has a color of 36.

Adelaide Lake. (Figs. 1, 4.) This small, deep lake (22 m.) is one of a group of moraine lakelets with deeply stained water; Adelaide is the largest of the group and the one with lowest color. Its water is relatively clear and color must be the main factor in cutting off radiation. Observations extended to 8 m., at which depth there remained 0.013 per cent of incident radiation. The transmission curve shows small irregularities but the mean transmission of 44 with zenith sun is maintained to the limits of observation and there seems to be no reason why it should not extend to considerably greater depths. There was no distinct sign of a rise in transmission in the lower meters observed, due to absorption of all radiation except that most freely transmitted by the water. Thus there is present a characteristic transmission for this lake; in lakes with more deeply stained water the situation is different, as is stated on a later page.

Big Carr Lake. (Figs. 1, 4.) In this lake and in the next one described, observations were more irregular than usual. In Big Carr Lake the irregularities were accidental. The characteristic transmission as observed was 57, and with zenith sun was 62, much the same as in earlier years. The last reading was at 14 m., and gave 0.015 per cent of incident radiation. The epilimnion is 6 m. thick. The lake is 22 m. deep and radiation might be transmitted to a considerably greater depth without much change of rate.

Nelson Lake. (Figs. 1, 4.) Readings in this lake were quite irregular, due to variations in the sun. There were scattered cumulus clouds, with wide spaces between them. All readings were taken in full sun, but with such a sky there is sure to be variation in radiation. The curve is platted from the most concordant readings. Characteristic transmission was 48 as observed, and 56 with zenith sun, extending without notable change to 11 m., about 4 m. above the bottom. At this depth the observed per cent of incident radiation was 0.012 with a transmission at the rate of 45 from 7 m. down. This rate must have fallen off greatly immediately below 11 m. since the bottom is so near. The epilimnion was 4 m. thick.

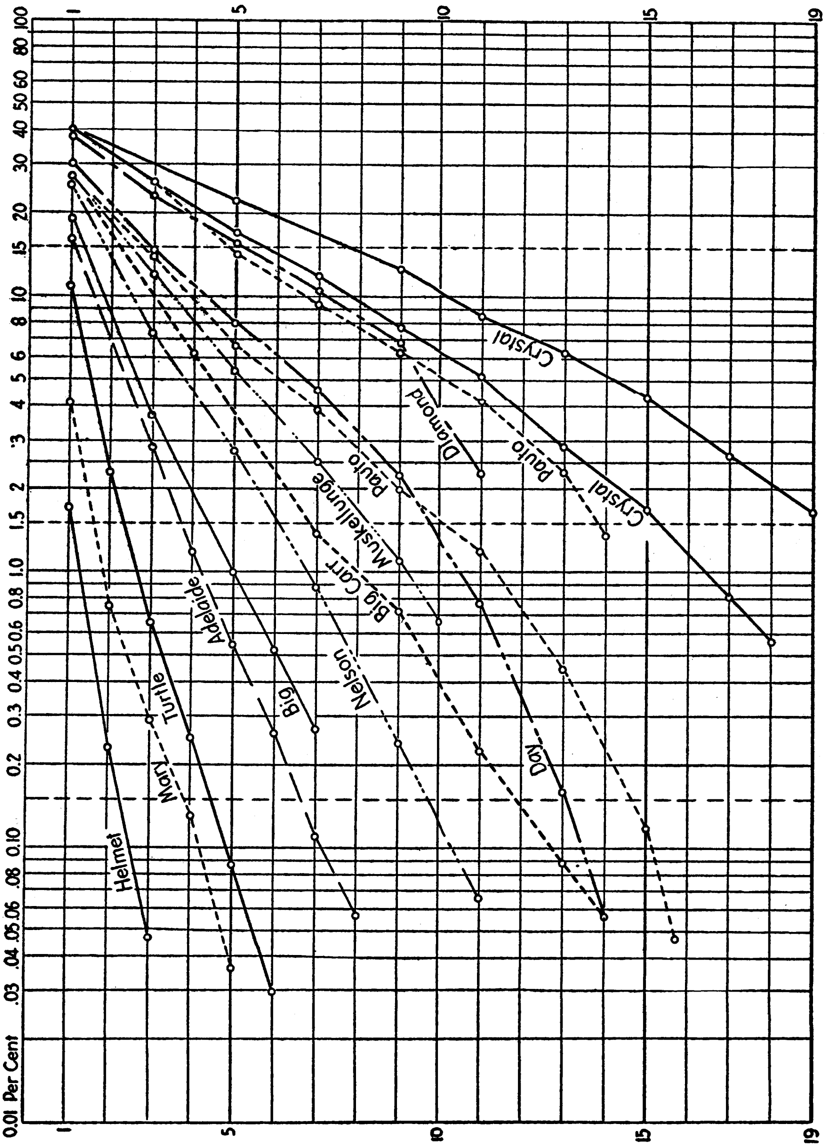

FIG. 4. Curves of Fig. 1 computed for zenith sun, according to the values of *cos* r stated in Table I. The changes thus made in the positions of the curves for characteristic transmission bring these into place for direct comparison with those published in earlier reports. The lower parts of curves, like that for Pauto Lake, are treated in the same way; but where transmission is rapidly changing, no great reliance should be placed on the correctness of results. It is especially dangerous to attempt to prolong such curves.

Group 3. Larger and deeper lakes.

In these lakes of large area and considerable maximum depth, the radiation was followed to depths on the slope of the main basin of the lake, determined by the length of cable connecting the galvanometer on shore with the boat and pyrlimnometer. In all cases the result lay within the region of characteristic transmission and the depth was so small that the limit of observation was not reached. Characteristic transmission probably went on to greater depths. In most cases turbidity sharply cut off transmission near the bottom.

Big Lake. (Figs. 1, 4.) Readings in Big Lake went to 7 m., about one meter below the epilimnion. At this depth there was observed about 0.066 per cent of incident radiation, or about 0.10 per cent wtih zenith sun. The instruments would have allowed readings to a somewhat greater depth, perhaps to about 9 m., where radiation would have been about 0.010 per cent. With zenith sun the characteristic transmission is 49; 0.10 per cent would come at 8:5 m. and 0.010 per cent at 12 m. The maximum depth is 18 m., so that transmission might continue uniformly to that depth; but the lake is large and turbid, and the area of deeper water is small. It is therefore quite probable that transmission began to fall off at a less depth.

Clear Lake. (Figs. 3, 6.) There are two series from this lake taken on July 13 and July 18, and extending to the depth of 18 m. They are platted together in Fig. 3 and show the kind of close general resemblance and difference in detail which would be expected in such a lake from series taken so near each other in time. In each series there was a more transparent stratum, 2—3 m. thick, near the depth of 10 m. where transmission rose to 80 or slightly more. This region was in the upper part of the hypolimnion. In the series of July 13 the reading at 18 m. was 0.016 per cent of incident radiation; at 17 m. it was 0.063 per cent, indicating a transmission of only about 25 in the bottom meter of water. This reading, as well as others of a similar kind, shows that there may be an accumulation of suspended matter close to the bottom of the water even on slopes and much above the greatest depth.

The data show that 0.10 per cent of incident radiation would be found at about 18 m. with zenith sun. The same rate of transmission would call for 5-6 m. more to reduce the amount

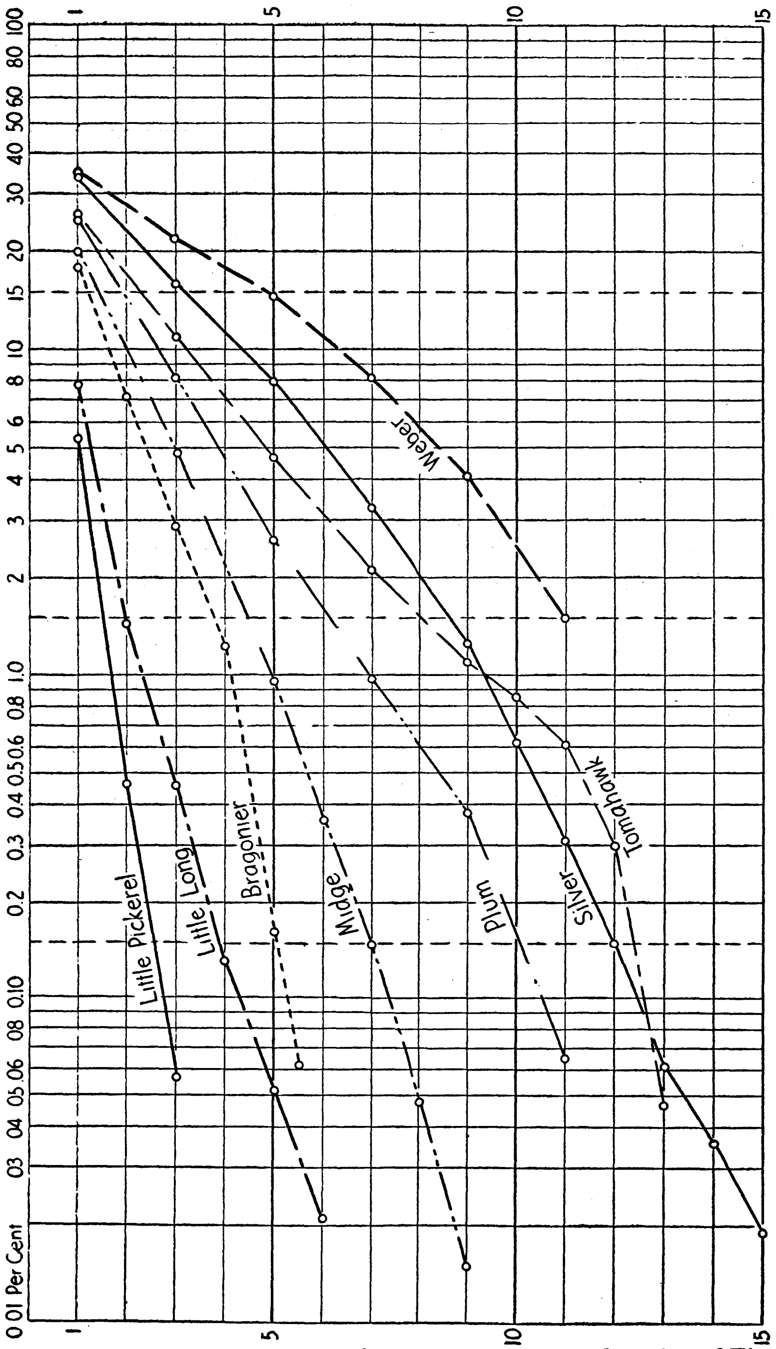

FIG. 5. Curves of Fig. 2 computed for zenith sun. See explanation of Fig. 4.

to 0.010 per cent. Since the maximum depth of the lake is 28 m. it is quite possible that transmission may continue at this rate to 23-24 m. But the lake is large, the bottom is irregular, and the area of the deep water is small, so that it is not improbable that opacity increases rapidly with depth below 18 m.

