THE FAUNA OF A SOLUTION POND.

By WILL SCOTT.

INTRODUCTION.

In 1909 I gave an account of the plankton of the subterranean stream in the caves of Indiana University's cave farm. Among other things it was found that the plankton is composed of epigean forms and is derived from ponds in such sink-holes as have an opening above their lowest points. A study of the fauna of the ponds furnishing the cave plankton became desirable.

[1]Contribution from the Zoölogical Laboratory of Indiana University No. 119.

Ponds of this kind form a fresh water "unit of environment" typical for an area covering a part of twenty counties of southern Indiana, a strip of Kentucky and a part of Tennessee. Instead, however, of making a general study of the faunæ of many of these ponds, a typical pond one-half mile northeast of the campus of Indiana University has been studied intensively. Its fauna has been determined, its physical factors and environment analyzed, and the processes at work determined in part, at least.

Observations on this pond extend from October, 1908, to June, 1909, and from September, 1909, to September, 1910, with occasional visits from September, 1910, to May, 1911. It was visited weekly or more often during all but the summer months. No observations were made during the summer of 1909, but the pond was visited monthly during the summer of 1910 (June 15, July 16, August 12).

Many other ponds have been examined, but detailed data concerning them have not been collected. The observations on these have been incorporated in this paper when they made clear facts that could not be determined from this pond alone.

Aside from presenting a picture of the conditions in this pond, I hope the data collected may furnish a basis for comparison with the larger bodies of fresh water (glacial lakes and rivers), so many of which have been under observation in recent years.

THE POND.

The form of the pond may be seen by reference to the map, No. 1. It is oval in shape and has a maximum length of 70 feet and width of 57 feet. Its greatest depth is 46 inches, but this is attained only during the heavy rains of spring. The south, east and north slopes are quite gentle, but the west slope is so abrupt that within one foot of the shore, on the north end of the west side, a depth is attained which is only six inches less than the greatest depth of the pond. The bottom is covered with plant debris mixed with a little fine clay derived from the wash from the slope above the pond. This silt is small in quantity, the slope being slight, the area drained small, and a narrow zone of grass surrounding the pond.

Location.—The location of this pond may be determined by examining the Bloomington Quadrangle of the United States Topographical Survey. It is 940 feet above sea level and about 150 feet above the floor of the valleys one mile distant. It is about 16 feet below the crest of an old monadnock, probably a remnant of the tertiary peneplain and near the level of the pleistocene peneplain which forms the "skyline" in this region.

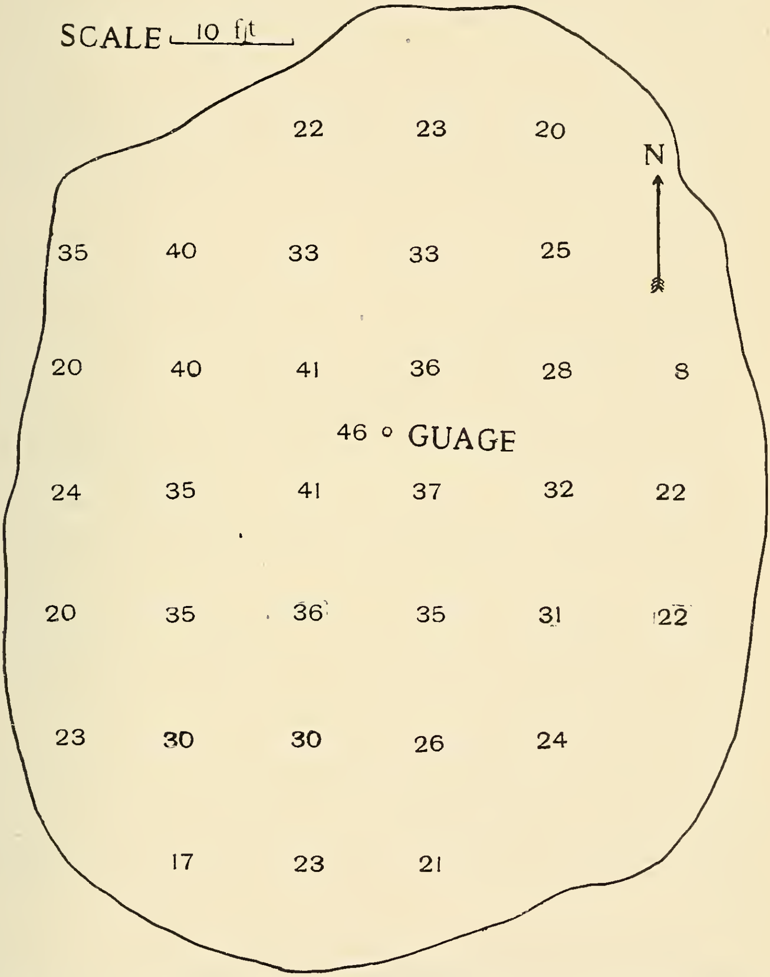

Fig. 1. Map of Hill Pond, showing depth in inches at 10-ft. intervals when at the overflow point.

The pleistocene peneplain is very much dissected in this locality. This particular monadnock is completely isolated, valleys having cut into its sides from three directions, viz., south, west and north. The valley to the north empties into Griffey Creek, a part of the drainage system of the West Fork of White River. The valleys to the west and south empty into Clear Creek, a part of the drainage system of the East Fork of White River.

No similar pond is nearer than two miles. The nearest perennial water is in springs .33, .56 and .66 miles distant, and 100, 146 and 165 feet respectively below the level of the pond. The accompanying profiles indicate these slopes graphically. Fig. II. These statements indicate the isolation of the pond.

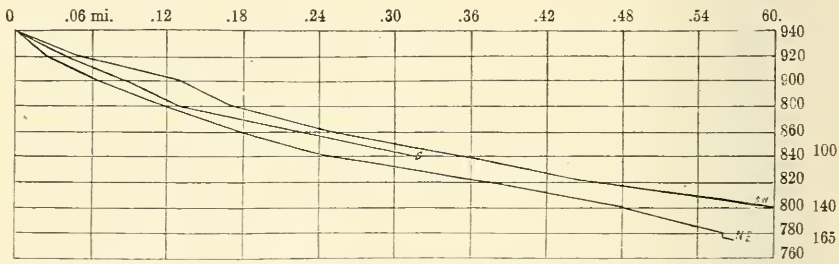

Fig. 2. Profiles of valleys leading away from hill on which pond is located, from pond to closest permanent water in each valley.

The pond is formed by solution in the Mitchell limestone which caps the hill to a depth of 50 feet and overlies the Bedford limestone, both being formations in the Mississippian series. The details of the formation of this pond are not different from those of any other of this region, consequently a general discussion will probably be more enlightening.

The development of sinkholes is coincident with that of subterranean drainage systems. Both depend upon two conditions: First, the presence of soluble rock, usually limestone; second, the movement of the solvent (meteoric water, containing as it always does, carbonic acid), through the rock.

In order to have a movement of meteoric water through the rock, it is necessary to have an outlet below the general level of the country. This is secured by the invasion of surface drainage. A study of the topography of a limestone region shows that in general the sinkholes are formed on the periphery of the valleys.

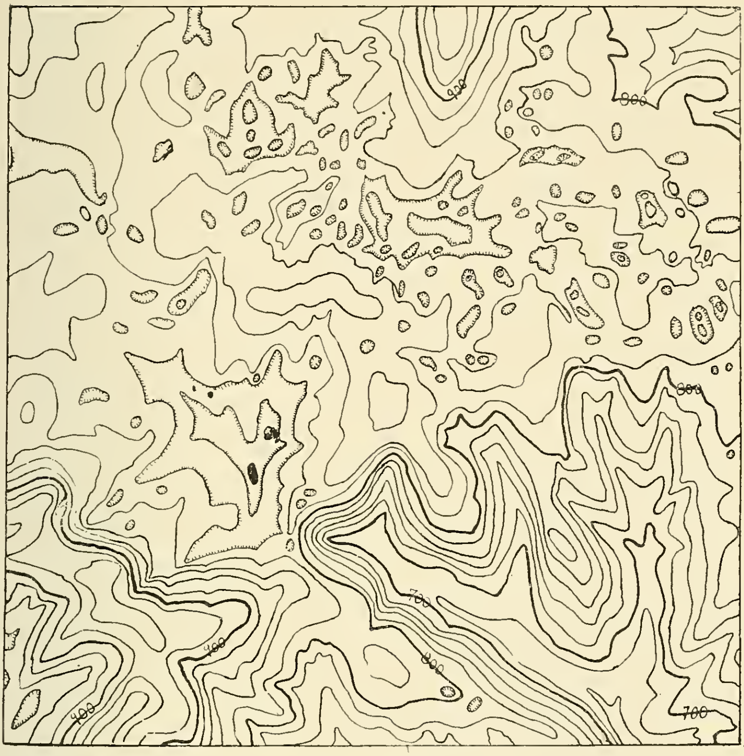

Fig. 3. Map showing the formation of sink holes on the periphery of a valley.

The accompanying map (Fig. III) beautifully illustrates this point. It is based on data from the Bloomington quadrangle of the United States Topographic Survey. A deep gorge from the southeast cuts well into the old peneplain, thus tapping the water table. The water on plain around the periphery of this valley "sinks" into the limestone and comes to the surface near the bottom of the gorge.

In the area under discussion, the Ohio river and its tributaries supply the surface drainage. Although any sort of limestone may develop sinkholes, the Mitchell is the sinkhole and cave-forming limestone par excellence. Its qualities in relation to cave formation have been discussed by Green ('08). He summarizes them as follows:

"The Mitchell limestone, otherwise known as the St. Louis, barren, or cavernous limestone, is a bluish or grayish, hard, compact, even-grained stone, generally having a conchoidal fracture. It is so compact as to make it rather impervious. Intercalated layers of blue-gray shale are frequent. Large concretions of chert are characteristic of certain horizons. When the stone weathers, these masses of chert do not dissolve, but break into more or less angular fragments which strew the ground over the Mitchell area. In Indiana the formation is also characterized by the common presence of a genus of corals known as Lithostrotion or Lonsdaleia. In some places, such as western Monroe or southern Crawford County, there is a typical white oölite found near the top of the formation.

"Analysis shows the Mitchell to be a very pure calcium carbonate, and at Mitchell, Lawrence County, from which place the formation received its name, it is extensively quarried for making lime and cement.[2]

"The Mitchell limestone has long been known as the Cavernous limestone. Both the Wyandotte Cave of Indiana and the Mammoth Cave of Kentucky occur in its strata. In three counties in the vicinity of Mammoth Cave, over five hundred caves are known to exist. These facts lead us to investigate the general adaptability of this limestone to cave formation.

"The reasons of this adaptability are numerous. Besides the bedding planes, two sets of vertical joint-planes exist, one set having a general east and west direction and the other a north and south direction. Vertical joint-planes are probably more numerous in this than any other of the Mississippian limestones. Owing to the fact that the Mitchell is rather impervious and often of a lithographic nature, the down flowing water is forced to follow the joint and bedding planes. The underlying Salem limestone contains joint-planes but is porous enough to become thoroughly saturated instead of confining the water to joint-planes."

The presence of joint-planes, its impermeability and its solubility, are the qualities of the Mitchell limestone which make it favorable to the development of caves and sinkholes. It is obvious that if a stone is impermeable and has joint-planes, the water will trickle down through these joints instead of being absorbed by the rock. If the rock is soluble and the

[2] In the southern part of the State it reaches a thickness of 350 to 400 feet; in the central part of its area, that is, in Lawrence and Monroe counties, the thickness is from 150 to 250 feet, and from here gradually thins toward the north."

water contains carbonic acid gas in solution, as all meteoric water does, cavities will be formed in it.