Muskellunge Lake. (Figs. 1, 4.) Readings in this lake went to the depth of 10 m., where there was found 0.18 per cent of incident radiation. The characteristic transmission as observed to 9 m. was 62; falling off to 45 between 9 m. and 10 m. This change is due to the influence of bottom debris. The characteristic transmission with zenith sun was 67; and since the maximum depth of the lake is 21 m. this rate might have been found to extend several meters farther. The epilimnion is 7 m. thick.

Tomahawk Lake. (Figs. 2, 5.) This lake was observed to the depth of 13 m. on the side of the slope extending to the greatest depth of water at 22 m. The conditions are not unlike those of Clear Lake. The mean transmission was 70 to the depth of 11 m. with a great and rapid decrease in the water below that depth, due to bottom turbidity. The observed transmission would bring 0.10 per cent of incident radiation at about 13 m.; and the transmission with zenith sun would place it at about 16 m. But the great size of the lake and the small volume of the deeper water render hazardous any extrapolation of observed results into deeper water than that investigated.

Trout Lake. (Figs. 3, 6.) In this lake the limiting depth was 15 m. and at that limit there was observed 0.044 per cent of incident radiation; at this rate reading might have gone 2 m.—3 m. further. The characteristic transmission was 71 with zenith sun, although there was a good deal of irregularity in the readings; for which see Fig. 3. Ordinarily the transmission in Trout Lake is less than 70, as is shown in Table III. In the series of 1931, 0.010 per cent of incident radiation would have been found at about 17 m. as observed, and at about 20 m. with zenith sun. This is probably about the maximum clearness of the water for summer, and since the greatest depth is 35 m. transmission at this rate might go on to even deeper water. Fig. 3 shows that there was a considerable decrease of transmission in the hypolimnion; but no marked decrease near the bottom.

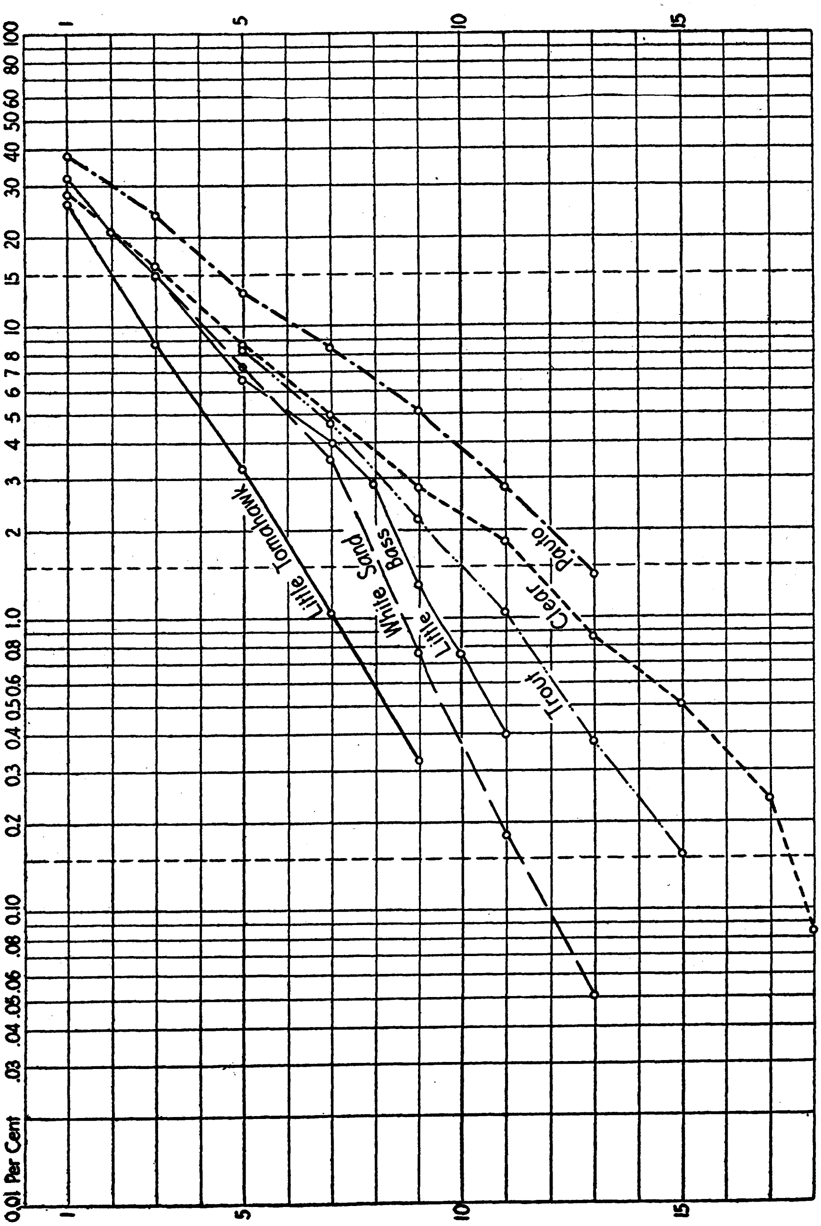

FIG. 6. Curves of Fig. 3 computed for zenith sun. See explanation of Fig. 4.

Group 4. Lakes in whose hypolimnion there is a notable decrease of transmission.

These lakes have a wide range of characteristic transmission; high (71—73) in Day, Pauto, and Little Bass lakes; high-medium (56—60) in Silver, Plum, and White Sand; low medium (48) in Midge Lake. In these lakes mechanical obstruction to the passage of radiation is present in the hypolimnion, not merely in water close to the bottom ooze (as in Diamond Lake) but also to a considerable distance above it. The part of the hypolimnion thus affected differs in the different lakes, reaching a maximum in White Sand Lake; where there is a sudden change of transmission at the junction of epilimnion and hypolimnion, with a fairly uniform and low transmission until the limit of observation is reached.

Table II shows the details of the observed transmission in these lakes. It brings out facts which are hardly noticeable in the diagrams. Such are the increase of transmission at the

TABLE II. *Observed percentages and transmission.*

Lake	Color	Epi	Per cent at meter indicated								
			0	1	2	5	7	9	11	13	14
Day	0	6	100	24	16	5.3	2.7	1.2	0.64	0.05	0.014
Little Bass	0	6	100	27	18	5.4	2.5	0.64	0.16	.....	.....
Midge	20	4	100	17	7.3	0.52	0.068	0.0035	......	.....	.....
Pauto	0	5	100	22	15	4.4	2.3	1.2	0.64	0.19	0.10
Plum	16	5	100	19	10	1.3	0.40	0.11	0.0116	.....	.....
Silver	5	6	100	29	19	5.6	2.0	0.68	0.12	0.026	0.012
White Sand	12	7	100	25	16	4.6	1.9	0.26	0.067	0.014	.....

Lake	Transmission between meters						
	1–2	2–5	5–7	7–9	9–11	11–13	13–14
Day	70	69	72	67	53	39	30
Little Bass	69	67	68	54	50	....	....
Midge	43	41	39	22	....	....	....
Pauto	68	66	73	72	73	55	53
Plum	53	51	56	53	38	....	....
Silver	67	67	59	59	42	43	43
White Sand	67	65	64	38	51	46	....

Column headed "Epi" gives the thickness of the epilimnion in meters.

thermocline in Day Lake; the similar increase for a considerable distance in Pauto Lake; the greater turbidity of White Sand Lake at the thermocline.

Day Lake. (Fig. 1, 4.) The lower water of this lake was much less transparent in 1931 than it was in 1929 ('30 : 295). The situation appears in the following table:

Percentage of incident radiation observed in Day Lake at the depths indicated

Date	*0 m.*	*1 m.*	*5 m.*	*10 m.*	*12 m.*	*14 m.*
Aug. 26, 1929	100	27	6.2	1.8	1.0	0.22
Aug. 20, 1931	100	24	5.3	0.64	0.26	0.012

The characteristic transmission, with zenith sun, to 9 m. was not very different — 75 in 1929, 73 in 1931. In 1931 transmission below 9 m. fell off rapidly. In 1929 there was nearly three times as much radiation at 10 m. as in 1931; at 12 m. four times; and at 14 m. nearly 20 times as much. This is a good illustration of the ordinary constancy of the characteristic transmission from year to year and of the great differences in deeper water where turbidity is likely to change.

Little Bass Lake. (Figs. 3, 6.) The values of radiation in this lake were read with the millivoltmeter and therefore were followed only to 11 m., where there was found 0.16 per cent of incident radiation. The lake is about 14 m. deep and radiation is probably very rapidly absorbed in water below 11 m. Transmission was little altered between surface and 8 m., where the temperature of the water was 15.7°, the epilimnion having 22.0°. Between 8 m. and 9 m. transmission was 40, while below, 9 m.-11 m., it was 50. This reading may be entirely correct or there may have been variations in radiation to account for part of the difference. There were white cumulus clouds in the sky, with large spaces between them. All readings were made in full sunshine, but it is probable that the value of radiation was variable from minute to minute.

Midge Lake. (Figs. 2, 5). Four series of observations were taken in Midge Lake during the summer, of which that of Aug. 5 is the most complete; the other agreed with it in general. Radiation was followed to 9 m., the maximum depth being 11.6 m. with very soft oozy bottom. The lake is surrounded by bog and the water is colored and turbid. The observations of Aug. 5 came in a very warm period of the summer and the temperature of the water declined from the surface, there being no real epilimnion. The lake is so small that the wind is unable to establish a regular epilimnion unless aided by cool days and nights. The surface temperature was 26.7°; that at 4 m. was 18.8°; at 7 m. 8.2°. Transmission was 49 in the 1-3 m. stratum; 46 between 3 m. and 5 m.; and 40 between 5 m. and 7 m. Below 7 m. there was a sudden decline to about 31. This indicates turbidity increasing with depth and having a marked rise as the bottom is neared. Color also rises and shows a sharp increase at 9 m. The color readings were: surface, 20; 5 m., 27; 9 m., 40. In this lake was found the minimum per cent of incident radiation observed during the summer — 0.0035 per cent at 9 m. The area of the 9 m. level of the lake is about 13 per cent of the surface area, and the volume of water below 9 m. is about 3 per cent of the whole. The small remainder of radiation left at 9 m. must be extinguished before penetrating much farther.

Pauto Lake. (Figs. 1, 3, 4, 6.) Three series are included from this lake in order to show differences in transmission due to increase of turbidity during the summer. In all cases the characteristic transmission extended to 11 m. or more, and therefore well into the hypolimnion; since the epilimnion at this time of year is about 5 m. or 6 m. thick. The series taken in August showed a lower characteristic transmission than those in July — 73 as compared with 78 or 79 in earlier series. The percentage of incident radiation present at 1 m. was also smaller in August — 27 as compared with 38 or 40. Both facts indicate increased turbidity in the upper water, probably due to plankton. In all series it appears that the lower water was turbid, and that the relation between it and the upper water was much the same at all dates. Readings on August 4 went to 15.7 m., close to the bottom at the place of observation. There was observed at that depth 0.012 per cent of incident radiation; with the same transmission and with zenith sun there would have been found at 16 m. about 0.01 per cent.

Plum Lake. (Figs. 2, 5.) This large and generally shallow lake has one relatively small area near the center where the depth is 18 m. The color of the water is 16 and there is much turbidity at all depths. The characteristic transmission, computed for zenith sun, was 60 (observed transmission, about 53) and extended to nearly 9 m. The epilimnion was 5 m. thick. At 9 m. there was an abrupt change in transmission, which was 38 to 11 m., the limit of observation; at this depth there was left 0.016 per cent of incident radiation.

Silver Lake. (Figs. 2, 5.) Radiation was followed in this lake to the depth of 15 m. (maximum depth 19.5 m.), where there was observed 0.006 per cent of incident radiation. Readings below the surface were made at 1 m., then at 5 m., 7 m., etc. Observed transmission 1 m. to 5 m. was 67, and declined to 59 in the 5—9 m. stratum, indicating greater turbidity of water from the epilimnion down. In this respect the lake shows a transition from lakes like Pauto, where the upper hypolimnion is as transparent as the epilimnion, to lakes like White Sand, in which the whole hypolimnion is turbid to a fairly uniform degree.

White Sand Lake. (Figs. 3, 6.) The characteristic transmission of this lake in 1931 was 70 with zenith sun; this is much higher than in former years, when it was 50—55 (Table V). Characteristic transmission ended at the thermocline and was succeeded by a much lower one in the stratum 7—13 m. Transmission between 7 m. and 9 m. was especially low, about 38 as observed. At 13 m. the observed per cent was 0.014, and with zenith sun 0.01 per cent would be found close to 15 m., about 6 m. above the bottom of the lake. Here the whole hypolimnion was much more opaque than the epilimnion; the difference being due not to color but to turbidity, as was shown by centrifuge catches. The relatively large area of the lake enables the wind to set up currents of considerable power, which sweep the lighter particles of debris from the bottom of the shallower parts of the lake and accumulate them in the deeper water.

This was the best example found in 1931 of a lake whose whole hypolimnion was made turbid by debris so that there was a sharp difference in transmission between it and the epilimnion. Among smaller lakes Hillis offered a somewhat similar case in 1929 ('30 : 300), as also did Finley ('30 : 298); but in these cases color of the lower water had much influence, as well as turbidity.

Bragonier Lake. (Figs. 2, 5). This small lake may well be treated here. It is small and shallow and the deeper water has a very small area and little volume. The shores are largely of bog and marsh; the bottom is of soft ooze; there is much color and much turbidity in the water. Characteristic transmission was 41 with zenith sun and went to 4 m.; below that depth there was a great and rapid increase of turbidity and also of color, with corresponding decrease of transmission. Observation ended at 5.5 m. where there remained 0.017 per cent of incident radiation.

This lake was visited in 1930 ('31: 397) and a comparison of the curve there shown with that in the present paper will illustrate the kind of additional knowledge brought by the use of the galvanometer. In the earlier year observation could not go below the depth of the characteristic transmission. The whole hypolimnion of the lake may well be regarded as "bottom water", in view of its small volume and the great amount of debris which it contains.

Group 5. Lakes with deeply stained water.

There is a very definite gap in the series of colors reported in Table I, coming between Adelaide (36) and Turtle (68); and the remainder of the list consists of lakes with higher color than Turtle. There is a difference also in the type of transmission found in these high colored waters and in those which are more transparent. In the case of the latter type there is a mean transmission (the "characteristic transmission") which can be stated and which usually extends through the epilimnion or deeper. The transmission in the 1-2 m. stratum may be somewhat lower than that in the meter below; and it should be, so far as the general effect of the water on solar radiation is concerned ('29 : 533); but the difference is not great and is often obscured or eliminated by variable accidents, such as the amount and position of plankton.

In each of the five lakes with high colored waters there is a marked difference between transmission in the 1-2 m. stratum and in that immediately following. The situation as shown by the transmission computed for zenith sun is given in the notes to Table I. The following table indicates it as directly observed.

In each lake the transmission rises in the 2-3 m. stratum as compared with that in the meter above. The difference may be strikingly large and may increase in lower strata. It is least

TABLE III.

Lake	Col-or	Per cent at depths indicated							Transmission between meters				
		0 m.	1 m.	2m.	3m.	4m.	5m.	6m.	1–2	2–3	3–4	4–5	5
Helmet	268	100	1.10	0.83	.012	....	....	....	8	15	....	....	...
Little Long	96	100	6.40	1.03	.30	.077	.029	.011	16	30	26	38	38
Little Pickerel	108	100	3.50	0.21	.017	....	....	....	6	8	....	....	...
Mary	132	100	2.90	0.41	.15	.060	.015	....	14	27	40	25	...
Turtle	68	100	7.26	1.23	.27	.087	.021	.007	17	22	32	24	33

in Little Pickerel Lake, which is a shallow lake with boggy shores, and whose water is not only high colored but also turbid with a great amount of organic debris. The other lakes are much less turbid, except sometimes the surface meter of Lake Mary. Turtle Lake, which has the lowest color has also the smallest increase with depth among the lakes with clearer water.

We can not speak of a "mean transmission" in the upper water of these lakes as we do for the others on our list. The transmission in the 1-2 m. stratum of these lakes is in somewhat the same condition as that in the 0-1 m. stratum of all lakes. Absorption goes on here much more rapidly than below; so much more rapidly that no significant mean can be made by combining the record of this stratum with that of those below. A reason for the situation lies in the high color of the water. This absorbs very rapidly the short-wave part of the spectrum and quickly reduces it to the part which most readily passes through water in this particular color. This is one cause, and perhaps the main one, for this rise of transmission.

The situation in lakes of this type is shown in '31 : 415, Fig. 20 and especially in '30 : 331, 333, Figs. 14, 15. The last named figures show for individual lakes the relation between the transmission of total radiation and that of the several colors. In lakes whose water is colored but not deeply stained, the maximum transmission is that of the central or yellow region of the spectrum; with increase of color the transmission of yellow falls off, both absolutely and relatively, so that it becomes less than that of total, which comes to coincide with red. It is a rough sort of division of the spectrum that is effected by these light-filters, but it shows that the light must soon be reduced to that part whose color is approximately that transmitted by the water. During this process of reduction there must be an increase of the rate of transmission of the remaining radiation, whose absorption is minimal for the lake under observation.

Observations with results similar to these have also been made by Poole ('30 : 142-149) in Lough Bray, Ireland, to the depth of 4 m. In this lake the per cent of incident light present at 1 m. was 0.5; transmission, 1-2 m. was 7; 2-3 m., 28.6. These observations were made with a neon discharge tube which responds to short-wave radiation only. Poole's explanation of the rise in transmission is that "longer waves penetrate deeper", and this, within limits, would be ours also. So far as we know, these interesting readings are the only observations of the kind that have been made in Europe.

There is a possible second cause for the rise in transmission with depth, and at present we can not differentiate its effects from those coming from color directly. In these lakelets with high colored water, temperature and consequently density, fall off rapidly from the surface. An extreme example was found in Helmet Lake on July 29, where the temperatures were as follows: surface, 29.2°; 1 m., 25.0°; 2 m., 18.9°; 3 m., 12.7°; 4 m., 9.3°; 5 m., 7.9°; 7 m., 7.6°; 9.5 m., 7.4°. With such conditions of temperature rain or seepage water entering through marginal bog and bringing color and turbidity would be confined to the water very close to the surface of the lake.