The regions in which sinkholes occur were originally covered with deciduous forests and as a result the surface was covered with decaying vegetable matter. It is well known that this condition reduces the surface *run off* and allows more water to sink into the ground. Shaler ('91) has also shown that this decaying humus produces a large amount of carbonic dioxide, so that the water, passing through it, is always saturated with this acid. From these facts, it is probable that the formation of caves and sinkholes formerly occurred more rapidly than at present.

What causes a sinkhole to develop at a particular point is somewhat conjectural. Something occurs which increases the rate of solution at a particular point. There may be a place in the stone which is more soluble than the surrounding rock. It has been suggested that fault-lines may be the initial cause of at least some of them. There is a fault near the mouth of Shawnee cave in the Mitchell limestone but no line of sinkholes has developed along it.

It is quite possible that the tap roots of some of the walnuts, oaks and similar trees of the original forests may have determined the location of some of these depressions. These tap roots undoubtedly reached bed rock in many places. When they decayed they left a funnel shaped opening in the soil, filled with their own decaying stems. This funnel would conduct meteoric water immediately to bed rock and charge it with CO^2 as it did so.

Cummings ('05, page 87) explains this formation as follows:

"Where two joints intersect, the enlargement is apt to be greatest, giving origin to funnels, narrowing gradually downward, and showing in a beautiful way the formation of sinkholes, which are only such funnels of solution grown large."

Whatever may initiate this process, after connection is once established with a subterranean system, the processes of weathering, erosion, etc., enlarge the funnel in every direction. The funnel is really a valley whose source or upper end is the perimeter of the cone and whose mouth or outlet is the opening in the center. The sides of a young sinkhole are usually very steep and its area limited, while those of an older one are more gentle, with a much larger area. At any stage in the development of a sinkhole, its outlet may become obstructed. The result is the formation of a pond. If a young sinkhole is obstructed, a small and relatively deep pond results. The obstruction of an old sinkhole results in the formation of a shallow pond of considerable area.

Destruction.—The ponds are no sooner formed than their destruction begins by means of those factors which destroy all such topographic forms. Few of them overflow, anl these only for a short time. Plant deposition and the deposition of silt are the two principal factors operating for their destruction. A pond formed in a young sinkhole which is located at or near the summit of a hill, i. e., near the level of an old peneplain, does not have as much silt washed into it as does a pond formed in an older sinkhole or one that is located on the lower slope of a hill. Plants are relatively a much greater factor in the destruction of the former than in the latter.

Our pond belongs to the first class. It has some clay deposited in it. but plant debris forms the major part of its sediment. The rate of its destruction is known approximately for a period of 24 years. In 1887, it was about eight or nine feet in depth ("deep enough to swim a horse"). It is now slightly less than four feet, a difference of four feet, or one-fifth foot deposition per year. So far as I know, this is the only case where the rate of plant deposition is reducible to even approximate figures.

The water is usually clear. A scum of iron oxide was found on the surface April 1, 1910. On August 12, 1910, the water had a dark purplish tinge, due to the decay of organic matter. The only time the pond was seen to be muddy was after the rain of July 14. On this date it was quite opaque and of a yellowish tinge, from the suspended silt. Silt is carried into the pond only after very heavy rains, for reasons previously stated.

METHODS.

For collecting insects, insect larvæ, algæ, amphibian larvæ, etc., ordinary insect nets and dip nets made of bobbinet and scrim, were used. A very useful net for collecting micro-organisms, when quantitative work is not demanded, is a sampling net, manufactured by the Simplex Net Company, Ithaca, New York. It is made of bolting cloth No. 20, is three inches in diameter, twelve inches long, and is operated by being thrown out into the water and then drawn in. The ring is quite heavy so that it will sink if properly handled. The depth at which the net moves can then be regulated by the rate at which it is drawn through the water.

The only difficulty experienced in operating this net was that the ring carried the open end under at once, thus catching enough air in the net to float it. To obviate this difficulty, a 25x80 mm. glass shell partially filled with water was fastened to the apex of the net by means of a cork stopper. This carried the net under at once, and when the catch was made, the cork was loosened and the collection dropped into the bottle.

For quantitative work, on such plankton as was present, the following variation of the pumping method was used: The whole apparatus had to be light enough to be portable. Some difficulty was experienced in getting a satisfactory pump. The pump used is known in the trade as the Barnes hydroject pump, manufactured by Barnes Mfg. Co., Mansfield, Ohio. It has a brass cylinder and throws one-fourth liter per stroke. Its general appearance is shown in Fig 4. To this was attached a net of bolting silk (Dufour No. 20) and a detachable bucket. (Windows covered with wire cloth, 200 meshes to the inch.) A three-quarter inch hose (inside measurement) was used. The end was closed with a cork and an opening made in the side of the hose just above the cork, so that the water from a given level might be secured with greater accuracy. The end of the hose was fastened to a float, so that the collection could be taken from any depth desired. By means of a rope and pulley, this float could be placed at any point in the pond.

Material was killed in a 4% solution of formalin. All organisms were counted in every collection except two. In investigating a small area, I believe that greater accuracy is secured by filtering a small amount of water and counting all the oragnisms than by filtering a large amount and counting a fraction of it. The amount counted in either case must be large enough to include samples of all the organisms present.

The source of error in the first case is the uneven distribution of organisms at a given level. In the second case, the error is due to the difficulty of thoroughly mixing organisms having a different specific gravity.

The soundings were taken when the pond was covered with ice. The ice was ruled at ten-foot intervals, holes bored at the intersections, depth measured through these openings and entered on the map of the pond. A guage was set December 21, 1909. From the readings of the gauge, the depth at any point at any time could be determined.

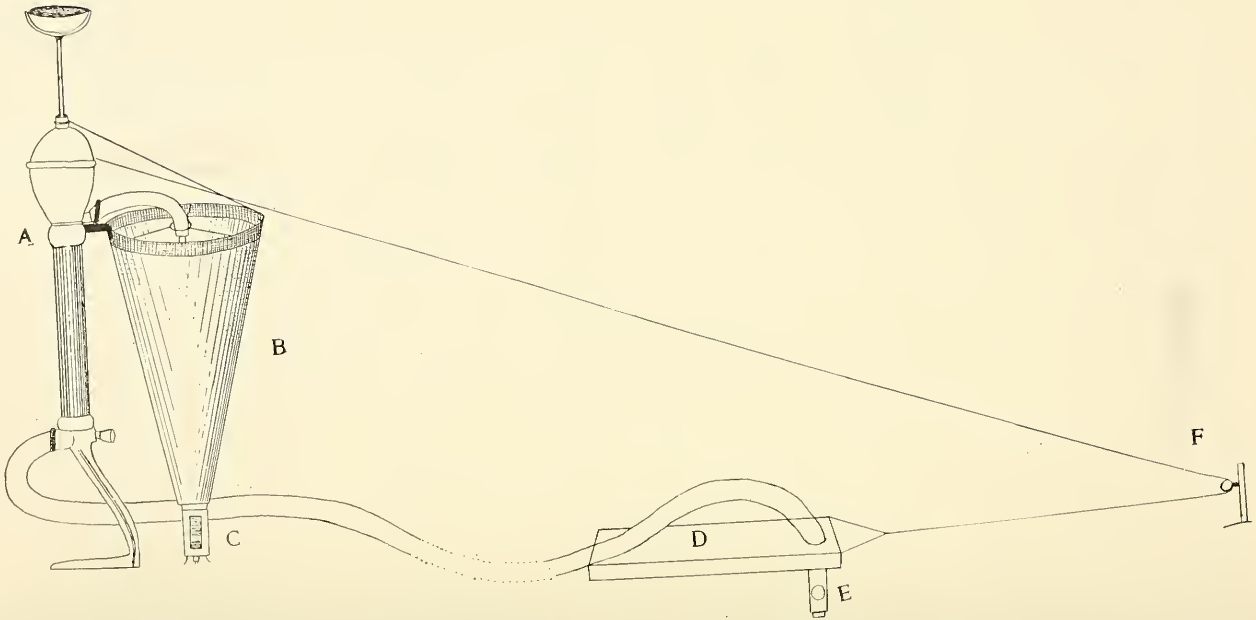

Fig. 4. Plankton outfit used on pond. A, pump; B, net of bolting silk; C, detachable bucket; D, float; E, intake; F, tackle for placing float.

The data concerning elevation were taken in part from the United States relief map of the Bloomington quadrangle, and in part from averages of the barometric readings. The bench mark established by the survey on the university campus rendered exact correlation possible.

The following annoted list of species gives a fairly complete picture of the life in this pond. The list of flagellates and desmids is not exhaustive. The diatoms were not identified because of the inadequacy of accessible literature. However, it may be stated that the diatom flora consists of bottom inhabiting forms.

PROTOZOA.

Rhizopoda—

Difflugia globulosa Dujardin.

This was the most common protozoan in the pond. It was found at all seasons but was more common in 1910 than in 1909. It is reduced in numbers during the winter but when the temperature begins to rise in the spring, this species begins to increase in numbers. In 1910 this increase was very regular from March to August. The Difflugia in the quantitative plankton collections of that year belonged for the most part to this species. In these collections the number per 100 liters varied from 28 on February 8 to 39,780 on August 12.

Difflugia oblonga Ehrenberg.

This variable species was a common form in 1909 but not so plentiful in 1910.

Difflugia acuminata Ehrenberg.

Not common.

Difflugia urceolata Carter.

Common in the winter of 1909-'10. Greatly outnumbered by D. globulosa in the spring and summer. In plankton material killed in formalin, I found a typical individual of *urceolata* with the mouth of its shell closely appressed to that of a specimen of D. Globulosa. Whether this was a case of fission, an animal building a new shell or an accident, I am unable to state. I am inclined to the belief that the animal was dividing. The rounded shell was slightly smaller than the spined one. If this be true, the distinction between the two forms is of course not specific.

Difflugia corona Wallick.

Observed occasionally.

Difflugia lobastoma Leidy.

Rare.

Many variations in the nature and form of the test have been observed. The studies of Penard ('02), Averintzev ('06) and others have resulted in more than forty species being referred to this genus. The many variations observed in the Difflugia in this limited habitat make evident the value of studies on the effect of age and environment upon the form of the test. Such studies would certainly define the species more clearly than they are at present. The difficulties of such experiments are obvious.

Lesquerensia spiralis Schlumberger.

Rare.

Pontigulasia compressa Carter.

Nov. 9, 1909.

Arcella vulgaris Ehrenberg.

This species was very common on the bottom and in the vegetable debris during the year 1909 but it was very much reduced in numbers the next year. In the collections taken with the pump from Jan. 5 to Aug. 12, it occurred but once.

Centropyxis aculeata Stein.

Occurred rarely. Taken Jan. 5, 1909.

Actinophrys sol. Ehrenberg.

It was not found until May 28, 1910, when the water temperature was 20° C. It was quite common on that date and during the following month.

Flagellata—

Euglena viridis Ehrenberg.

Always present, but reaching its maximum development in Aug., '10, when 27,560 per 100 liters of water were taken by filtering with No. 20 bolting silk. This filter undoubtedly allows some to pass through.

Phacus pleuronectes Müller.