The difference in transmission between successive meters seems to rise with color of the water; but no regular series can be made out. None would be expected, since more than one factor is concerned. Mary Lake, for instance may or may not have a considerable quantity of fine gummy debris in the surface water, and similar statements might be made for each lake.

In all of these lakes transmission was followed about as far as the instruments could go and in each case it is safe to extend the curve of observed radiation to 0.010 per cent of incident radiation. But it has not been thought quite safe to do so for radiation with zenith sun. The quantity of radiation is very small; the color of the water varies as also does the turbidity. For these reasons the depth stated for 0.010 per cent with zenith sun is bracketed; but the position can not be in error more than a small fraction of a meter. (See Table I).

THE MINIMUM OBSERVATIONS.

A special interest attaches to the value of the smallest readings made, those that are near the limit of sensitivity of the instrument. These usually come at the end of the series of readings, since observations are made in descending order. In many cases the pyrlimnometer was brought to the surface and an air reading taken immediately after that at the greatest depth. In other cases work was done at various depths before coming to the surface. If the minimum reading is computed as the last of a series which begins at one meter its value will differ slightly from that obtained from computing it as a percentage of the total radiation at the moment of observation. But such differences are inconsiderable.

The minimum scale-reading was 1.3 divisions of the 4 range of the galvanometer, and represented about 0.0035 per cent of the reading in air. This last was 61 divisions of the 20 mv. scale, equivalent to 37,200 of the 4 galv. scale. This observation was made near the bottom of Midge Lake in 9 meters of water. The last three discs of the pyrlimnometer were read there twice with concordant results. In Silver Lake (15.7 m.) and in Turtle Lake (6 m.) minimum readings were obtained of 2 divisions of the 4 galv. range. In both cases the reading in the air was low — 52-54 divisions of the 20 mv. range; and the reading shows, at the depth named, about 0.006 per cent of radiation incident on the surface. In 9 other lakes readings of 4-7 divisions gave values of 0.011-0.018 per cent of the radiation in air.

No minute accuracy can be claimed for such small scale-readings, though they were always repeated. There is often a variation of reading, as in the case of White Sand Lake, where readings equally good gave from 5 to 7 divisions of the scale.

Probably no great confidence would be placed in readings so small if the pyrlimnometer had been lowered from the air directly to the maximum depth; there is a great difference between 4-7 divisions of a scale which is read directly, and the 30,000 or 40,000 divisions of the same scale, which are needed to express the reading in the air. But the minimum is gradually approached, in the series of observations, by reasonable stages; and Figures 1, 2, and 3 show that it plats into the curve just about where extrapolation from the larger readings would place it.

From these minimum readings may be computed the extreme limit for the present combination of pyrlimnometer and galvanometer. Readings in air near noon in June and July have given more than 100 divisions of the 20 mv. scale. This would be equivalent to more than 60,000 divisions on the 4 galv. scale; a reading of two divisions of that scale would represent about 0.0030 per cent of the radiation delivered to the surface of the lake. Under such conditions, curves on semi-logarithmic paper could be carried through five cycles, without danger of serious error.

These actual and possible results may be compared with those obtained by other types of instruments. Shelford and Gail ('22 : 156), working in Puget Sound, found at 120 m. light to the amount of 0.108 per cent of that present at the "wet" photometer close to the surface. This would correspond to about 0.08-0.09 per cent of the light in the air. Poole and Atkins ('29), working in the ocean near Plymouth, found 0.016 per cent at 70 m., Jan. 3, 1928; 0.019 per cent at 60 m., July 23; 0.026 per cent at 40 m., Oct. 12. All of these observers used photo-electric cells.

Oberdorfer ('28) used a photographic method in the Bodensee. He reports 0.02 per cent of incident light at 30 m. on one occasion ('28 : 475). Apart from this case his minimum reading was 0.11 per cent at 25 m.

In all of these cases the base from which the percentage is computed is the light, not the total radiation which we employ. The percentages should therefore be divided by two in order to make them roughly comparable with ours. All of the reported percentages seem to be those observed, not those adjusted for zenith sun. So far, therefore, as the present record goes, all of these methods follow radiation to about the same minimum value. It can be followed to about 0.01 per cent of its surface value, and under favorable conditions readings can be obtained which enable the observer to carry his curves well into the next logarithmic cycle, which closes at 0.001 per cent.

Relation of Color, Turbidity, and Transmission

The number of observations is now large enough to permit a provisional classification of lakes according to color and transmission. There are not enough cases, especially in the groups with higher color, to give wholly satisfactory mean values. But taking the facts as they stand in the table several matters appear in them. (1) Transmission decreases as color rises and with fair regularity, as is shown by Fig. 7. (2) The range of transmission greatly overlaps in the several color groups. (3) There is a wide range of transmission in each color-group. (4) In spite of small numbers the maximum and minimum in the successive color-groups show much the same relation as do the means.

TABLE IV. *Classification of Lakes by Color-group and Transmission.*

Color	Transmission									Cases Total	Transmission		
	20–29	30–39	40–49	50–59	60–64	65–69	70–74	75–79	80+		Mean	Min.	Max.
0	.....	.....	.....	.....	.....	3	9	10	14	36	77	65	85
5–9	.....	.....	1	6	3	7	11	3	.....	31	68	46	76
10–14	.....	.....	2	2	6	2	3	.....	.....	15	61	41	73
15–19	.....	4	3	8	3	.....	.....	.....	.....	18	51	36	60
20–29	1	5	9	1	.....	.....	.....	.....	.....	16	42	28	49
30–39	1	2	4	.....	.....	.....	.....	.....	.....	7	38	25	46
40–49	3	.....	2	.....	.....	.....	.....	.....	.....	5	32	21	46
Total	5	11	21	17	12	12	23	13	14	128			

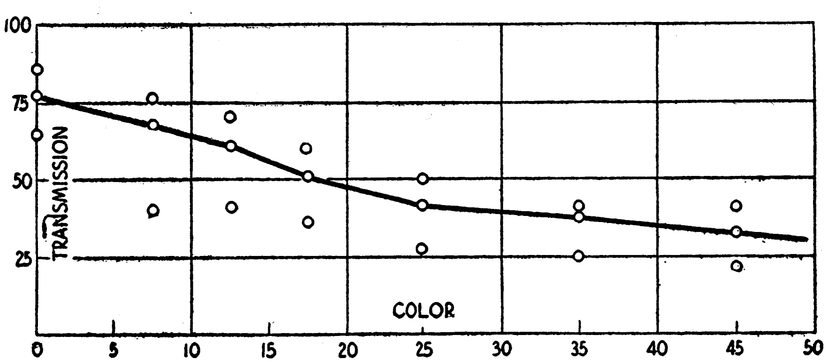

FIG. 7. Relation of color to transmission of radiation. The figure shows the facts of Table IV. At the center of each color-group is platted the mean transmission for that group, and with it are given the maximum and minimum transmission found in that group.

We seem warranted therefore in concluding that in all lakes the characteristic transmission is determined by factors of color and turbidity; that color is the main factor determining the place of the lake in the general scale of transmission; that turbidity causes much variation in transmission, causes overlapping of the several color groups, and wide range of transmission in each group.

If the water of a lake were colorless and optically pure transmission near the surface would be 90 or more, increasing with depth until it approached 98. In optically pure colored waters transmission would be lower than in colorless water and would follow the general order of the groups; but in any group transmission would be higher than any recorded for that group in the accompanying table.

TABLE V. *Per Cent at One Meter and Characteristic Transmission with Zenith Sun.*

Lake	1918		1926		1927		1928		1929		1930		1931	
	% 1m	Trm	% 1m	Trm	% 1m	Trm	% 1m	Trm	% 1m	Trm	% 1m	Trm	% 1m	Trm
Adelaide	....	....	....	....	12	33	12	38	12	35	18	40	16	44
Big	....	....	19	50	....	....	....	....	....	....	18	44	20	49
Big Carr	....	....	....	....	....	....	28	65	34	72	34	62	28	62
Bragonier	....	....	....	....	....	....	....	....	....	....	14	28	18	41
Clear	....	....	....	....	....	....	32	74	34	80	....	....	34	74
Crystal	....	....	40	84	....	....	39	80	34	83	38	84	40	83
Day	....	....	....	....	....	....	....	....	28	74	40	78	30	73
Diamond	....	....	....	....	....	....	....	....	37	81	41	81	38	81
Helmet	....	....	....	....	....	....	....	....	....	....	....	....	1.7	13
Little Bass	....	....	....	....	....	....	....	....	30	75	30	73	32	71
Little Long	....	....	....	....	....	....	....	....	....	....	5.4	21	7.9	18
Little Pickerel	....	....	....	....	....	....	....	....	2.5	10	4.9	10	5.3	10
Little Tomahawk	....	....	....	....	....	....	....	....	32	75	24	64	26	58
Mary	....	....	6.3	39	....	....	4.7	24	8.6	16	4.0	13	4.2	18
Midge	....	....	....	....	....	....	....	....	18	53	19	46	20	48
Muskellunge	....	....	27	66	....	....	24	67	21	60	31	63	28	67
Nelson	....	....	....	....	....	....	....	....	....	....	31	63	25	56
Pauto	....	....	....	....	....	....	34	70	35	71	....	....	40	79
Plum	....	....	24	61	....	....	....	....	21	59	26	58	24	60
Silver	....	....	....	....	....	....	....	....	31	67	31	73	34	70
Tomahawk	....	....	....	....	....	....	....	....	....	....	....	....	28	70
Trout	28	67	32	70	24	60	27	65	24	63	28	62	30	71
Turtle	10	28	....	....	4.7	18	....	....	10	23	....	....	11	21
Weber	....	....	....	....	34	76	....	....	36	75	39	76	36	75
White Sand	....	....	19	52	....	....	....	....	26	56	27	50	36	70

PER CENT AT ONE METER AND CHARACTERISTIC TRANSMISSION WITH ZENITH SUN.