Phacus pyrum Ehrenberg.

Both species were present among the filamentous algæ at all seasons but never in great quantity. The former was much the more common. On account of their association with the algæ they were always more plentiful in the margins of the pond.

Peridinium tabulatum Ehrenberg.

A form that was referred to this species was observed in some material brought into the laboratory Jan. 18, 1910. This material consisted of debris and water. It was kept in a clean glass jar covered with glass

Ordinarily this species develops in swarms but it never occurred in quantity in the pond.

Trachelomonas annata Ehrenberg.

Obtained Jan. 18 and Feb. 2 by the same method as *Peridinium*, already described.

Ciliata—

Halteris sp.

Common among algæ at south end of pond, Apr., 1910.

Vorticella.

This genus occurred sporadically during the warmer months. Specific identification was not made every time it was observed.

It was present as late as Nov. 25, 1909, and reappeared in May. The most common form was referred to *V. microstomata Ehrenberg*. *V. campanula Ehrenberg* was present in large quantities Oct. 26, 1910, when the water temperature was 13.6° C.

Epistylus sp.

A ciliate belonging to this well marked genus was taken March 11, attached to the edge of the thorax (usually near the posterior angle) of an aquatic beetle. It is not referable to any species to whose description I have access. The zooids, when completely expanded, are 1/5 mm. long by 1/12 mm. wide. The stems branch dichotomously and are segmented at the base of each branch. The planes of successive branchings are usually at right angles to each other. The branches are from 30 to 40 μ long and from 20 to 30 μ wide. From this method of branching the colony tends to form a spherical sector of increasing size. The outer surface of this sphere is formed by the zooids, which when contracted in a well developed colony, touch each other forming a continuous surface. The cell walls are fairly firm and a limited surface is exposed. Some water is probably retained among the stalks below the zooids. This seems to enable them to prevent desiccation in a degree. The following observations support this inference: A well developed colony attached to a bit of the thorax of a beetle was left on a slide under a cover glass at 4:20 p. m., room temperature about 70°. The water under the cover soon evaporated. At 7:50 a. m. the following day, the slide was examined. The outlines of the contracted zooids were still discernible. The colony was removed to tap water in a stentor dish. At noon, about 20% had revived and were actively feeding. The amount of drying to which they had been subjected seems to be near the limit for the species. They do not recover if completely desiccated. The relation of this to distribution will be noted subsequently.

PLATYHELMINTHES.

Trematoda—

Diplodiscus sp.[3]

Young trematodes belonging to this genus were taken from the alimentary tract of the larvæ of Rana catesbiana Shaw during Feb., '11.

They were free in the intestine of the amphibian larvæ. The contents of the digestive tract of the worm seemed to be derived from the surrounding medium, i. e., the food material in the intestine of the "tadpole." Sexually mature individuals were taken from larvæ of the same frog about one month later (Mar. 20, '11). I have been unable thus far to determine the invertebrate host of this trematode in this pond. The most numerous mollusc is Luccinea retusa Lea. But many dissections have failed to reveal trematode infection.

The following intermediate stages taken with the plankton catches in the open water have been noted. One cercaria on each of the following dates: May 5, '09; Jan. 11, '10; Apr. 15, '10.

A ciliated larva was taken May 28, '10. The only evidence that these are the developmental stages of Diplodiscus is that Diplodiscus is the only trematode known from this pond.

TROCHELMINTHES.

Ten rotifers were identified from the pond. Others were observed occasionally but were not identified. Their rare occurrence, and the fact that the methods used in the preservation of the material were not especially adapted to rotifers, often rendered exact identification impossible.

Of the ten rotifers, three, *Anuræa aculatea* Ehrenberg; *Hydatina senta* Ehrenberg, and *Monostyla lunaris* Ehrenberg, occurred in quantity in the open water of the pond. The first was common in 1908, the other two in 1910. The other five were never common.

[3]Identified by Prof. H. B. Ward,

Anuræa aculatea Ehrenberg.

Found Nov. 25, 1908, two days after the rain which ended the drouth of that year. It was quite numerous that fall and was present the following year until December, but not in such numbers. It was absent entirely in the collections of 1910.

Cathypna luna Ehrenberg.

May 15, 1910. Not common.

Diurella tenuior Gosse.

Spring 1907. Rare.

Pedalion mirum Hudson.

Present in considerable numbers during May and June, 1909.

Rotifera tardus Ehrenberg.

April 15, 1911.

Anuræa cochlearis Gosse.

In quantitative collection of April 14, 1910. One specimen; spines well developed.

Hydatina senta Ehrenberg.

Appeared rarely in spring of 1910. First observed April 14. It did not develop in any quantity until July. On July 15 there were 1,560 per 100 liters of water. Aug. 12, this had increased to 1,625.

Monostyla lunaris Ehrenberg.

Appeared April 19, 1910. On that date there were 88 per 100 liters. It reached its maximum development in July with 1,463 per 100 liters.

Monostyla cornuta Ehrenberg.

Aug. 15, 1910. This form may have been counted with preceding but partial re-examination of material did not show this to be true.

Diglema forcepata Ehrenberg.

Occasionally from Feb. 4 to Aug. 15, 1910.

ANNELIDA.

Oligochæta—

Limnodrilus sp.

An oligochæte worm belonging to the family Tubificidæ was referred to this genus. Its complete anatomy has not yet been worked out. It occurs in great numbers among the roots and about the root stalks of Typha. In this pond, this is its exclusive habitat. The alimentary tracts of these worms are always filled with decaying vegetable matter. They are ravenously eaten by Amblystoma larvæ and Diemyctylus. These two facts probably account for their occurrence in this limited habitat.

CRUSTACEA.

Arthropoda—

Daphnia pulex DeGeer.

Occurred twice, in March and April, 1909, and in May, June and July, 1910. Its maximum occurrence was on June 15, 1910, when there were 80 per hundred liters of water. In towing collections, often but a single specimen was taken.

Simocephalus vetellus Mueller.

The most conspicuous crustacean of the pond. It is numerous at all seasons among the plants and plant remains. It is rarely taken in the open water of the central part of the pond. Adults were taken two days after the rain which terminated the drouth in 1908. It was found that in cultures it takes from 10 to 12 days for adults to develop. From these facts, it appears that this crustacean was able to survive the drouth as an adult. To do this, it must have worked its way down through the vegetable debris to the water level. It is present at all periods of the year, producing a maximum of 25 young in a brood. It makes a slight diurnal vertical migration. This is difficult to demonstrate quantitatively because of its habitat. If the surface of the water be "skimmed" with a fine meshed net during the day, very few if any individuals are taken. However, many individuals are taken by this operation at any hour of the night during the summer months.

Alona quadrangularis Müller.

Appeared in March, 1910. Taken with young in brood chambers. Never more than 120 per hundred liters until May 28, when 696 per hundred were taken. It varied during June, July and August from 500 to 780 per hundred liters, the maximum occurring on Aug. 12. Eggs were present in brood chambers in a large per cent. of them from April till August of this year.

Cypridopsis vidua Brady.

Appeared as soon as the pond began to fill with water in Nov., 1908. During the following winter and spring it was one of the most conspicuous forms. No attempt was made to estimate its numbers, but a small quantity of water dipped from any part of the pond during this period always contained them. They could be seen feeding at any time on vegetable debris, Typha stems and algæ.

During the spring of 1909 the number began to decrease, and in the autumn they disappeared. They were never observed in 1910, although the pond was examined for them many times. This fact has an important bearing upon the general problem of distribution, as will be pointed out later.

Cypris virens Jurine.

This form has been present at all times but never developed in great quantity. Its greenish color and the fact that it is more closely confined to the substratum than *Cypridopsis vidua*, render it less conspicuous.

Cyclops serrulatus Fischer.

Taken March 17, 1910, with eggs. Numerous in the shallower parts of the pond during the latter part of the month.

Cyclops bicuspidatus Claus.

The typical form was present during the spring of 1910 but did not occur in great numbers.

Most females taken were carrying egg sacks. During July and August as noted in the discussion of the plankton, this species occurred in great numbers, the maximum being on August 12, when 704,600 per 100 liters were present. However, the individuals were smaller and the stylets shorter and relatively thicker than in the spring forms.

Pearse ('05) reports this species as occurring in the spring in Nebraska. In the Illinois River, it is reported as a winter form, Kofoid ('03). In Lake Michigan it is a summer form, Forbes ('82). In Wisconsin lakes it is active in the cooler parts of the year and passes the summer in a gelatinous cocoon. The seasonal distribution in different habitats of this variable form offers an enticing problem.

Cyclops phaleratus Koch.

Taken during March, 1910. Numerous April 15, 1911. Found among Typha and near the edge of the pond.

TARDIGRADA.

Macrobiotus.

A form which was referred to this genus was taken in the spring of 1910. They occurred in quantity on April 23, and for about one month thereafter, in the gelatinous matrix around the eggs of the mollusc *Succinea retusa Lea.* They did not occur in egg masses recently laid. As the eggs develop, the matrix gradually disintegrates and a large number of minute flagellates develops in the matrix during this process of disintegration. This, in part, accounts for the presence of the Tardigrada, for they were feeding on the flagellates, the disintegrating matrix or both.

On May 15, one was taken containing 10 eggs which almost filled the specimen. June 15, one was taken with 11 eggs. Others taken at this time also contained eggs.

None was taken after June 15. Those taken on this date were captured with a silk net in open water.

Hexapoda—

Notonecta sp.

This backswimmer emigrated from the pond when it dried up, if it had been present previously. It was not observed during the spring of 1909, but since that time it has been abundant.

Limnobates lineata sp.

Frequent near the margin of the pond.

Hygrothechus sp.

This water strider was first observed March 7, 1909. They appear soon after the ice melts and remain until the freezing weather. Adults hibernate. They are primarily the scavengers of the surface, yet the rapidity with which they perform their work makes observation difficult, as the following example indicates: On Mar. 24, 1910, an ichneumon fly accidentally fell into the water. Instantly it was punctured by three of these water-striders. In spite of its larger size and powerful struggle, the ichneumon was soon reduced to practically an empty shell.

Cnemidotus 12-punctatus Say.

Always present on plant stems and debris. Noted by Blatchley as more common in northern part of State than in southern. Hibernates.

Cnemidotus muticus Leclerc.

Occurs with preceding species. Rather more common. Hibernates.

Hydrocanthus iricolor Say.

Present in considerable numbers throughout the year.

Laccophilus maculosus Say.

Laccophilus fasciatus Aube.

Both species present in about equal numbers. Hibernate

Hydrovatus pustulatus Melsh.

About the southern limit of its range. Present throughout the year but not numerous.

Coptotomus interrogatus Fabricius.

One of the common beetles in the pond. Could be taken in numbers at any season.

Graphoderes liberus Say.

Blatchley notes concerning this beetle: "Putnam and Lawrence counties, frequent in woodland ponds." In this pond I have taken but one specimen and have seen no other. This was taken June 6, 1910. It is quite probable that it had just immigrated.

Dineutes assimilis Aube.

Present from April to October in characteristic groups on the surface of the pond.

Tropisternus mixtus Leclerc.

The most common beetle in the pond. Could be seen beneath the ice in winter.

Berosus peregrinus Herbst.

Not common.