Table V brings together the observations on radiation in the lakes of the list of 1931. Only one series is reported for each year, and reference is made to earlier reports for the record of lakes like Trout or Crystal which in some years were visited several times.

The table shows that in general the lakes retain their characters from summer to summer. Variations are often surprisingly small, as in Plum Lake. The greatest variability is shown by the high colored lakes in which transmission is ordinarily low. This variability is associated with the absence of a real epilimnion during most of the summer. Radiation penetrates into the water for a small distance only; wind has little effect on these small lakelets; and the temperature and density of the water fall off rapidly from the surface. The result is a corresponding change of color and turbidity in thin surface strata of water, with accompanying alterations of transmission. In these lakes transmission is given for the 1—2 m. strata only. For transmission in deeper strata, as found in 1931, see p. 554.

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TABLE VI. *General characters of lakes*

Lake	1 Location		2 Length km.	3 Area ha.	4 Depth m.	5 Type	6 Plankton mg/1	7 Total Organic mg/1
	Town north	Range east						
Adelaide	44	V	0.74	22	22.0	S	1.58	19.44
Big	42	VI	3.57	429	18.5	D	1.49	15.53
Big Carr	38	VII	1.35	95	22.0	S	0.74	6.94
Bragonier	40	IX	0.61	19	8.7	S	0.84	12.53
Clear	39	VII	2.15	343	28.0	S	0.73	6.94
Crystal	41	VII	1.00	32	21.0	S	0.64	3.58
Day	41	VI	1.22	52	17.0	S	0.65	5.29
Diamond	41	VI	0.94	48	12.3	S	0.68	2.98
Helmet	43	VI	0.14	2.7	8.5	S	1.69	55.50
Little Bass	40	VI	0.42	6.6	13.0	S	0.55	3.53
Little Long	43	V	0.80	15	18.0	D	1.35	31.51
Little Pickerel	39	VIII	0.47	8.5	5.0	S	1.82	20.77
Little Tomahawk	38	VII	0.96	5.4	14.6	D	0.80	8.58
Mary	44	V	0.12	1.2	22.0	S	1.65	38.86
Midge	41	VI	0.27	3.4	11.6	S	0.88	10.54
Muskellunge	41	VII	1.93	362	21.0	S	1.23	10.02
Nelson	42	VI	0.53	20	15.0	S	1.45	6.35
Pauto	40	VI	0.50	10	17.2	S	0.49	4.44
Plum	41	VIII	6.76	440	18.0	D	0.85	10.69
Silver	41	VI	1.69	87	19.5	D	0.83	7.63
Tomahawk	39	VI	7.24	1476	22.5	D	0.74	7.13
Trout	41	VII	7.24	1683	35.0	D	0.89	8.07
Turtle	43	V	2.00	259	14.5	D	1.02	27.75
Weber	41	VII	0.66	16	13.5	S	0.85	4.80
White Sand	42	VII	1.98	216	20.5	D	0.94	8.81

NOTES ON TABLE VI

Column 4 shows the maximum depth, i. e., the depth as measured by lead and line. It is ordinarily greater than would be found by a large flat instrument like the pyrlimnometer, since the weight of the sounding line sinks into the organic mud of the bottom. In lakes like Pickerel, Midge, and Pauto there is no exact depth which can be called the bottom, since the water passes almost insensibly into the soft organic ooze below it.

Column 5, Type. This classifies lakes as seepage (S) and drainage (D). Muskellunge Lake, classified as seepage, once had a regular outlet and in some years has now a very small overflow. Silver Lake ordinarily overflows, but has no outlet in years with little rainfall. Little Tomahawk Lake is at the head of a chain of lakes; it has an outlet but no affluent.

Column 6, Plankton. This column states in milligrams per liter the average amount of organic matter in the centrifuge plankton from the surface water. The number of observations ranges from one (Helmet Lake) to twelve (Crystal and Weber Lakes).

Column 7. Total organic. This states in milligrams per liter the average amount of the total organic matter in the surface water, including centrifuge plankton and dissolved material. It has been computed as crude protein and as carbohydrate. Number of observations as in Column 6.

PROCEEDINGS OF THE ACADEMY

SIXTIETH ANNUAL MEETING, 1930

The sixtieth annual meeting of the Wisconsin Academy of Sciences, Arts and Letters, in joint session with the Wisconsin Archeological Society and the Midwest Museums Conference, was held in the Biology Auditorium of the University of Wisconsin, Madison, on Friday and Saturday, April 11 and 12, 1930. The following papers were presented:

Friday morning, April 11: (1) Louise P. Kellogg: The Treaty at the Cedars, 1836; (2) Albert B. Reagan: Some myths of the Hoh and Quileute Indians; (3) May L. Bauchle: Wisconsin's hidden jewel—Nashota; (4) Milton F. Hulburt: Sauk County Indian trails; (5) E. R. McIntyre: John Wesley Hoyt—western pioneer; (6) George Overton: Old beach camp sites of the Winnebago County lake region; (7) Will F. Bauchle: Trailing civilization by footprints; (8) Theodore Brown: Joseph Jourdain, early French blacksmith; (9) John G. Gregory: Indians as neighbors; (10) M. E. Hathaway: Barbed stone axes of Michigan.

Friday afternoon, April 11: (11) Geo. R. Fox: The archeology of the Bahamas; (12) Paul B. Jenkins: The battle of Kings Mountain; (13) John B. McHarg: Lincoln—things new and old; (14) Harry H. Clark: Lowell and American political thought; (15) Ernst Voss: An edict of Philip, Landgrave of Hessia, issued in 1539; (16) Rufus M. Bagg: The economic and industrial development of South Africa; (17) John S. Bordner: Evaluation of land in terms of utilization; (18) William W. Morris: Reforestation problems in northern Wisconsin; (19) J. J. Davis: Notes on parasitic fungi in Wisconsin, XVIII; (20) James A. Lounsbury: A strange fungus from Transvaal soil; (21) Waldo E. Steidtmann: Studies of growth rings of some tropical woods; (22) W. E. Tottingham and J. G. Moore: Some effects of Vita glass upon plant growth; (23) A. H. Wiebe: Pond culture.

Saturday morning, April 12: (24) Eric R. Miller: A century of progressive changes of rainfall in Wisconsin; (25) Jeanette Jones: Notes on the late Ordovician strata of the Green Bay-Lake Winnebago region; (26) T. E. B. Pope: Wisconsin herpetological notes; (27) A. A. Granovsky: The use of the airplane in the control of forest insects; (28) J. B. Overton: Seasonal variations between the hydrostatic and pneumatic systems in trees; (29) W. T. McLaughlin: The origin of swamps and bogs; (30) L. R. Wilson: Some plant remains in a peat bog; (31) Bernice I. Quandt: Notes on some Washington County bogs; (32) N. C. Fassett: The ranges of some Wisconsin plants; (33) H. A. Schuette: Early accounts of the making of maple sugar; (34) Willoughby M. Babcock: Wing screen methods of displaying coins; (35) Nile Behncke and Mrs. E. E. Rogers: Results of special exhibits; (36) Edward R. Tyrrell: Materials used in museum model construction (celluloid and Balsa wood).

Business sessions were held immediately preceding each of the three sessions for the reading of papers. The secretary presented the following report, covering the period April 1, 1929 to March 31, 1930: Membership as of March 31, 1930: honorary members, 5; life members, 14; corresponding members, 15; active members, 329; total, 363. Membership losses during the year: deceased, 2; resigned, 1; dropped for non-payment of dues, 15; total lost, 18. The deaths of the following members were announced: Emil Godfrey Arzberger, January 29, 1930; William Christian Sieker, December 1, 1929. The secretary presented the following applications for membership, and on motion was unanimously instructed to cast the ballot of the Academy in their favor: Harry Hayden Clark, Madison; Samuel Eddy, Minneapolis, Minn.; Waldo E. Steidtmann, Milwaukee; Arthur N. Bragg, Milwaukee; W. T. McLaughlin, Madison; Leonard R. Wilson, Madison; Jeanette Jones, Evanston, Ill.; Alphonse L. Heun, Milwaukee; Alvin L. Throne, Milwaukee; Gilbert Raasch, Madison; Silas M. Evans, Ripon. The nominating committee, consisting of George Wagner, J. J. Davis and Charles E. Brown, reported nominations for the various offices, and on motion the officers nominated were unanimously elected for a term of three years: *President,* Charles E. Allen, Madison; *Vice-President in the Sciences,* Rufus M. Bagg, Appleton; *Vice-President in the Arts,* Otto L. Kowalke, Madison; *Vice-President in Letters,* William E. Alderman, Beloit; *Secretary-Treasurer,* Lowell E. Noland, Madison; *Curator,* Charles E. Brown, Madison; *Librarian,* Walter M. Smith, Madison; *Committee on Publication:* the president and secretary, ex officio; Arthur Beatty, Madison; *Committee on Library:* the librarian, ex officio; Howard Greene, Milwaukee; Mrs. Angie K. Main, Fort Atkinson; George Van Biesbroeck, Williams Bay; R. C. Mullenix, Appleton; *Committee on Membership:* the secretary, ex officio; Ralph N. Buckstaff, Oshkosh; E. F. Bean, Madison; A. M. Keefe, West De Pere; W. N. Steil, Milwaukee. The report of the Treasurer for the period, April 1, 1929 to March 31, 1930, was presented as follows:

RECEIPTS

Balance in State Treasury, April 1, 1929	$2,023.75
Received from dues	288.50
Received from sales of Transactions, etc.	129.62
Deposited from permanent fund	909.45
State appropriation, July 1, 1929	1,500.00
Total receipts	$4,851.32

DISBURSEMENTS

To State Printing Board for printing	$2,562.87
Allowance for secretary	200.00
Postage for mailing Volume 24 of Transactions	50.00
Other expenditures	31.50
Total disbursements	$2,844.37
Balance in State Treasury, April 1, 1930	2,006.95
Total	$4,851.32

SECURITIES AND CASH ON HAND

City of Madison bonds	$1,100.00
Chapman Block bonds	400.00
Commonwealth Telephone Company bonds	200.00
Trust agreement, Centr. Wis. Trust Co.	1,000.00
4 certificates of deposit	227.98
Cash	13.58
Total	$2,941.56

The auditing committee, consisting of Lowell E. Noland and Ralph N. Buckstaff, reported that it had examined the accounts of the treasurer and had found them correct.