Of the four families of beetles found in this pond, the Gyrinidæ are confined to the surface, the Haliplidæ occur at the bottom "crawling" over the plant stems and sticks, while the Dytiscidæ and Hydrophylidæ occupy the intervening space as well as surface and bottom. The surface supports one species, the bottom two, while eight species are more generally distributed. The Dytiscidæ are represented by six species, the Hydrophilidæ by two. The Dytiscidæ are much stronger swimmers and more voracious feeders than the Hydrophilidæ, which facts may account for their more successful occupancy of the pond.

Hetærina americana Fabricius.

Taken flying over pond Aug. 12, 1910.

Lestes congener Hagen.

Taken Sept. 1, 1910. On that date they were numerous over pond.

Ischnura verticalis Say.

Emerging June 18.

Anax junius Drury.

A single specimen Aug. 12.

Sympetrum vicinum Hagen.

Two specimens taken June 18.

Libellula pulchella Drury.

June 18, July 16, Aug. 12. Emerged from nymphs in aquaria during June and July. Nymphs of this form were the most numerous of the group.

Libellula lydia Drury.

Flying over pond Aug. 12.

Corethra.

Corethra larvæ either had never been in this pond before 1909, or had been exterminated by the drying up of the pond in the autumn of 1908. The latter proposition seems to be the correct one.

As stated previously, no collections were taken during the summer of 1909. In the autumn when observations were resumed, corethra larvæ were present in enormous numbers. Their numbers have not appreciably decreased since. The reappearance of the larvæ may be accounted for either (1) by eggs having lain dormant during the dry period and winter, and then hatching as the temperature increased the following spring, or (2) adult imagoes may have migrated to the pond during the spring and summer of 1909. I think that the first proposition is untenable because on May 25, 1910, larvæ 3 mm. long were present that had been hatched from the eggs of that year. It is not likely that larvæ of that size could have escaped observation the previous spring. If the species was re-introduced into the pond by the imago, it necessitated a migration of over a mile. Wind doubtless influences these flying forms, so that their migration was partially passive.

Chironomus sp.

Larvæ occurred rarely.

MOLLUSCA.

Gastropoda—

Succinea retusa Lea.

The most common mollusc of the pond. Eggs laid in April, May and June. Hatched in about 15 days. This period probably varies with temperature. At 12°-14° C., eggs laid April 8 hatched April 23.

Tebennophorus dorsalis Binney.

This slug is common in Indiana. However, only a single specimen was taken in the pond, Oct. 16, 1910, in the debris at the bottom. (It seems to have been recently introduced.)

Ancyclus tardus Say.

Not uncommon. This shell is reported by Call ('99) to be common in the Wabash, Ohio and Maumee rivers. In all references that I have been able to find, it is recorded from streams. But most expeditions that were for the special purpose of collecting molluscs, were made along streams. The forms from the land-locked pools have been collected more incidentally. These facts, together with the small size of the species, account for the oft repeated statement of its distribution.

Vertebrata—

AMPHIBIA.

Amblystoma jeffersonianum Green.

The adult of this form has not been taken in the pond, but is known from the ravine to the north. Egg masses, referred to this species, were present March 17, 1910. One mass contained 19 eggs and another 29. March 24, 1911, a mass was observed containing 24 unhatched larvæ. Diameter of outer envelope, 13 mm. Diameter of total mass, 60 mm. Length of larvæ, 13 mm. Fastened to grass 13 cm. below surface.

Diemyctylus viridescens Rafinesque.

Common. Six taken in an area about one foot square in February, 1911. Its habits have been worked out in detail by Gage ('91) and Jordan ('93).

Hyla pickeringii Holbrook.

Three. Numerous. Appeared March 24, 1910. Eggs in May.

Rana catesbiana Shaw.

Common. Nine specimens taken during May, 1910. Egg-laying period, June and July. Recently laid eggs as late as July 15. Reduction in level kills many eggs.

AVES.

Anas discors Linnæus.

A duck was flushed from the pond April 21, 1909. Identification was made while the bird was on the wing. It circled three times, coming quite near. The identification is probably correct. This bird has the greatest range of any individual organism found on the pond. The A. O. U. check list, 1910, gives its range as: North America in general, but chiefly the Eastern Province north to Alaska and south to West Indies and northern South America; breeds from northern United States northward.

It is altogether probable that other water birds visit this pond. I have seen various species of ducks and sand pipers on similar ponds in this region. On the water works reservoir, a small artificial lake about three miles distant, ducks, loons, grebes, etc., may be seen almost any time during their migration period. McAtee ('05) lists 44 water birds from this region, 20 of which he marks as regular migrants.

Agelaius phœniceus Linnæus.

Red winged blackbirds were first seen on the pond May 5, 1909. Two pairs nested during the summer of 1909 on the south part of the pond. The nests were attached to the Typha stems over the water. Three pairs nested near the same place in the pond in 1910.

Many other birds were seen near the pond or perched on the Typha stems. The most common of these were: Turtle Dove, *Zenaiduro macroura L.;* Quail, *Colinus virginianus L.;* Tree sparrow, *Spizella monticola Gmelin;* Fox sparrow, *Passerella iliaca Merrem;* Field sparrow, *Spizella pusilla Wilson;* Junco, *Junco hyemalis L.*

FLORA.

Algæ—

Closterium dianæ Ehrenberg.

April 1, 1910. Common among filamentous algæ.

Cosmarium botrytis Menegh.

Common, spring 1910.

C. tetraophthalmum Kuetzing.

Rare.

Docidium crenulatum Rabenhorst.

This and other species of this genus occurred sparingly in most collections.

Spirogyra majuscula Kuetzing.

During the winter of 1909-10. This alga developed in considerable quantity in the southern part of the pond.

Zygnema stetlum Agardh.

A few filaments observed Nov. 23, 1909, Jan. 9, 1910. Never observed in fruit.

Oedogonium undulatum Brebisson.

The most abundant alga in the pond. It is present throughout the year. It was observed fruiting sexually on Nov. 16, 1909, and April 13, 1910. After the sexual season in the spring the plants decline in vigor. There are enormous numbers of oospores present in the water at this time.

Chaetophora pisiformis Roth.

Common at all seasons on stems.

Typha latifolia L.

This is the most conspicuous plant in the pond. It covered the shallower two-thirds of the pond in 1908 and has since increased to about three-fourths of the total area. It is from this plant that most of the vegetable debris on the bottom of the pond is derived.

In 1910 shoots appeared from the stolons Mar. 24. Seeds began germinating April 8. flowers were formed in June and seeds were ripe early in September.

The seeds which fall in the water are usually blown to the lee side of the pond where they collect in dense masses. This results in very weak seedlings during germination. A slight reduction of level is fatal at this period. Besides this, the margin where these seeds germinate is already occupied by parent plants. From these facts, it is evident that the seeds of Typha are very inefficient in increasing the number of plants in a pond where it is already established. The increase is derived chiefly from buds from the stolons. The seeds, while ill adapted to this function, are very efficient in securing the introduction of the species into ponds unoccupied by it. On a spike 150 mm. long, I have estimated the number of seeds to be 27,000. How far they may be carried by wind is conjectural, and on that account this efficiency can not be reduced to figures. The chances of introduction of any wind-blown seed is inverse to the distance from the center of distribution, but the proportion is unknown. Certainly it is greater in the direction of the prevailing winds than in any other. It may be observed that if the seeds were distributed evenly over a circle whose radius is one mile (the distance to the nearest pond) a seed from each spike would have approximately five chances in six of hitting a pond of that size (70 ft. in diameter) placed anywhere in this circle.

TABLE No. 1.

Table Showing the Number per 100 Liters of the more strictly Plankton organisms present January–August, 1910.

SPECIES.	Date.											
	1/25/10	2/8/10	2/26/10	3/17/10	3/31/10	4/14/10	4/28/10	5/14/10	5/28/10	6/15/10	7/16/10	8/12/10
Euglena acus Ehr. (?)	140	2,860	3,712	18,240	25,680	132	....	....	....	....	....	....
Euglena viridis Ehr	280	2,552	7,880	4,184	548	17,616	1,316	488	736	848	300	27,560
Phacus	12	4	....	....	36	16	....	32	56	40	2,792	....
Difflugia	72	28	36	76	840	1,548	368	2,244	3,960	7,440	17,772	39,780
Polyarthra	....	....	....	....	....	....	246	5,612	27,564	7,468	184	....
Monostyla	....	....	....	....	....	....	88	240	604	368	1,467	1,040
Hydatina	....	....	....	....	....	....	....	16	....	....	6,240	6,500
Nauplii	....	....	....	68	236	408	20	52	....	....	2,136	80,860
Cyclops	....	....	....	4	28	52	8	4	8	80	1,048	70,460
Daphnia pulex	....	....	....	....	....	....	....	16	12	80	60	....
Alona quadrangularis	....	....	....	....	....	8	24	120	696	500	600	780

Alisma Plantago aquatica L.

Occurs sparsely at the margin of the pond.

Covers the bottom between the Typha stalks on the north and east sides of the pond.

These three phanerogams occur in the pond. Near the margin of the pond occur Bidens and Carex. whose principal relation to it is that they cause the deposition of much of the silt before it reaches the pond.

PLANKTON.

The accompanying table records the observations on the more abundant and more strictly plankton organisms in the pond from Jan. 25 to Aug. 12, 1910. The most apparent fact is the dearth of organisms in the open water during the extremely low temperature of January and February, Euglena virides Ehr., and Euglena acus Ehr. being the most abundant. A few rotifers were observed during the winter, but no marked development of this class was observed until the latter part of April. Polyarthra reached its maximum on May 28, and Monostyla in August. Hydatina is strictly a summer form.

Wesenberg-Lund ('08, p. 255) states: "Rhizopoda are, so far as my experience goes, of quite secondary importance in the pond plankton." This pond certainly differs from those of Denmark, for the development of Difflugia is constant and fairly regular from February to August, when 297,800 per cu. m. were present. Actinophrys was very common near the margins during May.

There are two pulses of cyclops. A very slight one in April and an enormous one in August. It is possible that some of the cyclops were able to avoid the intake of the collecting apparatus. This of course would make the members in the table too low. In April the cyclops were quite evident in the shallow water near the shore. However, it was difficult to apply quantitative methods to this region. During the August pulse, none was seen near the shore. This may have been due to the fact, noted elsewhere, that they were smaller than *C. bicuspidatus* usually is.

ECOLOGICAL RELATIONS.

In the ecology of any association of organisms, two complicated problems or sets of problems present themselves. These are (1) how was each of these organisms introduced, (2) what factors condition their continuance? Without presuming to give a final answer to these questions, I shall present such facts as bear on the distribution and interrelations of the organisms of this pond.

On the basis of methods of dispersal, these organisms fall into two groups, active migrants and passive migrants. The active migrants include the vertebrates and insects, which are limited, for the most part, to the American continent, while the passive migrants include all the other forms which are practically cosmopolitan in their distribution. To discuss the distribution of the active migrants would involve a consideration of their relationships and phylogeny which is not within the province of this paper.

Of the passive migrants, the crustacea, rotifera, protozoa, and most of the algæ are known from both Europe and America. Some of the forms have a much wider distribution. Difflugia, for example, is recorded by Bütschli from all the continents except Africa (where it doubtless exists). Recently Edmonson ('10) has reported *Difflugia pyriformis* from Tahiti. The presence of this form on a recently formed isle, geologically speaking, 4,000 miles from a mainland, certainly makes probable its worldwide distribution.

The cosmopolitan distribution of the passive migrants can, I think, be explained by an analysis of the agencies by which they are carried. Of these agencies, the principal ones are birds, beetles and wind.