The annual dinner was held at the Memorial Union on Friday evening, April 11. It was attended by 52 individuals. After the dinner S. A. Barrett, President of the Academy, delivered an address on the subject, "Tamest Africa", which was illustrated with lantern slides and moving pictures.

A committee appointed by President Barrett and consisting of three members, Rufus M. Bagg, George A. West and T. E. B. Pope, presented the following report: "Resolution of thanks to the University of Wisconsin and the members and officers of the Wisconsin Academy of Sciences, Arts and Letters for their courteous reception and entertainment during the convention held at Madison, April 11 and 12, 1930. We feel greatly indebted to all the officers and directors for the very interesting educational program presented and for their faithful services during the past year."

CHANCEY JUDAY,
Secretary-Treasurer.

SIXTY-FIRST ANNUAL MEETING, 1931

The sixty-first annual meeting of the Wisconsin Academy of Sciences, Arts and Letters, in joint session with the Wisconsin Archeological Society and the Midwest Museums Conference, was held at Ripon College, Ripon, on Friday and Saturday, April 10 and 11, 1931. The following papers were presented:

Friday morning, Section A, in the Little Theater: Silas M. Evans. Address of Welcome; (1) Alton K. Fischer: Vertebral pathology of prehistoric Wisconsin Indians; (2) George Overton: Silver ornaments from Grand Butte; (3) Charles E. Brown: An effigy pipe from Pepin, Wisconsin; (4) John B. McHarg: Indian mound photography; (5) Robert R. Jones: Central Pennsylvanian archeology; (6) Kermit Freckman: Pleasant Lake mound groups; (7) Alonzo W. Pond: A lower paleolithic site in the Sahara desert.

Friday morning, Section B, in the Biology Lecture Room: (8) H. V. Truman: The investigation of a post-glacial peat deposit near Lodi, Wisconsin; (9) L. R. Wilson: The interglacial forest bed at Two Creeks, Wisconsin; (10) N. C. Fassett: An aquatic desert; (11) W. T. McLaughlin: Some noteworthy plants of the Fox River valley; (12) J. J. Davis: Notes on parasitic fungi in Wisconsin, XIX (by title); (13) H. C. Greene: Some studies on the myxomycetes of Wisconsin (by title); (14) William W. Morris: Planting trees for profit in Wisconsin; (15) J. F. Groves: Studies on hybrid barberry; (16) R. A. Brink and D. C. Cooper: The association of semisterile-1 in maize with two linkage groups.

Friday afternoon, Section A, in the Little Theater: (17) Elmer W. Ellsworth: Varved clays of Wisconsin; (18) Ira Edwards: Observations on the pleistocene of the Black River Falls quadrangle, Wisconsin; (19) Albert B. Reagan: The Brush Creek region in northeastern Utah; (20) Theodore T. Brown: The Albert H. Mill collection; (21) Will F. Bauchle: Where the West begins; (22) Ernst Voss: Vom Schlauraffen Landt (About the Land of Plenty) (by title); (23) Albert H. Griffith: Lincoln literature, collectors and collections; (24) John B. McHarg: Early homes of the Lincolns.

Friday afternoon, Section B, in the Biology Lecture Room: (25) D. C. Cooper and R. A. Brink: Cytological evidence of segmental interchange between non-homologous chromosomes in Zea mays; (26) L. J. Cole: Crossing over in pigeon hybrids; (27) Agnes L. Zeimet: Embryo mortality in birds, particularly hybrids; (28) Alan Deakin: Pigmentation in the mammary gland of swine; (29) S. X. Cross: The development of immunity to the pathogenic effects of Trypanosoma lewisi in the rat; (30) C. A. Herrick: Some relationships between the rat and the parasite Trypanosoma equiperdum; (31) Eric R. Miller: Sunshine and cloudiness in Wisconsin.

Friday afternoon, General session in the Little Theater: (32) E. A. Birge: Limnological investigations in the Trout Lake region of Wisconsin. Illustrated by moving pictures.

Friday evening, General session in the College Chapel: (33) Alonzo W. Pond: Reliving the past. Illustrated by lantern slides and moving pictures of North African explorations.

Saturday morning, Section A, in the Little Theater: (34) G. M. W. Teyen: The relation of the museum's library to the museum; (35) Ruth Shuttleworth: Illustrating a museum special exhibit; (36) Frances S. Dayton: A Winnebago camp site; (37) R. C. Corwin: Features of Great Salt Lake; (38) W. D. Kline: Florida's tung oil industry.

Saturday morning, Section B, in the Biology Lecture Room: (39) H. W. Cornell: The mutual eclipses of Jupiter's satellites to occur in the autumn of 1931; (40) Edwin P. Creaser: The decapods of Wisconsin; (41) Lowell E. Noland: Recognizing the species of bell-animalcules (Vorticellae); (42) J. P. E. Morrison: Hydrogen-ion relations of certain molluscs in northeastern Wisconsin lakes; (43) T. E. B. Pope: Wisconsin herpetological notes; (44) Albert M. Fuller: Modern field methods in botany.

Saturday morning, General session in the Little Theater: (45) Huron H. Smith: The ethnobotany of the Oneida Indians.

The annual business meeting of the Academy was held in the Little Theater on Friday afternoon, April 10. The secretary presented the following report on membership: Membership as of April 1, 1931: honorary members, 5; life members, 15; corresponding members, 19; active members, 318; total, 357. Members lost during the year: deceased, 0; resigned, 15; dropped for non-payment of dues, 11; dropped for loss of address, 1; total lost, 27. The following names were presented by the secretary for election to membership: Milivoye Trifounovitch, Brussels, Belgium; S. Kabboor, Bangalore, India; Morris A. Gilbert, Milwaukee; Edwin P. Creaser, Ann Arbor, Michigan; Lellen Sterling Cheney, Barron, Wisconsin; H. C. Greene, Madison; Elmer W. Ellsworth, Stanford University, California; Joe E. Morrison, Madison; G. M. W. Teyen, Milwaukee; Elizabeth Mac Donald, Oshkosh. It was moved and seconded and carried that the secretary cast the unanimous ballot of the Academy for the new members.

The treasurer's report, as of April 9, 1931, was presented as follows:

RECEIPTS

Balance in State Treasury, April 1, 1930	$2006.95
State appropriation, July 1, 1930	1500.00
Dues received from members	467.80
Wis. Geol. & Nat. Hist. Survey for plates	429.90
Annual allowance from A. A. A. S.	116.00
From sale of Academy publications	84.67
From members for extra reprints	20.73
Total	$4626.05

DISBURSEMENTS

Printing of Vol. 25 of Transactions	$2198.01
Other printing (programs, stationery, etc.)	73.00
Zinc etchings for Vol. 26 of Transactions	119.28
Secretary's salary for the year	200.00
Postage for correspondence and mailing Vol. 25	72.00
Supplies for secretary's office	8.68
Balance in State Treasury, April 9, 1931	1955.08
Total	$4626.05

PERMANENT FUND

Trust agreement, Centr. Wis. Trust Co.	$1000.00
City of Madison bonds	1000.00
Bonds, Chapman block, Madison	400.00
Commonwealth Telephone Co. bonds	400.00
Capitol Square Realty Co., Madison, bonds	200.00
Cash on hand	77.15
Total	$3077.15

The auditing committee (Ira Edwards and C. A. Herrick) reported that it had examined the treasurer's accounts and securities and had found them correct as stated in the report. The treasurer's report and the auditing committee's report were approved.

It was moved, seconded and carried that the former secretary-treasurer, Chancey Juday, be elected to life membership in the Academy in recognition of his extended and valuable services during the nine years of his secretaryship.

The following amendments to the constitution were adopted: (1) MOVED, that Article III, Section 4, of the constitution be amended to read as follows: "4. Active members shall be elected by the Academy or by the council and shall enter upon membership on payment of the first annual dues." (2) MOVED, that the following sentence be stricken from Article VIII of the constitution: "All members of the Academy shall receive gratis the current issues of the Transactions."

The codified by-laws of the Academy, as recommended by the council, were then presented for action. L. J. Cole moved that the word "president" be stricken from Section 2. Carried. The remaining by-laws were adopted as presented. These will be found printed in full elsewhere in this issue of the Transactions.

The annual dinner of the Academy was held at the Grand View Hotel on Friday evening, April 10, with 49 persons in attendance.

LOWELL E. NOLAND,
Secretary-Treasurer.

THE CONSTITUTION OF THE WISCONSIN ACADEMY OF SCIENCES, ARTS AND LETTERS

(January 1, 1932)

ARTICLE I—NAME AND LOCATION

This association shall be known as the Wisconsin Academy of Sciences, Arts and Letters, and shall be located at the city of Madison.

ARTICLE II—OBJECT

The object of the Academy shall be the promotion of sciences, arts and letters in the state of Wisconsin. Among the special objects shall be the publication of the results of investigation and the formation of a library.

ARTICLE III—MEMBERSHIP

The Academy shall include four classes of members, viz.: life members, honorary members, corresponding members and active members, to be elected by ballot.

1. Life members shall be elected on account of special services rendered the Academy. Life membership may also be obtained by the payment of one hundred dollars and election by the Academy. Life members shall be allowed to vote and to hold office.