Of the birds, only the water birds need be considered as the relation of land birds to aquatic organisms is accidental.

De Guerne ('88) established that water birds do carry a great variety of small aquatic organisms. In examining the fresh water fauna of the Azores, he discovered that the micro-organisms belonged to species found in France. This suggested water birds as a distributing agency. He took a wild duck (Anas boschas L.) and made cultures from the dried particles of slime from its bill, feathers and feet. From these cultures he obtained protozoa, rotifera, nematoda, algæ, cladocera, ostracoda, bryozoa and insect larvæ.

Zacharias ('88) points out the fæces of these birds as an additional source of micro-organisms. I have seen but two water frequenting birds on this pond, but it is occasionally visited, in all probability, by those in whose migration path it lies. Of the twenty-two water birds which are *regular* migrants or residents (including the blue winged teal, the kildeer,

TABLE NO. --.

Showing the Water Birds Which Are Common in the Vicinity of the Pond at Some Time During the Year.

Species.	Regions Over Which They Are Distributed.							
	U. S. A.	Canada.	Mexico.	Central America.	South America.	West Indies.	Europe.	Greenland.
1. Horned grebe, Colymbus auritus Linn	+	+	+	+	....	+	+	....
2. Pied billed grebe, Podilymbus podiceps Linn	+	+	+	+	+	+	....	....
3. Loon, Gavia imber Brünnich	+	+	....	....	....	....	....	....
4. American merganser, Merganser americanus Cass	+	+	+	+	....	+	....	....
5. Hooded Merganser, Lophodytes cucullatus Linn	+	+	+	....	....	+	+	....
6. Mallard, Anas platyrhynchos	+	+	+	+	....	+	....	....
7. Green winged teal, Nettion carolinense Gmelin	+	+	+	+	....	+	....	....
8. Blue winged teal, Querquedula discors Linn	+	+	+	+	....	+	+	+
9. Shoveller, Spatula clypeata Linn	+	+	+	+	....	+	....	....
10. Pintail, Dafila acuta Linn	+	+	+	+	....	+	+	....
11. Wood duck, Aix sponsa Linn	+	+	....	....	....	....	....	....
12. Canvas-back, Marila vallisneria Wils	+	+	+	+	....	+	....	....
13. Lesser scaup-duck, Marila affinis Eyt	+	+	+	+	....	+	+	+
14. American golden eye clangula, Clangula americana Bonap.	+	+	+	....	....	+	+	+
15. Canada goose, Branta canadensis Linn	+	+	+	....	....	+	....	....
16. American bittern, Botaurus lentiginosus Montag	+	+	....	....	....	+	+	....
17. Great blue heron, Ardea herodias Linn	+	+	+	+	+	+	....	....
18. Wilson's snipe, Gallinago delicata Ord	+	+	+	+	+	+	+	....
19. Pectoral sandpiper, Picobia maculata Viell	+	+	+	+	+	+	+	+
20. Solitary sandpiper, Totanus solitaris Wils	+	+	+	+	+	+	+	+
21. Spotted sandpiper, Actitis macularia Linn	+	+	+	+	+	+	+	....
22. Killdeer, Œgialitis vocifera Linn	+	+	+	+	+	+	+	....
Total	22	22	19	16	7	20	11	5

and the twenty marked by McAtee ('05) as common), all are found in the United States and Canada, 19 reach Mexico, 16 Central America, 7 South America east of the Andes, 20 the West Indies, 5 Greenland and 11 are reported from Europe. (See Table No. 2.)

Of the 24 other water birds listed as rare or occasional from this region, three reach Chili and one Greenland. The range of no individual bird is as great as that of its species, but many of the water birds are gregarious at some season, so that the organisms which they carry would soon be distributed over their entire range. This does not necessarily mean that these organisms would develop over the entire area.

The following examples show how the area may be connected with the rest of the globe. Besides the four, indicated in the table as occurring more or less regularly in Europe, others appear accidentally (Headley, '95). The Turnstone (Headley l. c.) migrates from Greenland across Europe to Australia. Holbœll's Grebe (Colymbus holboelli Reinh) is distributed over North America, Greenland, Eastern Siberia, south to Japan, thus connecting America and Asia. These forms all breed inland so that they are related strictly to the fresh water fauna. The list may, of course, be extended almost indefinitely. Marine birds, such as the albatross have a much wider range but they rarely come inland.

Birds are the chief agencies in the distribution of crustacea (cladocera, copepoda), whose eggs are too large to be wind-blown. The reduction in the number of water birds which has taken place in the last half century certainly has reduced the chances of a crustacean reaching a pond at the period suitable to its development. In the larger bodies of water this relation is not so evident nor so patent because they are much more static.

Insects migrate very short distances compared with birds. However they do carry organisms from one pond to another in a limited locality. The aquatic beetles and some Hemiptera are the most efficient agencies because the imagoes spend most of their life in the water where algæ and protozoa become attached to them. Occasionally, however, they leave the water, as is attested by the fact that they collect around a light at some distance from their habitat.

In this pond I have often noted beetles with vorticellæ and other ciliates attached. The attachment of stalked ciliates to beetles is mentioned by Stein ('54) and others. Migula ('88) having found a single beetle associated with algæ in a pool 30 cm. in diameter near the summit of Biskiden mountains, concluded that the beetle had carried the algæ. Later he examined six beetles belonging to three species, from five different habitats and found attached to them twenty-three species of algæ.

These ciliates and algæ, however, were attached to beetles *in the water*. When the beetles leave the water these attached organisms are suddenly transferred from an aquatic to an ærial environment. This new environment differs from the old one in temperature and humidity. How long these organisms can resist these changed conditions and how long the beetles stay out of water are facts that must be known before the role of insects in the distribution of attached organisms can be accurately determined. The fact that aquatic beetles fly at night reduces the harmful effect of evaporation. Experiments are planned to solve these problems.

In the notes on *Epistylis*, I have indicated that that species of this genus can remain out of water for some time without fatal results. The colony referred to remained on a slide under cover in a room with low relative humidity for more than fifteen hours without it being fatal to all of the zooids. While a colony of this species attached to the thorax of a beetle making a nocturnal migratory flight would not have the protection against evaporation of the two glass plates, this would be compensated in some degree by the more humid and cooler night air.

That wind is responsible for the distribution of many protozoa and rotifers is a fact which is familiar to any one who has ever made a hay infusion. The presence of these organisms and of tardigrada in the pond, is probably due to wind distribution. Just how far an organism can be transported by wind depends upon the size and specific gravity of its spores, eggs or cysts, and upon its power to resist drying, extreme temperature, etc. These facts are, in a large number of cases, unknown.

Cysts of Euglena are common in almost every culture, but it does not follow that this is the form in which they are wind-blown. Assuming a constant specific gravity, it is certain that the buoyancy of a cyst increases as the reciprocal of its diameter. As an adaptation to this law, many organisms form extremely minute spores.

It is rendered very probable by Calkins ('07) that in *Amœba proteus* very minute spores are formed. From his figures I have determined the diameter of the tertiary nuclei (which with a bit of cytoplasm are presumed to form the spore), to be 1 μ or less. Comparing these spore nuclei in Calkins ('07), Fig. 14, with the amœba figured in his earlier papers.

Calkins ('04), it certainly becomes evident that there is an efficient adaptation to wind distribution.

Attention may be called to the analogous transportation of volcanic dust which has been known to drift round the world. Volcanic dust has a higher specific gravity than that of protoplasm but, on the other hand, it is blown to a very high altitude, while organic spores usually start from the surface.

The exact nature of the spore while in the air must be known before its distribution by wind can be even approximated by direct methods.

Distribution.—Of the complicated set of factors that condition the existence of these organisms, only four can be discussed at this time. These are level, light, temperature and food relations. The chemical composition of the water and its variations have not been determined. The determination of the dissolved oxygen, carbon dioxide and ammonia will probably yield valuable results in a comparative study of several ponds.

Level.—The factor that affects the organisms in this pond most vitally is the extreme changes in level. The level varies from zero to 46 inches above the lowest point. So far as ascertained, its level has been reduced to zero (i. e., it has dried up) but once in its history and that was in the late summer and early autumn of '08. It did not overflow until the following March. From March, '09 to August, '09, the lowest observed level was 35½ inches. The summer of '08 was the dryest in 13 years (local records are not available before 1896). That of '09 was rather wet, 4.75 inches of rain falling on July 14. For these two rather extreme years, the minima have been 35.5 and 0; or to put it another way, the level has decreased 25% and 100% from the maximum. This point will be discussed more fully later. As the destructive forces gradually elevate the bottom of the pond, it is probable that in future the pond will go dry more often. Level is determined by precipitation and evaporation. The extreme variability of these factors in this pond and similar ones in this region is indicated by the weather records of the local station and those from Indianapolis. Records of sunshine, wind velocity and relative humidity are not available for any station nearer than Indianapolis (56 miles distant).

In the accompanying table I have compiled all the climatological data available for this locality.

TABLE 3. CLIMATOLOGICAL DATA.

Bloomington, Monroe County, Ind.—Elevation, 800 feet.

Precipitation.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1887.........	2.50	6.35	3.35	3.48	1.25	......	......	......	......	......	......	......	......
1888.........	1.18	......	......	......	......	......	......	......	......	......	......	......	......
1895.........	......	......	......	......	......	......	......	......	......	......	......	3.47	......
1896.........	1.06	2.60	2.10	T.	5.12	3.52	7.78	7.49	4.16	1.35	4.36	0.90	40.44
1897.........	3.17	3.35	10.63	6.02	2.37	6.27	2.62	0.59	0.72	1.33	7.42	3.24	47.73
1898.........	6.42	2.15	10.30	1.88	3.94	3.03	2.69	4.43	7.28	4.00	3.13	2.90	52.15
1899.........	4.06	4.10	4.71	1.96	4.18	2.34	1.60	1.20	0.48	2.91	3.58	3.68	34.80
1900.........	2.25	3.55	3.35	1.14	4.79	5.73	3.54	1.64	2.54	4.00	3.30	2.05	37.88
1901.........	2.15	2.15	5.42	3.81	1.00	4.49	0.77	2.63	0.99	4.03	0.95	4.75	33.14
1902.........	0.90	2.50	2.89	2.86	4.40	5.02	4.19	4.64	4.06	3.40	4.51	5.28	44.65
1903.........	4.44	6.05	4.75	4.23	2.22	2.55	3.90	5.46	1.50	2.70	2.11	2.91	42.77
1904.........	5.50	4.05	9.86	2.80	3.67	4.44	2.20	1.60	4.84	1.30	1.00	6.10	47.36
1905.........	3.05	2.82	3.30	4.81	5.55	2.67	4.27	8.05	2.15	7.35	1.73	3.30	49.05
1906.........	4.61	2.05	9.31	2.15	2.45	3.39	2.30	7.38	2.99	1.08	4.90	4.94	47.55
1907.........	9.74	0.74	6.48	3.11	3.98	3.79	4.35	3.12	2.52	4.80	4.20	4.10	50.93
1908.........	1.50	7.85	5.26	5.51	8.91	1.93	1.81	2.06	0.83	0.29	2.65	2.05	40.65
Means...	3.57	3.59	5.84	3.13	3.84	3.78	3.23	3.87	2.70	2.96	3.37	3.55	43.43

	Length of record.	January.	February.	March.	April..	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Average number of days with 0.01 inch or more precipitation.......	13	8	7	10	8	10	10	7	7	6	5	7	8	93
Maximum temperature............	13	70	68	84	87	93	97	103	98	100	88	78	72	103
Minimum temperature.............	13	-11	-20	0	22	29	42	51	50	28	22	5	-10	-20
Mean temperature.................	13	30.7	29.3	43.3	51.0	64.5	71.9	76.6	75.1	68.6	57.4	44.2	33.2	53.8

Table 3—.Continued.