2. Honorary members shall be elected by the Academy and shall be men who have rendered conspicuous services to science, arts or letters.

3. Corresponding members shall be elected from those who have been active members of the Academy, but who have removed from the state. By special vote of the Academy men of attainments in science or letters may be elected corresponding members. They shall have no vote in the meetings of the Academy.

4. Active members shall be elected by the Academy or by the council, and shall enter upon membership on payment of the first annual dues.

ARTICLE IV—OFFICERS

The officers of the Academy shall be a president, a vice-president for each of the three departments, sciences, arts and letters, a secretary, a librarian, a treasurer, and a custodian. These officers shall be chosen by ballot, on recommendation of the committee on nomination of officers, by the Academy at an annual meeting and shall hold office for three years. Their duties shall be those usually performed by officers thus named in scientific societies. It shall be one of the duties of the president to prepare an address which shall be delivered before the Academy at the annual meeting at which his term of office expires.

ARTICLE V—COUNCIL

The council of the Academy shall be entrusted with the management of its affairs during the intervals between regular meetings, and shall consist of the president, the three vice-presidents, the secretary, the treasurer, the librarian, and the past presidents who retain their residence in Wisconsin. Three members of the council shall constitute a quorum for the transaction of business, provided the secretary and one of the presiding officers be included in the number.

ARTICLE VI—COMMITTEES

The standing committees of the Academy shall be a committee on publication, a library committee, and a committee on the nomination of members. These committees shall be elected at the annual meeting of the Academy in the same manner as the other officers of the Academy, and shall hold office for the same term.

1. The committee on publication shall consist of the president and secretary and a third member elected by the Academy. They shall determine the matter which shall be printed in the publications of the Academy. They may at their discretion refer papers of a doubtful character to specialists for their opinion as to scientific value and relevancy.

2. The library committee shall consist of five members, of which the librarian shall be *ex officio* chairman, and of which a majority shall not be from the same city.

3. The committee on nomination of members shall consist of five members, one of whom shall be the secretary of the Academy.

ARTICLE VIII—MEETINGS

The annual meeting of the Academy shall be held at such time and place as the council may designate; but all regular meetings for the election of the board of officers shall be held at Madison. Summer field meetings shall be held at such times and places as the Academy or the council may decide. Special meetings may be called by the council.

ARTICLE VIII—PUBLICATIONS

The regular publication of the Academy shall be known as its Transactions, and shall include suitable papers, a record of its proceedings, and any other matter pertaining to the Academy. This shall be printed by the state as provided in the statutes of Wisconsin.

ARTICLE IX—AMENDMENTS

Amendments to this constitution may be made at any annual meeting by a vote of three-fourths of all the members present; *provided,* that the amendment has been proposed by five members, and that notice has been sent to all the members at least one month before the meeting.

BY-LAWS OF THE WISCONSIN ACADEMY OF SCIENCES, ARTS AND LETTERS

1. The annual dues shall be two dollars for each active member, to be charged to his account on the first day of January of each year. Five dollars, paid in advance, shall constitute full payment for three years' annual dues.

2. The annual dues shall be remitted for the secretary-treasurer and librarian during their term of office.

3. As soon as possible after January first of each year the secretary-treasurer shall send to members statements of dues payable, and in case of non-payment shall, within the succeeding four months, send a second and, if necessary, a third notice.

4. The secretary-treasurer shall strike from the list of members the names of those who are one year or more in arrears in the payment of their dues, and shall notify such members of this action, offering at the same time to reinstate them upon receipt of the dues in arrears plus the dues for the current year.

5. Each member of the Academy shall receive the current issue of the Transactions, provided that his dues are paid. Any member in arrears at the time the Transactions are published shall receive his copy as soon as his dues are paid.

6. The fees received from life members shall be set apart as a permanent endowment fund, to be invested exclusively in securities which are legal as investments for Wisconsin trust companies or savings banks. The income alone from such fund may be used for the general purposes of the Academy.

7. The secretary-treasurer shall receive annually an allowance of two hundred dollars for services.

8. The secretary-treasurer shall be charged with the special duty of editing and overseeing the publication of the Transactions. In the performance of this duty he shall be advised by the committee on publication.

9. The Transactions shall contain in each volume: (a) a list of the officers of the Academy, (b) the minutes of the annual meeting, and (c) such papers as are accepted under the provisions of Section 10 of these By-Laws and no others.

10. Papers to be published in the Transactions must be approved as to content and form by the committee on publication. They must represent genuine, original contributions to the knowledge of the subject discussed. Preference shall be given to papers of special interest to the State of Wisconsin, and to papers presented at a regular meeting of the Academy. The privilege of publishing in the Transactions shall be reserved for the members of the Academy.

11. The Constitution and By-Laws and the names and addresses of the members of the Academy shall be published every third year in the Transactions. The Constitution and By-Laws shall also be available in reprint form from the secretary-treasurer at any time.

12. Amendments to these By-Laws may be made at any annual meeting by vote of three-fourths of all the members present.

SUBJECT AND AUTHOR INDEX TO THE PAPERS PUBLISHED BY THE ACADEMY, 1870–1932

Compiled by
LOWELL E. NOLAND,
Secretary

SUBJECT INDEX

The figures refer to the number of the article in the alphabetized author index which follows the subject index.

List of Articles

Published in Bulletins 1-5 (1870–1871) and in the Transactions, Vols. 1–27 (1872–1932)

1. Alder, Hugo, joint author; see H. A. Schuette.

2. Alderman, William E. 1924. Bibliograpical evidence of the vogue of Shaftesbury in the eighteenth century. Trans. 21 : 57–70.

3. Alderman, William E. 1931. Shaftesbury and the doctrine of benevolence in the eighteenth century. Trans. 26 : 137–159.

4. Ainsworth, Oliver M. 1924. Milton as a writer on education. Trans. 21 : 41–50.

5. Allen, Charles Elmer. 1904. Some Hepaticae of the Apostle Islands. Trans. 14 (2) : 485–486.

6. Allen, Ruth Florence. 1914. Studies in spermatogenesis and apogamy in ferns. Trans. 17 (1) : 1–56.

7. Allen, Ruth Florence, and Hally D. M. Jolivette. 1914. A study of the light reactions of Pilobolus. Trans. 17 (1) : 533–598. Figs.

8. Allen, William Francis. 1872. The rural population of England, as classified in the Domesday book. Trans. 1 : 167–177.

9. Allen, William Francis. 1874. The rural classes of England in the thirteenth century. Trans. 2 : 220–233.

10. Allen, William Francis. 1874. Ranks and classes among the Anglo-Saxons. Trans. 2 : 234–240.

11. Allen, William Francis. 1876. United States sovereignty—whence derived, and where vested. Trans. 3 : 125–132.

12. Allen, William Francis. 1879. Peasant communities in France. Trans. 4 : 1–6.

13. Allen, William Francis. 1879. The origin of the freeholders. Trans. 4 : 19–24.

14. Allen, William Francis. 1882. The English cottagers of the middle ages. Trans. 5 : 1–11.

15. Allen, William Francis. 1885. The primitive democracy of the Germans. Trans. 6 : 28–42.

16. Allen, William Francis. 1889. The village community and serfdom in England. Trans. 7 : 130–140.

17. Allen, William Francis. 1889. Town, township and tithing. Trans. 7 : 141–154.

18. Allen, William Francis. 1889. O. M. Conover. Trans. 7 : 257–258.

19. Almon, Lois. 1930. Preliminary reports on the flora of Wisconsin. XI. Ranunculaceae. Trans. 25 : 205–214.

20. Andrews, Edmund. 1879. Discoveries illustrating the literature and religion of the mound builders. Trans. 4 : 126–131.

21. Andrews, Joy Ella. 1921. Some experiments with the larva of the bee-moth, *Galleria mellonella.* Trans. 20 : 255–261.

22. Armitage, William Edmond. 1872. The German Sunday. Trans. 1 : 62–71.

23. Atwood, William Henry. 1918. The visceral anatomy of the garter snake. Trans. 19 (1) : 531–552. With figs.

24. Austin, Louis Winslow, and C. W. Eastman. 1902. On the relation between heat conductivity and density in some of the common woods. Trans. 13 (2) : 539–542.

25. Axtell, Luta. 1900. Wayland Samuel Axtell. Trans. 12 (2) : 560–561.

26. Bachmann, Freda Marie. 1927. A bacteriological study of salad dressings. Trans. 23 : 529–537.

27. Bagg, Rufus Mather. 1930. The diamond mining industry of South Africa. Trans. 25 : 79–87.

28. Baird, Edgar Alan. 1924. The structure and behavior of the nucleus in the life history of *Phycomyces nitens* (Agardh) Kunze and *Rhizopus nigricans* Ehrbg. Trans. 21 : 357–380. 2 pls.

29. Baker, Frank Collins. 1914. The molluscan fauna of Tomahawk Lake, Wisconsin. With special reference to its ecology. Trans. 17 (1) : 200–246. 7 pls.

30. Baker, Frank Collins. 1924. The fauna of the Lake Winnebago region; a quantitative and qualitative survey with special reference to the Mollusca. Trans. 21 : 109–146.

31. Baker, Frank Collins. 1926. Nomenclatorial notes on American fresh water Mollusca. Trans. 22 : 193–205.

32. Baker, Frank Collins. 1928. The fresh water Mollusca of Wisconsin. (This is a monograph published in two separate volumes. Part I Gastropoda. 507 pp. 28 plates. 202 text figures. Part II. Pelecypoda. 495 pp. 77 plates. 299 text figures.) Not published in the regular Transactions, but for sale by the Academy as a separate monograph.

33. Balg, Gerhard Hubert. 1892. The relation of Old English 'reomig' to Gothic 'rimis'. Trans. 8 : 167–168.

34. Barnes, Charles Reid. 1892. Artificial keys to the genera and species of mosses recognized in Lesquereux and James's Manual of the Mosses of North America. Trans. 8 : 11–81. Additions and corrections. Trans. 8 : 163–166.