Indianapolis, Ind.

	Length of record.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Relative humidity (percentage)...	21	79	77	73	66	67	68	65	67	68	68	73	77	71
Sunshine (percentage)............	12	41	47	40	51	53	62	68	63	66	61	52	40	54
Average hourly wind velocity (in miles)........................	12	11.7	11.5	12.1	11.3	9.9	8.9	8.2	7.4	8.3	9.4	10.4	11.5	10.0

During the period Nov.—June, the level of the pond is not rapidly reduced. September and October are on the average the dryest months of the year. July and August are the hottest. It is during this period (July—Oct.) that the level is reduced most rapidly and the stress on the organisms is most acute. In this period occurs the minimum precipitation, lowest relative humidity and smallest number of rainy days (i. e., .01 inch *or more* precipitation), the maximum temperature and the greatest sunshine percentage. All of these factors tend to reduce the level of ponds by evaporation. The lower wind velocity tends to reduce the evaporation to a slight degree.

The amount of stress produced by a reduction of the level varies in different years. In thirteen years of precipitation records for Bloomington, the minimum for four months, July—October, was in 1908. The maximum occurred in 1896. In 1908 the amount of precipitation for the four months was 4.99 inches. In 1896 the maximum was 20.78 inches. The average for the entire thirteen years for these months was 12.66 inches. To state it another way: the minimum for this period was 39+% of the average and 23.5+% of the maximum. That is, between four and five times as much rain fell during this period of one year as fell during the same period of another year. This irregularity, more than any other factor, prevents the fauna of this pond and all *small* solution ponds from becoming even relatively static. In the larger ponds the effect is less acute.

The drying up of the pond in '08 killed all the amphibian larvæ, the corethra larvæ and caused the emigration of some of the aquatic beetles.

(I am informed that *Dytiscus marginalis* Linn was formerly obtained from this pond in quantity for laboratory dissection material.) I have never taken a specimen from the pond. What other forms may have been eliminated by this "drying up," I do not know, because I began to study it at this period.

Not only were the conditions during this period of low level very different from those preceding it, but the conditions after the dry period were also very different.

When the pond began to fill with water in November, '08, the decaying amphibian larvæ and other organic matter developed conditions favorable to the production of an enormous number of flagellates. This decaying organic debris and possibly the flagellates furnished an immense amount of food for some of the crustacea, especially *Cypridopsis vidua* Brady. The algæ are eaten by both the amphibian larvæ and *Simocephalus vetellus.* The elimination of the former greatly increased the food material of the latter.

The dragon fly nymphs and possibly Corethra larvæ feed on on both of these crustaceans. Thus the conditions at this period furnished the crustacea an enormous food supply and few enemies. The result was a very great development of crustacea. Especially was this true of *Crypridopsis vidua* Brady. Since the winter of 1908, conditions which I have not been able to determine have resulted in the entire elimination of this form. It is evident that variations in the level may result in the elimination of a species or its abnormal development.

Temperature.—The seasonal development of different forms as indicated in the list and table, is probably due directly or indirectly to changes in temperature. The temperature in the water of the pond varies from 27.8° C to 0 at the surface (ice) and to 1.3° C at the bottom.

Except for the first few weeks the temperatures were taken with a centigrade thermometer graded to 1/5ths. The winter of 1908-1909 was fairly open. Ice formed December 2, lasting until January 20. Ice was present the latter part of February but there was none after March 3. The maximum thickness of ice for this year was 2.5 inches. The winter of 1909-1910 was very severe for this latitude. Ice formed December 7 and lasted until March 2 and had a maximum thickness of 9 inches on January 11. During the first winter, the temperature of the water a few inches under the ice, varied but slightly from the greatest density temperature.

The long period of low temperature during the winter of '09-'10 reduced the temperature of the water appreciably.

In order to determine the difference in temperature between the water immediately under the ice and that near the bottom, the following simple apparatus was used. A large mouthed bottle with a glass stopper was laced firmly to a stick of convenient length and a cord was tied to the stopper. The bottle was lowered to the level desired and the stopper removed by means of the cord. The bottle was thus filled with water of approximately the same temperature as that surrounding it. The thermometer was then lowered into the bottle and the whole apparatus was made fast to the ice for about an hour. The bottle with the thermometer in it was then raised and the reading made. The error resulting from this manipulation was very slight. The following readings were recorded:

Jan. 11, 3 inches under ice, 2.2; near bottom, 3.1 C.

Feb. 1, near surface, .8; near bottom, 2.8 C.

Feb. 26, lower surface of ice, .1; near bottom, 1.3 C.

These data indicate that after the pond is sealed with ice, the temperature of the water gradually approaches zero. This lowering of the temperature and the establishment of a difference between the upper and lower strata is due to surface radiation.

Another condition which reduces the temperature of the water is the partial melting of the ice. As has been stated, the pond has Typha growing in it near the edge. The Typha stems project through the ice all winter. When the ice begins to melt, the heat absorbed by these stems, melts holes through the ice around them. The pond then has a zone of openings at its periphery. On January 18, 1910, the ice was partially melted; five inches of solid ice remained. This was covered with four inches of water. The holes had formed around the Typha stems. A stiff wind was blowing from the west. The result was a movement of water from west to east above the ice, and from east to west below the ice. As the temperature of the water above was approximately that of melting ice, its circulation below the ice must have lowered the temperature of the water. (See Fig. V.)

Another factor which may have a slight influence on the temperature of the lower strata, is the decay of organic matter which covers the bottom. This, of course, goes on very slowly at low temperatures.

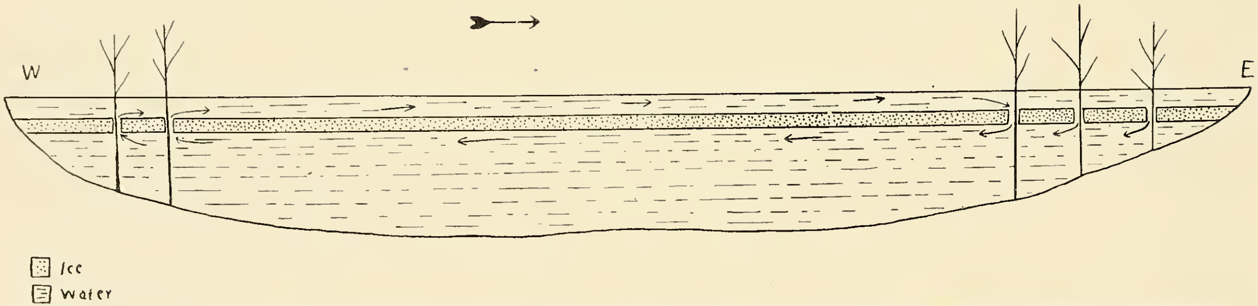

Fig. V. Showing the movement of water caused by wind when the ice is partially melted. Arrows in water indicate direction of water current. Arrow above indicates the direction of wind. Typha stems are indicated diagrammatically near the periphery.

The observed maximum (27.8° C.) is probably not the real maximum as no continuous series of summer temperatures was taken, and the diurnal change in temperature was very great during the variable periods of autumn and spring. The greatest observed variation for twenty-four hours being 10° C. on Oct. 11-12.

Temperature above 4° C. does not seem to affect the forms which are found in the pond throughout the year, i. e., beetles, Corethra larvæ, amphibian larvæ, etc. Below this temperature, however, their activity is decreased and below 2° C. they are quite passive. For some time after the ice formed in the winter of 1909-1910, the Corethra larvæ could be found in all parts of the pond. Amphibian larvæ came to the surface when the ice was cut, and the beetles could be seen crawling on the Typha stems beneath the ice. On Jan. 11, 1910, the upper layers of water (three inches under the ice) had a temperature of 2.2° C. The lower layer (24 inches under the ice) was 3.1° C. There were few Corethra larvæ in the upper layer and these were quite inactive. Near the bottom of the pond in the deepest part, they were present in great numbers and were much more active than those in the upper layers. Larvæ from either region became more active when the temperature was raised. Many dead larvæ were found just below the ice. It may be concluded then that a temperature below 4° C. reduces the activity of Corethra larvæ. At 2° they become quite passive and temperature lower than 2° may prove fatal.

Amphibian larvæ were active and could be captured in quantity during December and most of January. On Feb. 1, 1910, the central, Typha free part of the pond was carefully dredged for amphibian larvæ but none were captured. Holes were then cut in the ice nearer the margin of the pond. Two larvæ were captured ten feet from the north end. These were in the debris among the Typha stems. They were rarely captured until the ice disappeared in March. On March 3, the ice had disappeared and the larvæ were much in evidence. The temperature just under the ice on Feb. 1 was .8° C. and near the bottom was 2.8.

It seems that the formation of ice on the surface does not cause a quiescent stage in amphibian larvæ but a temperature of about 2° C. does reduce their activity. It may be, in both these cases, that it is the *continued* low temperature that causes these stages of inactivity. However, in the winter of 1908-1909, the water was not above 4° C. from Dec. 2 to Jan. 27 and no period of inactivity was observed in these forms.

TABLE 4. MONTHLY AVERAGE OF TEMPERATURE FOR THE PERIOD NOV., 1909—APRIL, 1910.

Month.	Temperature near Surface.	Temperature near Bottom.
November......	13.25° C.	
December	4.° C.	
January.........	3.4° C.	
February	.3..................................	2.05° C.
March	6.7° C.	
April............	15.4° C.	

Temperature records are not complete for warmer months, but those taken indicate that the temperature of the water approximates closely the average diurnal temperature of the air, which data are given in detail on page 425.

Most of the aquatic beetles of this pond hibernate as imagoes. After the freezing weather comes they are to be found in the plant remains that cover the bottom of the pond. Their movements are very slow, and usually consist in crawling rather than swimming. On Jan. 13, 1909, ½ inch ice, 5 inches snow, water temperature 2.2° C., a beetle (*Tropisternus mixtus* Lec.) was watched for 20 minutes. It was crawling on a Typha stem and during this time left it but once, swimming away a few inches and then returning.

It may be argued that this quiescent state of the larger forms in the pond is due to the reduction in the amount of oxygen rather than to low temperature. I have not determined the amount of oxygen present during different seasons of the year. However, the filamentous algæ which are present all winter certainly produce some oxygen and it is highly probable that the Typha stems allow some gaseous interchange to take place between the air above the ice and the water below it. I have made the following simple experiment with beetles (5 species), Corethra larvæ, and Notonecta. Two glass jars which were exactly alike, were filled with water to the same level. An equal amount of Typha stems was placed in each. In one, the stems were completely submerged, while in the other one, the end of each stem was allowed to protrude from the water. An equal number of organisms was introduced into each jar. The surface of the water was then covered with a mixture of paraffine and beeswax. The animals in the jar where the stems protruded through the seal invariably lived longer. The periods for the beetles were about 1 and 3 days respectively.

Light.—The pond is fairly well lighted throughout its entire depth during the day except when it is covered with snow. The light is reduced considerably by the growth of Typha. Kofoid ('04) found that, with the development of phanerogams in one of the backwater ponds tributary to the Illinois River, there was a marked reduction in the plankton. Some comparative observations were made on a pond about five miles west of this one. It has about the same area and depth but there is no Typha growing in it. Although no quantitative methods were applied, cladocera, copepoda, and chlorophyceæ were much more in evidence in it during September, '09, than in the pond under discussion. It seems probable that the reduction of the light by the Typha growth has resulted in fewer species and individuals developing in this pond.

On Jan. 11, 1909, the ice was partially melted. Openings had formed in the ice around the Typha stems and about 2½ to 3 inches of water stood above the remaining ice sheet. Cyclops was quite abundant in this upper layer of water which was certainly due to their being phototactic. It was the only organism detected. A lowering of the temperature under such conditions would certainly destroy many individuals. Thus an adaptation presumed to be beneficial under one condition becomes destructive under certain other conditions.

Food Relations.—Regarding the nutrition of aquatic organisms there are two theories, which, although not mutually exclusive, are essentially different.

The older one is that the ultimate source of food is chlorophyl bearing plants and the various forms of bacteria which produce nitrates and nitrites. The materials thus elaborated or their derivatives are ingested into food vacuoles, gastrovascular spaces, or alimentary tracts of animals, where they are acted on by secretions of the animal, reduced to a solution and absorbed. This theory has been assumed by most zoölogists in their discussions of food relations, and it is the most fundamental assumption in the investigations now being prosecuted by the International Fishery Organization.

The second theory is that proposed by Pütter ('08). He holds that the nutrition of many aquatic forms is essentially different from that of land animals. He shows that water contains large amounts of carbon compounds in solution and demonstrates experimentally that this is the source of nutrition for a sponge, *Suberites domuncula* and a holothurian (*Cucumaria grubei*). In this paper and two subsequent ones, he extends his theory to include representatives of every phylum of aquatic animals.

Possibly foreseeing the difficulty offered by the fact that in general, waste compounds of animals are less complex than their food, he suggests that a photochemical process may take place in aquatic animals, analogous to that of chlorophyl bearing plants. "Ob die gelösten Stoffe, die den niederen Tieren als Nahrung dienen, soviel Energie enthalten, dasz der Abbau durch Spaltungen und Oxydationen allein hinreicht, um den Energiebedarf der Tiere zudecken, oder ob hier in einer weiteren Analogie mit dem Stoffwechsel der Pflanze strahlende Energie ausgenutzt wird, um durch photochemische Prozesse aus den aufgenommenen gelösten Stoffen Substanzen von höherem Energiegehalt herzustellen, das ist eine Frage von so hoher prinzipieller Bedeutung, dasz, die wenigen Erfahrungen, die zu ihrer Erörterung gegenwärtig beigebracht werden könnten, nicht hinreichend zur Entscheidung sind."

With the exception of *Simocephalus vetellus*, the methods of Pütter have not been applied to species found in this pond. Wolff, '09, was able to show that *Simocephalus vetellus* could develop in a medium free from nutrition in the form of solids (geformte Nährung).

Without denying the possibility that aquatic animals derive some food from the water by direct absorption of nutrient solutions, it may be stated with certainty that the higher animals of this pond for the most part utilize solid food. This statement is based on observations on feeding and the examination of alimentary tracts.

In this discussion of the food relations of these animals, I shall ignore Pütter's alternative. If it be subsequently proven that the ingestion of food is merely incidental, it will also establish their complete independences so far as food relations are concerned.

I have tried to express in the accompanying diagram some of the important food relations between the organisms of the pond. These relations are very complicated because of the omniverous habits of some of the forms. Many of the forms derive their nutrition in part from the dead organic matter in the pond, to which all of the forms contribute. The ultimate food sources in the pond are (1) water; (2) carbon dioxide in solution in the water (derived from the air above the water); (3) nitrogen, free and in simple compounds, such as ammonia; (4) foreign organisms accidentally falling into the pond. e. g., insects. The formation of nitrates from simple nitrogen compounds was established by the well known work of Winogradsky ('89). He demonstrated two kinds of bacteria, one forming nitrous acid, another changing this to nitric acid which is neutralized by carbonates already present. This process may be assumed to form the first step in the proteid synthesis in this pond.

These bacteria and those present in the decaying organic matter of the pond are eaten by the flagellates and ciliates. The ciliates also use the flagellates for food. The carbohydrates of this group are derived from the dead organic matter in the pond. The synthesis of carbon dioxide and water into carbohydrates is of course due to chlorophyl bearing plants. These plants consist of desmids, diatoms, filamentous algæ and phanerogams. The inclusion of diatoms and the smaller desmids by Difflugia has been demonstrated by observation. *Simocephalus* is the only animal in the pond that is dependent wholly upon algæ for food. It may be able to adapt itself to some other food, but in this habitat its alimentary canal contains nothing else. It has not been demonstrated that any organism eats the living Typha plants except that the snails sometimes eat the more tender shoots. *Limnodrilus* lives among the roots but its alimentary tract contains rather finely comminuted material, some of which is clearly decaying plant stems. *Cypridopsis vidua* Brady feeds on the material which forms a slimy layer over the Typha stems, sticks, etc. Of course, this layer includes some organisms; however, their inclusion is accidental. I am sure they do not select algæ. *Simocephalus*, *Limnodrilus* and ostracoda are eaten by dragon fly nymphs. Naturally this is difficult to observe in the pond. In order to eliminate the unnatural instincts that develop in an aquarium, a deep soup plate was kept at the pond, into which dragon fly nymphs and other forms were introduced immediately on being taken from the pond. The white background made observation easy and accurate, and one may be reasonably sure that the feeding instincts exhibited were natural. The nymphs experimented with belonged to the family Libellulidæ. The preference of the dragon fly nymphs is indicated by the order

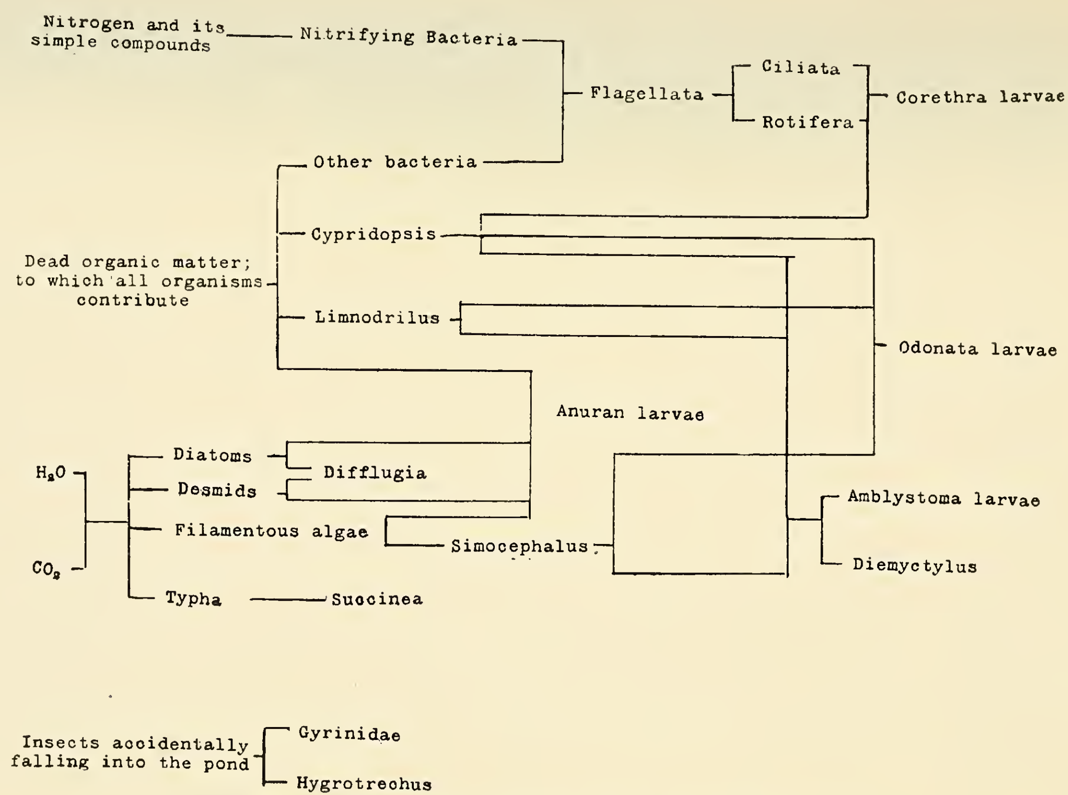

FIG. VI. Indicating the principal food relations existing between the organisms in the pond.

in which the forms are named. *Limnodrilus* is eaten voraciously by the *Amblystoma* larvæ and by *Diemyctylus*. *Diemyctylus* has been observed a few times to take *Simocephalus*.

The insects that accidentally fall into the pond are captured by the Gyrinidæ and *Hygrotrechus*.

The *Corethra* larvæ feed on ostracoda and possibly other forms in this pond. Miall ('95, page 115) says, "Corethra larvæ feed upon small aquatic animals such as Ephemera-larvæ, Daphnia, or Cypris." The Hydrophylidæ feed on the decaying organic matter. The Dytiscidæ have not been observed feeding in this pond, although they are known to be carniverous, Kellogg ('04, p. 258). The larvæ of the Anura of this pond are rather omniverous. They eat filamentous algæ, desmids, diatoms, protozoa, ostracoda and decaying organic material. There seems to be very little if any discrimination in the selection of food. Not all of the material eaten contributes to the nutrition of these larvæ. The rate of digestion in cold blooded vertebrates has been shown by Riddle ('09) to vary directly with temperature. However, at ordinary temperatures many organisms pass through their alimentary tracts unchanged. In the faeces of larvæ placed in tap water, *Oedogonium, Closterium* and *Doccidium* are common. From the alimentary tracts of larvæ kept for 5 days in water, which had been previously boiled, have been taken *Euglena, Phacus, Spirogyra, Oedogonium, Closterium, Doccidium.* The filamentous algæ and *Closterium* were in part disintegrated. The *Euglenæ* were very active. In another series that was kept 10 days, Ostracoda (Candona?) were found alive in the large intestine of six specimens. These facts indicate that the nutrition is derived from dead organic matter (filamentous algæ and Closterium) and that the inclusion of other, living organisms is accidental.

In connection with food relations may be mentioned the mechanical comminution of plant debris. When plants die in the pond, they stand for a time, then fall on the surface of the water where they float for a while and then sink. During this period they are being softened by the processes of decay. Their comminution is due to the action of the Ostracoda, especially *Cypridopsis* and the aquatic beetles belonging to the families Hydrophylidæ and Dytiscidæ. The specific gravity of the former is slightly greater than water and that of the latter slightly less. A piece of floating plant stem is covered with Ostracoda. A bit of the stem is often torn off by one of these ostracods. The ostracod remains attached to it until it reaches the bottom when it is released. The process is reversed in the case of the beetles. They clasp a bit of sunken plant stem in order to keep them at the bottom. A part of this often separates and is carried toward the surface. It is by the innumerable repetition of these processes that the mass of finely comminuted particles at the bottom of the pond is formed.

COMPARISON WITH LAKES.

The fundamental difference between this pond and a lake is that of dimension. It has a smaller area and is not so deep. A pond has no abysmal region but has some of the characters of the littoral and pelagic regions of lakes. From this fundamental difference, secondary differences arise. The changes in level affect the relative depth much more in ponds than in lakes. The lowering of the level of a lake one-half meter would not affect its fauna to any marked degree, while the same difference in level occurring in a pond whose depth was a meter or less would profoundly influence the organisms inhabiting it.