35. Barnett, James Duff. 1905. The state administration of taxation in Wisconsin. Trans. 15 (1) : 163–177.

36. Bartlett, James Lowell. 1909. The cold-waves of south-central Wisconsin. Trans. 16 (1) : 289–306. 7 pls.

37. Bascom, John. 1885. Freedom of will empirically considered. Trans. 6 : 2–20.

38. Beatty, Arthur. 1907. The St. George, or Mummers', plays: a study in the protology of the drama. Trans. 15 (2) : 273–324.

39. Bennett, Charles Edwin. 1892. Some new theories of the Greek ka-perfect. Trans. 8 : 141–155.

40. Bere, Ruby. 1931. Copepods parasitic on fish of the Trout Lake region, with descriptions of two new species. Trans. 26 : 427–436.

41. Bere, Ruby. 1931. Leeches from the lakes of northeastern Wisconsin. Trans. 26 : 437–440. 2 pls.

42. Bille, John H. 1898. A history of the Danes in America. Trans. 11 : 1–48. 1 pl.

43. Birge, Edward Asahel. 1879. Notes on Cladocera. I. Trans. 4 : 77–112. II. Trans. 8 : 379–398 (1892). III. Trans. 9 : 275–317 (1893). IV. Trans. 16 (2) : 1017–1066. Plates.

44. Birge, Edward Asahel, 1885. On the motor ganglion cells of the frog's spinal cord. Trans. 6 : 51–81. 1 pl.

45. Birge, Edward Asahel, O. A. Olson and H. P. Harder. 1895. Plankton studies on Lake Mendota. Trans. 10 : 421–484. Plates.

45a. Birge, Edward Asahel. 1898. Plankton studies on Lake Mendota. II. The Crustacea of the plankton from July, 1894, to December, 1896. Trans. 11 : 274–448.

46. Birge, Edward Asahel, and C. Juday. 1909. A summer resting stage in the development of *Cyclops bicuspidatus* Claus. Trans. 16 (1) : 1–9.

47. Birge, Edward Asahel. 1910. An unregarded factor in lake temperatures. Trans. 16 (2) : 989–1004. 2 pls.

48. Birge, Edward Asahel. 1910. On the evidence for temperature seiches. Trans. 16 (2) : 1005–1016. 1 pl.

49. Birge, Edward Asahel. 1916. The heat budgets of American and European lakes. Trans. 18 (1) : 166–213. Figs.

50. Birge, Edward Asahel. 1916. The work of the wind in warming a lake. Trans. 18 (2) : 341–391. Figs.

51. Birge, Edward Asahel. 1921. A second report on limnological apparatus. Trans. 20 : 533–552. Figs., 2 pls. (First report, Juday 1916)

52. Birge, Edward Asahel, C. Juday ,and H. W. March. 1927. The temperature of the bottom deposits of Lake Mendota; a chapter in the heat exchanges of the lake. Trans. 23 : 187–231. Figs.

53. Birge, Edward Asahel, and C. Juday. 1929. Transmission of solar radiation by the waters of inland lakes. Trans. 24 : 509–580. Figs.

54. Birge, Edward Asahel, and C. Juday. 1930. A second report on solar radiation and inland lakes. Trans. 25 : 285–335. Figs.

55. Birge, Edward Asahel, and C. Juday. 1931. A third report of solar radiation and inland lakes. Trans. 26 : 383–425. Figs.

56. Birge, Edward Asahel, and C. Juday. 1932. Solar radiation and inland lakes. Fourth report. Observations of 1931. Trans. 27 : 000–000. Figs.

57. Birge, E. A., joint author; see Chancey Juday.

58. Black, Charles Spurgeon. 1929. Chemical analyses of lake deposits. Trans. 24 : 127–133.

59. Blackstone, Dodge Pierce. 1885. The variation in attraction due to the figure of the attracting bodies. Trans. 6 : 197–254.

60. Blaisdell, James Joshua. 1893. Aaron Lucius Chapin. Trans. 9 : lxxi-lxxiv. Portrait.

61. Blaisdell, James Joshua. 1898. The methods of science, as being in the domain of logic. Trans. 11 : 49–65.

62. Blaisdell, James Joshua. 1893. Some suggestions concerning methods of psychological study. Trans. 9 : 33–43.

63. Blake, William Phipps. 1903. Arizona diatomite. Trans. 14 (1) : 107–111. 2 pls.

64. Blake, William Phipps. 1893. The process of geological surveys in the state of Wisconsin—a review and bibliography. Trans. 9 : 225–231.

65. Breakey, Edith W., and Ruth I. Walker. 1931. Preliminary reports on the flora of Wisconsin. XII. Polypodiaceae. Trans. 26 : 263–273. Figs.

66. Bremiker, Karl. 1902. On the errors with which logarithmic computations are affected. (Translated by Pearl Eugene Doudna and Elwyn Francis Chandler). Trans. 13 (2) : 427–474.

67. Brown, Charles Edward. 1907. Wisconsin quartzite implements. Trans. 15 (2) : 656–663. 2 pls.

68. Brues, Charles Thomas, and Beirne B. Brues. 1914. The grasses of Milwaukee County, Wisconsin. Trans. 17 (1) : 57–76. 3 pls.

69. Bruncken, Ernest. 1898. On some differences between private and public business. Trans. 12 (1) : 325–336.

70. Bruncken, Ernest. 1898. The use of parties in municipal government. Trans. 11 : 225–235.

71. Buck, Solon Justus. 1907. The settlement of Oklahoma. Trans. 15 (2) : 325–380. 6 pls.

72. Buckley, Ernest Robertson. 1901. Ice ramparts. Trans. 13 (1) : 141–162. 18 pls.

73. Buckley, Ernest Robertson. 1909. Sleet storm in the Ozark region of Missouri. Trans. 16 (1) : 307–310. 7 pls.

74. Buell, Ira Maynard. 1882. The corals of Delafield. Trans. 5 : 185–193.

75. Buell, Ira Maynard. 1893. Geology of the Waterloo quartzite area. Trans. 9 : 255–274. 3 pls.

76. Buell, Ira Maynard. 1895. Bowlder trains from the outcrops of the Waterloo quartzite areas. Trans. 10 : 485–509. 5 pls.

77. Bundy, Will F. 1882. A list of the Crustacea of Wisconsin. With notes on some new or little known species. Trans. 5 : 177–184.

77a. Burd, Henry A. 1918. Eight unedited letters of Joseph Ritson. Trans. 19 (1) : 1–21.

78. Butler, James Davie. 1874. The naming of America. Trans. 2 : 203–219.

79. Butler, James Davie. 1876. Copper tools found in the state of Wisconsin. Trans. 3 : 99–104.

80. Butler, James Davie. 1882. First French foot-prints beyond the Lakes; or, What brought the French so early into the Northwest? Trans. 5 : 85–145.

81. Butler, James Davie. 1882. The ἄπαξ λεγομενα in Shakespere. Trans. 5 : 161–174.

82. Butler, James Davie. 1892. William Francis Allen. Trans. 8 : 439–441. Portrait.

83. Butler, James Davie. 1895. Phases of witticism. Trans. 10 : 41–60.

84. Butler, James Davie. 1898. Dante. His quotations and his originality; the greatest imitator and the greatest original. Trans. 11 : 149–164.

85. Butler, James Davie. 1898. Codfish. Its place in American history. Trans. 11 : 261–273.

86. Butler, James Davie. 1898. George P. Delaplaine. Trans. 11 : 522–524.

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88. Butler, James Davie. 1900. Harlow S. Orton, 1817–1895. Trans. 12 (2) : 554–555.

89. Butler, James Davie. 1901. Household words: their etymology. Trans. 13 (1) : 366–383.

90. Butler, James Davie. 1902. Personal names: their significance and historical origin. Trans. 13 (2) : 475–485.

91. Butler, James Davie. 1903. The vocabulary of Shakespeare. Trans. 14 (1) : 40–55.

92. Cahn, Alvin Robert. 1918. Notes on the vertebrate fauna of Houghton and Iron counties, Michigan. Trans. 19 (1) : 483–510. 5 pls.

93. Campbell, Mrs. Katharine; see Katharine Bernice Stewart.

94. Carlton, E. P., joint author; see under W. S. Miller.

95. Carpenter, Stephen Haskins. 1874. The metaphysical basis of science. Trans. 2 : 23–34.

96. Carpenter, Stephen Haskins. 1874. The philosophy of evolution. Trans. 2 : 39–58.

97. Carpenter, Stephen Haskins. 1879. John Baptist Feuling. Trans. 4 : 316–318.

98. Caverno, Charles. 1871. Abstract of a paper on the relations between social and moral science. Bull. 4 : 59–61.

99. Caverno, Charles. 1872. Social science and woman suffrage. Trans. 1 : 72–89.

100. Caverno, Charles. 1876. The people and the railroads. Trans. 3 : 143–150.

101. Caverno, Charles. 1879. The abolition of the jury system. Trans. 4 : 7–18.

102. Caverno, Charles. 1882. Life insurance, savings banks, and the industrial situation. Trans. 5 : 21–37.

103. Chamberlin, Thomas C. 1871. Suggestions as to the basis for the gradation of the vertebrata. (An abstract). Bull. 5 : 76–80.

104. Chamberlin, Thomas C. 1871. Facts relating to the local geology of the Whitewater region. (An abstract). Bull. 5 : 81.

105. Chamberlin, Thomas C. 1871. On the 17-year cicada; its geographical distribution and time of appearance in this state. (Title only). Bull. 5 : 81.

106. Chamberlin, Thomas Crowder. 1872. Suggestions as to a basis for the gradation of the Vertebrata. Trans. 1 : 138–150.

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