The temperature in all parts of the pond is near that of the atmosphere above it. In this it resembles closely the shallow littoral region of some lakes, e. g., "barren shoals" of Walnut Lake (Hankinson, '07). So far as observed the difference in temperature in different parts of the pond at any given time has not exceeded 2° C. It is practically holothermous, the thermocline and associated phenomena are absent.

Forel ('04) has shown in the case of Lake Geneva, that the littoral region is one of variety. This fact is perfectly familiar to all students of lakes. In the same lake, one part of this region may be covered with rushes (*Scirpus*), another by water lilies (*Nymphea*), another by *Potamogeton,* while another may be barren sand or rock or an equally barren marl bed.

An individual pond lacks this variety. It is in this particular that this pond and others like it differ most from the littoral region of lakes. (It is more nearly comparable to a limited section of a lake shore.) If Typha is introduced, it soon spreads over the whole area, limiting the light, excluding other phanerogams, and developing very uniform conditions over the entire pond. If a pond is developed on the side of a hill so that silt is carried into it, a muddy, barren condition exists over the whole area. Ponds in the woods rarely develop aquatic seed plants; the leaves from the surrounding trees cover the bottom so that a very distinct but uniform condition is developed. Besides their limited area, a second cause of this uniformity is their sudden formation. During the summer of '08, four miles east of Mitchell, Indiana, an open sinkhole containing several acres became sealed. With the first rain a pond with an area of about one acre was formed. This is the typical phenomenon in the formation of solution ponds. It may take a very long time for the solution cone or sinkhole to form, but when the opening at its base becomes sealed, the pond reaches its maximum depth quite suddenly. The result is that an aquatic habitat is formed with no aquatic fauna. The first forms introduced into a pond at this stage have no competition and soon take possession of the entire area, thus making it more difficult for a related form to establish itself. Another difference between these ponds and lakes (which seems to be due to their fundamental difference in size) is the paucity of species in the former when compared with the latter. It seems probable that, other things being equal, the larger the lake, the greater the variety in the fauna. Forel ('04) reports 22 species and 10 varieties of cladocera, 9 ostracoda and 12 gastropoda from Lake Geneva, while from the smaller Plöner See, Zacharias ('93) reports 20 species and varieties of cladocera, one ostracoda and 10 gastropoda. Burchardt ('00) observes that the plankton of the Alpenacher See contains fewer species than the Vierwaldstädtersee. Dr. W. Halbfass collected from a number of lakes in northern Germany and sent the material to Zacharias for examination. The lists show only one cladoceran from Dolgensee bei Neustettin, a very small body of water, while Wilmsee, a much larger lakelet, contained six. The faunal list for any lake that has been explored with care, is much greater than that of this pond.

This is due to the uniformity of conditions that prevails over the entire area of a given pond at a particular period, and to the fact that the pond after its formation, changes very rapidly, thus making it suited for a particular species for a relatively short period. If the species is not introduced during the period in which conditions are adapted to it, it can never develop.

In a lake, conditions are relatively static and a large per cent of the forms capable of developing in it at a given stage in its history, succeed in reaching it, while in a pond this per cent is much smaller. Forel ('04, p. 408) states that the similarity of the microfauna (i. e., passive migrants) of one lake to that of another is due to the "reaction reciproque d'un lac a l'autre." It is evident that this can occur only when similar conditions (e. g., pelagic) are present in the different lakes. In lakes this similarity may exist in certain parts during the major part of their existence. In ponds the period for this reciprocal reaction is very limited.

Although a single pond contains relatively few species, all the ponds in an area of several square miles show a much greater variety.

Many ponds have been examined but detailed data concerning them have not yet been collected. However, the following note will illustrate what is meant. On Jan. 11, 1910, pond No. 1 P contained *Cyclops bicuspidatus*, Chydorus sphaericus, Cypridopsis vidua and alona. Pond No. 2 T contained *Cyclops serrulatus, C. leuckarti;* and an unidentified Daphnid. Pond No. 6 P contained a few *Cyclops serrulatus* and an enormous number of *Bosmina cornuta*. Other groups of organisms show an equal variety.

RELATION TO CAVE PLANKTON.

This variety in the fauna of different ponds has an important bearing upon the relation of pond plankton to that of caves. That the plankton of the cave streams of this region is derived from certain of these ponds is well established. Only a small number of the organisms in any pond are able to withstand the inimical cave conditions. I have never found all the species reported from the Shawnee Cave stream in any one pond.

These facts indicate that the cave plankton is a composite of such organisms of the contributing ponds as are able to withstand cave conditions. It is probable that the greater the number of contributing ponds, the richer will be the fauna at the outlet of the cave stream.

The relation of these solution ponds to a cave stream is quite comparable to the relation of backwater lakes, bayous, oxbow cutoffs, etc., to the river in whose valley they lie. Kofoid ('03, p. 546) states concerning the Illinois River, "The plankton indigenous to the channel itself is of small volume as compared with that contributed from the backwaters." There is, however, this difference. In the cave the processes of growth and reproduction are very much inhibited, while in the river they continue or may even be increased. Kofoid (lc) has shown that during periods of low water, the river may contain more plankton than the contributing waters. This condition never exists in cave streams and obviously never can exist.

UNSOLVED PROBLEMS.

This study, while it gives a fairly complete picture of a particular pond and establishes some general notions concerning ponds of this type, is to be regarded as opening up a new corner in the field of freshwater biology, rather than exhausting any part of it. The fauna of solution ponds needs to be more carefully and generally explored. The life history of many of the species is quite unknown. Experimental studies on the effects of varied conditions upon some of the organisms are certain to yield results. The details of the mode of dispersal are very imperfectly known in many forms.

The most important general investigation, it seems, is to carefully select a series of ponds having different combinations of environmental factors, i. e., area, depth, shade, plant growth, wash, etc., and to make a series of simultaneous observations extending over at least one year. Then by a process of elimination, determine the effect of these factors.

I desire to express my obligations to Prof. C. H. Eyenmann and Prof. Charles Zeleny for their valuable suggestions and criticisms.

BIBLIOGRAPHY.

A. O. U. check list of N. A. birds. Third edition, '10.

Awerinzew, C., '06. Die Süsswasser Rhizopoden. Travaux de la Societe Imperiale des Naturalistes de St. Petersbourg, Vol. 3,336, Livr. 2.

Banks, N., '04. A Treatise on the acarina, or mites. Proc. U. S. Nat. Mus., Vol. 28, pp. 1-114.

Blatchley, W. S., '10. Coleoptera of Indiana. Bull. No. 1 Ind. Dept of Geol. and Natural Resources.

Burchardt, C., '06. Quantitative Studien über das Zooplankton des Vierwaldstättersees.

Mitteil d. Naturf. Geo. Luzern, '00. Heft 3, pp. 129-434.

Bütschli, '87. Protozoa. Klassen und Ordnung des Thier-reichs. Band, 1, p. 229.

Calkins, G. N., '04. Evidences of a Sexual Cycle in the Life History of *Amœba proteus*. Arch of Protistenk. V, '04, pp. 1-16.

——————. '07. The Fertilization of Amœba proteus. Biol. Bull. 13, pp. 219-28.

Call, R. E., '99. A descriptive illustrated catalogue of the Mollusca of Indiana. 24th Annual Rep. Ind. Dept. of Geol. and Nat. Res.

Church, Verne H., '10. Summary of the climatological data for the U. S. by sections. Sec. 68. U. S. Dept. of Agri. Weather Bureau.

Cummings, E. R., '05. On the weathering of the subcarboniferous Limestones of Indiana. Proc. Ind. Acad. Sci., 1905, pp. 85-100.

Edmonson, C. H., '10. A report on the freshwater protozoa of Tahiti. Science N. S., Vol. XXII, No. 819, p. 349.

Forbes, S. A., '82. On some Entomostraca from Lake Michigan and adjacent Waters. Am. Nat., Vol. XVI, p. 640.

Forel, F. A., '04. Le Leman, Monographie Limnologique. Tome Troisieme.

Gage, S. H., '91. Life History of the Vermilion Spotted Newt. Am. Nat. Vol. ——, p. 1,084, Dec. '91.

Greene, F. C., '08. Caves and Cave Formations of the Mitchell limestone. Proc. Ind. Acad. Sci., 1908.

Guerne, Jules De., '88. Sur les dissemination des organismes d'eau douce par les Palmipedes. Extrait des Comptes Rendus hebd. des seances de la Societe de Biologie 1888 T. 48 eme Serie.

Hankinson, Thos L., '08. A Biological Survey of Walnut Lake, Michigan. Rep. Biol. Survey of State of Mich., 1907.

Headley, F. W., '95. Structure and Life of Birds.

Jordan, Edwin O., '93. The Habits and Development of the Newt. (Diemyctylus viridescens) Jour. Morph., Vol. VIII.

Kellogg, V., '04. American Insects.

Kofoid, C. A., '03. Plankton of the Illinois River. Bull. of the Ill. State Lab. Nat. Hist., Vol. 6, Art. 2.

Migula, W., '88. Die Verbreitungsweise der Algen. Biol. Cent. B. 13. Proc. Ind. Acad. of Sci., ———.

Miall, L. C., '95. The Natural History of Aquatic Insects.

Migula, W., '88. Die Verbreitungsweise der Algen. Biol. Cent. B. 13, p. 514.

Pearse, A. S., '05. Contribution to the Copepod fauna of Nebraska and other states. Studies from the Zool. Lab. Univ. of Nebraska.

Penard, E., '02. Faune Rhizopodes du bassin du Leman.

Pütter, August, '08. Die Ernährung des Wassertiere Zeitschrift f Allgemeine Physiologie, Vol. 7, pp. 20-283.

——————, '08. Der Stoffaushalt des Meers. ibid, pp. 321-368.

——————, '09. Die Ernährung der Fische. ibid, Vol. 9, pp. 147-242.

Riddle, O , '09. The rate of digestion in cold blooded vertebrates—the influence of season and temperature. Am. Jour. Physiol., Vol. 24, No. 5.

Scott, W., '09. An ecological study of the plankton of Shawnee Cave, with notes on the cave environment. Biol. Bull., Vol. 22, No. 6.

Shaler, N. S., '91. Origin and Nature of Soils. 12th Annual Rep. U. S. Geol. Sur., Part 1, pp. 219-344.

Stein, F., '54. Die Infusionsthiere.

Wesenberg-Lund, '08. Plankton investigations of the Danish Lakes. Danish Freshwater Biological Laboratory, p. 5.

Winogradsky, '89. Recherches sur les organismes de la nitrification. Annals de l'Institute Pasteur, 4.

Wolcott, R. H., '05. A review of the genera of the water mites. Studies from the Zool. Lab. Univ. Neb., 66.

Wolff, Max, '09. Ein einfacher Versuch zu Püttenchen Theorie von der Ernährung der Wasserbewohner. Int. Rev. Hydrob, u Hydrog. B. 2 heft 3-4.

Zacharias, Dr. Otto, '88. Über die Verbreitung niederer Wassertiere durch Schwimmvögel. Biol Centralblatt Band 8 No. 12, p. 368-9.

——————, '93. Fauna des grossen Plöner See's. Forschungsberichte aus der Biologischen Station zu Plön. Theil 1.

——————, '02. Uber die natürliche Nahrung einiger Süsswasserfische. Forschungsberichte aus der Biologischen Station zu Plön Teil 9, p. 62-69.